
Concrete and Masonry Databook

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*To Denise Wilson
and Robert W. Steinhaus*

Preface

Concrete and Masonry Databook is intended to provide quick reference to a wide variety of design and construction information on these two building systems. Only the most basic information is given in text format, with the vast majority of the data presented graphically. The greatest emphasis is on construction details and tabular data, and source citations refer the reader to other texts when in-depth discussion or explanation is required. While much of the information on masonry was derived from other books by Beall, including *Masonry Design and Detailing* (4th ed.), and *Masonry and Concrete for Residential Construction* (part of McGraw-Hill's Complete Construction Series), it has been supplemented extensively with new drawings, tables, and graphs. Jaffe's extensive experience at Construction Technology Laboratories (a subsidiary of the Portland Cement Association) provided her with access to the latest information and research on concrete, which has been incorporated into this text along with data from the American Concrete Institute, the Precast/Prestressed Concrete Institute, and other industry publications. The result is a comprehensive compilation of information organized into 17 sections and supplemented with an exhaustive glossary and list of relevant ASTM standards.

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1.1.1 ASTM C150 Portland Cement

Type I	For use when the special properties for any other type are not required.
Type IA	Air-entraining cement for the same uses as Type I, where air-entrainment is desired.
Type II	For general use, more especially when moderate sulfate resistance or moderate heat of hydration is desired.
Type IIA	Air-entraining cement for the same uses as Type II, where air entrainment is desired.
Type III	For use when high early strength is desired.
Type IIIA	Air-entraining cement for the same use as Type III, where air entrainment is desired.
Type IV	For use when a low heat of hydration is desired.
Type V	For use when high sulfate resistance is desired.

Property	Standard Physical Requirements							
	Cement Type							
	Type I	Type IA	Type II	Type IIA	Type III	Type IIIA	Type IV	Type V
Air content of mortar (% volume)								
maximum	12	22	12	22	12	22	12	12
minimum	—	16	—	16	—	16	—	11
Fineness, specific surface (m ² /kg)								
turbidimeter test, minimum	160	160	160	160	—	—	160	160
air permeability test, minimum	280	280	280	280	—	—	280	280
Autoclave expansion (maximum %)	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Strength, not less than the values shown for the ages indicated as follows:								
Compressive strength (psi)								
1 day	—	—	—	—	1,740	1,450	—	—
3 days	1,740	1,450	1,450	1,160	3,480	2,760	—	1,160
7 days	2,760	2,320	2,470	2,030	—	—	1,020	2,180
28 days	—	—	1,740	1,310	—	—	2,470	3,050
Time of setting (minutes)								
Gillmore test								
initial set, minimum not less than	60	60	60	60	60	60	60	60
final set, minimum not more than	600	600	600	600	600	600	600	600
Vicat test (minutes)								
time of setting, minimum not less than	45	45	45	45	45	45	45	45
time of setting, minimum not more than	375	375	375	375	375	375	375	375

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Property	Optional Physical Requirements							
	Cement Type							
	Type I	Type IA	Type II	Type IIA	Type III	Type IIIA	Type IV	Type V
False set, final penetration (minimum %)	50	50	50	50	50	50	50	50
Heat of hydration								
7 days, maximum (cal/g)	—	—	290	290	—	—	250	—
28 days, maximum (cal/g)	—	—	—	—	—	—	290	—
Strength, not less than the value shown								
Compressive strength (psi) at 28 days	4,060	3,190	4,060	3,190	—	—	—	—
Sulfate resistance, 14 days (maximum % expansion)	—	—	—	—	—	—	—	0.040

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1.1.2 Comparison of ASTM C150 Cement Types

Relative Compressive Strength, %				
Cement Type	Age of Specimens			
	3 Days	7 Days	28 Days	90 Days
I general purpose	100	100	100	100
II moderate sulfate resistance	85	89	96	100
III high early strength	195	120	110	100
IV low heat of hydration	—	36	62	100
V high sulfate resistance	67	79	85	85

Relative Heat of Hydration During First 7 Days of Hydration	
Cement Type	Relative Heat of Hydration (%)
I general purpose	100
II moderate sulfate resistance	85-95
III high early strength	150+
IV low heat of hydration	40-60
V high sulfate resistance	60-90

Typical Age-Strength Relationship of Air-Entrained Concrete Made With Normal and High-Early-Strength Cement		
Strength (psi)	Age of Concrete	
	Type IA—Normal Air-Entrained Cement	Type IIIA—High-Early-Strength Air-Entrained Cement
500	24 hours	12 hours
750	1-1/2 days	18 hours
1500	3-1/2 days	1-1/2 days
2000	5-1/2 days	2-1/2 days

(Tables on this page from Portland Cement Association.)

1.1.3 ASTM C595 Blended Hydraulic Cements

Blended hydraulic cements consist of interground portland cement clinker with fly ash, pozzolan, or slag. Blended cements generally provide increased resistance to alkali-aggregate reaction, sulfate attack, and seawater chemical attack, require longer curing, are less resistant to freeze-thaw and deicing salt damage, have lower heat of hydration, and gain strength more slowly especially at lower temperatures.

- Type IS portland blast furnace slag cement
- Type IP, P portland pozzolan cement
- Type S slag cement
- Type I(PM) pozzolan-modified portland cement
- Type I(SM) slag-modified portland cement

Suffix “A” denotes air-entrained mixture.

Suffix “(MS)” denotes moderate sulfate resistance.

Suffixes “(LH)” and “(MH)” denote low and moderate heat of hydration, respectively.

Physical Requirements								
Property	Cement Type							
	Type I(SM), IS, I(PM), IP	Type I(SM)-A, IS-A, I(PM)-A, IP-A	Type IS(MS), IP(MS)	Type IS-A(MS), IP-A(MS)	Type S	Type SA	Type P	Type PA
Autoclave expansion (maximum %)	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Autoclave contraction† (maximum %)	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Time of setting (minutes)								
Vicat test‡								
not less than	45	45	45	45	45	45	45	45
not more than	7	7	7	7	7	7	7	7
Air content of mortar (maximum volume %)	12	19 ± 3	12	19 ± 3	12	19 ± 3	12	19 ± 3
Compressive strength (minimum psi)								
3 days	13.0	10.0	11.0	9.0	—	—	—	—
7 days	20.0	16.0	18.0	14.0	5.0	4.0	11.0	9.0
28 days	25.0	20.0	25.0	20.0	11.0	9.0	21.0	18.0
Heat of hydration§ (maximum kJ/kg)								
7 days	290	290	290	290	—	—	250	250
28 days	330	330	330	330	—	—	290	290
Water requirement (maximum weight as % of cement)	—	—	—	—	—	—	64	56
Drying shrinkage (maximum %)	—	—	—	—	—	—	0.15	0.15
Mortar expansion* (maximum %)								
14 days	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
8 weeks	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060
Sulfate resistance, expansion at 180 days (maximum %)	optional (0.10)	optional (0.10)	0.10	0.10	—	—	op- tional (0.10)	op- tional (0.10)

† Specimen must remain firm and hard with no signs of distortion, cracking, checking, pitting or disintegration when tested.

‡ Time of setting refers to initial setting. Does not apply to cements with user-requested accelerating or retarding additive.

§ Applies only when moderate or low heat of hydration is specified, in which case the strength shall be 80% of that shown in table.

* Optional test when cement will be used with alkali-reactive aggregate.

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1.1.4 ASTM C91 Masonry Cement

Property	Physical Requirements		
	Masonry Cement Type		
	Type N	Type S	Type M
Fineness, residue on a No. 325 sieve (maximum %)	24	24	24
Autoclave expansion (maximum %)	1.0	1.0	1.0
Time of setting, Gillmore method (minutes)			
initial set not less than	120	90	90
final set not more than	1,440	1,440	1,440
Compressive strength (psi), average of 3 cubes, [§] equal to or higher than the values specified for the ages indicated below:			
7 days	500	1,300	1,800
28 days	900	2,100	2,900
Air content of mortar, prepared and tested in accordance with requirements of ASTM C91			
minimum (% volume)	8	8	8
maximum (% volume)	21	19	19
Water retention value (minimum % of original flow)	70	70	70

[§] Mortar cubes composed of 1 part cement and 3 parts blended sand (half graded standard sand and half standard 20-30 sand) by volume, prepared and tested in accordance with ASTM C91.

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1.1.5 ASTM C1329 Mortar Cement

Property	Physical Requirements		
	Masonry Cement Type		
	Type N	Type S	Type M
Fineness, residue on a No. 325 sieve (maximum %)	24	24	24
Autoclave expansion (maximum %)	1.0	1.0	1.0
Time of setting, Gillmore method (minutes)			
initial set not less than	120	90	90
final set not more than	1,440	1,440	1,440
Compressive strength (psi), average of 3 cubes, [§] equal to or higher than the values specified for the ages indicated below:			
7 days	500	1,300	1,800
28 days	900	2,100	2,900
Flexural bond strength, 28 days, minimum (psi)	70	100	115
Air content of mortar, prepared and tested in accordance with requirements of ASTM C91			
minimum (% volume)	8	8	8
maximum (% volume)	16	14	14
Water retention value (minimum % of original flow)	70	70	70

[§] Mortar cubes composed of 1 part cement and 3 parts blended sand (half graded standard sand and half standard 20-30 sand) by volume, prepared and tested in accordance with ASTM C91.

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1.2.1 **ASTM C207 Hydrated Lime**

- Type N Normal hydrated lime for masonry purposes.
- Type S Special hydrated lime for masonry purposes.
- Type NA Normal air-entraining hydrated lime for masonry purposes.
- Type SA Special air-entraining hydrated lime for masonry purposes.

Property	Type N	Type NA	Type S	Type SA
Calcium and magnesium oxides (minimum %)	95	95	95	95
Carbon dioxide (maximum %)				
If sample is taken at place of manufacture	5	5	5	5
If sample is taken at any other place	7	7	7	7
Unhydrated oxides (maximum %)	—	—	8	8
Plasticity of putty when tested within 30 minutes after mixing with water	—	—	200	200
Water retention after suction for 60 seconds (%)	75	75	85	85

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1.2.2 **ASTM C5 Quicklime**

Quicklime must be slaked (hydrated) with water at the job site to form a lime putty. After slaking, the lime putty is mixed with all or part of the masonry sand required for the mortar mix and must be stored for a minimum of 24 hours before use. Because of its greater convenience, hydrated lime has typically replaced quicklime for use in masonry mortar in the United States.

ASTM C5 Requirements for Chemical Composition of Quicklime for Structural Purposes		
Chemical or Compound Type	Calcium Lime	Magnesium Lime
Calcium oxide, min. %	75	—
Magnesium oxide, min. %	—	20
Calcium and magnesium oxide, min. %	95	95
Silica, alumina, and oxide of iron, max. %	5	5
Carbon dioxide, max. %		
If sample taken at place of manufacture	3	3
If sample taken at any other location	10	10

1.3.1 Concrete Admixtures

Admixtures are added to cement, water, and aggregates either immediately before or during mixing. The primary reasons for using an admixture are:

- To reduce the cost of concrete construction
- To achieve certain properties in concrete more effectively than by other means
- To ensure the quality of concrete placed and cured in adverse weather conditions
- To overcome certain emergencies during concreting operations

Concrete admixtures may be classified by function as:

- Air-entraining
- Water-reducing
- Set accelerating
- Set retarding
- Superplasticizing
- Finely divided mineral admixtures
- Miscellaneous admixtures, including bonding, dampproofing, coloring, corrosion inhibiting, and pumping admixtures

Although admixtures can enhance the quality of concrete, they are not a substitute for good concreting practice. *Water-reducing* admixtures reduce the quantity of mixing water used in the concrete by 5 to 10%, and are used to either lower the water-cement ratio or increase slump. *Set retarding* admixtures are used to slow the rate of concrete setting. In temperatures above 85°F, concrete has an increased rate of hardening, which makes placing and finishing more difficult. An alternative to set retarding admixtures is to cool the mixing water or aggregates. *Set accelerating* admixtures increase concrete compressive strength at an early age. Other means of achieving this effect are to use Type III portland cement, add cement to lower the water-cement ratio, or cure the concrete at higher temperatures. Calcium chloride is the most common ingredient in set accelerating admixtures. However, calcium chloride is not an antifreeze agent and does not take the place of cold weather precautions. Although non-chloride accelerators are available, they are not as effective as calcium chloride and are more expensive. The table below lists recommended maximum chloride ion content for corrosion protection. Calcium chloride is not recommended under the following conditions:

- In prestressed concrete due to possible corrosion of embedded metals
- In concrete containing embedded aluminum (conduit, for example) due to possible corrosion
- In concrete subjected to alkali-aggregate reaction or exposed to soil or water containing sulfates
- In floor slabs intended to receive dry-shake metallic finishes
- In hot weather, generally
- In massive concrete placements

Superplasticizers are high-range water reducers added to concrete with low-to-normal slump and water-cement ratio to make high-slump, flowing concrete. Flowing concrete is defined as a highly fluid but workable concrete that can be placed with little or no vibration or compaction, but is still free of excessive bleeding or segregation. Superplasticizers are more effective, but more expensive, than regular water-reducing admixtures and are commonly used in the following applications:

- In thin section placements
- In areas of closely spaced and congested reinforcing steel
- In underwater placements
- In pumped concrete
- In areas where conventional consolidation methods are impractical or impossible

Type of Member	Maximum Water-Soluble Chloride Ion (Cl ⁻) in Concrete by Weight of Cement(%)
Prestressed concrete	0.06
Reinforced concrete exposed to chloride in service	0.15
Reinforced concrete that will be dry or protected from moisture in service	1.00
Other reinforced concrete construction	0.30

(From Design and Control of Concrete Mixtures, 13th ed., PCA, 1990)

1.3.2 Concrete Admixtures by Classification

Type of Admixture	Desired Effect(s)	Common Ingredients
Accelerators (ASTM C494, Type C)	Accelerate setting and early strength development	calcium chloride (ASTM D98), Triethanolamine, sodium thiocyanate, calcium formate, calcium nitrite, calcium nitrate
Air detrainers	Decrease air content	Tributyl phosphate, dibutyl phthalate, octyl alcohol, water-insoluble esters of carbonic and boric acid, silicones
Air-entraining admixtures (ASTM C260)	Improve durability in environments of freeze-thaw, deicers, sulfate, and alkali reactivity. Improve workability.	Salts of wood resins (vinsol resins), some synthetic detergents, salts of sulfonated lignin, salts of petroleum acids, salts of proteinaceous material, fatty and resinous acids and their salts, alkylbenzene sulfonates, salts of sulfonated hydrocarbons
Alkali-reactivity reducers	Reduce alkali-reactivity expansion	Pozzolans (fly ash, silica fume), blast-furnace slag, salts of lithium and barium, air-entraining agents
Bonding admixtures	Increase bond strength	Rubber, polyvinyl chloride, polyvinyl acetate, acrylics, butadiene-styrene copolymers
Coloring agents	Colored concrete	Modified carbon black, iron oxide, phthalocyanine, umber, chromium oxide, titanium oxide, cobalt blue (ASTM C979)
Corrosion inhibitors	Reduce steel corrosion activity in chloride environments	Calcium nitrite, sodium nitrite, sodium benzoate, certain phosphates or fluosilicates, fluoaluminates
Dampproofing admixtures	Retard moisture penetration into dry concrete	Soaps of calcium or ammonium stearate or oleate, butyl stearate, petroleum products
Fungicides, germicides, and insecticides	Inhibit or control bacterial and fungal growth	Polyhalogenated phenols, dieldrin emulsions, copper compounds
Gas formers	Cause expansion before setting	Aluminum powder, resin soap and vegetable or animal glue, saponin, hydrolized protein
Grouting agents	Adjust grout properties for specific applications	See air-entraining admixtures in Section 1.3.3, accelerators, retarders, workability agents
Permeability reducers	Decrease permeability	Silica fume, fly ash (ASTM C618), ground slag (ASTM C989), natural pozzolans, water reducers, latex
Pumping aids	Improve pumpability	Organic and synthetic polymers, organic flocculents, organic emulsions of paraffin, coal tar, asphalt, acrylics, bentonite and pyrogenic silicas, natural pozzolans (ASTM C618, Class N), fly ash (ASTM C618, Classes F and C), hydrated lime (ASTM C141)
Retarders (ASTM C494, Type B)	Retard setting time	Lignin, borax, sugars, tartaric acid and salts
Superplasticizers (ASTM C1017, Type 1)	Increase concrete flow, reduce water-cement ratio	Sulfonated melamine formaldehyde condensates, sulfonated naphthalene formaldehyde condensates, lignosulfonates
Superplasticizer & retarder (ASTM C1017, Type 2)	Increase concrete flow, retard set, reduce water-cement ratio	See superplasticizers and also water reducers
Water reducer (ASTM C494, Type A)	Reduce water demand at least 5%	Lignosulfonates, hydroxylated carboxylic acids, carbohydrates (also tend to retard set, so accelerator is often added)
Water reducer & accelerator (ASTM C494, Type E)	Reduce water demand at least 5% and accelerate set	See water reducer, Type A (accelerator is added)
Water reducer & retarder (ASTM C494, Type D)	Reduce water demand at least 5% and retard set	See water reducer, Type A
Water reducer, high range (ASTM C494, Type F)	Reduce water demand at least 12%	See superplasticizers
Water reducer, high range & retarder (ASTM C494, Type G)	Reduce water demand at least 12% and retard set	See superplasticizers and water reducers
Workability agents	Improve workability	Air-entraining admixtures, finely divided admixtures except silica fume (see Section 1.3.4), water reducers

(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

1.3.3 Air-Entrainment for Concrete

Entrained air is different from entrapped air. Entrapped air usually accounts for about 1 to 2% of the volume of fresh concrete and its inclusion is not intentional. Small amounts of air are inadvertently entrapped during the concrete mixing process. Air content can be intentionally increased by a controlled process called *air-entrainment*, which introduces uniformly distributed, microscopic air bubbles into the concrete. These bubbles improve the durability of concrete that is exposed to moisture during cycles of freezing and thawing. The tiny bubbles relieve the pressure that is exerted when water in the pores of the concrete freezes and expands. Concrete with entrained air is also more resistant to surface scaling caused by chemical deicers. Another benefit is enhanced workability and reduced segregation and bleeding. Air-entrainment is particularly effective in improving the workability of lean mixes and mixes containing poorly graded or sharp, angular aggregate. Air entrainment also reduces segregation, slows the rate of bleeding, and shortens finishing time. Although concrete strength is somewhat reduced, a lower water-to-cement ratio can be used, which increases strength.

In hardened concrete air-entrainment increase the winter durability of horizontal elements such as sidewalks, driveways, patios, and steps which are most frequently exposed to moisture and to repeated freeze-thaw cycles. For vertical elements, which are less often saturated with rain, and in mild climates where freeze-thaw cycles are infrequent, air entrainment adds little value to hardened concrete but still may be used to increase the workability of fresh concrete. Air entrainment is sometimes credited with decreasing the permeability of concrete, but this is probably because the increased workability of the mix is conducive to better placement, consolidation, and finishing.

Either a separate air-entraining agent or an air-entrained cement may be used. A separate air-entraining admixture batched at a ready-mix plant provides better control of air content. For job-site mixing of small batches, air-entrained cements are easier to use but always require mechanical rather than hand mixing to assure even distribution.

The table below provides recommended entrained air contents for concrete that will be exposed to severe weather. However, the tabulated values should be modified by the following:

- Add 2% to the recommended values when structural lightweight concrete is used.
- Increase the percentage of air when placing concrete in hot weather.
- When air-entrainment is used in conjunction with a water reducer, retarder, or superplasticizer, confirm whether those admixtures will affect the air-entrainment admixture by checking with the admixture supplier and/or manufacturer.
- A water-reducing admixture may be needed in addition to the air-entrainment admixture in concrete with very low slump in order to achieve the required air content.
- Soupy or watery mixtures may lose entrained air rapidly when vibrated.

Recommended Air Content for Concrete Subject to Severe Exposure Conditions, by Aggregate Size	
Maximum Size Coarse Aggregate (in.)	Air Content by Volume of Concrete [§] (%)
1-1/2, 2, or 2-1/2	5 ± 1
3/4 or 1	6 ± 1
3/8 or 1/2	7-1/2 ± 1

[§] Air content in cement mortar alone should be about 9%.

(From National Association of Home Builders, Residential Concrete, 3rd ed., 1999)

1.3.4 **Finely Divided Mineral Admixtures for Concrete**

Finely divided mineral admixtures are powdered or pulverized, natural or byproduct materials which may be classified as:

- cementitious materials
- pozzolans
- pozzolanic and cementitious materials
- nominally inert materials

Finely divided mineral admixtures are used to produce a variety of effects on plastic and hardened concrete properties as noted in the table below.

Type of Finely Divided Mineral Admixture	Desired Effect(s)	Common Materials
Cementitious	Hydraulic properties, partial cement replacement	Ground granulated blast-furnace slag (ASTM C989), natural cement, hydraulic hydrated lime (ASTM C141)
Pozzolans	Pozzolanic activity; improve workability, plasticity, surface resistance; reduce alkali reactivity, permeability, heat of hydration; partial cement replacement; filler	Diatomaceous earth, opaline cherts, clays, shales, volcanic tuffs, pumicites (ASTM C618, Class N), fly ash (ASTM C618, Classes F and C), silica fume
Pozzolanic and cementitious	Same as cementitious and pozzolan types	High-calcium fly ash (ASTM C618, Class C), ground granulated blast-furnace slag (ASTM C989)
Nominally inert	Improve workability; filler	Marble, dolomite, quartz, granite

1.3.5 ASTM C1384 Modifiers for Masonry Mortar

Physical Requirements for Modified Mortars (In Addition to ASTM C270 Mortar Requirements)					
Property	Bond Enhancer	Workability Enhancer	Set Accelerator	Set Retarder	Water Repellent
Minimum compressive strength (% of reference)					
7 day	80	80	80	70	80
28 day	80	80	80	80	80
Minimum water retention (% of reference)	report*	100	report*	report*	report*
Air content of plastic mortar	report*	report*	report*	report*	report*
Minimum board life (% of reference)	report*	120	report*	120	report*
Time of setting, allowable deviation from reference (hr:min)					
Initial set: at least	—	—	1:00 earlier	1:00 later	—
not more than	1:00 earlier nor 1:30 later	1:00 earlier nor 3:30 later	3:30 earlier	8:00 later	1:00 earlier nor 1:30 later
Final set: at least	—	—	1:00 earlier	—	—
not more than	1:00 earlier nor 1:30 later	1:00 earlier nor 3:30 later	—	8:00 later	1:00 earlier nor 1:30 later
Minimum flexural bond strength (% of reference)	110	—	—	—	—
Maximum rate of water absorption (% of reference, 24 hr.)	—	—	—	—	50

* Report test results.

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1.3.6 Chemical Admixtures for Masonry Grout

Type of Admixture	Uses
Shrinkage compensating	Expands grout to compensate for moisture shrinkage
Set retarding	Delays set during hot weather, long transit, or time delays
Set accelerating (noncorrosive)	Accelerates set during cold weather
Corrosion inhibiting	Reduces corrosion in harsh environments
Superplasticizing	Increases slump without additional water and without strength reduction
Antifreeze compound	THERE IS NO SUCH THING AS AN "ANTIFREEZE" ADMIXTURE

1.4.1 Concrete and Mortar Coloring Pigments

Concrete or Mortar Color [§]	Pigments Used [†]
Black, Gray	Black iron oxide, mineral black, carbon black
Brown, Red	Red iron oxide, brown iron oxide, raw umber, burnt umber
Rose, Pink	Red iron oxide (varying amounts)
Buff, Cream, Ivory	Yellow ochre, yellow iron oxide
White	White cement and white sand (no pigments required)
Green	Chromium oxide, phthalocyanine green
Blue	Cobalt blue, ultramarine blue, phthalocyanine blue

[§] Color of finished concrete and mortar is affected by color of cement and aggregates.
[†] Synthetic iron oxides have more tinting power than natural iron oxides, so less pigment is required per unit of concrete or mortar to produce a given color. Synthetic oxides also produce brighter, cleaner colors.

1.4.2 Dry-Shake Concrete Coloring Agents and Surface-Applied Stains

Dry-shake coloring agents and surface-applied stains are less expensive than coloring an entire batch of concrete, but may result in uneven or blotchy color. Dry-shake coloring agents are powder dyes sprinkled onto a wet concrete surface and bull-floated to distribute the color. One pound of dye covers about 20 sq.ft. of surface, and penetrates the concrete to a depth of 1/4 to 1/2 in. Although some early hand trowel work may be required to help blend the color evenly, once the color has been applied and floated in, dusted concrete is treated exactly the same as any other. Troweling, edging, and control jointing work is the same.

Surface-applied stains are essentially coatings applied in one or more colors to create simple color or artistic effects. The stains are applied to fully cured concrete. Lighter colors should be applied first to the entire surface, with darker colors added on top and sponged, brushed, rubbed or stippled to produce the desired effect.

Colored concrete must be sealed to protect against fading caused by ultraviolet exposure and harsh weather conditions. Liquid sealers are applied using an ordinary garden hose sprayer. Dusted concrete should not be sealed until the concrete has hardened sufficiently to allow walking on the surface without leaving impressions. Stained concrete should not be sealed until the color coatings have fully dried and cured according to the stain manufacturer’s recommendations.

1.5.1 Concrete Aggregate Characteristics and Tests

Characteristic	Significance	ASTM Test	Requirement or Item Reported
Resistance to abrasion and degradation	Index of aggregate quality; wear resistance of floors and pavements	ASTM C131 ASTM C535 ASTM C779	Maximum percentage of weight loss, depth of wear and time
Resistance to freezing and thawing	Surface scaling, roughness, loss of section, and unsightliness	ASTM C666 ASTM C682	Maximum number of cycles or period of frost immunity, durability factor
Resistance to disintegration by sulfates	Soundness against weathering action	ASTM C88	Weight loss, particles exhibiting distress
Particle shape and surface texture	Workability of fresh concrete	ASTM C295 ASTM D3398	Maximum percentage of flat and elongated pieces
Grading	Workability of fresh concrete and economy	ASTM C117 ASTM C136	Minimum and maximum percentage passing standard sieves
Bulk unit weight or bulk density	Mix design calculations and classification	ASTM C29	Compact weight and loose weight
Specific gravity	Mix design calculations	ASTM C127 for fine aggregate ASTM C128 for coarse aggregate	—
Absorption and surface moisture	Control of concrete quality	ASTM C70 ASTM C127 ASTM C128 ASTM C566	—
Compressive and flexural strength	Acceptability of fine aggregate failing other tests	ASTM C39 ASTM C78	Strength to exceed 95% of strength achieved with purified sand
Definitions of constituents	Clear understanding and communication	ASTM C125 ASTM C294	—
Aggregate constituents	Determine amount of deleterious and organic materials	ASTM C40 ASTM C87 ASTM C117 ASTM C123 ASTM C142 ASTM C295	Maximum percentage of individual constituents
Resistance to alkali reactivity and volume change	Soundness against volume change	ASTM C227 ASTM C289 ASTM C295 ASTM C342 ASTM C586	Maximum length change, constituents and amount of silica, alkalinity

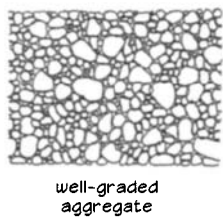
Note: The majority of the tests and characteristics listed are referenced in ASTM C33.

(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

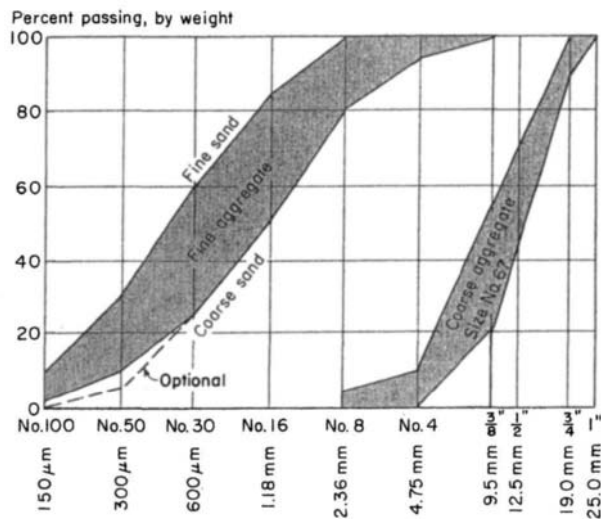
1.5.2
ASTM C33 Normal Weight Aggregates for Concrete and Concrete Masonry Units

Grading Requirements for Fine and Coarse Aggregate																	
Size	Nominal Aggregate Size	Amounts Finer Than Each Laboratory Sieve With Square Openings (% by Weight)															
		4 in.	3-½ in.	3 in.	2-½ in.	2 in.	1-½ in.	1 in.	¾ in.	½ in.	⅜ in.	#4	#8	#16	#30	#50	#100
Fine	—	—	—	—	—	—	—	—	—	—	100	95-100	80-100	50-85	25-60	5-30	2-10
Coarse Aggregate—Size No.	1 3-½ to 1-½ in.	100	90-100	—	25-60	—	0-15	—	0-5	—	—	—	—	—	—	—	—
	2 2-½ to 1-½ in.	—	—	100	90-100	35-70	0-15	—	0-5	—	—	—	—	—	—	—	—
	3 2 to 1 in.	—	—	—	100	90-100	35-70	0-15	—	0-5	—	—	—	—	—	—	—
	357 2 in. to #4	—	—	—	100	95-100	—	35-70	—	10-30	—	0-5	—	—	—	—	—
	4 1-½ to ¾ in.	—	—	—	—	100	90-100	20-55	0-15	—	0-5	—	—	—	—	—	—
	467 1-½ to #4	—	—	—	—	100	95-100	—	35-70	—	10-30	0-5	—	—	—	—	—
	5 1 to ½ in.	—	—	—	—	100	90-100	20-55	0-10	0-5	—	—	—	—	—	—	—
	56 1 to ⅜ in.	—	—	—	—	100	90-100	40-85	10-40	0-15	0-5	—	—	—	—	—	—
	57 1 in. to #4	—	—	—	—	100	95-100	—	25-60	—	0-10	0-5	—	—	—	—	—
	6 ¾ to ⅜ in.	—	—	—	—	—	100	90-100	20-55	0-15	0-5	—	—	—	—	—	—
	67 ¾ in. to #4	—	—	—	—	—	100	90-100	—	20-55	0-10	0-5	—	—	—	—	—
	7 ½ in. to #4	—	—	—	—	—	—	100	90-100	40-70	0-15	0-5	—	—	—	—	—
	8 ⅜ in. to #8	—	—	—	—	—	—	—	100	85-100	10-30	0-10	0-5	—	—	—	—
	89 ⅜ in. to #16	—	—	—	—	—	—	—	—	100	90-100	20-55	5-30	0-10	—	0-5	—
	9 ^s #4 to #16	—	—	—	—	—	—	—	—	—	100	85-100	10-40	0-10	—	0-5	—

^s Size 9 aggregate is defined as a fine aggregate, but is considered coarse aggregate when combined with Size 8 to create Size 8 9.



Coarse aggregate is gravel or crushed stone larger than 1/4 in. Fine aggregate is natural or manufactured sand 1/4 in. and smaller. A mix with well-graded aggregate produces more economical concrete. Fine aggregates with low percentages passing No. 50 and 100 sieves cause difficulties with concrete workability, pumping operations, and excessive bleeding of mix water at slab surfaces. Methods used to provide the deficient fines include the addition of air-entraining agents, more cement, or a mineral admixture. Deleterious substances should be within limits established by ASTM C33.



Curves indicate the limits specified in ASTM C33 for fine aggregate and for one typically used nominal coarse aggregate size. (From Portland Cement Association)

1.5.3 ASTM C330 Aggregates for Lightweight Structural Concrete

Grading Requirements for Fine and Coarse Aggregates																	
Grade	Nominal Aggregate Size	Amounts Finer Than Each Laboratory Sieve With Square Openings (% by Weight)															
		4 in.	3-½ in.	3 in.	2-½ in.	2 in.	1-½ in.	1 in.	¾ in.	½ in.	⅜ in.	#4	#8	#16	#30	#50	#100
Fine	#4 to 0	—	—	—	—	—	—	—	—	—	100	85-100	—	40-80	—	10-35	5-25
	1 in. to #4	—	—	—	—	—	—	95-100	—	25-60	—	0-10	—	—	—	—	—
Coarse	¾ in. to #4	—	—	—	—	—	—	100	90-100	—	10-50	0-15	—	—	—	—	—
	½ in. to #4	—	—	—	—	—	—	—	100	90-100	40-80	0-20	0-10	—	—	—	—
	⅜ in. to #8	—	—	—	—	—	—	—	—	100	80-100	5-40	0-20	0-10	—	—	—
Fine &	½ in. to 0	—	—	—	—	—	—	—	100	95-100	—	50-80	—	—	—	5-20	2-15
Coarse	⅜ in. to 0	—	—	—	—	—	—	—	—	100	90-100	65-90	35-65	—	—	10-25	5-15

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1.5.4 ASTM C331 Lightweight Aggregates for Concrete Masonry Units

Grading Requirements for Fine and Coarse Aggregate								
Nominal Aggregate Size	Amounts Finer Than Laboratory Sieves With Square Openings (% by Weight)							
	¾ in.	½ in.	⅜ in.	#4	#8	#16	#50	#100
Fine aggregate #4 to 0	—	—	100	85-100	—	40-80	10-35	5-25
Coarse aggregate ½ in. to #4	100	90-100	40-80	0-20	0-10	—	—	—
⅜ in. to #8	—	100	80-100	5-40	0-20	0-10	—	—
Fine and coarse aggregate ½ in. to 0	100	95-100	—	50-80	—	—	5-20	2-15
⅜ in. to 0	—	100	90-100	65-90	35-65	—	10-25	5-15

Maximum Bulk Density Requirements for Fine and Coarse Aggregates	
Aggregate Size	Maximum Dry, Loose, Bulk Density (lb/cu.ft.)
Fine	70
Coarse	55
Combined fine and coarse	65

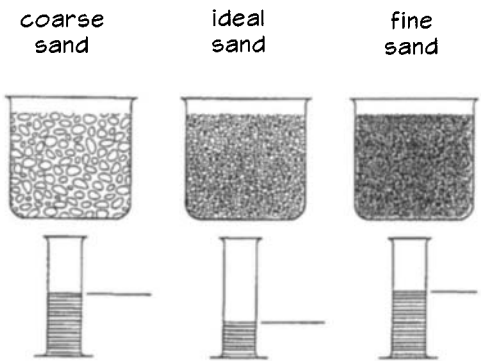
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1.5.5 ASTM C144 Masonry Mortar Sand

ASTM C144 Sand Gradation Requirements [‡]		
Sieve Size	Percent Passing	
	Natural Sand	Manufactured Sand
4	100	100
8	95 to 100	95 to 100
16	70 to 100	70 to 100
30	40 to 75	40 to 75
50	10 to 35	20 to 40
100	2 to 15	10 to 25
200	0 to 5	0 to 10

[§] Not more than 50% shall be retained between any two sieve sizes nor more than 25% between No. 50 and 100 sieve sizes.
[‡] If an aggregate does not meet the gradation requirement limits, it may be used if the mortar meets the property specification of ASTM C270.

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The level of liquid in the cylinders represents the volume of voids in the sand mixture. A sand with the ideal mix of coarse and fine grains (complying with ASTM C 144 gradation limits) has a lower volume of voids and is therefore more economical because it requires less cementitious material to properly coat the particles.

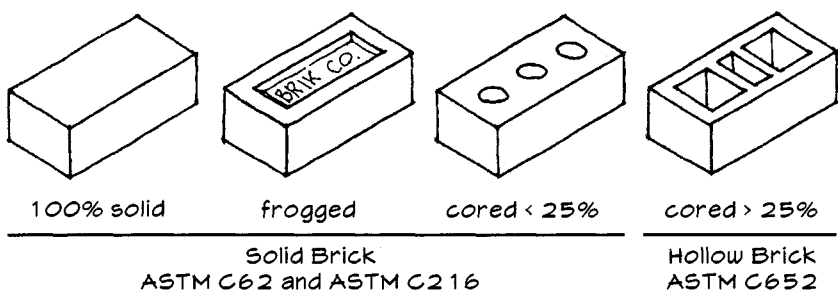
(From Portland Cement Association, Trowel Tips—Mortar Sand)

1.5.6 ASTM C404 Masonry Grout Aggregates

Sieve Size	Amounts Finer Than Each Laboratory Sieve (weight %)				
	Fine Aggregate			Coarse Aggregate	
	Size No. 1	Size No. 2		Size No. 8	Size No. 89
		Natural	Manufactured		
1/2 inch	—	—	—	100	100
3/8 inch	100	—	—	85 to 100	90 to 100
4	95 to 100	100	100	10 to 30	20 to 55
8	80 to 100	95 to 100	95 to 100	0 to 10	5 to 30
16	50 to 85	70 to 100	70 to 100	0 to 5	0 to 10
30	25 to 60	40 to 75	40 to 75	—	0 to 5
50	10 to 30	10 to 35	20 to 40	—	—
100	2 to 10	2 to 15	10 to 25	—	—
200	0 to 5	0 to 5	0 to 10	—	—

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1.6.1 Solid Brick and Hollow Brick

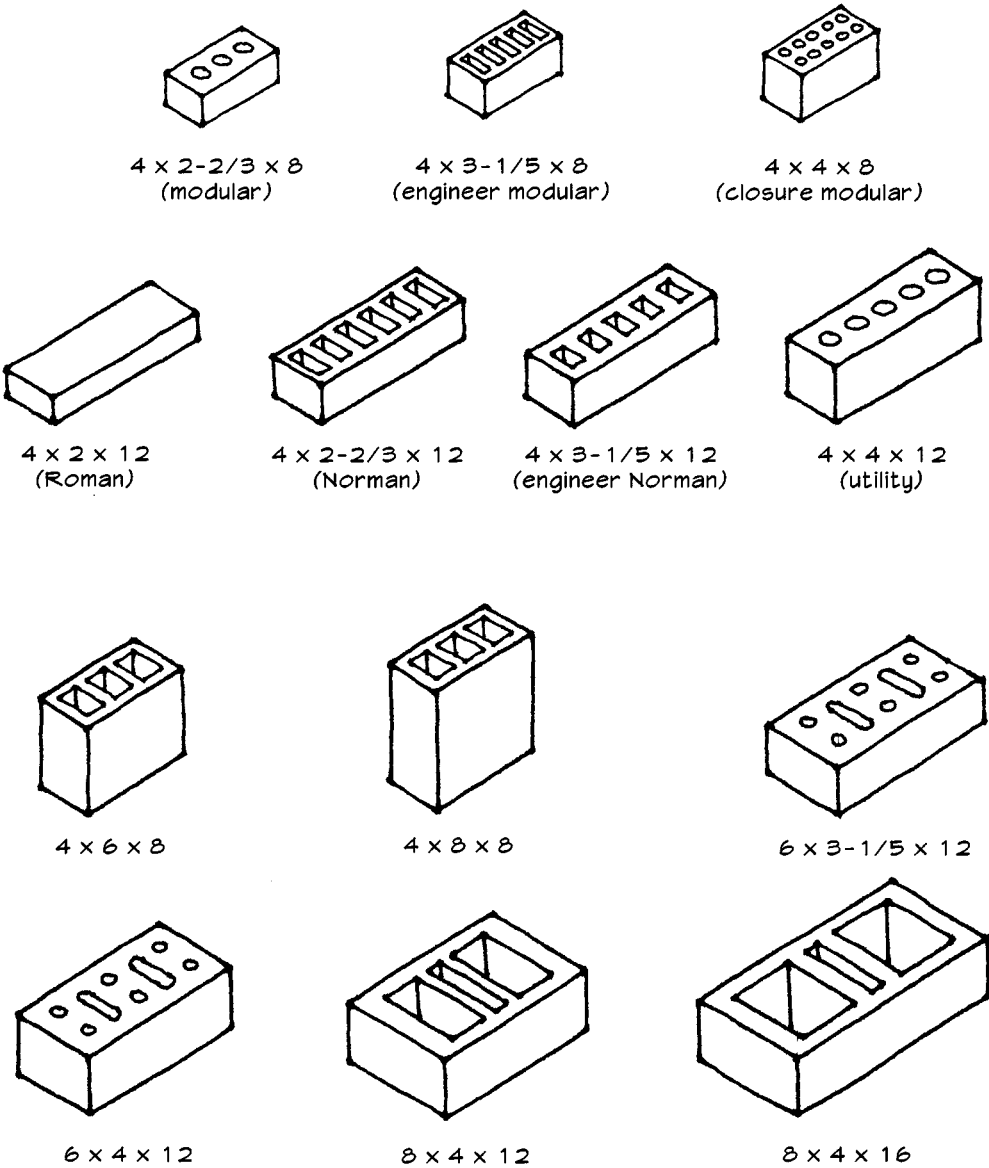


1.6.2 Building Brick, Face Brick, and Hollow Brick

- Grade SW brick for use where high and uniform resistance to damage caused by cyclic freezing is desired, and where brick may be frozen when saturated with water
- Grade MW brick for use where moderate resistance to damage caused by cyclic freezing is permissible, or where brick may be damp but not saturated with water when freezing occurs
- Grade NW brick with little resistance to damage caused by cyclic freezing, but which are acceptable for applications protected from water absorption and freezing
- Type FBS and HBS brick for general use in masonry
- Type FBX and HBX brick for general use in masonry where a higher degree of precision and lower permissible variation in size than permitted for Type FBS is required
- Type FBA and HBA brick for general use in masonry, selected to produce characteristic architectural effects resulting from non-uniformity in size and texture of the individual units

Brick	Grade	Type
ASTM C62 Building Brick	SW, MW, NW	N/A
ASTM C216 Face Brick	SW, MW	FBS, FBX,FBA
ASTM C652 Hollow Brick	SW, MW	HBS, HBX, HBA

1.6.3 Modular Brick Sizes



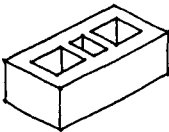
Dimensions shown are nominal. Specified dimensions are usually 3/8" less than the nominal dimension.

1.6.4 Brick Size and Coursing Tables

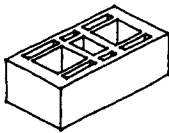
Modular Brick Sizes and Coursing								
Unit Designation	Nominal Dimensions (in.)			Joint Thickness (in.)	Specified Dimensions (in.)			Vertical Coursing
	W	H	L		W	H	L	
Modular	4	2-2/3	8	3/8 1/2	3-5/8 3-1/2	2-1/4 2-1/4	7-5/8 7-1/2	3 courses = 8 in.
Engineer modular	4	3-1/5	8	3/8 1/2	3-5/8 3-1/2	2-3/4 2-13/16	7-5/8 7-1/2	5 courses = 16 in.
Closure modular	4	4	8	3/8 1/2	3-5/8 3-1/2	3-5/8 3-1/2	11-5/8 11-1/2	1 course = 4 in.
Roman	4	2	12	3/8 1/2	3-5/8 3-1/2	1-5/8 1-1/2	11-5/8 11-1/2	2 courses = 4 in.
Norman	4	2-2/3	12	3/8 1/2	3-5/8 3-1/2	2-1/4 2-1/4	11-5/8 11-1/2	3 courses = 8 in.
Engineer Norman	4	3-1/4	12	3/8 1/2	3-5/8 3-1/2	2-3/4 2-13/16	11-5/8 11-1/2	5 courses = 16 in.
Utility	4	4	12	3/8 1/2	3-5/8 3-1/2	3-5/8 3-1/2	11-5/8 11-1/2	1 course = 4 in.
	4	6	8	3/8 1/2	3-5/8 3-1/2	5-5/8 5-1/2	7-5/8 7-1/2	2 courses = 12 in.
	4	8	8	3/8 1/2	3-5/8 3-1/2	7-5/8 7-1/2	7-5/8 7-1/2	1 course = 8 in.
	6	3-1/5	12	3/8 1/2	5-5/8 5-1/2	2-3/4 2-13/16	11-5/8 11-1/2	5 courses = 16 in.
	6	4	12	3/8 1/2	5-5/8 5-1/2	3-5/8 3-1/2	11-5/8 11-1/2	1 course = 4 in.
	8	4	12	3/8 1/2	7-5/8 7-1/2	3-5/8 3-1/2	11-5/8 11-1/2	1 course = 4 in.
	8	4	16	3/8 1/2	7-5/8 7-1/2	3-5/8 3-1/2	15-5/8 15-1/2	1 course = 4 in.

Non-Modular Brick Sizes and Coursing					
Unit Designation	Joint Thickness (in.)	Specified Dimensions (in.)			Vertical Coursing
		W	H	L	
Standard	3/8 1/2	3-5/8 3-1/2	2-1/4 2-1/4	8 8	3 courses = 8 in.
Engineer standard	3/8 1/2	3-5/8 3-1/2	2-3/4 2-13/16	8 8	5 courses = 16 in.
Closure standard	3/8 1/2	3-5/8 3-1/2	3-5/8 3-1/2	8 8	1 course = 4 in.
King	3/8	3 3	2-3/4 2-5/8	9-5/8 9-5/8	5 courses = 16 in.
Queen	3/8	3	2-3/4	8	5 courses = 16 in.
	3/8	3	2-3/4	8-5/8 8-5/8	5 courses = 16 in.

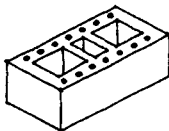
1.6.5 **ASTM C652 Hollow Brick Coring and Shell Variations**



solid shell



double shell



cored shell

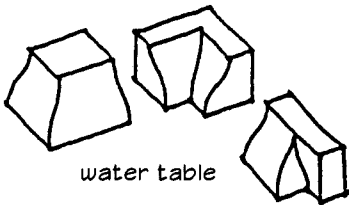
- Class H40V—Hollow brick with voids 25 to 40%
- Class H60V—Hollow brick with voids 40 to 60%

Class H60V Hollow Brick Minimum Thickness of Face Shells and Webs (in.)			
Nominal Width of Units	Face Shell Thickness		End Shells or End Webs
	Solid	Cored or Double Shell	
3 and 4	3/4	—	3/4
6	1	1-1/2	1
8	1-1/4	1-1/2	1
10	1-3/8	1-5/8	1-1/8
12	1-1/2	2	1-1/8

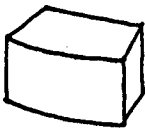
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1.6.6 **Special Brick Shapes**

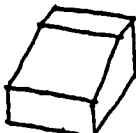
A variety of special brick shapes are available from many manufacturers. Availability will vary. Some of the more commonly used special shapes are illustrated below. Many special shapes require inside and outside corner units as well as stretchers and rowlocks. The color of special shape bricks may not exactly match the standard shape units in a project because they are typically fired in a different run.



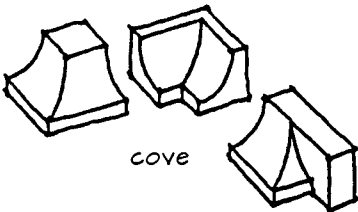
water table



radial



sill



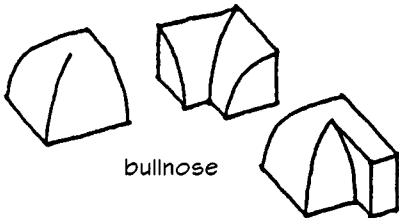
cove



outside octagon



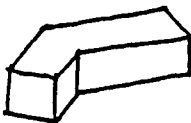
lintel brick with lip



bullnose

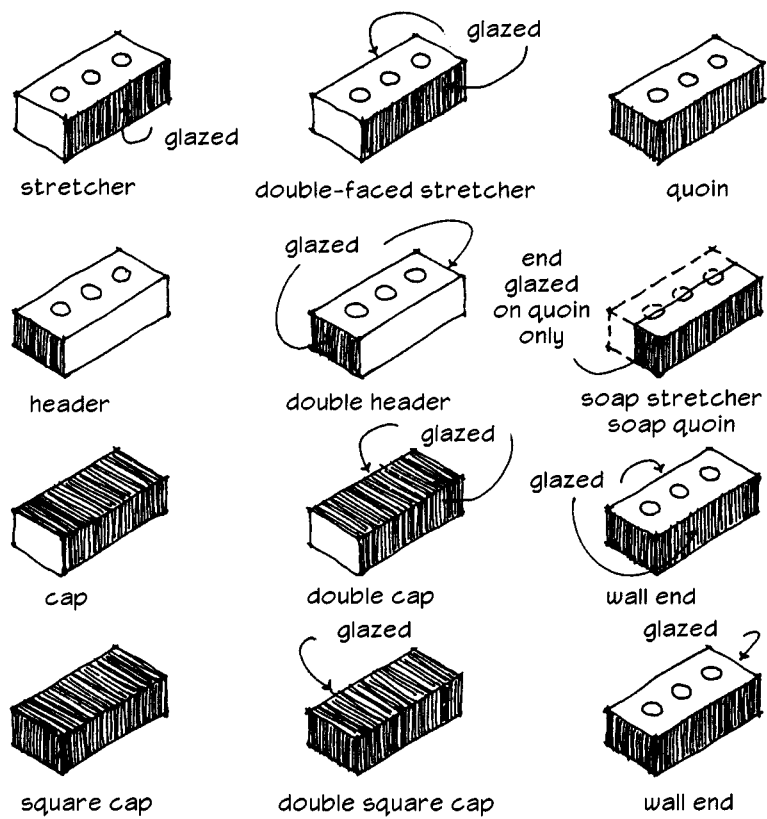


45° outside corner



45° inside corner

1.6.7 ASTM C1405 Glazed Brick



- Type I—Single-faced units for general use where only one finished face will be exposed.
- Type II—Two-faced units for general use where two opposite finished faces will be exposed.
- Grade S (Select)—For use with comparatively narrow mortar joints.
- Grade SS (Select Sized or Ground Edge)—For use where variation of face dimension must be very small.
- Class—Exterior
- Class—Interior

Walls of glazed masonry are not as breathable as walls of unglazed masonry so moisture evaporation is slower. In cold climates, freezing temperatures may cause face spalling.

ASTM C1405 Physical Requirements					
Class	Minimum Compressive Strength, Gross Area (psi)		Maximum Water Absorption by 24 hr. Cold, 7°	Maximum Saturation Coefficient	
	Average of 5 Brick	Individual Brick		Average of 5 Brick	Individual Brick
Exterior	6000	5000	7.0	0.78	0.80
Interior	3000	2500	—	—	—

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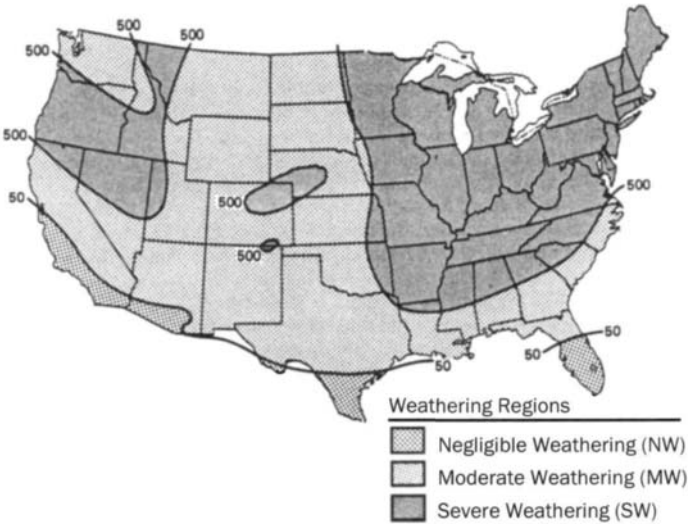
1.6.8 Minimum Physical Requirements for Brick

Unit	Weathering Grade	Minimum Compressive Strength, Gross Area (psi)		Maximum Water Absorption by 5-Hour Boiling (%)		C/B Maximum Saturation Coefficient	
		Average of 5 Tests	Individual Unit	Average of 5 Tests	Individual Unit	Average of 5 Tests	Individual Unit
Face brick (ASTM C216)	SW	3000	2500	17	20	0.78	0.80
	MW	2500	2200	22	25	0.88	0.90
Building brick (ASTM C62)	SW	3000	2500	17	20	0.78	0.80
	MW	2500	2200	22	25	0.88	0.90
	NW	1500	1250	no limit	no limit	no limit	no limit
Hollow brick (ASTM C652)	SW	3000	2500	17	20	0.78	0.80
	MW	2500	2200	22	25	0.88	0.90
Glazed brick (ASTM C1405)	Exterior	6000	5000	—	7 (cold water)	0.78	0.80
	Interior	3000	2500	—	—	—	—
Glazed brick (ASTM C126)	—	3000	2500	—	—	—	—
	—	2000	1500	—	—	—	—

Grade Recommendations for Brick Exposures in Exterior Walls

Exposure	Weathering Index	
	Less Than 50	50 and Greater
In vertical surfaces: In contact with earth Not in contact with earth	MW MW	SW SW
In other than vertical surfaces: In contact with earth Not in contact with earth	SW MW	SW SW

- Grade SW Brick intended for use where high and uniform resistance to damage caused by cyclic freezing is desired, and where the brick may be frozen when permeated with water.
- Grade MW Brick which may be used where moderate resistance to cyclic freezing damage is permissible or where the brick may be damp but not permeated with water when freezing occurs.



1.6.9 Compressive Strength of Brick

Brick Classification by Compressive Strength		
Designation	Minimum Compressive Strength (psi)	
	Average of 5 Units	Individual Unit
2,500	2,500	2,200
4,500	4,500	4,000
6,000	6,000	5,300
8,000	8,000	7,000
10,000	10,000	8,800
12,000	12,000	10,600
14,000	14,000	12,300

(From Schneider and Dickey, Reinforced Masonry Design).

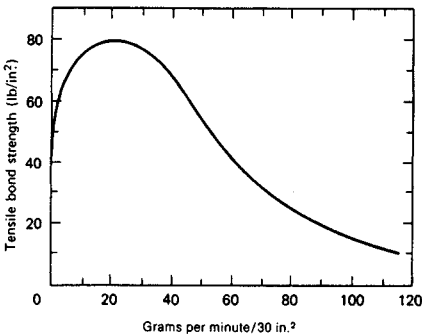
(from Brick Industry Association [BIA], Principles of Brick Masonry, 1973)

Actual Compressive Strength of Brick Produced in the United States	
Range (psi)	Percentage of Production Within Range (%)
21,001 to 22,500	0.46
19,501 to 21,000	0.69
18,001 to 19,500	0.46
16,501 to 18,000	2.04
15,001 to 16,500	1.49
13,501 to 15,000	3.71
12,001 to 13,500	4.76
10,501 to 12,000	7.78
9,001 to 10,500	8.61
7,501 to 9,000	11.92
6,001 to 7,500	15.47
4,501 to 6,000	16.81
3,001 to 4,500	17.97
1,501 to 3,000	7.46
0 to 1,500	0.36
Total Percent	99.99

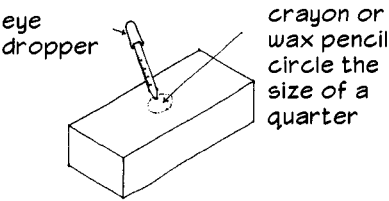
1.6.10 Bond Strength and IRA

High-suction brick absorb excessive water from the mortar which retards cement hydration, weakens bond, and results in water permeable joints. Optimum bond is produced with units having initial rates of absorption (IRA) between 5 and 25 grams/minute/30 sq.in. (the requirement is based on the area of the bed surface of a typical brick being approximately 30 sq.in.). Brick with an IRA greater than 30 grams/minute/30 sq. in. should be thoroughly wetted by spray, dip, or soaker hose a day or so before installation so the moisture is fully absorbed but the surfaces are dry to the touch before the units are laid.

To field test for absorption, draw a circle the size of a quarter on the bed surface of a brick using a crayon or wax pencil. With a medicine dropper, place 12 drops of water inside the circle. If the water is completely absorbed in less than one minute, the brick is too dry and should be wetted before laying.



(from Schneider and Dickey, Reinforced Masonry Design)



field test for brick absorption

1.6.11 Brick Manufacturing Tolerances

Tolerances on Dimensions								
Specified Dimension (in.)	Maximum Permissible Variation (inches) Plus or Minus From							
	Specified Dimension	Specified Dimension or Average Brick Size in Job Lot Sample		Specified Dimension		Average Brick Size in Job Lot Sample [§]		
	ASTM 62	ASTM C652 Type HBX	ASTM C652 Type HBS and HBB	ASTM C216 Type FBX	ASTM C216 Type FBS	ASTM C216 Type FBX	ASTM C216 Type FBX Smooth [†]	ASTM C216 Type FBX Rough [‡]
3 and under	3/32	1/16	3/32	1/16	3/32	1/16	1/16	3/32
Over 3 to 4	1/8	3/32	1/8	3/32	1/8	1/16	3/32	1/8
Over 4 to 6	3/16	1/8	3/16	1/8	3/16	3/32	3/32	3/16
Over 6 to 8	1/4	5/32	1/4	5/32	1/4	3/32	1/8	1/4
Over 8 to 12	5/16	7/32	5/16	7/32	5/16	1/8	3/16	5/16
Over 12 to 16	3/8	9/32	3/8	9/32	3/8	3/16	1/4	3/8

[§] Lot size as determined by agreement between purchaser and seller. If not specified, lot size is understood to mean all brick of one size and color in the job order.

[†] Type FBS Smooth units have relatively fine texture and smooth edges, including wire cut surfaces.

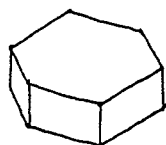
[‡] Type FBS Rough units have textured, rounded, or tumbled edges or faces.

Tolerances on Distortion				
Maximum Dimension (inches)	Maximum Permissible Distortion (inches)			
	ASTM C216		ASTM C652	
	Type FBX	Type FBS	Type HBX	Type HBS
8 and under	1/16	3/32	1/16	3/32
Over 8 to 12	3/32	1/8	3/32	1/8
Over 12 to 16	1/8	5/32	1/8	5/32

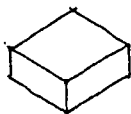
Maximum Permissible Extent of Chippage						
Unit Type	Percentage Allowed [§]	Chippage (in.) in from		Percentage Allowed [§]	Chippage (in.) in from	
		Edge	Corner		Edge	Corner
FBX	5% or less	1/8 to 1/4	1/4 to 3/8	95 to 100%	0 to 1/8	0 to 1/4
FBS Smooth	10% or less	1/4 to 5/16	3/8 to 1/2	90 to 100%	0 to 1/4	0 to 3/8
FBS Rough	15% or less	5/16 to 7/16	1/2 to 3/4	85 to 100%	0 to 5/16	0 to 1/2
FBA	To meet designated sample or as specified by purchaser, but not more restrictive than Type FBS rough					
HBX	5% or less	1/8 to 1/4	1/4 to 3/8	95 to 100%	0 to 1/8	0 to 1/4
HBS Smooth	10% or less	1/4 to 5/16	3/8 to 1/2	90 to 100%	0 to 1/4	0 to 3/8
HBS Rough	15% or less	5/16 to 7/16	1/2 to 3/4	85 to 100%	0 to 5/16	0 to 1/2
HBA and HBB	To meet designated sample or as specified by purchaser, but not more restrictive than Type HBS rough					

[§] Percentage of exposed brick allowed in wall with chips measured the listed dimension in from an edge or corner.

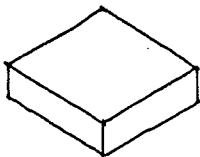
1.6.12 ASTM C902 Pedestrian / Light Traffic Paving Brick



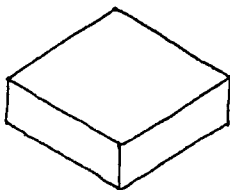
4", 6", or 8"
hexagonal



4" square

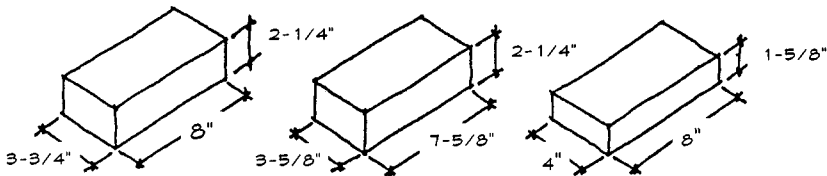


6" square



8" square

- Class SX—Severe Weathering
- Class MX—Moderate Weathering
- Class NX—No Weathering (Interior Use Only)
- Type I—Heavy Traffic
- Type II—Intermediate Traffic
- Type III—Low Traffic
- Application PS—Standard Mortar Installation
- Application PX—Precision Dry Joint Installation
- Application PA—Architectural Effects



actual dimensions

Physical Requirements						
Unit	Minimum Compressive Strength, Flatwise, Gross Area (psi)		Maximum Cold Water Absorption (%)		Maximum Saturation Coefficient	
	Average of 5 Brick	Individual	Average of 5 Brick	Individual	Average of 5 Brick	Individual
Class SX	8000	7000	8	11	0.78	0.80
Class MX	3000	2500	14	17	no limit	no limit
Class NX	3000	2500	no limit	no limit	no limit	no limit

Abrasion Requirements		
Unit	Maximum Abrasion Index	Volume Abrasion Loss, (Max. cm ³ /cm ²)
Type I	0.11	1.7
Type II	0.25	2.7
Type III	0.50	4.0

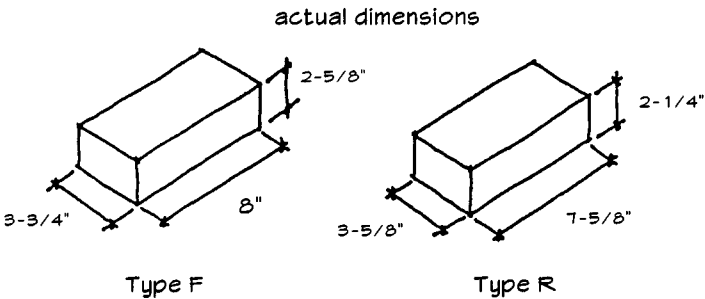
Maximum Permissible Extent of Chippage		
Application	Chippage (in.) in From	
	Edge	Corner
PS	5/16	1/2
PX	1/4	3/8
PA	as specified by purchaser	

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1.6.13 ASTM C1272 Heavy Vehicular Paving Brick

- Type R—brick intended to be set in a mortar setting bed supported by an adequate concrete base, or an asphalt setting bed supported by an adequate asphalt or concrete base
- Type F—brick intended to be set in a sand setting bed, with sand joints, and supported by an adequate base
- Application PS—pavers intended for general use
- Application PX—pavers intended for use where dimensional tolerances, warpage, and chippage are limited
- Application PA—pavers intended to produce characteristic architectural effects resulting from non-uniformity in size, color, and texture

Abrasion Requirements		
Type	Maximum Abrasion Index	Volume Abrasion Loss, (Max. cm ³ /cm ²)
R	0.11	1.7
F	0.11	1.7



Tolerances on Dimensions			
Dimension (in.)	Maximum Permissible Variation (± in.)		
	Application PS	Application PX	Application PA
3 and under	1/8	1/16	no limit
Over 3 to 5	3/16	3/32	no limit
Over 5 to 8	1/4	1/8	no limit
Over 8	5/16	7/32	no limit

Maximum Permissible Extent of Chippage		
Application	Chippage (in.) in From	
	Edge	Corner
PS and PX	5/16	1/2
PA	no limit	no limit

Tolerances on Distortion			
Specified Dimension (in.)	Maximum Permissible Distortion (in.)		
	Application PS	Application PX	Application PA
8 and under	3/32	1/16	no limit
Over 8 to 12	1/8	3/32	no limit
Over 12	5/32	1/8	no limit

Physical Requirements						
Type	Minimum Compressive Strength, Gross Area (psi)		Maximum Cold Water Absorption (%)		Minimum Modulus of Rupture (psi)	
	Average of 5 Brick	Individual	Average of 5 Brick	Individual	Average of 5 Brick	Individual
R	8000	7000	6.0	7.0	1200	1000
F	10000	8800	6.0	7.0	1500	1275

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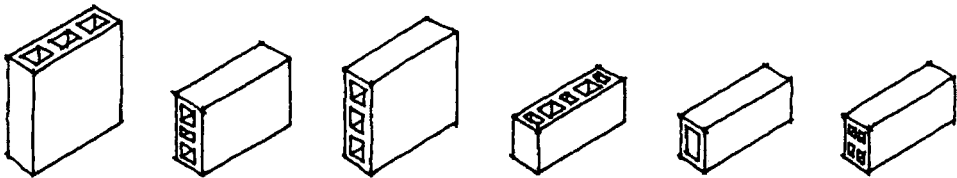
1.6.14 ASTM C1261 Firebox Brick

Firebox brick are used as the lining in the fireboxes of residential fireplaces, and must have resistance to very high temperatures for extended periods of time. Firebox brick are often made from fireclay which has a higher softening point than surface clay and shale. The low oxide content which raises the softening point also causes the brick to burn to a very light brown or light buff color approaching white. Firebox brick are typically installed using a mortar made from ground fire clay. Mortar joints are typically only 1/8 in., or just thick enough to accommodate dimensional variations in the units. Tolerances on dimensional variations are important because tight fit is required to prevent heat loss through the back or sides of the firebox which could result in both thermal inefficiency and fire hazard.

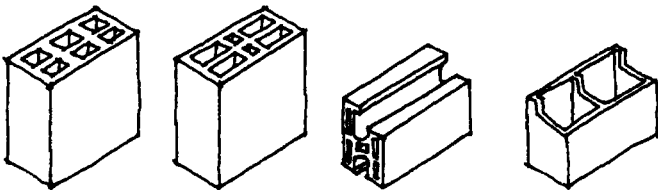
Physical Requirements		
	Minimum Modulus of Rupture (psi)	Minimum Pyrometric Cone Equivalent (PCE)
Firebox brick	500	13

Tolerances on Dimensions		
Specified Dimension (in.)	Maximum Permissible Variation in Dimension (± in.)	Maximum Permissible Distortion (in.)
3 and under	1/16	1/32
Over 3 to 4	1/16	3/64
Over 4 to 6	3/32	1/16
Over 6 to 8	1/8	5/64
Over 8 to 12	5/32	1/8

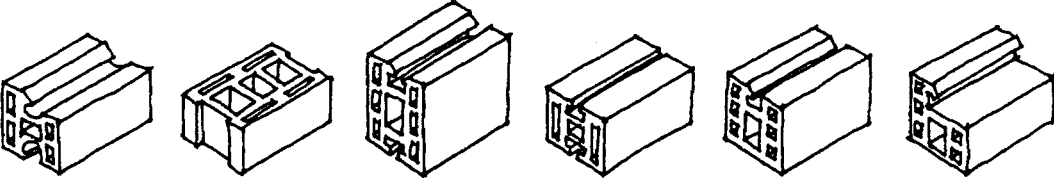
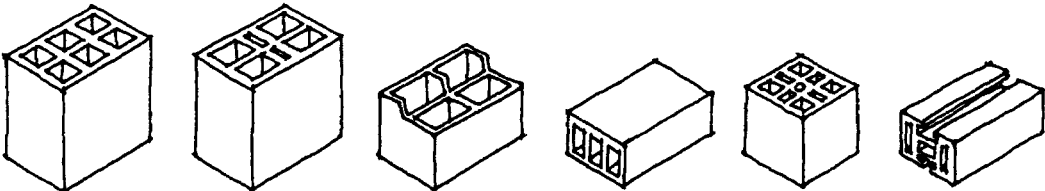
1.7.1 Structural Clay Tile Shapes and Sizes



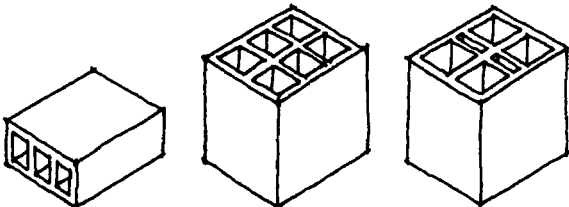
4" wall thickness



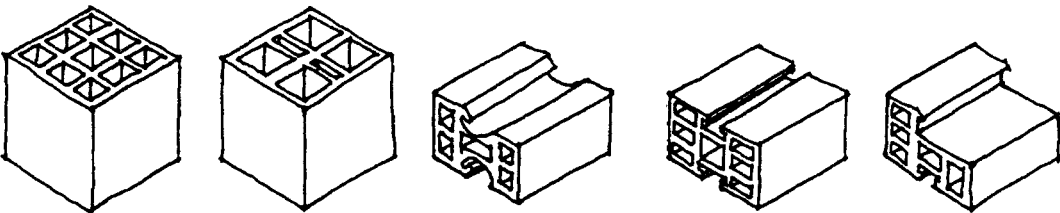
6" wall thickness



8" wall thickness



10" wall thickness



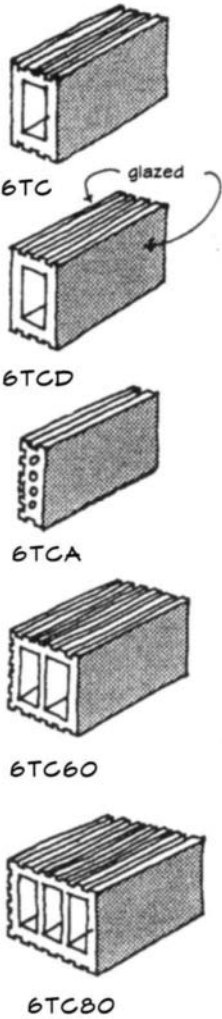
12" wall thickness

1.7.2 Glazed Structural Clay Tile Shapes

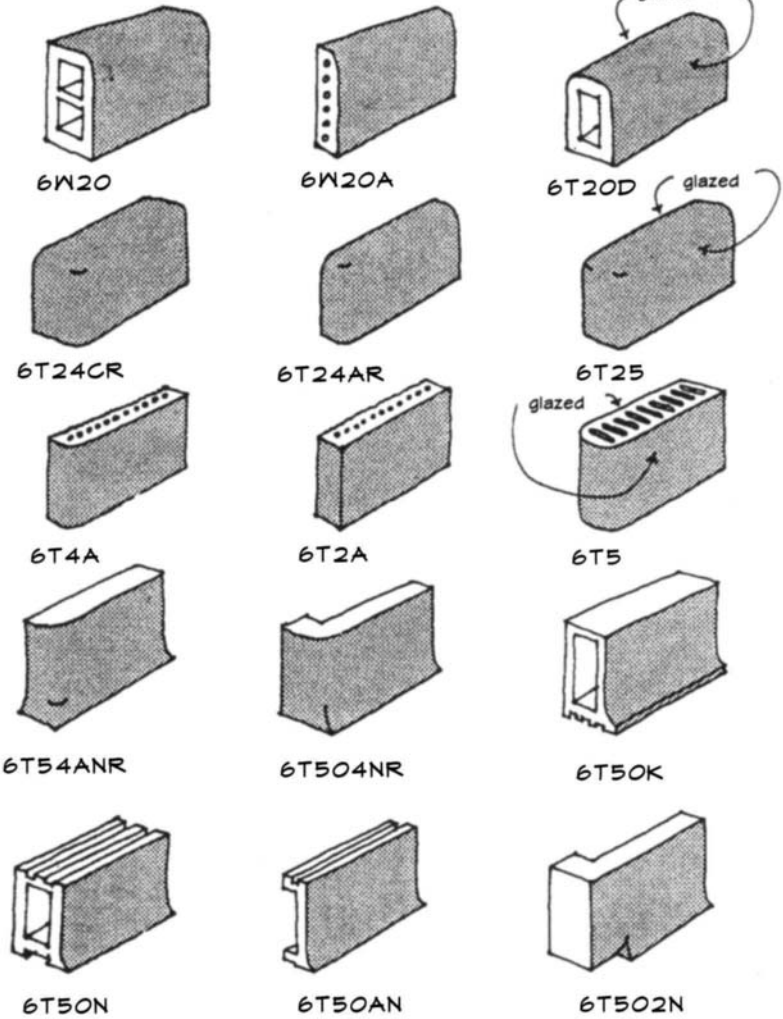
Available Sizes		
Series	Nominal Face Dimensions (in.)	Nominal Thickness (in.)
6T	5-1/3 X 12	2, 4, 6, 8
4D	5-1/3 X 8	2, 4, 6, 8
4S	2-2/3 X 8	2, 4
4W	8 X 8	2, 4, 6, 8
8W	8 X 16	2, 4, 6, 8

Nomenclature	
Prefix: denotes face size	6T, 8W, etc
Number: denotes horizontal or vertical axis and bed depth	bullnose, stretcher, quoin, etc.
Suffix: denotes return, reveal, back face, and right- or left-hand shape	
Example: 6T 2 4 C R	
5-1/3 x 12	right-hand unit
horizontal bullnose	4" bed, 4" return
vertical bullnose	

stretchers



sills, caps, corners, jambs, cove bases



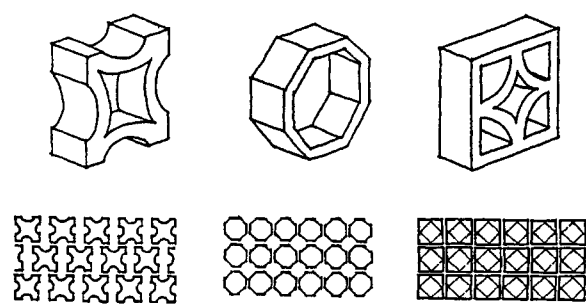
(From Beall, Masonry Design and Detailing, 4th ed., McGraw-Hill, 1997)

1.7.3 Physical Requirements for Structural Clay Tile

Type and Grade	Maximum Water Absorption by 1-Hour Boiling (%)		Minimum Compressive Strength [§] (psi)			
			End Construction Tile		Side Construction Tile	
	Average of Five Units	Individual Unit	Minimum, Average of Five Tests	Minimum, Individual	Minimum, Average of Five Tests	Minimum, Individual
Loadbearing Tile (ASTM C34)						
Grade LBX	16	19	1400	1000	700	500
Grade LB	25	28	1000	700	700	500
Non-Loadbearing Tile (ASTM C56)						
Grade NB	—	28	—	—	—	—
Facing Tile (ASTM C212)						
Type FTX	9	11	—	—	—	—
Type FTS	16	19	—	—	—	—
Standard Class	—	—	1400	1000	700	500
Special Duty Class	—	—	2500	2000	1200	1000
Glazed Tile (ASTM C126)	—	—	3000	2500	2000	1500

§ Based on gross area, obtained as a product of horizontal face dimension (as placed in the wall) times thickness.

1.7.4 ASTM C530 Structural Clay Non-Loadbearing Screen Tile



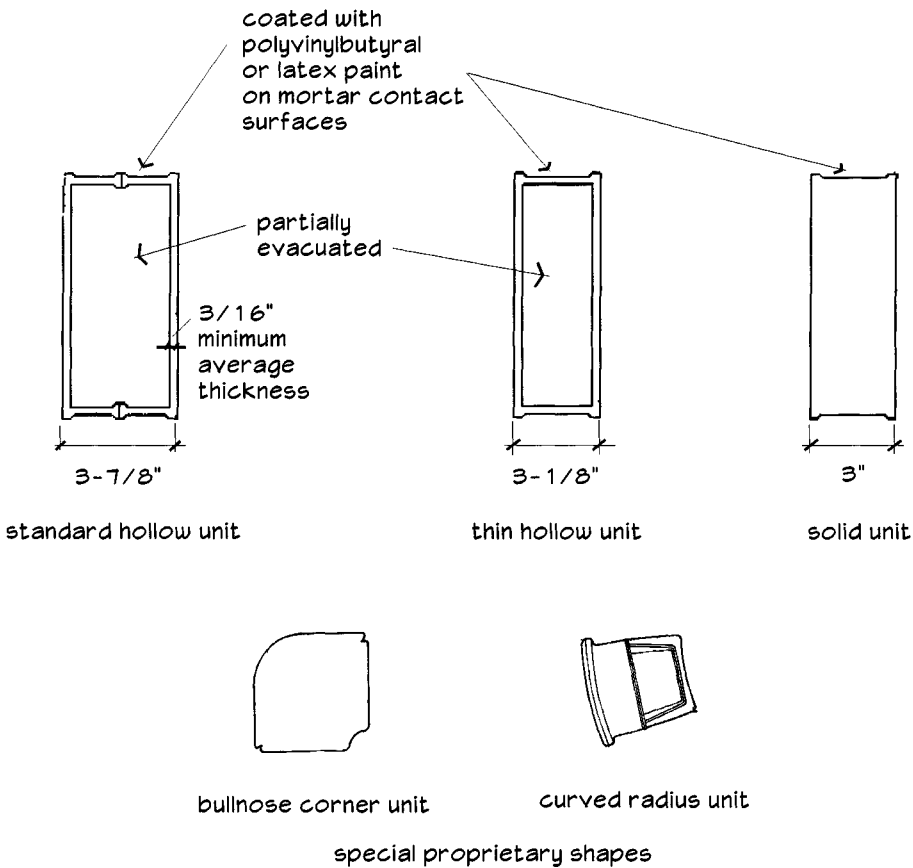
- Grade SE—uniformly high resistance to disintegration by weathering or by freezing or thawing in the presence of moisture
- Grade ME—moderate and somewhat non-uniform resistance to weathering (good durability in areas of mild to moderate exposure, but may not be adequate for severe exposures)
- Grade NE—interior use only
- Type STX—high degree of mechanical perfection and minimum size variation
- Type STA—characteristic architectural effects resulting from larger degree of size variation

Specified Dimension (in.)	Maximum Permissible Variation from Specified Dimensions (±in.)	
	Type STX	Type STA
4 and under	3/32	1/8
Over 4 to 6	1/8	3/16
Over 6 to 8	5/32	1/4
Over 8 to 12	7/32	5/16
Over 12	9/32	3/8

Grade	Maximum Water Absorption by 1-Hour Boiling (%)	
	Average of 5 Tests	Individual Unit
SE	10	12
ME	14	16
NE	20	24

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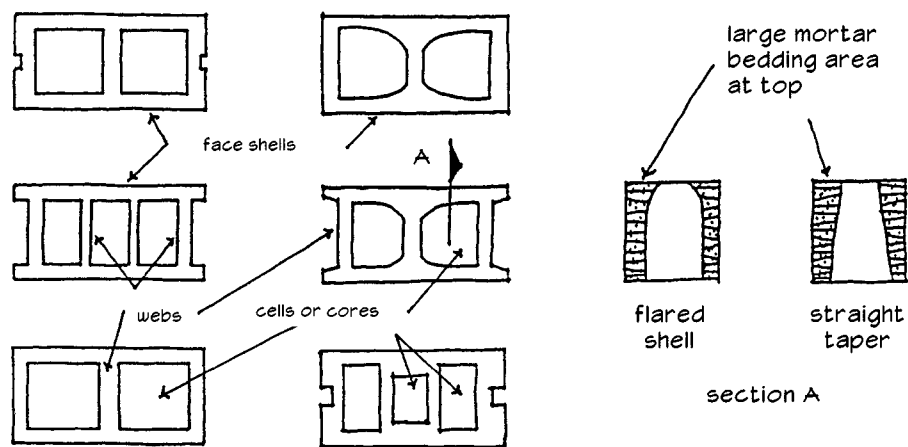
1.8.1 Glass Block Sizes and Shapes



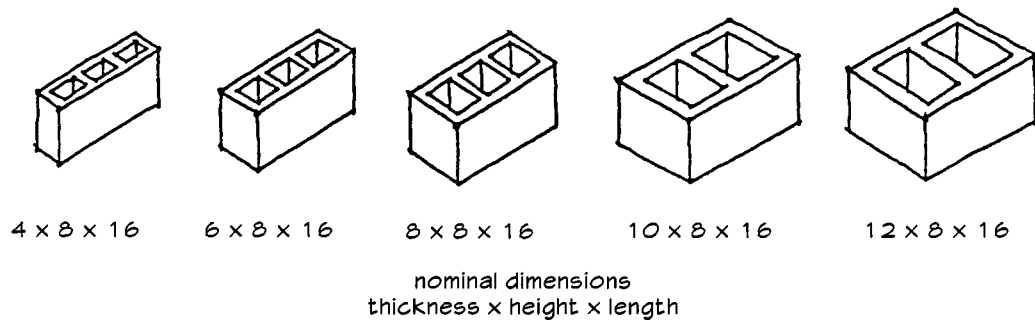
1.8.2 Glass Block Light Transmission and Thermal Performance

Unit Type	Light Transmitted (%)	U-Value	Shading Coefficient	Heat Gain (Btu/hr/sq.ft)
Solid	80	—	—	—
Hollow	50-75	—	—	—
Diffusion	28-40	—	—	—
Reflective	5-20	—	—	—
8 x 8 reflective	20	0.51	0.25	42
8 x 8 clear	62	0.51	0.65	140
1/4" clear sheet glass	90	1.04	1.00	215

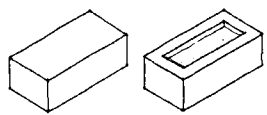
1.9.1 Standard Concrete Masonry Unit (CMU) Stretchers and Unit Coring



two-core and three-core concrete block

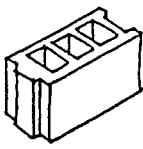


concrete block

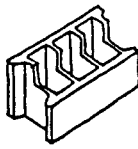


concrete and calcium silicate (sand lime) brick

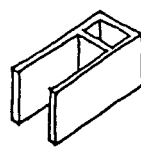
1.9.2 Special Shape Concrete Masonry Units



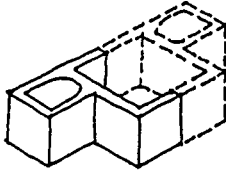
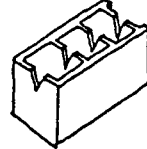
control joint unit



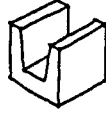
header unit



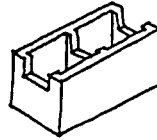
plumbing or conduit units



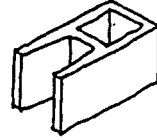
half pilaster unit



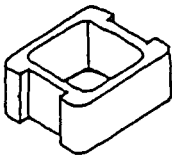
channel lintel



bond beam



open end unit for
vertical
reinforcing steel



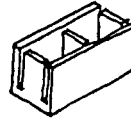
full pilaster



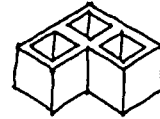
sill



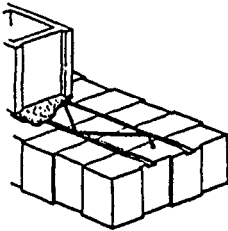
coping



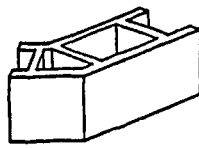
knockout web
bond beam



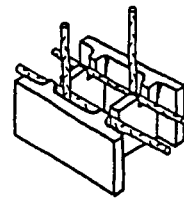
corner
pilaster



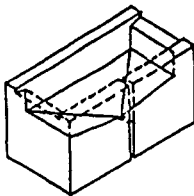
footer block



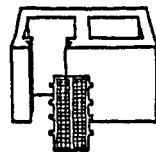
45° angle corner



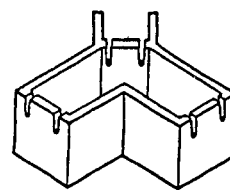
"ivany" block



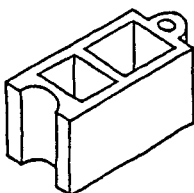
integral flashing unit



inspection and
cleanout unit

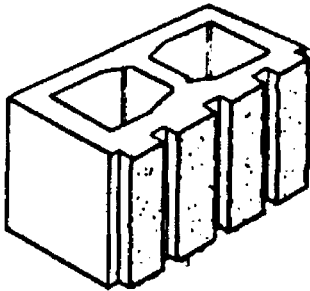


3-way
intersection

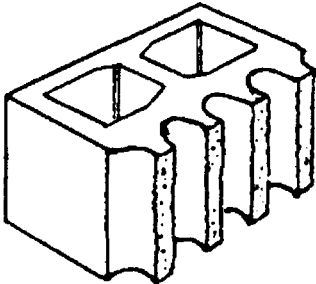


radial unit

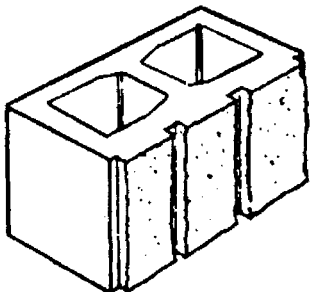
1.9.3 Architectural Concrete Masonry Units



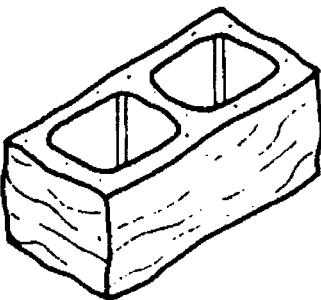
4-scored split face



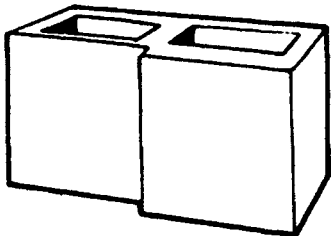
fluted split face



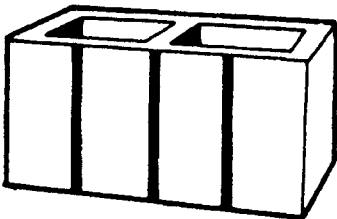
3-scored split face



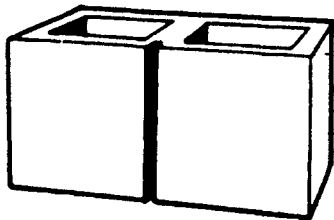
slump block



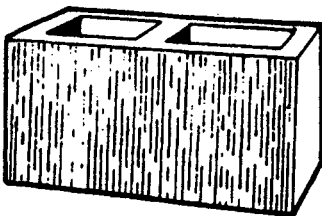
offset smooth face



4-scored smooth face



scored burnished face



combed, split face or burnished

1.9.4 Physical Requirements for Concrete Masonry Units

Strength and Absorption Requirements

Unit	Minimum Compressive Strength (psi)		Maximum Water Absorption (pcf), Average of 3 Units, Weight Classification—Oven Dry Weight of Concrete		
	Average of 3 Units	Individual Unit	Lightweight (less than 105 pcf)	Medium Weight (105 to 125 pcf)	Normal Weight (125 pcf or more)
Loadbearing CMU (ASTM C90)	1900 (net area)	1700 (net area)	18	15	13
Non-Loadbearing CMU (ASTM C129)	600 (net area)	500 (net area)	—	—	—
Concrete Brick (ASTM C55)					
Grade N	3500 (gross area)	3000 (gross area)	15	13	10
Grade S	2500 (gross area)	2000 (gross area)	18	15	13
Calcium Silicate Brick (Sand Lime Brick) (ASTM C73)					
Grade SW	4500 (gross area)	3500 (gross area)	—	—	10
Grade MW	2500 (gross area)	2000 (gross area)	—	—	13

Minimum Face Shell and Web Thickness for ASTM C90 Loadbearing CMU

Nominal Width of Units (in.)	Minimum Face Shell Thickness (in.) [§]	Minimum Web [§] Thickness (in.)	Minimum Equivalent Web Thickness (in./lin.ft.) ^{†‡}
3	3/4	3/4	1-5/8
6	1	1	2-1/4
8	1-1/4*	1	2-1/4
10	1-3/8*	1-1/8	2-1/2
12	1-1/2	1-1/8	2-1/2

[§] Average of measurements on 3 units taken at the thinnest point when measured as described in ASTM C140 Standard Test Methods of Sampling and Testing Concrete Masonry Units. When this standard is used for split face units, a maximum of 10% of a split face shell area may have thickness less than those shown, but not less than 3/4 in. When the units are solid grouted, the 10% limit does not apply.

[†] Average of measurements on 3 units taken at the thinnest point when measured as described in ASTM C140 Standard Test Methods of Sampling and Testing Concrete Masonry Units. The minimum web thickness for units with webs closer than 1 in. apart shall be 3/4 in.

[‡] Sum of the measured thicknesses of all webs in the unit, multiplied by 12 and divided by the length of the unit. Equivalent web thickness does not apply to the portion of the unit to be filled with grout. The length of that portion shall be deducted from the overall length of the unit for the calculation of the equivalent web thickness.

* For solid grouted masonry construction, minimum face shell thickness shall be not less than 5/8 in.

† This face shell thickness is applicable where allowable design load is reduced in proportion to the reduction in thickness from basic face shell thicknesses shown, except that allowable design loads on solid grouted units shall not be reduced.

1.9.5 ASTM C744 Prefaced Concrete Masonry Units

Requirements for Facing [§]	
Property or Characteristic	Requirement
Resistance to crazing, cracking, or spalling	None when tested in accordance with specified method
Chemical resistance	No change after testing with specified chemicals [†]
Adhesion of facing	No failure of adhesion of facing material at unit compression test failure
Abrasion resistance	Wear index shall exceed 130 when tested in accordance with specified method
Surface burning characteristics	Flame spread less than 25, smoke density less than 50
Color, tint and texture	As specified by purchaser, change less than 5 Delta units when tested in accordance with specified method
Soiling and cleansability	Visible stain not to exceed trace when tested in accordance with specified method Spotting media completely removed when tested in accordance with specified method

§ Facing of resin, resin and inert filler, or cement and inert filler producing a smooth resinous tile facing.

† See table below.

Chemical Resistance	
Chemical	Duration of Test (hr.)
Acetic acid, CH ₃ COOH, 5%	24
Hydrochloric acid, HCl, 10%	3
Potassium hydroxide, KOH, 10%	3
Trisodium phosphate, Na ₃ PO ₄ , 5%	24
Hydrogen peroxide, H ₂ O ₂ , 3%	24
Laundry detergent, 10%	24
Vegetable oil	24
Blue-black ink	1
Ethyl alcohol, industrial denatured, 95%	3

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Manufacturing Tolerances	
Type of Tolerance	Requirement
Size	Total variation from specified dimensions of finished face height and length shall not exceed ± 1/16 in.
Distortion	Distortion of plane and edges of facing from plane and edges of unit, maximum 1/16 in.
Cracking, chippage	Units shall be sound and free of cracks or other defects which interfere with placement or impair strength. Facing shall be free of chips, crazes, cracks, blisters, crawling, holes, and other imperfections which detract from appearance when viewed from a distance of 5 ft. perpendicular to facing surface using daylight without direct sunlight.

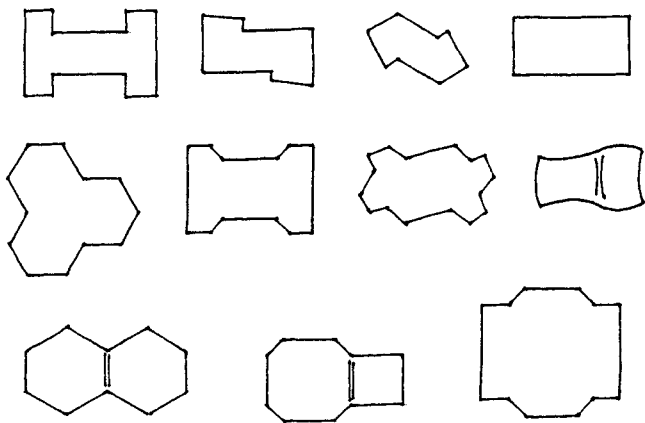
1.9.6 CMU Aggregate Type and Unit Weight

Effect of Aggregate on Weight and Physical Properties						
Classification	Aggregate	Unit Weight of Concrete (pcf)	Average Weight of 8 x 8 x 16 Unit (lb)	Net Area Compressive Strength (psi)	Water Absorption (lb/cu.ft of concrete)	Thermal Expansion Coefficient (per °F x 10 ⁻⁴)
Normal weight	Sand and gravel	135	44	2200-3400	7-10	5.0
	Crushed stone	135	40	2000-3400	8-12	5.0
Medium weight	Air-cooled slag	120	35	2000-2800	10-15	4.6
Light weight	Coal cinders	95	28	1300-1800	12-18	2.5
	Expanded slag	95	28	1300-2200	12-16	4.0
	Scoria	95	28	1300-2200	12-16	4.0
	Expanded clay, shale, and slate	85	25	1800-2800	12-15	4.5
	Pumice	75	22	1300-1700	13-18	4.0

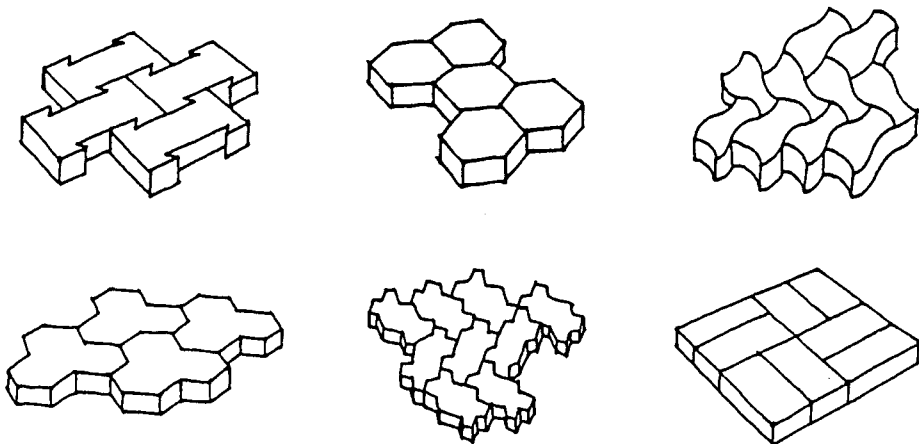
Average Weight of Concrete Masonry Units (lbs/unit)															
Unit Thickness (in.) →	Light Weight 103 pcf concrete					Medium Weight 115 pcf concrete					Normal Weight 135 pcf concrete				
	4	6	8	10	12	4	6	8	10	12	4	6	8	10	12
4" high units	8	11	13	15	20	9	13	15	17	22	10	16	18	20	26
8" high units	16	23	27	32	42	18	28	32	36	47	21	33	37	42	55

(From Beall, Masonry Design and Detailing, 4th ed., McGraw-Hill, 1997)

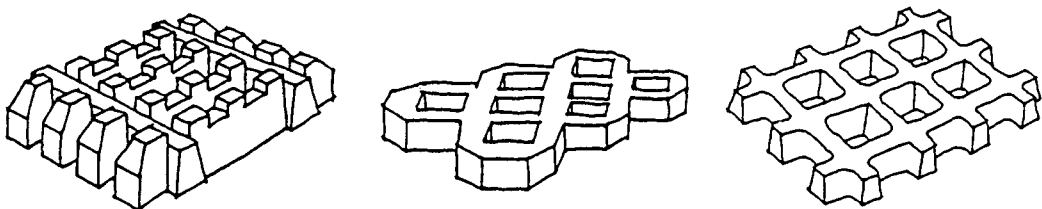
1.9.7 Concrete Masonry Pavers



solid concrete masonry
paver shapes



solid concrete masonry paver patterns



concrete masonry grid pavers

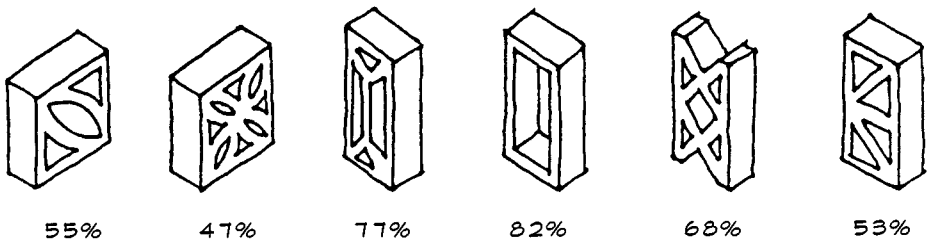
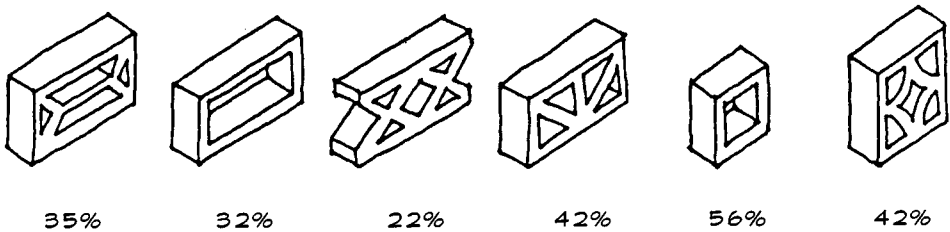
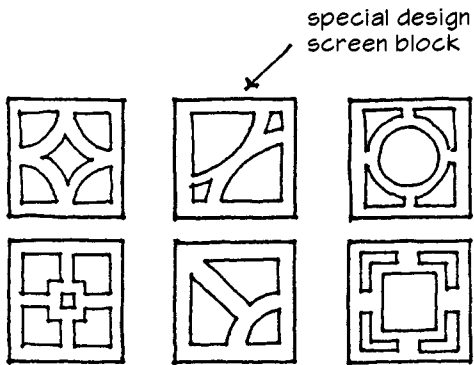
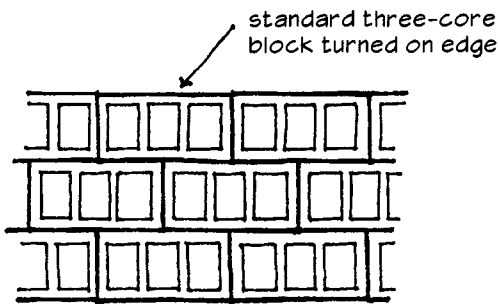
1.9.8 Physical Requirements of Concrete Masonry Pavers

ASTM C936 Requirements for Solid Concrete Interlocking Paving Units								
Compressive Strength (psi)		Absorption (%)		Freeze-Thaw Resistance, Loss in Dry Mass (%)	Abrasion Resistance		Dimensional Tolerance (± in.)	
Average	Individual Unit	Average	Individual		Volume Loss (in³/7.75 in²)	Thickness Loss (in.)	Length or Width	Height
8000	7200	5	7	1.0	0.915	0.118	1/16	1/8

ASTM C1319 Requirements for Concrete Grid Paving Units					
Net Area Compressive Strength (psi)		Maximum Water Absorption (lb/cu.ft)	Minimum Net Area (%)	Web Width (in.)	
Average of 3 Units	Individual Unit	Average of 3 Units		Minimum	Average
5000	4500	10	50	1.00	1.25

(Tables this page copyright ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428. Reprinted with permission.)

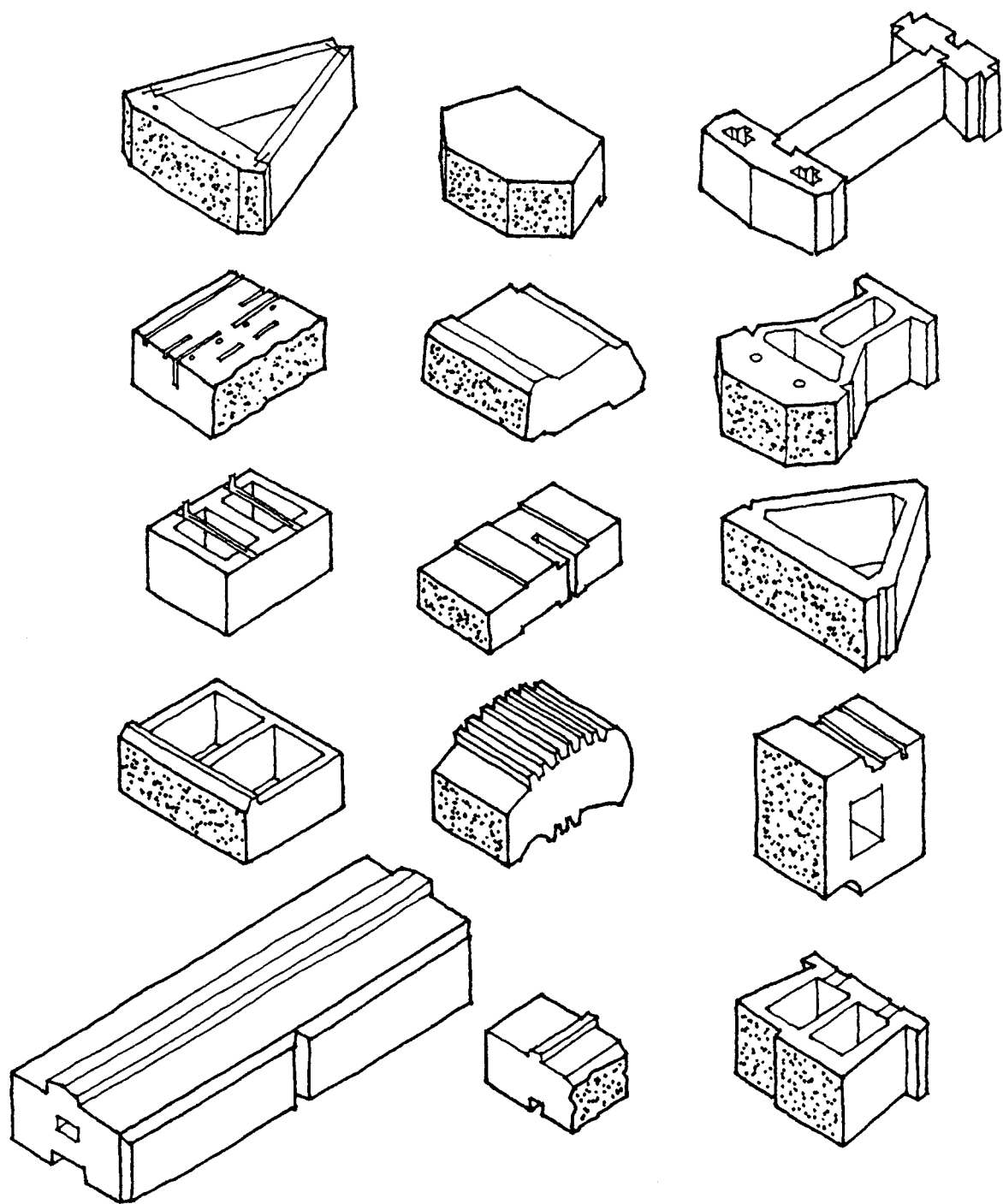
1.9.9 Concrete Masonry Screen Block



values represent the relative compressive strength of units loaded as shown, expressed as a percentage of strength when loaded with cores vertically oriented

(From Beall, Masonry Design and Detailing, 4th ed., McGraw-Hill, 1997)

1.9.10 Concrete Masonry Segmental Retaining Wall (SRW) Units



proprietary interlocking SRW systems use a variety of unit shapes

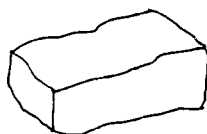
1.10.1 Stone Forms and Surface Finishes



fieldstone
rubble

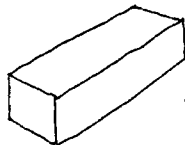


quarried
rubble



roughly squared
rubble

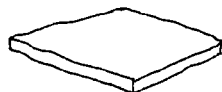
building stone may be
fabricated or used in
any of several forms



ashlar cut stone



mosaic flagstone



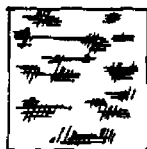
geometric flagstone



rock or
pitch-faced



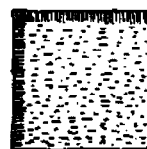
gang or
chat-sawed



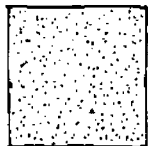
shot sawed



machined
(planar)



pointed (with
tooled margin)



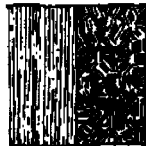
bush-hammered



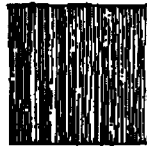
patent-hammered



drove or
boasted



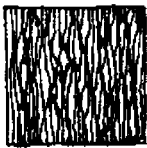
hand tooled



machine
tooled



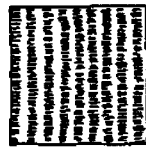
crandalled



plucked



pean-hammered



tooth chiseled



very smooth

carborundum



smooth

wet rubbed



very smooth

rubbed and honed



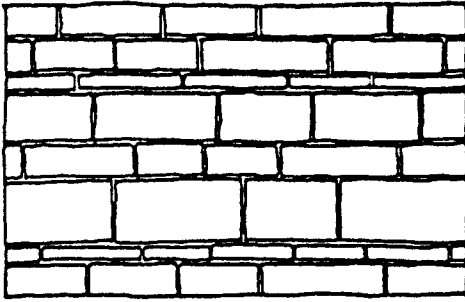
very smooth
high gloss

honed and polished

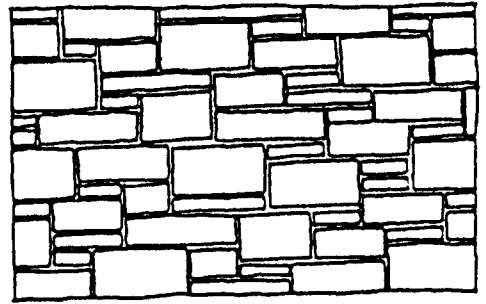
stone
surface
finishes

(From Ramsey and Sleeper, Architectural Graphic Standards, 6th edition, ed. Joseph Boaz. Copyright 1970 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc.)

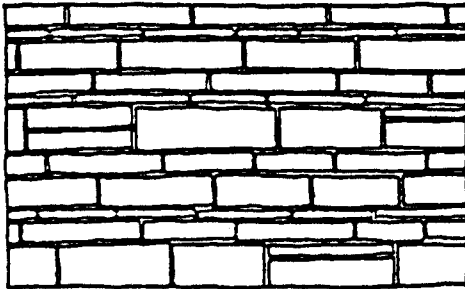
1.10.2 Stone Bonding Patterns



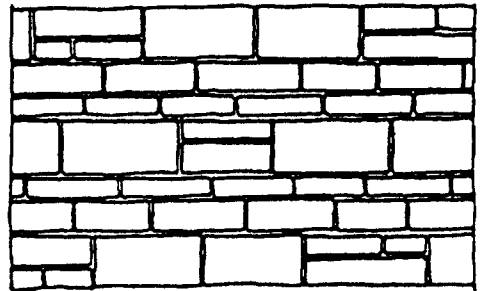
coursed ashlar



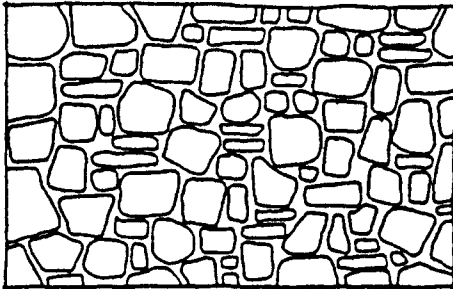
random ashlar



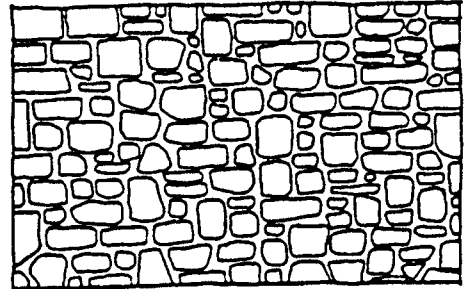
coursed ashlar



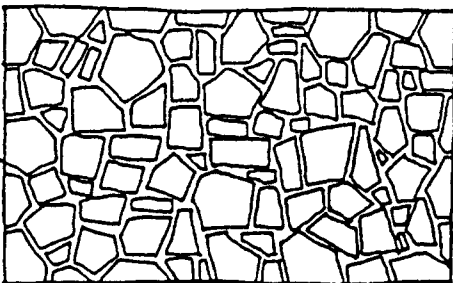
coursed ashlar



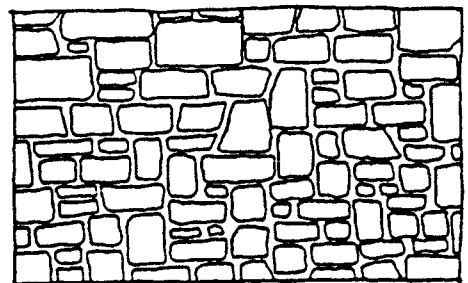
uncoursed rubble



coursed rubble



random mosaic rubble



coursed, roughly squared rubble

1.10.3 Properties of Building Stone

Physical Properties and Minimum ASTM Requirements

Stone Type	Maximum Absorption by Weight, ASTM C97 (%)	Minimum Density, ASTM C97 (%)	Minimum Compressive Strength, ASTM C170 (psi)	Minimum Modulus of Rupture, ASTM C99 (psi)	Minimum Abrasion Resistance, ASTM C241 (hardness)	Minimum Flexural Strength, ASTM C880 (psi)	Maximum Acid Resistance, ASTM C217 (in.)	Thermal Expansion Coefficient (10 ⁻⁶ /°F)	Modulus of Elasticity (psi)	Ultimate Shear Strength (psi)	Ultimate Tensile Strength (psi)
Marble ASTM C503								3.69–12.30	1,970,000 to 14,850,000	1638 to 4812	50 to 2300
I. Calcite	0.20	162	7500	1000	10	1000	N/A				
II. Dolomite	0.20	175	7500	1000	10	1000	N/A				
III. Serpentine	0.20	168	7500	1000	10	1000	N/A				
IV. Travertine	0.20	144	7500	1000	10	1000	N/A				
Limestone ASTM C568								2.4–3.0	3,300,000 to 5,400,000	900 to 1800	300 to 715
I. Low Density	12.0	110	1800	400	10	—	N/A				
II. Medium Density	7.5	135	4000	500	10	—	N/A				
III. High Density	3.0	160	8000	1000	10	—	N/A				
Granite ASTM C615	0.40	160	19000	1500	—	—	N/A	6.3–9.0	5,700,000 to	2000 to	600 to
Sandstone ASTM C616								5.0–12.0	1,900,000 to 7,700,000	300 to 3000	280 to 500
I. Sandstone	20.0	140	2000	300	8	—	N/A				
II. Quartzite	3.0	150	10000	1000	8	—	N/A				
Sandstone											
III. Quartzite (Bluestone)	1.0	160	20000	2000	8	—	N/A				
Slate ASTM C629								9.4–12.0	9,800,000 to 18,000,000	2000 to 3600	3000 to 4300
I. Exterior	0.25	—	—	across grain 9000 along grain 7200	8	—	0.015				
II. Interior	0.24	—	—		8	—	0.025				

1.10.4 Fabrication Tolerances for Building Stone

Allowable Tolerances for Marble Building Stone		
Thickness	Panel Finished on Both Faces (in.)	Panel Finished on One Face (in.)
Thin stock (3/4" to 2")	+0, -1/16	+1/8, -1/16
Cubic stock (over 2")	±1/16	+3/16, -1/8
Marble tile	—	±1/32
Sizes and Squareness		
Thin stock	±1/16	±1/16
Cubic stock	—	±1/16

Dimensional Tolerances for Indiana Limestone						
Type of Stone	Length (in.)	Height (in.)	Deviation From Flat Surface, Exposed Face (in.)	Critical Depth (in.)	Non-Critical Depth (in.)	Deviation From Square (in.)
Smooth machine finish	±1/16	±1/16	±1/16	±1/16	±1/2	±1/16
Diamond gang finish	±1/16	±1/16	±1/4	±1/8	±1/2	±1/16
Chat sawed finish	±1/16	±1/16	±1/4	±1/8	±1/2	±1/16
Shot sawed finish	±1/16	±1/16	±1/2	±1/4	±1/2	±1/16
Pre-assembled units	±1/8	±1/8	±1/8	±1/8	±1/2	±1/8
Panels over 50 sq.ft.	±1/8	±1/8	±1/8	±1/8	±1/2	±1/8

Note: Tolerances for deviation from flat surface, exposed face and dimension from square are measured within the length of a standard 4'-0" straightedge applied at any angle on the face of the stone.

Variations from True Plane for Granite Building Stone	
Type of Finish	Variations From True Plane on Parts of Face Surfaces Other Than Bed and Joint Arris Lines (in.)
Polished, honed or fine rubbed	±3/64
Rubbed or fine stippled sand blasted	±1/16
Shot ground, 8- and 6- cut	±3/32
4-cut and sawn	±1/8
Thermal and coarse stippled sand blasted	±3/16

Concrete, Mortar, and Grout Mixes

2.1 Concrete, Mortar, and Grout

- 2.1.1 Basics of Cementitious Mixes
- 2.1.2 Components of Concrete, Mortar, and Grout
- 2.1.3 Comparison of Concrete, Mortar, and Grout Characteristics

2.2 Normal Weight Concrete Mixes

- 2.2.1 Properties of Fresh Concrete
- 2.2.2 Properties of Hardened Concrete
- 2.2.3 Effects of Cement Content on Concrete
- 2.2.4 Water-Cement Ratio in Concrete
- 2.2.5 Concrete Slump
- 2.2.6 Aggregate Size and Gradation
- 2.2.7 Maximum Concrete Aggregate Size Relative to Formwork and Reinforcement
- 2.2.8 Effect of Maximum Aggregate Size on Volume of Other Ingredients
- 2.2.9 Concrete Shrinkage as a Function of Aggregate Content
- 2.2.10 Water and Air Content in Concrete Mixes
- 2.2.11 Effect of Air Content on Other Concrete Properties
- 2.2.12 Effect of Mix Design and Concrete Ingredients on Air Content
- 2.2.13 Recommended Concrete Mixes for Various Exposure Conditions
- 2.2.14 Concrete Proportions by Weight
- 2.2.15 Concrete Proportions by Volume
- 2.2.16 Estimating Concrete Quantity

2.3 Masonry Mortar

- 2.3.1 Properties of Fresh Masonry Mortar
- 2.3.2 Properties of Hardened Masonry Mortar
- 2.3.3 Mortar Types and Applications
- 2.3.4 ASTM C270 Mortar Proportion and Mortar Property Specifications
- 2.3.5 ASTM C270 Mortar Proportion and Mortar Property Specification Requirements
- 2.3.6 Volume Measurement of Mortar Materials
- 2.3.7 Relationship Between Mortar Composition, Strength, and Water Retention

- 2.3.8 Recommended Repointing Mortars

- 2.3.9 Estimating Mortar Quantities

2.4 Masonry Grout

- 2.4.1 ASTM C476 Masonry Grout Requirements
- 2.4.2 ASTM C1019 Masonry Grout Test Prisms
- 2.4.3 Masonry Grout Space Requirements
- 2.4.4 Maximum Area of Steel per CMU Core
- 2.4.5 Maximum Number of Reinforcing Bars per CMU Core
- 2.4.6 Estimating Masonry Grout Quantities

2.5 Fiber Reinforced Concrete

- 2.5.1 Aggregate Gradation and Mix Proportions for Steel Fiber Reinforced Concrete
- 2.5.2 Steel Fiber Volume and Geometry
- 2.5.3 Glass Fiber Reinforced Concrete (GFRC)

2.6 Lightweight Concrete

- 2.6.1 Aggregate for Lightweight Concrete
- 2.6.2 Structural Lightweight Concrete Mixes
- 2.6.3 Lightweight Insulating Concrete Mixes

2.7 High-Strength Concrete

- 2.7.1 Recommendations for High-Strength Concrete
- 2.7.2 Water-Cement Ratios for High-Strength Concrete

2.1.1 Basics of Cementitious Mixes

Cementitious mixes of concrete, mortar, and grout are simply combinations of cement, aggregate, and water. Through a chemical process known as hydration, cement particles combine with water to develop long crystals that act to bond the mix together. In the continued presence of water and in temperatures that are not too low, crystals continue to grow and increase the strength of the cementitious mix.

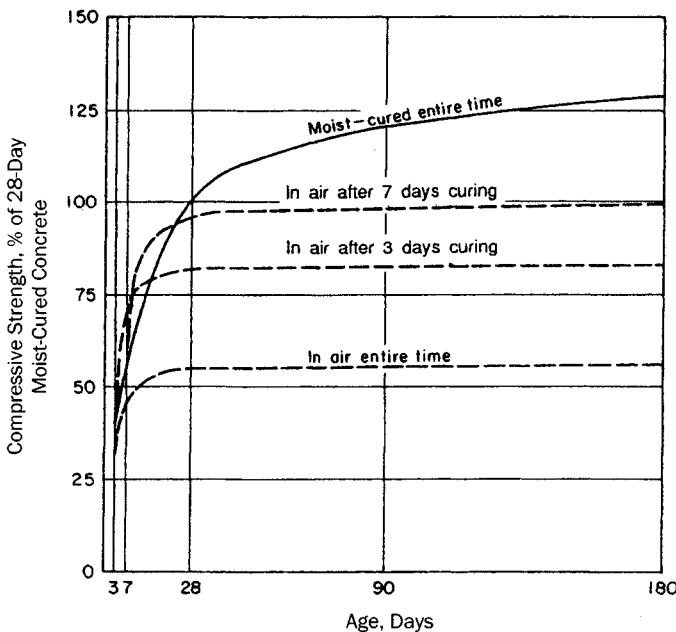
The ratio of water to cement is important. Typically, the ratio should be no more than 0.50 by weight (i.e. 1/2 pound of water to 1 pound of cement). In mortar and grout mixes, the ratio is permitted to be greater because the masonry units absorb some of the water out of the mix. In concrete, the water to cement ratio greatly influences durability, watertightness, and strength. Decreasing strength with increased ratios of water to cement is illustrated in Section 2.2.4.

Concrete curing is important because gains in both strength and watertightness continue for years after placement, if curing is continued. The greatest gains occur during the first one to two weeks after placement, when curing is most important. Uncured concrete dries out and may reach only half of its design strength. Curing also reduces shrinkage stresses and, therefore, shrinkage cracking.

Consistency, stiffness, and workability of a cementitious mix are equally important to strength. These properties are commonly measured on site by performing a slump test. The amount of water influences the slump, but so do the type of aggregate, air content, admixtures, temperature, and proportions of ingredients, as well as mixing time and standing. The slump test is illustrated in Section 2.2.5.

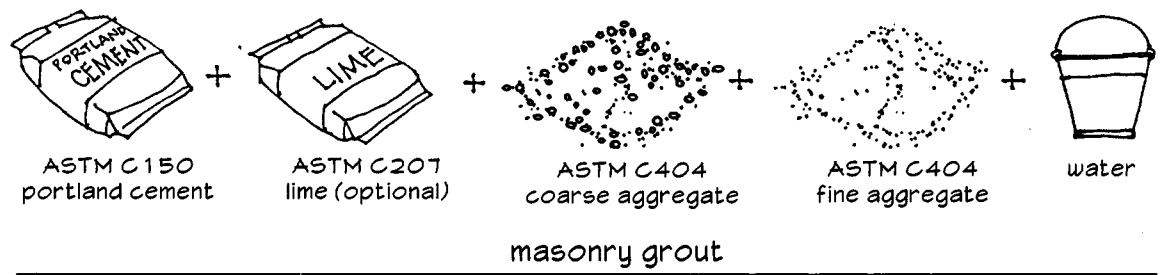
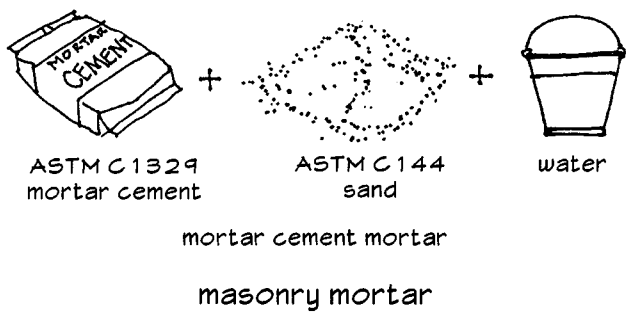
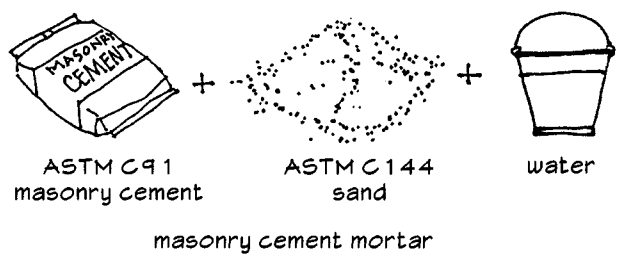
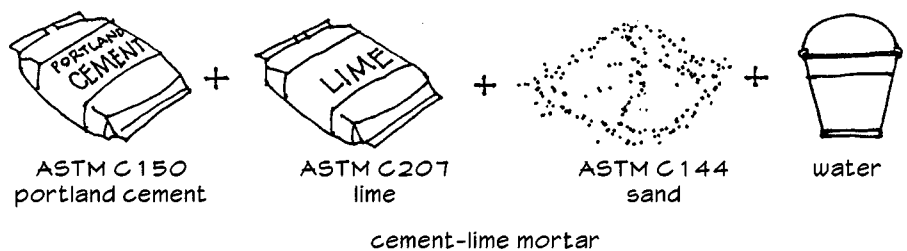
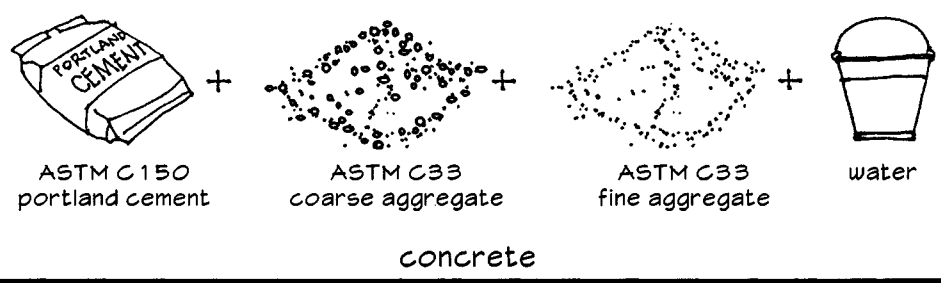
General mix design recommendations:

- Limit water-to-cement ratio to optimize strength and durability.
- Properly cure concrete to increase watertightness and resistance to spalling and crazing.
- Avoid too much cement paste, which reduces resistance to abrasion and cracking.
- Avoid too much aggregate, which causes the mix to be stiff, harsh, and difficult to place and finish.
- Avoid too much fine aggregate in concrete, which increases water demand, and leads to cracking and excessive shrinkage.
- Avoid too much coarse aggregate in concrete and grout, which produces porous and honeycombed concrete and grout.

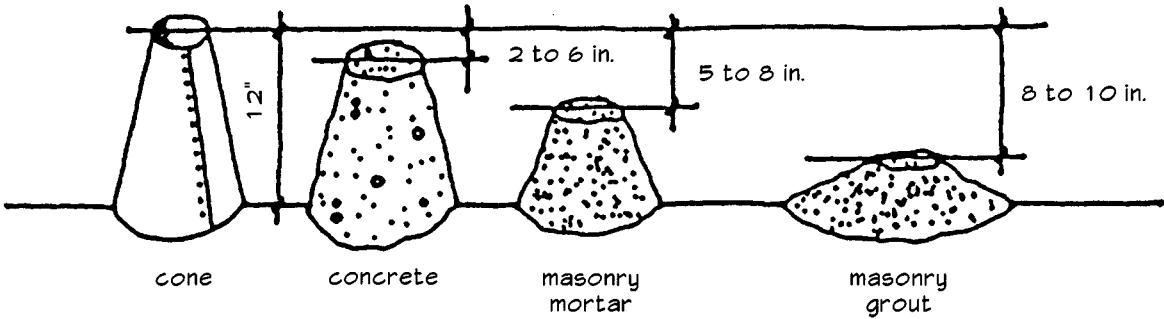


(From PCI Design Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)

2.1.2 Components of Concrete, Mortar, and Grout



2.1.3 Comparison of Concrete, Mortar and Grout Characteristics



relative consistency of concrete, mortar, and grout

Concrete	Masonry Mortar	Masonry Grout
<p>Concrete mix design is based on attaining adequate compressive strength and appropriate workability for the intended application. Strength is derived from the bonding of aggregate and reinforcing steel with cement paste, and workability is related to water content.</p> <p>Compressive strength increases with a higher cement content and a lower water-cement ratio. For a given amount of cement, decreasing the amount of mixing water increases the strength of the paste, making the concrete stronger and more durable. Forms must be fabricated of non-absorptive materials or treated before concrete placement to prevent absorption of mixing water and maintain water-cement ratio.</p> <p>Concrete is generally mixed with the <i>minimum</i> amount of water required to produce workability appropriate to the method of placement. The amount of water is determined by laboratory mix design.</p>	<p>Masonry mortar is used to bind units, anchors, ties, and joint reinforcement together. It must have maximum bond strength, but only the minimum compressive strength required for the imposed loads. Compressive strength is determined by cement content. As cement content and compressive strength increase, bond strength increases slightly.</p> <p>Bond strength is closely related to workability, which is in turn affected by the absorption characteristics of the masonry units being used. To compensate for the absorption of porous masonry units, masonry mortar must be made with a higher initial water content than concrete. The water content is immediately reduced by the absorption of the masonry units.</p> <p>Masonry mortar is generally mixed with the <i>maximum</i> amount of water required to produce good workability with a given unit. The amount of water is determined by the mason based on masonry unit absorption and field conditions.</p>	<p>Masonry grout is used to bind units, ties, and reinforcing steel together. It must have maximum bond strength, but only the minimum compressive strength required for the imposed loads. Grout compressive strength should not greatly exceed the compressive strength of the masonry units.</p> <p>Masonry grout must be very fluid for pouring or pumping into the small cores of hollow units or narrow cavities between multiple wythes of masonry and must flow easily around reinforcing steel in tight spaces. The excess mixing water required to produce this fluidity is immediately absorbed by the masonry units.</p> <p>Masonry grout is usually mixed with the <i>maximum</i> amount of water required to produce good flow properties. The amount of water is determined by the mason based on masonry unit absorption and field conditions.</p>

2.2.1 Properties of Fresh Concrete

- Workability:** Workability is the relative ease with which a fresh concrete mix can be handled, placed, compacted, and finished without segregation or separation of the ingredients. Good workability is required to produce concrete that is both economical and high in quality. Fresh concrete has good workability if it can be formed, compacted, and finished to its final shape and texture with minimal effort and without segregation of the ingredients. Concrete with poor workability does not flow smoothly into forms and properly envelop reinforcing steel and embedded items, and it is difficult to compact and finish. Depending on the application, however, a mix that has good workability for one type or size of element may be too stiff or harsh for another, so the term is relative. Each mix must be suitable for its intended use, achieving a balance among required fluidity, strength, and economy. Workability is related to the consistency and cohesiveness of the mix, and is affected by cement content, aggregates, water content, and admixtures.
- Consistency:** Consistency is the aspect of workability related to the flow characteristics of fresh concrete. It is an indication of the fluidity or wetness of a mix and is measured by the slump test. Fresh concrete is placed in a metal cone. When the cone is removed, the concrete slumps a certain amount depending on how fluid it is. A wet, soft mix slumps more than a drier, stiffer one. A high-slump concrete is one that is very fluid, and a low-slump concrete is drier and more stiff. A high-slump mix may cause excessive bleeding, shrinkage, cracking, and dusting of the hardened concrete surface. There is a certain range of consistency that is appropriate for each type of work. Workability is at a maximum in concrete of medium consistency with a slump between 3 and 6 in. Both very dry (low-slump) and very wet (high-slump) mixes are less workable.
- Cohesiveness:** Cohesiveness is the element of workability which indicates whether a mix is harsh, sticky, or plastic. *Plasticity* is a desirable property in concrete, indicating that a mix can be molded and hold a shape when formed. A *harsh mix* lacks plasticity and the ingredients may tend to separate. Harshness can be caused by either an excess or deficiency of mixing water (high- or low-slump mixes), a deficiency of cement (*lean mixes*), or a deficiency of fine aggregate particles. Harshness may also be caused by an excess of rough, angular, flat, or elongated aggregate particles. Harsh mixes can sometimes be improved by air entrainment or by increasing the fine aggregate or cement content, but adjustments must be made to the overall mix to maintain the proper proportion of all ingredients. A *sticky mix* may have a high cement content (*fat mixes*) or large amounts of rock dust, fine sand, or similar fine materials (*oversanded mixes*). Sticky mixes do not segregate easily, but because they require a lot of water to achieve even minimal workability, sticky mixes often develop excessive shrinkage cracking. A plastic mix is cohesive without being either sticky or harsh, and the ingredients do not easily segregate unless the concrete is handled improperly.

2.2.2 Properties of Hardened Concrete

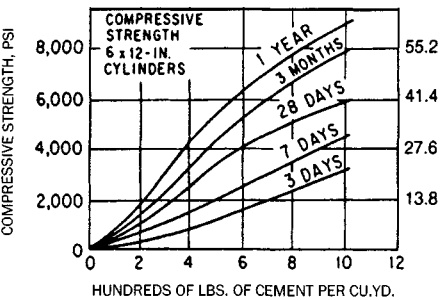
Strength: Concrete is strong in compression but relatively weak in tension and bending. It takes a great deal of force to crush concrete, but very little force to pull it apart or cause bending cracks. Compressive strength is determined primarily by the amount of cement used, but is also affected by the ratio of water to cement, as well as proper mixing and placing, and the adequacy and extent of hydration and curing. Tensile strength usually ranges from 7 or 8 % of compressive strength in high-strength mixes to 11 or 12% in low-strength mixes. Both tensile strength and flexural bending strength can be increased by adding steel or fiber reinforcement.

Required compressive strength is based on an analysis of the loads that will be applied and the soil conditions at the project site. Actual compressive strength is verified by testing samples in a laboratory using standardized equipment and procedures. On commercial projects, numerous samples are tested throughout construction to verify that the concrete being put into place actually has the specified strength. Laboratory testing is not often required in residential work, except perhaps on large high-end projects or on projects with difficult sites where special foundation designs make concrete strength critical. A concrete that is stronger than necessary for its intended use is not economical, and one that is not strong enough can be dangerous.

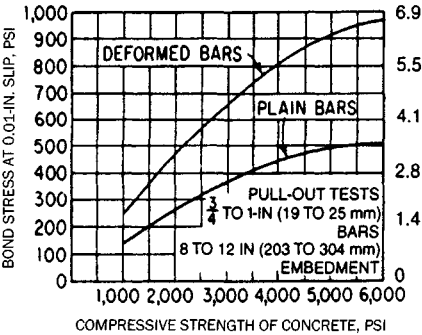
Durability: Durability might be defined as the ability to maintain satisfactory performance over an extended service life. Satisfactory performance is related to intended use. Concrete that will be walked or driven on must be abrasion resistant so that it doesn't wear away. Concrete that will be exposed on the outside of a building must be weather resistant so that it doesn't deteriorate from repeated freezing and thawing. The durability of concrete exposed to repeated freeze-thaw cycles can be significantly increased by air entrainment. Concrete in which steel reinforcement is embedded must resist excessive moisture absorption in order to protect the metal from corrosion. Natural wear and weathering will cause some change in the appearance of concrete over time, but in general, durability also includes the maintenance of aesthetic as well as functional characteristics. Just as concrete mix designs can be adjusted to produce a variety of strengths, appropriate concrete ingredients, mix proportions, and finishes can and should be adjusted on the basis of required durability.

Volume Stability: All materials expand and contract with changes in temperature, and porous materials like concrete also expand and contract with changes in moisture content. Cement-based products such as concrete, concrete masonry, and stucco experience initial shrinkage as the cement hydrates and excess mixing water evaporates. This initial shrinkage is permanent, and is in addition to reversible expansion and contraction caused by later temperature or moisture changes. Excessive shrinkage can cause concrete to crack. The cracks allow moisture to penetrate, and a vicious cycle of deterioration may begin. Shrinkage cracking can be restrained to some extent by steel or fiber reinforcement, and the location and weather resistance of shrinkage cracks can be controlled through the use of control joints which divide the concrete into smaller panels or sections. However, the mix design and ingredient proportions also have an effect on the potential for shrinkage cracking. The higher the cement content, the greater the tendency for shrinkage cracks to form while the concrete is curing and hardening.

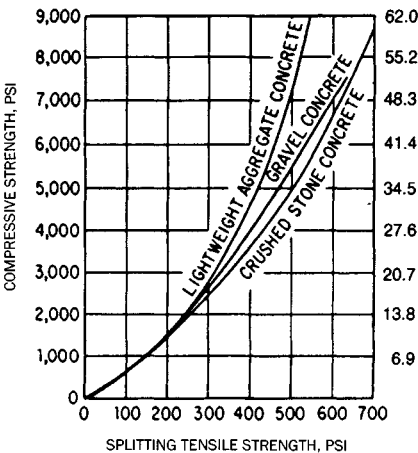
2.2.3 Effects of Cement Content on Concrete



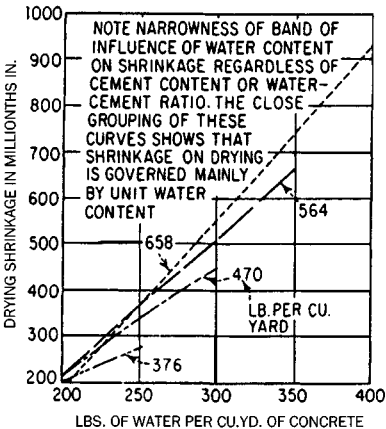
Effect of Cement Content on Strength of Concrete



Variation of Bond with Compressive Strength of Concrete



Relation Between Compressive Strength and Splitting Tensile Strength For Concrete Made with Three Different Aggregates



Relation Between Drying Shrinkage, Cement Content, and Water Content

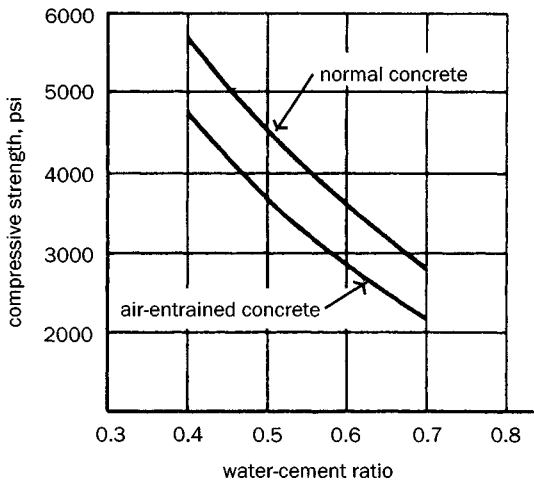
(Graphs on this page from Dobrowolski, Concrete Construction Handbook, 4th ed., McGraw-Hill, 1998.)

2.2.4 Water-Cement Ratio in Concrete

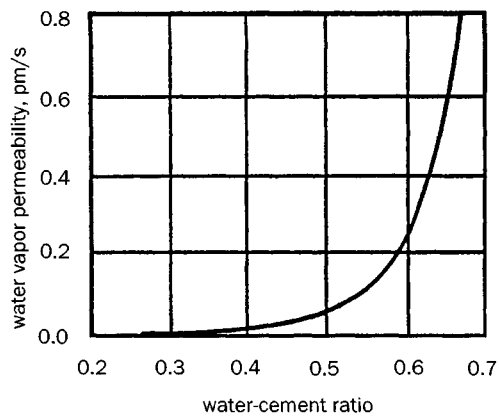
Given a proper gradation of aggregates, the strength of cured concrete is primarily dependent on the amount of cement in the mix and the water-cement ratio. While water is required for curing concrete, a much larger quantity of water must be added than is needed for cement hydration in order to give the concrete mix the fluidity and plasticity necessary for placing and finishing. The excess water eventually evaporates from the concrete, leaving microscopic voids which impair strength and surface characteristics (Figure A). Water-cement ratio also affects permeability of the concrete (Figure B). Absolute water-cement ratios by weight for most concrete applications should be kept below 0.50. Moisture in the sand should be included when measuring water content. In certain applications, such as slabs on grade that will be finished with a non-breathable floor covering, the water-cement ratio should be reduced to 0.40 or less.

Too much water in the mix creates water reservoirs. Channels lead from the reservoirs to the surface, where a watery laitance forms. A weak surface results, leading to concrete crazing, dusting, and scaling, especially if finishing operations work the bleed water back into the surface before it can evaporate (Figure C). When the water reservoirs and channels dry out, air pockets remain that allow water and deicers to enter. When water in the reservoirs freezes and expands, stresses are induced in the concrete making it less durable.

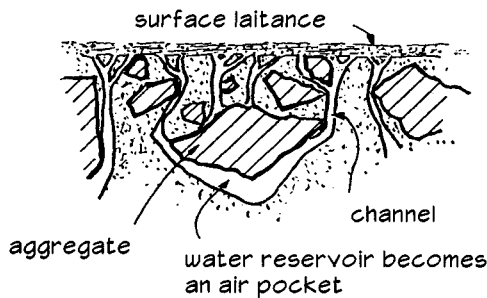
It is almost impossible to make a mix with too little water, since a non-workable mix would result. However, inadequate blending can cause segregation. Water may also be lost to the subgrade, which should always be moistened (but not saturated) prior to concrete placement (Figure D).



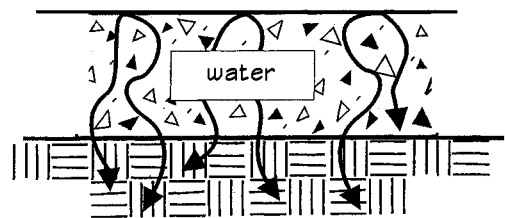
A. Effect of Water-Cement Ratio on Concrete Strength
(From Portland Cement Association)



B. Effect of Water-Cement Ratio on Permeability of Concrete
(From National Research Council of Canada)



C. Section at Surface of Concrete Mixed with Too Much Water



D. Subgrade should be properly moistened before placing concrete so that too much water from the mix is not absorbed by the soil. Proper curing will retain water in the concrete.

(Figures C and D from PCI Design Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)

2.2.4 Continued

Maximum Water-Cement Ratios for Various Exposure Conditions	
Exposure Condition	Maximum Water-Cement Ratio by Weight for Normal Weight Concrete
Concrete protected from exposure to freezing and thawing or application of deicing chemicals	Select water-cement ratio on basis of strength, workability, and finishing needs
Concrete intended to be watertight:	
a. concrete exposed to fresh water	0.50
b. concrete exposed to brackish water or seawater	0.45
Concrete exposed to freezing and thawing in a moist condition (air-entrained concrete):	
a. curbs, gutters, guardrails, or thin sections	0.45
b. other elements	0.50
c. in presence of deicing chemicals	0.45
For corrosion protection for reinforced concrete exposed to deicing salts, brackish water, seawater, or spray from these sources	0.40 ^s

^s If minimum concrete cover required by ACI 318 Section 7.7 is increased by 1/2 inch, water-cement ratio may be increased to 0.45 for normal weight concrete.

Maximum Permissible Water-Cement Ratios for Concrete When Strength Data from Field Experience or Trial Mixtures Are Not Available		
Specified 28-Day Compressive Strength, f_c (psi)	Water-Cement Ratio by Weight	
	Non-Air-Entrained Concrete	Air-Entrained Concrete
2500	0.67	0.54
3000	0.58	0.46
3500	0.51	0.40
4000	0.44	0.35
4500	0.38	†
5000	†	†

With most materials, water-cement ratios shown will provide average strengths greater than required. This table should be used only with special permission from the design engineer. It is not intended for use in designing trial batches. Use the table below for trial batch design.

† For strengths above 4500 psi (non-air-entrained concrete) and 4000 psi (air-entrained concrete), concrete proportions shall be established from field data or trial mixtures.

Typical Relationship Between Water-Cement Ratio and Concrete Compressive Strength		
Compressive Strength at 28 Days (psi)	Water-Cement Ratio by Weight	
	Non-Air-Entrained Concrete	Air-Entrained Concrete
6000	0.41	—
5000	0.48	0.40
4000	0.57	0.48
3000	0.68	0.59
2000	0.82	0.74

Strength values estimated for concrete with not more than the recommended air content in Table 2.2.10. For a constant water-cement ratio, concrete strength is reduced as air content increases. Strength is based on 6 x 12 cylinders moist cured 28 days at 73.4°F ± 3°F in accordance with Section 9b of ASTM C31. Relationship assumes maximum aggregate size of about 3/4 to 1 inch.

(Tables on this page from Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

2.2.4 Continued

Chemical Limits for Wash Water Used as Mixing Water (ASTM C94)		
Chemical	Maximum Concentration† (ppm)	Test Method‡
Chloride (as Cl) prestressed concrete or concrete in bridge decks other reinforced concrete in moist environments or containing alum- inum embedments or dissimilar metals or with stay-in-place galvan- ized metal forms	500§ 1,000§	ASTM D512 —
Sulfate (as SO ₄)	3,000	ASTM D516
Alkalis (as Na ₂ O + 0.658 K ₂ O)	600	—
Total solids	50,000	AASHTO T26

† Wash water reused as mixing water in concrete can exceed the listed concentrations of chloride and sulfate if it can be shown that the concentration calculated in the total mixing water, including mixing water on the aggregates and other sources, does not exceed the stated limits.

‡ Other test methods that have been demonstrated to yield comparable results may be used.

§ For conditions allowing use of CaCl₂ accelerator as an admixture, the chloride limitation may be waived by the purchaser.

Acceptance Criteria for Questionable Water Supplies (ASTM C94)		
Property	Limits	Test Method
Compressive strength, mini- mum percentage of control at 7 days	90	ASTM C109
Time of set, deviation from control (hours:minutes)	from 1:00 earlier to 1:30 later	ASTM C191

Note: Comparisons should be based on fixed proportions and the same volume of test water compared to control mix, using either city water or distilled water.

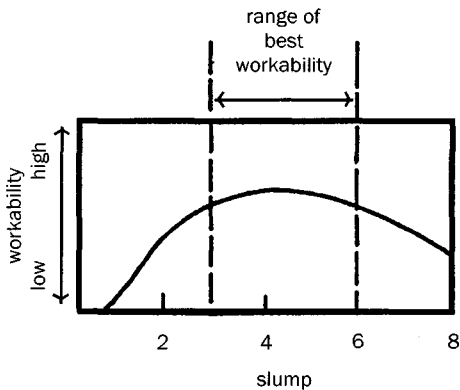
2.2.5 Concrete Slump

Concrete slump is used as a simple field measure of the consistency of the mix. Consistency is the aspect of workability related to flow characteristics of fresh concrete, and is an indication of the fluidity or wetness of the mix. Some concrete applications may require a relatively low slump mix, while others require a higher slump and greater fluidity for proper placement. Fresh concrete is placed in a metal cone. When the cone is removed, the concrete slumps a certain amount, depending on how fluid it is. A wet, soft mix slumps more than a drier, stiffer one. A high-slump concrete is one that is very fluid, and a low-slump concrete is drier and more stiff. A high-slump mix may cause excessive bleeding, shrinkage, cracking, and dusting of the hardened concrete. Workability is at a maximum in concrete of medium consistency with a slump between 3 and 6 inches. Both very dry (low-slump) and very wet (high slump) mixes are less workable.

Recommended Maximum and Minimum Slump		
Element	Maximum Slump (in.) [§]	Minimum Slump (in.)
Reinforced foundation walls and footings	3	1
Plain footings, caissons, and substructure walls	3	1
Beams and reinforced walls	4	1
Building columns	4	1
Pavements and slabs	3	1
Mass concrete	2	1

§ May be increased 1 in. for hand methods of consolidation such as rodding and spading.

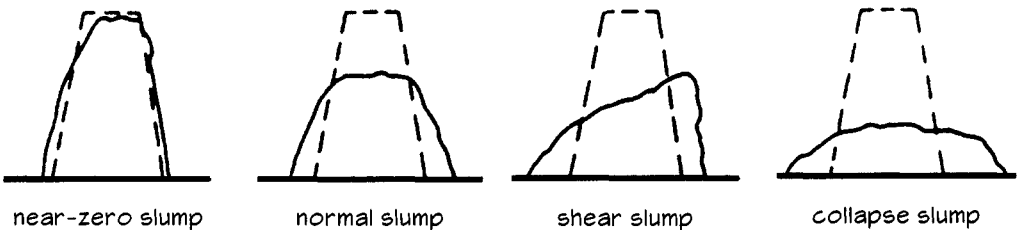
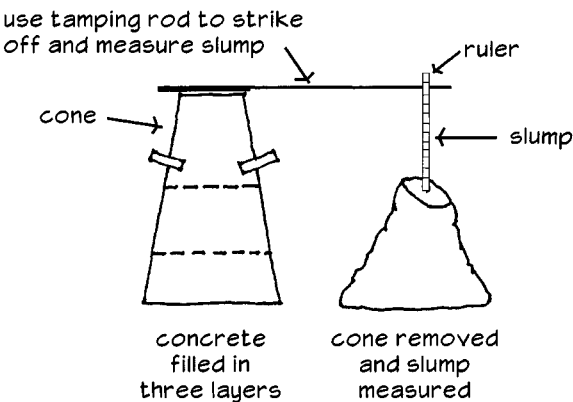
(From Portland Cement Association)



Relationship Between Slump and Workability (From Waddell, Concrete Manual.)

measuring concrete slump

1. Fill cone in three layers of equal volume, rodding each layer 25 times.
2. Strike off top, then remove the cone slowly with an even motion, taking from 5 to 12 seconds. Do not jar the mixture or tilt the cone in the process.
3. Measure the slump with tamping rod and ruler. The slump test should not take longer than 1-1/2 minutes. Do not use the same batch of concrete for any other test.



(From Dobrowolski, Concrete Construction, 4th ed., McGraw-Hill, 1998)

2.2.6 Aggregate Size and Gradation

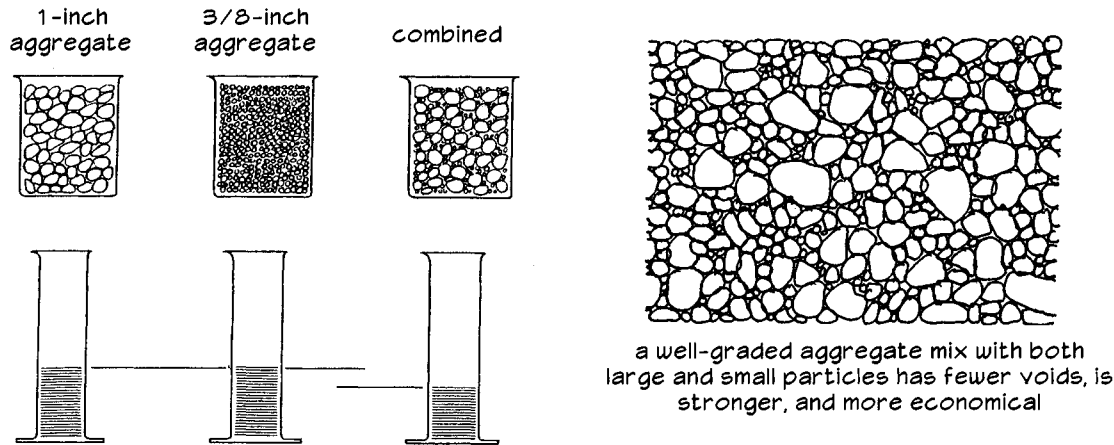
Maximum Size of Aggregate for Various Types of Construction (in.)			
Minimum Dimension of Section (in.)	Reinforced Walls, Beams, and Columns	Heavily Reinforced Slabs	Lightly Reinforced Slabs
2-1/2 to 5	1/2 to 3/4	3/4 to 1	3/4 to 1-1/2
6 to 11	3/4 to 1-1/2	1-1/2	1-1/2 to 3
12 to 29	1-1/2 to 3	1-1/2 to 3	3
30 or more	1-1/2 to 3	1-1/2 to 3	3 to 6

(From Concrete Primer, American Concrete Institute, 1987)

Volume of Dry-Rodded Coarse Aggregate [§] per Unit Volume of Concrete				
Maximum Size of Aggregate (in.)	Fineness Moduli of Fine Aggregate			
	2.40	2.60	2.80	3.00
3/8	0.50	0.48	0.46	0.44
1/2	0.59	0.57	0.55	0.53
3/4	0.66	0.64	0.62	0.60
1	0.71	0.69	0.67	0.65
1-1/2	0.75	0.73	0.71	0.69
2	0.78	0.76	0.74	0.72
3	0.82	0.80	0.78	0.76
6	0.87	0.85	0.83	0.81

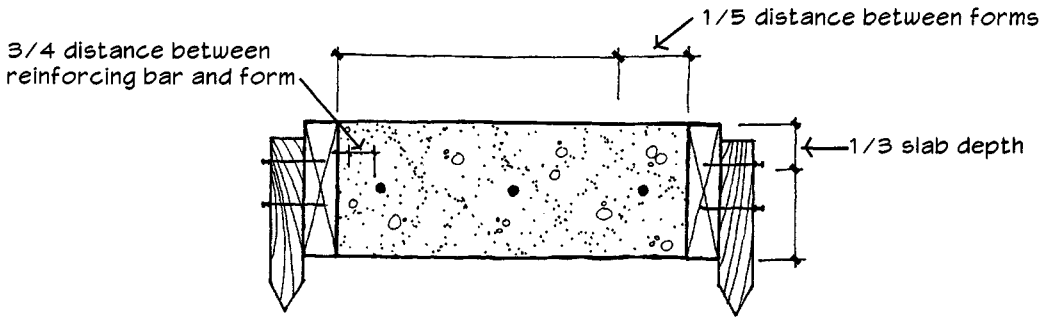
§ Bulk volumes are based on aggregates in dry-rodded condition as described in ASTM C29. These volumes are selected from empirical relationships to produce concrete with a degree of workability suitable for usual reinforced construction. For less workable concrete such as required for concrete pavement construction, they may be increased about 10%. For more workable concrete such as may sometimes be required when placement is to be by pumping, they may be reduced up to 10%.

(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

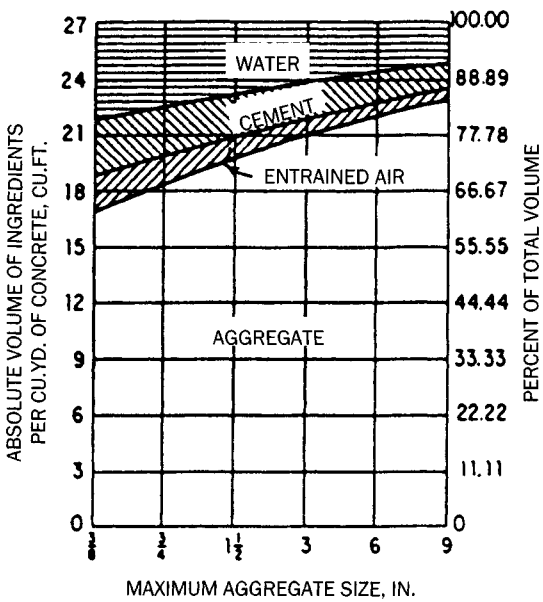


The level of liquid in the cylinders represents voids and is constant for equal absolute volumes of aggregates of uniform but different size. Void content decreases when different sizes are combined.
(From Portland Cement Association)

2.2.7 Maximum Concrete Aggregate Size Relative to Formwork and Reinforcement



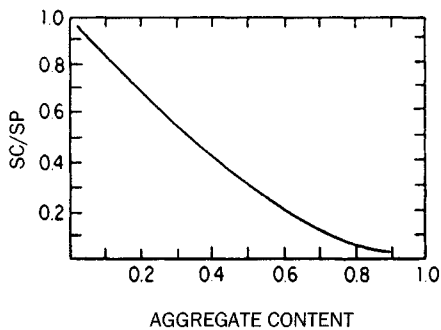
2.2.8 Effect of Aggregate Maximum Size on Volume of Other Ingredients



Effect of maximum aggregate size on percentage of entrained air, cement, and water. Graph based on natural aggregates of average grading in mixes with a water-cement ratio of 0.54 by weight, 3-in. slump, and recommended air contents. (From U.S. Bureau of Reclamation, Concrete Manual, 8th ed. 1971)



2.2.9 Concrete Shrinkage as a Function of Aggregate Content



Ratio of overall concrete shrinkage (SC) to shrinkage of concrete paste (SP) as a function of aggregate content. (From Dobrowolski, Concrete Construction Handbook, 4th ed., McGraw-Hill, 1998)

2.2.10 Water and Air Content in Concrete Mixes

Approximate Mixing Water (lb./cu.yd.) and Target Air Content Requirements for Different Concrete Slumps and Maximum Sizes of Aggregate ^s								
Maximum Aggregate Size →	3/8 in.	1/2 in.	3/4 in.	1 in.	1-1/2 in.	2 in.†	3 in.†	6 in.†
Non-Air-Entrained Concrete								
Slump 1 to 2 in.	350	335	315	300	275	260	220	190
Slump 3 to 4 in.	385	365	340	325	300	285	245	210
Slump 6 to 7 in.	410	385	360	340	315	300	270	—
Approximate amount of entrapped air in non-air-entrained concrete (%)	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-Entrained Concrete								
Slump 1 to 2 in.	305	295	280	270	250	240	205	180
Slump 3 to 4 in.	340	325	305	295	275	265	225	200
Slump 6 to 7 in.	365	345	325	310	290	280	260	—
Recommended average total air content for level of exposure (%)‡								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5	3.0
Severe exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

^s Mixing water quantities are for use in computing cement factors for trial batches. They are maximums for reasonably well shaped angular coarse aggregates graded within limits of accepted specifications.

[†] Slump values for concrete containing aggregate larger than 1-1/2 in. are based on slump tests made after removal of particles larger than 1-1/2 in. by wet screening.

[‡] The air content in project specifications should be specified to be delivered within -1 to +2 percentage points of the table target value for moderate and severe exposures.

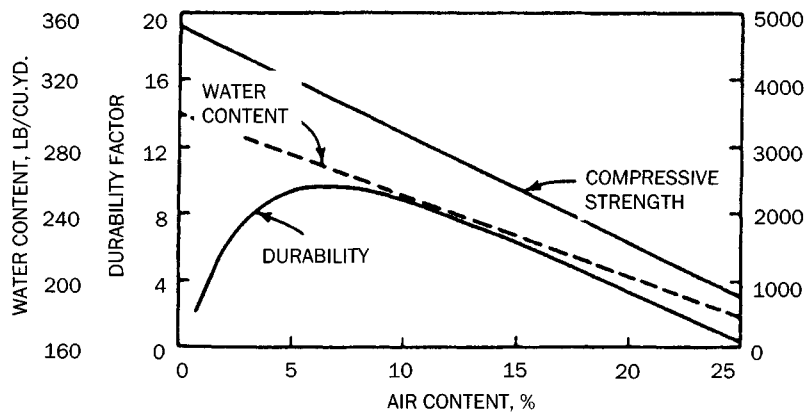
(From Kosmata and Panarese, Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

2.2.11 Effect of Air Content on Other Concrete Properties

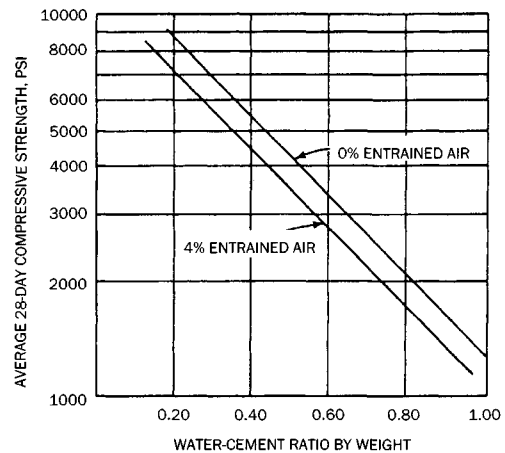
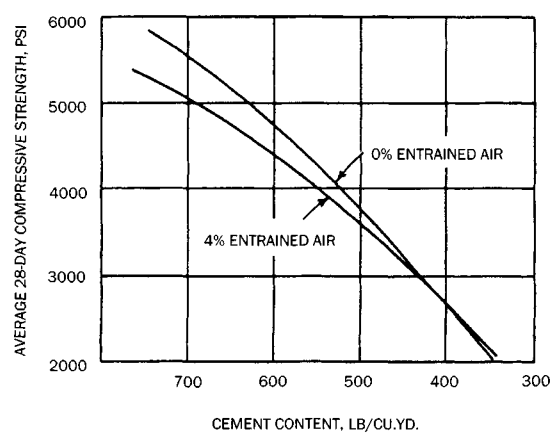
Property	Effect
Abrasion	Little effect; increased strength increases abrasion resistance somewhat
Absorption	Little effect
Alkali-silica reactivity	Expansion decreases with increased air
Bleeding	Reduced significantly
Bond to steel	Decreased
Compressive strength	Reduced approximately 2 to 6% for each percentage point increase in air; harsh or lean mixes may gain strength
Creep	Little effect
Deicer scaling	Significantly reduced
Fatigue	Little effect
Flexural strength	Reduced approximately 2 to 4% for each percentage point air increase
Freeze-thaw resistance	Significantly improved resistance to water-saturated freeze-thaw deterioration
Heat of hydration	No significant effect
Modulus of elasticity (static)	Decreases with increased air approximately 105,000 to 200,000 psi per percentage point increase of air
Permeability	Little effect; reduced water-cement ratio reduces permeability somewhat
Scaling	Significantly reduced
Shrinkage (drying)	Little effect
Slump	Increases with increased air, approximately 1 in. per 1/2 to 1% increase in air
Specific heat	No effect
Sulfate resistance	Significantly improved
Temperature of wet concrete	No effect
Thermal conductivity	Decreases 1 to 3% for each percentage point increase in air
Thermal diffusivity	Decreases about 1.6% for each percentage point increase in air
Unit weight	Decreases with increased air
Water demand of wet concrete for equal slump	Decreases approximately 5 to 10 lbs./cu.yd. for each percentage point increase in air
Watertightness	Increases slightly; reduced water-cement ratio increases watertightness somewhat
Workability	Increases with increased air

(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

2.2.11 Continued



Effects of air content on durability, compressive strength, and required water content of concrete. Graph assumes water-cement ratio, slump, and sand percentage held constant, and maximum aggregate size of 1-1/2 in. (From U.S. Bureau of Reclamation, Concrete Manual, 8th ed., 1971.)



(From Dobrowolski, Concrete Construction Handbook, 4th ed., McGraw-Hill, 1998)

2.2.12 Effect of Mix Design and Concrete Ingredients on Air Content

Type of Ingredient	Air Content	Air-Void System	Corrective Action
Accelerator	Calcium chloride increases air, other types have little effect.	Unknown.	Decrease air-entraining admixture when calcium chloride is used.
Cement composition	Higher fineness (Type III) requires more air-entraining admixture. Alkali increases air.	Effects not well defined.	Use 50 to 100% more air-entraining admixture for Type III cement. Decrease air-entraining admixture dosage 20 to 40% for high alkali.
Cement contaminants	Oxidized oils increase air. Unoxidized oils decrease air.	Little apparent effect.	Obtain certification on cement. Test for contaminants if problems develop.
Cement content in mix design	Air decreases with increase in cement.	Smaller voids and greater number with increasing cement content.	Increase air-entraining admixture 50% for 200 lb./cu.yd. increase in cement. Increase air-entraining admixture 10 times or more for very rich, low-slump mixtures.
Coarse aggregate	Air decreases as maximum size of aggregate increases. Crusher fines on coarse aggregate decrease air.	Little effect.	No action needed as required air decreases with increase in aggregate size. Hold percentage of fines below 4%.
Fine aggregate	Air increases with increase in sand content. Organic impurities may increase or decrease air.	Surface texture may affect specific surface of voids.	Decrease air-entraining admixture as sand content increases. Check sand against ASTM C40 prior to acceptance.
Fly ash	High loss on ignition or carbon decreases air. Fineness of ash may have an effect.	Little effect.	Increase air-entraining admixture. May need up to 5 times more with high-carbon ash. Foam index test is useful check procedure. Air reduction with long mixing times (90 minutes) can be significant with high-carbon ash. Add more air-entraining admixture.
Mix-water contaminants	Truck mixer wash water decreases air. Extreme water hardness may decrease air. Algae increases air.	Unknown.	Test water supplies for algae and other contaminants prior to acceptance.
Pigments	Carbon black and black iron oxide based pigments may absorb air-entraining admixture and depress air content.	Unknown.	Prequalification of pigment with job materials.
Slump of mix	Air increases 1/2 to 1% per 1-in. slump increase for slumps up to 6 or 7 in., then higher slumps result in decreased air.	Becomes coarser with higher slumps.	Reduce air-entraining admixture dosage.
Superplasticizer (high-range water reducer)	Melamine-based materials may decrease air or have little effect. Naphthalene and lignosulfonate-based materials increase air. Highly fluid mixtures may lose air.	Produces coarser air-void systems. Spacing factors increase.	Use less air-entraining admixture with naphthalenes. Specify 1 to 2% higher air content if possible.
Water content in mix design	Air increases with increase in water content about 1/2 to 1% per gallon of water. Fluid mixes show loss of air.	Becomes coarser at high water content.	Decrease air-entraining admixture accordingly.
Water reducer or set retarder	Lignosulfonates increase air. Other types have less effect.	Spacing factors increase at higher dosages.	Decrease air-entraining admixture 50 to 90% for lignosulfonates especially at lower temperatures. Decrease air-entraining admixture 20-40% for other types. Do not mix admixtures prior to batching.

Note: Table information may not apply to all situations.

(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

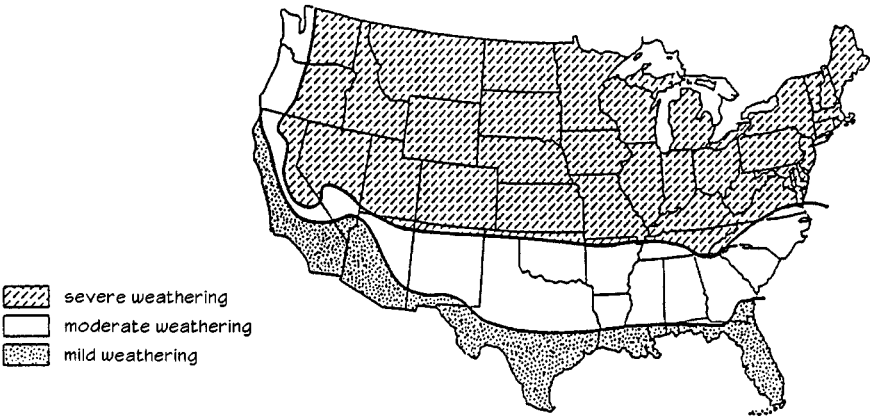
2.2.13 Recommended Concrete Mixes for Various Exposure Conditions

Element	Weathering Probability [§]	Minimum Compressive Strength (psi)	Typical Maximum Coarse Aggregate Size (in.)	Minimum Cement Content (sacks/cu.yd.)	Air Content by Volume (%)	Slump (in.)
Foundations, basement walls, and slabs <i>not</i> exposed to weather (except garage slabs)	severe	2500	1	5-1/2	—	*
	moderate	2500	1	5-1/2	—	*
	mild	2500	1	5-1/2	—	*
Foundations, basement walls, exterior walls, and other vertical concrete work exposed to weather	severe	3000	1	6 [†]	5 to 7	6±1
	moderate	3000	1	5-1/2 [†]	5 to 7	6±1
	mild	2500	1	5-1/2	—	6±1
Driveways, garage slabs, walks, porches, patios, and stairs exposed to weather	severe	3500	1	6 [†]	5 to 7	5±1
	moderate	3000	1	5-1/2 [†]	5 to 7	5±1
	mild	2500	1	5-1/2	—	5±1

§ See map below weathering probability. Alaska is classified as severe weathering and Hawaii as mild weathering.

† Use air-entrained cement.

* Use concrete with a slump of 5±1 for horizontal elements, and 6±1 for vertical elements.



(Minimum required strength and weathering probability map from CABO One and Two Family Dwelling Code.)

Requirements for Concrete Exposed to Sulfate-Containing Solutions					
Sulfate Exposure	Water-Soluble Sulfate (SO ₄) in Soil (% by Weight)	Sulfate (SO ₄) in Water (ppm)	Cement Type [§]	Maximum Water-Cement Ratio by Weight	Minimum Compressive Strength (psi)
Negligible	0.00—0.10	0—150	—	—	—
Moderate [†]	0.10—0.20	150—1500	II, IP(MS), IS(MS), P(MS), I(PM)(MS), I(SM)(MS)	0.50	3750
Severe	0.20—2.00	1500—10,000	V	0.45	4250
Very Severe	Over 2.00	Over 10,000	V plus pozzolan [†]	0.45	4250

§ Cement types II and V are specified in ASTM C150, and the remaining types are blended cements specified in ASTM C595.

† Seawater.

† Pozzolan (ASTM C618 or silica fume) that has been determined by test or service records to improve sulfate resistance when used in concrete containing Type V cement.

(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

2.2.14 Concrete Proportions by Weight

Sand contains moisture, which must be included as part of the calculated mixing water. The proportions given in the table below are based on wet sand which is the condition of most commercially available sand. When squeezed in the hand, wet sand forms a ball and leaves no noticeable moisture on the palm. Damp sand falls apart when squeezed in the hand. Very wet sand (such as that exposed to recent rain) forms a ball when squeezed in the hand and leaves noticeable moisture on the palm. Increase or decrease the proportion of water and sand as indicated in the table note.

Proportions by Weight to Make One Cubic Foot of Concrete								
Maximum Size Coarse Aggregate (in.)	Air-Entrained Concrete				Concrete Not Air-Entrained			
	Cement (lb.)	Wet Sand [§] (lb.)	Wet Coarse Aggregate [†] (lb.)	Water (lb.)	Cement (lb.)	Wet Sand [§] (lb.)	Wet Coarse Aggregate [†] (lb.)	Water (lb.)
3/8	29	53	46	10	29	59	46	11
1/2	27	46	55	10	27	53	55	11
3/4	25	42	65	10	25	47	65	10
1	24	39	70	9	24	45	70	10
1-1/2	23	38	75	9	23	43	75	9

§ Proportions are based on wet sand. If sand is damp rather than wet, decrease the quantity of sand by one pound and increase the water by one pound. If sand is very wet, increase the quantity of sand by one pound and decrease water by one pound.

† If crushed stone is used rather than gravel, decrease coarse aggregate by three pounds and increase sand by three pounds.

(From Portland Cement Association.)

Weights of Ingredients	
Material	Weight (lbs.)
Portland cement, bag	94
Wet sand, cu.ft.	100
Coarse aggregate, cu.ft.	100
Water cu.ft.	62.4
one gallon	8.34

Observed Average Weight of Fresh Concrete								
Maximum Aggregate Size (in.)	Air Content (%)	Water (lbs./cu.yd.)	Cement (lbs./cu.yd.)	Unit Weight (pcf) [§] for Concrete With Aggregates With Different Specific Gravities [†]				
				2.55	2.60	2.65	2.70	2.75
3/4	6.0	283	566	137	139	141	143	145
1-1/2	4.5	245	490	141	143	146	148	150
3	3.5	204	408	144	147	149	152	154
6	3.0	164	282	147	149	152	154	157

§ Air-entrained concrete with indicated air content.

† On saturated surface-dry basis.

(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

2.2.15 Concrete Proportions by Volume

Proportions by Volume to Make One Cubic Foot of Concrete								
Maximum Size Coarse Aggregate (in.)	Air-Entrained Concrete				Concrete Not Air-Entrained			
	Cement	Wet Sand	Wet Coarse Aggregate	Water [§]	Cement	Wet Sand	Wet Coarse Aggregate	Water [§]
3/8	1	2-1/4	1-1/2	1/2	1	2-1/2	1-1/2	1/2
1/2	1	2-1/4	2	1/2	1	2-1/2	2	1/2
3/4	1	2-1/4	2-1/2	1/2	1	2-1/2	2-1/2	1/2
1	1	2-1/4	2-3/4	1/2	1	2-1/2	2-3/4	1/2
1-1/2	1	2-1/4	3	1/2	1	2-1/2	3	1/2

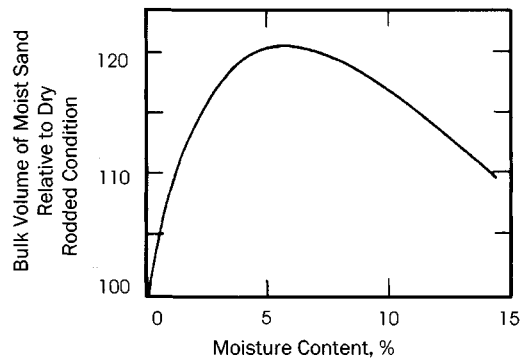
The combined volume of concrete is approximately two-thirds of the sum of the original bulk volumes of the ingredients. Proportions are only a guide and may need adjustment to produce a workable mix with locally available aggregates.

§ One cubic foot of water is 7.48 gallons. One gallon of water is 0.134 cu.ft.

(From Portland Cement Association.)

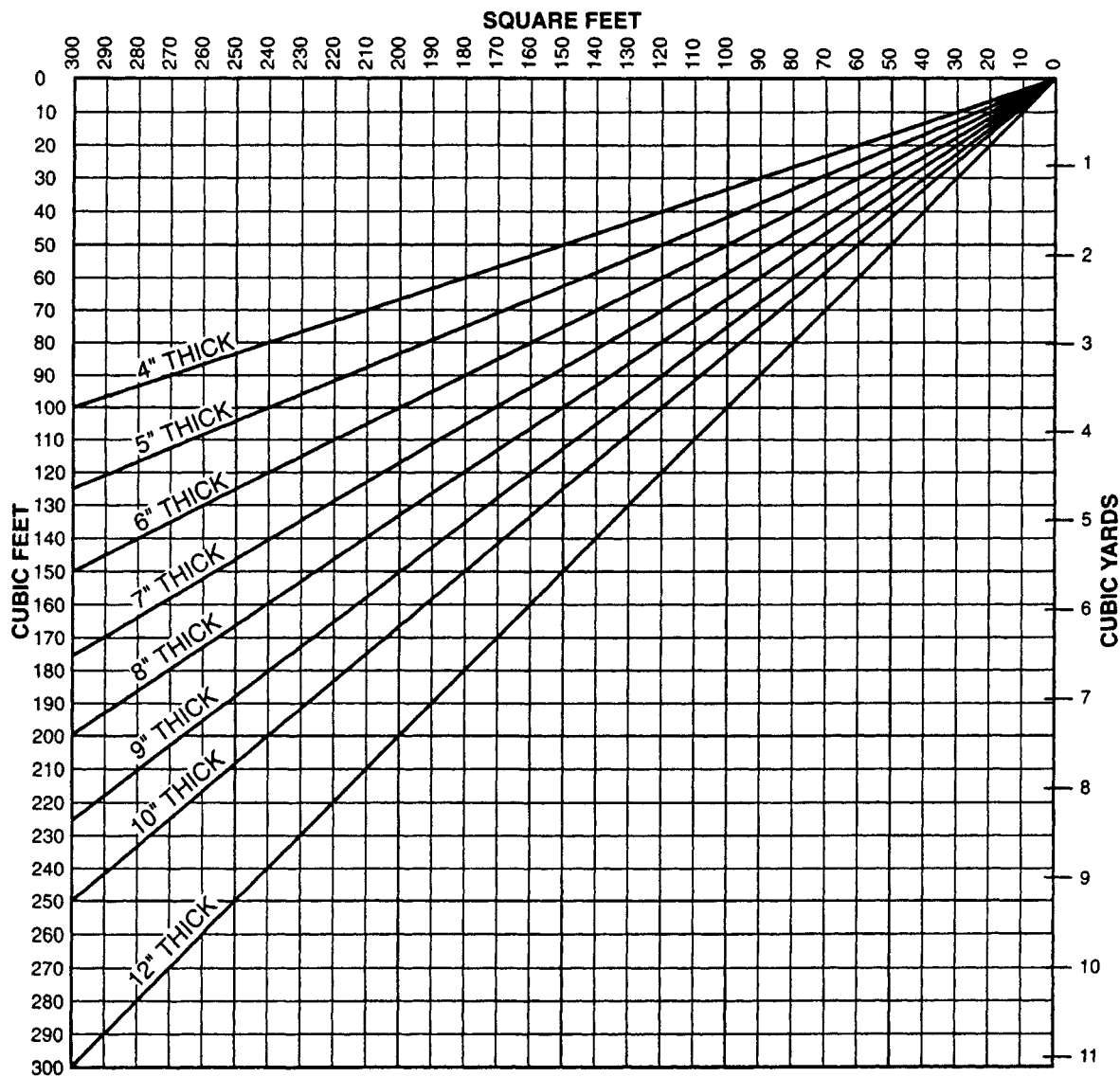
Sand contains moisture, which must be included as part of the calculated mixing water. The proportions given in the table above are based on wet sand, which is the condition of most commercially available sand. When squeezed in the hand, wet sand forms a ball and leaves no noticeable moisture on the palm. Damp sand falls apart when squeezed in the hand. Very wet sand (such as that exposed to recent rain) forms a ball when squeezed in the hand and leaves noticeable moisture on the palm.

Moisture in sand causes an increase in volume called “bulking.” The extent of bulking depends on the amount of moisture in the sand and its fineness. The volume of wet sand can be as much as 1-1/4 times its dry volume. When measuring concrete proportions by volume, always use wet sand for consistency from batch to batch. Keep sand at the job site covered with polyethylene sheets to prevent evaporation and, if necessary, wet the sand with a garden hose the day before mixing.



(From Dobrowolski, Concrete Construction, 4th ed., McGraw-Hill, 1998)

2.2.16 Estimating Concrete Quantity



Find the area in square feet along the top of the graph. Follow the vertical line down until it intersects the diagonal line for the appropriate thickness. Read horizontally to the left to find the volume in cubic feet. Read horizontally to the right to find the volume in cubic yards.

2.3.1 Properties of Fresh Masonry Mortar

Workability: Workability is a complex property of fresh masonry mortar that includes adhesion, cohesion, density, flow, and plasticity. A workable mortar has a smooth, plastic consistency, is easily spread with a trowel, and readily adheres to vertical surfaces. Well-graded, smooth sand enhances workability as do lime, air entrainment, and proper amounts of mixing water. Lime increases plasticity and the water-carrying capacity of the mix. Air entrainment introduces minute bubbles that act as lubricants in promoting flow of the mortar particles, but excessive air content also reduces bond strength. When structural reinforcement is incorporated in mortar, cement-lime and mortar cement mixes are limited to 12% air content, and masonry cement mixes to 18%.

Variations in masonry units and environmental conditions affect optimum mortar consistency and workability. Mortar for heavy units must be drier to prevent uneven settling or excessive extrusion of mortar from the joints. Hot weather requires a wetter mix to compensate for evaporation. Unlike concrete, mortar requires a maximum amount of water for workability, and retempering to replace evaporated moisture is permitted. Although it is easily recognized by the mason, the variables affecting workability preclude a statement of minimum requirements in mortar specifications. The "proper" amount of mixing water in masonry mortar is universally agreed upon as the maximum amount judged by the mason to produce good workability for the absorption properties of a specific masonry unit laid under specific weather conditions.

Water Retentivity: Water retentivity allows mortar to resist evaporation and unit suction, to maintain moisture for proper cement hydration, and to retain its plasticity so that the mason can carefully align and level the units without breaking the bond between mortar and unit. Water retentivity generally increases as the proportion of lime in the mix increases. Construction mortars need *minimum* water retention rates of about 75%. Mortars with higher water retentivity should be used in summer or with high-suction units. Mortars with minimum water retentivity should be used in winter or with low-suction units.

Flow: Under laboratory conditions, water retentivity is measured by flow tests, and expressed as the percentage of flow after suction to initial flow. Low-flow mixes lose too much water to unit suction and will not cure properly. High-flow mixes cause units to float, and will decrease bond strength. The amount of mixing water required to produce proper flow and water retention is quickly and accurately adjusted to unit suction properties and weather conditions by experienced masons.

Retempering (the addition of mixing water to compensate for evaporation) is not only an acceptable practice in masonry construction, it is a necessary one. A partially dried and stiffened mortar does not have good flow properties and cannot produce good bond if the evaporated water is not replaced. Since it is difficult to determine by either sight or touch whether mortar stiffening is due to evaporation or cement hydration, it is customary to determine the suitability of mortar based on the time elapsed after initial mixing. All mortar should be used within 2-1/2 hours after mixing, and may be retempered as frequently as needed within this time period. Tests have shown that retempering causes only a slight reduction in compressive strength if it occurs within this time limit, and that retempering improves masonry performance by maximizing workability and bond.

2.3.2 Properties of Hardened Masonry Mortar

- Bond Strength:** The single most important property of masonry mortar is bond. Bond includes both *extent of bond*, or area of contact between unit and mortar, and *bond strength*, or adhesion of mortar to the units. Strength and extent of the bond are affected by many variables of material and workmanship. All other factors being equal, bond strength increases slightly as cement content and compressive strength increase, but mortars with high cement content and low lime content are stiff and do not readily penetrate porous unit surfaces. This leaves voids and gaps, which decrease the extent of bond and therefore decrease bond strength. Increasing air content, or adding air-entraining ingredients, lowers both compressive and bond strength because the air voids decrease mortar contact area.
- Compressive Strength:** Masonry compressive strength depends on both the unit and the mortar. As with concrete, the strength of mortar is determined by the cement content and the water-cement ratio of the mix. Compressive strength increases with the proportion of cement in the mix and decreases as the lime proportion is maximized. Increases in air entrainment, sand, or mixing water also reduce compressive strength. For veneer construction and for two- and three-story loadbearing masonry, mortar compressive strength is rarely a critical design factor because both the mortar and the masonry are usually much stronger in compression than necessary. Compressive strength is important in engineered, loadbearing construction, but structural failure due to compressive loading is rare. More critical properties such as flexural bond strength are usually given higher priority. An unnecessarily hard, strong mortar will restrain the shrinkage of concrete masonry units and increase wall cracking as a result of the stress. Mortar with a higher lime proportion is more flexible and permits more movement, giving better overall performance as long as minimum compressive strength requirements are met.
- Volume Change:** Volume changes in mortar can result from the curing process, from repeated cycles of wetting and drying, and from temperature change. Differential thermal expansion between the units and mortar does not normally affect the masonry, but substantial moisture shrinkage can occur in mortars with a high cement content or high water content. This moisture shrinkage can cause separations at the unit-to-mortar interface.
- Extensibility:** The elastic properties of mortar often counteract moisture shrinkage. Extensibility is defined as the amount per unit length that a specimen will elongate, and is sufficiently high in mortar so that when it is combined with the added plasticity which lime imparts to the hardened mix, slight movement can be accommodated without joint separations. For maximum extensibility (such as that required in chimney construction), mortar should be mixed with the highest lime content compatible with compressive strength requirements.
- Durability:** Durability is a measure of resistance to age and weathering, and particularly to repeated freeze-thaw cycles. Mortars with high compressive strength can be very durable, but a number of factors other than strength affect mortar durability. Ingredients, workmanship, volume change, elasticity, and the proper design and placement of expansion and control joints all influence durability and determine the maintenance characteristics of the construction. The best defense against freeze-thaw destruction is the elimination of moisture leaks at the joints with high quality mortar ingredients and good bond, and the use of details that permit differential movement and provide adequate protection at the top of the wall and at penetrations.

2.3.3 Mortar Types and Applications

- Type N Mortar for general use in interior loadbearing walls and above grade exterior loadbearing walls and parapets (most appropriate mortar for the majority of masonry applications)
- Type O Mortar for general use in non-loadbearing walls in interior and above-grade exterior masonry.
- Type S Mortar for use in exterior work at or below grade, and an alternative mortar with higher compressive strength for interior loadbearing walls and exterior masonry above grade (most appropriate mortar for long-span, unreinforced, above-grade masonry, and for below-grade masonry applications)
- Type M Alternative mortar with highest compressive strength for interior and exterior loadbearing walls and exterior work at or below grade (lowest workability)
- Type K Mortar with high lime content often used for repointing historic structures.

ASTM C270 Recommended Mortar Type Applications			
Location	Building Segment	Mortar Type	
		Recommended	Alternative
Exterior, above grade	Loadbearing walls	N	S or M
	Non-loadbearing walls	O [§]	N or S
	Parapet walls	N	S
Exterior, at or below grade	Foundation walls, retaining walls, manholes, sewers, pavements [†] , walks [†] and patios [†]	S	M or N
Interior	Loadbearing walls	N	S or M
	Non-loadbearing partitions	O [§]	N

§ Type O mortar is recommended for use where the masonry is unlikely to be frozen when saturated and unlikely to be subjected to high winds or other significant lateral loads. Type N or S should be used in other cases.

† Masonry exposed to weather in a nominally horizontal surface is extremely vulnerable to weathering. Mortar for such masonry should be selected with due caution.

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RULE OF THUMB

Bond strength is usually more important in masonry mortar than compressive strength. Mortars with high compressive strength are produced at the expense of workability, flow, and water retentivity, which are necessary to achieve maximum extent of bond and bond strength. Always select the mortar type with the lowest compressive strength appropriate to its location and use.

2.3.4 ASTM C270 Mortar Proportion and Mortar Property Specifications

ASTM C270 *Specification for Masonry Mortar* permits the specification of masonry mortar by *either* the proportion method (which is a prescriptive specification) or the property method (which is a performance specification). If the project specifications do not stipulate either the proportion or property method, the proportion method governs by default.

- The proportion method does not require laboratory mix design or testing. The proportion method is appropriate for veneer and empirically designed masonry, for which field testing is generally unnecessary. The strength of mortars prepared by the proportion method may be either higher or lower than those of mortars prepared by the property method. However, the proportion mixes are very conservative and often produce mortars with compressive strengths higher than those required by the property method and higher than is necessary for applied loads. Excessive compressive strength usually comes at the sacrifice of bond strength, which is more important in most low-rise and mid-rise masonry applications.
- The property method requires laboratory mix design to verify minimum strength, water retention, and air content values. The property method is appropriate for projects whose size or complexity makes it desirable to optimize mortar performance and economy by using mortars with the minimum compressive strength required for applied loads, or for projects where field sampling and testing for quality control are desired.

The compressive strength requirements for mortars prepared by the property method *do not apply* to mortars prepared by the proportion method. The strength requirements for property mortars are determined by a test method prescribed in ASTM C270 and are not comparable with the results of tests performed by ASTM C780 *Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Masonry*. Differences between the two test methods and the materials used to form the mortar cubes and the amount of mixing water used affect the test results. An identical mix design field-sampled and tested by ASTM C780 methods would yield compressive strength results only about 70 to 75% of the results obtained using ASTM C270 test methods because C270 does not compensate for the additional mixing water required in the field because of the absorption of the masonry units.

If field sampling and testing of mortars prepared by the property method is desired, a laboratory mix design should be prepared and tested by the ASTM C270 test method, and pre-construction benchmark testing should then be done on the design mix using the ASTM C780 test method. The ASTM C780 pre-construction benchmark test results can then be used to determine the acceptability of field-sampled mortars tested under the same ASTM C780 test method.

2.3.5 **ASTM C270 Mortar Proportion and Mortar Property Specification Requirements**

Mortar should be specified by *either* the proportion *or* property specification requirements, and should incorporate only materials conforming to the following standards.

- Portland Cement, ASTM C150

Blended Cement, ASTM C595

Masonry Cement, ASTM C91

Sand Aggregate, ASTM C144
- Mortar Cement, ASTM C1329

Hydrated Lime, ASTM C207

Quicklime, ASTM C5

Mortar Proportions (by Volume)										
Mortar	Type	Portland Cement or Blended Cement	Masonry Cement Type			Mortar Cement Type			Hydrated Lime or Lime Putty	Aggregate (Sand) Measured in a Damp, Loose Condition
			M	S	N	M	S	N		
Cement-Lime	M	1							¼	not less than 2¼ and nor more than 3 times the sum of the separate volumes of cement and lime
	S	1							over ¼ to ½	
	N	1							over ½ to 1½	
	O	1							over 1¼ to 2½	
Mortar Cement	M	1						1		
	M					1				
	S	½					1			
	S						1			
	N							1		
Masonry Cement	O							1		
	M	1			1					
	M		1							
	S	½		1						
	S				1					
	N									
	O				1					

Mortar Properties ^s (ASTM C270 Test Methods)				
Mortar	Type	Minimum Average Compressive Strength at 28 Days (psi)	Minimum Water Retention (%)	Maximum Air Content† (%)
Cement-Lime	M	2500	75	12
	S	1800	75	12
	N	750	75	14
	O	350	75	14
Mortar Cement	M	2500	75	12
	S	1800	75	12
	N	750	75	14
	O	350	75	14
Masonry Cement	M	2500	75	18
	S	1800	75	18
	N	750	75	20
	O	350	75	20

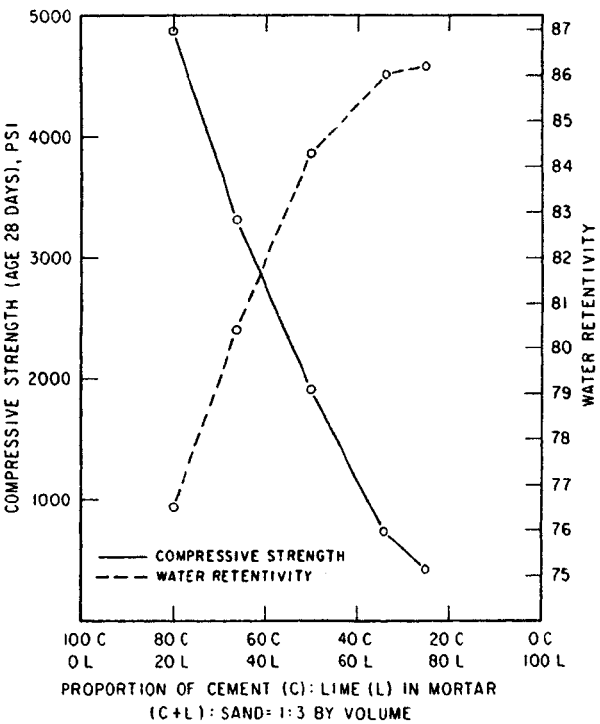
^s The aggregate ratio, measured in a damp, loose condition, shall not be less than 2¼ and not more than 3 times the sum of the separate volumes of cement and lime.

[†] When structural reinforcement is incorporated in cement-lime or mortar cement mortars, maximum air content shall not exceed 12%. When structural reinforcement is incorporated in masonry cement mortars, maximum air content shall not exceed 18%.

2.3.6 Volume Measurement of Mortar Materials

Material	Volume (cu.ft.)
1 bag portland cement	1.0
1 bag hydrated lime	1.0
1 ton wet sand	20.25
1 ton damp, loose sand	18.25
1 ton dry sand	16.25

2.3.7 Relationship Between Mortar Composition, Strength, and Water Retention



(From National Research Council of Canada.)

2.3.8 Recommended Repointing Mortars

Location	Mortar Type	
	Recommended	Alternative
Interior	O	K, N
Exterior, above grade exposed on one side, unlikely to be frozen when saturated, not subject to high wind or other significant lateral load	O	N, K
Exterior, other than above	N	O

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Masonry Material	Recommended Mortar Mix Proportions for Various Weathering Exposures		
	Sheltered	Moderate	Severe
Highly durable granite or hard brick	1 part cement 2 parts lime 8 to 9 parts sand	1 part cement 1½ parts lime 5 to 6 parts sand	1 part cement ½ part lime 4 to 4½ parts sand
Moderately durable stone or brick	1 part cement 3 parts lime 10 to 12 parts sand	1 part cement 2 parts lime 8 to 9 parts sand	1 part cement 1½ parts lime 5 to 6 parts sand
Poorly durable soft brick or friable stone	0 parts cement 2 parts hydraulic lime 5 parts sand	1 part cement 3 parts lime 10 to 12 parts sand	1 part cement 2 parts lime 8 to 9 parts sand

(Adapted from the Ontario Ministry of Citizenship and Culture, Annotated Master Specifications for the Cleaning and Repointing of Historic Masonry Structures, 1985.)

2.3.9 Estimating Mortar Quantities

Type of Masonry	Mortar Quantity (cu.yds.)
3-5/8" x 2-1/4" x 7-5/8" modular brick with 3/8" mortar joints	0.515 per 1000 brick
Nominal 8" x 8" x 16" concrete block with 3/8" mortar joints	1.146 per 1000 block
4" x 1-1/2" x 8" paving brick 3/8" mortar joints 1" thick mortar setting bed	0.268 per 1000 pavers 0.820 per 1000 pavers
Cut stone	0.04 to 0.10 per cu.yd. of stone
Fieldstone	0.15 to 0.40 per cu.yd. of stone

(Adapted from Kolkoski, Masonry Estimating.)

2.4.1 ASTM C476 Masonry Grout Requirements

Masonry grout should be specified either by mix proportions or by minimum compressive strength, and should incorporate only materials conforming to the standards listed below. Selection of grout type depends on the size of the space to be grouted. ASTM C476 and most building codes require a minimum grout compressive strength of 2000 psi when tested in accordance with ASTM C1019.

- Portland Cement, ASTM C150

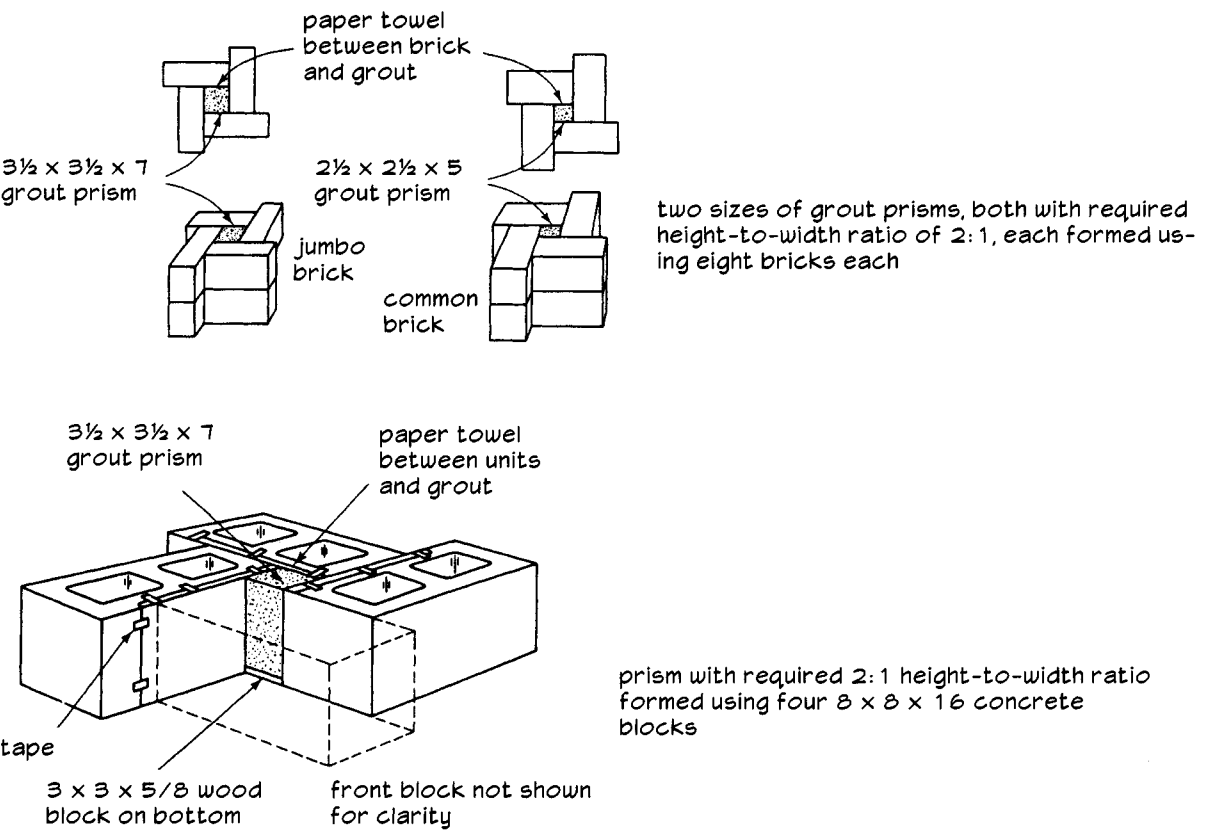
Blended Cement, ASTM C595

Grout Aggregate, ASTM C404
- Hydrated Lime, ASTM C207

Quicklime, ASTM C5

Grout Type	Parts by Volume of Portland Cement or Blended Cement	Parts by Volume of Hydrated Lime or Lime Putty	Aggregate Measured in Damp, Loose Condition	
			Fine	Coarse
Fine	1	0 to 1/10	2-1/4 to 3 times the sum of the volumes of the cement and lime	—
Coarse	1	0 to 1/10	2-1/4 to 3 times the sum of the volumes of the cement and lime	1 to 2 times the sum of the volumes of the cement and lime

2.4.2 ASTM C1019 Masonry Grout Test Prisms



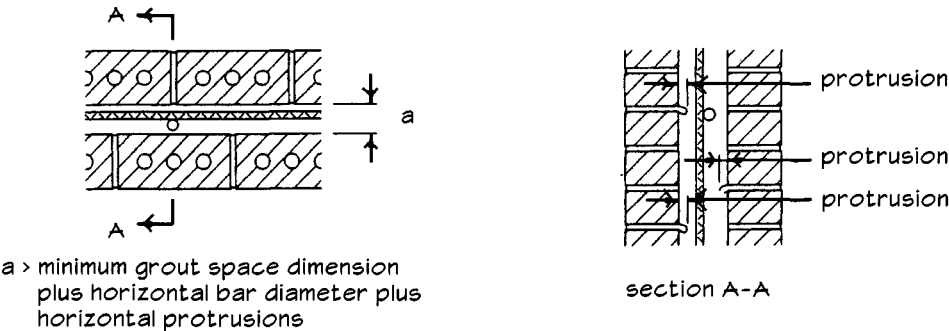
2.4.3 Masonry Grout Space Requirements

Minimum Grout Space Requirements for ASTM C476 Grout (with tolerance of +3/8" or -1/4")			
Grout Type	Maximum Grout Pour Height (ft.)	Minimum Width of Grout Space Between Wythes of Masonry [§] (in.)	Minimum Grout Space Dimensions for Grouting Cells or Cores of Hollow Units ^{§†} (in. x in.)
Fine	1	¾	1½ x 2
Fine	5	2	2 x 3
Fine	12	2½	2½ x 3
Fine	24	3	3 x 3
Coarse	1	1½	1½ x 3
Coarse	5	2	2½ x 3
Coarse	12	2½	3 x 3
Coarse	24	3	3 x 4

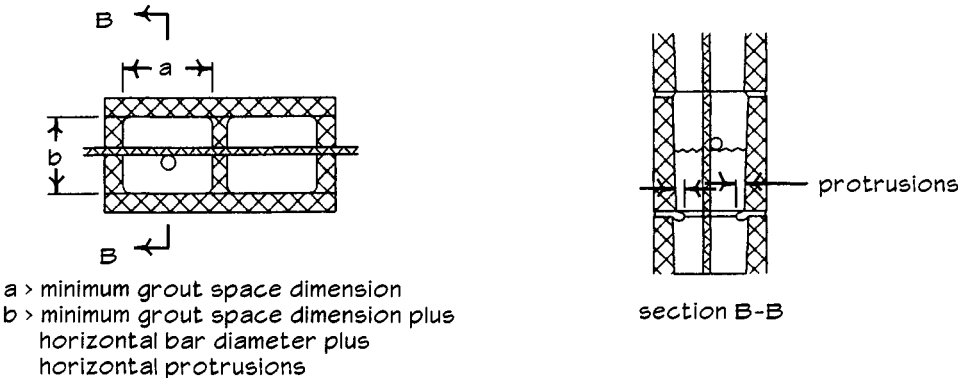
§ Grout space dimension is the clear dimension between any masonry protrusion and shall be increased by the diameters of the horizontal bars within the cross section of the grout space.

† Area of vertical reinforcement not to exceed 6% of the area of the grout space.

(From *Masonry Standards Joint Committee Building Code Requirements for Masonry Structures, ACI 530/ASCE 5/TMS 402*).



grout space requirements for cavity between wythes of masonry



grout space requirements for cells or cores of hollow units

2.4.4 Maximum Area of Steel per CMU Core

Nominal Unit Thickness (in.)	Actual Unit Thickness (in.)	Cell or Core Area (sq.in.)	Maximum 6% Allowable Area of Steel [§] (sq.in.)	Alternate 5% Area of Steel (sq.in.)
4	3-5/8	12.6	0.76	0.63
6	5-5/8	21.0	1.26	1.05
8	7-5/8	30.0	1.80	1.50
10	9-5/8	42.0	2.52	2.10
12	11-5/8	54.0	3.24	2.70

[§] Based on Uniform Building Code requirements.

(From Amrhein, Reinforced Masonry Engineering Handbook.)

2.4.5 Maximum Number of Reinforcing Bars per CMU Core

	Nominal Unit Thickness (in.)	Area of Steel (sq.in.)	Bar Size and Sq.In. per Bar							
			No. 4 0.20	No. 5 0.31	No. 6 0.44	No. 7 0.60	No. 8 0.79	No. 9 1.00	No. 10 1.27	No. 11 1.56
Alt. 5%	4	0.63	3	2	1	1	*	*	*	*
Alt. 5%	6	1.05		3	2	1	1	1	*	*
Alt. 5%	8	1.50		4	3	2	1	1	1	*
Alt. 5%	10	2.10				3	2	2	1	1
Alt. 5%	12	2.70				4	3	2	2	1
Max. 6%	4	0.76	3	2	1	1	1	*	*	*
Max. 6%	6	1.26		4	2	2	1	1	1	*
Max. 6%	8	1.80			4	3	1	1	1	1
Max. 6%	10	2.52				4	3	2	2	1
Max. 6%	12	3.24					4	3	2	2

* Exceeds Uniform Building Code allowance.

(Adapted from Amrhein, Reinforced Masonry Engineering Handbook.)

2.4.6 Estimating Masonry Grout Quantities

Approximate Grout Quantities in Single-Wythe Concrete Masonry Walls ^{§†}				
Nominal Thickness of Standard Two-Core CMU	Spacing of Grouted Cores and Vertical Reinforcing Bars (in. on center)	Volume of Grout per Square Foot of Wall (cu.yd.)	Volume of Grout per 100 8 x 16 Masonry Units (cu.yd.)	Number of 8 x 16 Units Filled per Cubic Yard of Grout
6	all cores grouted solid	0.93	0.83	120
	16	0.55	0.49	205
	24	0.42	0.37	270
	32	0.35	0.31	320
	40	0.31	0.28	360
	48	0.28	0.25	396
8	all cores grouted solid	1.12	1.00	100
	16	0.65	0.58	171
	24	0.50	0.44	225
	32	0.43	0.38	267
	40	0.37	0.33	300
	48	0.34	0.30	330
10	all cores grouted solid	1.38	1.23	80
	16	0.82	0.73	137
	24	0.63	0.56	180
	32	0.53	0.47	214
	40	0.47	0.42	240
	48	0.43	0.38	264
12	all cores grouted solid	1.73	1.54	65
	16	1.01	0.90	111
	24	0.76	0.68	146
	32	0.64	0.57	174
	40	0.57	0.51	195
	48	0.53	0.47	215

§ Table assumes horizontal bond beams at 48" on center, and includes a 3% allowance for grout waste and various job conditions.

† For open-end block, increase quantities by about 10%. For slump block, reduce quantities by about 5%.

Approximate Grout Quantities in Double-Wythe Masonry Walls [§]		
Width of Grout Space (in.)	Quantity of Grout per 100 sq.ft. of Wall (cu.yd.)	Square Feet of Wall Filled per Cubic Yards of Grout
2.0	0.64	157
2.5	0.79	126
3.0	0.96	105
3.5	1.11	90
4.0	1.27	79
4.5	1.43	70
5.0	1.59	63
5.5	1.75	57
6.0	1.91	52
6.5	2.07	48
7.0	2.23	45
8.0	2.54	39

§ Table includes 3% allowance for waste and various job conditions.

(From Amrhein, Reinforced Masonry Engineering Handbook.)

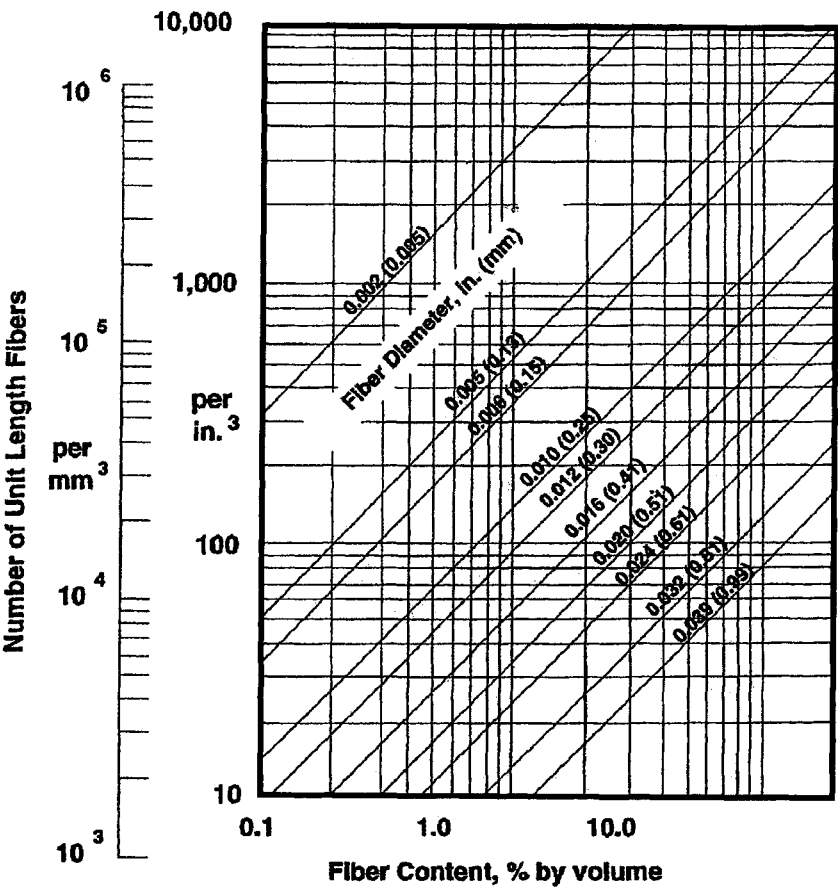
2.5.1 Aggregate Gradation and Mix Proportions for Steel Fiber Reinforced Concrete

Recommended Combined Aggregate Gradations for Steel Fiber Reinforced Concrete					
U.S. Standard Sieve Size	Percent Passing for Maximum Aggregate Size in Inches				
	3/8	1/2	3/4	1	1-1/2
2	100	100	100	100	100
1-1/2	100	100	100	100	85–100
1	100	100	100	94–100	65–85
3/4	100	100	94–100	76–82	58–77
1/2	100	93–100	70–88	65–76	50–68
3/8	96–100	85–96	61–73	56–66	46–58
No. 4	72–84	58–78	48–56	45–53	38–50
No. 8	46–57	41–53	40–47	36–44	29–43
No. 16	34–44	32–42	32–40	29–38	21–34
No. 30	22–33	19–30	20–32	19–28	13–27
No. 50	10–18	8–15	10–20	8–20	7–19
No. 100	2–7	1–5	3–9	2–8	2–8
No. 200	0–2	0–2	0–2	0–2	0–2

Range of Proportions for Normal Weight Steel-Fiber-Reinforced Concrete			
Mix Parameters	Maximum Aggregate Size (in.)		
	3/8	3/4	1-1/2
Cement (lb./cu.yd.)	600–1000	500–900	470–700
Water-cement ratio	0.35–0.45	0.35–0.50	0.35–0.55
Percent of fine to coarse aggregate	45–60	45–55	40–55
Entrained air content (%)	4–8	4–6	4–5
Fiber content, volume (%)			
deformed fiber	0.4–1.0	0.3–0.8	0.2–0.7
smooth fiber	0.8–2.0	0.6–1.6	0.4–1.4

(From State-Of-the-Art Report on Fiber Reinforced Concrete, ACI 544.1R-96, American Concrete Institute, 1996)

2.5.2 Steel Fiber Volume and Geometry



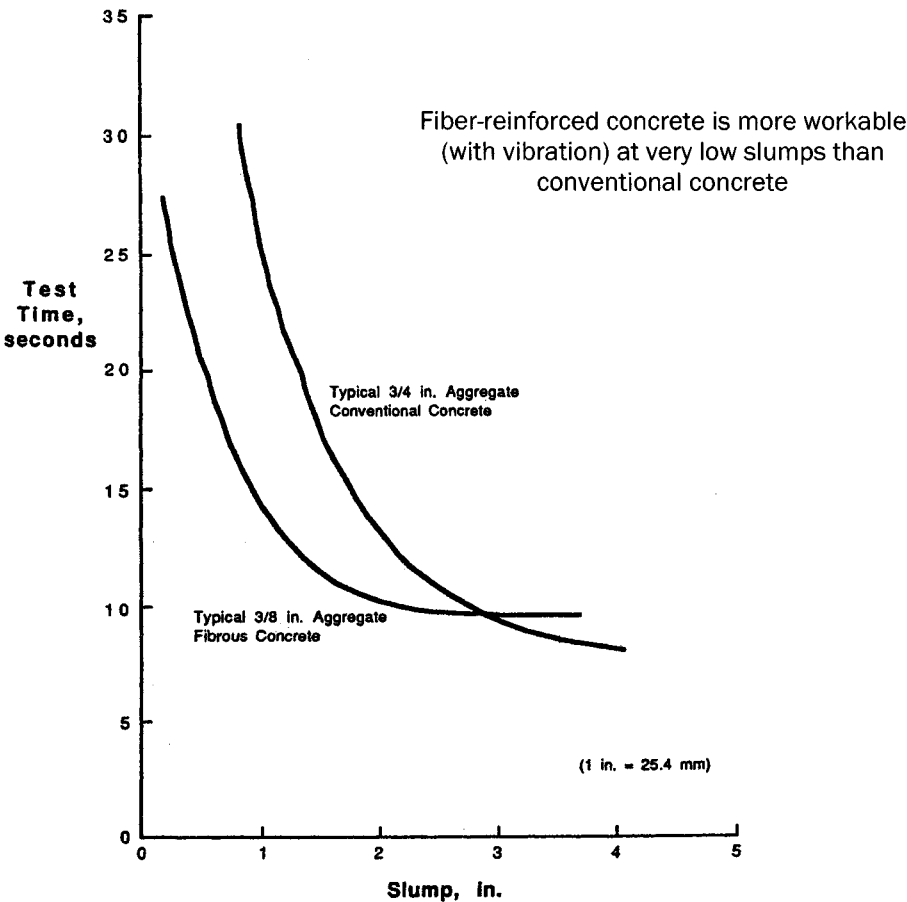
(From ACI 544.1R-96)

2.5.3 Glass Fiber Reinforced Concrete (GFRC)

Typical 28-Day Material Property Values For AR-GFRC	
Property	AR-GFRC System ^s
Flexural strength (psi)	
modulus of rupture (MOR)	2,500–4,000
proportional elastic limit (PEL)	900–1,500
Tensile strength (psi)	
ultimate tensile strength (UTS)	1,000–1,600
bend over point (BOP)	700–1,000
Shear strength (psi)	
interlaminar	400–800
in-plane	1,000–1,600
Impact strength (in.-lb./sq.in.)	
Charpy	55–140
Dry density (pcf)	120–140

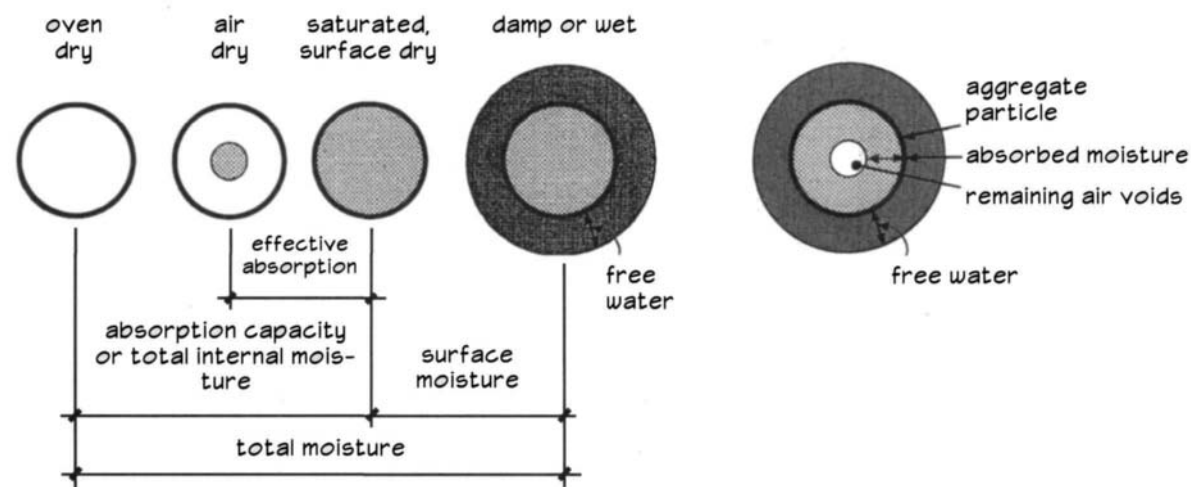
^s Sprayed (non-dewatered) with 5% by weight of AR-fibers, sand:cement ratios range from 1:3 to 1:1, and water-cement ratios range from 0.25 to 0.35.

(From ACI 544.1R-96)



(From ACI 544.2R-89, re-approved 1999)

2.6.1 Aggregate for Lightweight Concrete



states of moisture in aggregate
(heavy circle represents the aggregate; crosshatching represents moisture)

"as-is" condition
(heavy middle circle represents the aggregate particle; crosshatching represents moisture)

Comparison of Fineness Modulus for Typical Lightweight Aggregate						
Sieve Size No.	Opening (in.)	Percent Retained by Weight	Cumulative Percent Retained by Weight	Bulk Specific Gravity, SSD Basis	Percent Retained by Volume	Cumulative Percent Retained by Volume
4	0.187	0	0	—	0	0
8	0.0937	22	22	1.55	26	26
16	0.0469	24	46	1.78	25	51
30	0.0234	19	65	1.90	19	70
50	0.0117	14	79	2.01	13	83
100	0.0059	12	91	2.16	10	93
pan	—	9	100	2.40	7	100

Note: Fineness modulus by weight = 3.03. Fineness modulus by volume = 3.23.

Volume of Coarse Aggregate per Unit Volume of Concrete ^s				
Maximum Aggregate Size (in.)	Fineness Moduli of Sand			
	2.40	2.60	2.80	3.00
3/8	0.58	0.56	0.54	0.52
1/2	0.67	0.65	0.63	0.61
3/4	0.74	0.72	0.70	0.68

§ Volumes are based on aggregates in oven-dry, loose condition as described in ASTM C29. These volumes are selected from empirical relationships to produce concrete with a degree of workability suitable for usual reinforced construction. For more workable concrete such as may sometimes be required when placement is to be by pumping, they may be reduced up to 10%.

(From ACI 211.2-98 Standard Practice for Selecting Proportions for Structural Lightweight Concrete, American Concrete Institute)

2.6.2 Structural Lightweight Concrete Mixes

Approximate Mixing Water (lb./cu.yd.) and Target Air Content Requirements for Different Concrete Slumps and Maximum Sizes of Aggregate ^s			
Maximum Aggregate Size →	3/8 in.	1/2 in.	3/4 in.
Non-Air-Entrained Concrete			
Slump 1 to 2 in.	350	335	315
Slump 3 to 4 in.	385	365	340
Slump 5 to 6 in.	400	375	350
Approximate amount of entrapped air in non-air-entrained concrete (%)	3	2.5	2
Air-Entrained Concrete			
Slump 1 to 2 in.	305	295	280
Slump 3 to 4 in.	340	325	305
Slump 5 to 6 in.	355	335	315
Recommended average total air content for level of exposure (%) [†]			
Mild exposure	4.5	4.0	4.0
Moderate exposure	6.0	5.5	5.0
Severe exposure	7.5	7.0	6.0

^s Mixing water quantities are maximums for use in designing trial batches at 68 to 77°F with reasonably well shaped angular coarse aggregates graded within limits of accepted specifications. Water-reducing admixtures may reduce mixing water by 5% or more. Mixing water for air-entrained concrete based on typical requirements for "moderate exposure."

[†] Additional air content recommendations given in ACI and ASTM documents and may not always agree, so consideration must be given to selecting an air content which will meet the needs of the project and the applicable specifications.

First Estimate of Weight of Fresh Lightweight Structural Concrete (lb./cu.yd.) Comprised of Lightweight Coarse Aggregate and Normal Weight Sand			
Specific Gravity Factor	Entrained Air (%)		
	4	6	8
1.00	2690	2630	2560
1.20	2830	2770	2710
1.40	2980	2910	2850
1.60	3120	3050	2990
1.80	3260	3200	3130
2.00	3410	3340	3270

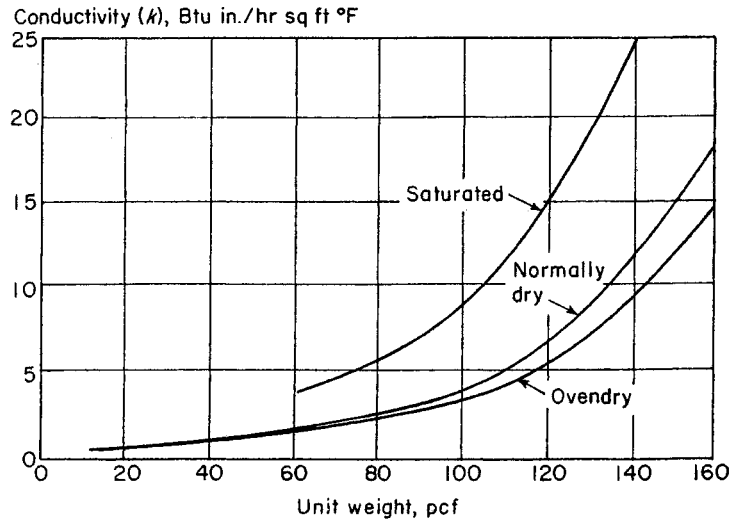
Values for concrete of medium richness (550 lb. cement per cu.yd.) and medium slump with requirements based on values for 3 to 4 in. slump. For each 10 lb. difference in mixing water from table at top, correct weight per cu. yd. 15 lb. in the opposite direction. For each 100 lb. difference in cement content from 550 lb., correct the weight per cu.yd. 15 lb. in the same direction.

2.6.3 Lightweight Insulating Concrete Mixes

Examples of Lightweight Insulating Concrete Mixes

Type of Concrete	Volume Ratio: Portland Cement to Aggregate	Oven Dry Density (pcf)	Type I Portland Cement (lb./cu.yd.)	Water-Cement Ratio by Weight	28-Day Compressive Strength (psi), 6 x 12 in. Cylinders
Perlite	1:4	30 to 38	610	0.94	400
	1:5	26 to 36	516	1.12	325
	1:6	22 to 34	414	1.24	220
	1:8	20 to 32	395	1.72	200
Vermiculite	1:4	31 to 37	640	0.98	300
	1:5	28 to 31	498	1.30	170
	1:6	23 to 29	414	1.60	130
	1:8	20 to 21	300	2.08	80
Polystyrene† 0 lb. sand	1:3.4	34§	750	0.40	325
	1:3.1	39§	750	0.40	400
	1:2.9	44§	750	0.40	475
	1:2.5	48§	800	0.40	550
Cellular (neat cement)	—	39	884	0.57	350
	—	34	790	0.56	210
	—	28	668	0.57	130
	—	23	535	0.65	50
Cellular (with dry-rodded sand weighing 100 pcf)	1:1	58	724	0.40	460
	1:2	78	630	0.41	820
	1:3	100	602	0.51	2190

§ Air-dry density at 28 days, 50% relative humidity.
† Mix also includes air entrainment and a water reducer.



Approximate relationship between unit weight and thermal conductivity of insulating structural lightweight and normal weight concretes

(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

2.7.1 Recommendations for High-Strength Concrete

Recommended Volume of Coarse Aggregate Per Unit Volume of Concrete	
Maximum Size Aggregate (in.)	Optimum Fractional Volume of Coarse Aggregate
3/8	0.65
1/2	0.68
3/4	0.72
1	0.75

Volumes are based on oven-dry rodded coarse aggregate to be used with sand with a fineness modulus of 2.5 to 3.2.

Suggested Maximum Size Coarse Aggregate	
Required Concrete Strength (psi)	Suggested Maximum Size Coarse Aggregate (in.)
Less than 9000	3/4 to 1
Greater than 9000	3/8 to 1/2

When using high-range water reducers and selected coarse aggregates, concrete compressive strengths in the range of 9,000 to 12,000 psi can be attained using larger than recommended nominal maximum size coarse aggregates of up to 1 in.

First Estimate of Mixing Water Requirement (lb./cu.yd.) and Air Content [§]				
Maximum Aggregate Size →	3/8	1/2	3/4	1
Slump 1 to 2 in.	310	295	285	280
Slump 2 to 3 in.	320	310	295	290
Slump 3 to 4 in.	330	320	305	300
Entrapped Air Content† (%)				
without high-range water reducer	3.0	2.5	2.0	1.5
with high-range water reducer	2.5	2.0	1.5	1.0

§ Based on using sand with 35% voids.

† Values for air content must be adjusted for sands with voids other than 35%.

Recommended Slump for Concretes Made With and Without High-Range Water Reducers	
Type of Concrete	Slump (in.)
Made without high-range water reducer	2 to 4
Made with high-range water reducers [§]	1 to 2 (before adding high-range water reducer)

§ Adjust slump to that desired in field through the addition of high-range water reducing admixture.

2.7.2 Water-Cement Ratios for High-Strength Concrete

- A comparison of the values for the ratio of water to cementitious material (portland cement plus pozzolan) in the tables below for concrete made with and without high-range water reducing admixtures (superplasticizers) permits, in particular, the following conclusions.
- For a given water-cementitious material ratio, the field strength of concrete is greater with the use of high-range water reducing admixtures than without, and this greater strength is reached within a shorter period of time.
 - With the use of high-range water reducing admixtures, a given concrete field strength can be achieved in a given period of time using less cementitious material than would be required when not using a high-range water reducing admixture.

Recommended Maximum Ratio of Water to Cementitious Material (Cement + Pozzolan) for Concrete Made Without High-Range Water Reducer

Field Strength, f_{cr} (psi)		Maximum Aggregate Size (in.)			
		3/8	1/2	3/4	1
7,000	28-day	0.42	0.41	0.40	0.39
	56-day	0.46	0.45	0.44	0.43
8,000	28-day	0.35	0.34	0.33	0.33
	56-day	0.38	0.37	0.36	0.35
9,000	28-day	0.30	0.29	0.29	0.28
	56-day	0.33	0.31	0.31	0.30
10,000	28-day	0.26	0.26	0.25	0.25
	56-day	0.29	0.28	0.27	0.26

Note: $f_{cr}' = f_c' + 1400$
where f_c' = strength of concrete (psi), and
 f_{cr}' = field strength of concrete (psi)

Recommended Maximum Ratio of Water to Cementitious Material (Cement + Pozzolan) for Concrete Made With High-Range Water Reducer

Field Strength, f_{cr} (psi)		Maximum Aggregate Size (in.)			
		3/8	1/2	3/4	1
7,000	28-day	0.50	0.48	0.45	0.43
	56-day	0.55	0.52	0.48	0.46
8,000	28-day	0.44	0.42	0.40	0.38
	56-day	0.48	0.45	0.42	0.40
9,000	28-day	0.38	0.36	0.35	0.34
	56-day	0.42	0.39	0.37	0.36
10,000	28-day	0.33	0.32	0.31	0.30
	56-day	0.37	0.35	0.33	0.32
11,000	28-day	0.30	0.29	0.27	0.27
	56-day	0.33	0.31	0.29	0.29
12,000	28-day	0.27	0.26	0.25	0.25
	56-day	0.30	0.28	0.27	0.26

Note: $f_{cr}' = f_c' + 1400$
where f_c' = strength of concrete (psi), and
 f_{cr}' = field strength of concrete (psi)

Recommended Values for Fly Ash Replacement of Portland Cement

Fly Ash	Recommended Replacement (% by Weight)
Class F	15 to 25
Class C	20 to 35

(From ACI 211.4R-93 Guide For Selecting Proportions for High-Strength Concrete with Portland Cement and Fly Ash, American Concrete Institute)

Concrete and Masonry Performance Characteristics

3.1 Strength

- 3.1.1 Compressive, Tensile, and Flexural Strength
- 3.1.2 Compressive Strength of Concrete
- 3.1.3 Concrete Modulus of Elasticity
- 3.1.4 Ultimate Strength of Masonry Materials
- 3.1.5 MSJC and IBC Unit Strength/Masonry Compressive Strength (f'_m) Tables
- 3.1.6 UBC Unit Strength/Masonry Compressive Strength (f'_m) Tables

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- 3.2.1 Thermal Values of Common Concrete, Masonry and Insulation Materials
- 3.2.2 Properties of Insulation Materials
- 3.2.3 Insulated Concrete Masonry Units
- 3.2.4 Insulating Concrete and Masonry Walls
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- 3.2.6 Reflectance, Absorptance, and Emittance
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- 3.4.10 Doweled Concrete Joints
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- 3.4.12 Concrete Control Joint Spacing for Slabs-On-Ground
- 3.4.13 Concrete Joint Locations
- 3.4.14 Concrete Masonry Control Joints
- 3.4.15 Clay Masonry Expansion Joints
- 3.4.16 Masonry Joint Locations
- 3.4.17 Formulas for Calculating Required Sealant Joint Width

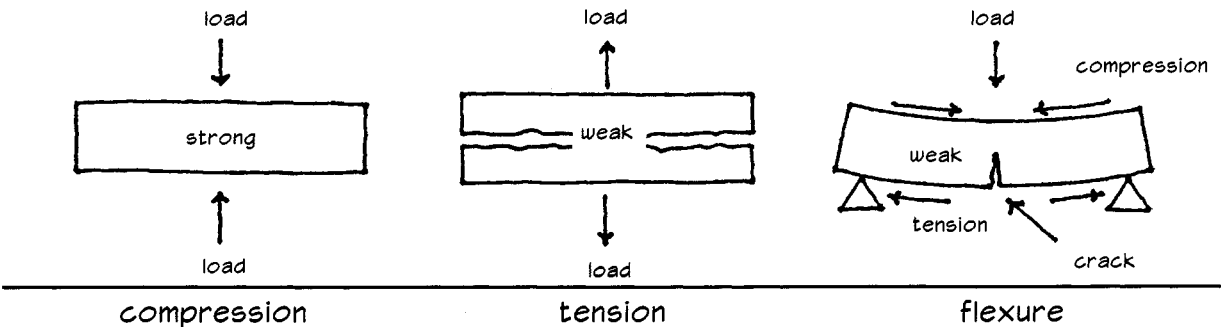
3.5 Acoustical Resistance

- 3.5.1 Types of Acoustical Ratings
- 3.5.2 Noise Reduction Coefficients (NRC) for Various Building Materials and Furnishings
- 3.5.3 Sound Absorption Test Data for Concrete Masonry "Sound Block"
- 3.5.4 Sound Transmission Class and Wall Weight
- 3.5.5 STC Ratings for Clay Masonry Walls
- 3.5.6 STC Ratings for Lightweight CMU Walls
- 3.5.7 STC Ratings for Medium Weight CMU Walls
- 3.5.8 STC Ratings for Normal Weight CMU Walls
- 3.5.9 STC and IIC Ratings for Concrete Assemblies

3.6 Weather Resistance

- 3.6.1 Barrier, Drainage and Rain Screen Walls
- 3.6.2 Weather-Resistant Concrete
- 3.6.3 IBC Minimum Strengths for Concrete
- 3.6.4 IBC Special Requirements for Concrete

3.1.1 Compressive, Tensile, and Flexural Strength

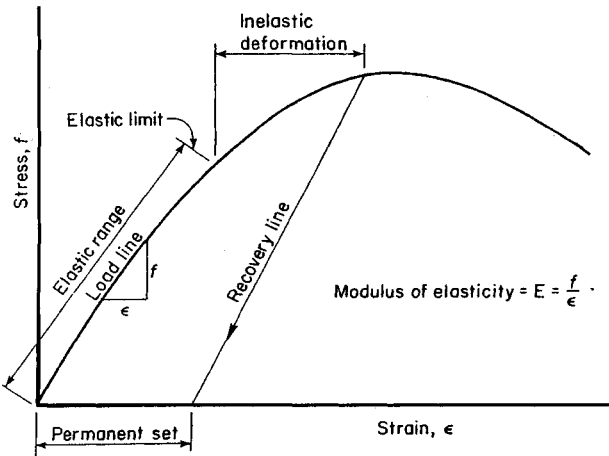


Masonry and concrete are strong in compression and resist tensile and flexural stresses through the incorporation of reinforcing steel.

3.1.2 Compressive Strength of Concrete

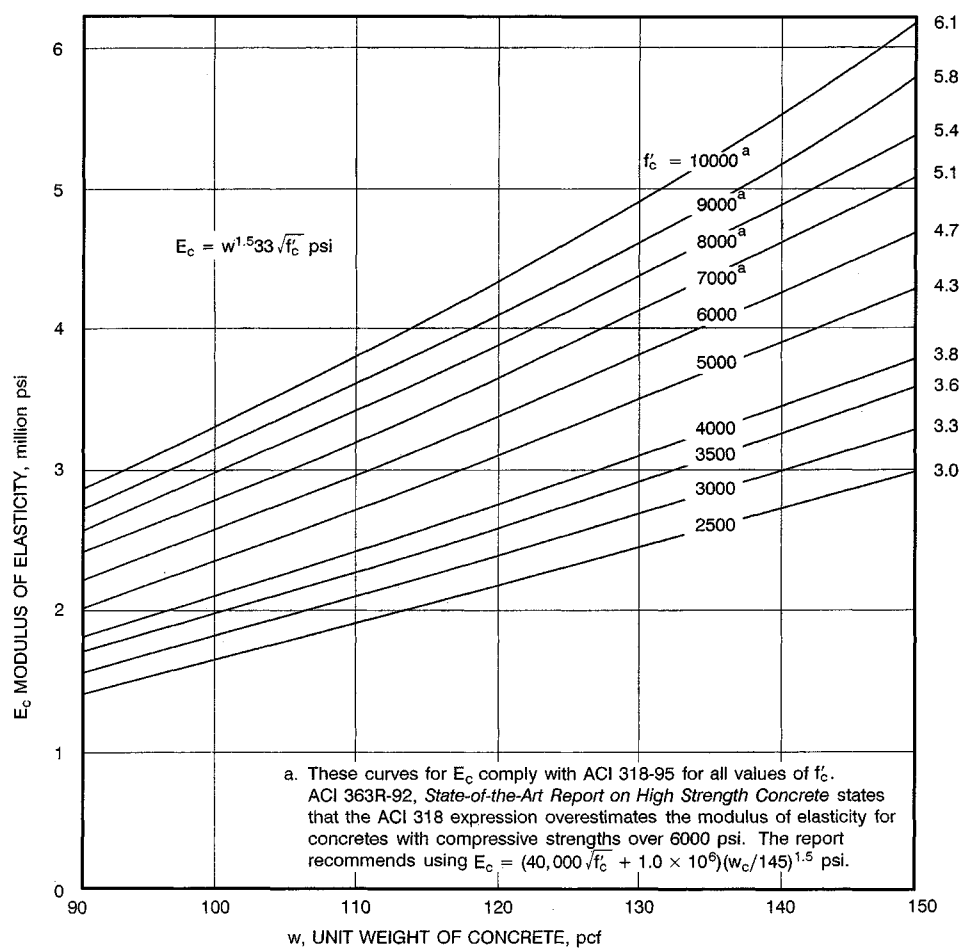
f'_c	$0.45f'_c$	$0.6f'_c$	$\sqrt{f'_c}$	$2\sqrt{f'_c}$	$3.5\sqrt{f'_c}$	$4\sqrt{f'_c}$	$5\sqrt{f'_c}$	$6\sqrt{f'_c}$	$7.5\sqrt{f'_c}$	$12\sqrt{f'_c}$
2500	1125	1500	50	100	175	200	250	300	375	600
3000	1350	1800	55	110	192	219	274	329	411	657
3500	1575	2100	59	118	207	237	296	355	444	710
4000	1800	2400	63	126	221	253	316	379	474	759
5000	2250	3000	71	141	247	283	354	424	530	849
6000	2700	3600	77	155	271	310	387	465	581	930
7000	3150	4200	84	167	293	335	418	502	627	1004
8000	3600	4800	89	179	313	358	447	537	671	1073
9000	4050	5400	95	190	332	379	474	569	712	1138
10000	4500	6000	100	200	350	400	500	600	750	1200

(From PCI Design Handbook, 5th ed., Precast / Prestressed Concrete Institute, 1999)



Generalized stress-strain curve for concrete. (From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

3.1.3 Concrete Modulus of Elasticity as Affected by Unit Weight and Strength



(From PCI Design Handbook, 5th ed., Precast / Prestressed Concrete Institute, 1999)

3.1.4 Ultimate Strength of Masonry Materials

Material	Ultimate Compressive Strength (psi)	Density (lb/ft. ³)
Brick	2,000–20,000	100–140
Concrete masonry	1,500–6,000	75–135
Limestone	2,600–21,000	130–170
Sandstone	4,000–28,000	140–165
Marble	9,000–18,000	165–170
Granite	15,600–30,800	165–170

(From Allen, Fundamentals of Building Construction, John Wiley & Sons, 1999)

3.1.5 **MSJC and International Building Code Tables for Unit Strength Method of Verifying Masonry Compressive Strength (f'_m)**

The *unit strength method* of verifying specified compressive strength uses the tables below to show the net area compressive strength produced by combining units of a specific strength with either Type M, S or N mortar. The unit strength method of verifying f'_m may be used instead of laboratory prism testing when:

- units conform to ASTM requirements,
- bed joint thickness does not exceed 5/8 in., and
- grout meets ASTM C476 requirements, or grout compressive strength is equal to f'_m but not less than 2000 psi.

Required Net Area Compressive Strength of Clay Masonry Units (psi)		For Net Area Compressive Strength of Masonry (psi)
When Used With Type M or S Mortar	When Used With Type N Mortar	
1,700	2,100	1,000
3,350	4,150	1,500
4,950	6,200	2,000
6,600	8,250	2,500
8,250	10,300	3,000
9,900	---	3,500
13,200	---	4,000

(From *Masonry Standards Joint Committee Specifications for Masonry Structures*, ACI 530.1/ASCE 6/TMS 602-99)

Required Net Area Compressive Strength of Clay Masonry Units (psi)		For Net Area Compressive Strength of Masonry (psi)
When Used With Type M or S Mortar	When Used With Type N Mortar	
2,400	3,000	1,000
4,400	5,500	1,500
6,400	8,000	2,000
8,400	10,500	2,500
10,400	13,000	3,000
12,400	---	3,500
14,400	---	4,000

(From *International Building Code 2000*)

Required Net Area Compressive Strength of Concrete Masonry Units (psi)		For Net Area Compressive Strength of Masonry (psi)
When Used With Type M or S Mortar	When Used With Type N Mortar	
1,250	1,300	1,000
1,900	2,150	1,500
2,800	3,050	2,000
3,750	4,050	2,500
4,800	5,250	3,000

(From *International Building Code 2000 and Masonry Standards Joint Committee Specifications for Masonry Structures*, ACI 530.1/ASCE 6/TMS 602-99)

3.1.6 Uniform Building Code Tables for Unit Strength Method of Verifying Masonry Compressive Strength (f'_m)

The *unit strength method* of verifying masonry compressive strength uses the tables below to show the net area compressive strength produced by combining units of a specific strength with either Type M, S, or N mortar. The unit strength method of verifying f'_m may be used instead of laboratory prism testing when:

- units conform to UBC requirements,
- mortar and grout conform to UBC proportion requirements,
- mortar is portland cement and lime without air entraining materials, and
- compressive strength of grout for hollow concrete masonry is equal to compressive strength of units

Required Compressive Strength of Clay Masonry Units (psi)	Specified Compressive Strength of Masonry (psi)	
	When Using Type M or S Mortar	When Using Type N Mortar
14,000 or more	5,300	4,400
12,000	4,700	3,800
10,000	4,000	3,300
8,000	3,350	2,700
6,000	2,700	2,200
4,000	2,000	1,600

Required Compressive Strength of Concrete Masonry Units (psi)	Specified Compressive Strength of Masonry (psi)	
	When Using Type M or S Mortar	When Using Type N Mortar
4,800 or more	3,000	2,800
3,750	2,500	2,350
2,800	2,000	1,850
1,900	1,500	1,350
1,250	1,000	950

Note: The specified compressive strength of masonry (f'_m) is based on gross area strength when using solid units or solid grouted masonry, and on net area strength when using ungrouted hollow units.

(Tables from ICBO Uniform Building Code).

3.2.1 Thermal Values of Common Concrete, Masonry, and Insulation Materials

Description	Density (lb/ft³)	Conductivity (k)	Conduc- tance (C)	Resistance per Inch of Thickness (R)	Resistance for Thickness Listed (R)
INSULATION MATERIALS					
Board Insulation					
extruded polystyrene	1.8-3.5	0.20	—	5.40 at 40°F 5.00 at 75°F	—
expanded polystyrene	1.0	0.26	—	4.17 at 40°F 3.85 at 75°F	—
polyurethane/polyisocyanurate (unfaced)	1.5	0.16-0.18	—	6.25-5.56	—
polyurethane/polyisocyanurate (vapor permeable facers)	1.5-2.5	0.16-0.18	—	6.25-5.56	—
polyurethane/polyisocyanurate (vapor impermeable facers)	2.0	0.14	—	7.20	—
Loose Fill					
perlite	2.0-4.1	0.27-0.31	—	3.7-3.3	—
	4.1-7.4	0.31-0.36	—	3.3-2.8	—
vermiculite	4.0-6.0	0.44	—	2.13	—
	7.0-8.2	0.47	—	2.27	—
BRICK					
common brick	80	2.2-3.2	—	0.45-0.31	—
	90	2.7-3.7	—	0.37-0.27	—
	100	3.3-4.3	—	0.30-0.23	—
	110	3.5-5.5	—	0.29-0.18	—
	120	4.4-6.4	—	0.23-0.16	—
	130	5.4-9.0	—	0.19-0.11	—
face brick	130	5.4-9.0	—	0.19-0.11	—
CONCRETE					
lightweight aggregate and cellular concrete	120	5.5-11.0	—	0.18-0.09	—
	100	3.7-5.9	—	0.27-0.17	—
	80	2.5-3.5	—	0.40-0.29	—
	60	1.6-1.8	—	0.63-0.56	—
	40	0.93-1.11	—	1.08-0.90	—
sand and gravel or crushed stone aggregate	140	10.0-20.0	—	0.10-0.05	—
CONCRETE BLOCK					
normal weight aggregate					
6" nominal thickness	125+	—	—	—	1.6-2.0
with perlite fill	125+	—	—	—	2.2-3.7
with vermiculite fill	125+	—	—	—	2.2-3.5

3.2.1 Continued

Description	Density (lb/ft ³)	Conductivity (k)	Conduc- tance (C)	Resistance per Inch of Thickness (R)	Resistance for Thickness Listed (R)
CONCRETE BLOCK					
normal weight aggregate					
8" nominal thickness	125+	—	—	—	1.7-2.2
with perlite fill	125+	—	—	—	2.7-4.8
with vermiculite fill	125+	—	—	—	2.7-4.6
12" nominal thickness	125+	—	—	—	1.9-2.3
with perlite fill	125+	—	—	—	3.6-6.8
with vermiculite fill	125+	—	—	—	3.6-6.5
medium weight aggregate	105-124	—	—	—	
6" nominal thickness	105-124	—	—	—	1.8-2.2
with perlite fill	105-124	—	—	—	3.0-4.8
with vermiculite fill	105-124	—	—	—	2.9-4.5
8" nominal thickness	105-124	—	—	—	2.0-2.4
with perlite fill	105-124	—	—	—	3.8-6.3
with vermiculite fill	105-124	—	—	—	3.7-5.9
12" nominal thickness	105-124	—	—	—	2.1-2.6
with perlite fill	105-124	—	—	—	5.2-9.1
with vermiculite fill	105-124	—	—	—	5.1-8.5
light weight aggregate	85-104	—	—	—	
6" nominal thickness	85-104	—	—	—	2.1-2.5
with perlite fill	85-104	—	—	—	4.1-6.1
with vermiculite fill	85-104	—	—	—	3.9-5.6
8" nominal thickness	85-104	—	—	—	2.3-2.7
with perlite fill	85-104	—	—	—	5.3-8.2
with vermiculite fill	85-104	—	—	—	5.0-7.5
12" nominal thickness	85-104	—	—	—	2.4-3.0
with perlite fill	85-104	—	—	—	7.6-12.1
with vermiculite fill	85-104	—	—	—	7.2-11.0
STONE					
granite and marble	150-175	20	—	0.05	—
limestone and sandstone	—	12.5	—	0.08	—

3.2.1 Continued

Description	Density (lb/ft³)	Conductivity (k)	Conduc- tance (C)	Resistance per Inch of Thickness (R)	Resistance for Thickness Listed (R)
PLASTER AND STUCCO					
cement plaster, sand aggregate stucco	116	5.0	—	0.20	—
5/8" thickness	116	—	13.3	—	0.08
3/4" thickness	116	—	6.66	—	0.15
gypsum plaster					
lightweight aggregate, 1/2"	45	—	3.12	—	0.32
lightweight aggregate, 5/8"	45	—	2.67	—	0.39
lightweight aggregate on metal lath, 3/4"	—	—	2.13	—	0.47
perlite aggregate	45	1.5	—	0.67	—
sand aggregate	105	5.6	—	0.18	—
sand aggregate, 1/2"	105	—	11.10	—	0.09
sand aggregate, 5/8"	105	—	9.10	—	0.11
sand aggregate on metal lath, 3/4"	—	—	7.70	—	0.13
vermiculite aggregate	45	1.7	—	0.59	—

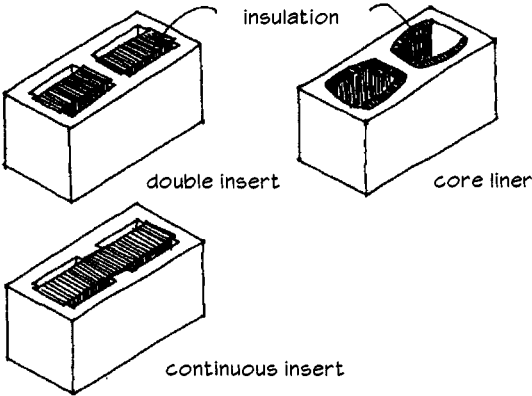
3.2.2 Properties of Insulation Materials

Material	Density (lb/ft³)	R-Value per Inch of Thickness	Water Vapor Perme- ability (perm-In.)	Water Absorption (% by weight)	Dimensional Stability
Molded polystyrene	0.9-1.8	3.6-4.4	1.2-5.0	2-3§	no change
Extruded polystyrene	1.6-3.0	4.0-6.0	0.3-0.9	1-4	no change
Polyurethane, unfaced	1.7-4.0	5.8-6.2	2.0-3.0	negligible	0-12% change
Polyisocyanurate, unfaced	1.7-4.0	5.8-7.8	2.5-3.0	negligible	0-12% change
Perlite, loose fill	5.0-8.0	2.63	100	low	Settles 0-10%
Vermiculite, loose fill	4.0-10.0	2.4-3.0	100	none	Settles 0-10%

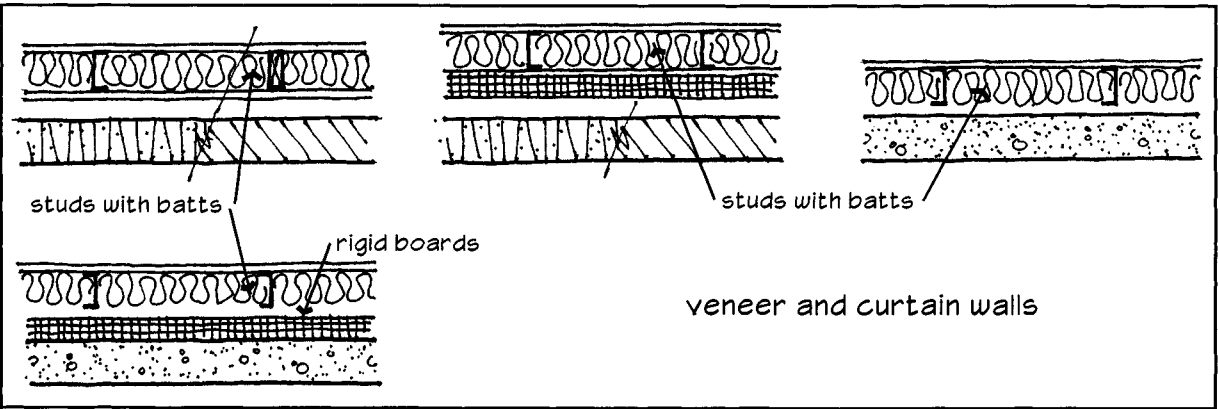
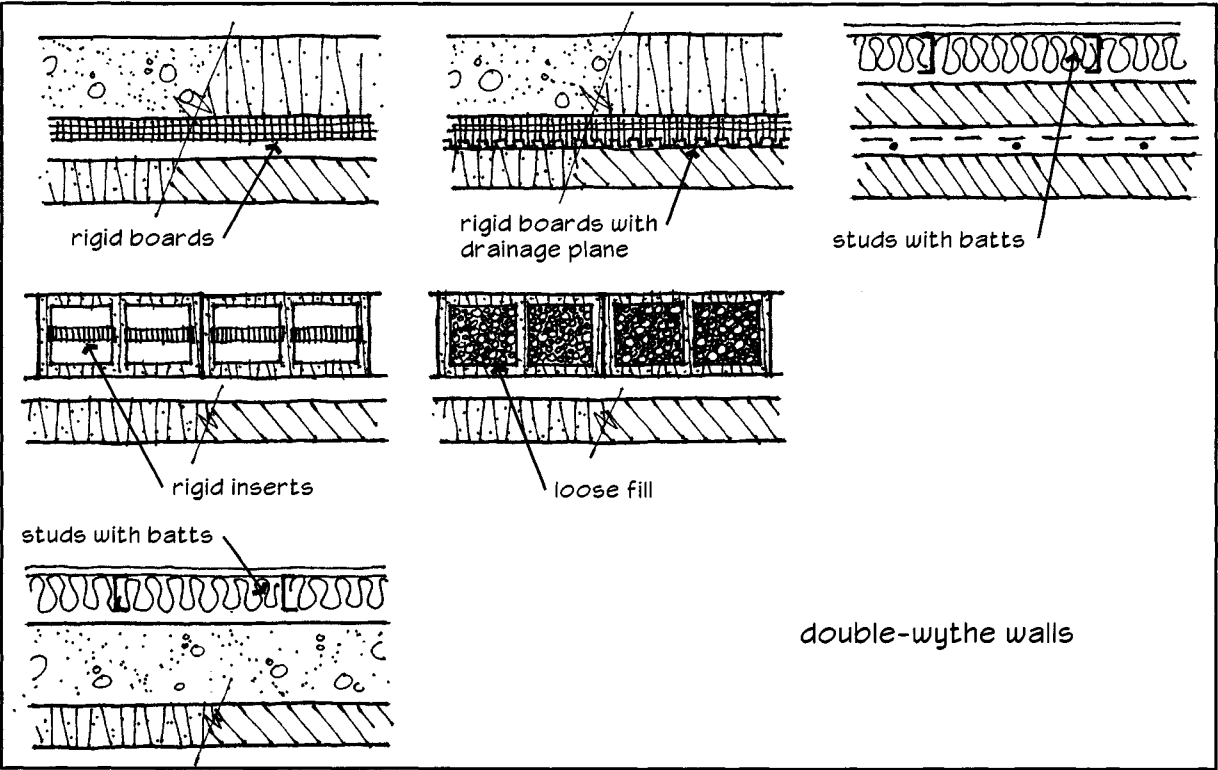
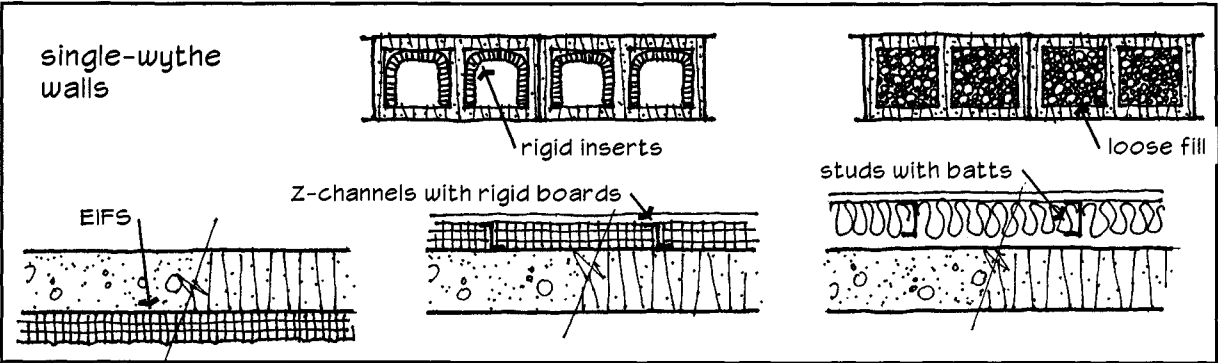
§ Water absorption given as percent by volume for molded polystyrene only.

(From Architectural Graphic Standards, 9th ed., John Wiley & Sons, 1994)

3.2.3 Insulated Concrete Masonry Units



3.2.4 Insulating Concrete and Masonry Walls



3.2.5 R-Values for Wood and Metal Stud Backing Walls

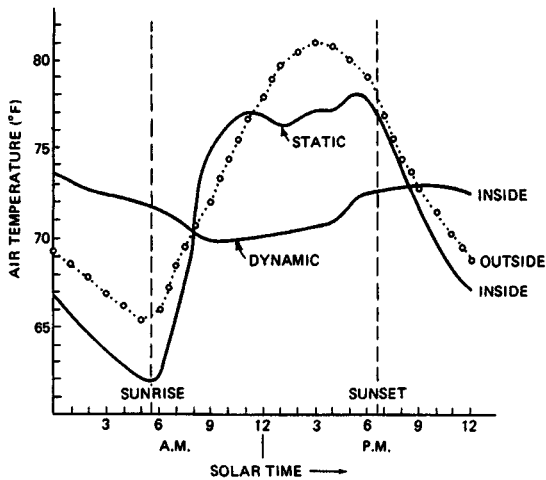
Component	R-Value		
	At Uninsulated Cavity	At Insulated Cavity	At Wood Stud
Inside air film	0.68	0.68	0.68
1/2" gypsum board	0.45	0.45	0.45
3-5/8" air space	1.14	—	—
3-1/2" batt insulation	—	13.0	—
2 x 4 wood stud	—	—	3.22-4.89
1/2" gypsum sheathing	0.45	0.45	0.45
Outside air film, winter	0.17	0.17	0.17
TOTAL	2.89	14.75	4.97-6.64

Stud Size (in.x in.) (16-18 gauge C- Channel or Lighter)	Center-to-Center Spacing of Studs (in.)	Cavity Insulation R-Value	Effective Framing/Cavity R-Value
2 x 4	16	11	5.5
2 x 4	16	13	6.0
2 x 4	16	15	6.4
2 x 4	24	11	6.6
2 x 4	24	13	7.2
2 x 4	24	15	7.8
2 x 6	16	19	7.1
2 x 6	16	21	7.4
2 x 6	24	19	8.6
2 x 6	24	21	9.0
2 x 8	16	25	7.8
2 x 8	24	25	9.6

3.2.6 Reflectance, Absorptance, and Emittance of Various Surfaces

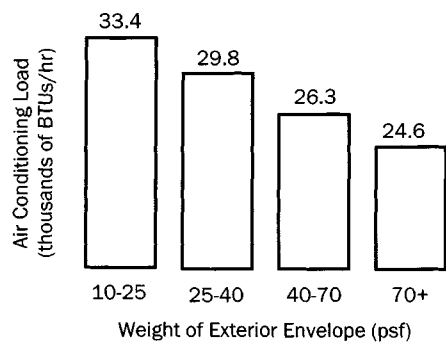
Material	Solar Reflectance	Solar Absorptance	Thermal Emittance (ϵ)
Brick, light buff	.30-.50	.50-.70	.95
Brick, red	.15-.35	.65-.85	.95
Brick, white	.50-.75	.25-.50	.95
Concrete, natural	.35	.65	.92-.95
Marble, white	.42	.58	.85
Surface color			
black	.5	.95	.95
dark gray	.20	.80	.93
light gray	.35	.65	.90
white	.55	.45	.90

3.2.7 Example of Static and Dynamic Thermal Calculations for a Masonry Wall



(From Francisco Arumi, Thermal Inertia in Architectural Walls, National Concrete Masonry Association, 1977)

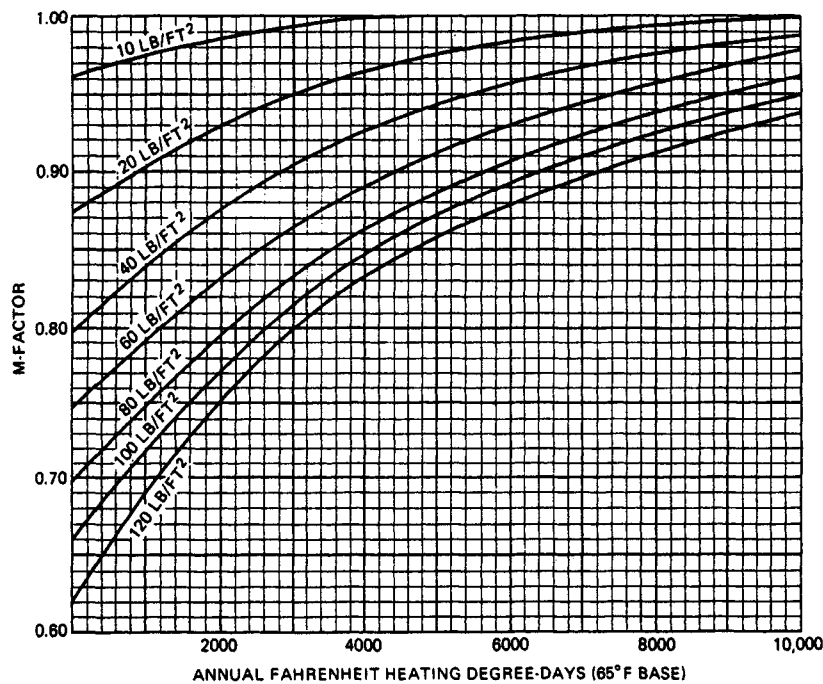
3.2.8 Effect of Wall Weight on Air-Conditioning Load



(From National Concrete Masonry Association, TEK 82, NCMA Herndon, VA)

3.2.9 M-Factor Correction Graph

M-factors adjust the normal ratings of heavy walls, taking into account the effect of *thermal inertia* (the time lag of heat transfer through heavy construction). Find the number of heating degree days for the project location, move vertically to intersect the curve representing the weight of the wall construction, and read to the right to find the correction factor. The M-factors in the graph below are used to modify standard heat-loss calculations only, and should not be used in cooling calculations.



(From BIA Technical Note 4B)

3.3.1 Fire Resistance of Loadbearing and Non-Loadbearing Concrete Walls

Concrete Type	Minimum Equivalent Wall Thickness (inches) for Fire Resistance Rating of				
	1-hr.	1½-hrs.	2-hrs.	3-hrs.	4-hrs.
Siliceous	3.5	4.3	5.0	6.2	7.0
Carbonate	3.2	4.0	4.6	5.7	6.6
Sand-lightweight	2.7	3.3	3.8	4.6	5.4
Lightweight	2.5	3.1	3.6	4.4	5.1

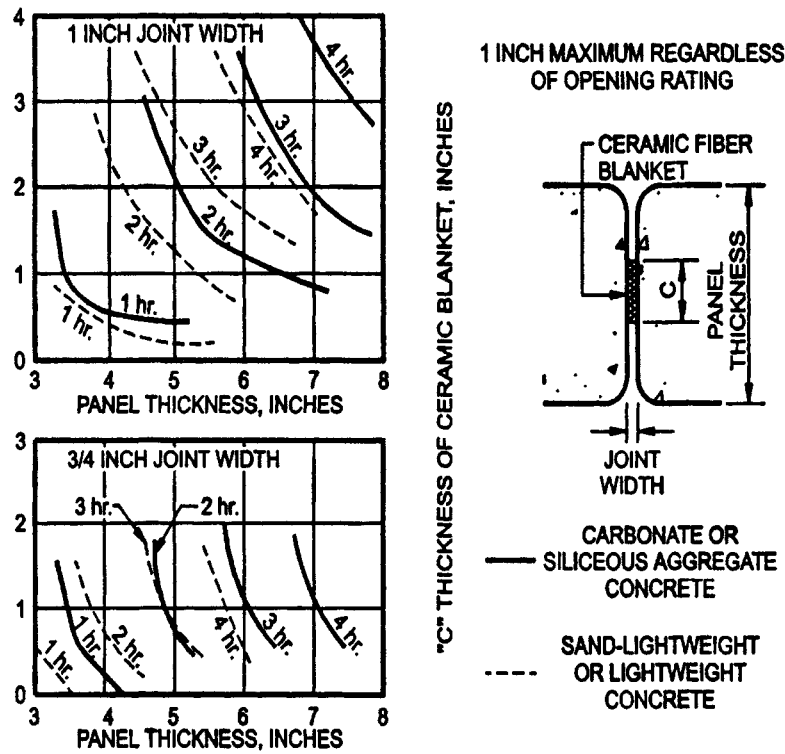
Notes:

- For solid walls with flat vertical surfaces, the equivalent thickness is the same as the actual thickness.
- For hollow-core precast wall panels with cores of constant cross section throughout the length, equivalent thickness is calculated by dividing the net cross-sectional area (gross cross section minus area of cores) of the panel by its width.
- For hollow-core panels with core spaces filled with loose material such as expanded shale, clay, slag, vermiculite, or perlite, the equivalent thickness is the same as the actual thickness.
- For panels with tapered cross sections, thickness is determined at a distance of 2t or 6 inches (whichever is less) from the point of minimum thickness, where t is the minimum thickness.
- The thickness of panels with ribbed or undulating surfaces is determined by one of the following expressions:
 - for $s \geq 4t$, thickness used shall be t
 - for $s \leq 2t$, thickness used shall be t_e
 - for $4t > s > 2t$, thickness used shall be $t + [(4t/s)-1] (t_e - t)$where:
 - s = spacing of ribs or undulations
 - t = minimum thickness
 - t_e = equivalent thickness of the panel calculated as the net cross-sectional area of the panel divided by the width, in which the maximum thickness used in the calculation may not exceed 2t

(From International Building Code 2000)

3.3.2 Fire-Protected Joints in Precast Concrete Wall Panels

Joints between precast concrete wall panels which are required to be protected must have ceramic fiber blankets (or other approved materials) of thickness as shown in the following graphs for various panel thicknesses and joint sizes.

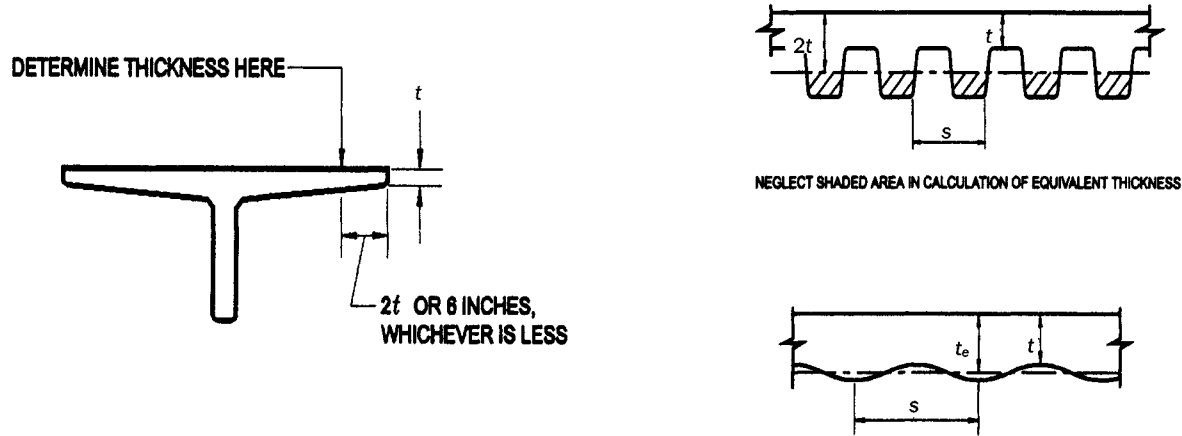


(From International Building Code 2000)

3.3.3 Fire Resistance of Concrete Slabs

Concrete Type	Minimum Slab Thickness (inches) for Fire Resistance Rating of				
	1-hr.	1½-hrs.	2-hrs.	3-hrs.	4-hrs.
Siliceous	3.5	4.3	5.0	6.2	7.0
Carbonate	3.2	4.0	4.6	5.7	6.6
Sand-lightweight	2.7	3.3	3.8	4.6	5.4
Lightweight	2.5	3.1	3.6	4.4	5.1

- Notes:
- For hollow-core prestressed slabs with cores of constant cross section throughout the length, equivalent thickness is calculated by dividing the net cross-sectional area (including grout in the joints) by its width.
 - For slabs with sloping soffits, thickness is determined at a distance $2t$ or 6 inches (whichever is less) from the point of minimum thickness, where t is the minimum thickness.
 - For slabs with ribbed or undulating soffits, thickness is determined by one of the following expressions:
for $s \geq 4t$, thickness used shall be t
for $s \leq 2t$, thickness used shall be t_e
for $4t > s > 2t$, thickness used shall be $t + [(4t/s)-1] (t_e - t)$
where:
 s = spacing of ribs or undulations
 t = minimum thickness
 t_e = equivalent thickness of the panel calculated as the net cross-sectional area of the panel divided by the width, in which the maximum thickness used in the calculation may not exceed $2t$
 - Joints between adjacent precast concrete slabs are not considered in calculating slab thickness as long as a 1-inch thick concrete topping is used. If no topping is used, joints must be grouted to a depth of at least one third the slab thickness at the joint, but not less than 1 inch, or the joint must be made fire resistant by other approved methods.



(From International Building Code 2000)

3.3.4 Fire Resistance of Concrete Columns

Concrete Type	Minimum Dimension of Concrete Columns (inches) For Fire Resistance Rating of				
	1-hr.	1½-hrs.	2-hrs.‡	3-hrs.‡	4-hrs.*
Siliceous	8	9	10	12	14
Carbonate	8	9	10	11	12
Sand-lightweight	8	8½	9	10½	12

‡ Minimum dimension may be reduced to 8 inches for rectangular columns with two parallel sides at least 36 inches in length.

* Minimum dimension may be reduced to 10 inches for rectangular columns with two parallel sides at least 36 inches in length.

(From International Building Code 2000)

3.3.5 Fire Resistance of Loadbearing and Non-Loadbearing Clay Masonry Walls

Material Type	Minimum Wall Thickness (inches) for Fire Resistance Rating of‡±			
	1-hr.	2-hr.	3-hr.	4-hr.
Solid brick of clay or shale‡	2.7	3.8	4.9	6.0
Hollow brick or tile of clay or shale, unfilled	2.3	3.4	4.3	5.0
Hollow brick or tile of clay or shale, grouted or filled with sand, pea gravel, crushed stone, slag, pumice, scoria, expanded clay, shale or fly ash, cinders, perlite, or vermiculite	3.0	4.4	5.5	6.6

‡ Equivalent thickness determined by the formula

$$T_E = V_n / LH$$

where:

T_E = equivalent thickness of the clay masonry unit (inches)

V_n = net volume of the clay masonry unit (inch³)

L = specified length of clay masonry unit (inches)

H = specified height of clay masonry unit (inches)

± Calculated fire resistance between hourly increments listed may be determined by linear interpolation.

‡ Where combustible members are framed into the wall, the thickness of solid material between the end of each member and the opposite face of the wall, or between members set in from opposite sides, shall be not less than 93% of the thickness shown.

± For units in which the net cross-sectional area of cored brick in any plane parallel to the surface containing the cores is at least 75% of the gross cross-sectional area measured in the same plane.

(From International Building Code 2000)

3.3.6 Fire Resistance of Clay Masonry Columns

	Fire Resistance Rating			
	1-hr.	2-hr.	3-hr.	4-hr.
Minimum column dimension (inches)	8	10	12	14

(From International Building Code 2000)

3.3.7 Fire Resistance of Loadbearing and Non-Loadbearing Concrete Masonry Walls

Type of Aggregate	Fire Resistance Rating (hours)														
	½	¾	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4
Pumice or expanded slag	1.5	1.9	2.1	2.5	2.7	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.5	4.7
Expanded shale, clay, or slate	1.8	2.2	2.6	2.9	3.3	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	4.9	5.1
Limestone, cinders, or unexpanded slag	1.9	2.3	2.7	3.1	3.4	3.7	4.0	4.3	4.5	4.8	5.0	5.2	5.5	5.7	5.9
Calcareous or siliceous gravel	2.0	2.4	2.8	3.2	3.6	3.9	4.2	4.5	4.8	5.0	5.3	5.5	5.8	6.0	6.2

- Notes:
- Values between those shown in the table may be determined by direct interpolation.
 - Where combustible members are framed into the wall, the thickness of solid material between the ends of each member and the opposite face of the wall, or between members set in from opposite sides, shall not be less than 93% of the thickness shown.
 - Minimum required equivalent thickness corresponding to the hourly fire resistance rating for units with a combination of aggregates shall be determined by linear interpolation based on the percent by volume of each aggregate used in manufacture.

(From International Building Code 2000)

3.3.8 Fire Resistance of Concrete Masonry Columns

	Fire Resistance Rating			
	1-hr.	2-hr.	3-hr.	4-hr.
Minimum column dimension (inches)	8	10	12	14

(From International Building Code 2000)

3.3.9 Volume Characteristics of Some Typical Concrete Masonry Units

Width (in.)	Gross Volume (cu.in.)	Minimum Thickness (in.)		Three-Core Units		Two-Core Units	
		Shell	Web	Percent Solid Volume	Equivalent Solid Thickness (in.)	Percent Solid Volume	Equivalent Solid Thickness (in.)
3-5/8	432	0.75	0.75	63	2.28	64	2.32
		1.00	1.00	73	2.66	73	2.66
5-5/8	670	1.00	1.00	59	3.32	57	3.21
		1.12	1.00	63	3.54	61	3.43
		1.25	1.00	66	3.71	64	3.60
		1.37	1.12	70	3.94	68	3.82
7-5/8	908	1.25	1.00	56	4.27	53	4.04
		1.37	1.12	60	4.57	57	4.35
		1.50	1.12	62	4.73	59	4.50
9-5/8	1145	1.25	1.12	53	5.10	48	4.62
		1.37	1.12	55	5.29	51	4.91
		1.50	1.25	58	5.58	54	5.20
11-5/8	1395	1.25	1.12	49	5.70	44	5.12
		1.37	1.12	51	5.93	46	5.35
		1.50	1.25	54	6.28	49	5.70
		1.75	1.25	57	6.63	52	6.04

3.3.10 Calculated Fire Resistance

The fire resistance of wall or floor assemblies made up of different materials or types of masonry units can be calculated using the formula

$$R_A = (R_1^{0.59} + R_2^{0.59} + \dots + R_n^{0.59} + A_1 + A_2 + \dots + A_n + pl)^{1.7}$$

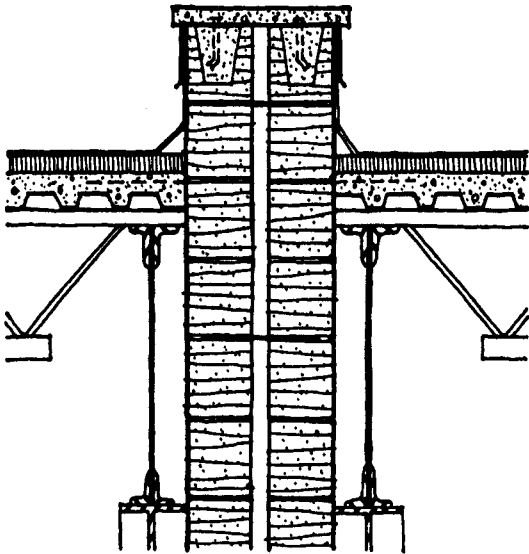
Where

R_A	=	fire endurance rating of assembly (hours)
R_1, R_2, \dots, R_n	=	fire endurance rating of assembly components or wythes 1, 2, ..., n, respectively (hours)
A_1, A_2, \dots, A_n	=	0.30 coefficient for each continuous air space of at least 1/2 inch between wythes 1, 2, ..., n, respectively
pl	=	coefficient for thickness of plaster (from table below)

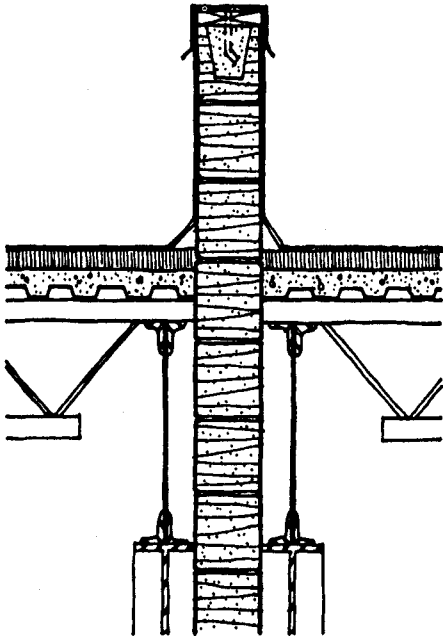
Thickness of Sanded Gypsum Plaster (inch)	Coefficient for Plaster One Side	Coefficient for Plaster Two Sides
1/2	0.30	0.60
5/8	0.37	0.75
3/4	0.45	0.90

(Formula and table from International Building Code 2000)

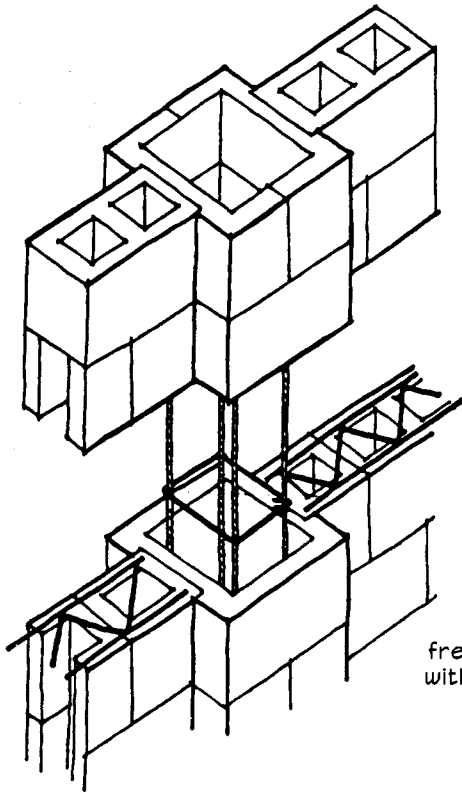
3.3.11 Concrete Masonry Fire Walls



double fire wall



cantilever or
self-supporting fire wall



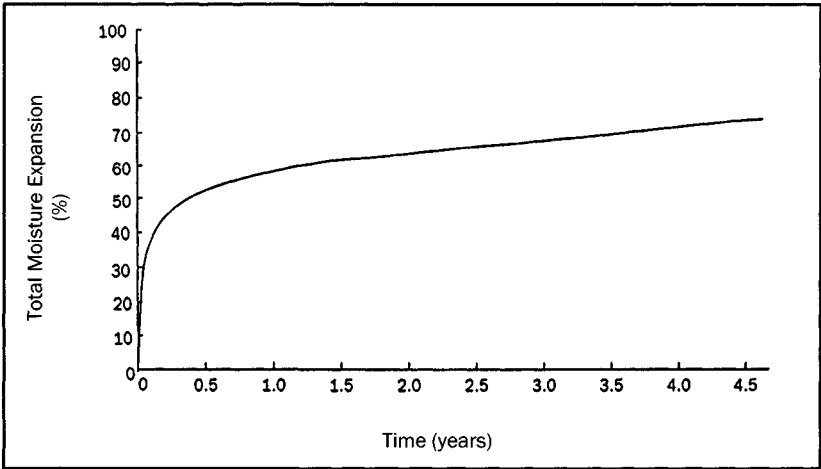
freestanding fire wall
with integral pilasters

3.4.1 Moisture Movement Coefficients

Material	Coefficient	Type of Movement
Concrete, gravel aggregate	−0.0003 to −0.0008	shrinkage
Concrete, limestone aggregate	−0.0003 to −0.0004	shrinkage
Concrete, lightweight aggregate	−0.0003 to −0.0009	shrinkage
Concrete block, dense aggregate	−0.0002 to −0.0006	shrinkage
Concrete block, lightweight aggregate	−0.0002 to −0.0006	shrinkage
Brick, clay face	+ 0.0003 to + 0.0008	expansion

(From O'Connor, Design of Sealant Joints in ASTM STP 1069 Building Sealants: Materials, Properties and Performance, American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428.)

3.4.2 Time/Expansion Graph for Clay Brick



(From Brick Industry Association)

3.4.3 Thermal Expansion Coefficients

Material	in/in/°F (multiply by 10 ⁻⁶)
Brick	
clay or shale	3.6
fire clay	2.5
Concrete Masonry	
normal weight	
sand and gravel aggregate	5.2
crushed stone aggregate	5.2
medium weight	
air-cooled slag	4.6
lightweight	
coal cinders	3.1
expanded slag	4.6
expanded shale	4.3
pumice	4.1
Stone	
granite	2.8–6.1
limestone	2.2–6.7
marble	3.7–12.3
sandstone	4.4–6.7
slate	4.4–5.6
travertine	3.3–5.6
Concrete	
calcareous aggregate	5.0
siliceous aggregate	6.0
quartzite aggregate	7.0
EIFS Lamina	
light colored	7.5
dark colored	10.0
Metals	
aluminum	13.2
steel, carbon	6.7
steel, stainless	5.8–9.6
copper	9.4
lead	15.9
zinc	18.0
Plaster, Gypsum	
sand aggregate	6.5–6.75
perlite aggregate	7.3–7.35
vermiculite	8.4–8.6
Glass	4.9
Plastic	
acrylic sheet	41.0
polycarbonate sheet	38.0
Wood	
parallel to fiber	
fir	2.1
pine	3.0
oak	2.7
perpendicular to fiber	
fir	32.0
pine	19.0
oak	30.0

3.4.4 Thermal Expansion Variations in Concrete

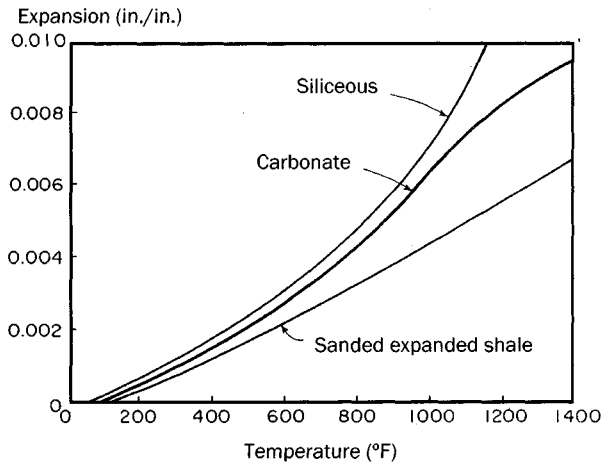
Like all materials, concrete expands slightly with increases in temperature and moisture content. It also contracts slightly with decreases in temperature and moisture content. Movement can be as much as 1/16 inch in 10 feet. These changes in size are called volume changes.

Because concrete has high compressive strength but low tensile strength, concrete may crack when restrained against contraction or shrinkage. It is usually unrealistic to try to eliminate cracking. Instead, concrete cracking is usually controlled.

Cracking is minimized when water content is kept to a minimum, good curing techniques are used, the subgrade or structural support is good, and abrupt changes in temperature and moisture content are avoided, especially during curing. Cracking is controlled by properly installing joints, using reinforcement, or by a combination of these methods. Joint types are control, construction, and isolation.

Range of Thermal Expansion Coefficients of Aggregates		
Aggregate Type	Coefficient (%)	
	Per 100°F	Per 100°C
Marble	0.006 to 0.009	0.011 to 0.160
Gravel, chert	0.041 to 0.073	0.074 to 0.131
Quartzite	0.073	0.131
Gravel	0.059 to 0.071	0.106 to 0.128
Sands	0.060 to 0.070	0.108 to 0.126
Granite	0.010 to 0.066	0.018 to 0.119
Sandstone	0.066	0.119
Limestone	0.019 to 0.064	0.034 to 0.115
Slag	0.051	0.092
Traprock	0.043 to 0.047	0.077 to 0.085
Basalt	0.045	0.081

(From Building Movements and Joints, Portland Cement Association, 1982)



(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

Difference Between Thermal Expansion Coefficient of Cement Mortar and Coarse Aggregate			
Fine Aggregate in the Cement Mortar	Coarse Aggregate Alone	Coefficient (%)	
		Per 100°F	Per 100°C
Siliceous	Limestone	0.008 to 0.052	0.014 to 0.094
Glacial	Limestone	0.027 to 0.034	0.049 to 0.061
Limestone	Limestone	0.009 to 0.028	0.016 to 0.050
Syenite	Syenite	0.019	0.034
Siliceous	Quartzite	0.007 to 0.017	0.013 to 0.031
Siliceous	Traprock	0.019 to 0.028	0.034 to 0.050
Syenite	Traprock	0.017	0.031
Limestone	Traprock	0.008 to 0.011	0.014 to 0.020

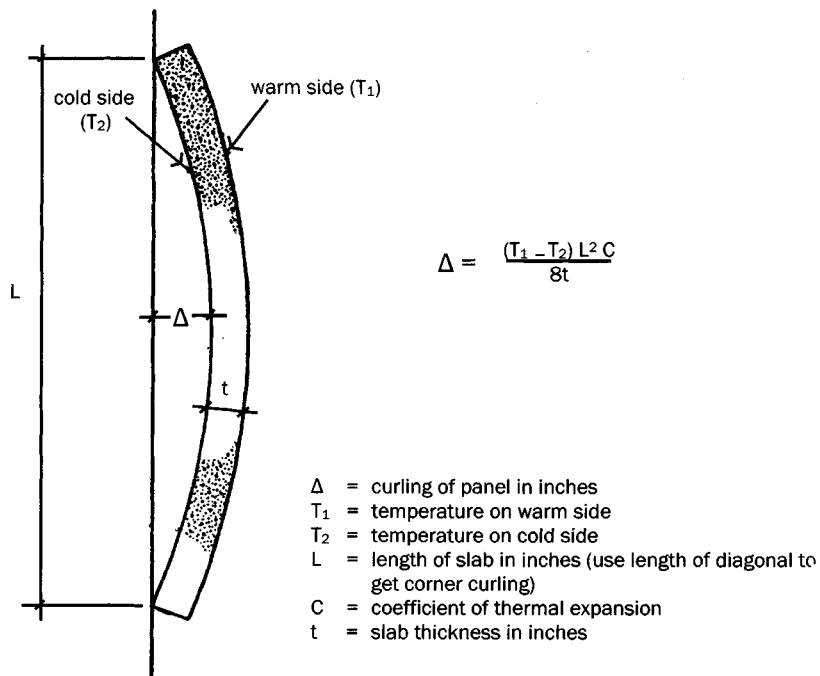
(From Building Movements and Joints, Portland Cement Association, 1982)

Thermal Expansion Coefficient of Concrete Depending on Aggregate Type	
Aggregate Type (from one source)	Coefficient ($\times 10^{-4}$ per °F)
Quartz	6.6
Sandstone	6.5
Gravel	6.0
Granite	5.3
Basalt	4.8
Limestone	3.8

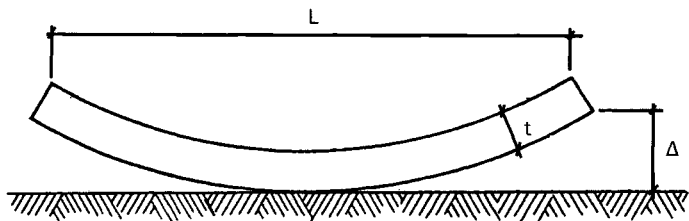
Note: Coefficients of concrete made with aggregates from different sources may vary widely from these values, especially those for gravels, granites, and limestones.

(From Building Movements and Joints, Portland Cement Association, 1982)

3.4.5 Curling in Concrete Panels and Slabs



curling of a plain concrete panel due to temperature
(temperature varies uniformly from inside to outside)



$\Delta = \frac{S_c L^2}{8t}$

Δ = upward curling of slab in inches
 S_c = difference in linear unit shrinkage between top and bottom of slab
 L = length of slab in inches (use length of diagonal to get corner curling)
 t = slab thickness in inches

slab curling

(From Building Movements and Joints, Portland Cement Association, 1982)

3.4.6 Factors Affecting Concrete Shrinkage

Factors Affecting Magnitude and Rate of Concrete Drying Shrinkage		
Factor	Positive Effect (Decreased Drying Shrinkage)	Negative Effect (Increased Drying Shrinkage)
Composition of cement type fineness	Generally no greater or less shrinkage from one type to another Finer cements generally exhibit small increase in shrinkage	
Type of aggregate (major factor)		
modulus of elasticity	high	low
absorption	low	high
shrinkage	low	high
size	large	small
gradation	good	poor
Water content and mix proportions (major factor)		
water content	low	high
volume concentration	high	low
volume of coarse aggregate	large	small
volume of fine aggregate	low	high
cement content	not a significant factor	not a significant factor
slump	low	high
concrete temperature	cooler	hotter
Chemical admixtures	no appreciable effect at normal percent some increase at early ages some increase substantial increase at early ages, moderate at later ages	
air-entraining	no appreciable effect at normal percent	
water-reducing	some increase at early ages	
set-retarding	some increase	
set-accelerating	substantial increase at early ages, moderate at later ages	
Pozzolans (minor factor)	some have little effect, others some increase some may or may not increase shrinkage	
fly ash	some have little effect, others some increase	
natural materials	some may or may not increase shrinkage	
Size and shape of concrete members	larger member—less shrinkage	smaller member—more shrinkage
Duration of moist curing		
moist cure	no effect	no effect
steam cure at atmospheric pressure	reduced	reduced

(From ACI 224-81, Control of Cracking in Concrete Structures, American Concrete Institute)

Effect of Cement Content on Drying Shrinkage of Concrete [§]									
Cement Content (bags/cu.yd.)	Concrete Composition by Absolute Volume [†]					Water + Air	Water-Cement Ratio (By Weight)	Slump (in.)	Shrinkage [‡]
	Cement	Water	Air	Total (Paste)	Aggregate				
4.99	0.089	0.202	0.017	0.308	0.692	0.219	0.72	3.3	0.0330
5.99	0.107	0.207	0.016	0.330	0.670	0.223	0.62	3.6	0.0330
6.98	0.124	0.210	0.014	0.348	0.652	0.224	0.54	3.8	0.0289
8.02	0.143	0.207	0.015	0.365	0.635	0.223	0.46	3.8	0.0300

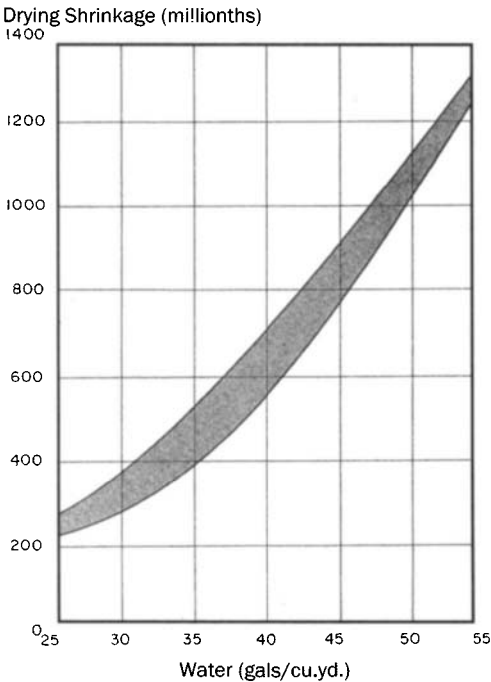
[§] American River sand and gravel graded to 1 in. maximum.

[†] Average of three batches.

[‡] Average of nine 3 x 3 x 10 in. prisms cured wet for 7 days, then dried for 14 days.

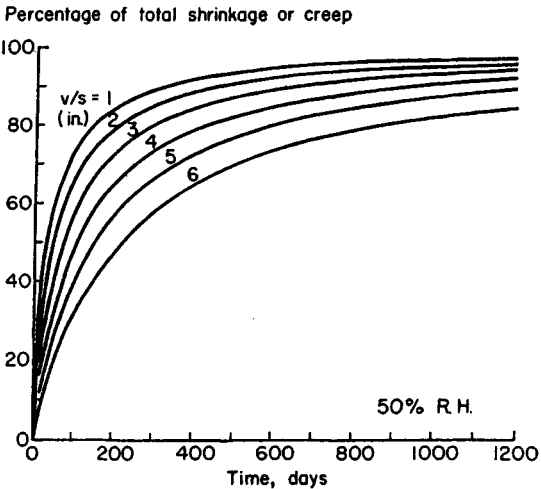
(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

3.4.7 Effect of Water Content and Aggregate on Concrete Shrinkage



Dependence of Concrete Shrinkage on Water Content

(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)



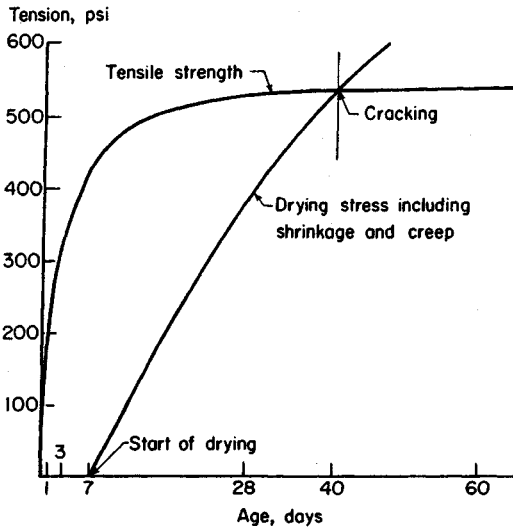
Calculated Variation of Shrinkage and Creep with Time for Given Volume-To-Surface Ratios Regardless of Aggregate Type

(From Building Movements and Joints, Portland Cement Association, 1982)

Effect of Aggregate Type on Concrete Shrinkage	
Aggregate Type	Two-Year Shrinkage (%)
Siliceous sand and gravel	0.086
Granite and fine quartzite sand	0.061
Elgin sand and gravel (carbonate and siliceous)	0.055
Commercial Elgin	0.054
Granite	0.053
Traprock	0.040
Quartzite sand and gravel	0.038
Lightweight	0.057 to 0.089

(From Building Movements and Joints, Portland Cement Association, 1982)

3.4.8 Concrete Shrinkage Cracking



Graph showing how drying stress converges on tensile strength for a concrete that is fully restrained against shortening, with temperature and ambient humidity constant.

(From Building Movements and Joints, Portland Cement Association, 1982)

Tolerable Crack Widths for Reinforced Concrete	
Exposure Condition	Tolerable Crack Width (in.)
Dry air or protective membrane	0.016
Humidity, moist air, soil	0.012
Deicing chemicals	0.007
Seawater and seawater spray, wetting and drying	0.006
Water retaining structures ^s	0.004

^s Excluding nonpressure pipes.

(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

Temperature Drop Required to Crack a Slab or Wall That is Fully Restrained Against Shortening

The coefficient of thermal contraction for concrete = ϵ

Assume $\epsilon = 5.5 \times 10^{-6}/^{\circ}\text{F}$

If held tightly against contraction at its ends, the tensile stress in the concrete is

$$f = \epsilon E$$

$$E = 57,000 \sqrt{f'_c} = 3,120,000 \text{ when } f'_c = 3000 \text{ psi}$$

$$\text{Thus tension } f = \frac{5.5 \times 3.12 \times 1,000,000}{1,000,000} = 17.2 \text{ psi}/^{\circ}\text{F}$$

$$\text{Tensile strength of concrete } f_t = 7.5 \sqrt{f'_c}$$

$$f_t = 410 \text{ psi when } f'_c = 3000 \text{ psi}$$

Temperature drop necessary to crack concrete = Δ_t and

$$\Delta_t = \frac{410}{17.2} = 24^{\circ}\text{F} \text{ when concrete has 3000 psi strength}$$

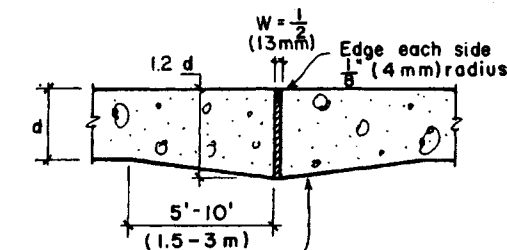
The general formula for Δ_t at any age is

$$\Delta_t = \frac{f_t}{\epsilon E} = \frac{7.5 \sqrt{f'_c}}{\epsilon \times 57,000 \sqrt{f'_c}} = \frac{1}{7600\epsilon}$$

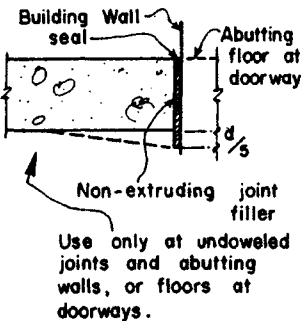
And when $\epsilon = 5.5 \times 10^{-6}$, $\Delta_t = 24^{\circ}\text{F}$ at any age or strength of concrete

(From Building Movements and Joints, Portland Cement Association, 1982)

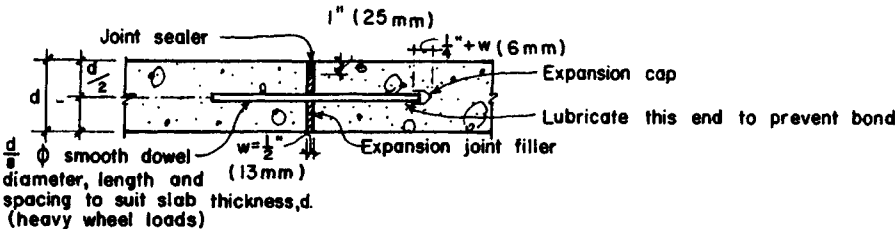
3.4.9 Concrete Isolation, Construction, and Control Joints



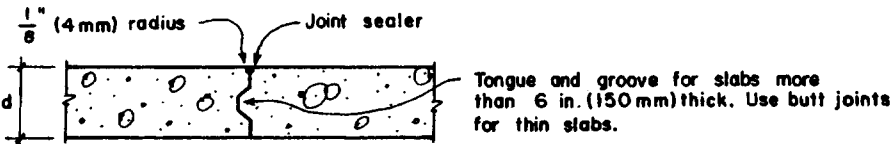
Thickened edge to reduce deflection under wheel load, hold surface in alignment, permit wheel to roll smoothly over joint.



TYPE A
Expansion
(Isolation)
Joint

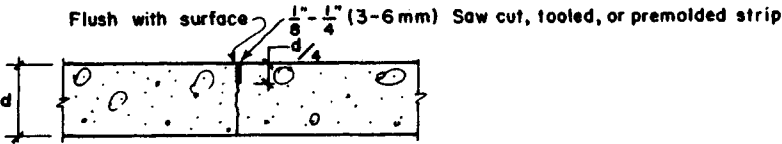


TYPE A
ALTERNATE
Expansion
(Isolation)
Joint



TYPE B
Longitudinal
Construction
Joint

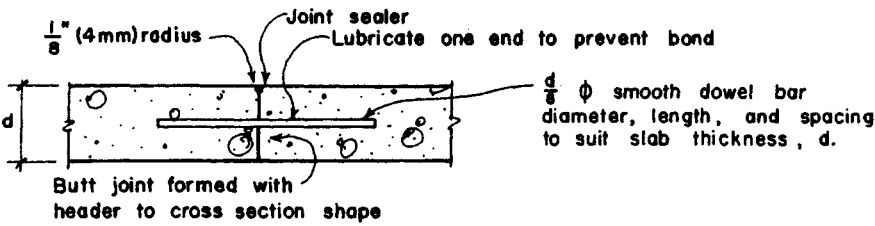
Tie bars may be used across these joints when necessary to hold slabs together.



TYPE C
Sawn,
Tooled, or
Premolded
Strip
Longitudinal
or Transverse
Contraction
(Control)
Joint

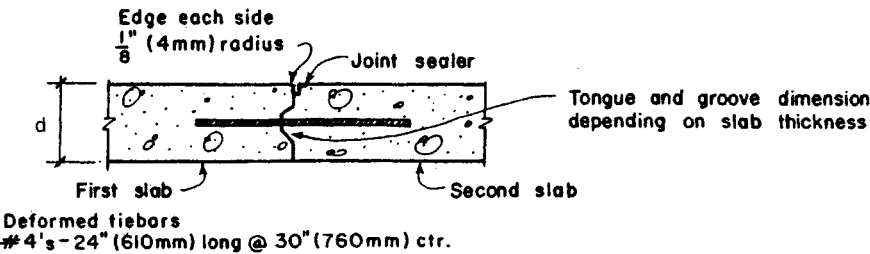
(From Building Movements and Joints, Portland Cement Association, 1982)

3.4.9 Continued



TYPE D
Planned
Transverse
Construction
Joint

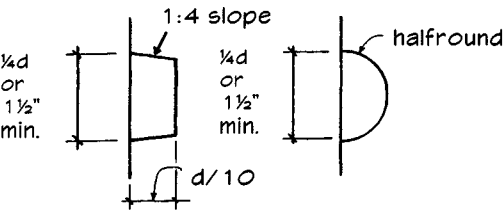
(Used at normal joint spacing, will function as
contraction (control) joint)



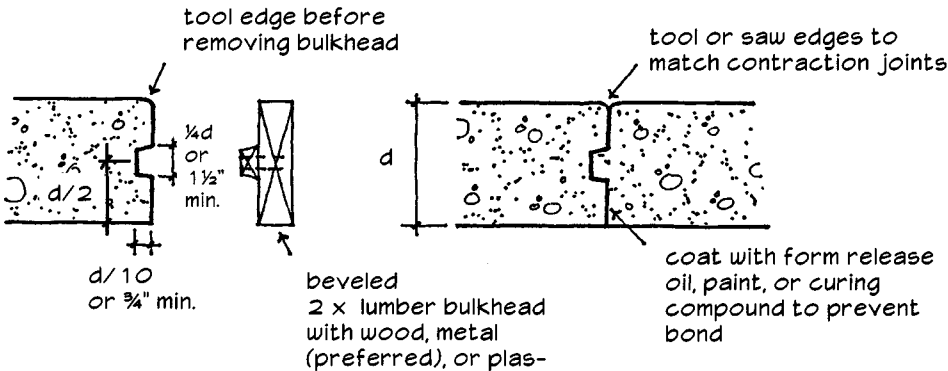
TYPE E
Emergency
Tie
Transverse
Construction
Joint

(Used in panel at middle third of normal joint spacing)
Not a contraction (control) joint.

3.4.9 Continued

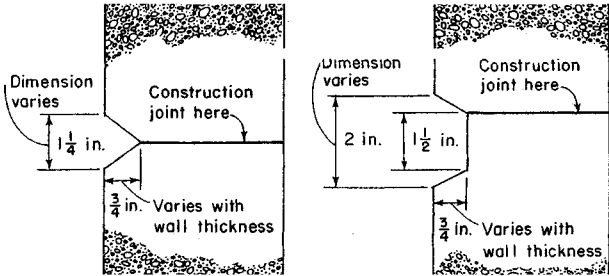


Slab Thickness (in.)	Key Thickness (in.)	Key Height (in.)
5	3/4	1-5/8
6	3/4	1-5/8
7	3/4	1-5/8
8	3/4	2



Keyways for Type B and E Construction Joints

(From Building Movements and Joints, Portland Cement Association, 1982)

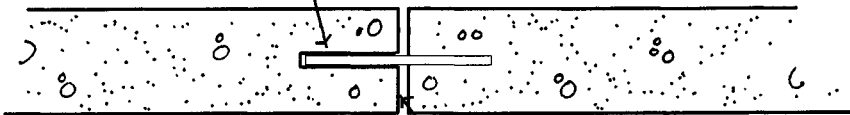


horizontal rustication joints in walls with
V-shaped and beveled rustication strips

(From Design and Control of Concrete Mixtures, 13th ed., Portland
Cement Association, 1990)

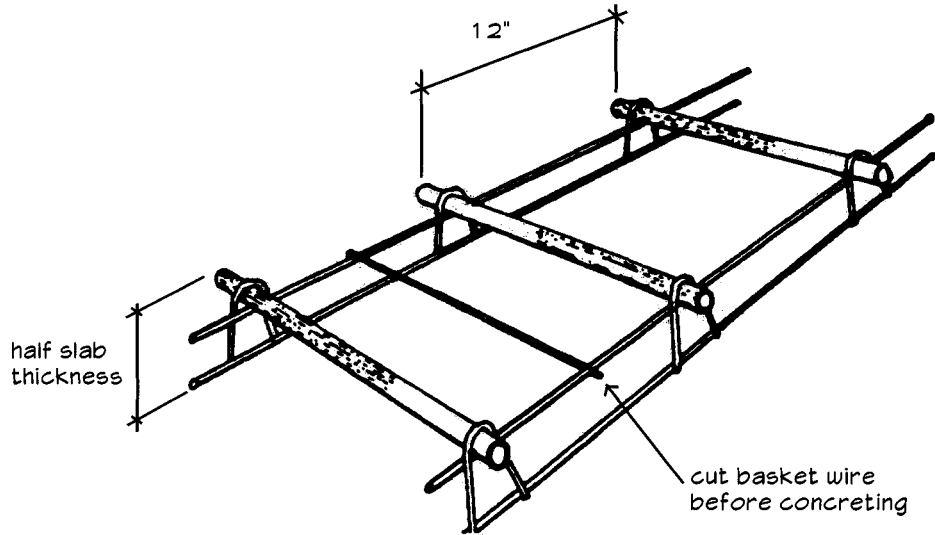
3.4.10 Doweled Concrete Joints

dowels with sleeve, attached covering, or coating on alternating halves or on entire length to serve as bond breaker



paint face of concrete with bond breaker compound before adjacent slab is poured

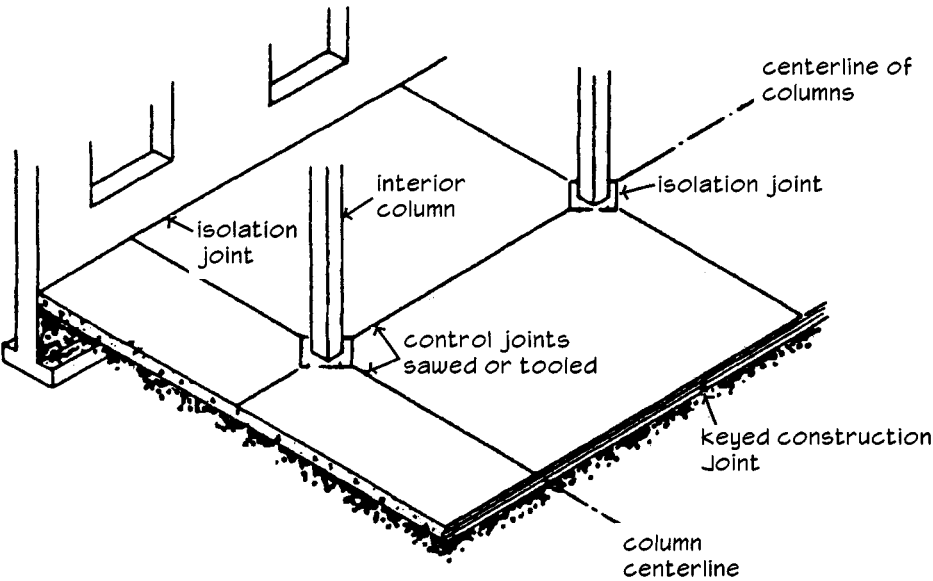
ACI Recommended Smooth Dowel Length and Diameter with Dowels Spaced 12 in. on Center		
Slab Thickness (in.)	Dowel Diameter (in.)	Dowel Length (in.)
5 to 6	3/4	16
7 to 8	1	18
9 to 11	1-1/4	18



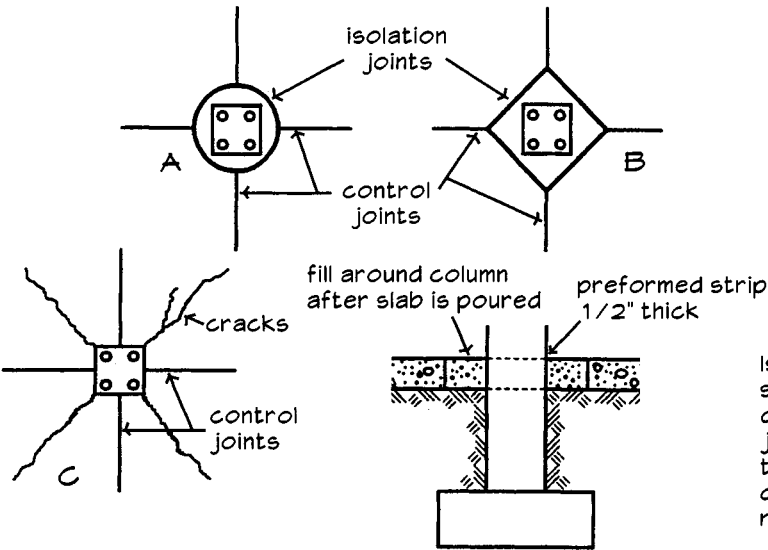
Doweled concrete joints may be formed with a prefabricated dowel bar assembly called a dowel basket. The basket must be positioned so that the slab joint is aligned with the midpoint of the dowels. Dowels must be parallel to one another, and basket wire must be cut as indicated before concreting to avoid restricting movement.

(From Building Movements and Joints, Portland Cement Association, 1982)

3.4.11 Concrete Control and Isolation Joints at Columns



Isolation joints permit the slab to move up or down slightly relative to walls, columns, footings, or other adjacent construction. Control (contraction) joints permit slabs to shrink without excessive cracking between joints. Construction joints are stopping places between pours.



Isolation joints around columns should be either circular (A) or diamond shaped (B). If no isolation joints are used around columns, or if the corners of the isolation joints do not meet the control joints, radial cracking may occur (C).

(From Building Movements and Joints, Portland Cement Association, 1982)

3.4.12 Concrete Control Joint Spacing for Slabs-On-Ground

A rule of thumb for plain (unreinforced) slabs is that joint spacing should not exceed:

- 24 slab thicknesses for concrete made with less than 3/4-in. maximum size coarse aggregate
- 30 slab thicknesses for concrete made with maximum size coarse aggregate larger than 3/4 in.
- 36 slab thicknesses for low-slump concrete

For reinforced slabs on ground, joint spacing normally varies from 30 to 80 ft. The percentage of reinforcement increases with an increase in joint spacing. In a continuously reinforced concrete slab that is without joints except for construction and expansion or isolation joints where needed, the percentage of distributed reinforcing steel is 0.6 and higher.

Slabs with joint spacings longer than those in the table usually will crack in the middle with the cracks generally held tightly closed by the reinforcement. The amount of steel (see graph) needed to hold a crack tight can be calculated using this subgrade-drag-method equation:

$$A_s = \frac{WFL}{2f_s}$$

where A_s = required cross-sectional area of steel in sq.in. per foot of width of slab

W = weight of slab only, psf

F = coefficient of resistance to movement (generally assumed to be 1.5 but can vary from about 1.0 to 2.5)

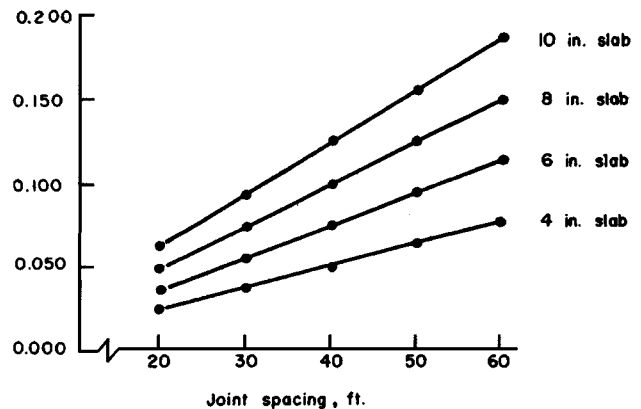
f_s = allowable stress in steel, commonly assumed to be 30,000 psi for welded wire fabric

L = length of slab between free ends (a free end is any joint where horizontal movement is permitted)

To be effective in controlling cracks, the steel must be positioned at or above the mid-depth of the slab. Distributed steel placed in a slab on ground for crack control does not increase significantly the load-carrying capacity of the floor.

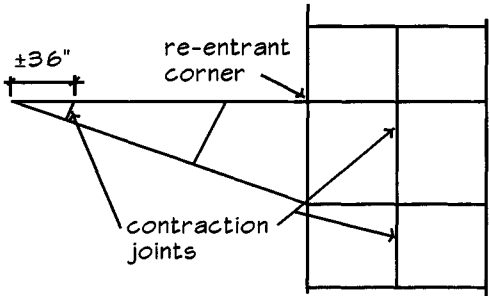
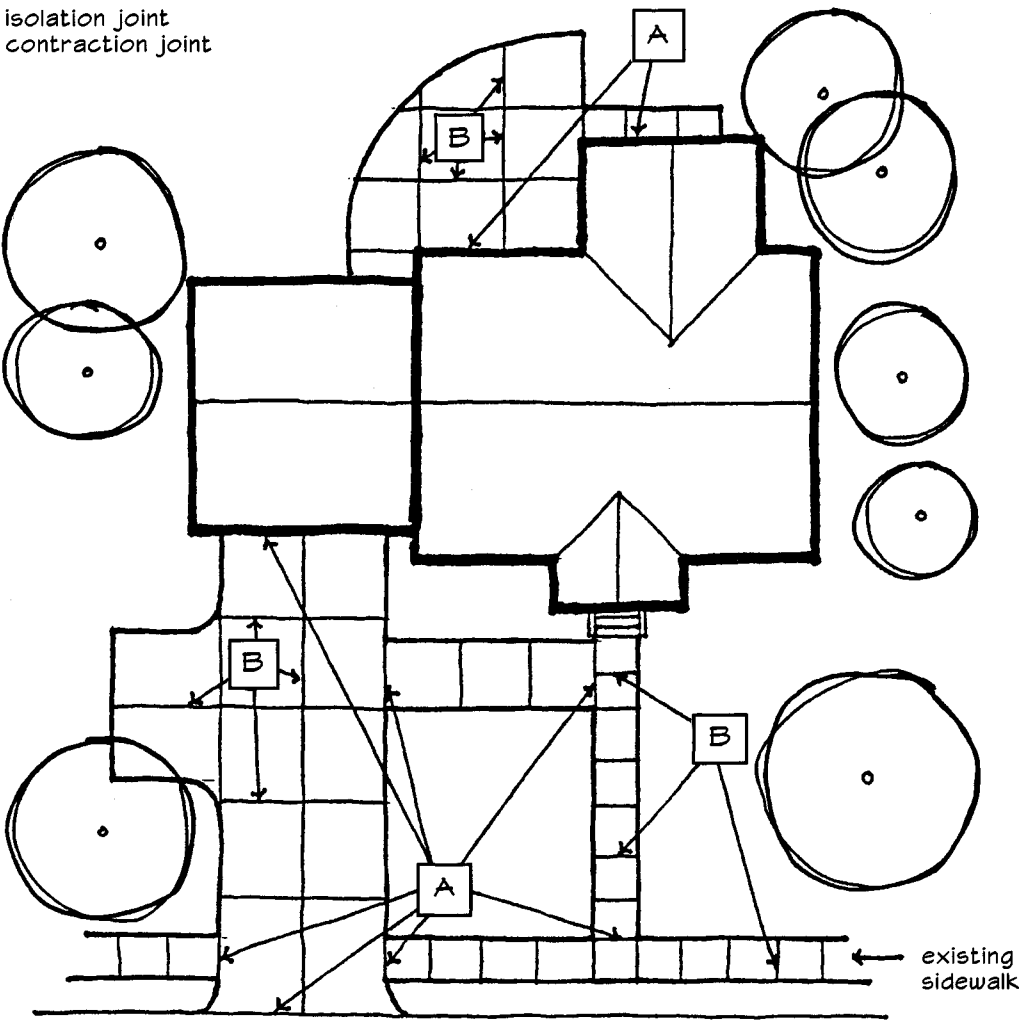
Slab Thickness (inches)	Recommended Control Joint Spacing (ft.)		
	Slump Greater Than 4 in.		Slump Less Than 4 in.
	Max. Agg. Size Less Than 3/4 in.	Max. Agg. Size 3/4 in. and Larger	
4	8	10	12
5	10	13	15
6	12	15	18
7	14	18	21
8	16	20	24
9	18	23	27
10	20	25	30

Area, A_s , in Sq. in. per ft.



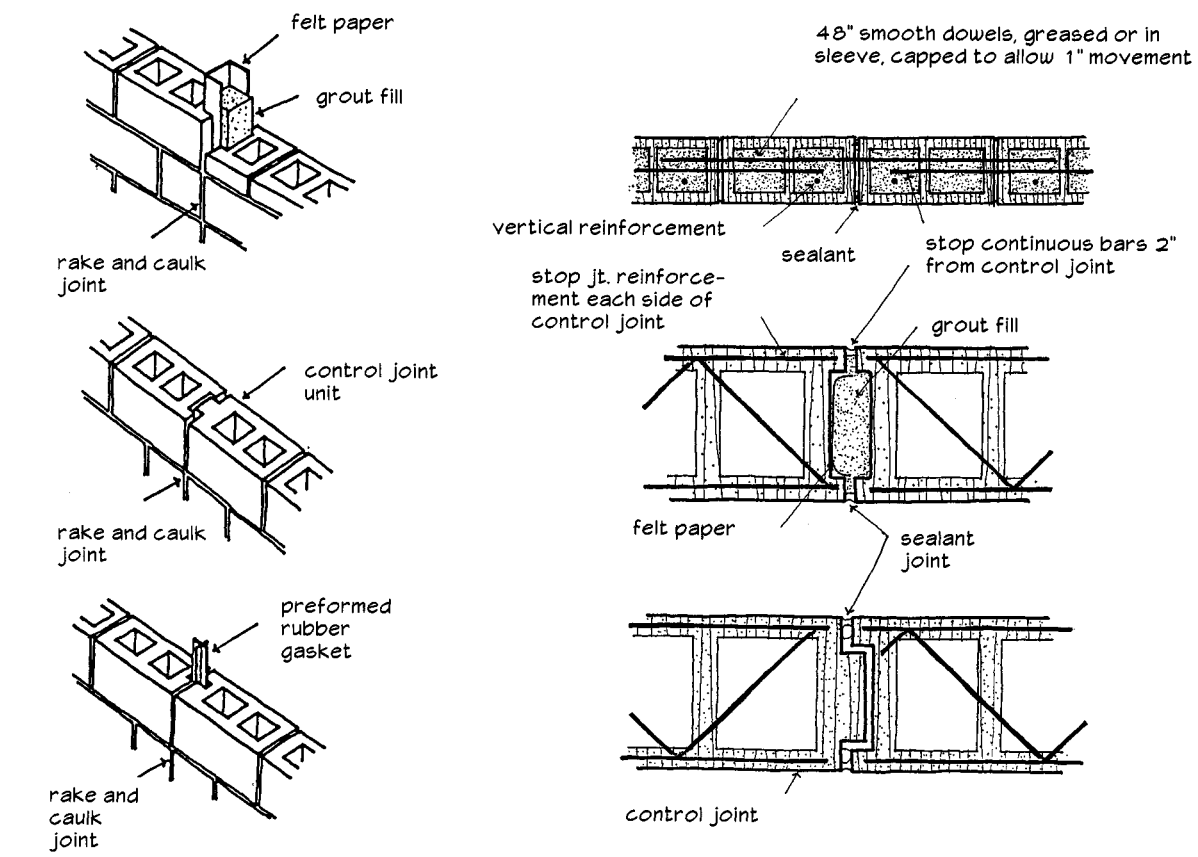
3.4.13 Concrete Joint Locations

A = isolation joint
B = contraction joint

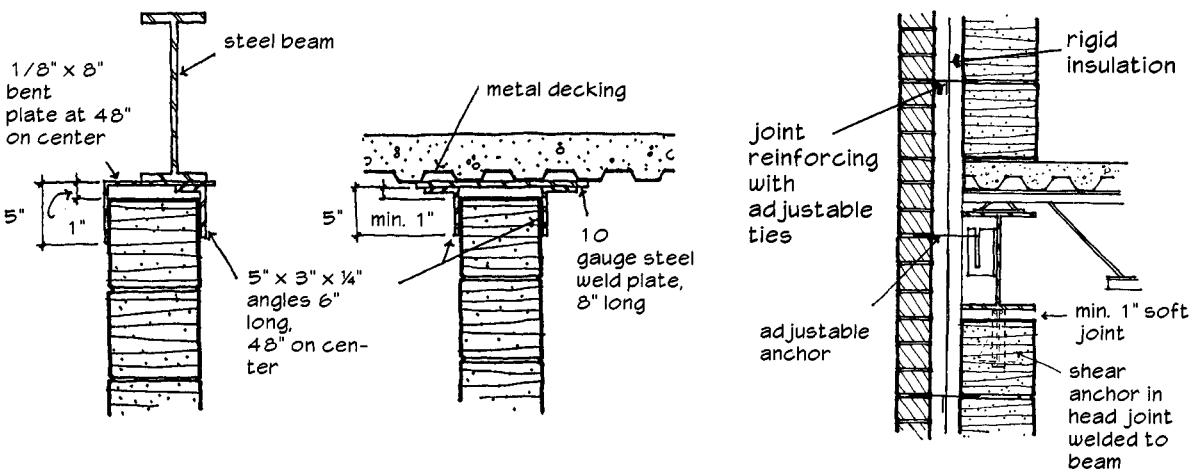


locate contraction joints at all re-entrant corners and wherever the slab must have a sharp corner

3.4.14 Concrete Masonry Control Joints

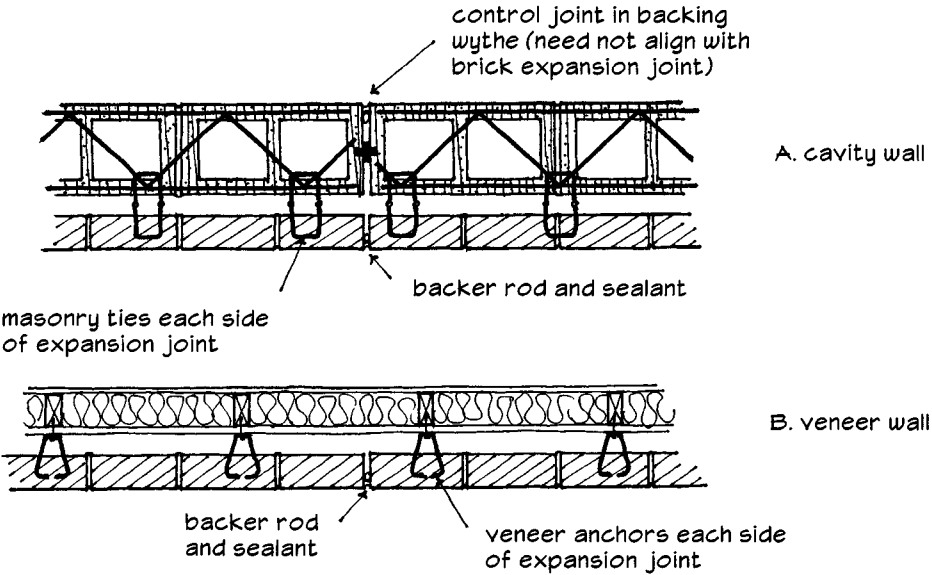


vertical control joints

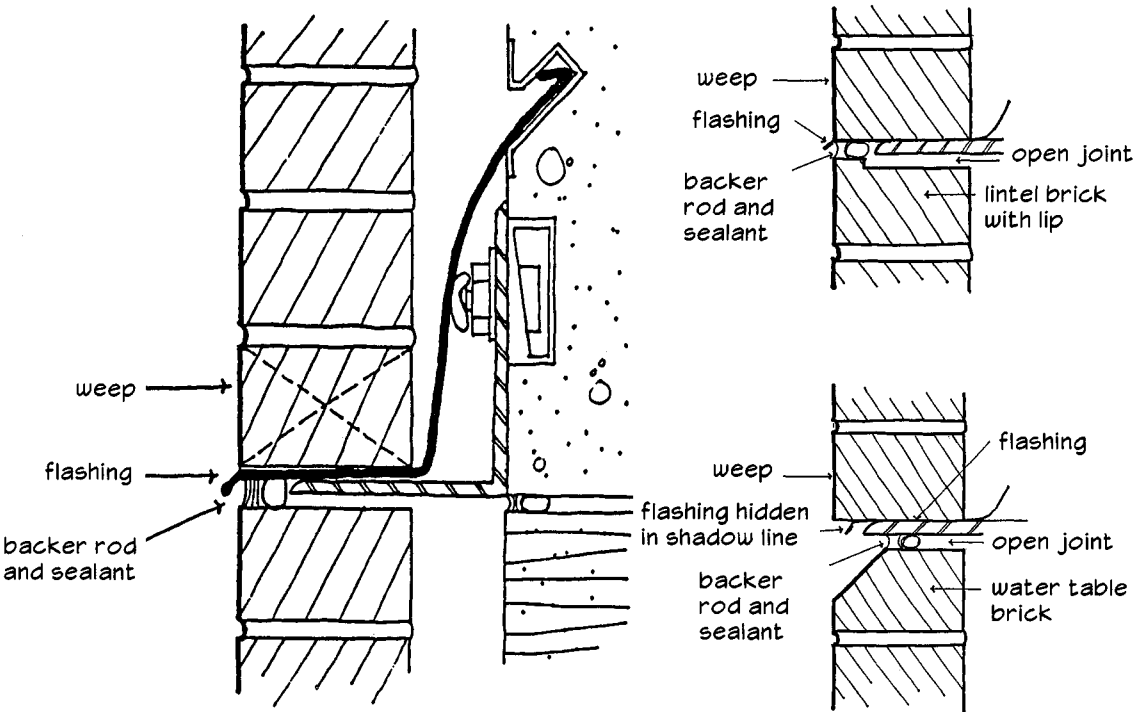


horizontal soft joints

3.4.15 Clay Masonry Expansion Joints



vertical expansion joints



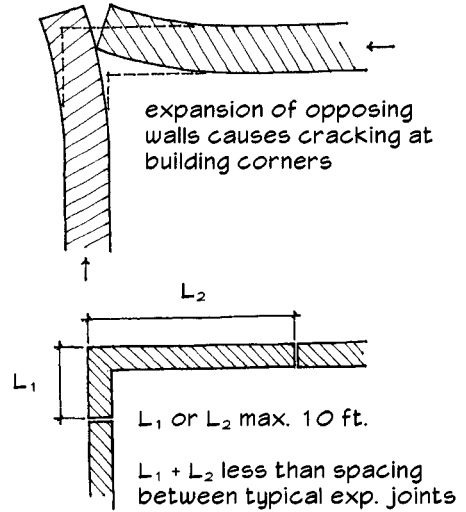
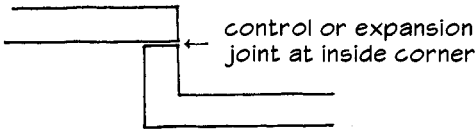
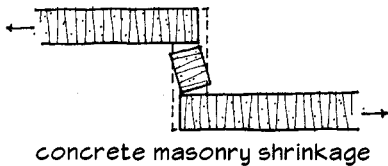
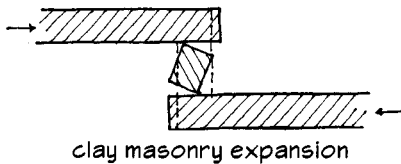
horizontal soft joints at shelf angle

(From Beall, Masonry Design and Detailing, 4th ed., McGraw-Hill, 1997)

3.4.16 Masonry Control and Expansion Joint Locations

Rule of Thumb Joint Locations

- Changes in wall height
- Changes in wall thickness
- Offsets in parallel walls
- One side of openings 6 ft. or less in width
- Both sides of openings more than 6 ft. wide
- Near corners in clay masonry construction
- At calculated spacing



joint at offset in wall

joint at building corner

(From Brick Industry Association Technical Notes on Brick Construction)

Recommended Control Joint Spacing For Above Grade Exposed Concrete Masonry Walls ^{§±*}	
Length to Height Ratio	Spacing Between Joints (ft.)
1-1/2	25

[§] Table based on horizontal reinforcement with equivalent area of at least 0.025 in² per foot of wall height to keep random cracks closed. See table at right.

[±] Spacing based on experience over wide geographical area. Adjust spacing where local experience justifies, but not to exceed 25 ft. on center.

^{*} Applies to all concrete masonry units.

(From NCMA TEK 10-2B, National Concrete Masonry Association, Herndon, VA)

Maximum Spacing of Horizontal Reinforcement to Meet Criteria of 0.025 in ² per Foot of Wall Height	
Reinforcement Size	Maximum Vertical Spacing (in.)
W1.7 (9 gauge) two wire [§]	16
W2.8 (3/16 in.) two wire [§]	24
W1.7 (9 gauge) four wire [†]	32
W2.8 (3/16 in.) four wire [†]	48
No. 3 bars	48
No. 4 bars	96
No. 5 bars or larger	144

[§] Two-wire joint reinforcement = one wire per face shell.

[†] Four-wire joint reinforcement = two wires per face shell.

(From NCMA TEK 10-2B, National Concrete Masonry Association, Herndon, VA)

3.4.17 Formulas for Calculating Required Sealant Joint Width

JOINT WIDTH	THERMAL MOVEMENT	MOISTURE MOVEMENT
$J = T + M + CT$ where: J = required joint width T = thermal movement M = moisture movement CT = construction tolerance (varies with type of material)	$T = (T_c)(\Delta T)(L)$ where: T_c = thermal expansion coefficient (from Table 1) ΔT = $T_s - T_w$ T_s = summer air temp. (°F) plus thermal storage coefficient (TSc from Table 2) x solar absorption coefficient (SAC from Table 3) T_w = winter air temperature (°F)	$M = (M_c/100)(L)$ where: M_c = moisture movement coefficient (Table 4) L = panel length or joint spacing, inches

TABLE 1 Thermal Expansion Coefficient (T_c)

Material	T_c
Brick	
clay or shale	3.6
fire clay	2.5
Concrete Masonry	
normal weight	
sand and gravel aggregate	5.2
crushed stone aggregate	5.2
medium weight	
air-cooled slag	4.6
lightweight	
coal cinders	3.1
expanded slag	4.6
expanded shale	4.3
pumice	4.1
Stone	
granite	2.8–6.1
limestone	2.2–6.7
marble	3.7–12.3
sandstone	4.4–6.7
slate	4.4–5.6
travertine	3.3–5.6
Concrete	
calcareous aggregate	5.0
siliceous aggregate	6.0
quartzite aggregate	7.0

TABLE 2 Thermal Storage Coefficient (TSc)

Type of Material	(TSc)
Low heat capacity materials [§]	100 or 130
Solar radiation reflected on low heat capacity materials ⁺	
High heat capacity materials [§]	75 or 100
Solar radiation reflected on high heat capacity materials ⁺	

[§] Materials such as EIFS and well-insulated metal panel curtain walls have low thermal storage capacity. Materials such as concrete and masonry have high thermal storage capacity.
⁺ If the wall surface receives reflected as well as direct solar radiation, use the larger coefficient. Reflected radiation may be from adjacent wall surfaces, roofs, and paving.

TABLE 3 Solar Absorption Coefficient (SAC)

Material	SAC
Brick, light buff	.50-.70
Brick, red	.65-.85
Brick, white	.25-.50
Concrete, natural	.65
Marble, white	.58
Surface color	
black	.95
dark gray	.80
light gray	.65
white	.45

TABLE 4 Moisture Movement Coefficient (M_c)

Material	M_c	Type of Movement
Concrete, gravel aggregate	–0.0003 to –0.0008	shrinkage
Concrete, limestone aggregate	–0.0003 to –0.0004	shrinkage
Concrete, lightweight aggregate	–0.0003 to –0.0009	shrinkage
Concrete block, dense aggregate	–0.0002 to –0.0006	shrinkage
Concrete block, lightweight aggregate	–0.0002 to –0.0006	shrinkage
Brick, clay face	+ 0.0003 to + 0.0008	expansion

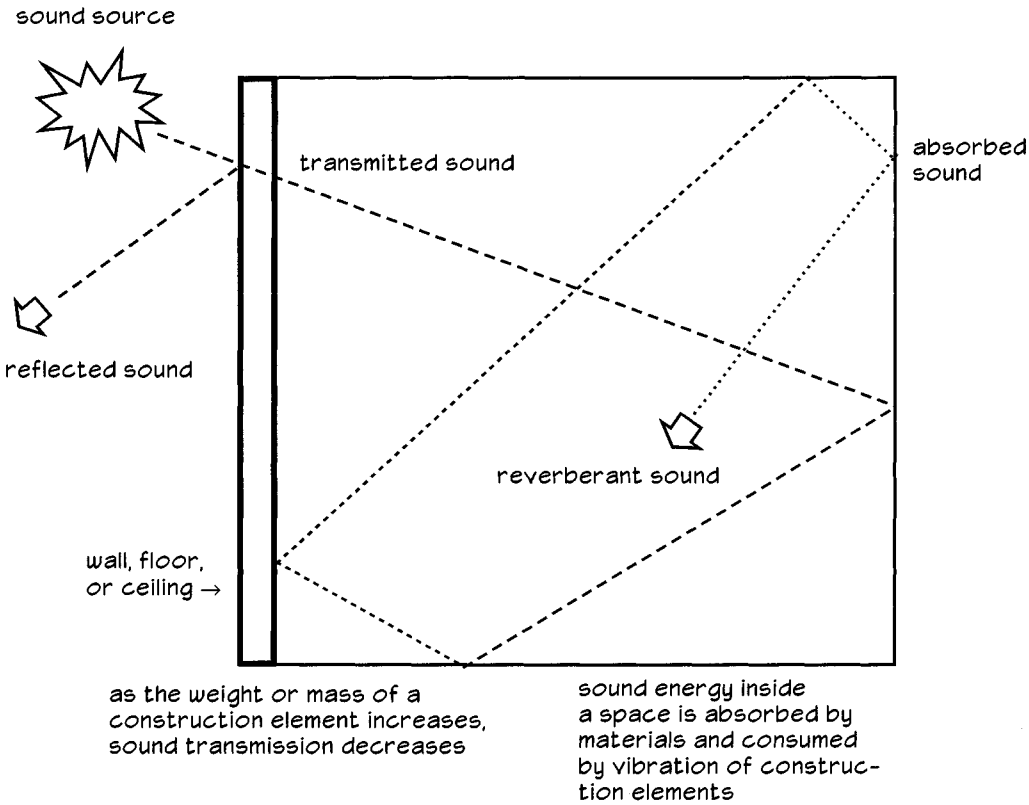
(From O'Connor, Design of Sealant Joints in ASTM STP 1069 Building Sealants: Materials, Properties and Performance, American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428)

3.5.1 Types of Acoustical Ratings

Type of Rating	Sound Absorption	Sound Transmission
At specific frequencies	Sound Absorption Coefficient (SAC)	Sound Transmission Loss (STL)
Overall performance	Noise Reduction Coefficient (NRC)	Sound Transmission Class (STC)

Sound Absorption Coefficient						
Frequency (cps)	125	250	500	1000	2000	4000
Coefficient (numeric example for ceiling system)	22	62	85	70	65	58

numerical average of Sound Absorption Coefficients
at middle frequencies = Noise Reduction Coefficient (NRC)

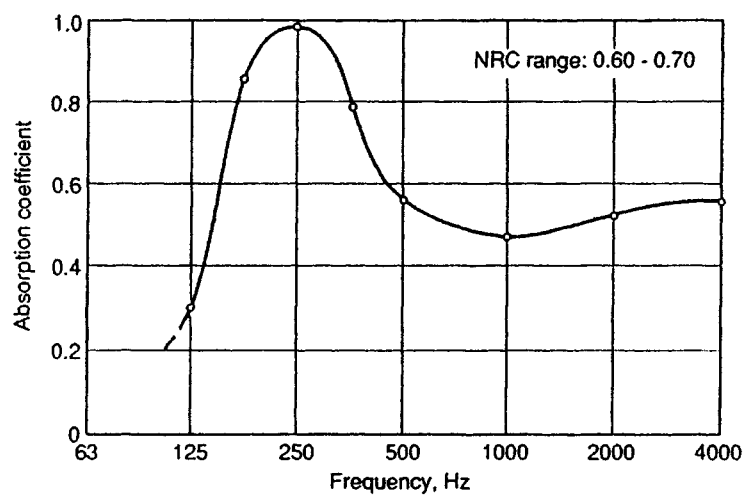
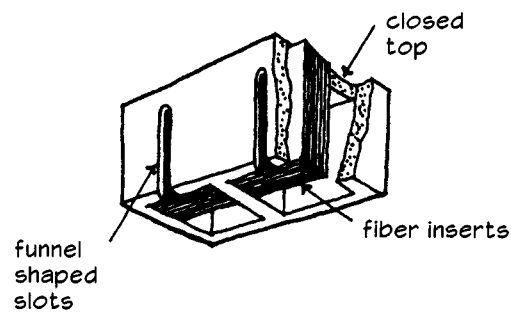


3.5.2 Noise Reduction Coefficients (NRC) for Various Building Materials and Furnishings

Material	NRC [§]
Brick, unglazed	0.04
Carpet	
on concrete	0.30
on pad	0.55
CMU, lightweight	
coarse texture	0.40
medium texture	0.45
fine texture	0.50
CMU, normal weight	
coarse texture	0.26
medium texture	0.27
fine texture	0.28
Deduct for paint	
all types, sprayed on	
1 coat	-10%
2 coats	-20%
oil, brushed on	
1 coat	-20%
2 coats	-55%
latex, brushed on	
1 coat	-30%
2 coats	-55%
Sound-insulated CMU	0.45 to 0.85
Concrete floor	0.01
Vinyl tile on concrete	0.03
Wood floor	0.08
Marble or glazed tile	0.01
Single-strength window glass	0.12
Plate glass	0.04
Gypsum board on 2 x 4 framing	0.07
Gypsum board on concrete	0.03
Plaster or brick on CMU	0.03
Wood paneling on furring strips	0.13
Draperies	
lightweight	0.14
medium weight	0.40
heavy weight	0.55
Furniture	
bed	0.80
sofa	0.85
wood table, chairs, etc.	0.20
leather upholstered chair	0.50
cloth upholstered chair	0.70

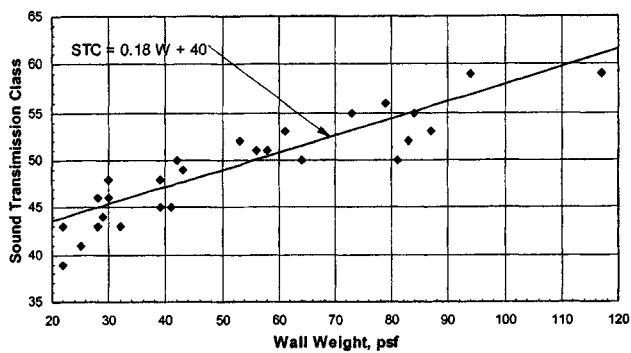
[§] Higher NRC indicates better sound absorption

3.5.3 Sound Absorption Test Data for Concrete Masonry "Sound Block"



(From Concrete Masonry Handbook, Portland Cement Association)

3.5.4 Sound Transmission Class (STC) and Wall Weight



(From TMS Standard Method for Determining the Sound Transmission Class Rating for Masonry Walls TMS 0302-00)

Average Weight of Single-Wythe Hollow Unit Masonry Walls (lb/ft ²) [§]								
Nominal Thickness (inches)	Medium Weight Units 105-125 lb/ft ³ Average 120 lb/ft ³			Normal Weight Units 125 lb/ft ³ or More Average 138 lb/ft ³			Hollow Clay Units	
	6	8	12	6	8	12	5	8
UngROUTed	31	35	50	69	92	140	32	45
Fully grouted	56	77	118	68	92	140	45	88
Vertical cores grouted at								
16" on center	46	60	90	58	75	111	—	71
24" on center	42	53	79	53	68	99	35	64
32" on center	40	50	73	51	65	93	—	61
40" on center	38	47	70	50	62	89	—	58
48" on center	37	46	68	49	61	87	33	55

§ Average weight of completed walls of various thickness in pounds per square foot of wall face area. A small quantity has been included for bond beams and reinforcing steel. Grout and mortar made with sand and gravel aggregate.

(From Schneider and Dickey, Reinforced Masonry Design)

Average Weight of Double-Wythe Grouted and Reinforced Brick Walls [§]	
Wall Thickness (inches)	Wall Weight (lb/ft ²)
8	86
8½	93
9	100
9½	106
10	112
10½	118
11	125
11½	131
12	138
13	151
14	164

§ Based on average brick weight of 10 lb/ft ² of vertical surface per inch of thickness and grout core at 13 lb/ft ² per inch of thickness.

(From Schneider and Dickey, Reinforced Masonry Design)

3.5.5 STC Ratings for Clay Masonry Walls

Calculated STC Ratings for Clay Masonry Walls [§]								
Nominal Wall Thickness (inches)	Hollow Units		Grout Filled		Sand Filled		Solid Units	
	Weight	STC	Weight	STC	Weight	STC	Weight	STC
3	—	—	—	—	—	—	30	45
4	20	44	38	47	32	46	35	46
6	32	46	63	51	50	49	55	50
8	42	48	86	55	68	52	75	53
10	53	50	109	60	86	55	95	57
12	62	51	132	64	104	59	115	61

[§] Based on unit dimension at smaller of specified less manufacturing tolerance; clay density of 120 lb/ft³; grout density of 144 lb/ft³; and sand density of 100 lb/ft³. STC values for grout filled and sand filled units assume the materials completely fill all void areas in and around the units. STC values for solid units are based on bed and head joints solidly filled with mortar.

(From TMS Standard Method for Determining the Sound Transmission Class Rating for Masonry Walls, TMS 0302-00)

3.5.6 STC Ratings for Lightweight CMU Walls

Calculated STC Ratings for Lightweight Concrete Masonry Walls [§]					
Nominal Wall Thickness (inches)	Density	Hollow Units	Grout Filled	Sand Filled	Solid Units
4	80	43	45	45	45
	85	43	46	45	45
	90	44	46	45	45
	95	44	46	45	45
	100	44	46	45	46
6	80	44	49	47	47
	85	44	49	47	47
	90	44	50	48	48
	95	44	50	48	48
	100	45	50	48	49
8	80	45	53	50	50
	85	45	53	50	50
	90	45	53	50	51
	95	46	53	51	51
	100	46	54	51	52
10	80	46	56	52	52
	85	46	56	53	53
	90	47	57	53	53
	95	47	57	53	54
	100	47	57	54	55
12	80	47	60	55	55
	85	47	60	55	55
	90	48	60	56	56
	95	48	61	56	57
	100	48	61	57	58

[§] Based on grout density of 140 lb/ft³ and sand density of 90 lb/ft³. Percent solid thickness of units based on mold manufacturer's literature for typical units as follows: 4 in = 73.8% solid, 6 in = 55% solid, 8 in = 53% solid, 10 in = 51.7% solid, and 12 in = 48.7% solid. STC values for grout-filled and sand-filled units assume the materials completely fill all void areas in and around the units. STC values for solid units are based on bed and head joints solidly filled with mortar.

(Adapted from TMS Standard Method for Determining the Sound Transmission Class Rating of Masonry Walls TMS 0302-00)

3.5.7 STC Ratings for Medium Weight CMU Walls

Calculated STC Ratings for Medium Weight Concrete Masonry Walls [§]					
Nominal Wall Thickness (inches)	Density	Hollow Units	Grout Filled	Sand Filled	Solid Units
4	105	44	46	46	46
	110	44	46	46	46
	115	44	47	46	46
	120	45	47	46	47
6	105	45	50	48	49
	110	45	50	49	49
	115	45	51	49	50
	120	45	51	49	50
8	105	46	54	51	52
	110	47	54	52	53
	115	47	55	52	53
	120	47	55	52	54
10	105	48	58	54	55
	110	48	58	54	56
	115	48	58	55	57
	120	49	59	55	57
12	105	49	62	57	59
	110	49	62	57	59
	115	49	62	58	60
	120	50	63	58	61

[§] Based on grout density of 140 lb/ft³ and sand density of 90 lb/ft³. Percent solid thickness of units based on mold manufacturer's literature for typical units as follows: 4 in = 73.8% solid, 6 in = 55% solid, 8 in = 53% solid, 10 in = 51.7% solid, and 12 in = 48.7% solid. STC values for grout-filled and sand-filled units assume the materials completely fill all void areas in and around the units. STC values for solid units are based on bed and head joints solidly filled with mortar.

(Adapted from TMS Standard Method for Determining the Sound Transmission Class Rating of Masonry Walls TMS 0302-00)

3.5.8 STC Ratings for Normal Weight CMU Walls

Calculated STC Ratings for Normal Weight Concrete Masonry Walls [§]					
Nominal Wall Thickness (inches)	Density	Hollow Units	Grout Filled	Sand Filled	Solid Units
4	125	45	47	46	47
	130	45	47	46	47
	135	45	47	47	47
	140	45	49	47	48
	145	46	48	47	48
	150	46	49	47	48
6	125	46	51	49	51
	130	46	51	49	51
	135	46	52	50	51
	140	46	52	50	52
	145	47	52	50	52
	150	47	52	50	53
8	125	47	55	52	54
	130	48	55	53	55
	135	48	56	53	55
	140	48	56	53	56
	145	49	56	54	56
	150	49	57	54	57
10	125	49	59	56	58
	130	49	60	56	59
	135	50	60	56	59
	140	50	60	57	60
	145	50	61	57	61
	150	51	61	57	61
12	125	50	63	59	62
	130	51	63	59	63
	135	51	64	59	63
	140	51	64	60	64
	145	52	65	60	65
	150	52	65	61	66

[§] Based on grout density of 140 lb/ft³ and sand density of 90 lb/ft³. Percent solid thickness of units based on mold manufacturer's literature for typical units as follows: 4 in = 73.8% solid, 6 in = 55% solid, 8 in = 53% solid, 10 in = 51.7% solid, and 12 in = 48.7% solid. STC values for grout-filled and sand-filled units assume the materials completely fill all void areas in and around the units. STC values for solid units are based on bed and head joints solidly filled with mortar.

(Adapted from TMS Standard Method for Determining the Sound Transmission Class Rating of Masonry Walls TMS 0302-00)

3.5.9 STC and IIC Ratings for Concrete Assemblies

Airborne Sound Transmission Class (STC) and Impact Insulation Class (IIC) Ratings
from Tests of Precast Concrete Assemblies

Description	STC	IIC
Wall Systems		
4 in. flat panel, 54 psf	49	—
5 in. flat panel, 60 psf	52	—
6 in. flat panel, 75 psf	55	—
6 in. flat panel with "Z" furring channels, 1 in. insulation, and 1/2 in. gypsum board, 75.5 psf	62	—
6 in. flat panel with wood furring, 1-1/2 in. insulation, and 1/2 in. gypsum board, 73 psf	63	—
6 in. flat panel with 1/2 in. space, 1-5/8 in. metal stud row, 1-1/2 in. insulation, and 1/2 in. gypsum board, 76 psf	63	—
8 in. flat panel, 95 psf	58	—
10 in. flat panel, 120 psf	59	—
14 in. prestressed tees with 4 in. flange, 75 psf	54	—
Floor-Ceiling Systems		
8 in. hollow-core prestressed units, 57 psf	50	28
8 in. hollow-core prestressed units with carpet and pad, 58 psf	50	73
8 in. hollow-core prestressed units with 1/2 in. wood block flooring adhered directly to concrete, 58 psf	51	47
8 in. hollow-core prestressed units with 1/2 in. wood block flooring adhered to 1/2 in. sound deadening board underlayment adhered to concrete, 60 psf	52	55
8 in. hollow-core prestressed units with 1/2 in. wood block flooring adhered to 1/2 in. sound deadening board underlayment adhered to concrete and with acoustical ceiling, 62 psf	59	61
8 in. hollow-core prestressed units with quarry tile, 1-1/4 in. reinforced mortar bed with 0.4 in. nylon and carbon black spinerette matting, 76 psf	60	54
8 in. hollow-core prestressed units with quarry tile, 1-1/4 in. reinforced mortar bed with 0.4 in. nylon and carbon black spinerette matting and with suspended 5/8 in. gypsum board ceiling with 3-1/2 in. insulation, 78.8 psf	61	62
14 in. prestressed tees with 2 in. concrete topping, 75 psf	54	24
14 in. prestressed tees with 2 in. concrete topping, carpet, and pad, 76 psf	54	72
14 in. prestressed tees with 2 in. concrete topping, and with resiliently suspended acoustical ceiling with 1-1/2 in. mineral fiber blanket above, 77 psf	59	51
14 in. prestressed tees with 2 in. concrete topping, carpet, and pad, and with resiliently suspended acoustical ceiling with 1-1/2 in. mineral fiber blanket above, 78 psf	59	82
4 in. flat slabs, 54 psf	49	25
5 in. flat slabs, 60 psf	52	24
5 in. flat slab concrete with carpet and pad, 61 psf	52	68
6 in. flat slabs, 75 psf	55	34
8 in. flat slabs, 95 psf	58	34
10 in. flat slabs, 120 psf	59	31
10 in. flat slab concrete with carpet and pad, 121 psf	59	74

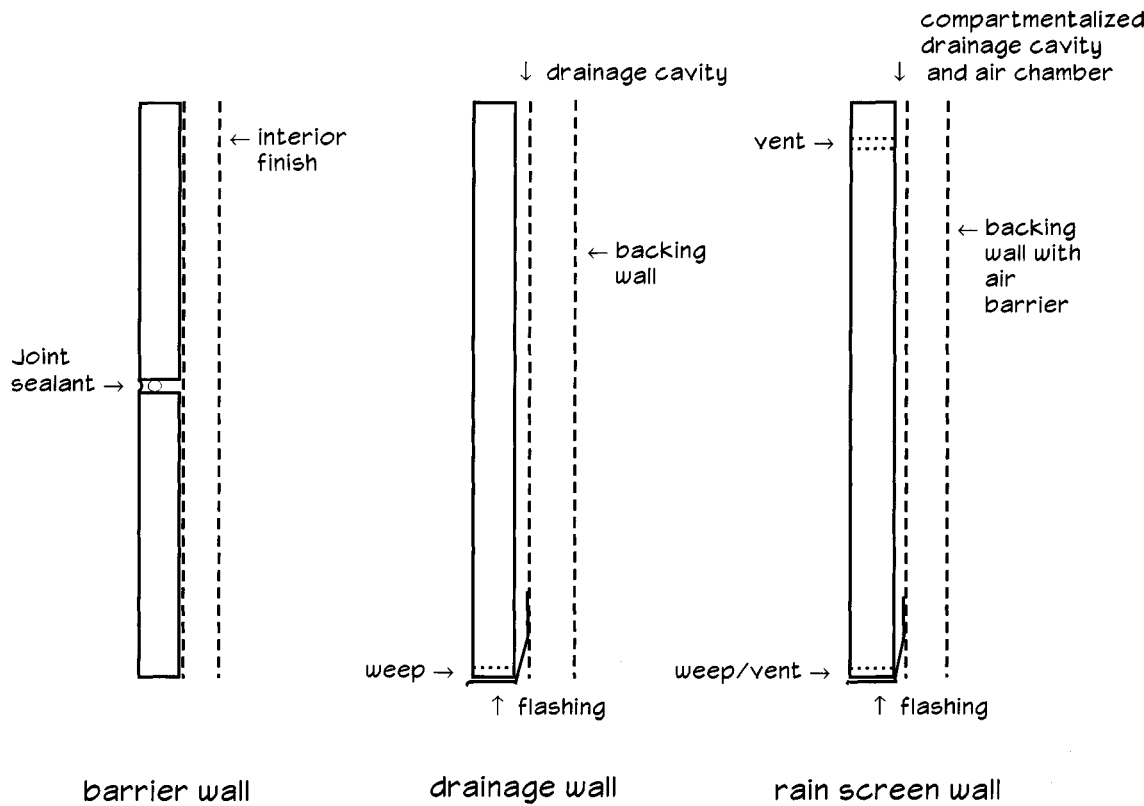
STC improvements for wall treatments (one side): 3/4 in. furring, 3/4 in. insulation and 1/2 in. gypsum board, +3. Metal stud wall with 1-1/2 in. insulation in stud cavity, 1/2 in. gypsum board, + 5 to 10. Plaster direct to concrete, +0.

(From PCI Design Handbook, 5th ed., and Architectural Precast Concrete, Precast/Prestressed Concrete Institute)

3.6.1 Barrier, Drainage, and Rain Screen Wall Systems

Exterior wall systems may incorporate a number of moisture protection strategies, but can generally be divided into three basic wall types: barrier walls, drainage walls, and rain screen walls.

- *Barrier wall systems* must entirely exclude rain penetration at the exterior wall surface because there is no accommodation for moisture drainage. Barrier walls assume that surfaces are impervious and rely on the integrity of joint sealants and perimeter detailing to achieve adequate performance. Some systems require unrealistic perfection in the construction process to prevent moisture damage to component materials. Precast concrete cladding, concrete tilt wall construction, and many EIF systems typically use barrier wall strategies.
- *Drainage wall systems* are more forgiving because they do not require the total exclusion of moisture. A drainage wall can tolerate minor rain penetration because its drainage capability prevents moisture accumulation and damage to materials. A continuous clear and open cavity or drainage plane is required behind the exterior surface. Flashing membranes and weep holes must be properly detailed and installed to control moisture flow and facilitate drying. Masonry cavity and veneer walls, some precast concrete cladding, and some newer EIF systems, and most stucco applications are typically designed as drainage walls.
- *Rain screen wall systems* incorporate the elements of a drainage wall plus air pressure equalization for additional protection against wind-driven rain. Rain screen systems require compartmentalization of the drainage cavity or air chamber behind the exterior surface and the incorporation of an air barrier in the backing wall. The rain screen concept works most effectively in glass and metal curtain wall systems where the air chamber size is very small and air pressure equalization is very rapid. Although rain screen technology can be used with concrete and masonry walls, it is not common in the United States and the enhanced performance increases construction costs.



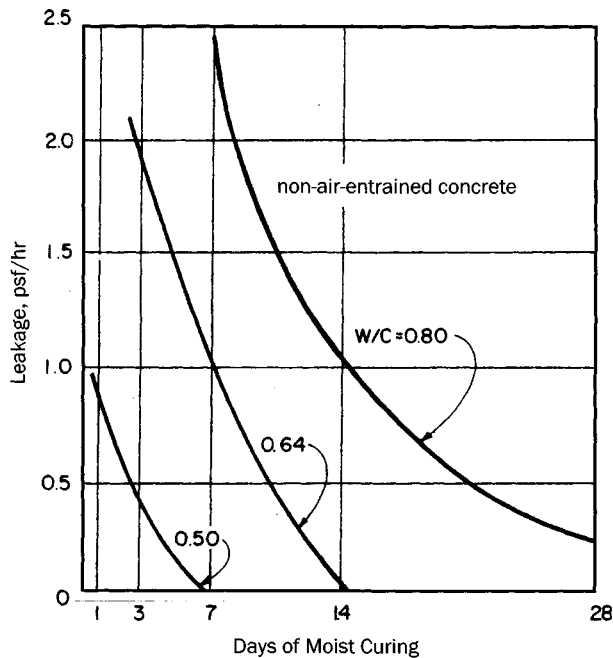
3.6.2 Weather-Resistant Concrete

The same precautions that make concrete strong and crack resistant also make it watertight. These precautions include:

- Low water-to-cement ratio: maximum 0.5 by weight
- Good cement proportions: 6 bags of cement per cubic yard of concrete (with 1-inch maximum aggregate)
- Entrained air: 6% plus or minus 1% (with 1-inch maximum aggregate)
- Non-porous aggregate
- Avoiding segregation during placement
- Good curing: 7 to 14 days or longer

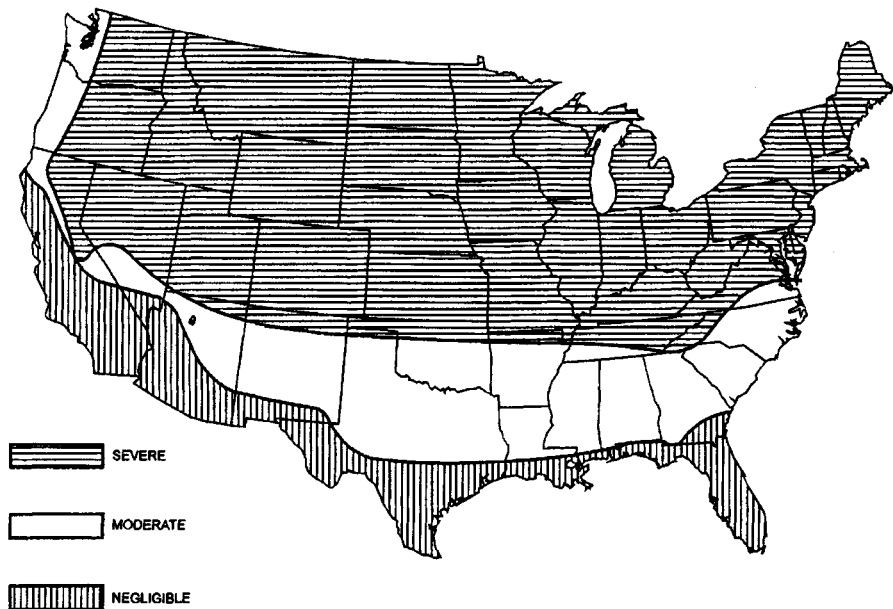
Watertightness is resistance to passage of liquid water. Even the best-cured concrete will permit the passage of water in vapor form.

If the site is unusually wet, special precautions may be needed to protect the concrete against moisture. These steps may include installation of waterproofing, dampproofing, or vapor retarders.



(From Residential Concrete, 3rd ed., National Association of Home Builders, 1999)

3.6.3 International Building Code Weathering Map and Minimum Strengths for Concrete



- Lines defining areas are approximate only. Local areas can be more or less severe than indicated by the region classification.
- A “severe” classification is where weather conditions encourage or require the use of deicing chemicals or where there is a potential for a continuous presence of moisture during frequent cycles of freezing and thawing. A “moderate” classification is where weather conditions occasionally expose concrete in the presence of moisture to freezing and thawing, but where deicing chemicals are not generally used. A “negligible” classification is where weather conditions rarely expose concrete in the presence of moisture to freezing and thawing.
- Alaska and Hawaii are classified as severe and negligible, respectively.

Type or Location of Concrete Construction	Minimum Specified Compressive Strength (psi)		
	Negligible Exposure	Moderate Exposure	Severe Exposure
Basement walls [§] and foundations not exposed to the weather	2,500	2,500	2,500 [†]
Basement slabs and interior slabs on grade, except garage floor slabs	2,500	2,500	2,500 [†]
Basement walls, [§] foundation walls, exterior walls, and other vertical concrete surfaces exposed to the weather	2,500	3,000 [‡]	3,500 [‡]
Driveways, curbs, walks, patios, porches, carport slabs, steps, and other flatwork exposed to the weather, and garage floor slabs	2,500	3,000 [‡]	3,500 [‡]

[§] Structural plain concrete basement walls are exempt from the requirements for special exposure conditions.

[†] Concrete in these locations that can be subjected to freezing and thawing during construction shall be of air-entrained concrete.

[‡] Concrete shall be air entrained.

(from International Building Code, 2000).

3.6.4 International Building Code Special Exposure Requirements for Concrete

Requirements for Special Exposure Conditions		
Exposure Condition	Maximum Water-Cementitious Materials Ratio by Weight, Normal Weight Aggregate Concrete	Minimum Specified Compressive Strength of Concrete at 28 days, Normal Weight and Lightweight Aggregate Concrete (psi)
Concrete intended to have low permeability when exposed to water	0.50	4,000
Concrete exposed to freezing and thawing in a moist condition or to deicing chemicals	0.45	4,500
For corrosion protection of reinforcement in concrete exposed to chlorides from deicing chemicals, salt, salt water, brackish water, seawater or spray from these sources	0.40	5,000

Nominal Maximum Aggregate Size (inches)	Total Air Content for Frost-Resistant Concrete (%)	
	Severe Exposure [§]	Moderate Exposure [§]
3/8	7-1/2	6
1/2	7	5-1/2
3/4	6	5
1	6	4-1/2
1-1/2	5-1/2	4-1/2
2 [†]	5	4
3 [†]	4-1/2	3-1/2

[§] For this table, severe exposure occurs where concrete will be in almost continuous contact with moisture prior to freezing, or where deicing salts are used (such as pavements, bridge decks, sidewalks, parking garages and water tanks). Moderate exposure occurs where concrete will be only occasionally exposed to moisture prior to freezing, and where deicing salts are not used (such as certain exterior walls, beams, girders and slabs not in direct contact with soil).

[†] These air contents apply to total mix, as for the preceding aggregate sizes. When testing these concretes, however, aggregate larger than 1-1/2" is removed by hand picking or sieving and air content is determined on the minus 1-1/2" fraction of the mix (tolerance on air content as delivered applies to this value). Air content of total mix is computed from value determined on the minus 1-1/2" fraction.

Cementitious Material	Maximum Percent of Total Cementitious Material by Weight
Fly ash or other pozzolans	25
Slag	50
Silica fume	10
Total of fly ash or other pozzolans, slag and silica fume	50
Total of fly ash or other pozzolans and silica fume	35

(from International Building Code, 2000).

Formwork**4.1 Form Materials**

- 4.1.1 Form Materials and Uses
- 4.1.2 Plywood Form Materials
- 4.1.3 Steel Pan Forms for Concrete
- 4.1.4 Pan Joist Forms
- 4.1.5 "Sonotube" Column Forms
- 4.1.6 Typical Insulating Concrete Forms
- 4.1.7 Flat Block Type Insulating Concrete Forms
- 4.1.8 Flat Panel Type Insulating Concrete Forms
- 4.1.9 Flat Plank Type Insulating Concrete Forms
- 4.1.10 Post and Beam Panel Type Insulating Concrete Forms
- 4.1.11 Post and Beam Block Type Insulating Concrete Forms
- 4.1.12 Screen-Grid Panel Type Insulating Concrete Forms
- 4.1.13 Waffle-Grid Block Type Insulating Concrete Forms

4.2 Construction Details

- 4.2.1 Simple Bracing for Short Forms
- 4.2.2 Wall Forms
- 4.2.3 Wall, Slab, and Beam Forms
- 4.2.4 Wall and Grade Beam Forms
- 4.2.5 Architectural Form Liners
- 4.2.6 Stair Forms
- 4.2.7 Metal Form Stakes, Braces and Spreaders
- 4.2.8 Forms and Shoring for Elevated Slab and Beam
- 4.2.9 Column Forms
- 4.2.10 Retaining Wall Forms
- 4.2.11 Form Ties
- 4.2.12 Concrete Pressure on Wall, Column, and Slab Forms
- 4.2.13 Form Openings and Blockouts

4.1.1 Form Materials and Uses

Item	Principle Use(s)
Sawn lumber	Form framing, sheathing, and shoring
Engineered wood	Form framing and sheathing
Plywood	Form sheathing and panels
Steel	Panel framing and bracing; heavy forms and falsework; column and joist forms
Aluminum§	Stay-in-place forms; lightweight panels and framing; bracing and horizontal shoring
Reconstituted wood panel products†	Form liners and sheathing
Insulating board, wood or glass fiber	Stay-in-place liners or sheathing
Fiber or laminated paper pressed tubes or forms	Column and beam forms; void forms for slabs, beams, girders, and precast piles
Corrugated cardboard	Internal and under-slab voids; voids in beams and girders (normally with internal “egg-crate” stiffeners)
Concrete	Footings, stay-in-place forms, molds for precast units
Fiberglass-reinforced plastic	Ready-made column and dome pan forms; custom-made forms for special architectural effects
Cellular plastics	Form lining and insulation; permanent forms
Other plastics polystyrene polyethylene polyvinyl chloride	Form liners for decorative concrete
Rubber	For liners and void forms
Form ties, anchors and hangers	For securing formwork against placing loads and pressures
Plaster	Waste molds for architectural concrete
Coatings	Facilitate form removal
Steel joists	Formwork support
Steel frame shoring	Formwork support
Form insulation	Cold weather protection of concrete

§ Shall be readily weldable, nonreactive to concrete or concrete containing calcium chloride, and protected against galvanic action at points of contact with steel.

† Check surface reaction with wet concrete.

4.1.2 Plywood Form Materials

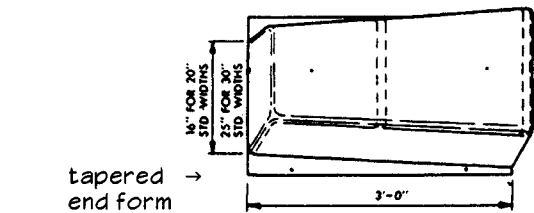
American Plywood Association Grade-Use Guide for Plywood Concrete Forms				
Specification	Description	Veneer Grade		
		Faces	Inner Plies	Backs
APA B-B Plyform Class I and II	Specifically manufactured for concrete forms. Many reuses. Smooth, solid surfaces. Mill-treated unless otherwise specified.	B	C	B
APA High Density Overlaid Plyform Class I and II	Hard, semi-opaque resin-fiber overlay, heat-fused to panel faces. Smooth surface resists abrasion. Up to 200 reuses. Light application of releasing agent recommended between pours.	B	C-Plugged	B
APA Structural I Plyform	Especially designed for engineered applications. All Group 1 species. Stronger and stiffer than Plyform Class I and II. Recommended for high pressures where face grain is parallel to supports. Also available with High Density Overlay Faces.	B	C or C-Plugged	B
Special overlays, proprietary panels, and Medium Density Overlaid plywood specially designed for concrete forming.	Produces a smooth uniform concrete surface. Generally mill-treated with form release agent. Check with manufacturer for specifications, proper use, and surface treatment recommendations for greatest number of reuses.	—	—	—
APA B-C EXT	Sanded panel often used for concrete forming where only one smooth, solid side is required.	B	C	C

The following bending radii have been found appropriate as minimums for mill-run plywood panels of the thicknesses shown, when the panels are bent dry. Tighter radii can be formed by selecting panels that are free of knots and short grain, and/or by wetting or steaming. Occasionally, a panel may develop localized failure at these tighter radii.

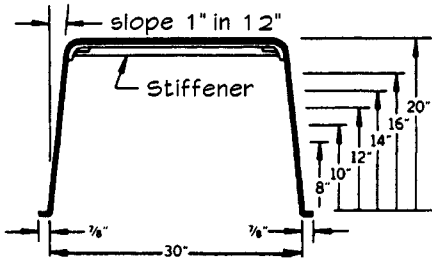
Minimum Bending Radii for Plywood Forms		
Plywood Thickness (in.)	Bending Radius Across the Grain (ft.)	Bending Radius Parallel to Grain (ft.)
1/4	2	5
5/16	2	6
3/8	3	8
1/2	6	12
5/8	8	16
3/4	12	20

(From American Plywood Association)

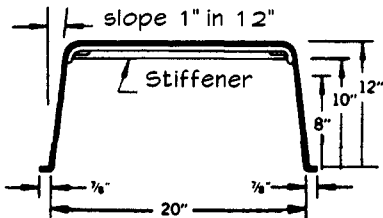
4.1.3 Steel Pan Forms for Concrete



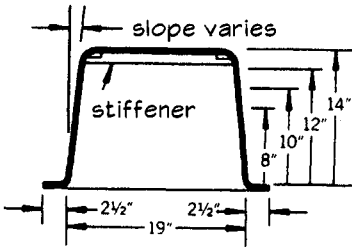
standard steel form dimensions for one-way concrete floor joist construction



Filler widths (10" and 15") are available for filling non-standard spaces only

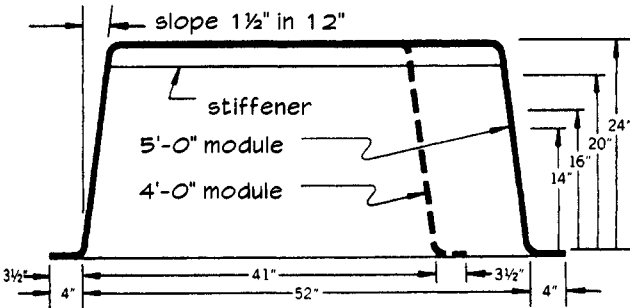
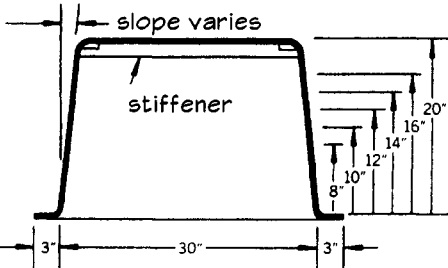


2'-0" module



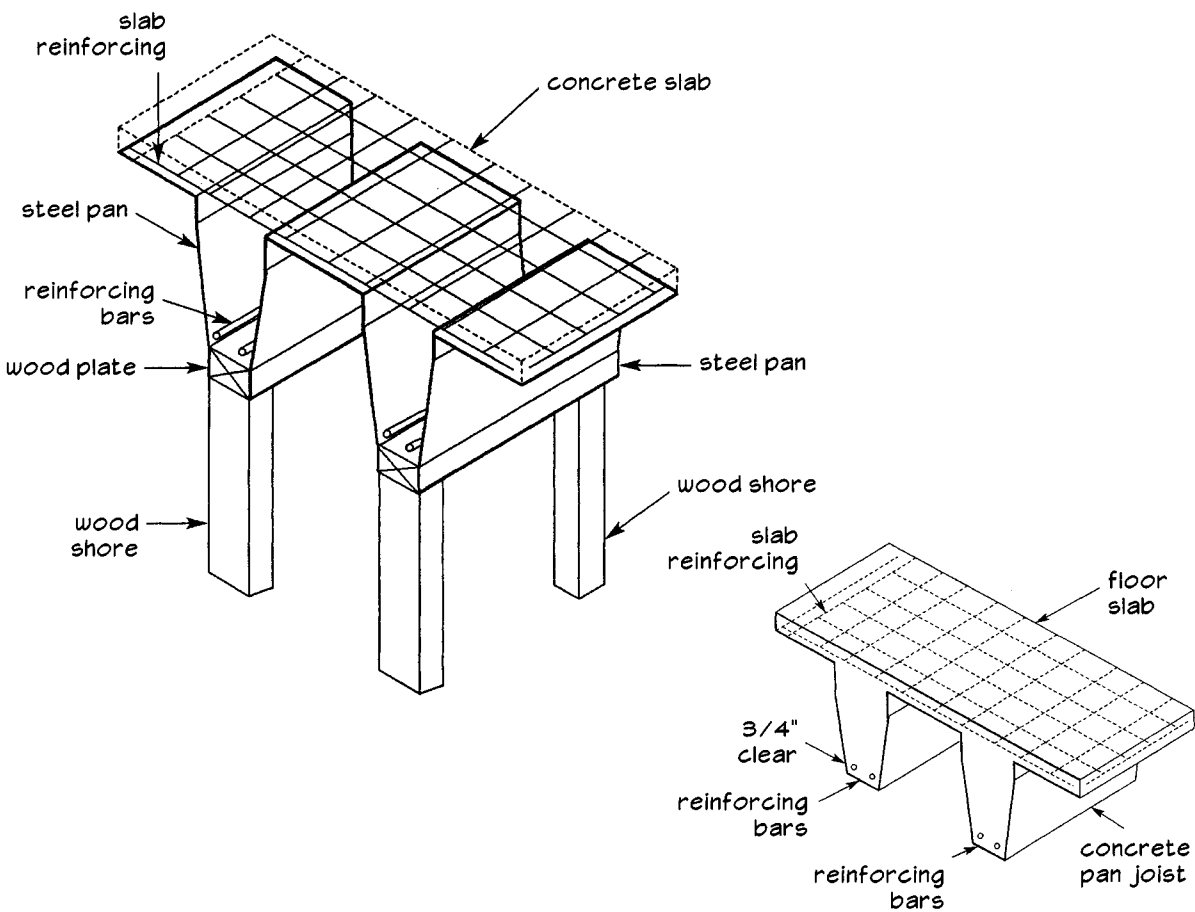
standard steel dome forms for two-way concrete floor joist construction

3'-0" module



(From Ceco Corporation, Oakbrook Terrace, Illinois).

4.1.4 Pan Joist Forms

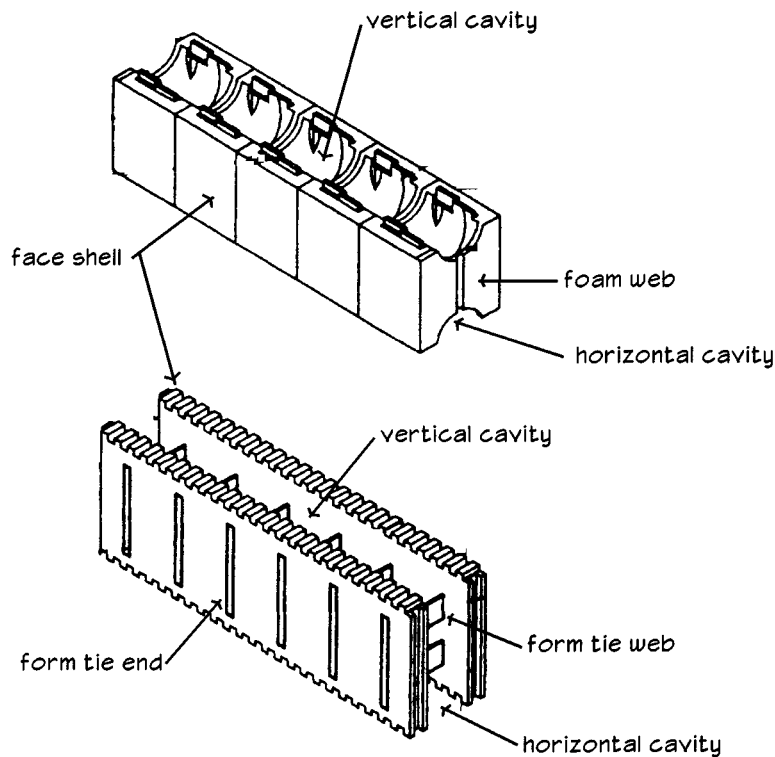


4.1.5 “Sonotube” Column Forms

Sizes and Weights of “Sonotube” Fiber Forms			
Inside Diameter (in.)	Weight Per Foot (lbs.)	Inside Diameter (in.)	Weight Per Foot (lbs.)
8	1.7	28	10.4
10	2.3	30	11.8
12	2.8	32	12.6
14	3.6	34	13.4
16	4.8	36	14.5
18	5.4	38	16.9
20	7.5	40	17.8
22	8.2	42	18.6
24	8.9	44	20.5
26	9.6	48	23.5

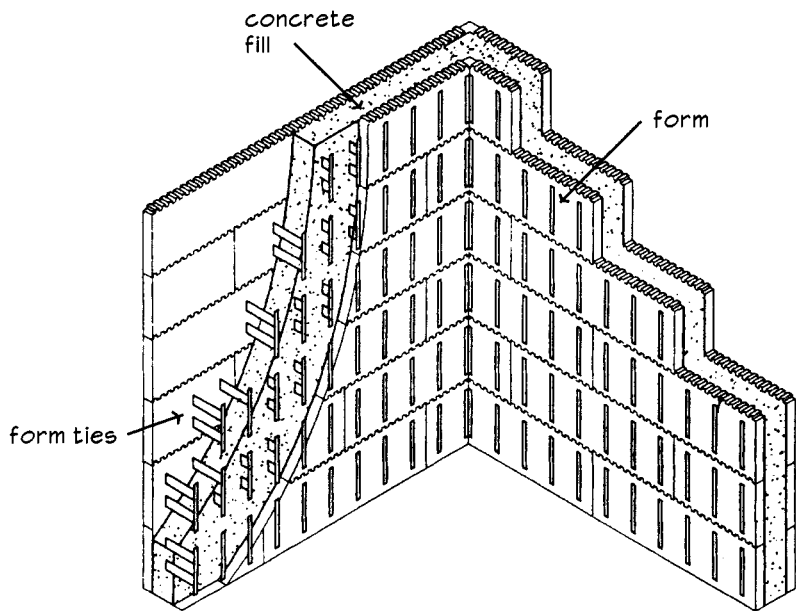
(From Waddell, Concrete Manual, 1989)

4.1.6 Typical Insulating Concrete Forms



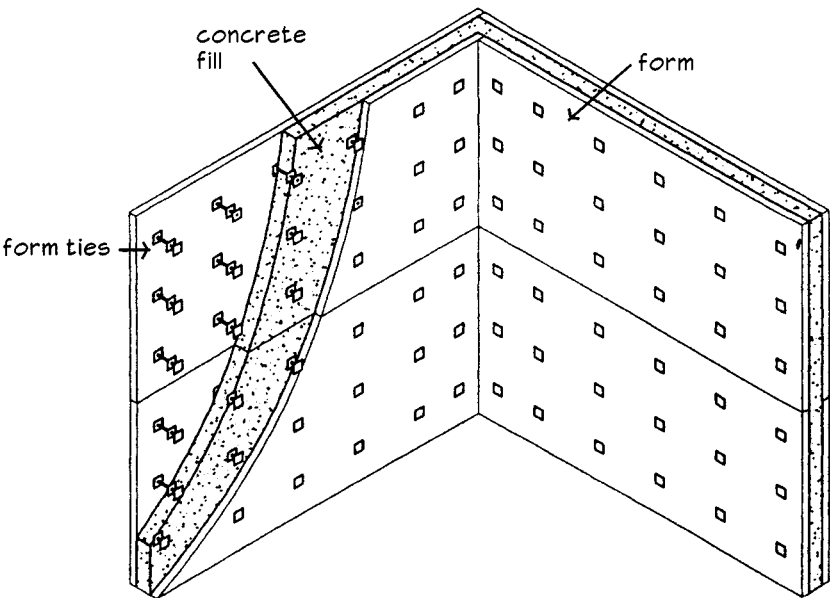
(From VanderWerk, Insulating Concrete Forms, McGraw-Hill, 1997.)

4.1.7 Flat Block Type Insulating Concrete Forms



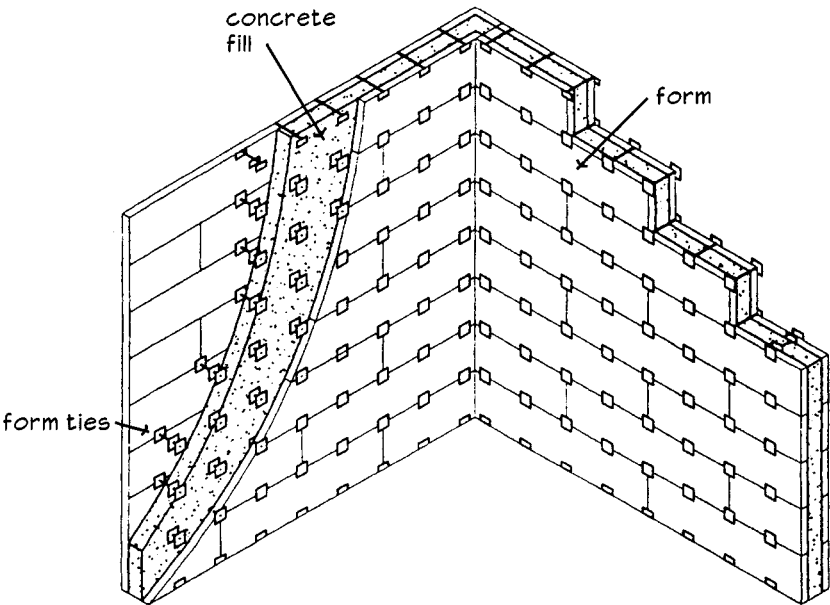
(From VanderWerk, Insulating Concrete Forms, McGraw-Hill, 1997.)

4.1.8 Flat Panel Type Insulating Concrete Forms



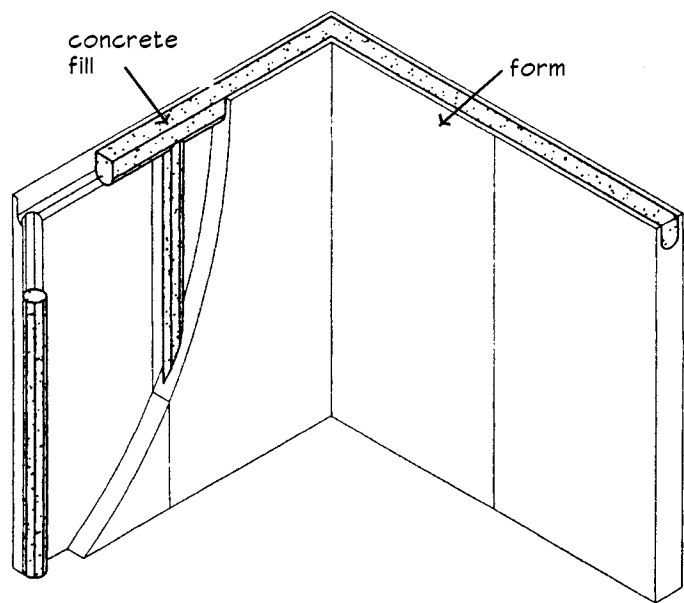
(From VanderWerk, Insulating Concrete Forms, McGraw-Hill, 1997.)

4.1.9 Flat Plank Type Insulating Concrete Forms



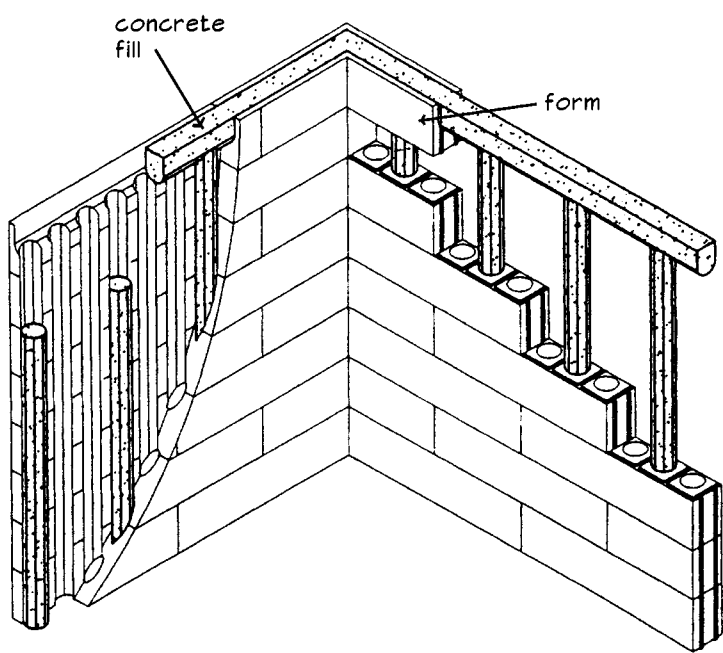
(From VanderWerk, Insulating Concrete Forms, McGraw-Hill, 1997.)

4.1.10 Post and Beam Panel Type Insulating Concrete Forms



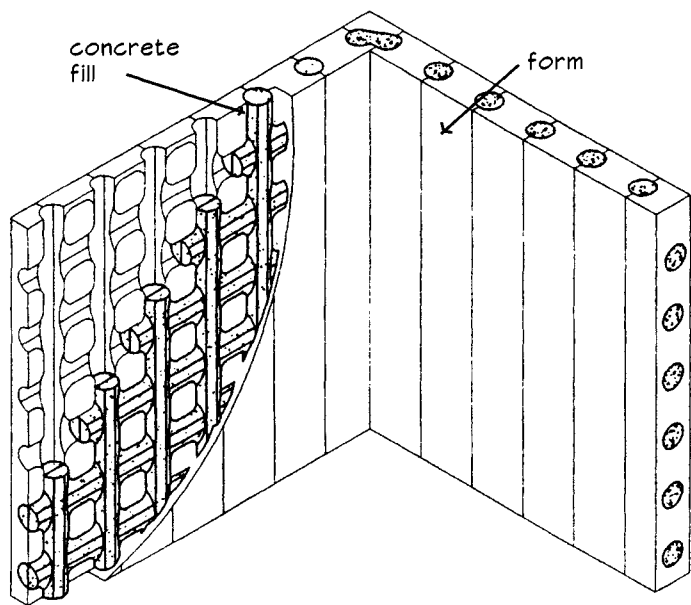
(From VanderWerk, Insulating Concrete Forms, McGraw-Hill, 1997.)

4.1.11 Post and Beam Block Type Insulating Concrete Forms



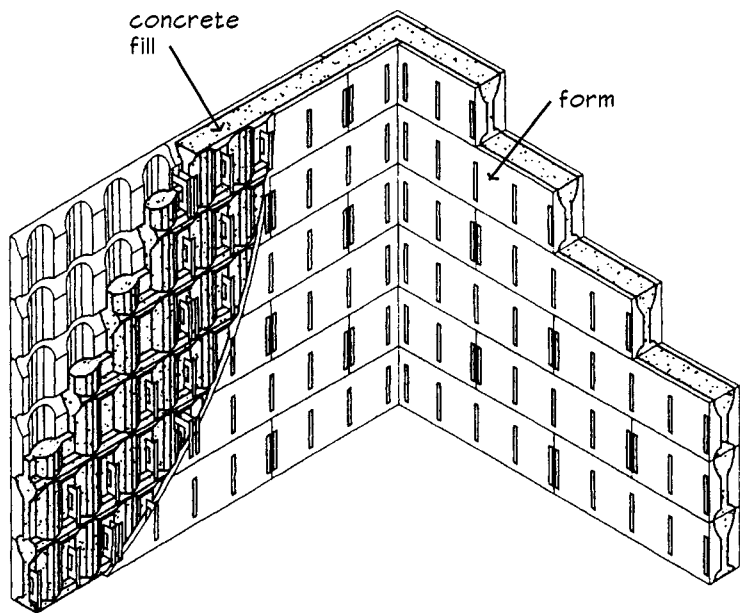
(From VanderWerk, Insulating Concrete Forms, McGraw-Hill, 1997.)

4.1.12 Screen-Grid Panel Type Insulating Concrete Forms



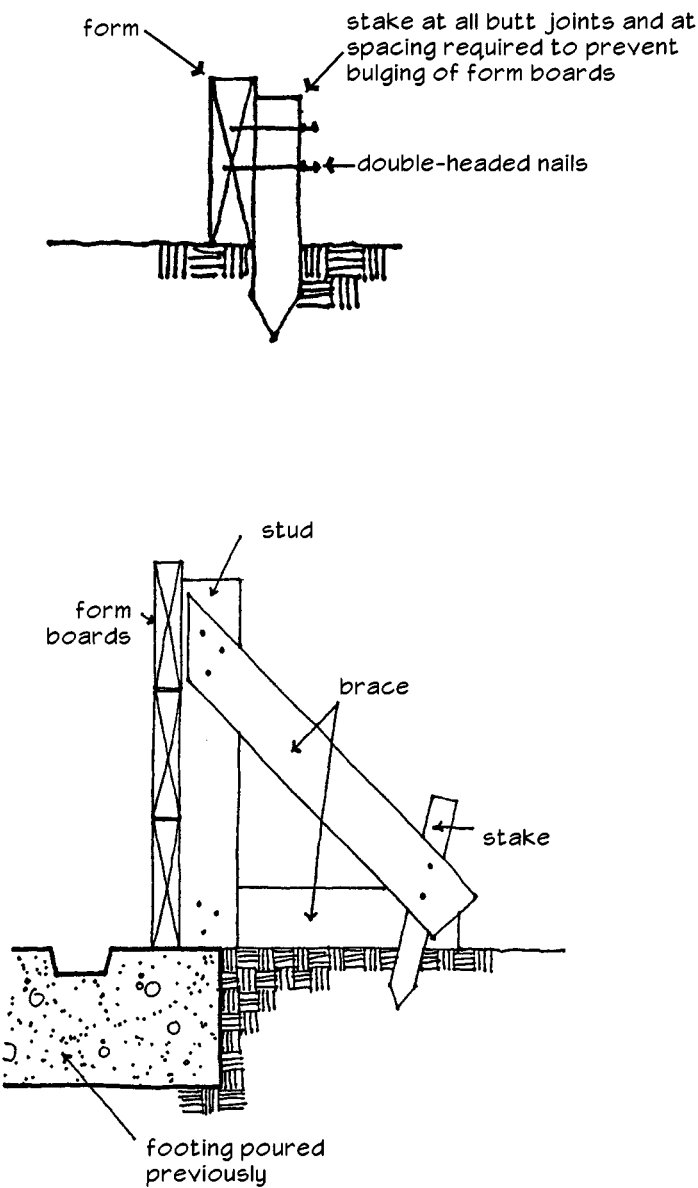
(From VanderWerk, Insulating Concrete Forms, McGraw-Hill, 1997.)

4.1.13 Waffle-Grid Block Type Insulating Concrete Forms

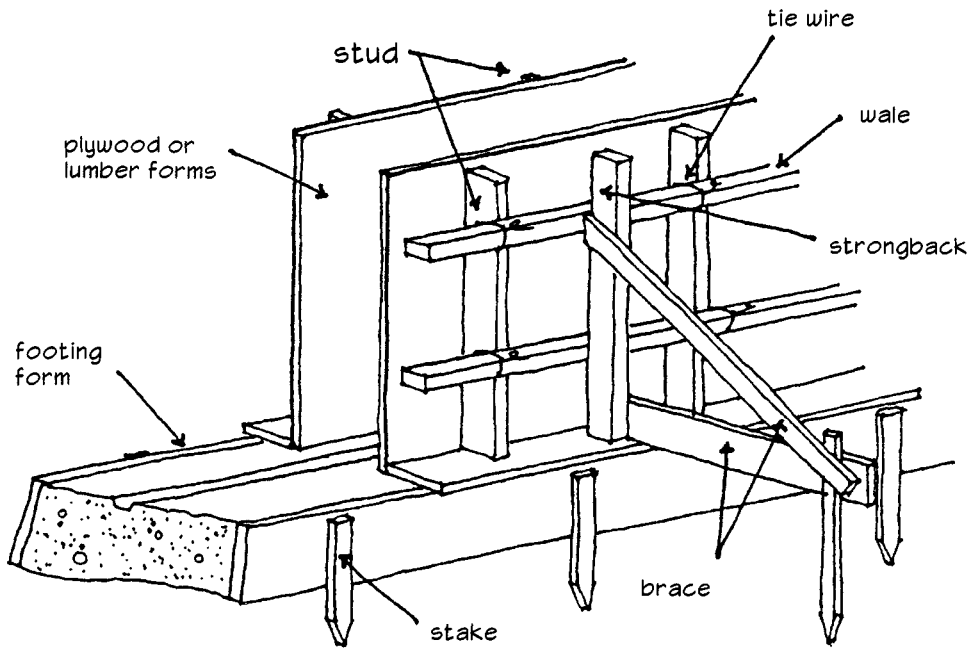


(From VanderWerk, Insulating Concrete Forms, McGraw-Hill, 1997.)

4.2.1 Simple Bracing for Short Forms

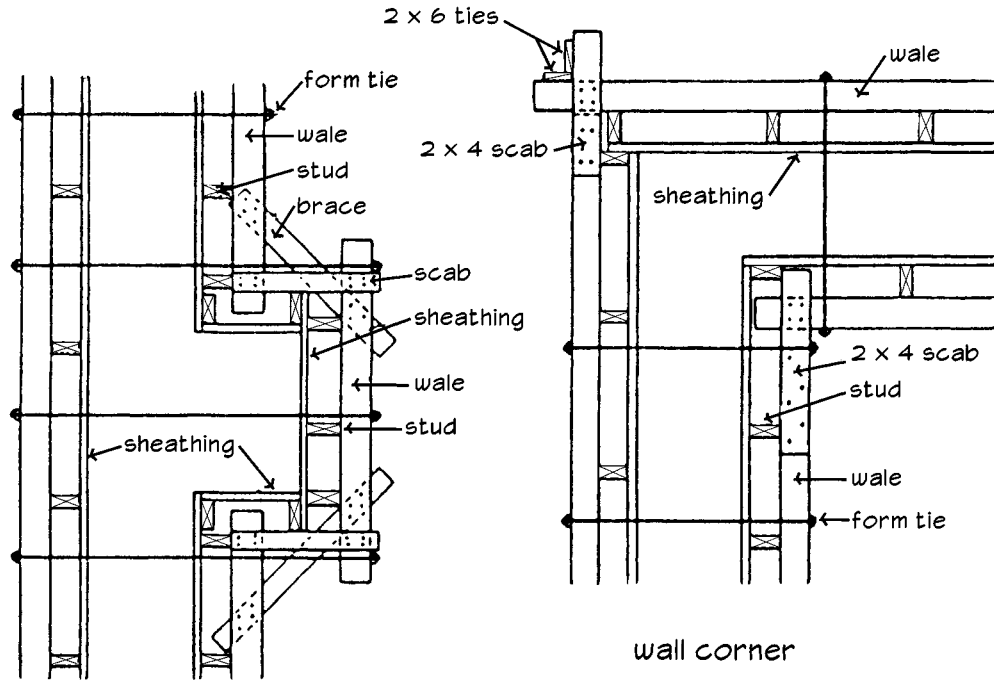


4.2.2 Wall Forms



formwork components

(From U.S. Army Corps of Engineers, Concrete, Masonry and Brickwork.)

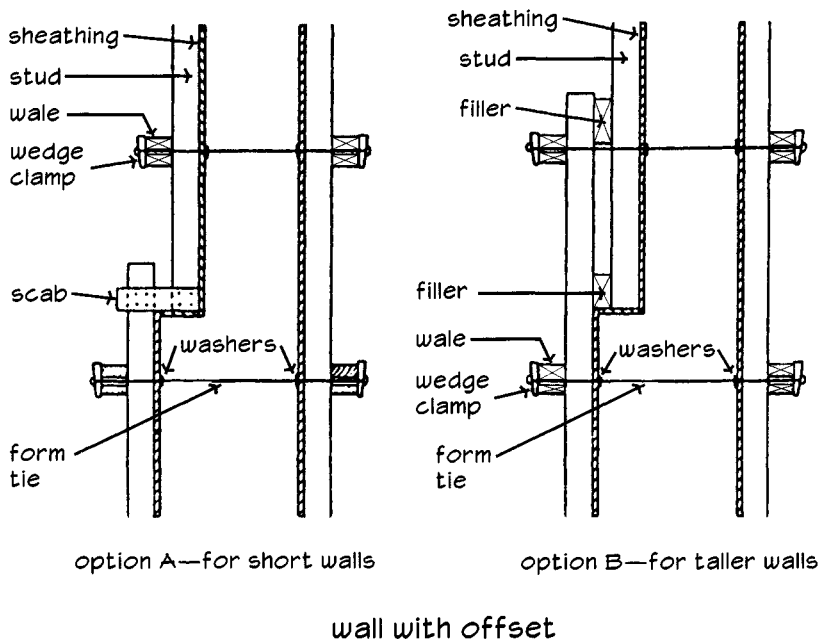
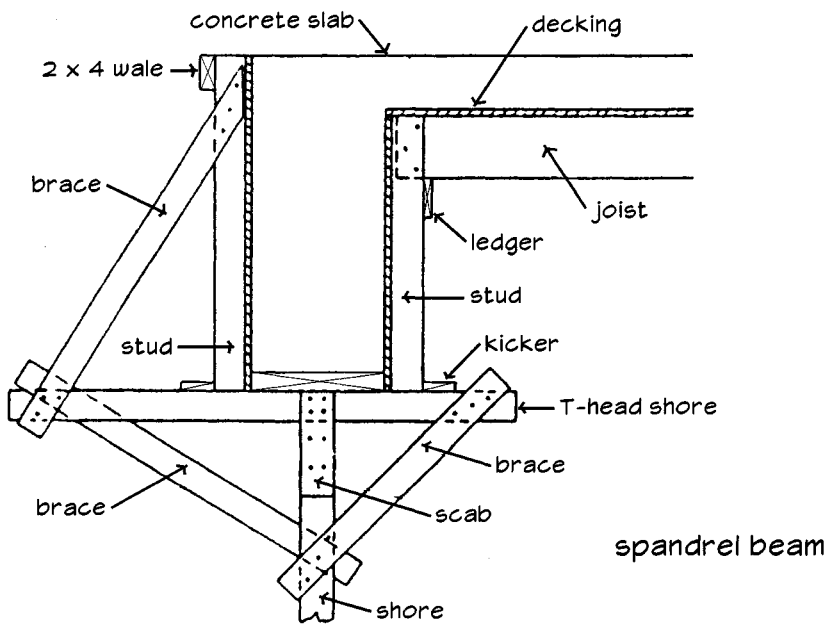


pilaster

wall corner

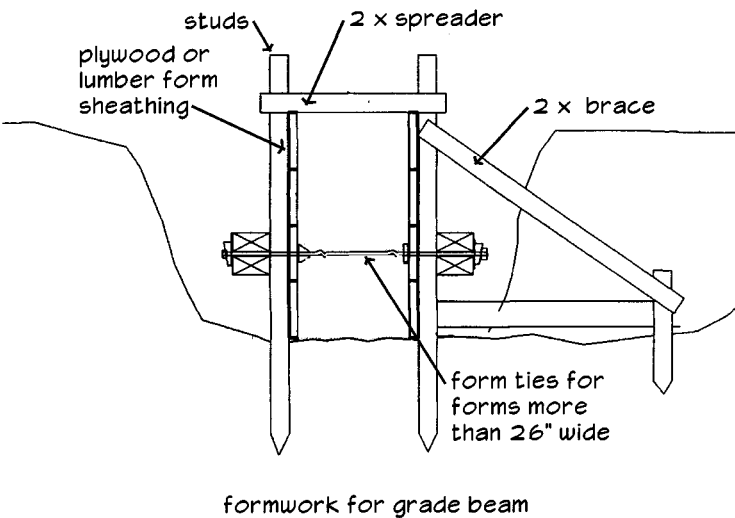
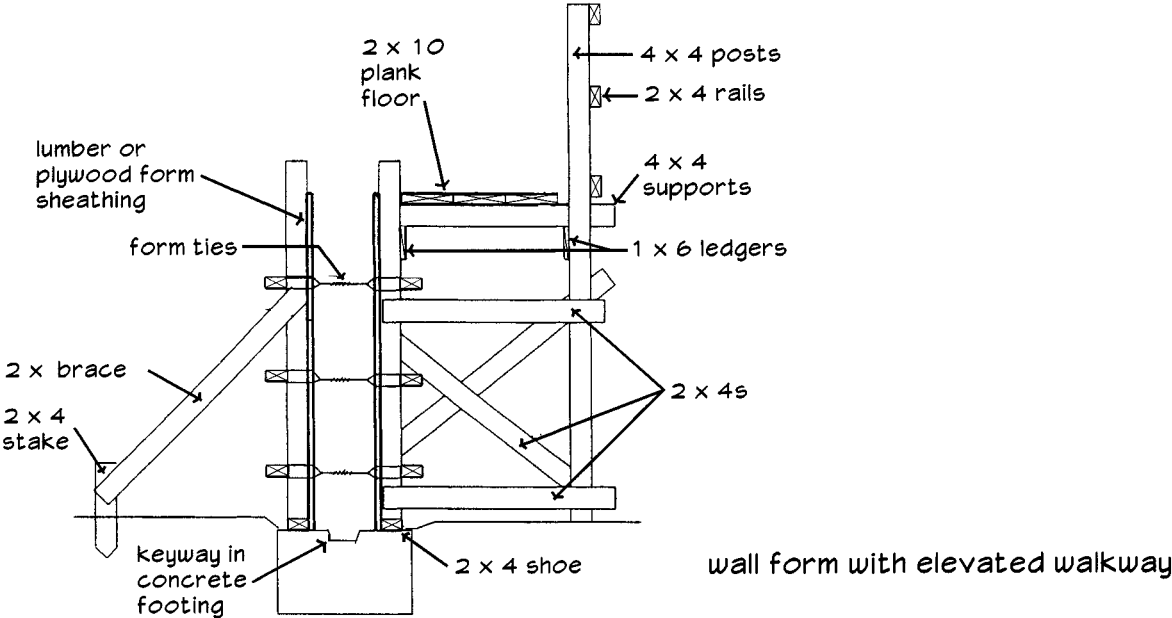
(From Peurifoy and Oberlender, Formwork for Concrete Structures, McGraw-Hill, 1996.)

4.2.3 Wall, Slab, and Beam Forms



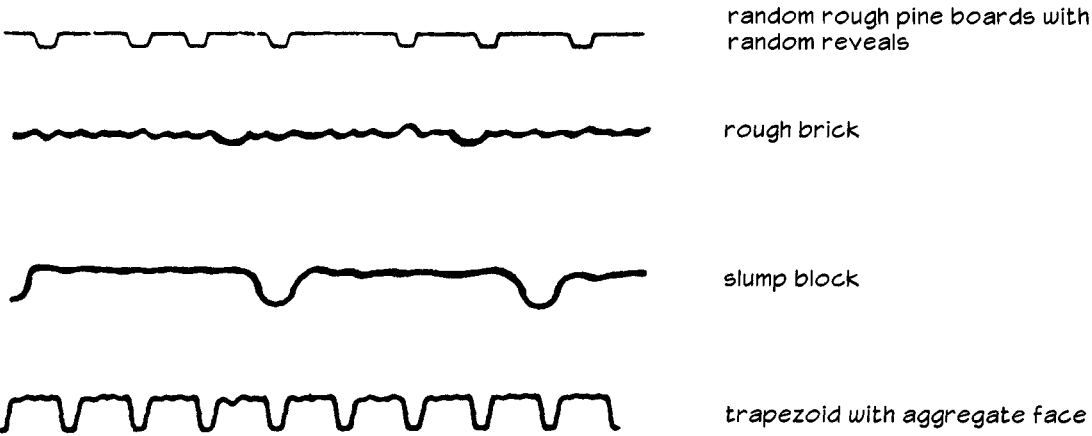
(From Peurifoy and Oberlender, Formwork for Concrete Structures, McGraw-Hill, 1996.)

4.2.4 Wall and Grade Beam Forms



(From Schwartz, Basic Concrete Engineering for Builders, Craftsman Books, 2000.)

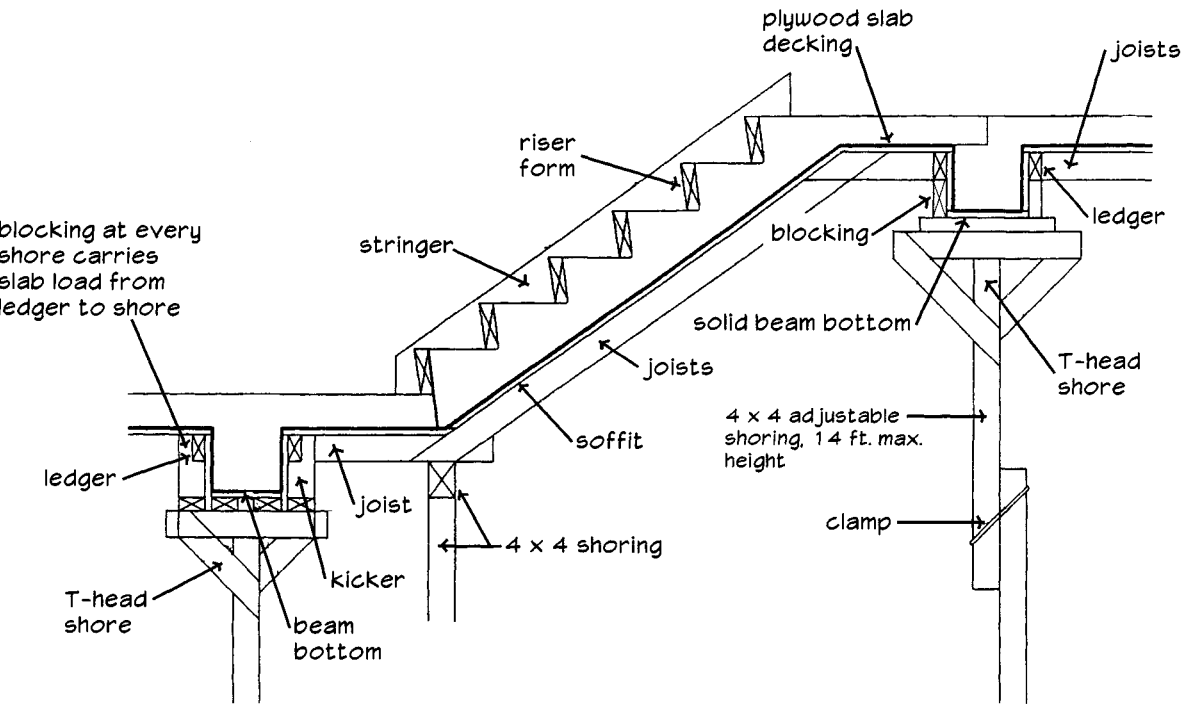
4.2.5 Architectural Form Liners



(From Greenstreak Plastic Products Company, Inc.)

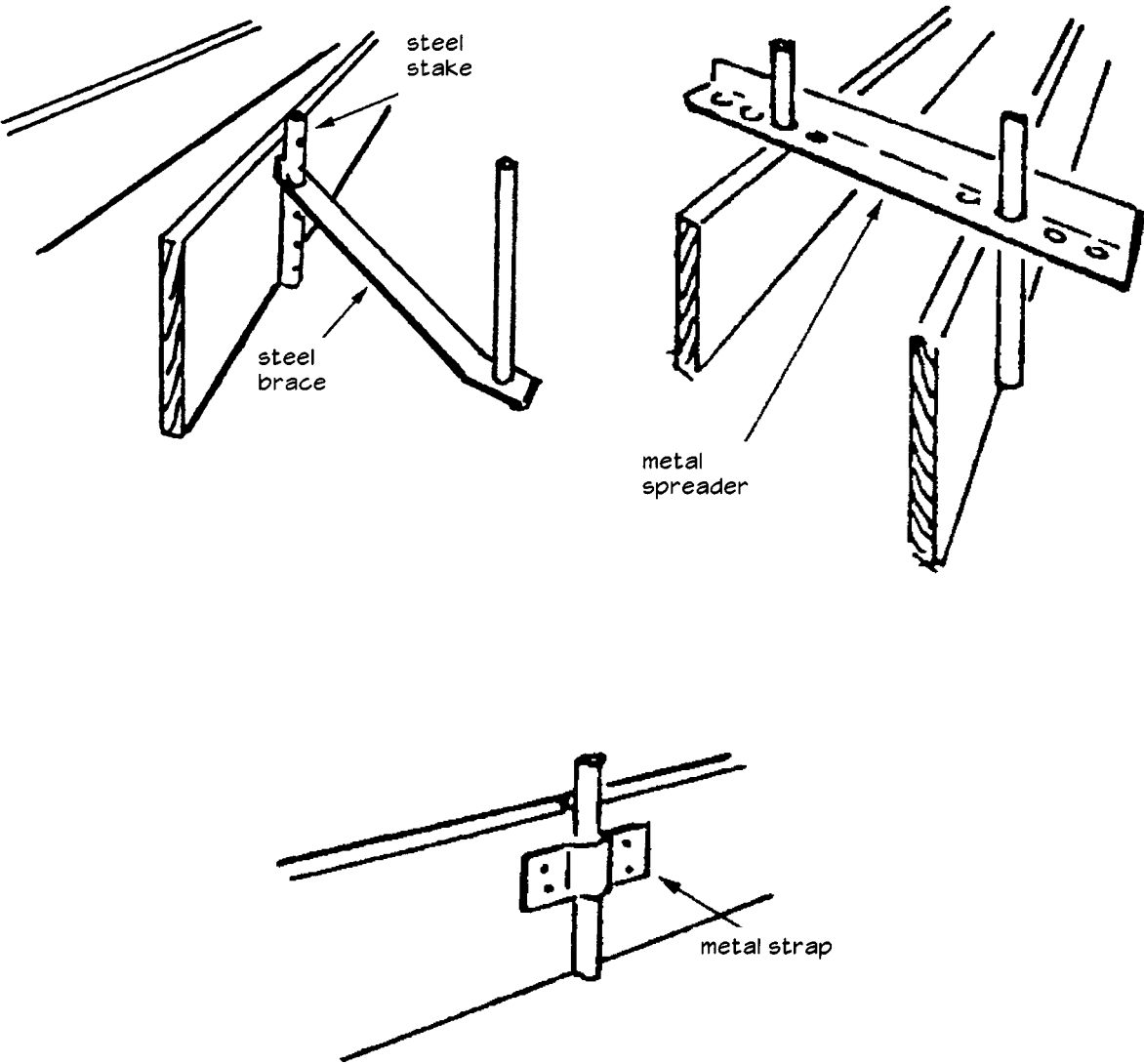
examples of form liners used to produce textures on finished concrete for exposed architectural applications

4.2.6 Stair Forms

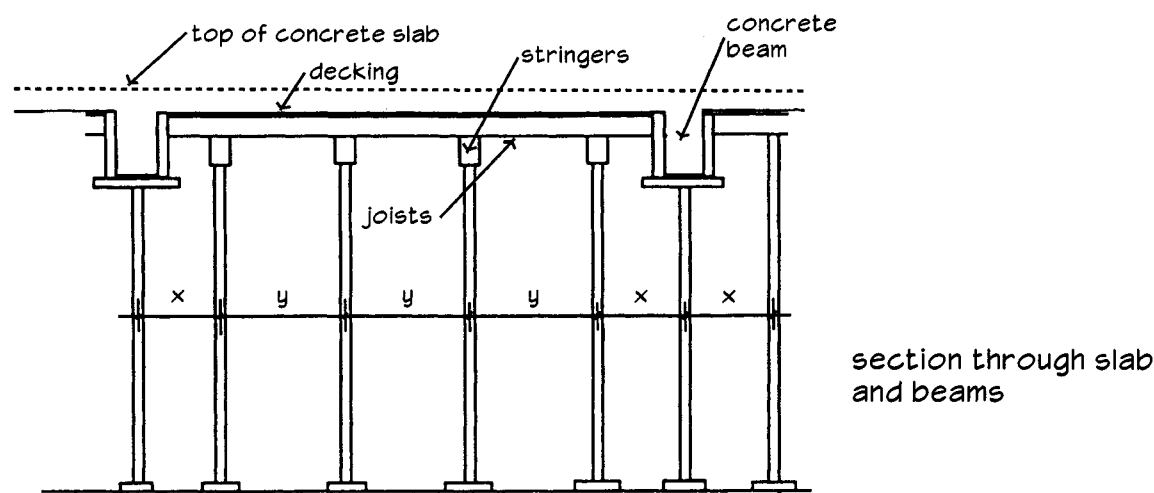


(From Schwartz, Basic Concrete Engineering for Builders, Craftsman Books, 2000.)

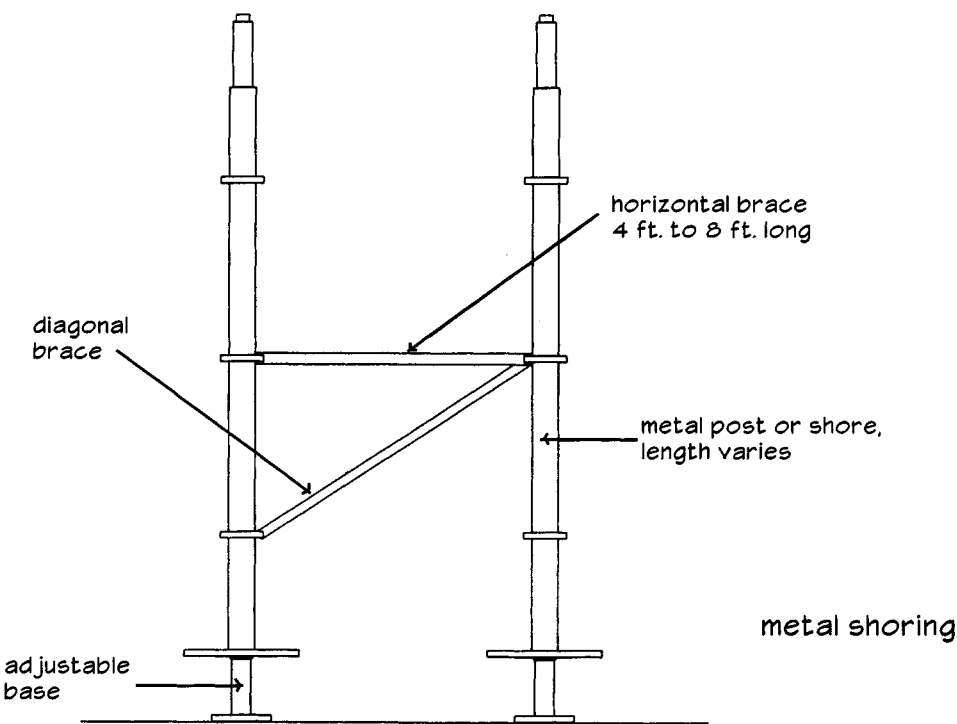
4.2.7 Metal Form Stakes, Braces, and Spreaders



4.2.8 Forms and Shoring for Elevated Slab and Beam

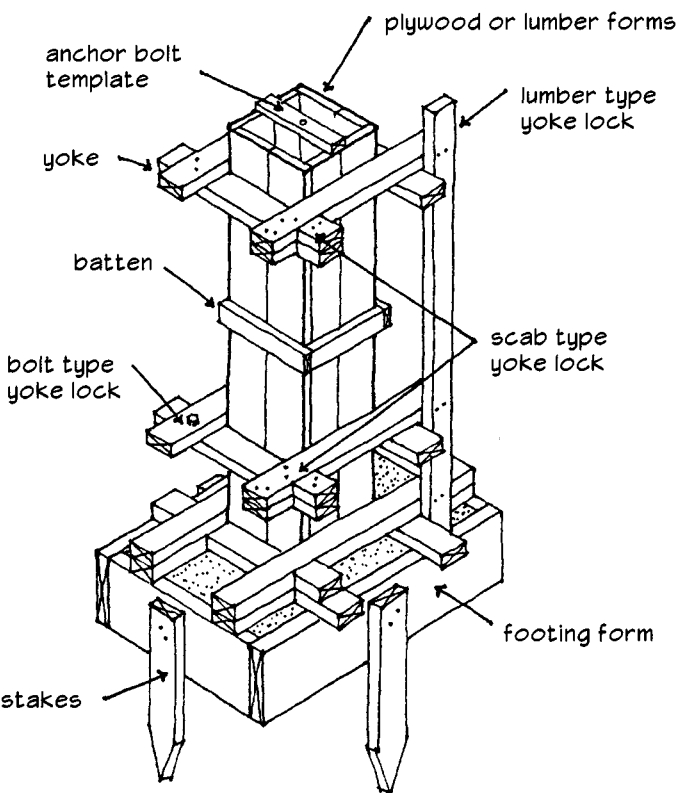


(From Peurifoy and Oberlender, Formwork for Concrete Structures, McGraw-Hill, 1996.)



(From Schwartz, Basic Concrete Engineering for Builders, Craftsman Books, 2000.)

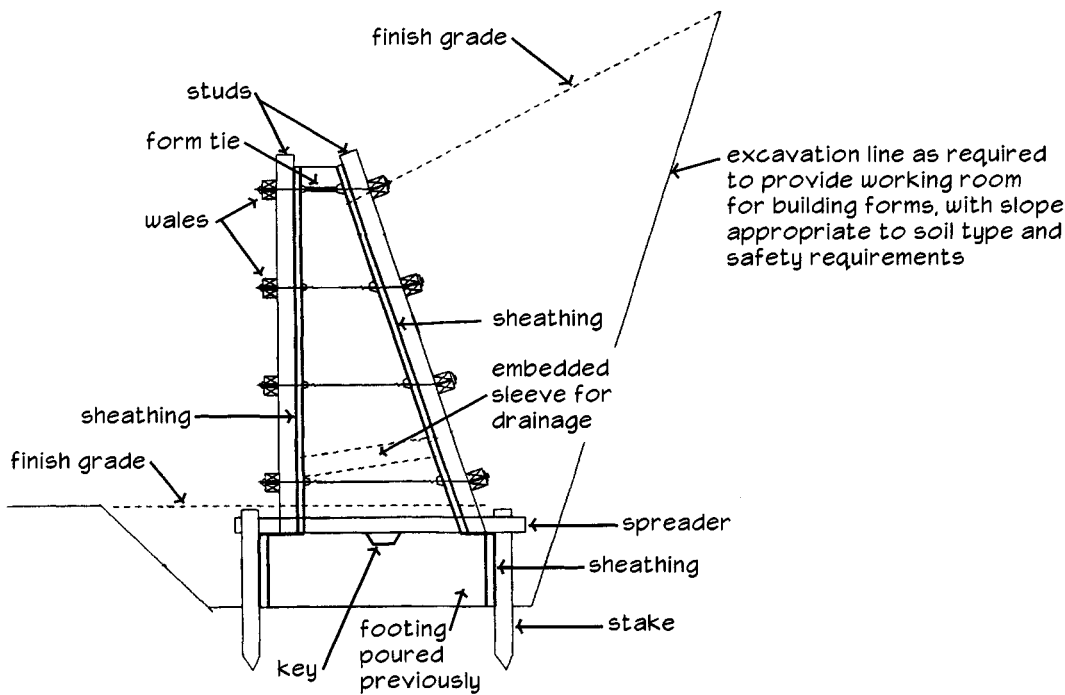
4.2.9 Column Forms



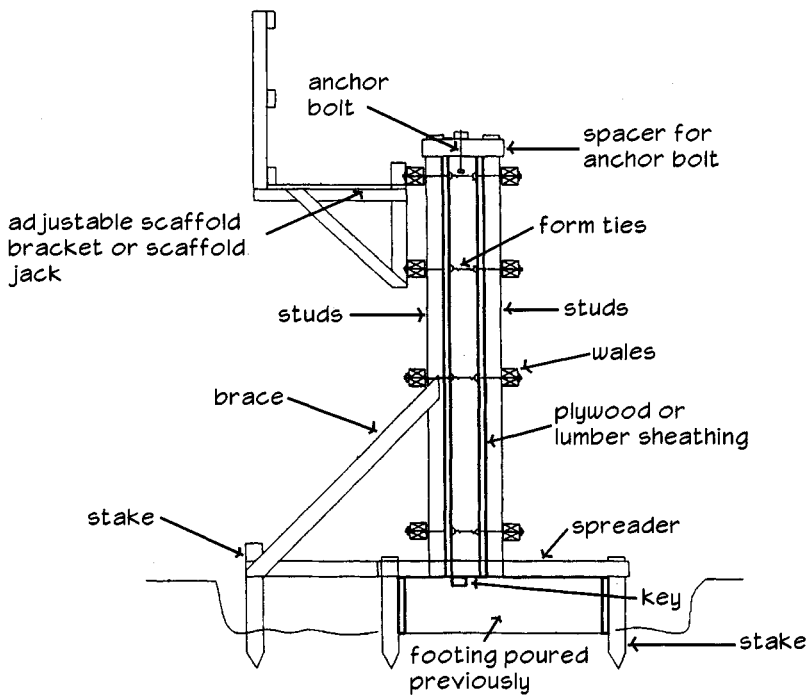
Column Form Yoke Spacing (in.)				
Column Height (ft.)	Largest Dimension of Column, L (in.)			
	16	18	20	24
1	31	29	27	23
2	31	29	27	23
3	31	28	26	23
4	31	28	26	23
5	31	28	26	23
6	30	28	26	23
7	30	28	24	22
8	30	26	24	16
9	29	26	19	16
10	29	20	19	14
11	21	20	16	13
12	21	18	15	12
13	20	16	15	11
14	18	16	14	10
15	18	15	12	9
16	15	13	11	9

(Adapted from U.S. Army Corps of Engineers, Concrete, Masonry and Brickwork.)

4.2.10 Retaining Wall Forms



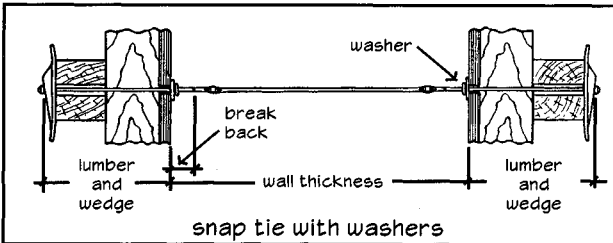
gravity retaining wall



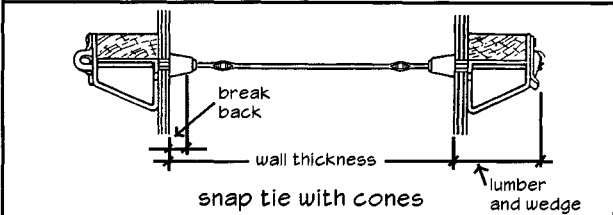
cantilever retaining wall

(From Schwartz, Basic Concrete Engineering for Builders, Craftsman Books, 2000.)

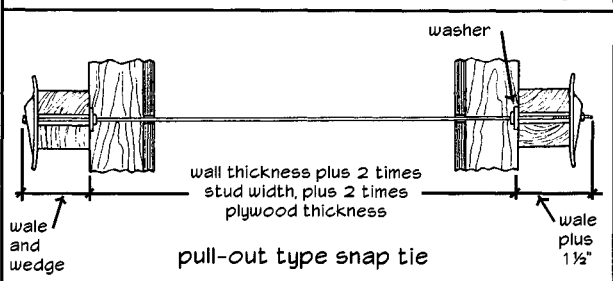
4.2.11 Form Ties



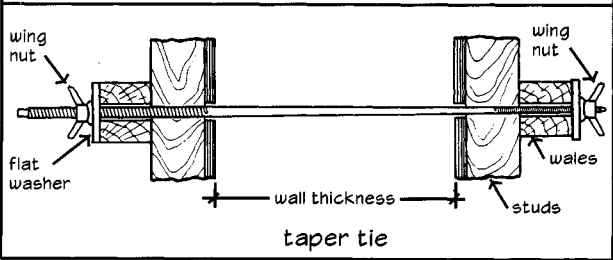
snap tie with washers



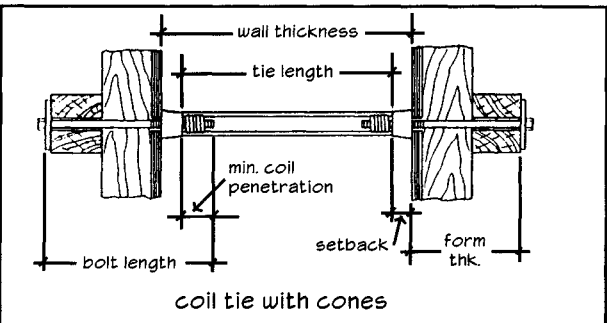
snap tie with cones



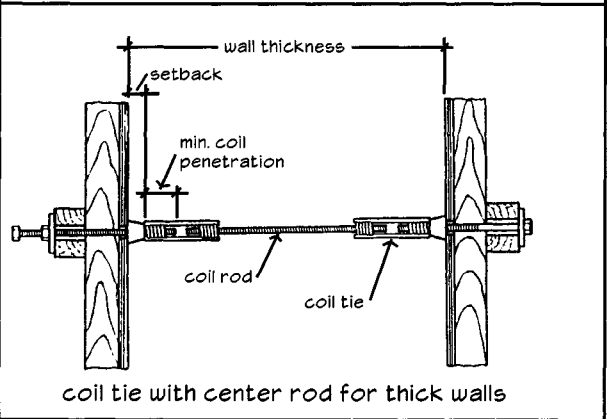
pull-out type snap tie



taper tie

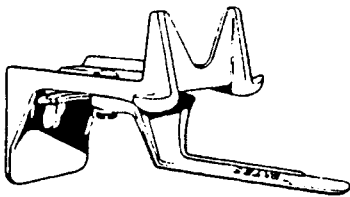


coil tie with cones

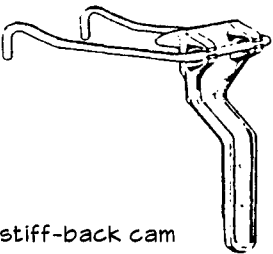


coil tie with center rod for thick walls

wall form ties
(From Dayton Superior Corporation.)



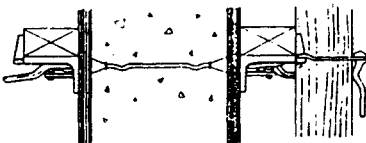
cam-lock bracket



stiff-back cam



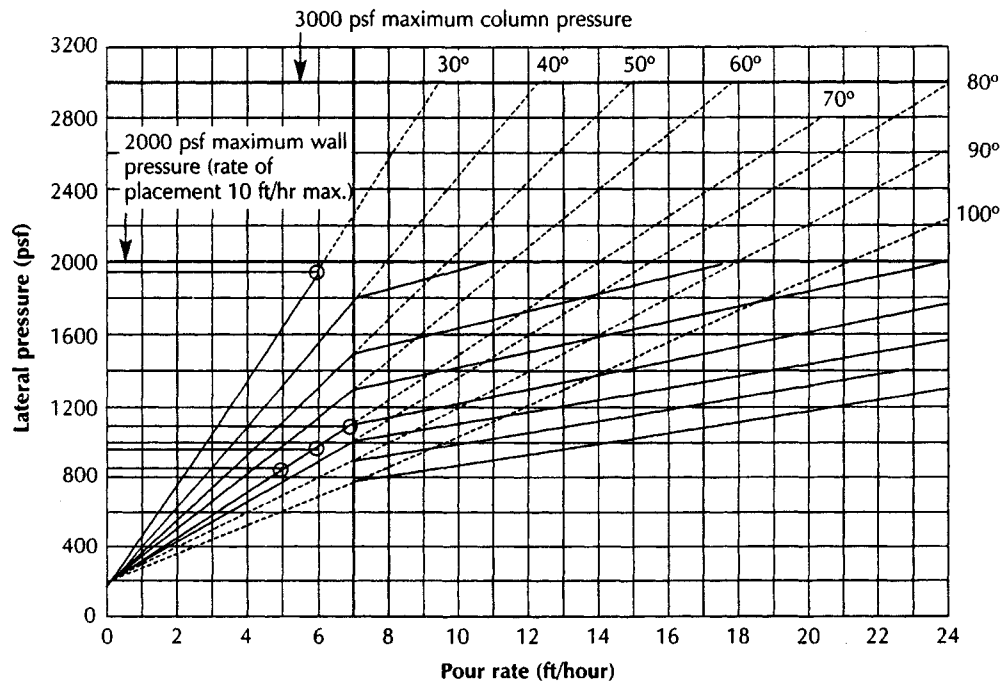
self-centering loop cone tie



cam-lock assembly with
loop cone ties

patented cam-lock hardware (From Gates & Sons, Inc.)

4.2.12 Concrete Pressure on Wall, Column, and Slab Forms



- Legend:**
- All walls & columns with pour rates less than 7 ft/hr.
 - Columns with pour rate greater than 7 ft/hr.

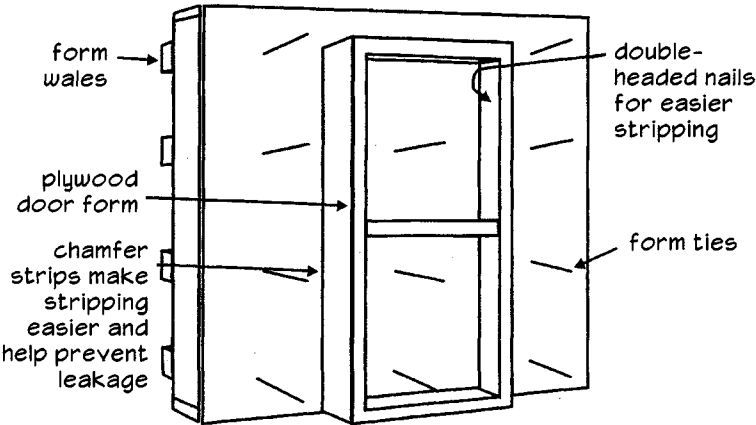
Based on concrete made with Type I portland cement weighing 150 pcf, containing no pozzolans or admixtures, having a slump of 4 in. or less, and placed with normal internal vibration to a depth of 4 ft. or less.

Lateral Pressure on Wall and Column Forms at Various Temperatures and Pour Rates

Vertical Concrete Pressures on Slab Forms		
Slab Thickness (in.)	Design Load (psf)	
	Non-Motorized Buggies	Motorized Buggies
4	100	125
5	113	138
6	125	150
7	138	163
8	150	175
9	163	188
10	175	200
12	200	225

(From American Concrete Institute.)

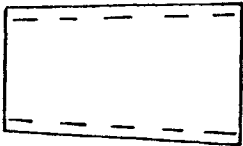
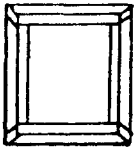
4.2.13 Form Openings and Blockouts



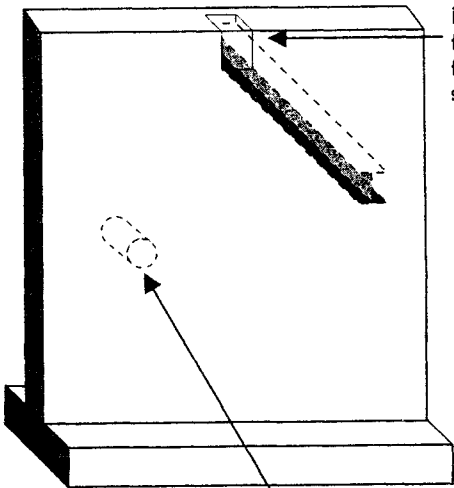
form for door opening



forms for small openings can be tapered for easy removal



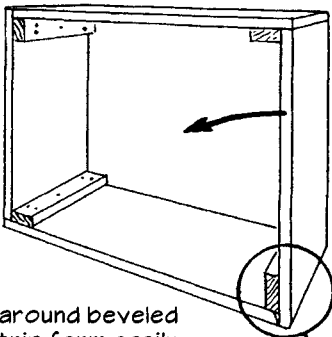
tapered forms



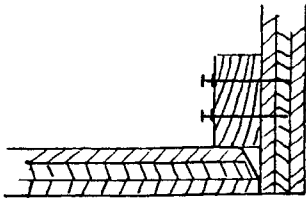
insert box or foam block in form for I-beam shelf

insert pvc pipe for plumbing and electrical penetrations

form penetrations



rotate around beveled end to strip form easily



window opening form

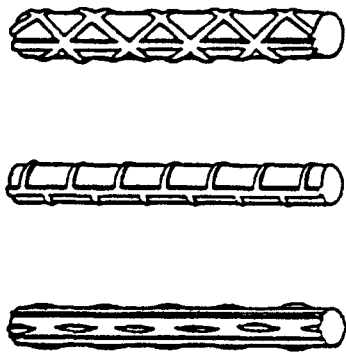
Reinforcement

- 5.1 Steel Reinforcing Bars**
 - 5.1.1 Reinforcing Bar Standards
 - 5.1.2 Reinforcing Bar Section Properties
 - 5.1.3 Required Development Lengths for Reinforcing Bars
 - 5.1.4 Steel Spirals for Reinforced Concrete Columns
 - 5.1.5 Typical Reinforcing Bar Welds
 - 5.1.6 Minimum Weld Length to Fully Develop Bar
 - 5.1.7 Reinforcing Bar Couplers
 - 5.1.8 Compression-Only Mechanical Connections
 - 5.1.9 Tension-Compression Mechanical Connections
- 5.2 Welded Wire Fabric Reinforcement**
 - 5.2.1 Welded Wire Fabric Reinforcement Sheets and Rolls
 - 5.2.2 Welded Wire Fabric Reinforcement Properties
 - 5.2.3 Structural Welded Wire Reinforcement Material Properties
- 5.3 Prestressing Wire, Strands, and Bars**
 - 5.3.1 ASTM A416 - Seven-Wire Prestressing Strand
 - 5.3.2 ASTM A779 - Stress-Relieved, Compacted Seven-Wire Prestressing Strand
 - 5.3.3 ASTM A886 - Stress-Relieved, Indented Seven-Wire Prestressing Strand
 - 5.3.4 ASTM A910 - Two-Wire and Three-Wire Prestressing Strand
 - 5.3.5 ASTM A722 - High-Strength Prestressing Bar
 - 5.3.6 ASTM A421 - Stress-Relieved Prestressing Wire
 - 5.3.7 Material Properties of Prestressing Steel
 - 5.3.8 Transfer and Development Length of Seven-Wire Uncoated Prestressing Strand
 - 5.3.9 Uncoated, Compacted, and Uncompacted Prestressing Strand
- 5.3.10 Prestressing Strand Elongation
- 5.4 Prefabricated Masonry Joint Reinforcement**
 - 5.4.1 Masonry Joint Reinforcement Standards
 - 5.4.2 Masonry Joint Reinforcement Selection Guide
- 5.5 Corrosion Protection**
 - 5.5.1 ASTM Standards for Corrosion Protection of Steel Reinforcing
 - 5.5.2 Maximum Chloride Ion Content for Corrosion Protection of Reinforcement
 - 5.5.3 Corrosion-Inhibiting Coatings for Prestressing Tendons
- 5.6 Fiber Reinforcement**
 - 5.6.1 Fiber Reinforcement for Concrete
 - 5.6.2 Glass Fiber Reinforcement
 - 5.6.3 Synthetic Fiber Reinforcement
 - 5.6.4 Aramid Fiber Reinforced Concrete Composites
 - 5.6.5 Natural Fiber Reinforcement

5.1.1 Reinforcing Bar Standards

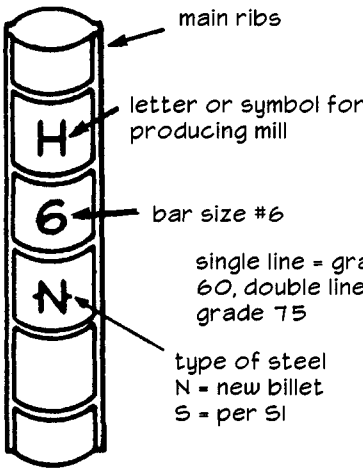
ASTM Standards for Steel Reinforcing Bars				
Type of Steel	Bar Sizes	Grade	Minimum Yield Strength (psi)	Minimum Tensile Strength (psi)
ASTM A615 Billet Steel	No. 3 through No. 6	40	40,000	70,000
	No. 3 through No. 11, 14 and 18	60	60,000	90,000
	No. 6 through 11, 14 and 18	75	75,000	100,000
ASTM A616 Rail Steel	No. 3 through No. 6	50	50,000	80,000
	No. 3 through No. 11, 14 and 18	60	60,000	90,000
ASTM A617 Axle Steel	No. 3 through No. 6	40	40,000	70,000
	No. 3 through No. 11, 14 and 18	60	60,000	90,000
ASTM A706 Low-Alloy Steels ^s	No. 3–11, 14 and 18	60	60,000	80,000

^s For low-alloy steel reinforcing bars, ASTM A706 prescribes a maximum yield strength of 78,000 psi and tensile strength must be 1.25 times the actual yield strength.

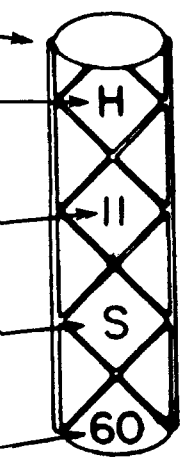
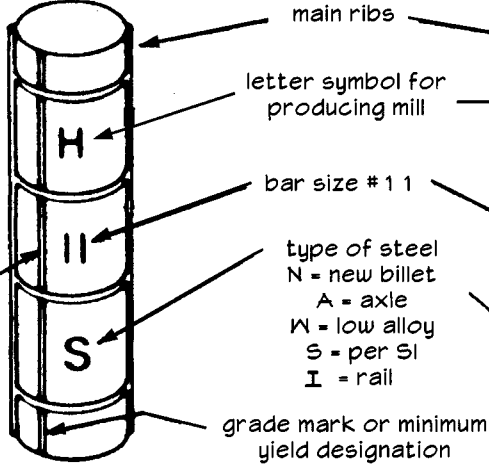


Most steel reinforcing bars used in concrete and masonry work have surface deformations which are designed to increase the mechanical bond between the steel and the concrete, mortar or grout. Some common styles of deformations are shown at left. Bar size designations are based on the nominal diameter of the bars in eighths of an inch. A No. 3 bar for example, has a 3/8 in. diameter, a No. 4 bar 4/8 or 1/2 in., and so on. Common bar sizes range from No. 3 to No. 18. ASTM A615, Grade 60, deformed steel bars are the most commonly used.

Reinforcing bars are identified with designations for the producing mill, the size and type of steel as shown on the examples below. Grades 60 and 75 must also have grade marks.



line system
grade marks

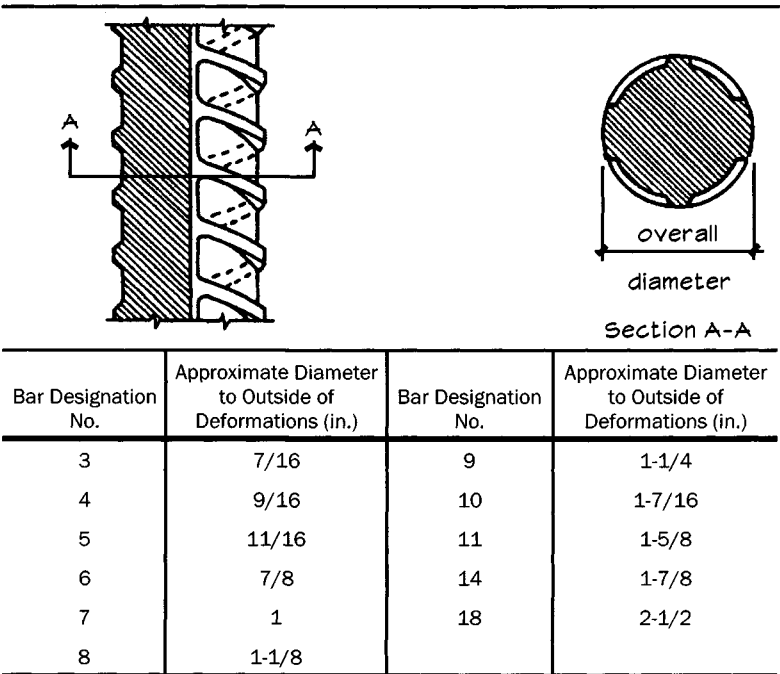


number system
grade marks

5.1.2 Reinforcing Bar Section Properties

Section Properties of Standard Deformed Steel Reinforcing Bars							
Bar Designation No.	Nominal Dimensions [§]			Nominal Weight (plf)	Deformation Requirements		
	Diameter (in.)	Cross-Sectional Area (sq.in.)	Perimeter (in.)		Maximum Average Spacing (in.)	Minimum Average Height (in.)	Maximum Gap (Chord of 12.5% of Nominal Perimeter)
3	0.375	0.11	1.178	0.376	0.262	0.015	0.143
4	0.500	0.20	1.571	0.668	0.350	0.020	0.191
5	0.625	0.31	1.963	1.043	0.437	0.028	0.239
6	0.750	0.44	2.356	1.502	0.525	0.038	0.286
7	0.875	0.60	2.749	2.044	0.612	0.044	0.334
8	1.000	0.79	3.142	2.670	0.700	0.050	0.383
9	1.128	1.00	3.544	3.400	0.790	0.056	0.431
10	1.270	1.27	3.990	4.303	0.889	0.064	0.487
11	1.410	1.56	4.430	5.313	0.987	0.071	0.540
14	1.693	2.25	5.320	7.650	1.185	0.085	0.648
18	2.257	4.00	7.090	13.600	1.58	0.102	0.864

§ Nominal dimensions of deformed bars are the same as a round bars having the same weight per foot as the deformed bar.
(From Manual of Standard Practice, Concrete Reinforcing Steel Institute, 1973)



(From Manual of Standard Practice, Concrete Reinforcing Steel Institute, 1973)

5.1.3 Required Development Lengths for Reinforcing Bars

Tension Development Length:

$$\ell_d = 2400 d_b / \sqrt{f'_c}; \text{ min. 12 in. (\#6 and smaller)}$$

$$\ell_d = 3000 d_b / \sqrt{f'_c}; \text{ min. 12 in. (\#7 and larger)}$$

(Note: for Grade 40 bars, replace 2400 and 3000 with 1600 and 2000 respectively.)

Multiply ℓ_d values by :

(a) 1.3 for lightweight concrete

(b) 1.3 for "top bars"

(c) 1.5 for epoxy coated bars with cover $< 3d_b$ or clear spacing $< 6d_b$, otherwise multiply by 1.2.

(Note: Product of factors (b) and (c) need not exceed 1.7)

(d) 1.5 for bars with less than minimum stirrups or ties, clear spacing less than $2d_b$ or clear cover less than d_b .

(e) A_s (required)/ A_s (provided) for excess reinforcement unless development of f_y is specifically required. This multiplier is not to be applied to lap splices per ACI 318-95, Sect. R12.15.1.

Compression Development Length:

$$\ell_d = 1200 d_b / \sqrt{f'_c}; \text{ min. } 18d_b \text{ and } 8 \text{ in.}$$

(Note: For Grade 40 bars, replace 1200 with 800 and 18 with 12)

Multiply ℓ_d values by :

(a) A_s (required)/ A_s (provided) for excess reinforcement

(b) 0.75 for adequate spiral or tie enclosure

(See ACI 12.3.3.2)

Compression Splice Lap Length:

Lap length = $30d_b$; min. 12 in.

The values of $\sqrt{f'_c}$ used in these equations shall not exceed 100 psi (See Sect. 12.1.2, ACI 318-95).

Bar Size	$f'_c = 3000 \text{ psi}$				$f'_c = 4000 \text{ psi}$				$f'_c = 5000 \text{ psi}$				$f'_c = 6000 \text{ psi}$				Min. Comp Splice
	Tension			Com-pres-sion	Tension			Com-pres-sion	Tension			Com-pres-sion	Tension			Com-pres-sion	
	ℓ_d	$1.3 \ell_d$	$1.5 \ell_d$	ℓ_d	ℓ_d	$1.3 \ell_d$	$1.5 \ell_d$	ℓ_d	ℓ_d	$1.3 \ell_d$	$1.5 \ell_d$	ℓ_d	ℓ_d	$1.3 \ell_d$	$1.5 \ell_d$	ℓ_d	
3	16	21	25	8	14	18	21	8	13	17	19	8	12	15	17	8	12
4	22	28	33	11	19	25	28	9	17	22	25	9	15	20	23	9	15
5	27	36	41	14	24	31	36	12	21	28	32	11	19	25	29	11	19
6	33	43	49	16	28	37	43	14	25	33	38	14	23	30	35	14	23
7	48	62	72	19	42	54	62	17	37	48	56	16	34	44	51	16	26
8	55	71	82	22	47	62	71	19	42	55	64	18	39	50	58	18	30
9	62	80	93	25	54	70	80	21	48	62	72	20	44	57	66	20	34
10	70	90	104	28	60	78	90	24	54	70	81	23	49	64	74	23	38
11	77	100	116	31	67	87	100	27	60	78	90	25	55	71	82	25	42

Bar Size	$f'_c = 7000 \text{ psi}$				$f'_c = 8000 \text{ psi}$				$f'_c = 9000 \text{ psi}$				$f'_c = 10,000 \text{ psi}$				Min. Comp Splice
	Tension			Com-pres-sion	Tension			Com-pres-sion	Tension			Com-pres-sion	Tension			Com-pres-sion	
	ℓ_d	$1.3 \ell_d$	$1.5 \ell_d$	ℓ_d	ℓ_d	$1.3 \ell_d$	$1.5 \ell_d$	ℓ_d	ℓ_d	$1.3 \ell_d$	$1.5 \ell_d$	ℓ_d	ℓ_d	$1.3 \ell_d$	$1.5 \ell_d$	ℓ_d	
3	12	14	16	8	12	13	15	8	12	12	14	8	9	12	14	8	12
4	14	19	22	9	13	17	20	9	13	16	19	8	12	16	18	8	15
5	18	23	27	11	17	22	25	11	16	21	24	8	15	20	23	8	19
6	22	28	32	14	20	26	30	14	19	25	28	9	18	23	27	9	23
7	31	41	47	16	29	38	44	16	28	36	42	11	26	34	39	11	26
8	36	47	54	18	34	44	50	18	32	41	47	13	30	39	45	12	30
9	40	53	61	20	38	49	57	20	36	46	54	14	34	44	51	14	34
10	46	59	68	23	43	55	64	23	40	52	60	16	38	49	56	15	38
11	51	66	76	25	47	61	71	25	45	58	67	17	41	54	62	17	42

a. For limitations and items related to hooked bars, stirrups or ties in excess of minimum, and spacing of non-contact lap splices, etc., see ACI 318-95, Chapter 12.

(From PCI Design Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)

5.1.4 Steel Spirals for Reinforced Concrete Columns

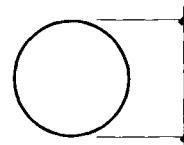
Recommended Core Diameters and Pitches of Standard Spirals

Outside core diam- eters ¹ inches	WIRE OR BAR SIZE									
	3/8" Ø or #3					1/2" Ø or #4			5/8" Ø or #5	
	Percentage of spiral reinforcement									
	1/2	3/4	1	1 1/2	2	1	1 1/2	2	1 1/2	2
	Pitch									
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
11					1 3/4					
12					1 3/4					
13				2 1/4	1 3/4					
14				2						
15			2 1/2	2				2 1/2		
16			2 3/4	1 3/4				2 1/2		
17			2 1/2	1 3/4				2 1/4		
18			2 1/2	1 3/4			3	2 1/4		
19		3	2 1/4				2 3/4	2		
20		3	2 1/4				2 1/2	2		3
21		2 3/4	2				2 1/2			3
22		2 3/4	2				2 1/2			2 3/4
23		2 1/2	2				2 1/4			2 3/4
24		2 1/2	1 3/4				2 1/4			2 1/2
25		2 1/4	1 3/4				2			2 1/2
26		2 1/4	1 3/4			3	2			2 1/4
27		2 1/4				3	2		3	2 1/4
28		2				2 3/4			3	2 1/4
29	3	2				2 3/4			2 3/4	2
30	3	2				2 1/2			2 3/4	2
31	2 3/4	2				2 1/2			2 3/4	2
32	2 3/4	1 3/4				2 1/2			2 1/2	2
33	2 3/4	1 3/4				2 1/2			2 1/2	
34	2 1/2	1 3/4				2 1/4			2 1/2	
35	2 1/2	1 3/4				2 1/4			2 1/4	
36	2 1/2					2 1/4			2 1/4	
37	2 1/4					2			2 1/4	
38	2 1/4					2			2 1/4	
39	2 1/4					2			2	

¹ The core diameter is identical to the outside diameter of the spiral with a tolerance of plus or minus one-half inch.

Minimum Requirements for Spacers Used to Maintain Proper Pitch of Spirals

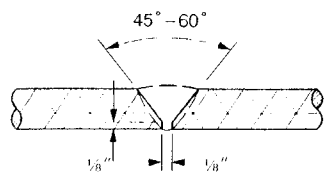
Section Modulus for Spiral Spacers		Number of Spacers per Spiral		
Spiral Wire or Bar Size	Min. Spacer Sect. Modulus (in. ³)	Spiral Wire or Bar Size	Spiral Core Diameter	Min. No. of Spacers
$\frac{3}{8}$ " \emptyset or #3	0.008	$\frac{3}{8}$ " \emptyset or #3	20 in. or less	2
$\frac{1}{2}$ " \emptyset or #4	0.030		21 to 30 in.	3
$\frac{5}{8}$ " \emptyset or #5 (up to 15 ft. high)	0.030	$\frac{1}{2}$ " \emptyset or #4	More than 30 in.	4
$\frac{5}{8}$ " \emptyset or #5 (over 15 ft. high)	0.050	$\frac{5}{8}$ " \emptyset or #5	24 in. or less	3
			More than 24 in.	4

Fabrication Tolerances for
Reinforcing Spirals

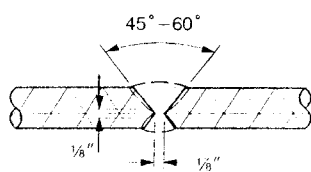
$\pm 1/2$ in. for diameters ≤ 30 in.
 ± 1 in. for diameters > 30 in.

(From Manual of Standard Practice, Concrete Reinforcing Steel Institute, 1973)

5.1.5 Typical Reinforcing Bar Welds



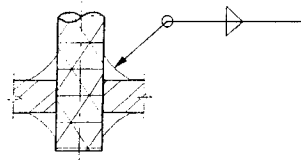
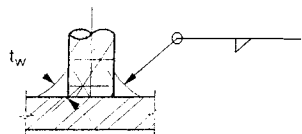
SINGLE V-GROOVE WELD



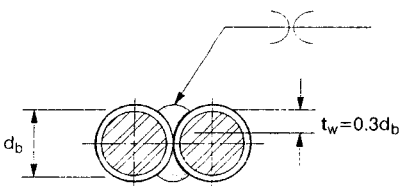
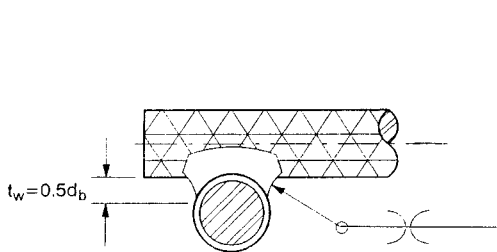
DOUBLE V-GROOVE WELD

FULL PENETRATION WELDS

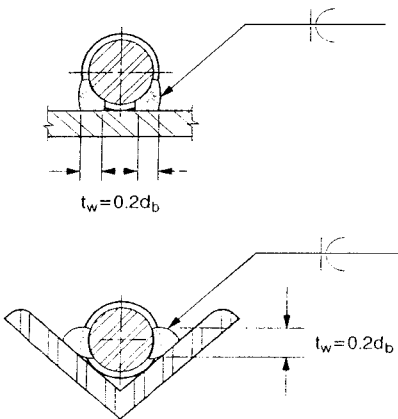
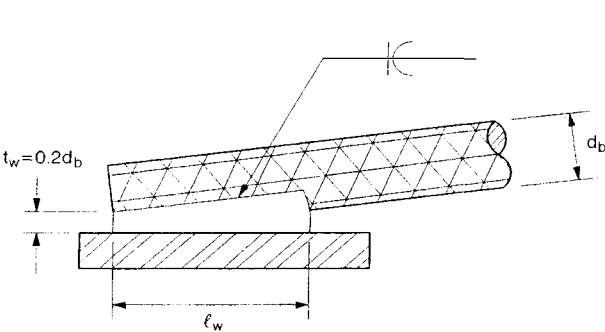
NOTE: AS SHOWN FOR #9 AND LARGER BARS. #8 AND SMALLER BARS REQUIRE APPROPRIATE BACKING.



FILLET WELDS



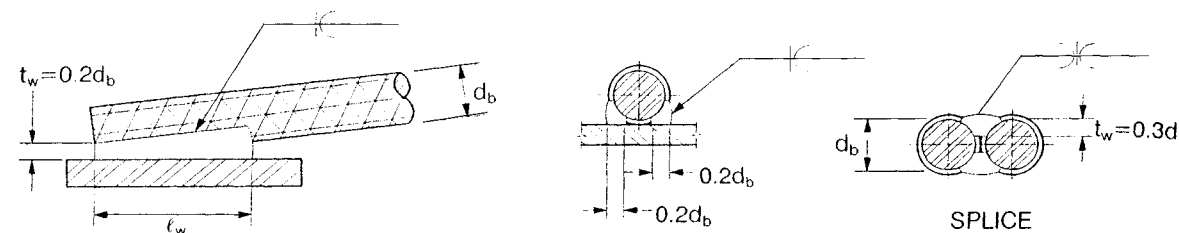
FLARE-V-GROOVE WELDS



FLARE-BEVEL-GROOVE WELDS

(From PCI Design handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)

5.1.6 Minimum Weld Length to Fully Develop Bar



Electrode	<div> <div>Plate thickness in.</div> <div>Bar size</div> </div>	Minimum length of weld, in. ^a					Min. splice length, in.
		1/4	5/16	3/8	7/16	1/2	
E70	3	1 1/2	1 1/2	1 1/2	1 1/2	1 1/2	1
	4	2	2	2	2	2	1 1/2
	5	2 1/2	2 1/2	2 1/2	2 1/2	2 1/2	1 3/4
	6	3	3	3	3	3	2
	7	3 1/4	3 1/4	3 1/4	3 1/4	3 1/4	2 1/4
	8	3 3/4	3 3/4	3 3/4	3 3/4	3 3/4	2 1/2
	9	4 3/4	4 1/4	4 1/4	4 1/4	4 1/4	3
	10	6	4 3/4	4 3/4	4 3/4	4 3/4	3 1/4
	11	7 1/4	5 3/4	5 1/4	5 1/4	5 1/4	3 1/2
E80	3	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4	1
	4	1 3/4	1 3/4	1 3/4	1 3/4	1 3/4	1 1/4
	5	2 1/4	2 1/4	2 3/4	2 1/2	2 1/2	1 1/2
	6	2 1/2	2 1/2	2 1/2	2 1/2	2 1/2	1 3/4
	7	3	3	3	3	3	2
	8	3 1/2	3 1/2	3 1/2	3 1/2	3 1/2	2 1/4
	9	4 3/4	3 3/4	3 3/4	3 3/4	3 3/4	2 1/2
	10	6	4 3/4	4 1/4	4 1/4	4 1/4	3
	11	7 1/2	5 3/4	5 3/4	4 3/4	4 3/4	3 3/4
E90	3	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4	1
	4	1 1/2	1 1/2	1 1/2	1 1/2	1 1/2	1
	5	2	2	2	2	2	1 1/4
	6	2 1/4	2 1/4	2 1/4	2 1/4	2 1/4	1 1/2
	7	3	2 3/4	2 3/4	2 3/4	2 3/4	1 3/4
	8	3 3/4	3	5	5	5	2
	9	4 1/4	3 1/4	3 1/2	3 1/2	3 1/2	2 1/4
	10	6	4 3/4	4	3 3/4	3 3/4	2 1/2
	11	7 1/4	5 3/4	5	4 1/4	4 1/4	2 3/4

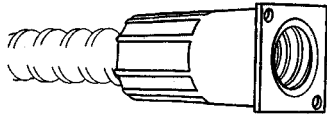
a. Lengths below heavy line are governed by plate shear. Lengths above heavy line are governed by weld strength.
 Basis: bar $f_y = 60$ ksi; plate $F_y = 36$ ksi; shear on net section limited to $0.75(0.6)(58)$ ksi.

(From PCI Design handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)

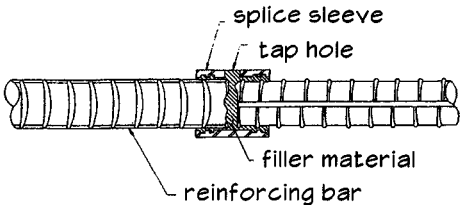
5.1.7 Reinforcing Bar Couplers



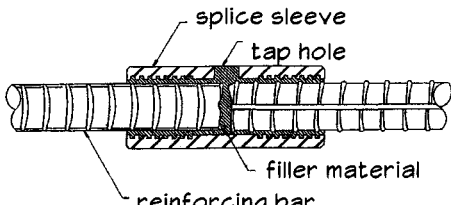
coupler for thread-deformed reinforcing bars



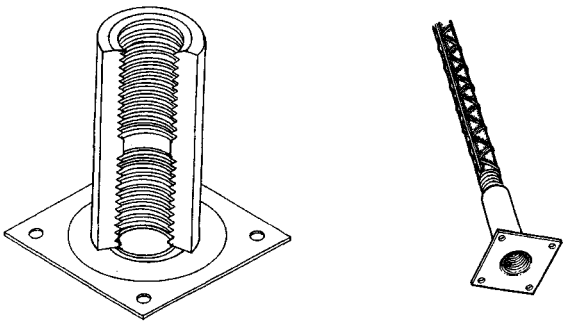
cold-swaged steel coupler with nail-on flange connector



steel-filled compression coupling sleeve



steel-filled tension-compression coupling sleeve



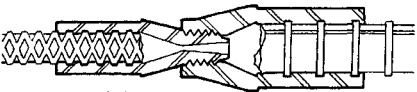
separate couplers with standard threads



two-piece

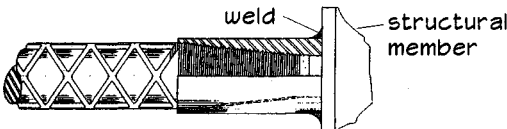


three-piece

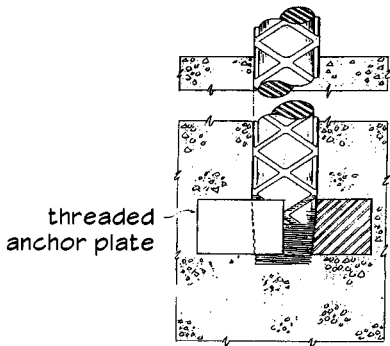


transition

cold-swaged steel coupling sleeves with threaded ends acting as a coupler

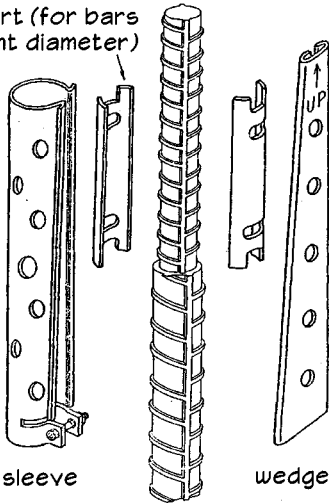


structural connection



reinforcing bar anchor
taper-threaded connections

reducer insert (for bars of different diameter)



wedge-locking coupling sleeve

(From ACI 439.3R-91, Mechanical Connections of Reinforcing Bars)

5.1.8 Compression-Only Mechanical Connections

Category	Item	Boiled Steel Sleeve		Steel-Filled Coupling Sleeve	Wedge-Locking Coupling Sleeve
		Solid-Type Steel Coupling Sleeve	Strap-Type Steel Coupling Sleeve		
Coupling sleeve	Bar size range	#8 through #18	#7 through #18	#11 through #18	#7 through #18
	Connects different bar sizes	yes	yes	yes	yes
Clear spacing required between adjacent connections	#18	1-1/2 bar dia.	1-1/2 bar dia.	1-1/2 bar dia.	1-1/2 bar dia.
	#14	1-1/2 bar dia.	1-1/2 bar dia.	1-1/2 bar dia.	1-1/2 bar dia.
	#11	1-1/2 bar dia.	1-1/2 bar dia.	1-1/2 bar dia.	1-1/2 bar dia.
#18 coupling sleeve installation requirements (normal)	Minimum dowel projection	6 in.	6 in.	1-7/8 in.	6 in.
	Coupling sleeve length	12 in.	12 in.	12 in.	12 in.
	Coupling sleeve maximum diameter/across corners	2-3/4 in.	4 in.	3-1/4 in.	2-3/4 in.
	Coupling sleeve side wall thickness (nominal)	nil	nil	5/16 in.	nil
Bar end preparations	Cut square within 1-1/2 degrees	yes	yes	no	yes
	Cleaning /special cleaning	no	no	remove concrete and loose rust	no
	Predrying / heating	no	no	yes	no
	Thread cutting / rolling	no	no	no	no
	Special coating removal (epoxy, zinc)	no	no	remove coatings 2-in. above sleeve	no
Installation tools	Hand-held tool adequate	yes	yes	no	yes
	Special tools required	no	no	yes	no
	Weather restrictions	no	no	bars must be dry	no
	Fire precaution	no	no	yes	no
	Ventilation required	no	no	yes	no

(From ACI 439.3R-91, Mechanical Connections of Reinforcing Bars)

5.1.9 Tension-Compression Mechanical Connections

Category	Item	Cold-Swaged Steel Coupling Sleeve	Cold-Swaged Coupling Sleeve With Threaded Ends Acting as a Coupler	Extruded Steel Coupling Sleeve	Hot-Forged Steel Coupling Sleeve	Grout-Filled Coupling Sleeve	Coupler for Thread-Deformed Reinforcing Bars	Steel-Filled Coupling Sleeve	Taper-Threaded Steel Coupler	Integrally-Forged Coupler With Upset NC Thread	Three-Piece Coupler With NC Thread	Steel Coupling Sleeve With Wedge [§]
Coupling sleeve/coupler	Bar size range	#3—#18	#3—#18	#5—#18	#5—#18	#5—#18	#6—#18	#4—#18	#4—#18	#4—#11	#4—#18 [†]	#3—#7
	Connects different bar sizes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	no
Clear spacing required between adjacent connections	#18	2-3/4 in.	1-1/2 in.	5-7/8 in.	1-1/2 d _b	4.72 in.	1-1/2 d _b	1-1/2 d _b	1-1/2 in.	NA	1-1/2 in.	NA
	#14	2-3/4 in.	1 in.	4-1/2 in.	1-1/2 d _b	3.90 in.	1-1/2 d _b	1-1/2 d _b	1-1/2 in.	NA	1 in.	NA
	#11	2 in.	1 in.	4-1/2 in.	1-1/2 d _b	3.50 in.	1-1/2 d _b	1-1/2 d _b	1-1/2 in.	1-1/2 in.	1 in.	NA
#18 sleeve/coupler installation req. (normal)	Minimum dowel projection	12 in.	None	21-3/4 in.	18 in.(v) 20 in.(h)	18 in.	4 & 7-1/2 in. [‡]	3-7/8 in.	3-1/2 in.	NA	4 in.	NA
	Sleeve/coupler length	12 in.	14 in.	12-1/4 in.	9 in.	36-1/4 in.	8 & 15 in. [‡]	7 in.	6-1/4 in.	NA	6 in.	NA
	Coupling sleeve/coupler max. dia. across corners	3-3/4 in.	3-5/8 in.	3-3/4 in.	4-1/4 in.	4-3/4 in.	3-1/2 in.	3-5/8 in.	3 in.	NA	3 in.	NA
	Coupling sleeve/coupler side wall thk. (nominal)	5/8 in.	9/16 in.	5/8 in.	1/2 in.	1/2 in.	5/8 in.	1/2 in.	min. 3/8 in.	NA	NA	NA
Bar end preparation	Cut square within 1-1/2 deg.	no	no	no	no	no	no/yes [†]	no	no	no	no	no
	Cleaning / special cleaning	no	no	no	Remove loose particles	no	no	Remove concrete, loose rust	no	no	no	no
	Predrying/heating	no	no	no	coupling sleeve	no	no	yes	no	no	no	no
	Thread cutting/rolling	no	no	no	no	no	no	no	yes ^{††}	no	yes	no
	Special coating removal (epoxy, zinc)	no	no	no	yes	no	no	no	no	no	no	no
Installation tools	Hand-held tools adequate	no	yes	no	no	yes	yes < #11 no > #11	no	yes	yes	yes	no
	Special tools required	yes	no	yes	yes	grout pump	yes	yes	no	no	no	hydraulic wedge driver
	Weather restrictions	no	no	no	bars must be dry	no	no	bars must be dry	no	no	no	no
	Fire precaution	no	no	no	yes	no	no	yes	no	no	no	no
	Ventilation required	no	no	no	no	no	no	yes	no	no	no	no

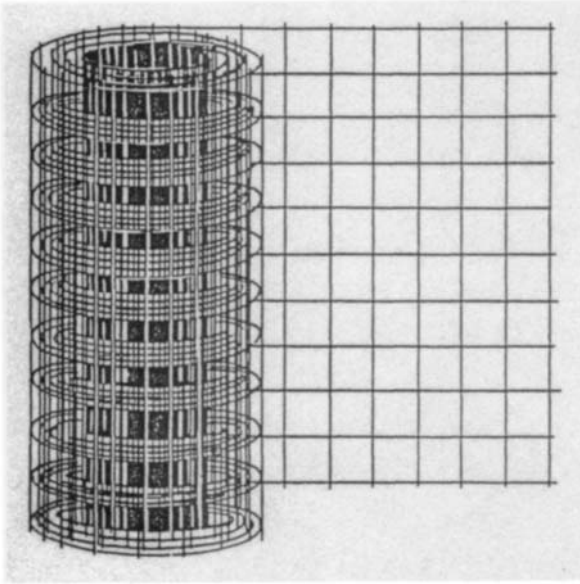
[§] Accepted for general use for tension-only, pending current experimental work in progress to evaluate the general applicability to connecting longitudinal reinforcement in compression.

[†] #4 through #14 meet ACI 318, Section 12.14.3.

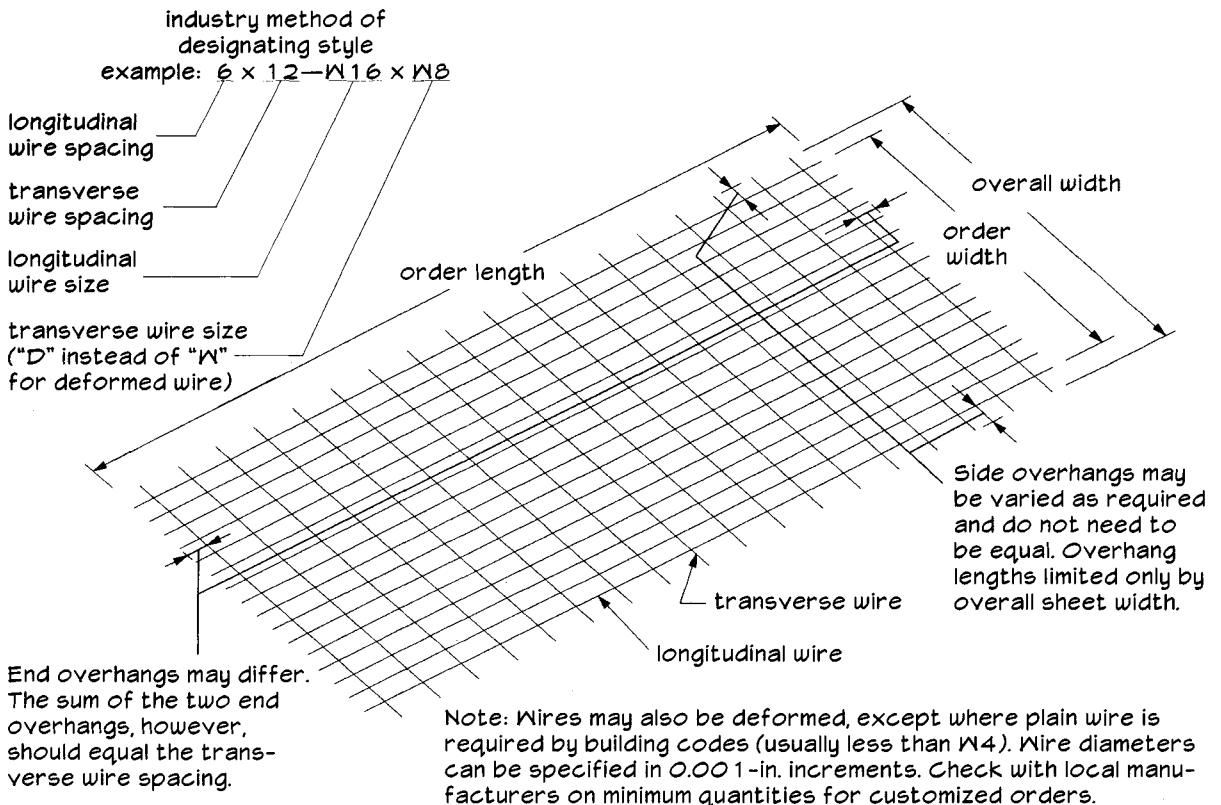
[‡] When jam nuts are used.

^{††} Bar-end threading normally done by bar fabricator.

5.2.1 Welded Wire Fabric Reinforcement Sheets and Rolls



- ASTM A 185—Plain Welded Wire Fabric Reinforcement
- ASTM A 497—Deformed Wire Welded Wire Fabric Reinforcement



(From PCI Design Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)

5.2.2 Welded Wire Fabric Reinforcement Properties

Common Styles of Plain Welded Wire Fabric				
Style Designation		Longitudinal Steel Area (sq.in/ft)	Transverse Steel Area (sq.in/ft)	Approximate Total Weight (lb/100 sq.ft)
Current Designation (by W-number)	Previous Designation (by steel wire gauge)			
Rolls				
6 x 6—W1.4 x W1.4	6 x 6—10 x 10	0.028	0.028	21
6 x 6—W2.0 x W2.0	6 x 6—8 x 8	0.040	0.040	30
6 x 6—W2.9 x W2.9	6 x 6—6 x 6	0.058	0.058	42
6 x 6—W4.0 x W4.0	6 x 6—4 x 4	0.080	0.080	58
4 x 4—W1.4 x W1.4	4 x 4—10 x 10	0.042	0.042	31
4 x 4—W2.0 x W2.0	4 x 4—8 x 8	0.060	0.060	44
4 x 4—W2.9 x W2.9	4 x 4—6 x 6	0.087	0.087	62
4 x 4—W4.0 x W4.0	4 x 4—4 x 4	0.120	0.120	85
Sheets				
6 x 6—W2.9 x W2.9	6 x 6—6 x 6	0.058	0.058	42
6 x 6—W4.0 x W4.0	6 x 6—4 x 4	0.080	0.080	58
6 x 6—W5.5 x W5.5	6 x 6—2 x 2	0.110	0.110	80
4 x 6—W4.0 x W4.0	4 x 4—4 x 4	0.120	0.080	85

(Adapted from PCI Design Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)

5.2.3 Structural Welded Wire Reinforcement Material Properties

Special Welded Wire Reinforcement for Double Tee Flanges				
Application	Style Designation	Steel Area in ² per ft		Approx. Weight lb per 100 ft ²
		Longit.	Trans.	
8-ft wide DT, 2-in. flange	12 X 6-W1.4 X W2.5	.014	.050	23
10-ft wide DT, 2-in. flange	12 X 6-W2.0 X W4.0	.020	.080	35
10-ft wide DT, 2½-in. flange	12 X 6-W1.4 X W2.9	.014	.058	27

Wires Used in Structural Welded Wire Reinforcement^a

Wire Size Number		Nominal Diameter in.	Nominal Weight plf	Area – in ² per ft of width						
Plain ^b	Deformed ^c			Center to Center Spacing, in.						
				2	3	4	6	8	10	12
W45	D45	0.757	1.530	2.70	1.80	1.35	.90	.625	.54	.45
W31	D31	0.628	1.054	1.86	1.24	.93	.62	.465	.372	.31
W30	D30	0.618	1.020	1.80	1.20	.90	.60	.45	.36	.30
W28	D28	0.597	.952	1.68	1.12	.84	.56	.42	.336	.28
W26	D26	0.575	.934	1.56	1.04	.78	.52	.39	.312	.26
W24	D24	0.553	.816	1.44	.96	.72	.48	.36	.288	.24
W22	D22	0.529	.748	1.32	.88	.66	.44	.33	.264	.22
W20	D20	0.504	.680	1.20	.80	.60	.40	.30	.24	.20
W18	D18	0.478	.612	1.08	.72	.54	.36	.27	.216	.18
W16	D16	0.451	.544	.96	.64	.48	.32	.24	.192	.16
W14	D14	0.422	.476	.84	.56	.42	.28	.21	.168	.14
W12	D12	0.390	.408	.72	.48	.36	.24	.18	.144	.12
W11	D11	0.374	.374	.66	.44	.33	.22	.165	.132	.11
W10.5	D10.5	0.366	.357	.63	.42	.315	.21	.157	.126	.105
W10	D10	0.356	.340	.60	.40	.30	.20	.15	.12	.10
W9.5	D9.5	0.348	.323	.57	.38	.285	.19	.142	.114	.095
W9	D9	0.338	.306	.54	.36	.27	.18	.135	.108	.09
W8.5	D8.5	0.329	.289	.51	.34	.255	.17	.127	.102	.085
W8	D8	0.319	.272	.48	.32	.24	.16	.12	.096	.08
W7.5	D7.5	0.309	.255	.45	.30	.225	.15	.112	.09	.075
W7	D7	0.298	.238	.42	.28	.21	.14	.105	.084	.07
W6.5	D6.5	0.288	.221	.39	.26	.195	.13	.097	.078	.065
W6	D6	0.276	.204	.36	.24	.18	.12	.09	.072	.06
W5.5	D5.5	0.264	.187	.33	.22	.165	.11	.082	.066	.055
W5	D5	0.252	.170	.30	.20	.15	.10	.075	.06	.05
W4.5	W4.5	0.240	.153	.27	.18	.135	.09	.067	.054	.045
W4	D4	0.225	.136	.24	.16	.12	.08	.06	.048	.04
W3.5		0.211	.119	.21	.14	.105	.07	.052	.042	.035
W3		0.195	.102	.18	.12	.09	.06	.045	.036	.03
W2.9		0.192	.098	.174	.116	.087	.058	.043	.035	.029
W2.5		0.178	.085	.15	.10	.075	.05	.037	.03	.025
W2.1		0.162	.070	.126	.084	.063	.042	.031	.025	.021
W2		0.159	.068	.12	.08	.06	.04	.03	.024	.02
W1.5		0.138	.051	.09	.06	.045	.03	.022	.018	.015
W1.4		0.135	.049	.084	.056	.042	.028	.021	.017	.014

a. Source: Manual of Standard Practice—Structural Welded Wire Reinforcement, Wire Reinforcement Institute, 1992, Findlay, Ohio.

b. ASTM A 82, Available $f_y=65,000$ psi to 80,000 psi in 2500 psi increments.c. ASTM A 496, Available $f_y=70,000$ psi to 80,000 psi in 2500 psi increments.

(From PCI Design Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)

5.3.1 **ASTM A416—Seven-Wire Prestressing Strand**

Nominal Diameter of Strand (in.)	Nominal Weight of Strand (plf)	Nominal Steel Area of Strand (sq.in.)	Minimum Breaking Strength (lb.)	Yield Strength	
				Minimum Normal Relaxation (lb.)	Minimum Low Relaxation (lb.)
Grade 250					
1/4	0.12	0.036	9,000	8,100	7,650
5/16	0.20	0.058	14,500	13,050	12,300
3/8	0.27	0.080	20,000	18,000	17,000
7/16	0.37	0.108	27,000	24,300	23,000
1/2	0.49	0.144	36,000	32,400	30,600
0.6	0.74	0.216	54,000	48,600	45,900
Grade 270					
3/8	0.29	0.085	23,000	20,700	19,550
7/16	0.40	0.115	31,000	27,900	26,350
1/2	0.52	0.153	41,300	37,170	35,100
0.6	0.74	0.217	58,600	52,740	49,800

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5.3.2 **ASTM A779—Stress-Relieved, Compacted Seven-Wire Prestressing Strand**

Nominal Diameter of Strand (in.)	Nominal Weight of Strand (lb/1000 ft.)	Nominal Steel Area of Strand (sq.in.)	Grade	Minimum Breaking Strength (lb.)	Yield Strength	
					Minimum Stress-Relieved (lb.)	Minimum Low-Relaxation (lb.)
0.5	600	0.174	270	47,000	40,900	42,300
0.6	873	0.256	260	67,400	58,700	60,690
0.7	1176	0.346	245	85,430	74,300	76,800

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5.3.3 ASTM A886—Stress-Relieved, Indented Seven-Wire Prestressing Strand

Nominal Diameter of Strand (in.)	Nominal Weight of Strand (lb/1000 ft.)	Nominal Steel Area of Strand (sq.in.)	Minimum Breaking Strength (lb.)
Grade 2501			
1/4	122	0.036	9,000
5/16	197	0.058	14,500
3/8	272	0.080	20,000
7/16	367	0.108	27,000
1/2	490	0.144	36,000
0.600	737	0.216	54,000
Grade 2701			
5/16	210	0.061	16,500
3/8	290	0.085	23,000
7/16	390	0.115	31,000
1/2	520	0.153	41,300
0.600	740	0.217	58,600

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5.3.4 ASTM A910—Two-Wire and Three-Wire Prestressing Strand

Description	Nominal Diameter (in.)	Nominal Weight of Strand (lb/1000 ft.)	Nominal Steel Area of Strand (sq.in.)	Minimum Breaking Strength (lb)
Grade 250				
2 x 0.114	0.228	69.9	0.020	5,000
3 x 0.089	0.189	63.3	0.019	4,750
3 x 0.095	0.205	71.9	0.021	5,250
3 x 0.114	0.244	104.0	0.031	7,750
3 x 0.118	0.256	112.0	0.033	8,250
3 x 0.138	0.295	153.0	0.045	11,250
3 x 0.158	0.340	200.6	0.058	14,500
Grade 270				
2 x 0.114	0.228	69.9	0.020	5,400
3 x 0.089	0.189	63.3	0.019	5,130
3 x 0.095	0.205	71.9	0.021	5,670
3 x 0.114	0.244	104.0	0.031	8,370
3 x 0.118	0.256	112.0	0.033	8,910
3 x 0.138	0.295	153.0	0.045	12,150
3 x 0.158	0.340	200.6	0.058	15,660

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5.3.5 **ASTM A722—High-Strength Prestressing Bar**

Nominal Diameter (in.)	Nominal Weight (lb/ft.)	Nominal Area (sq.in.)
Type I (Plain) Bar		
3/4	1.50	0.44
7/8	2.04	0.60
1	2.67	0.78
1-1/8	3.38	0.99
1-1/4	4.17	1.23
1-3/8	5.05	1.48
Type II (Deformed) Bar		
5/8	0.98	0.28
3/4	1.49	0.42
1	3.01	0.85
1-1/4	4.39	1.25
1-3/8	5.56	1.58

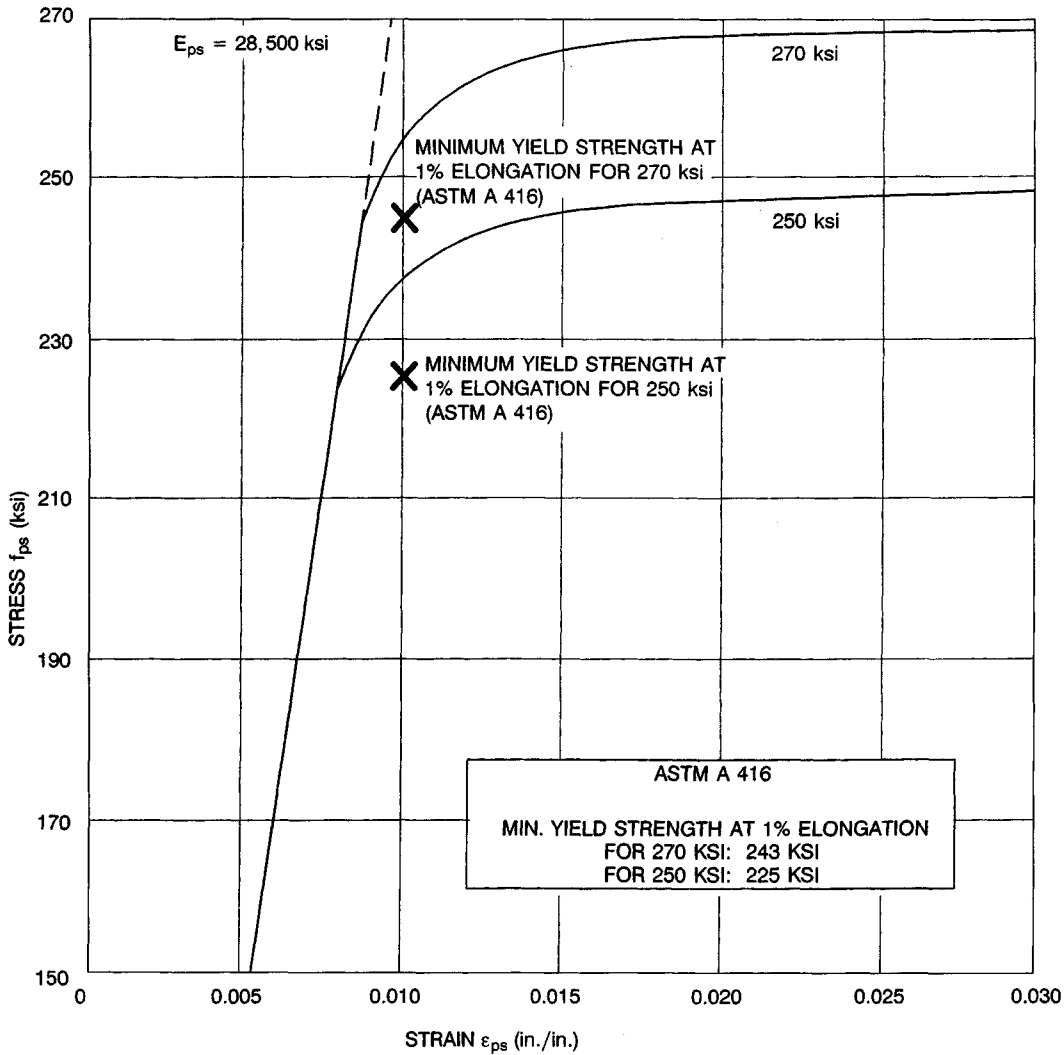
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5.3.6 **ASTM A421—Stress-Relieved Prestressing Wire**

Nominal Diameter (in.)	Nominal Weight (lb/ft)	Nominal Area (sq.in.)	Minimum Tensile Strength (psi)		Minimum Yield Strength (psi)			
			Type BA	Type WA	Stress-Relieved		Low-Relaxation	
					Type BA	Type WA	Type BA	Type WA
0.192	0.0983	0.02895	—	250,000	—	212,500	—	225,000
0.196	0.1025	0.02017	240,000	250,000	204,000	212,500	216,000	225,000
0.250	0.1667	0.04909	240,000	240,000	204,000	204,000	216,000	216,000
0.276	0.2032	0.05983	235,000	235,000	199,750	199,750	211,500	211,500

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5.3.7 Material Properties of Prestressing Steel



These curves can be approximated by the following equations:

250 ksi

270 ksi

$$\epsilon_{ps} \leq 0.0076 : f_{ps} = 28,500 \epsilon_{ps} \text{ (ksi)}$$

$$\epsilon_{ps} \leq 0.0086 : f_{ps} = 28,500 \epsilon_{ps} \text{ (ksi)}$$

$$\epsilon_{ps} > 0.0076 : f_{ps} = 250 - \frac{0.04}{\epsilon_{ps} - 0.0064} \text{ (ksi)}$$

$$\epsilon_{ps} > 0.0086 : f_{ps} = 270 - \frac{0.04}{\epsilon_{ps} - 0.007} \text{ (ksi)}$$

The ACI 318-95 (Sect. 12.9.1) equation^a for required development length may be rewritten as:

$$\ell_d = (f_{se}/3)d_b + (f_{ps} - f_{se})d_b$$

where:

ℓ_d = required development length, in.

f_{se} = effective prestress, ksi

f_{ps} = stress in prestressing steel at nominal strength, ksi

d_b = nominal diameter of strand, in.

The first term in the equation is the transfer length and the second term is the additional length required for the stress increase, $(f_{ps} - f_{se})$ corresponding to the nominal strength.

Transfer and development length^b in inches

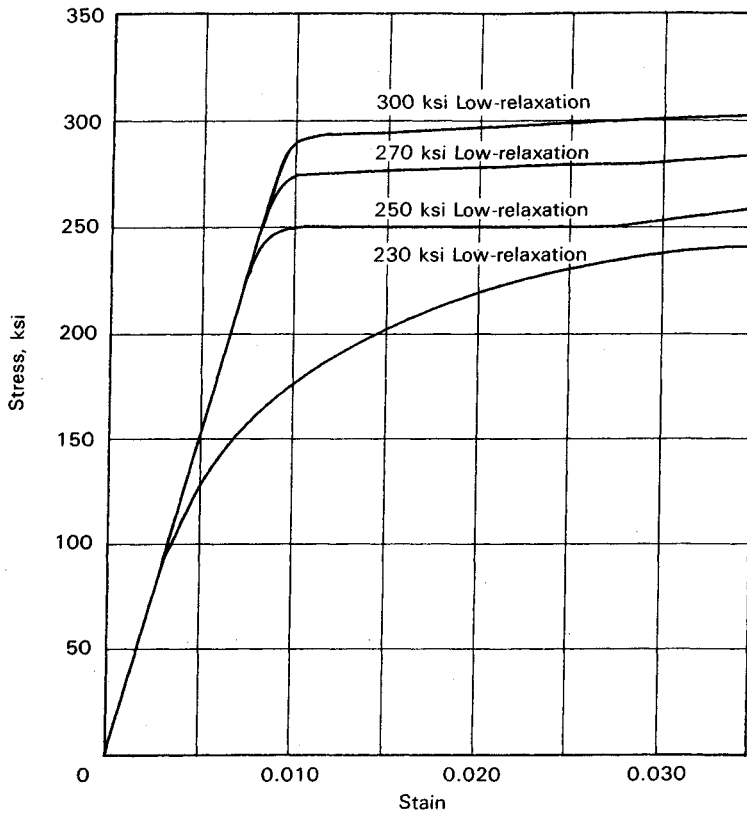
Nominal Diam- eter, in.	$f_{se} = 150 \text{ ksi}$					$f_{se} = 160 \text{ ksi}$					$f_{se} = 170 \text{ ksi}$				
	Transfer Length	Development Length				Transfer Length	Development Length				Transfer Length	Development Length			
		f_{ps} , ksi					f_{ps} , ksi					f_{ps} , ksi			
		240	250	260	270		240	250	260	270		240	250	260	270
$\frac{3}{8}$	18.8	52.5	56.3	60.0	63.8	20.0	50.0	53.8	57.5	61.3	21.3	47.5	51.3	55.0	58.8
$\frac{7}{16}$	21.9	61.3	65.6	70.0	74.4	23.3	58.3	62.7	67.0	71.4	24.8	55.4	59.8	64.2	68.5
$\frac{1}{2}$	25.0	70.0	75.0	80.0	85.0	26.7	66.7	71.7	76.7	81.7	28.3	63.3	68.3	73.3	78.3
$\frac{1}{2}$ S ^c	26.1	73.1	78.4	83.6	88.8	27.9	69.7	74.9	80.1	85.4	29.6	66.1	71.3	76.6	81.8
$\frac{9}{16}$	28.1	78.8	84.4	90.0	95.6	30.0	75.0	80.6	86.3	91.9	31.9	71.3	76.9	82.5	88.1
0.600	30.0	84.0	90.0	96.0	102.0	32.0	80.0	86.0	92.0	98.0	34.0	76.0	82.0	88.0	94.0

a. The ACI 318-95 equation was derived based on tests on $\frac{1}{4}$, $\frac{3}{8}$ and $\frac{1}{2}$ in. diameter strands. Its use for other sizes included in the table is based on inter/extrapolation as necessary. Research is underway to produce recommendations on transfer and development lengths for epoxy coated strand.

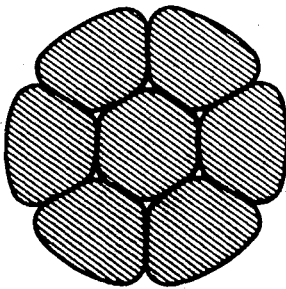
b. The development length values given in the table must be doubled where bonding of the strand does not extend to the member end and the member is designed such that tension in the precompressed tensile zone is produced under service loads (see ACI Code Sect. 12.9.3).

c. The $\frac{1}{2}$ in. special ($\frac{1}{2}$ S) strand has a larger nominal diameter than the $\frac{1}{2}$ in. regular ($\frac{1}{2}$) strand. The table values for transfer and development length reflect this difference in diameters.

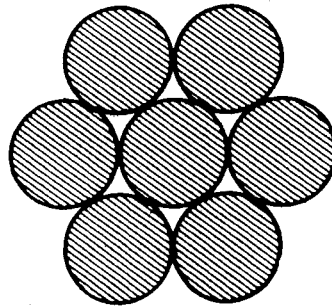
5.3.9 Uncoated, Compacted, and Uncompacted Prestressing Strand



Partial Stress-Strain Curves for Uncoated, Low-Relaxation Prestressing Strand of Different Grades Compared to Galvanized Strand



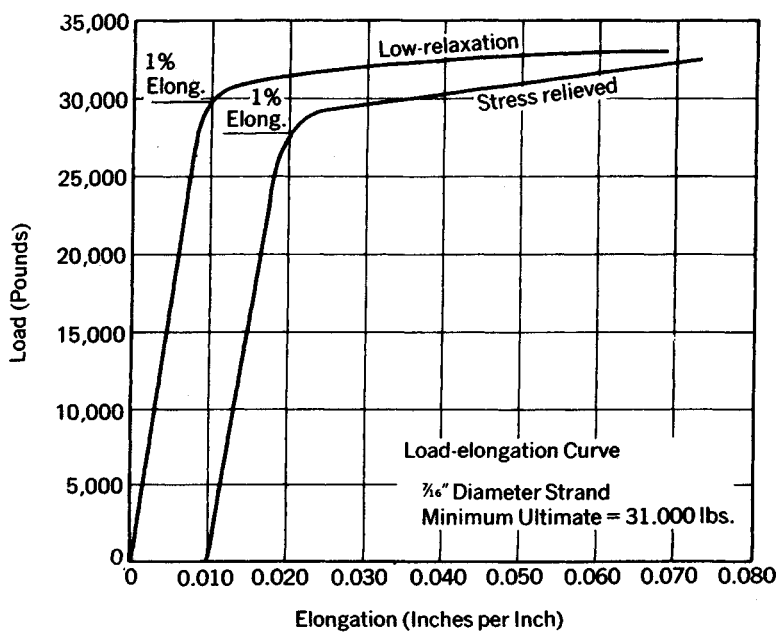
enlarged cross-section of compacted prestressing strand



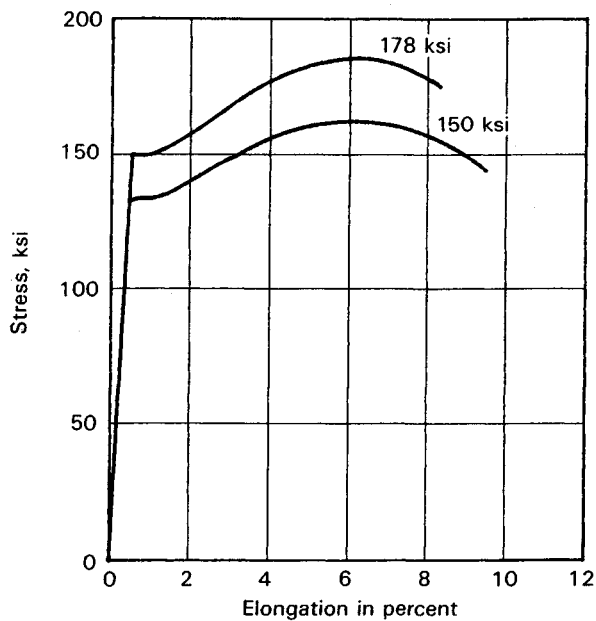
enlarged cross-section of typical 7-wire strand

comparison of cross-sections of compacted and uncompacted 7-wire strand

5.3.10 Prestressing Strand Elongation



Typical Load-Elongation Curves for 7/16 in. Diameter, Low-Relaxation and Stress-Relieved 7-Wire Prestressing Strands



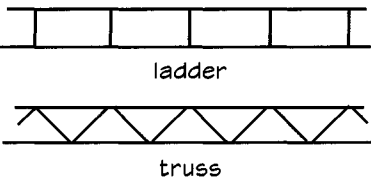
Typical Load-Strain Curves for Grade 150 and 178 Prestressing Bars

(From Libbey, Modern Prestressed Concrete Design Principles and Construction Methods, 4th ed.)

5.4.1 Masonry Joint Reinforcement Standards

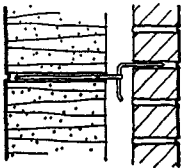
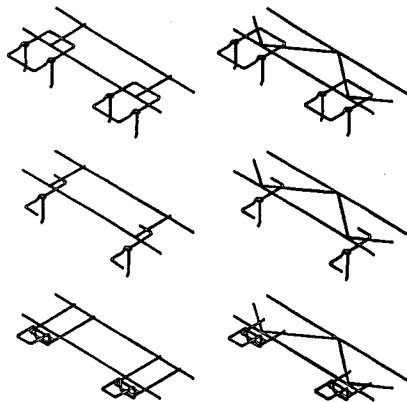
ASTM A951—Standard Specification for Masonry Joint Reinforcement
ASTM A82—Plain Steel Wire
ASTM A580—Stainless Steel Wire

ASTM Wire Size	Wire Gauge No.	Nominal Diameter (in.)	Nominal Area (sq.in.)	Nominal Perimeter (in.)	Weight (lb./ft.)	Tensile Strength	
						Yield (lb.)	Ultimate (lb.)
W1.1	11	0.1205	0.0114	0.379	0.0387	798	912
W1.7	9	0.1483	0.0173	0.466	0.0587	1,211	1,384
W2.1	8	0.1620	0.0206	0.509	0.0700	1,442	1,648
W2.8	3/16 in.	0.1875	0.0276	0.589	0.1250	1,932	2,228
W4.9	1/4 in.	0.2500	0.0491	0.785	0.1667	3,437	3,928



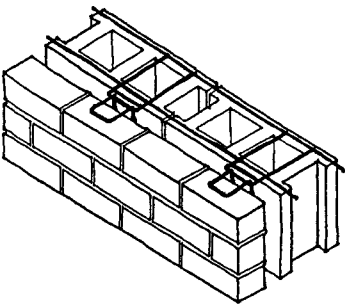
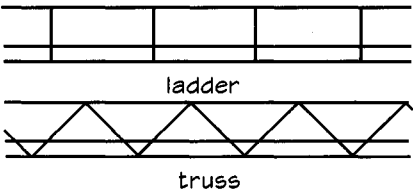
two-wire joint reinforcement for use in single-wythe walls

two-wire joint reinforcement with adjustable ties for use in multi-wythe walls

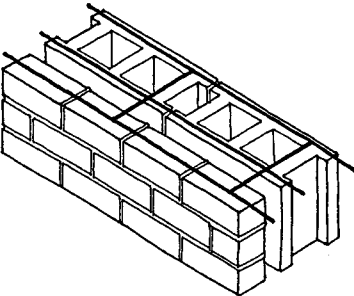
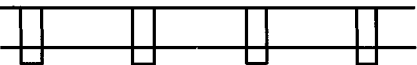


maximum vertical offset 1-1/4"
maximum horizontal play 1/16"

three-wire joint reinforcement for use in multi-wythe walls



two-wire joint reinforcement with fixed tabs for multi-wythe walls



5.4.2
Joint Reinforcement Selection Guide

Horizontal joint reinforcement is used to control shrinkage cracking in concrete masonry unit walls. It can also be used to tie the wythes of multi-wythe walls together, to bond intersecting walls, to assure maximum flexural wall strength against lateral loads, and as structural reinforcement. The basic types of joint reinforcement are shown on the previous page. Some designs are better for certain applications than others. The following guide summarizes the general recommendations for using various types of joint reinforcement in various applications.

Wall Configuration	2-Wire Ladder	2-Wire Truss	3-Wire Ladder	3-Wire Truss	2-Wire Ladder or Truss With Adjustable Ties	2-Wire Ladder or Truss With Fixed Tab Ties	2-Wire Ladder or Truss With Seismic Ties
Single-Wythe CMU <ul style="list-style-type: none"> with vertical reinforcing steel 	•						
Single-Wythe CMU <ul style="list-style-type: none"> without vertical reinforcing steel 		•					
Multi-Wythe Wall <ul style="list-style-type: none"> insulated cavity both wythes laid at same time backing and facing wythes both CMU 			•				
Multi-Wythe Wall <ul style="list-style-type: none"> uninsulated cavity both wythes laid at same time backing and facing wythes both CMU 			•	•			
Multi-Wythe Wall <ul style="list-style-type: none"> insulated cavity wythes laid at different times backing wythe CMU, facing wythe clay masonry or CMU 					•		
Multi-Wythe Wall <ul style="list-style-type: none"> uninsulated cavity both wythes laid at same time backing wythe CMU, facing wythe clay masonry 						•	
Multi-Wythe Wall <ul style="list-style-type: none"> both wythes laid at same time backing and facing wythes both CMU Seismic Performance Category C 			•	•			
Multi-Wythe Wall <ul style="list-style-type: none"> wythes laid at different times backing wythe CMU, facing wythe CMU or clay masonry Seismic Performance Category C 							•

5.5.1 ASTM Standards for Corrosion Protection of Steel Reinforcing

Steel reinforcement for concrete is usually protected against corrosion by embedding it within the concrete sufficiently so that it is not exposed to moisture from the air or from the soil. Epoxy-coated reinforcing bars are available for especially harsh or corrosive environments.

Masonry joint reinforcement is required by most codes to be galvanized for corrosion protection. The requirements may vary slightly among codes. Generally, for exterior walls and for interior walls exposed to a relative humidity of 75% or higher, joint reinforcement should be hot-dip galvanized after fabrication in accordance with ASTM A153—*Zinc Coating (Hot-Dipped) on Iron and Steel Hardware*, Class B2. For interior walls not exposed to the weather and exposed to lower interior humidity levels, joint reinforcement can usually be zinc-coated in accordance with ASTM A641—*Zinc Coated (Galvanized) Carbon Steel Wire*. Stainless steel joint reinforcement will provide the highest corrosion protection in severe exposures, and should conform to ASTM A580—*Stainless and Heat Resisting Steel Wire*, Type 304. Masonry construction also requires a minimum amount of mortar cover over the joint reinforcement to limit exposure to moisture.

For ASTM A641, the metal is normally galvanized before fabrication, so there is no zinc coating on sheared ends, at holes, or at welds. Since the metal is usually bent during fabrication, the coating thickness is also limited to prevent flaking when the metal is formed. For ASTM A153, articles are galvanized after fabrication, so the sheared ends and welds are protected as well.

Bonded tendons for prestressed concrete or masonry must be encapsulated in corrosion-resistant, watertight, grout-filled ducts of high-density polyethylene or polypropylene. Unbonded tendons must be coated with a material meeting code requirements and sheathed in an approved polyethylene or polypropylene protective covering. Stainless steel or ASTM A153 galvanized tendons are a code approved alternative, but the galvanized coating should not produce hydrogen embrittlement of the steel.

5.5.2 Maximum Chloride Ion Content for Corrosion Protection of Reinforcement

Type of Member	Maximum Water-Soluble Chloride Ion in Concrete, Mortar, or Grout (% by Weight of Cement)
Prestressed concrete (or masonry)	0.06
Reinforced concrete (or masonry) exposed to chloride in service	0.15
Reinforced concrete (or masonry) that will be dry or protected from moisture in service	1.00
Other reinforced concrete (or masonry) construction	0.30

(Adapted from International Building Code 2000 requirements for concrete construction.)

5.5.3 Corrosion-Inhibiting Coatings for Prestressing Tendons

Performance Specifications for Corrosion-Inhibiting Coatings for Prestressing Tendons		
Test	Test Method	Acceptance Criteria
Dropping point (°F)	ASTM D566 or ASTM D2265	minimum 300
Oil separation at 160°F (% by weight)	FTMS 791B, Method 321.2	maximum 0.5
Water (% maximum)	ASTM D95	0.1
Flash point of oil component (°F)	ASTM D92	minimum 300
Corrosion test 5% salt fog at 100°F, 5 mils, minimum hours (Q panel type S)	ASTM B117	For normal environments: rust grade 7 or better after 720 hours of exposure according to ASTM D610. For corrosive environments: rust grade 7 or better after 1000 hours of exposure according to ASTM D610 [§]
Water-soluble ions [†] (ppm maximum) chlorides nitrates sulfides	ASTM D512	10 ppm maximum 10 ppm maximum 10 ppm maximum
Soak test 5% salt fog at 100°F, 5 mils coating, Q panels, type S immerse panels 50% in a 5% salt solution and expose to salt fog	ASTM B117 (modified)	no emulsification of the coating after 720 hours of exposure
Compatibility with sheathing hardness and volume change of polymer after exposure to grease, 40 days at 150°F	ASTM D4289	15% permissible change in hardness 10% permissible change in volume
tensile strength change of polymer after exposure to grease, 40 days at 150°F	ASTM D638	30% permissible change in tensile strength

[§] Extension of exposure time to 1000 hours for greases used in corrosive environments requires use of more or better corrosion-inhibiting additives.

[†] Procedure: The inside (bottom and sides) of a 33.8 oz. Pyrex beaker, approximate outside diameter 4.1 in., height 5.7 in., is thoroughly coated with 35.3 ± 3.5 oz. corrosion-inhibiting coating material. The coated beaker is filled with approximately 30.4 oz. of distilled water and heated in an oven at a controlled temperature of 100°F ± 2°F for 4 hours. The water extraction is tested by the noted test procedures for the appropriate water-soluble ions. Results are reported as ppm in the extracted water.

(From MSJC Specification for Masonry Structures, ACI 530.1/ASCE 6/TMS 602)

5.6.1 Fiber Reinforcement for Concrete

Fibers made from metal or synthetic materials may be added to concrete to improve its performance. They are most commonly added to concrete to reduce early plastic shrinkage in slab-on-grade construction, to increase impact resistance, to increase abrasion resistance, and to improve toughness.

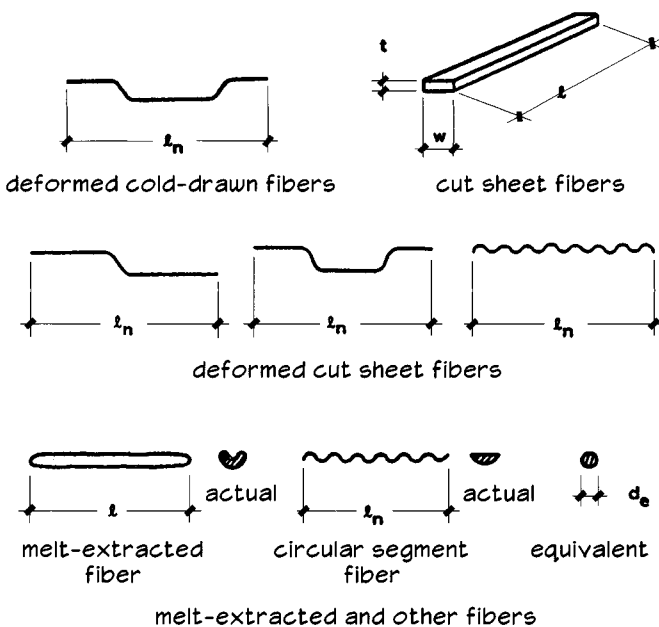
It is not appropriate to substitute fibers for primary structural reinforcement. Fibers are usually randomly oriented in the concrete, but may be oriented in two dimensions. The non-specific orientation makes them inefficient in providing tensile strength. The volume in which fibers may be added to the concrete is limited by the mixing equipment, workability, and finishing requirements. A sufficient volume cannot be added to completely replace steel reinforcing bars.

ASTM A820 *Standard Specification for Steel Fibers for Fiber-Reinforced Concrete* defines five types of fibers (see illustrations below left).

- Straight cold-drawn wire fibers
- Deformed cold-drawn wire fibers
- Cut sheet fibers
- Deformed cut sheet fibers
- Melt-extracted or other fibers

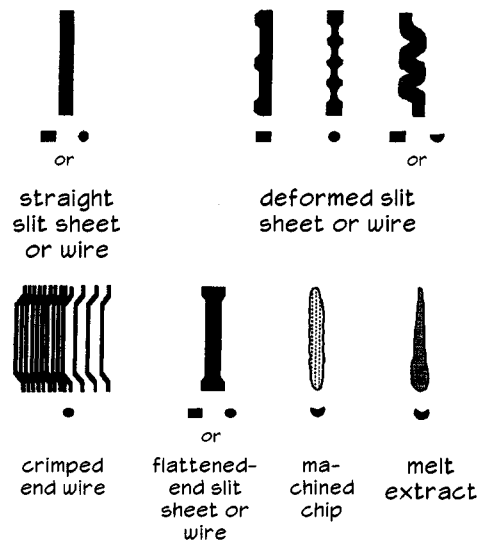
ACI 544.1 *State-of-the-Art Report on Fiber Reinforced Concrete* uses slightly different terminology for the steel fibers (below right).

In addition to steel, fibers of many other materials may be used to reinforce concrete. Common fiber materials are glass; synthetics, including acrylic, aramid, carbon, nylon, polyester, polyethylene, and polypropylene; and natural materials, ranging from coconut, jute, and elephant grass to wood fibers. Glass fiber reinforced concrete is known to lose strength and ductility over time, the rate of which is environment-dependent.



ASTM A820 steel fiber types

(From ASTM A820 Standard Specification for Steel Fibers for Fiber-Reinforced Concrete, Copyright ASTM, 100 Bar Harbor Drive, West Conshohocken, PA.)



ACI terminology for steel fiber geometries

(From ACI 544.1 State-of-the-Art Report on Fiber Reinforced Concrete)

5.6.2 Glass Fiber Reinforcement

Chemical Composition of Selected Glasses for Fiber Reinforcement				
Component	A-glass	E-glass	Cem-FIL AR-glass	NEG AR-glass
SiO ₂	73.0	54.0	62.0	61.0
Na ₂ O	13.0	—	14.8	15.0
CaO	8.0	22.0	—	—
MgO	4.0	0.5	—	—
K ₂ O	0.5	0.8	—	2.0
Al ₂ O ₃	1.0	15.0	0.8	—
Fe ₂ O ₃	0.1	0.3	—	—
B ₂ O ₃	—	7.0	—	—
ZrO ₂	—	—	16.7	20.0
TiO ₂	—	—	0.1	—
Li ₂ O	—	—	—	1.0

Properties of Selected Glasses for Fiber Reinforcement				
Property	A-Glass	E-Glass	Cem-FIL AR-Glass	NEG AR-Glass
Specific gravity	2.46	2.54	2.70	2.74
Tensile strength, ksi	450	500	360	355
Modulus of elasticity, ksi	9400	10,400	11,600	11,400
Strain at break, percent	4.7	4.8	3.6	2.5

(From ACI 544.1 State-of-the-Art Report on Fiber Reinforced Concrete)

Selected Synthetic Fiber Types and Properties*

Fiber type	Equivalent diameter, in. x 10 ⁻³	Specific gravity	Tensile strength, ksi	Elastic modulus, ksi	Ultimate elongation, percent	Ignition temperature, degrees F	Melt, oxidation, or decomposition temperature, degrees F	Water absorption per ASTM D 570, percent by weight
Acrylic	0.5-4.1	1.16-1.18	39-145	2000-2800	7.5-50.0	—	430-455	1.0-2.5
Aramid I	0.47	1.44	425	9000	4.4	high	900	4.3
Aramid II†	0.40	1.44	340	17,000	2.5	high	900	1.2
Carbon, PAN HM‡	0.30	1.6-1.7	360-440	55,100	0.5-0.7	high	752	nil
Carbon, PAN HT§	0.35	1.6-1.7	500-580	33,400	1.0-1.5	high	752	nil
Carbon, pitch GP**	0.39-0.51	1.6-1.7	70-115	4000-5000	2.0-2.4	high	752	3-7
Carbon, pitch HP††	0.35-0.70	1.80-2.15	220-450	22,000-70,000	0.5-1.1	high	932	nil
Nylon‡‡	0.90	1.14	140	750	20	—	392-430	2.8-5.0
Polyester	0.78	1.34-1.39	33-160	2500	12-150	1100	495	0.4
Polyethylene‡‡	1.0-40.0	0.92-0.96	11-85	725	3-80	—	273	nil
Polypropylene‡‡	—	0.90-0.91	20-100	500-700	15	1100	330	nil

*Not all fiber types are currently used for commercial production of FRC.

†High modulus.

‡Polyacrylonitrile based, high modulus.

§Polyacrylonitrile based, high tensile strength.

**Isotropic pitch based, general purpose.

††Mesophase pitch based, high performance.

‡‡Data listed is only for fibers commercially available for FRC.

Metric equivalents: 1 in. = 25.4 mm; 1 ksi = 6.895 MPa; (degrees F - 32)/1.8 = degrees C.

(From ACI 544.1 State-of-the-Art Report on Fiber Reinforced Concrete)

5.6.4 Aramid Fiber Reinforced Concrete Composites

Material Properties of Aramid Fiber Reinforced Concrete Properties

Curing/aging conditions		Tensile properties					Bending properties				Impact strength, ft-lb/in. ²
		UTS stress, psi	UTS strain, percent	PEL stress, psi	PEL strain, millionths	Young's Modulus, ksi	MOR stress, psi	PEL stress, psi	PEL strain, millionths	Modulus of elasticity, ksi	
Water 68 F	28 days	2335	1.53	1285	318	4045	6440	2235	891	2900	8.1
	180 days	2175	1.28	1340	252	5380	6440	2365	773	3115	7.0
	2 years	1970	1.08	1030	210	4915	6310	2565	850	3250	5.7
Air 68 F	180 days	2088	1.79	1050	265	3990	6775	1825	853	2235	8.4
	2 years	2146	1.69	554	167	3495	6585	1395	587	2540	10.5
Weather	2 years	2088	1.40	685	168	4105	6315	2275	768	3205	6.7
Water 140 F	7 days	2130	1.24	1295	258	4945	5730	1915	713	2725	8.1
	50 days	2390	1.26	1045	230	4555	6020	1855	785	2320	5.9
	180 days	1780	1.11	910	185	4915	5540	2305	710	3320	5.2
Air 300 F	7 days	1900	1.69	1075	348	3335	4990	1985	1300	1665	7.1
	45 days	1755	1.91	530	252	2335	5455	1990	964	2405	9.5
Autoclave 180 F	16 hrs	1365	1.14	805	212	3990	3610	1915	1290	1535	7.5
Control	28 days	1940	1.41	1110	283	3930	5280	1740	883	1985	10.9

Metric equivalents: 1 ksi = 1000 psi = 6.895 MPa; 1 ft-lb/in² = 2.102 kJ/m²; (deg F-32)/1.8 = deg C.

(From ACI 544.1 State-of-the-Art Report on Fiber Reinforced Concrete)

5.6.5 Natural Fiber Reinforcement

Typical Properties of Natural Fibers

Fiber type	Coconut	Sisal	Sugar cane Bagasse	Bamboo	Jute	Flax	Elephant grass	Water reed	Plantain	Musamba	Wood fiber (kraft pulp)
Fiber length, in.	2-4	N/A	N/A	N/A	7-12	20	N/A	N/A	N/A	N/A	0.1-0.2
Fiber diameter, in.	0.004-0.016	N/A	0.008-0.016	0.002-0.016	0.004-0.008	N/A	N/A	N/A	N/A	N/A	0.001-0.003
Specific gravity	1.12-1.15	N/A	1.2-1.3	1.5	1.02-1.04	N/A	N/A	N/A	N/A	N/A	1.5
Modulus of elasticity, ksi	2750-3770	1880-3770	2175-2750	4780-5800	3770-4640	14,500	710	750	200	130	N/A
Ultimate tensile strength, psi	17,400-29,000	40,000-82,400	26,650-42,000	50,750-72,500	36,250-50,750	145,000	25,800	10,000	13,300	12,000	101,500
Elongation at break, percent	10-25	3-5	N/A	N/A	1.5-1.9	1.8-2.2	3.6	1.2	5.9	9.7	N/A
Water absorption, percent	130-180	60-70	70-75	40-45	N/A	N/A	N/A	N/A	N/A	N/A	50-75

Note: N/A = properties not readily available or not applicable.

Mechanical Properties of Several Types of Natural Fibers

Type of fiber	Average diameter, in.	Average length, in.	Absorption after 24 hr, percent	Average fiber density (SG)	Average tensile strength, psi	Average bonding strength, psi	Average elongation, percent
Bagasse	0.020	1.38	122.5	0.639	3,570	36	N/A
Coconut	0.027	11.02	58.5	0.580	8,825	40	2.600
Jute	0.004	15.75	62.0	1.280	53,500	20	N/A
Maguey	0.014	15.75	63.0	1.240	54,400	N/A	N/A
Lechuguilla	0.014	15.75	102.0	1.360	54,100	N/A	N/A
Banana	0.011	3.70	276.0	0.298	10,960	35	3.000
Guaney (palm)	0.017	17.44	129.9	1.195	50,000	40	2.880
Bamboo	Variable	Variable	51.0	0.720	54,680	45	1.800

Note: N/A = Not available

(From ACI 544.1 State-of-the-Art Report on Fiber Reinforced Concrete)

Accessories

6.1 Masonry Connectors

- 6.1.1 ASTM Standards for Metals Used in Concrete and Masonry Accessories
- 6.1.2 Sheet Metal Properties
- 6.1.3 Steel Wire Properties
- 6.1.4 Rigid Masonry Ties
- 6.1.5 Adjustable Masonry Ties
- 6.1.6 Masonry-To-Steel Veneer Anchors
- 6.1.7 Masonry-To-Concrete Veneer Anchors
- 6.1.8 Masonry-To-Stud Veneer Anchors
- 6.1.9 Seismic Veneer Anchors
- 6.1.10 Retrofit Veneer Anchors
- 6.1.11 Stone Cladding Anchors
- 6.1.12 Anchor Bolts for Masonry
- 6.1.13 Masonry Fasteners

6.2 Reinforcing Bar Supports and Positioners

- 6.2.1 Steel Wire Bar Supports for Concrete Reinforcement
- 6.2.2 Plastic Bar Supports for Concrete Reinforcement
- 6.2.3 Precast Concrete Bar Supports for Concrete Reinforcement
- 6.2.4 Bar Positioners for Masonry Reinforcement

6.3 Concrete Connectors

- 6.3.1 Threaded Rods and Anchor Bolts for Concrete
- 6.3.2 Nuts for Threaded Rods and Anchor Bolts
- 6.3.3 Anchor Bolt Head Dimensions
- 6.3.4 Coil Bolts and Threaded Coil Rods for Concrete
- 6.3.5 Threaded Inserts for Concrete
- 6.3.6 Expansion Inserts for Concrete
- 6.3.7 Steel Embedments, Headed Anchor Studs, and Deformed Bar Anchors
- 6.3.8 Welding of Steel Embedments and Reinforcement
- 6.3.9 Weld Symbols
- 6.3.10 Sand-Cement Grout, Epoxy, and Epoxy Grout

- 6.3.11 Bearing Pads for Concrete and Masonry
- 6.3.12 Miscellaneous Concrete Anchors and Fasteners
- 6.3.13 GFRC Connectors

6.4 Corrosion Protection

- 6.4.1 Corrosion Protection for Masonry Accessories
- 6.4.2 Life Expectancy of Galvanized Coatings
- 6.4.3 Galvanic Series of Metals
- 6.4.4 Compatibility of Metals

6.5 Flashing and Weep Accessories

- 6.5.1 Flashing Types and Properties
- 6.5.2 Self-Flashing Concrete Masonry Unit
- 6.5.3 Weep Accessories
- 6.5.4 Drainage Accessories

6.1.1 ASTM Standards for Metals Used in Concrete and Masonry Accessories

Function	ASTM Specification		Minimum Yield Strength (psi)	Minimum Tensile Strength (psi)
Wire ties and anchors	ASTM A82	Cold-Drawn Steel Wire for Concrete Reinforcement	70,000	80,000
	ASTM A580	Stainless and Heat-Resisting Wire	30,000	75,000
Sheet metal ties and anchors	ASTM A366	Cold-Rolled Carbon Steel Sheet, Commercial Quality	—	—
	ASTM A525	General Requirements for Steel Sheet, Zinc-Coated (Galvanized) by the Hot-Dip Process (Class G60)	30,000	75,000
	ASTM A167	Stainless and Heat-Resisting Chromium-Nickel Steel Plate, Sheet and Strip		
Anchor bolts	ASTM A307	Carbon Steel Bolts and Studs (Grade A)	—	—
Plate and bent bar anchors	ASTM A666	Austenitic Stainless Steel Sheet, Strip, Plate and Flat Bar for Structural Applications	30,000	75,000
Rolled shapes, lintels, and plate and bent bar anchors	ASTM A36	Carbon Structural Steel	36,000	58,000 to 80,000

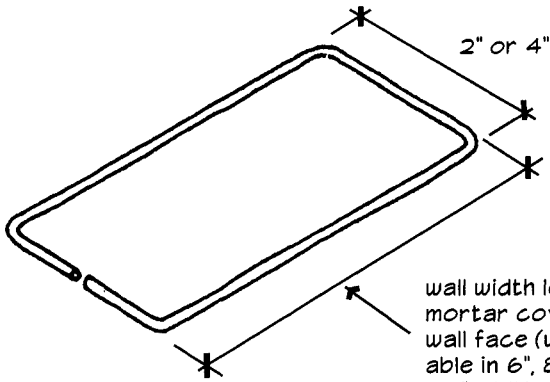
6.1.2 Sheet Metal Properties

Gauge	Thickness (in.)	Weight (oz/sq.ft.)
10	0.1345	90
12	0.1046	70
14	0.0747	50
16	0.0598	40
18	0.0478	32
20	0.0359	24
22	0.0299	20
24	0.0239	16
26	0.0179	12
30	0.0149	10

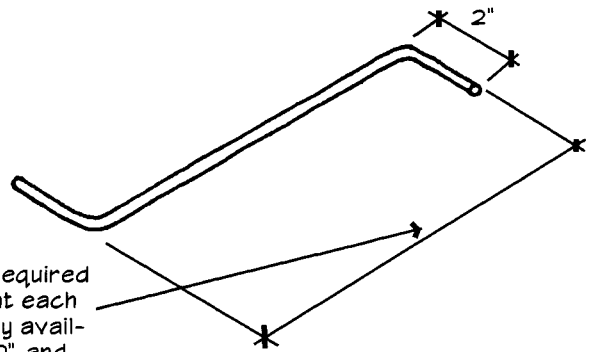
6.1.3 Steel Wire Properties

ASTM Wire Size	Wire Gauge No.	Nominal Diameter (in.)	Nominal Area (sq.in.)	Nominal Perimeter (in.)	Weight (lb/ft.)	Tensile Strength	
						Yield (lb.)	Ultimate (lb.)
W1.1	11	0.1205	0.0114	0.379	0.0387	798	912
W1.7	9	0.1483	0.0173	0.466	0.0587	1,211	1,384
W2.1	8	0.1620	0.0206	0.509	0.0700	1,442	1,648
W2.8	3/16 in.	0.1875	0.0276	0.589	0.1250	1,932	2,228
W4.9	1/4 in.	0.2500	0.0491	0.785	0.1667	3,437	3,928

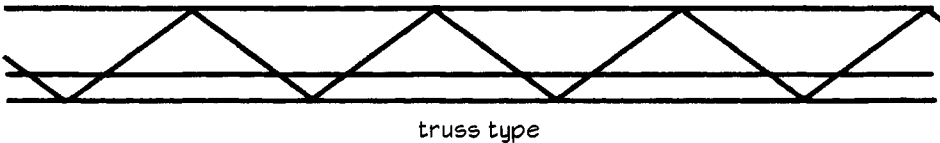
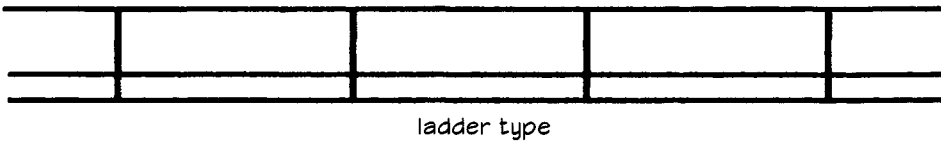
6.1.4 Rigid Masonry Ties



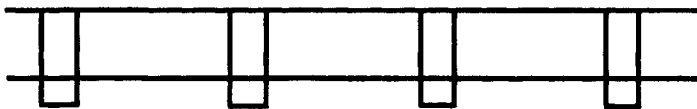
rigid rectangular wire tie, 3/16" diameter wire, used to connect wythes of hollow masonry units



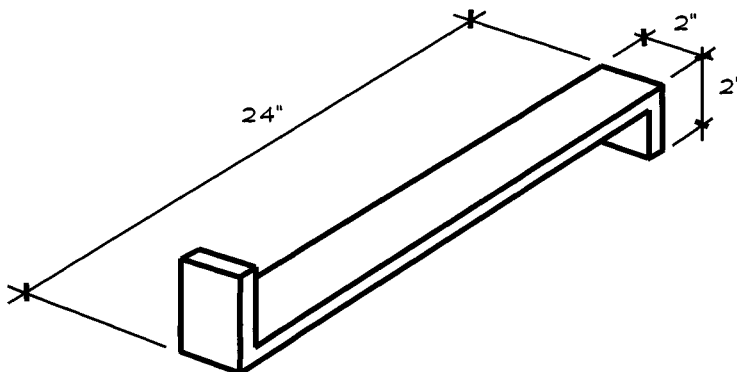
rigid wire "Z" tie, 3/16" diameter wire, used to connect wythes of solid masonry units



three-wire joint reinforcement used to connect CMU backing wythe to CMU facing wythe

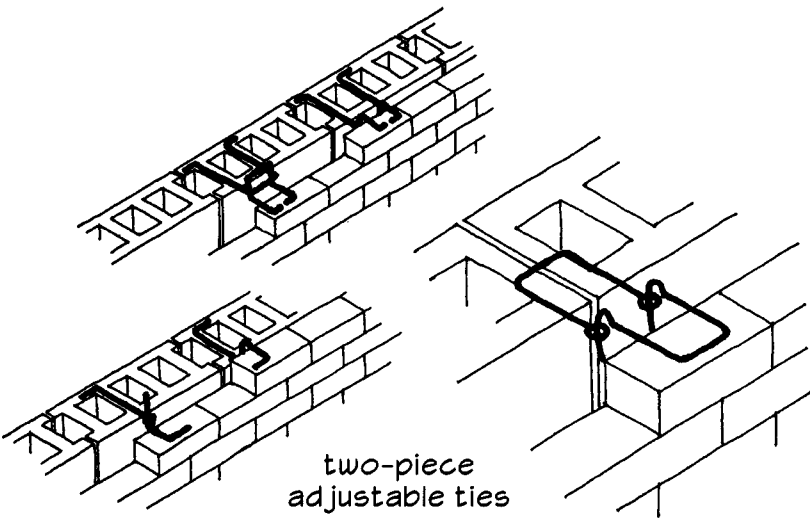


two-wire joint reinforcement used to connect CMU backing wythe to clay masonry facing wythe in uninsulated or solidly grouted walls

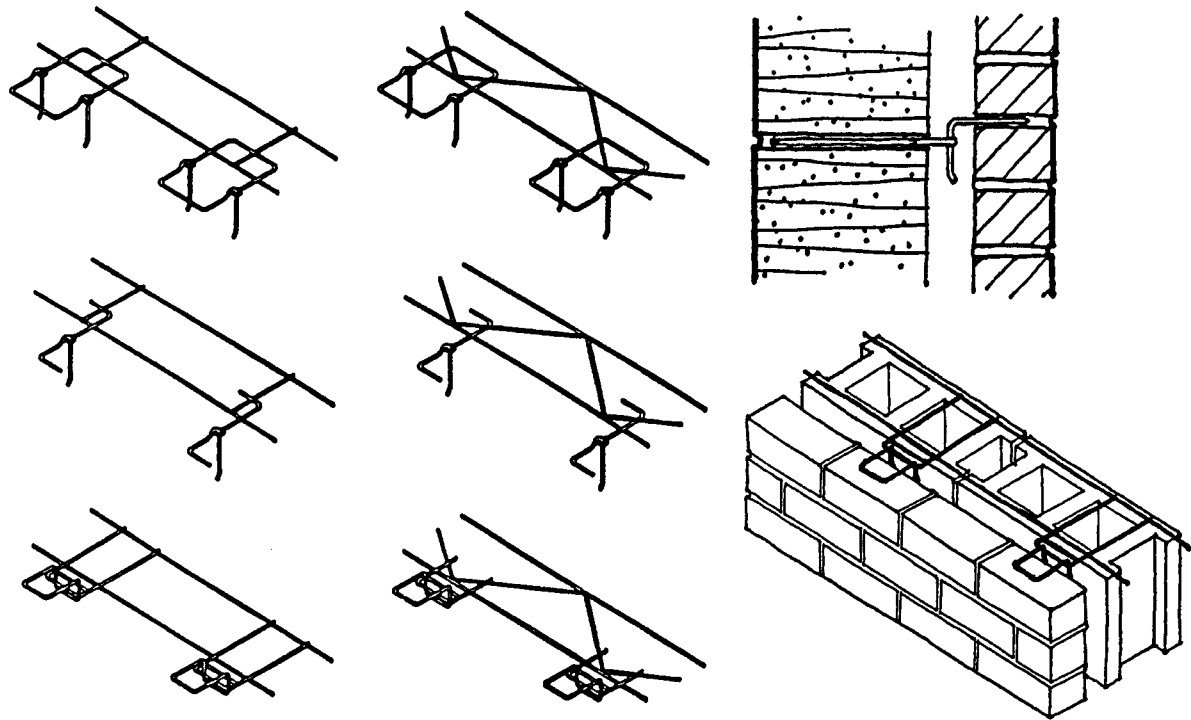


1/4" thick steel bar used to rigidly connect intersecting CMU walls (ends grouted into respective unit cores) for structural load transfer

6.1.5 Adjustable Masonry Ties

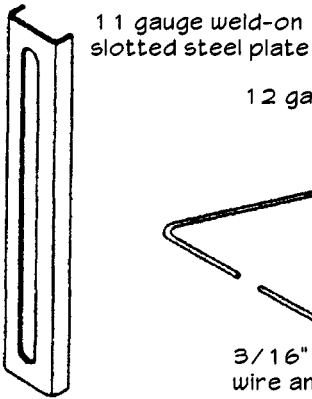
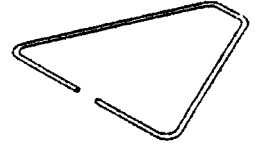
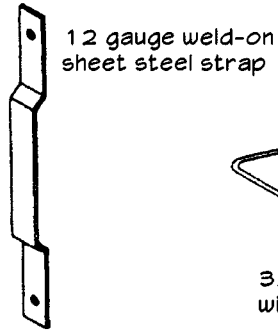
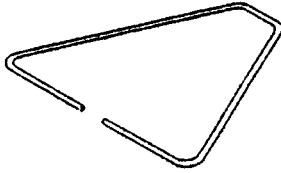
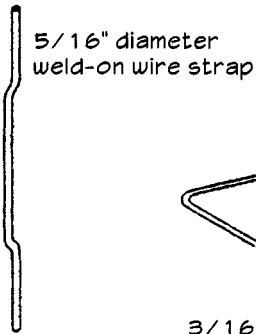


adjustable masonry ties permit differential movement between backing and facing wythes of masonry walls

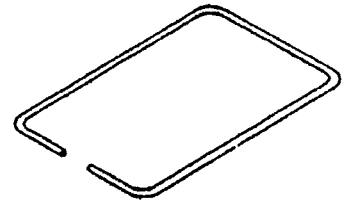
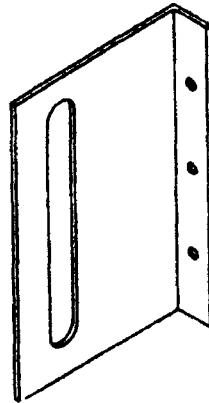
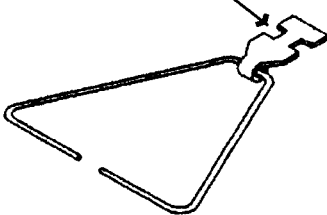


joint reinforcement with separate adjustable ties

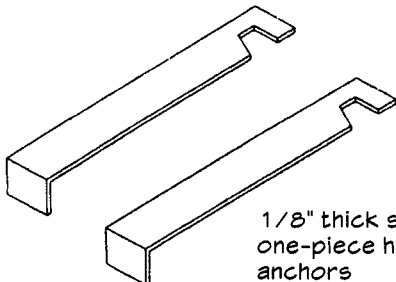
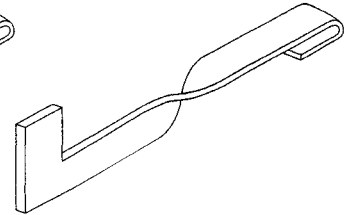
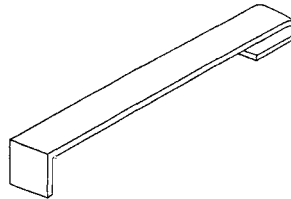
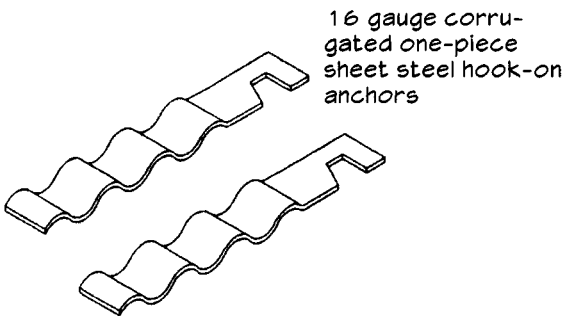
6.1.6 Masonry-To-Steel Veneer Anchors



12 gauge steel hook

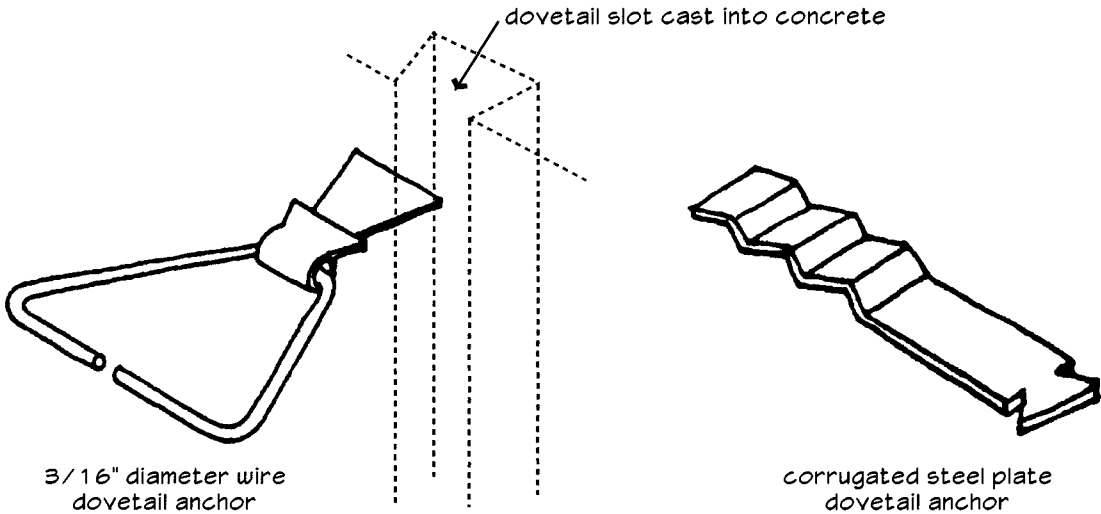


weld-on type, two-piece anchors

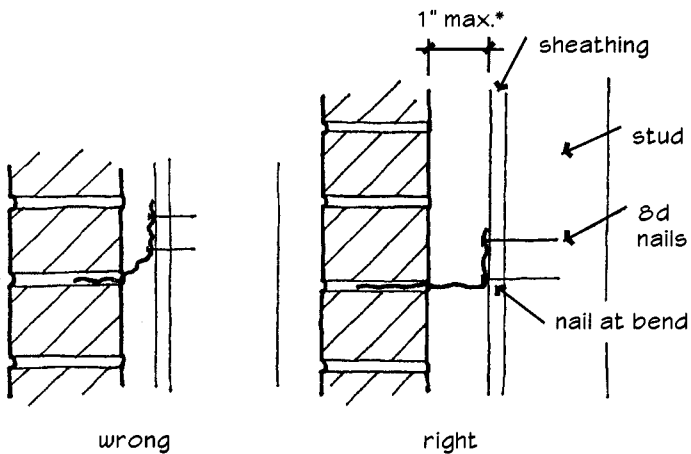
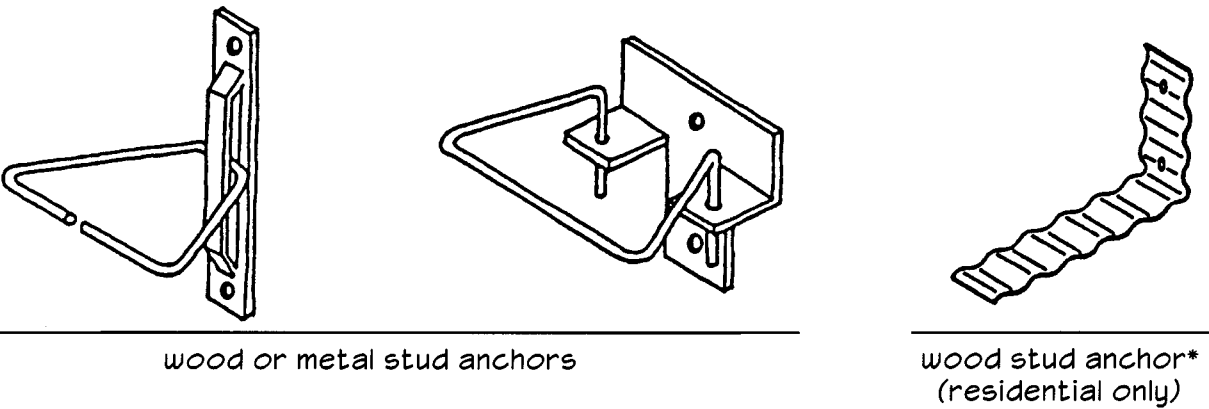


hook-on type, one-piece anchors

6.1.7 Masonry-To-Concrete Veneer Anchors



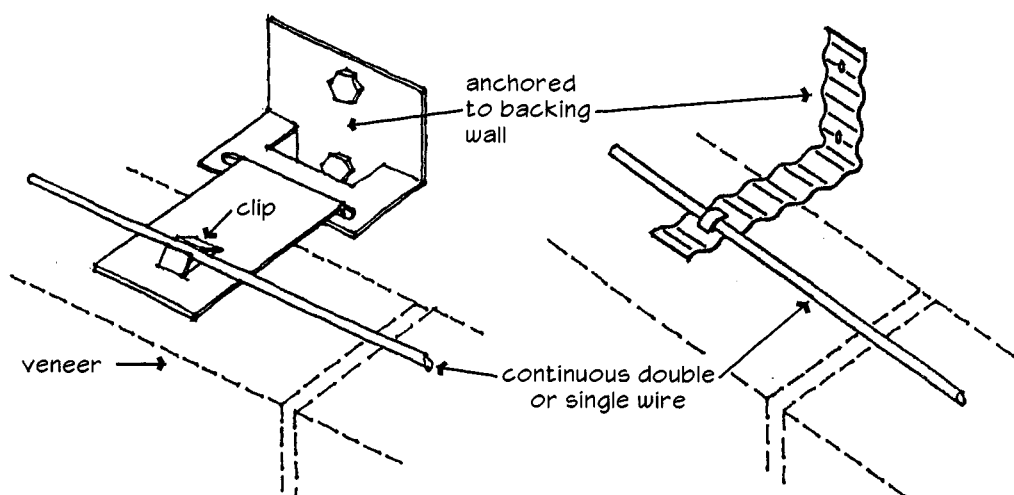
6.1.8 Masonry-To-Stud Veneer Anchors



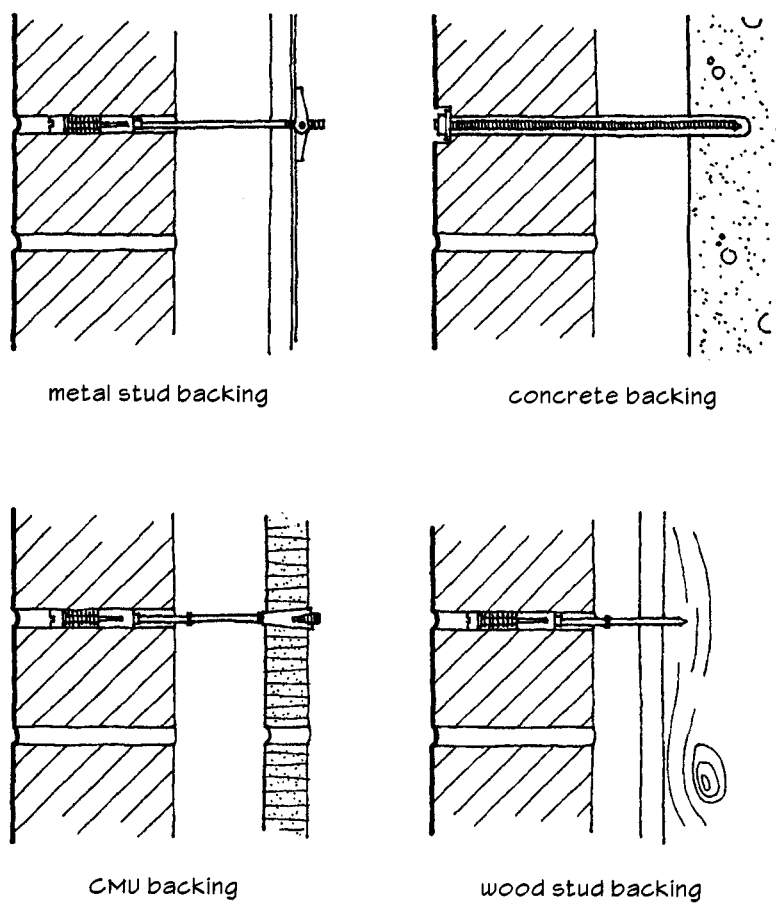
* codes do not permit the use of corrugated sheet metal anchors in walls with cavity widths greater than 1 in. because they may buckle or deform under lateral loading.

corrugated anchor installation

6.1.9 Seismic Veneer Anchors

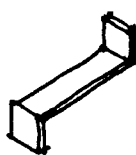


6.1.10 Retrofit Veneer Anchors

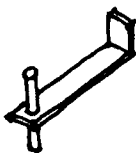


(From BIA Technical Note 44B, Brick Industry Association, Reston, Va.)

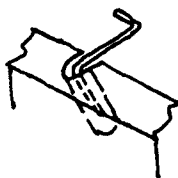
6.1.11 Stone Cladding Anchors



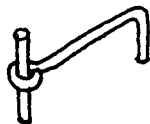
strap anchor



strap and dowel



rod anchor



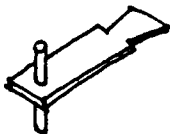
eye rod and dowel



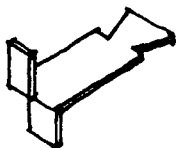
clip and loop



rod clamp



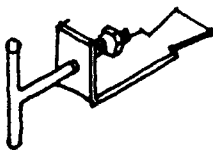
dovetail and dowel



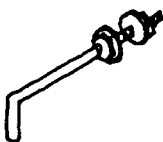
two-way dovetail



twisted strap



dovetail clip and tee



hooked bolt

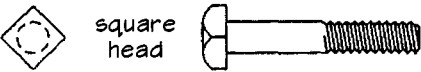


disc and rod

6.1.12 Anchor Bolts for Masonry



hex head

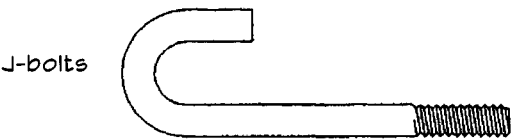


square head

headed bolts

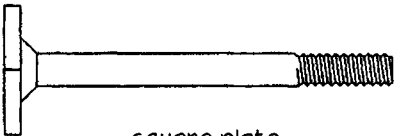
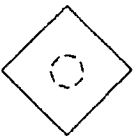


L-bolts

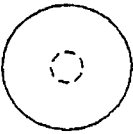


J-bolts

bent bolts



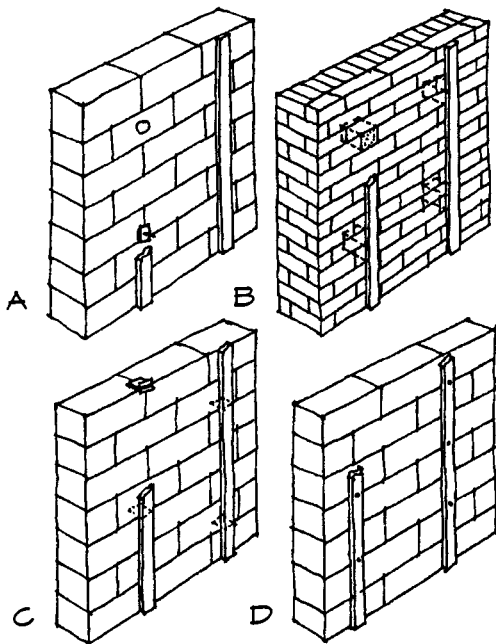
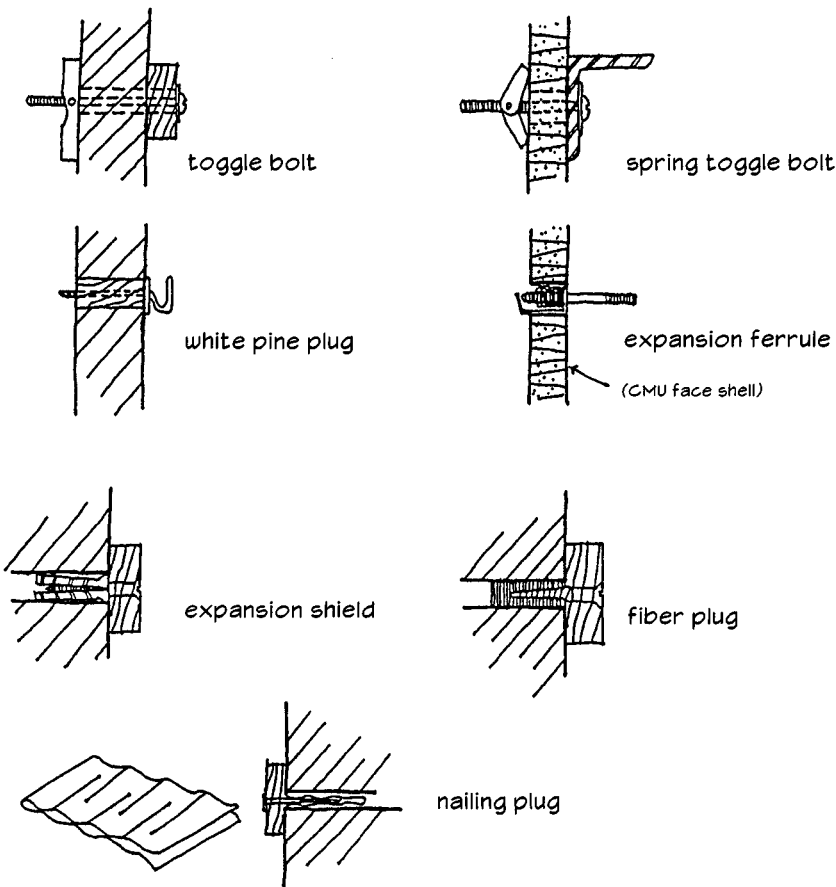
square plate



round plate

plate bolts

6.1.13 Masonry Fasteners





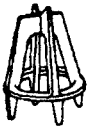


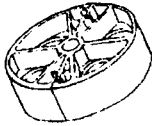

- wood furring strips
- A. adhesive cement and nails
 - B. wood nailing blocks
 - C. metal nailing plugs
 - D. case-hardened nails into mortar joints

(From BIA Technical Note Vol. 2, No. 10, Brick Industry Association, Reston Va.)

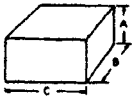
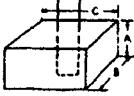
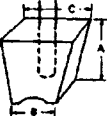
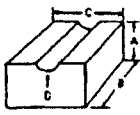
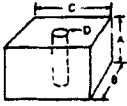


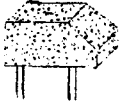
6.2.1 Steel Wire Bar Supports for Concrete Reinforcement

SYMBOL	BAR SUPPORT ILLUSTRATION	BAR SUPPORT ILLUSTRATION PLASTIC CAPPED OR DIPPED	TYPE OF SUPPORT	SIZES
SB			Slab Bolster	$\frac{3}{4}$, 1, $1\frac{1}{2}$, and 2 inch heights in 5 ft. and 10 ft. lengths
SBU			Slab Bolster Upper	Same as SB
BB			Beam Bolster	1, $1\frac{1}{2}$, 2, over 2" to 5" heights in increments of $\frac{1}{4}$ " in lengths of 5 ft.
BBU			Beam Bolster Upper	Same as BB
BC			Individual Bar Chair	$\frac{3}{4}$, 1, $1\frac{1}{2}$, and $1\frac{3}{4}$ " heights
JC			Joist Chair	4, 5, and 6 inch widths and $\frac{3}{4}$, 1 and $1\frac{1}{2}$ inch heights
HC			Individual High Chair	2 to 15 inch heights in increments of $\frac{1}{4}$ inch
HCM			High Chair for Metal Deck	2 to 15 inch heights in increments of $\frac{1}{4}$ in.
CHC			Continuous High Chair	Same as HC in 5 foot and 10 foot lengths
CHCU			Continuous High Chair Upper	Same as CHC
CHCM			Continuous High Chair for Metal Deck	Up to 5 inch heights in increments of $\frac{1}{4}$ in.
JCU			Joist Chair Upper	14" Span. Heights -1" thru +3 1/2" vary in $\frac{1}{4}$ " increments

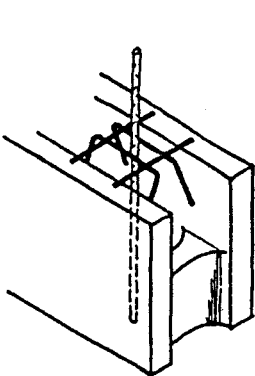
6.2.2 Plastic Bar Supports for Concrete Reinforcement

SYMBOL	BAR SUPPORT ILLUSTRATION	TYPE OF SUPPORT	TYPICAL SIZES	DESCRIPTION
BS		Bottom Spacer	Heights, ¾" to 6"	Generally for horizontal work. Not recommended for ground or exposed aggregate finish.
BS-CL		Bottom Spacer	Heights, ¾" to 2"	Generally for horizontal work, provides bar clamping action. Not recommended for ground or exposed aggregate finish.
HC		High Chair	Heights, ¾" to 5"	For use on slabs or panels.
HC-V		High Chair, Variable	Heights 2½" to 6¼"	For horizontal and vertical work. Provides for different heights.
WS		Wheel Spacer	Concrete Cover ¾" to 3"	Generally for vertical work. Bar clamping action and minimum contact with forms. Applicable for column reinforcing steel.
DSWS		Side Spacer for drilled shaft applications	Concrete Cover 2½" to 6"	Generally used to align rebar in a drilled shaft.* Two piece wheel that closes and locks on to the stirrup or spiral assuring proper clearance from the shaft wall surface.
VLWS		Locking Wheel Spacer for all vertical applications	Concrete Cover ¾" to 6"	Generally used in both drilled shaft and vertical applications where excessive loading occurs. Surface spines provide minimal contact while maintaining required tolerance.

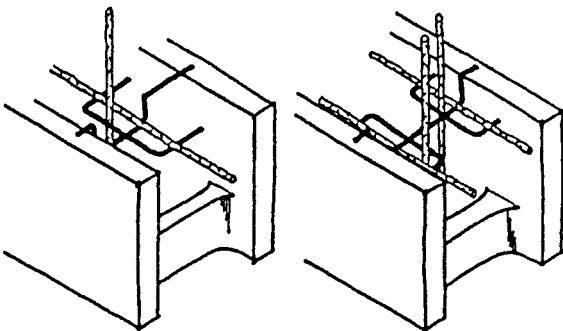
6.2.3 Precast Concrete Bar Supports for Concrete Reinforcement

SYMBOL	BAR SUPPORT ILLUSTRATION	TYPE OF SUPPORT	TYPICAL SIZES	DESCRIPTION
PB		Plain Block	A— $\frac{3}{4}$ " to 6" B—2" to 6" C—2" to 48"	Used when placing rebar off grade and formwork. When "C" dimension exceeds 16" a piece of rebar should be cast inside block.
WB		Wired Block	A— $\frac{3}{4}$ " to 4" B—2" to 3" C—2" to 3"	Generally 16 ga. tie wire is cast in block, commonly used against vertical forms or in positions necessary to secure the block by tying to the rebar.
TWB		Tapered Wired Block	A— $\frac{3}{4}$ " to 3" B— $\frac{3}{4}$ " to 2 $\frac{1}{2}$ " C—1 $\frac{1}{4}$ " to 3"	Generally 16 ga. tie wire is cast in block, commonly used where minimal form contact is desired.
CB		Combination Block	A—2" to 4" B—2" to 4" C—2" to 4" D—fits #3 to #5 bar	Commonly used on horizontal work.
DB		Dowel Block	A—3" B—3" to 5" C—3" to 5" D—hole to accommodate a #4 bar	Used to support top mat from dowel placed in hole. Block can also be used to support bottom mat.
DSSS		Side Spacer - Wired	Concrete cover, 2" to 6"	Used to align the rebar cage in a drilled shaft.* Commonly 16 ga. tie wires are cast in spacer. Items for 5" to 6" cover have 9 ga. tie wires at top and bottom of spacer.
DSBB		Bottom Bolster - Wired	Concrete cover, 3" to 6"	Used to keep the rebar cage off of the floor of the drilled shaft.* Item for 6" cover is actually 8" in height with a 2" shaft cast in the top of the bolster to hold the vertical bar.
DSWS		Side spacer for drilled shaft applications	Concrete cover, 3" to 6"	Generally used to align rebar in a drilled shaft. Commonly manufactured with two sets of 12 ga. annealed wires, assuring proper clearance from the shaft wall surface.

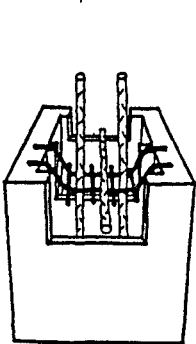
6.2.4 Bar Positioners for Masonry Reinforcement



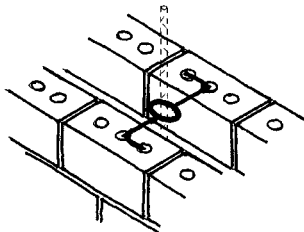
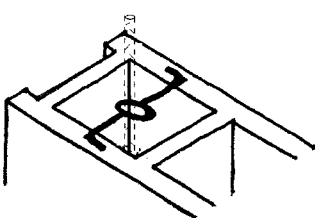
vertical bar
positioner



vertical and horizontal bar positioners

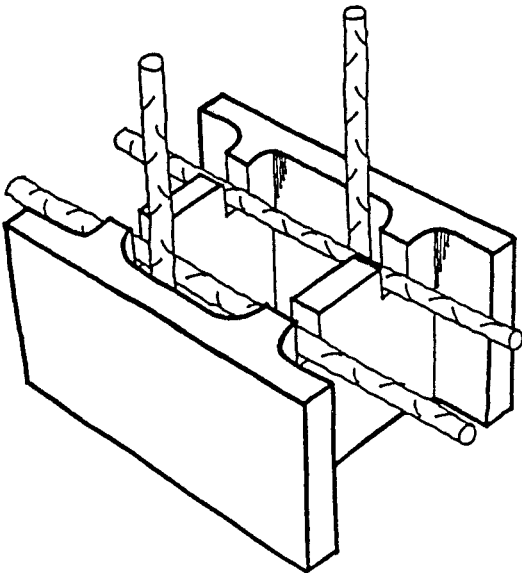


vertical and
horizontal
bar positioner



vertical bar positioners

steel wire reinforcing bar positioners
for use with grouted hollow unit masonry
or grouted double-wythe walls



patented concrete masonry unit with
webs designed to support and position
horizontal reinforcing bars (vertical
bars must be held away from unit face
shell to permit grout encapsulation)

6.3.1 Threaded Rods and Anchor Bolts for Concrete

Threaded rods and standard anchor bolts are medium-strength materials, suitable for anchoring light loads. They are not appropriate for friction-type connections, where high-strength anchor bolts should be used. High-strength bolts are not usually embedded in concrete because concrete pullout strength controls the connection design, making the high-strength steel inefficiently used. High-strength bolts are commonly used to connect steel components. Threaded rods and standard anchor bolts are commonly used to connect concrete to steel.

When designing the connection using a threaded rod or anchor bolt, both the capacity of the steel and the concrete must be checked. For high-strength bolts, design values depend upon whether or not the threads are in the shear plane. The material standards for threaded rods and anchor bolts are as follows:

- Threaded rods: ASTM A36 *Standard Specification for Structural Steel*
- Standard anchor bolts: ASTM A307 *Standard Specification for Carbon Steel Externally Threaded Fasteners*
- High-strength anchor bolts: ASTM A325 *Standard Specification for High-Strength Bolts for Structural Steel Joints, Including Suitable Nuts and Plain Hardened Washers* or ASTM A490 *Standard Specification for Quenched and Tempered Alloy Steel Bolts for Structural Steel Joints*
- Threading conforms to ANSI B1.1 *Unified Inch Screw Threads*

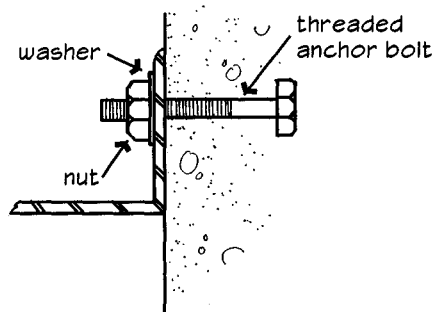
Allowable Working Tension Loads (kips) [§]						
ASTM Designation	Allowable Working Stress (ksi)	Nominal Bolt Diameter (in.)				
		5/8	3/4	7/8	1	1-1/4
A36 Threaded Rod	19.1	5.9	8.4	11.5	15.0	23.4
A307 Bolt	20.0	6.1	8.8	12.0	15.7	24.5
A325 Bolt	44.0	13.5	19.4	26.5	34.6	54.0

[§] Based on nominal (gross) area of the bolt.
(From AISC Manual of Steel Construction, 8th ed.)

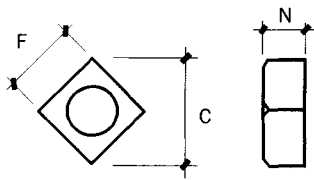
Allowable Working Single Shear Loads (kips) [§]						
ASTM Designation	Allowable Working Stress (ksi)	Nominal Bolt Diameter (in.)				
		5/8	3/4	7/8	1	1-1/4
A36 Threaded Rod	9.9	3.0	4.4	6.0	7.8	12.1
A307 Bolt	10.0	3.1	4.4	6.0	7.9	12.3
A325 Bolt	21.0	6.4	9.3	12.6	16.5	25.8

[§] Bearing-type steel to steel connection with threads included in shear plane.
(From AISC Manual of Steel Construction, 8th ed.)

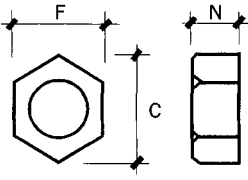
typical application
of embedded bolts



6.3.2 Nuts for Threaded Rods and Anchor Bolts



Square



Hex

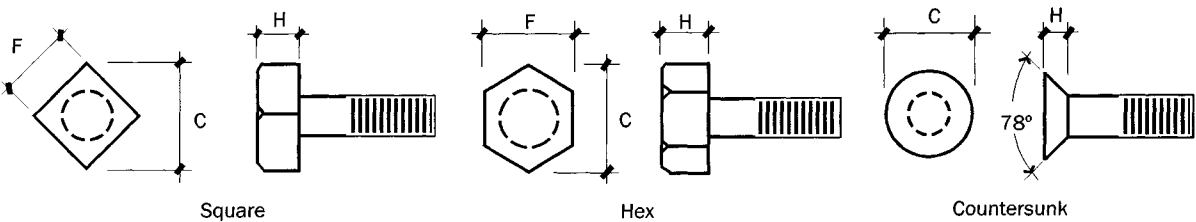
Dimensions for Nuts (rounded to nearest 1/16 in.)[§]

Nut Size	Square			Hex			Heavy Square			Heavy Hex		
	Width F	Width C	Height N	Width F	Width C	Height N	Width F	Width C	Height N	Width F	Width C	Height N
1/4	7/16	5/8	1/4	7/16	1/2	1/4	1/2	11/16	1/4	1/2	9/16	1/4
3/8	5/8	7/8	5/16	9/16	5/8	5/16	11/16	1	3/8	11/16	13/16	3/8
1/2	13/16	1-1/8	7/16	3/4	7/8	7/16	7/8	1-1/4	1/2	7/8	1	1/2
5/8	1	1-7/16	9/16	15/16	1-1/16	9/16	1-1/16	1-1/2	5/8	1-1/16	1-1/4	5/8
3/4	1-1/8	1-9/16	11/16	1-1/8	1-5/16	5/8	1-1/4	1-3/4	3/4	1-1/4	1-7/16	3/4
7/8	1-5/16	1-7/8	3/4	1-5/16	1-1/2	3/4	1-7/16	2-1/16	7/8	1-7/16	1-11/16	7/8
1	1-1/2	2-1/8	7/8	1-1/2	1-3/4	7/8	1-5/8	2-5/16	1	1-5/8	1-7/8	1
1-1/8	1-11/16	2-3/8	1	1-11/16	1-15/16	1	1-13/16	2-9/16	1-1/8	1-13/16	2-1/16	1-1/8
1-1/4	1-7/8	2-5/8	1-1/8	1-7/8	2-3/16	1-1/16	2	2-13/16	1-1/4	2	2-5/16	1-1/4
1-3/8	2-1/16	2-15/16	1-1/4	2-1/16	2-3/8	1-3/16	2-3/16	3-1/8	1-3/8	2-3/16	2-1/2	1-3/8
1-1/2	2-1/4	3-3/16	1-5/16	2-1/4	2-5/8	1-5/16	2-3/8	3-3/8	1-1/2	2-3/8	2-3/4	1-1/2
1-3/4	—	—	—	—	—	—	—	—	—	2-3/4	3-3/16	1-3/4
2	—	—	—	—	—	—	—	—	—	3-1/8	3-5/8	2
2-1/4	—	—	—	—	—	—	—	—	—	3-1/2	4-1/16	2-3/16
2-1/2	—	—	—	—	—	—	—	—	—	3-7/8	4-1/2	2-7/16
2-3/4	—	—	—	—	—	—	—	—	—	4-1/4	4-15/16	2-11/16
3	—	—	—	—	—	—	—	—	—	4-5/8	5-5/16	2-15/16
3-1/4	—	—	—	—	—	—	—	—	—	5	5-3/4	3-3/16
3-1/2	—	—	—	—	—	—	—	—	—	5-3/8	6-3/16	3-7/16
3-3/4	—	—	—	—	—	—	—	—	—	5-3/4	6-5/8	3-11/16
4	—	—	—	—	—	—	—	—	—	6-1/8	7-1/16	3-15/16

[§] In accordance with ANSI B18.2.2– 1972 (R1983).

(From AISC Manual of Steel Construction, 8th ed.)

6.3.3 Anchor Bolt Head Dimensions



Standard Dimensions for Bolt Heads (rounded to nearest 1/16 in.)[§]

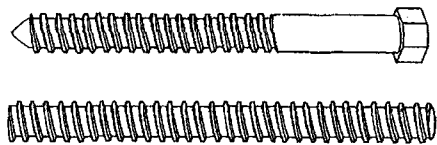
Bolt Diameter	Square			Hex			Heavy Hex			Countersunk	
	Width F	Width C	Height H	Width F	Width C	Height H	Width F	Width C	Height H	Diameter C	Height H
1/4	3/8	1/2	3/16	7/16	1/2	3/16	—	—	—	1/2	1/8
3/8	9/16	13/16	1/4	9/16	5/8	1/4	—	—	—	11/16	3/16
1/2	3/4	1-1/16	5/16	3/4	7/8	3/8	7/8	1	3/8	7/8	1/4
5/8	15/16	1-5/16	7/16	15/16	1-1/16	7/16	1-1/16	1-1/4	7/16	1-1/8	5/16
3/4	1-1/8	1-9/16	1/2	1-1/8	1-5/16	1/2	1-1/4	1-7/16	1/2	1-3/8	3/8
7/8	1-5/16	1-7/8	5/8	1-5/16	1-1/2	9/16	1-7/16	1-11/16	9/16	1-9/16	7/16
1	1-1/2	2-1/8	11/16	1-1/2	1-3/4	11/16	1-5/8	1-7/8	11/16	1-13/16	1/2
1-1/8	1-11/16	2-3/8	3/4	1-11/16	1-15/16	3/4	1-13/16	2-1/16	3/4	2-1/16	9/16
1-1/4	1-7/8	2-5/8	7/8	1-7/8	2-3/16	7/8	2	2-5/16	7/8	2-1/4	5/8
1-3/8	2-1/16	2-15/16	15/16	2-1/16	2-3/8	15/16	2-3/16	2-1/2	15/16	2-1/2	1-1/16
1-1/2	2-1/4	3-3/16	1	2-1/4	2-5/8	1	2-3/8	2-3/4	1	2-11/16	3/4
1-3/4	—	—	—	2-5/8	3	1-3/16	2-3/4	3-3/16	1-3/16	—	—
2	—	—	—	3	3-7/16	1-3/8	3-1/8	3-5/8	1-3/8	—	—
2-1/4	—	—	—	3-3/8	3-7/8	1-1/2	3-1/2	4-1/16	1-1/2	—	—
2-1/2	—	—	—	3-3/4	4-5/16	1-11/16	3-7/8	4-1/2	1-11/16	—	—
2-3/4	—	—	—	4-1/8	4-3/4	1-13/16	4-1/4	4-15/16	1-13/16	—	—
3	—	—	—	4-1/2	5-3/16	2	4-5/8	5-5/16	2	—	—
3-1/4	—	—	—	4-7/8	5-5/8	2-3/16	—	—	—	—	—
3-1/2	—	—	—	5-1/4	6-1/16	2-5/16	—	—	—	—	—
3-3/4	—	—	—	5-5/8	6-1/2	2-1/2	—	—	—	—	—
4	—	—	—	6	6-15/16	2-11/16	—	—	—	—	—

[§] In accordance with ANSI B18.2.1- 1981 (square and hex) and ANSI 18.5- 1978 (countersunk).

6.3.4 Coil Bolts and Threaded Coil Rods for Concrete

Coil bolts and threaded coil rods are coarsely threaded fasteners that are used with helically coiled inserts (discussed later). Standard diameters range from 1/2 inch to 1-1/2 inches and lengths up to 10 feet are available. Coil bolts and coil rods are primarily used for lifting and temporary connections. They are not recommended for permanent connections in areas of high seismic risk. When used for lifting and temporary connections, these fasteners may be reused many times. However, their threads should be regularly examined for wear.

Tensile and shear capacities of coil bolts and threaded coil rods, based on working loads and regular-strength material, are given in the table below. Manufacturers who use high-strength materials can furnish capacities for their fasteners. Generally, the safe tensile working load is 2/3 of the minimum tensile strength and the safe shear working load is 2/3 of the safe tensile working load.



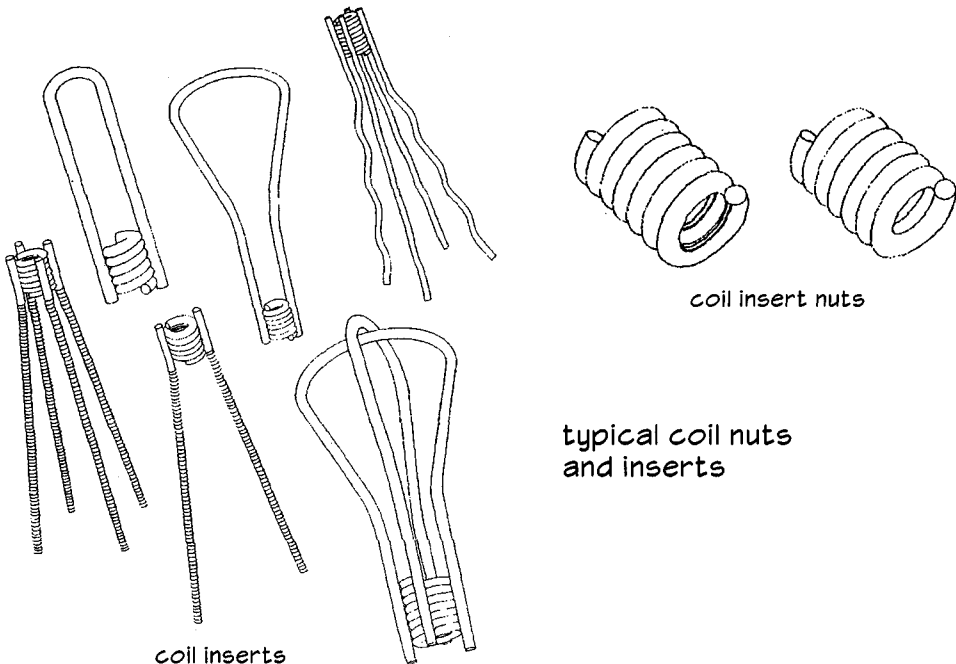
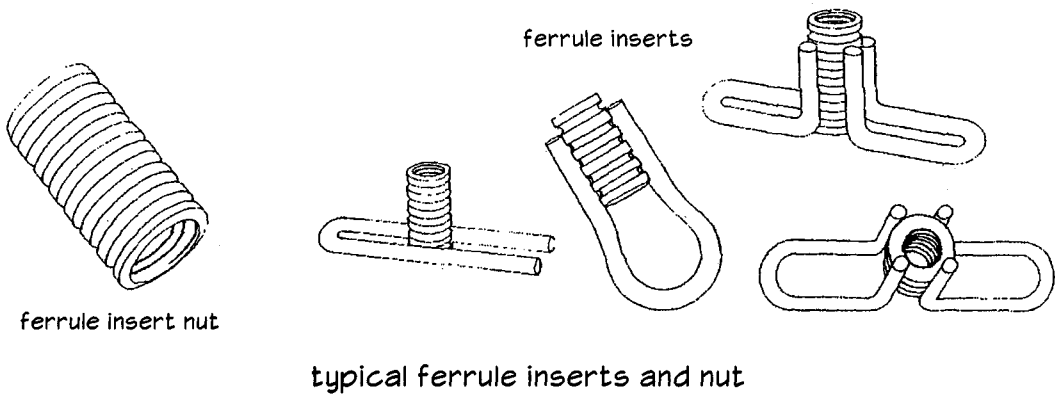
Safe Working-Load Capacity of Coil Bolts and Threaded Coil Rods§		
Bolt Diameter (in.)	Tensile Working Load (lbs.)	Shear Working Load (lbs.)
1/2†	9,000	6,000
3/4†	18,000	12,000
1†	38,000	25,300
1-1/4†	58,000	37,500
1-1/2	88,000	45,300

§ Approximate factor of safety is 2 to 1.
† Strength requirements similar to ASTM A325.
Note: A minimum of two threads beyond coil is required to develop full capacity.
(From *Prestressed Concrete Institute Design Handbook for Precast and Prestressed Concrete*, 5th ed.)

6.3.5 Threaded Inserts for Concrete

There are two categories of threaded inserts: ferrule inserts and coil inserts. *Ferrule inserts* are nutlike anchors that are embedded into concrete for use with standard bolts. Steel wire loops are welded to each nut to provide better anchorage to concrete. Available sizes range from 1/4 to 1-1/2 inches. *Coil inserts* consist of helically wound coil wire that forms a nutlike anchor into which a coil bolt or rod can be threaded. One or more wires or wire loops are welded to the inserts to provide anchorage to concrete. Available sizes are 1/2 to 1-1/2 inches.

Threaded inserts are especially useful for lifting and bracing connections. They rely on the anchorage of the wire loops to provide load capacity. Capacity may be limited by either concrete pullout strength or wire tensile strength. Placement of inserts near a free edge reduces the load-carrying capacity. Manufacturers provide test data and recommended allowable loads, usually for normal weight concrete. An engineer should determine the capacity of the insert based on the specific detail utilized, the weight of the concrete, and the seismic risk.

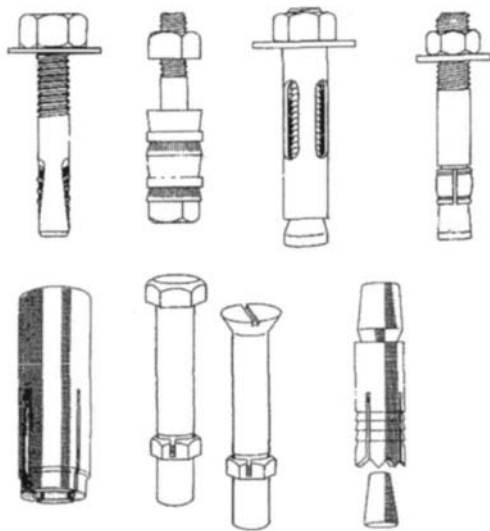


6.3.6 Expansion Inserts for Concrete

Expansion inserts are anchors that are placed into holes that are drilled into hardened concrete. Radial expansion of the inserts exerts force on the walls of the hole, providing friction and anchorage. Bolts or threaded rods may be used with expansion inserts, which are shown below.

Expansion inserts are most efficiently used for retrofitting misplaced or omitted cast-in-place concrete inserts, usually for temporary connections and bracing. They are not normally recommended for permanent connections.

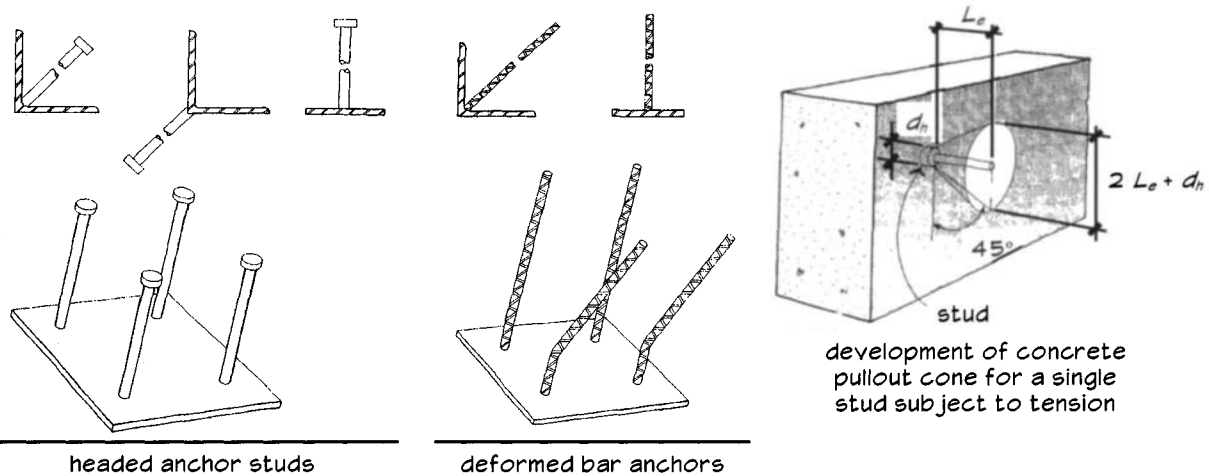
Because the capacity of expansion inserts is developed as a result of pressure exerted against the sides of the drilled hole, the distance between inserts and the orientation and distance of the insert relative to a free edge are critical. Other factors are embedment depth, anchor size, and shape of the hole. Tight tolerances are required on the drilled holes and on the torque applied to the bolts during installation of most expansion anchors. Some expansion inserts require using a calibrated torque wrench to control the torque and obtain proper expansion. An engineer, working with manufacturer's data, should determine the appropriate working loads based on the nature and details of the connection design.

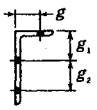
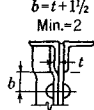


6.3.7 Steel Embedments, Headed Anchor Studs, and Deformed Bar Anchors

Steel embedments are fabricated from multiple elements including headed anchor studs, deformed bar anchors, standard reinforcing bars, plates, and structural shapes. Headed anchor studs conform to ASTM A108 *Standard Specification for Steel Bars, Carbon, Cold finished, Standard Quality*. Headed anchors studs used with steel angles and plates and deformed bar anchors are shown below. Reinforcing bars conform to ASTM A615 *Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement*.

Steel embedments are generally used for connections that will be welded, usually for attaching wall panels to other building components. Typically, the plate or angle is set flush with the concrete surface so that the anchors provide the attachment into the concrete. Steel embedments may be used to resist tension, compression, and shear, either singly or in combination. For quality control, attachment of headed anchor studs and deformed bar anchors to the structural steel shape is usually accomplished by automatic stud-welding machines. Capacity of steel embedments with headed anchor studs is usually governed by a concrete pullout cone. Required development lengths for reinforcing bars and deformed bar anchors are given in the table below.



Usual Gauges for Angles (in.)																Crimps
	Leg	8	7	6	5	4	3-1/2	3	2-1/2	2	1-3/4	1-1/2	1-3/8	1-1/4	1	
	g	4-1/2	4	3-1/2	3	2-1/2	2	1-3/4	1-3/8	1-1/8	1	7/8	7/8	3/4	5/8	
	g ₁	3	2-1/2	2-1/4	2	—	—	—	—	—	—	—	—	—	—	
	g ₂	3	3	2-1/2	1-3/4	—	—	—	—	—	—	—	—	—	—	

(From AISC Manual of Steel Construction, 8th ed.)

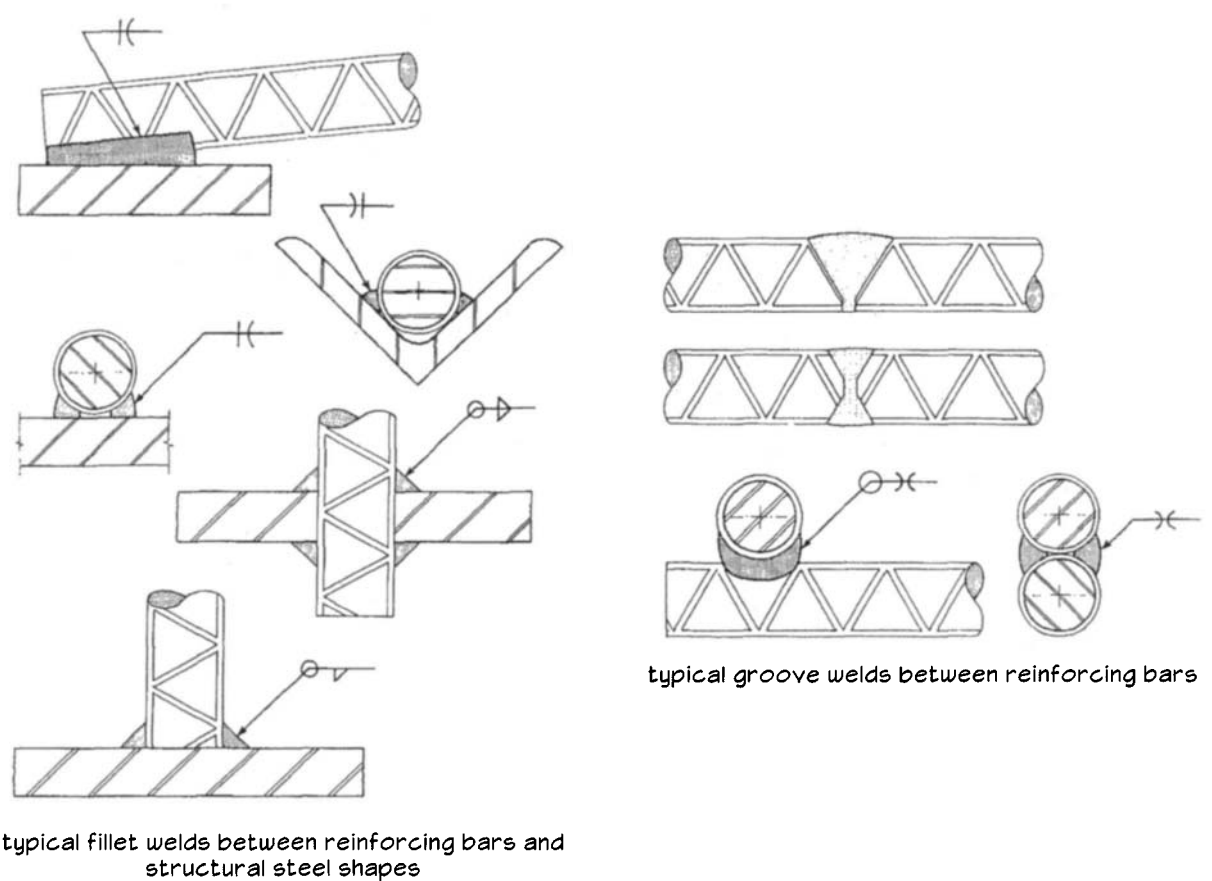
Development Length (in.) for Reinforcing Bars and Deformed Bar Anchors								
Concrete Strength, f_c (psi)	Normal Weight Concrete ($\lambda = 1.0$)				Normal Weight Concrete ($\lambda = 0.85$)			
	Bar Diameter (in.)				Bar Diameter (in.)			
	1/4	3/8	1/2	5/8	1/4	3/8	1/2	5/8
3,000	12	12	12	15	12	12	14	18
4,000	12	12	12	15	12	12	14	18
5,000	12	12	12	15	12	12	14	18
6,000	12	12	12	15	12	12	14	18
7,000	12	12	12	15	12	12	14	18
8,000	12	12	12	15	12	12	14	18

$f_y = 60,000$ psi; for values above 60,000 psi multiply by 2 - $(60,000 \div f_y)$
(From Portland Cement Association, Connections for Tilt-Up Wall Construction)

6.3.8 Welding of Steel Embedments and Reinforcement








Welds are commonly used to join individual steel elements to form steel embedments and to connect structural members. The most commonly used welds are fillet welds and groove welds (shown below). Welds are generally made by the shielded metal arc-welding process. Structural-steel shapes usually conform to ASTM A36 *Specification for Structural Steel*, while reinforcing steel conforms to ASTM A615 *Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement*.

Welded connections restrain movement between the connected parts and are generally rigid. Therefore, welded connections are not recommended when large volume changes are anticipated. Proper procedures for welding, reliable workmanship, compatibility of welding materials with metals to be joined, and welding accessibility must be considered in the design of welded connections. Welding in a down-hand position is preferred. Details of structural steel welding are given in AWS D1.1, *Structural Welding Code – Steel*. Design of welds for reinforcement can be found in AWS D1.4, *Structural Welding Code – Reinforcing Steel*.



6.3.9 Weld Symbols

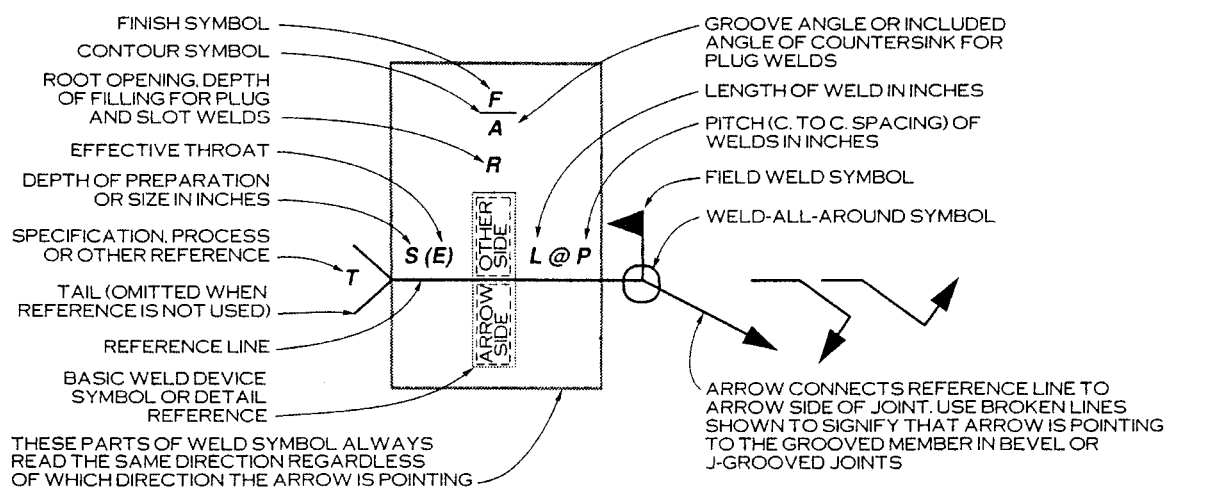
BASIC WELD SYMBOLS

BACK WELD	FILLET WELD	PLUG OR SLOT WELD	GROOVE OR BUTT WELDS						
			SQUARE	V	BEVEL	U	J	FLARE V	FLARE BEVEL
									

SUPPLEMENTARY WELD SYMBOLS

BACKING	SPACER	WELD ALL AROUND	FIELD WELD	FLUSH	CONVEX

(For other basic and supplementary weld symbols, see AWS A2.4-86.)



- Note:
- Size, weld symbol, length of weld, and spacing must read in that order from left to right along the reference line. Neither orientation of reference line nor location of the arrow alters this rule.
 - The perpendicular leg of fillet, bevel, J, and flare bevel weld symbols must be at left.
 - Arrow and Other Side welds are of the same size unless shown otherwise. Dimensions of fillet welds must be shown on both the Arrow Side and the Other Side symbol.
 - Flag of field weld symbol must be placed above and at right angle to the reference line of junction with arrow.
 - Symbols may apply between abrupt changes in direction of welding unless governed by the "all around" symbol or otherwise dimensioned.
 - These symbols do not explicitly provide for the case that frequently occurs in structural work, where duplicate material (such as stiffeners) occurs on the far side of a web or gusset plate. The fabricating industry has adopted this convention: that when the billing of the detail material discloses the existence of a member on the far side as well as on the near side, the welding shown for the near side shall be duplicated on the far side.

6.3.10 Sand-Cement Grout, Epoxy, and Epoxy Grout

These materials are generally used to fill small voids where normal concrete cannot be placed. Examples include the gap between foundations and wall panels to transfer bearing loads, and anchoring dowels into hardened concrete.

Sand-cement grout is a combination of portland cement, sand, and water that is usually mixed to a high slump. Sand-cement ratios range between 1 to 1 and 1 to 3. Low-slump may be used where high-slump grout cannot be held in place. Low-slump grouts are generally hand-tamped into place. High-slump grouts with a water-cement ratio of 0.5 or greater may shrink excessively. This shrinkage can be reduced by using compensating admixtures. Dry-pack grout, which has a lower water-cement ratio, may not have as much of a shrinkage problem. Sand-cement grouts should be moist-cured.

Epoxyes are two-component systems that, when combined, produce bonding agents with high tensile strengths. These materials are governed by ASTM C881, *Standard Specification for Epoxy-Resin-Base Bonding System for Concrete*. Epoxyes are often used in field repair when mechanical connectors are not practical. Although high tensile strengths can be achieved with epoxyes, available data on response to cyclic loads is limited. Epoxyes can have thermal expansion of up to seven times that of concrete. They also have a limited time during which they are workable. Temperature, humidity, and surface water may affect performance. Since properties may change with time, careful consideration should be given to each application.

Epoxy grout consist of two-component systems combined with an aggregate filler. It is a more economical alternative to epoxy. The filler is added when a large amount of bonding agent is needed. Design considerations for epoxy grout are the same as for epoxy, with some exceptions. Since it includes aggregate filler, epoxy grout has thermal expansion about twice that of concrete. The aggregate filler also affects the material strength and may reduce bond.

6.3.11 Bearing Pads for Concrete and Masonry

Bearing pads are used under simply supported members to distribute loads evenly over a bearing surface. They are designed to allow some displacement and some rotation to occur between the structural members to avoid transferring loads for which the bearing member is not designed. They are relatively simple and easy to install. However, they may move out of position under repetitive loading. Also, they generally degrade when exposed to fire.

A variety of bearing pad materials are available to suit different applications. Material selection may be based on compressibility, resilience, frictional characteristics, or response to environmental conditions. Available materials include:

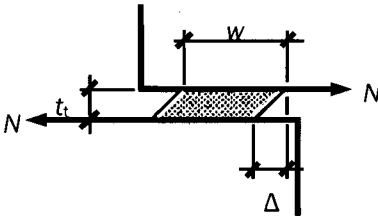
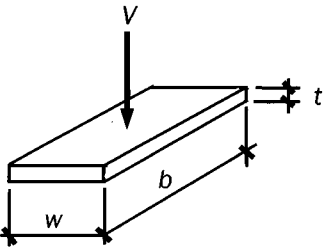
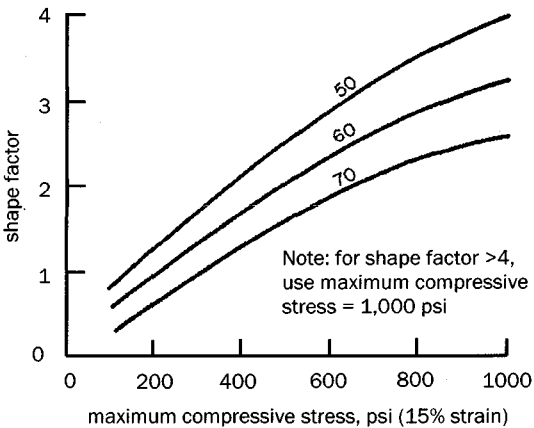
- structural-grade (elastomeric) neoprene pads
- laminated steel and neoprene pads
- laminated fabric and rubber pads
- laminated synthetic fiber pads
- teflon pads
- multipolymer-plastic bearing strips
- tempered hardboard strip

Design recommendations for structural-grade elastomeric pads are shown below. Manufacturers should be contacted for design data for the other types of bearing pads.

Design Recommendations

- use unfactored loads for design
- maximum compressive stress = 1000 psi
- maximum shear stress = 100 psi
- maximum shear deformation = $t/2$
- maximum compressive strain = 15%
- $w \geq 5t$ or 4 in.
- $t_t \geq 1/4$ in. for stems, $3/8$ in. for beams

Design	Shear Modulus, G (psi)		
	Durometer		
70	110	160	215
20	121	176	236
0	138	200	269
20	209	304	408



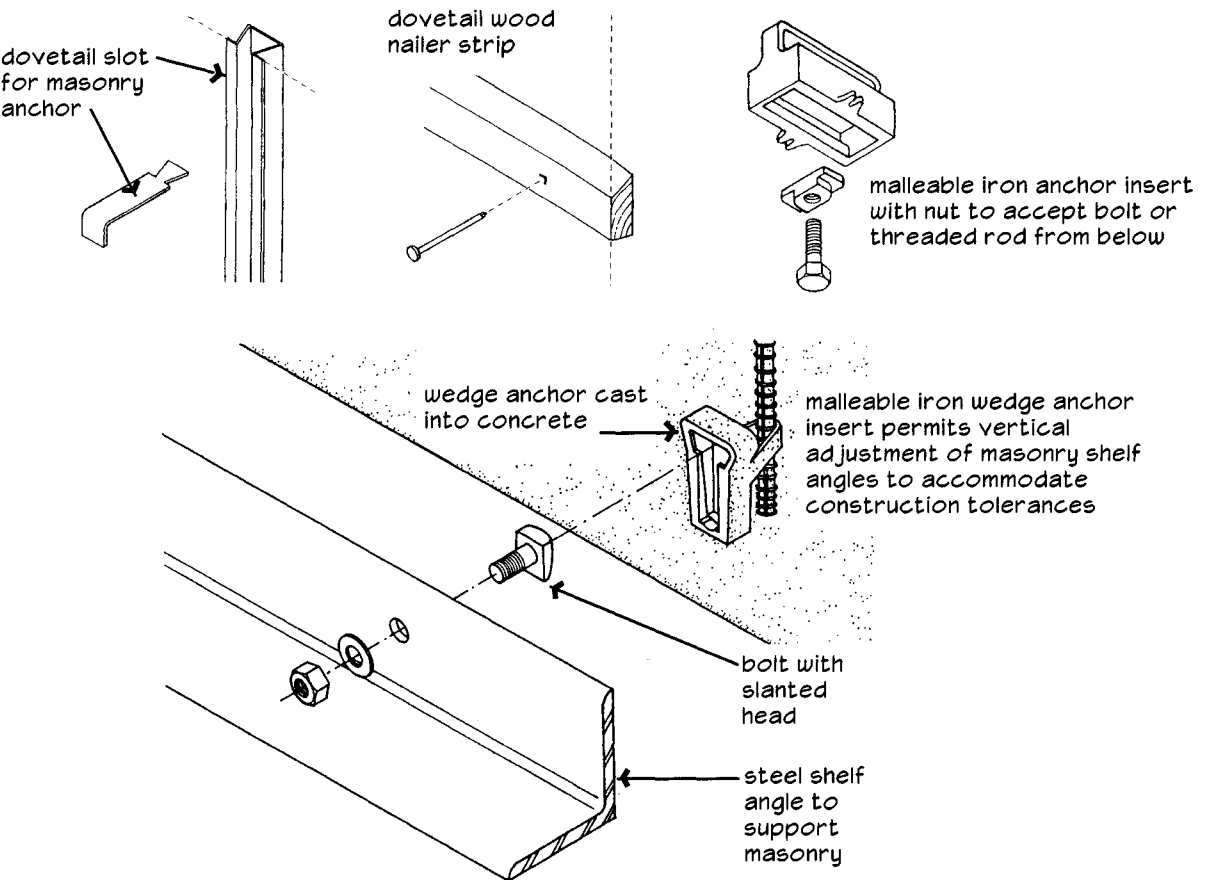
$$\text{shape factor} = \frac{wb}{2(w+b)t}$$

$$f = \frac{V}{wb}$$

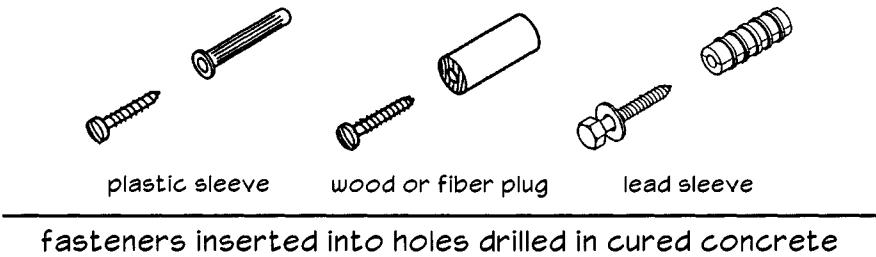
$$N = \frac{\Delta wbG}{t_t}$$

(From Portland Cement Association, Connections for Tilt-Up Wall Construction)

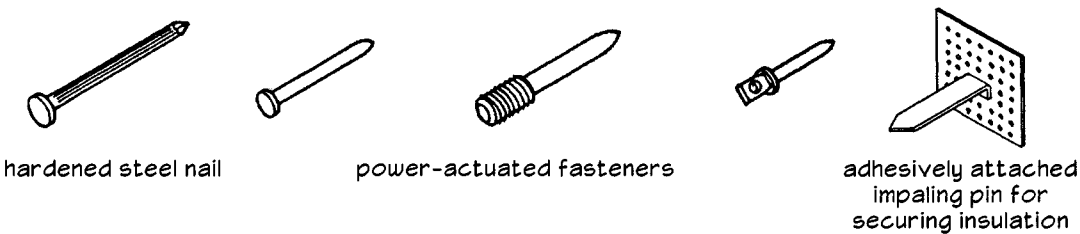
6.3.12 Miscellaneous Concrete Anchors and Fasteners



anchors cast into concrete



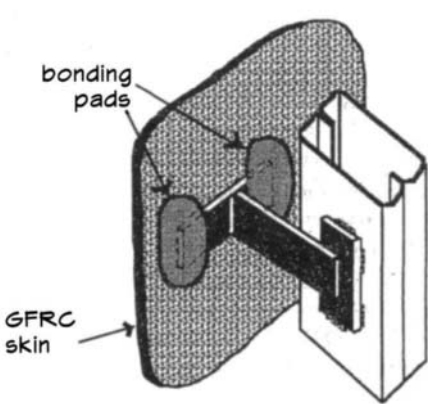
fasteners inserted into holes drilled in cured concrete



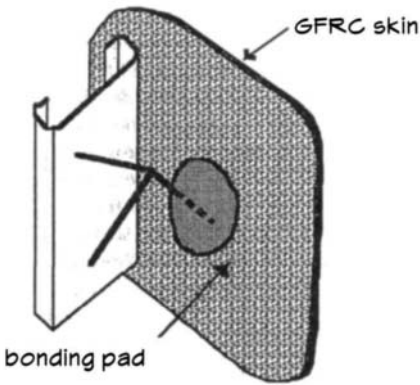
fasteners attached to hardened concrete surface

(Adapted from Fundamentals of Building Construction, 3rd ed.)

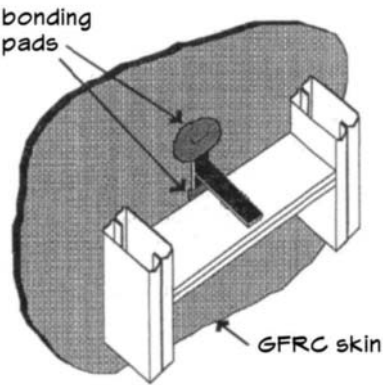
6.3.13 GFRC Connectors



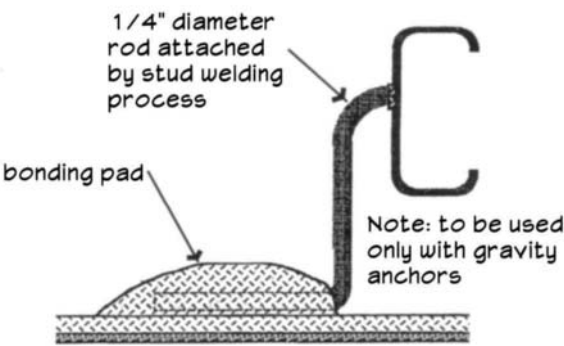
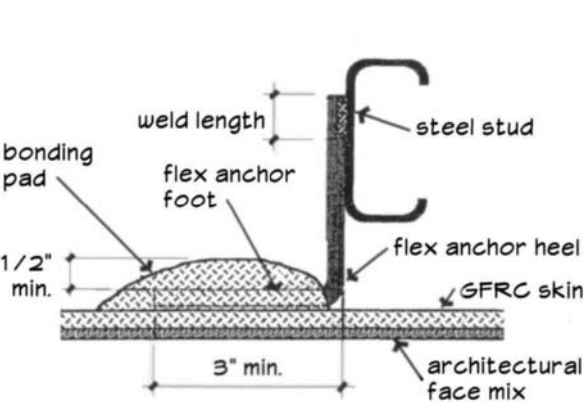
flat plate tee gravity anchor



round-bar trussed gravity anchor



flat plate tee longitudinal seismic anchor



examples of flex anchors

(From ACI 544.1R-96, State of the Art Report on Fiber Reinforced Concrete)

6.4.1 Corrosion Protection for Masonry Accessories

Corrosion can be caused by chemical attack, galvanic action, weathering, prolonged exposure to condensed moisture, or humidity in excess of 75%. Salt spray in coastal areas is also very corrosive and can accelerate the deterioration of both exposed and embedded metals. Corroded metal occupies 10 to 14 times the volume of the original and exerts expansive forces which can cause severe cracking in concrete and masonry.

Embedded metals require corrosion protection in relation to the severity of their exposure to moisture. The table below lists minimum requirements for protection of masonry reinforcement and accessories. Corrosion protection may be provided by galvanized or epoxy coatings. Stainless steel is less susceptible to corrosion than galvanized steel and can be used instead of galvanized steel to provide greater long-term durability.

Masonry Standards Joint Committee Specification for Masonry Structures (ACI 530.1/ ASCE 6/TMS 602) Requirements for Corrosion Protection [§]			
Accessory Item	ASTM Standard [†]	Class	Weight or Thick- ness of Coating
Galvanized Coatings			
Joint reinforcement, interior walls	A641	1	0.10 oz/sq.ft.
Wire ties or anchors in exterior walls completely embedded in mortar or grout	A641	3	0.80 oz/sq.ft.
Wire ties or anchors in exterior walls not completely embedded in mortar or grout	A153	B2	1.50 oz/sq.ft.
Joint reinforcement in exterior walls or interior walls exposed to a mean relative humidity exceeding 75% (e.g., food processing or swimming pool)	A153	B2	1.50 oz/sq.ft.
Sheet metal ties or anchors in exterior walls or interior walls exposed to a mean relative humidity exceeding 75% (e.g., food processing or swimming pool)	A153	B2	1.50 oz/sq.ft.
Sheet metal ties or anchors in interior walls	A653	G60	0.60 oz/sq.ft.
Steel plates and bars (as applicable to size and form indicated)	A123	—	—
	A153	B	—
Epoxy Coatings			
Joint reinforcement	A884	B2	18 mils
Wire ties and anchors	A899	C	20 mils
Sheet metal ties and anchors	—	—	20 mils [‡]

[§] Corrosion protection may also be provided by using AISI Type 304 stainless steel as follows:
joint reinforcement, ASTM A580 *Stainless and Heat-Resisting Steel Wire*
plate and bent bar anchors, ASTM A666 *Austenitic Stainless Steel Sheet, Strip, Plate and Flat Bar for Structural Applications*
sheet metal ties and anchors, ASTM A167 *Stainless and Heat-Resisting Chromium-Nickel Steel Plate, Sheet and Strip*
wire ties and anchors, ASTM A580 *for Stainless and Heat-Resisting Steel Wire*

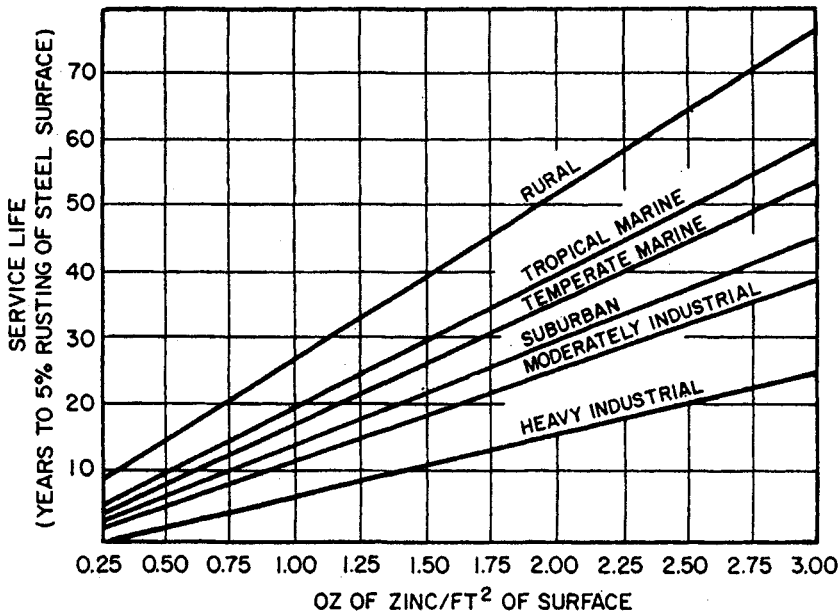
[†] ASTM A641 *Zinc Coated (Galvanized) Carbon Steel Wire*
ASTM A153 *Zinc Coating (Hot-Dipped) on Iron and Steel Hardware*
ASTM A653 *Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvanealed) by the Hot-Dip Process*
ASTM A884 *Epoxy-Coated Steel Wire and Welded Wire Fabric for Reinforcement*
ASTM A899 *Steel Wire Epoxy Coated*

[‡] Per surface or manufacturer's specification.

6.4.2 Life Expectancy of Galvanized Coatings

Although zinc is susceptible to corrosive attack, it is used in the galvanizing process to provide a barrier coating to isolate steel from corrosive elements. Zinc provides a sacrificial coating that is consumed to protect the steel at uncoated areas such as scratches and cut ends. The protective film of zinc used in galvanizing is so thin that the expansive pressure it exerts when it is sacrificially corroded is not sufficient to cause cracking in the same way as the corrosion of unprotected steel.

Mill galvanizing and electro-galvanizing before fabrication (ASTM A641) do not provide protection at cut edges, wire ends, shop welds, and penetrations in the same way that hot-dip galvanizing after fabrication does (ASTM A153 and A653). The life expectancy of the corrosion protection afforded by galvanizing is directly proportional to its thickness.



Probability of Occurrence (%)	Corrosion Rate (10 ⁻⁴ oz. zinc/sq.ft./yr.)	Life Expectancy (yrs.)			
		ASTM A153, Class B2		ASTM A153, Class B1	
		Minimum	Average	Minimum	Average
5	2415	5.2	6.2	7.5	8.3
10	1791	7.0	8.4	10.1	11.2
20	1075	11.6	14.0	16.7	18.6
25	875	14.3	17.1	20.6	22.9
33	656	19.1	22.9	27.4	30.5
50	393	31.8	38.2	45.8	50.9

(From American Galvanizers Association.)

6.4.3 Galvanic Series of Metals

Galvanic corrosion occurs when metals are exposed to a conductive solution that allows an electric or galvanic current to flow between an anodic and a cathodic region. Galvanic corrosion most often occurs between dissimilar metals in the presence of an electrolyte such as water. The degree of galvanic corrosion that can occur between dissimilar metals depends on the intimacy of contact, the type of electrolyte, and the voltage developed between the two metals. An electric current is conducted through the electrolyte, corroding one metal (the anode) and plating the other (the cathode). Less noble metals are subject to corrosion by more noble metals. The further apart two metals are in the galvanic series, the more severe the corrosion of the less noble metal. Galvanic corrosion occurs most readily when materials touch, but may also occur when water runs from one material to another.

The density of the corrosion current, or the size of the current relative to the anode surface, is also important. If a fastener’s surface is small compared to the metal to be fastened, the current density is concentrated at the fastener and the fastener is therefore subject to rapid corrosion. Corrosion of the anode (fastener) can be 100 to 1000 times more severe than if its surface area were approximately the same as the cathode. Therefore, as a general rule, a fastener in a given environment should be more noble than the larger metal to be fastened. To protect against galvanic corrosion when dissimilar metals are used, isolation can be provided by an electrical insulator such as neoprene rubber, asphalt impregnated felt, or a mastic coating.

Metal or Alloy	Position
Platinum	<div>Cathode (-) most noble</div> <div>↑</div> <div>↓</div> <div>Anode (+) least noble</div>
Gold	
Graphite	
Titanium	
Silver	
Austenitic stainless steel (passive)	
Ferritic stainless steel (passive)	
Nickel (passive)	
Silver solder	
Monel	
Bronze	
Copper	
Brass	
Nickel (active)	
Tin	
Lead	
Austenitic stainless steel, 18-8 series (active)	
Ferritic stainless steel, 400 series (active)	
4-6% chromium steel	
Iron or carbon steel	
Aluminum, 2024-T4 alloy	
Aluminum, 6061 alloy	
Aluminum, 5052 alloy	
Zinc	
Magnesium	

6.4.4 Compatibility of Metals

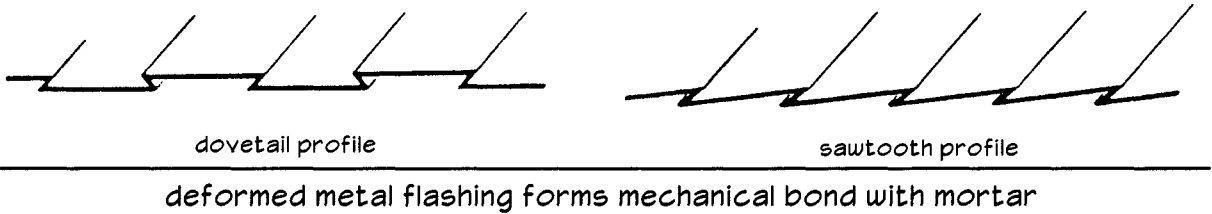
Compatibility of Common Building Metals						
	Copper	Aluminum	Stainless Steel	Galvanized Steel	Zinc Alloy	Lead
Aluminum	1	—	—	—	—	—
Stainless Steel	1	3	—	—	—	—
Galvanized Steel	2	3	2	—	—	—
Zinc	1	3	1	3	—	—
Lead	2	2	2	3	3	—
Brass	2	1	1	2	1	2
Bronze	2	1	1	2	1	2
Monel	2	3	1	2	1	2
Iron/steel	1	2	2	2	1	3

1. Galvanic action will occur.
2. Galvanic action may occur under certain conditions or over a period of time.
3. Galvanic action is insignificant under normal conditions.

6.5.1 Flashing Types and Properties

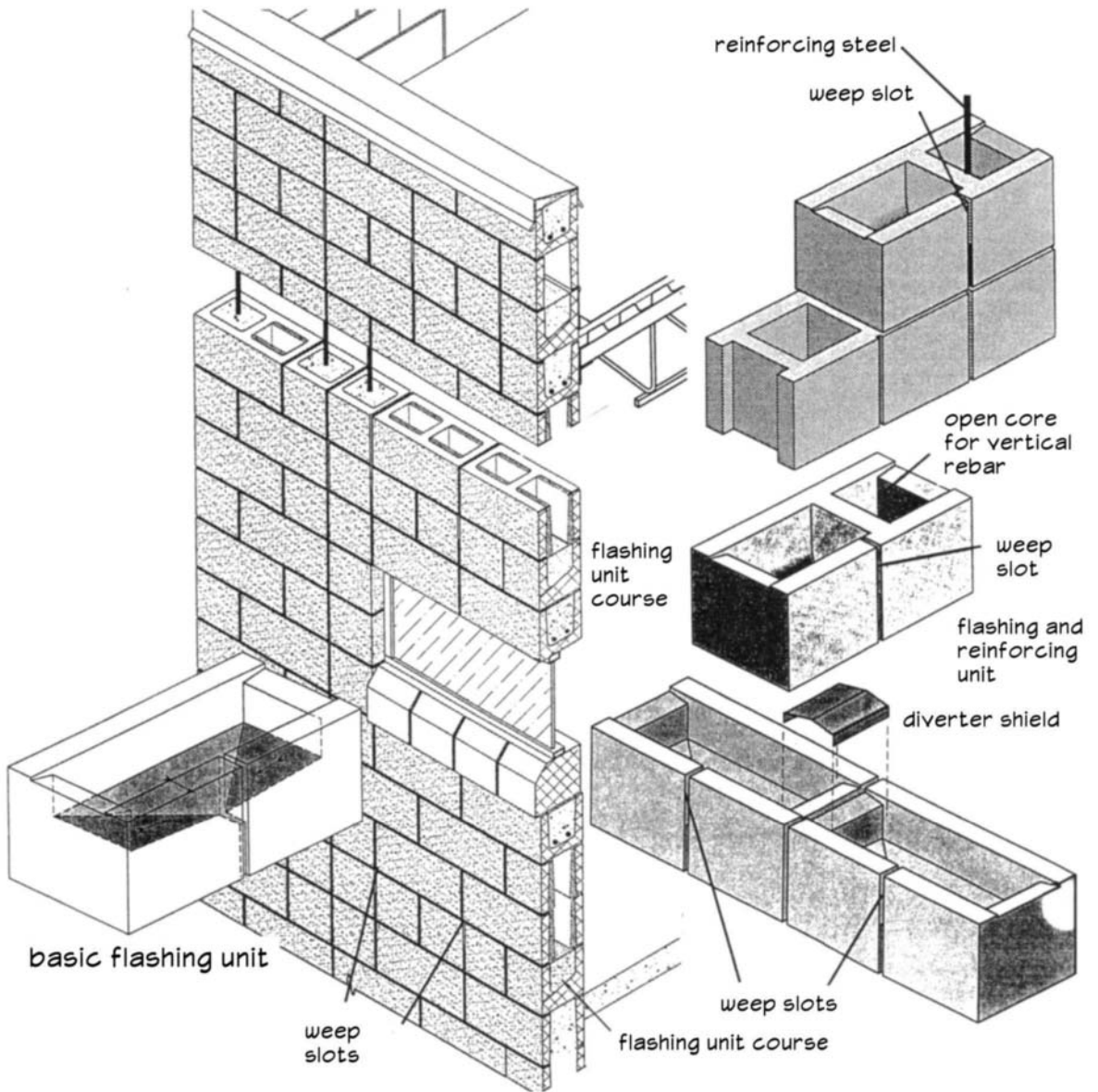
Flashing may be used in masonry and concrete building systems as a barrier against the intrusion of moisture, and as a moisture collection device. Properly designed and installed flashing and weeps are critical to the performance of drainage type walls. The most commonly used flashing materials are listed below, with advantages and disadvantages for each. The cost of flashing is usually minimal compared to the overall construction budget, and it is usually counterproductive to economize on flashing materials at the expense of durability. The selection of flashing materials should take into account the function, environment, and expected service life of the building. For institutional buildings and others which will be in service for long periods of time, only the most durable materials should be used.

Metal flashings should be shop fabricated. Two-piece fabrications will better accommodate construction tolerances in wall and cavity widths. Flashing materials that are subject to ultraviolet deterioration or which cannot be bent and formed should be used with a separate metal drip edge where required. Where concealed metal flashing is required to form a mechanical bond with mortar, it must be deformed in a dovetail or sawtooth profile.



Masonry Flashing Materials			
Material	Minimum Thickness or Gauge	Advantages	Disadvantages
Stainless steel	26 gauge/0.018 in.	Very durable, non-staining	Difficult to solder and form
Cold-rolled copper	16 oz.	Flexible, durable, easily formed and jointed	Damaged by excessive flexing, can stain surfaces below where water runs off, bitumen and fire-retardant treated wood containing salts are corrosive to copper
Galvanized steel	28 gauge/0.015 in.	Durable and easy to paint	Difficult to solder, corrodes early in acidic and salty air
Lead-coated copper	16 oz.	Flexible, durable, non-staining	Heat control of soldering irons is critical, 60-40 tin-lead solder must be used, damaged by excessive flexing
Copper laminates	5 oz. (copper)	Easy to form and join	Fabric degrades in UV light, more easily torn than full copper
EPDM	45 mil	Flexible, easy to form and join, non-staining	Metal drip edge required, full support recommended
Rubberized asphalt	40 mil	Fully adhered, separate lap adhesive not needed, self-healing, flexible, easy to form and join	Full support required, degrades in UV light, metal drip edge required, difficult adhesion in cold weather, surfaces must be clean and some require priming
PVC	30 mil	Easy to form and join, non-staining, low cost	Easily damaged, full support required, metal drip edge required, questionable durability, embrittled and often cracked by age and thermal cycling

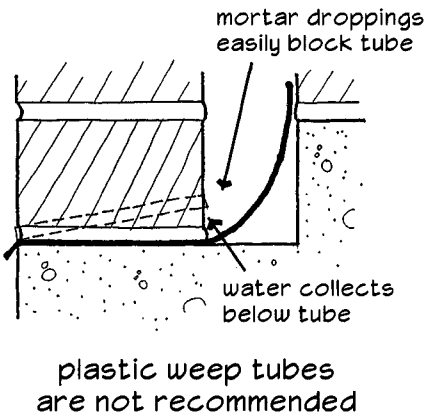
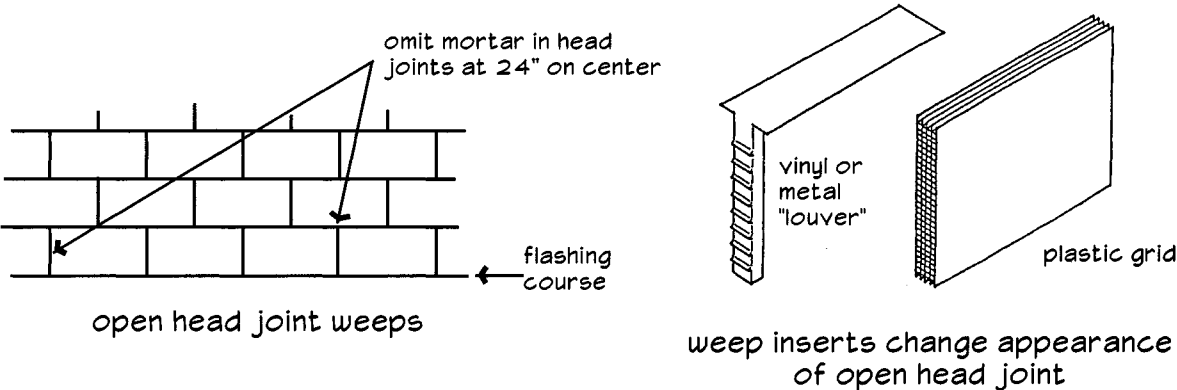
6.5.2 Self-Flashing Concrete Masonry Unit



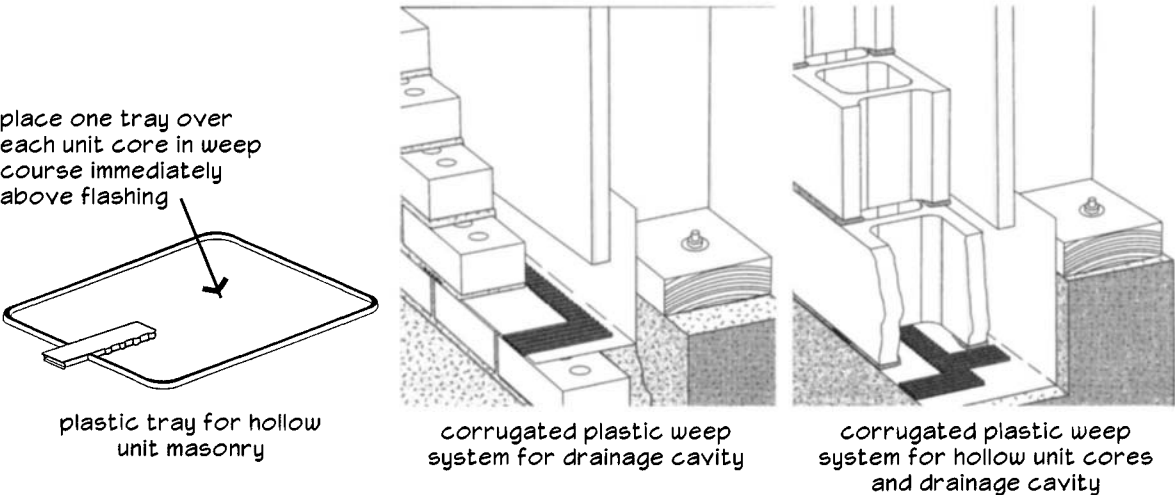
patented block design with self-flashing and weeping capability
for single-wythe concrete masonry walls

6.5.3 Weep Accessories

Moisture that is collected on the flashing in masonry wall systems must be drained to the outside through weep holes. Weeps may be of several different types as shown below. Weep spacing depends on relative drainage capacity.



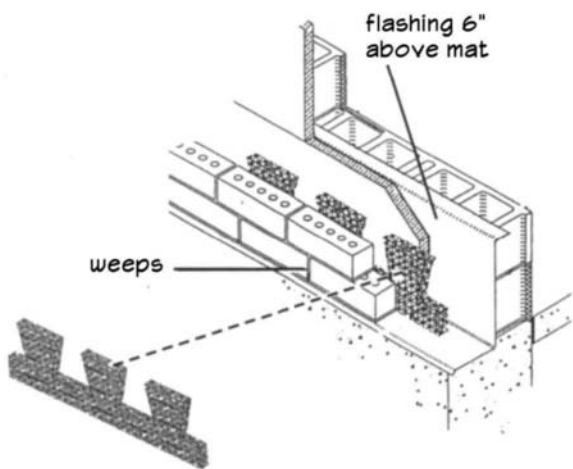
Comparison of Most Common Weep Types			
Weep Type	Advantages	Disadvantages	Recommended Spacing (in.o.c.)
Open head joint	Maximum drainage rate, ventilation	Appearance, insect intrusion	24 (brick) 32 (block)
Open joint with insert	Good drainage rate	Extra cost	24 (brick) 32 (block)
Cotton rope wick	Appearance	Slower drainage	16 (brick only)
Plastic tube	Appearance	Easily blocked	16 (brick only)



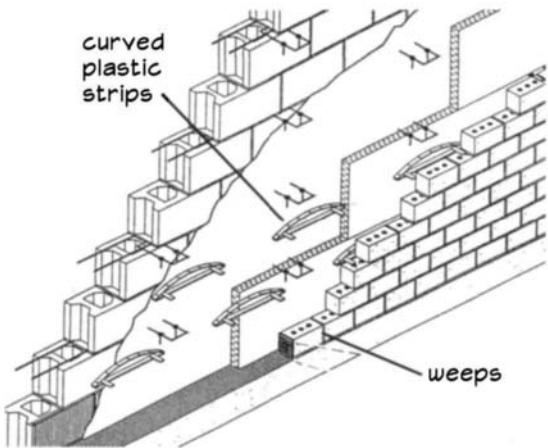
examples of proprietary weep systems

6.5.4 Drainage Accessories

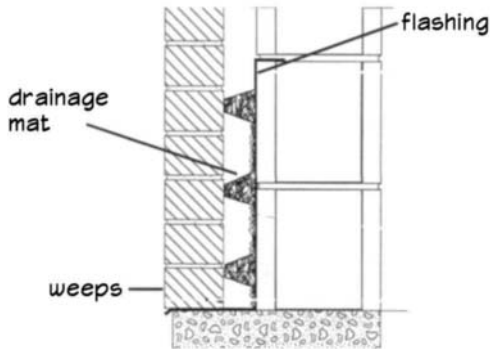
Moisture flow to weeps must be unobstructed by mortar droppings for drainage to be effective. There are a number of proprietary products available which collect, divert, or inhibit mortar droppings.



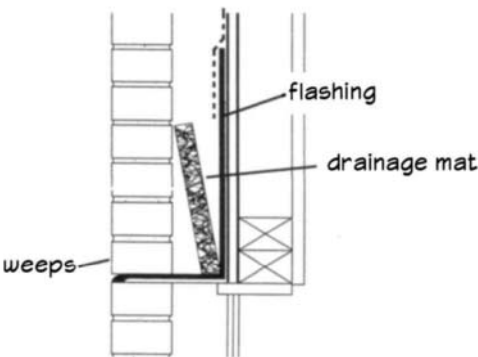
articulated woven filament



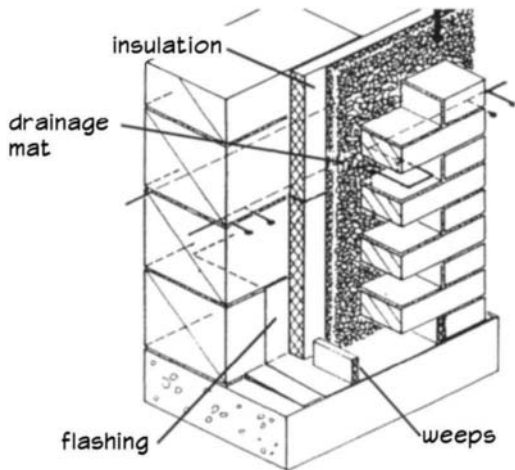
plastic diverter strips



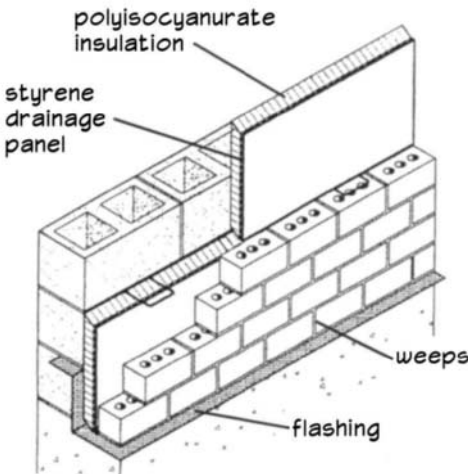
woven filament mat with staggered protrusions



flat woven filament mat



woven filament mat adhered to polystyrene insulation



polyisocyanurate insulation with adhered drainage panel

Construction Procedures

7.1 Masonry Unit Bonding and Coursing

- 7.1.1 Masonry Unit Orientation and Nomenclature
- 7.1.2 Bonding with Masonry Unit Headers
- 7.1.3 Bonding at Corners and Intersecting Walls
- 7.1.4 Modular Brick and Block
- 7.1.5 Modular Unit Layout at Openings
- 7.1.6 Modular Unit Coursing Tables

7.2 Masonry Construction

- 7.2.1 Masonry Tie and Anchor Placement
- 7.2.2 Masonry Anchor Bolt Placement
- 7.2.3 Masonry Flashing and Weep Placement
- 7.2.4 Masonry Flashing Details
- 7.2.5 Brick Suction
- 7.2.6 Masonry Mortar Mixing and Placement
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- 7.5.1 Low-Lift Masonry Grouting, 12" or Less
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- 7.5.3 High-Lift Masonry Grouting
- 7.5.4 Grouting Requirements

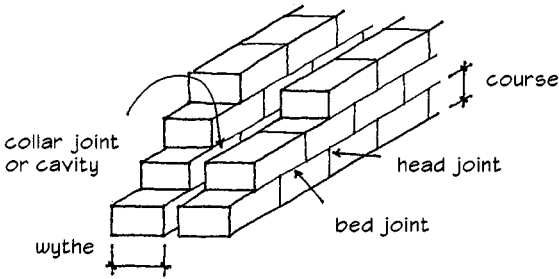
7.6 Curing Concrete and Masonry

- 7.6.1 Curing Concrete
- 7.6.2 Curing Concrete with Sheet Membranes
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- 7.6.4 Comparison of Concrete Curing Methods
- 7.6.5 Age-Strength Relationships in Concrete
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7.7 Hot And Cold Weather Procedures

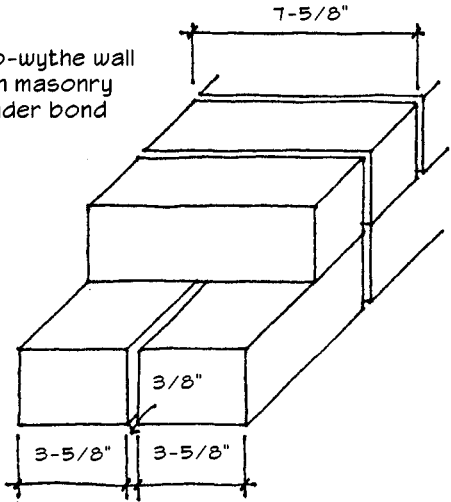
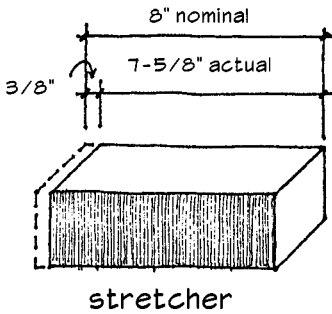
- 7.7.1 Effect of Freezing on Concrete
- 7.7.2 Recommended Concrete Temperatures for Cold Weather Construction
- 7.7.3 Mixing Water Temperatures for Concrete
- 7.7.4 Recommended Protection Period for Cold-Weather Concreting
- 7.7.5 Recommended Concrete Temperatures, and Heat of Hydration
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- 7.7.7 Insulation Blankets for Cold Weather Concrete Protection
- 7.7.8 Evaporation in Hot Weather Concreting
- 7.7.9 Cold Weather Masonry Construction
- 7.7.10 Hot Weather Masonry Construction

7.1.1 Masonry Unit Orientation and Nomenclature



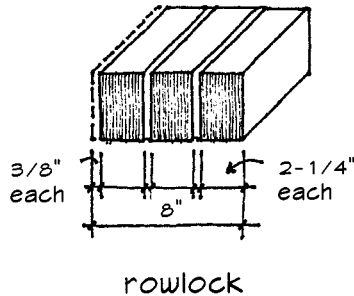
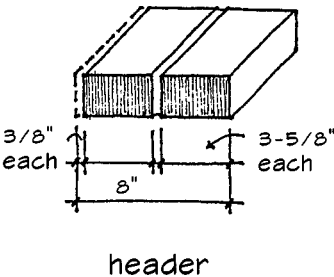
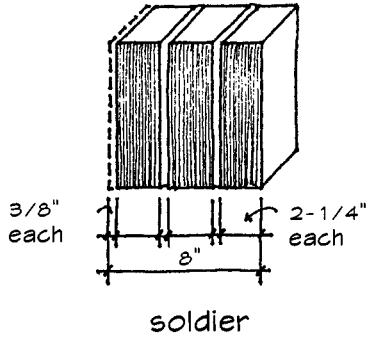
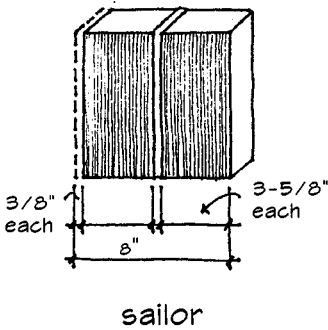
A single horizontal row of units is called a *course*. A vertical section one unit wide is called a *wythe*. Horizontal joints are called *bed joints*. Vertical joints between individual units are called *head joints*, and the longitudinal joint between wythes is called a *collar joint* if it is narrow and filled with mortar or grout, and called a *cavity* if it is an open air space for drainage.

A unit that is laid lengthwise in the wall is called a *stretcher*. Standing upright with the narrow side facing out, it is called a *soldier*—with the wide side facing out, a *sailor*. A stretcher unit that is rotated 90° in a wall so that the end is facing out is called a *header*. If the unit is then stood on its edge, it's called a *rowlock*.

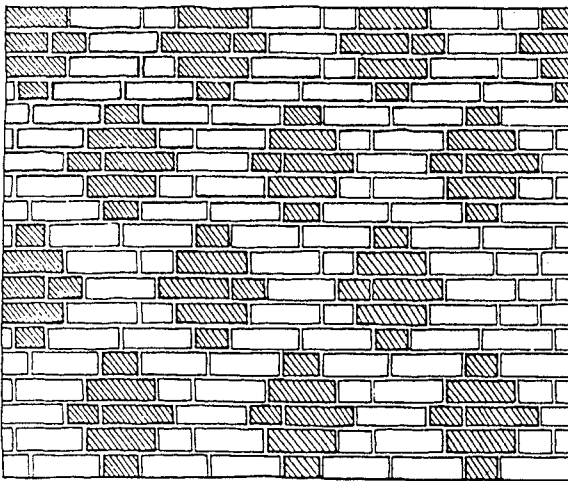
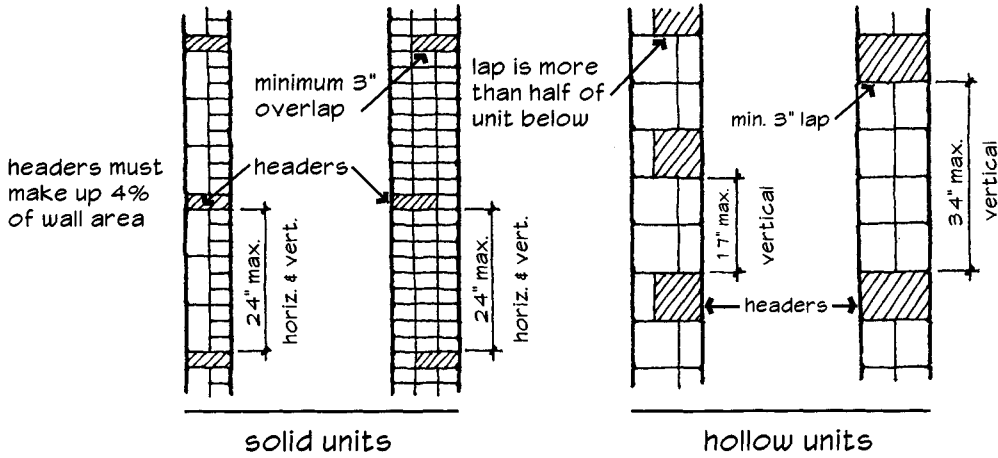


A unit whose length is cut in half is called a *bat*. One that is halved in width is called a *soap*, and one that is cut to half height is called a *split*.

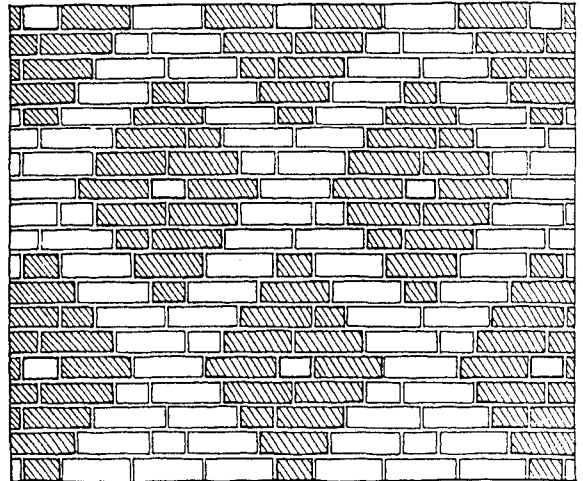
With modular brick, no matter which way you turn the units, they will work in a 4-in. module. Turning a brick stretcher crosswise in a two-wythe wall, the header unit is exactly the same width as a wall built of two wythes of brick with a 3/8" collar joint in between. Two header units or three rowlock units are the same length as one stretcher brick. One soldier course is the same height as three stretcher or header courses, and so on.



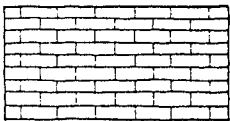
7.1.2 Bonding with Masonry Unit Headers



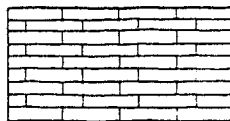
double stretcher garden wall bond with units in diagonal lines



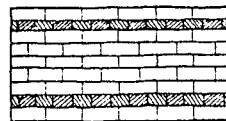
garden wall bond with units in dovetail pattern



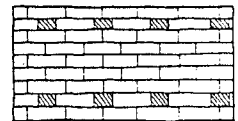
running bond



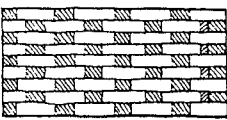
1/3 running bond



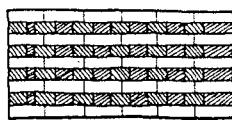
common bond or American bond
6th course headers



common bond or American bond
6th course Flemish headers



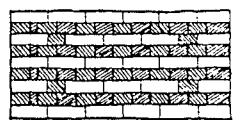
Dutch corner



English corner



stack bond



English corner

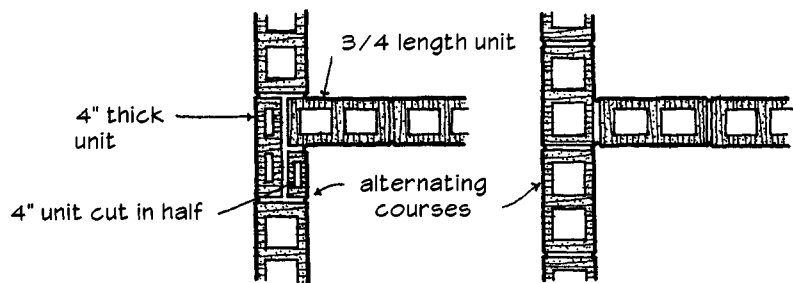
Dutch corner

Flemish bond

English bond

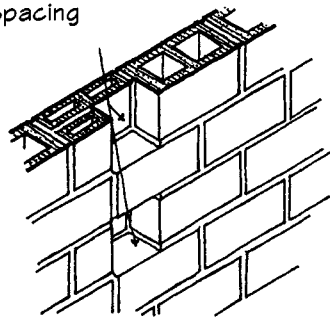
English cross or Dutch bond

7.1.3 Bonding at Corners and Intersecting Walls

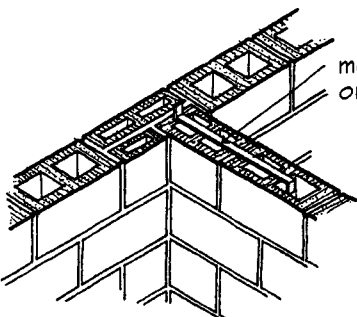


plan view of 8" walls laid up simultaneously

cavities at 8" max.
vertical spacing

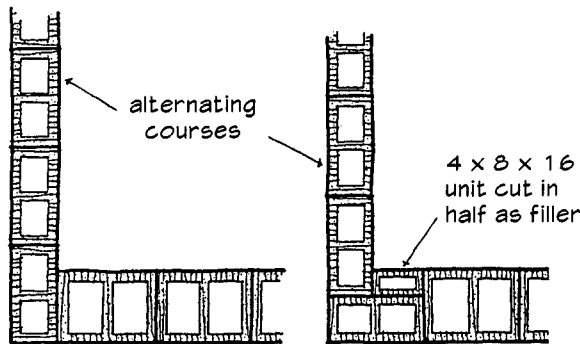


first wall constructed

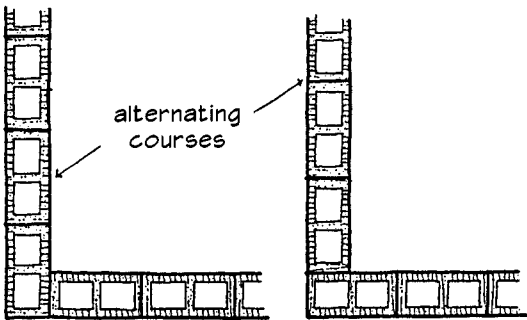


bonding and anchoring second wall to first

isometric view of walls laid up separately

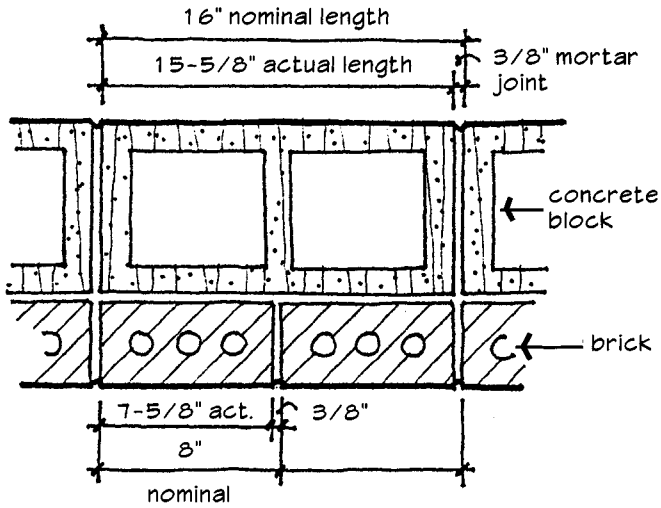


corner walls of different thickness

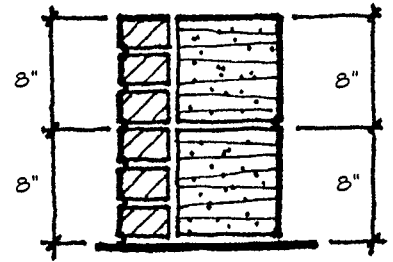


corner walls of same thickness

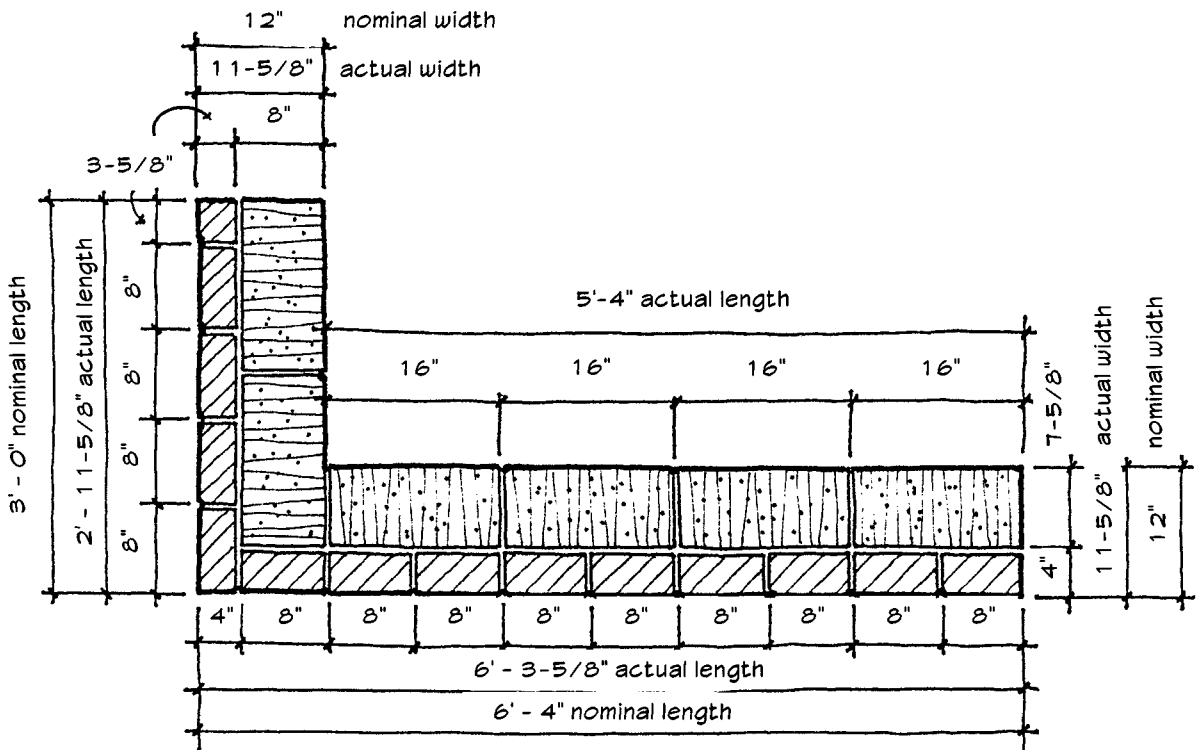
7.1.4 Modular Brick and Block



unit lengths

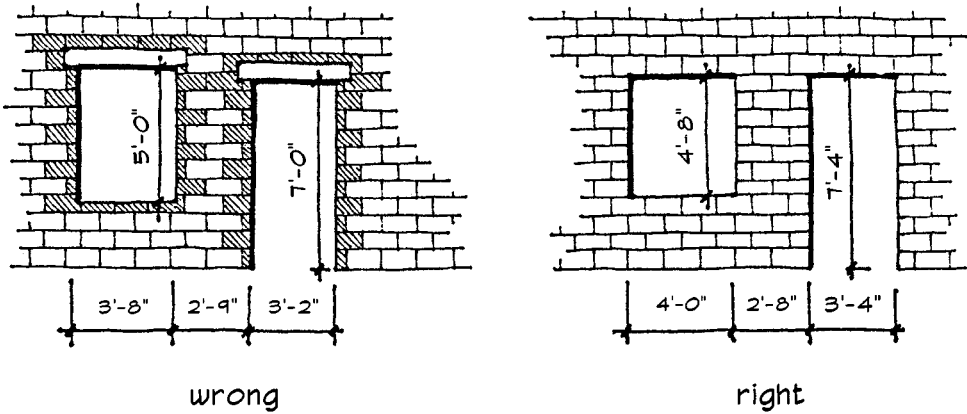


unit heights

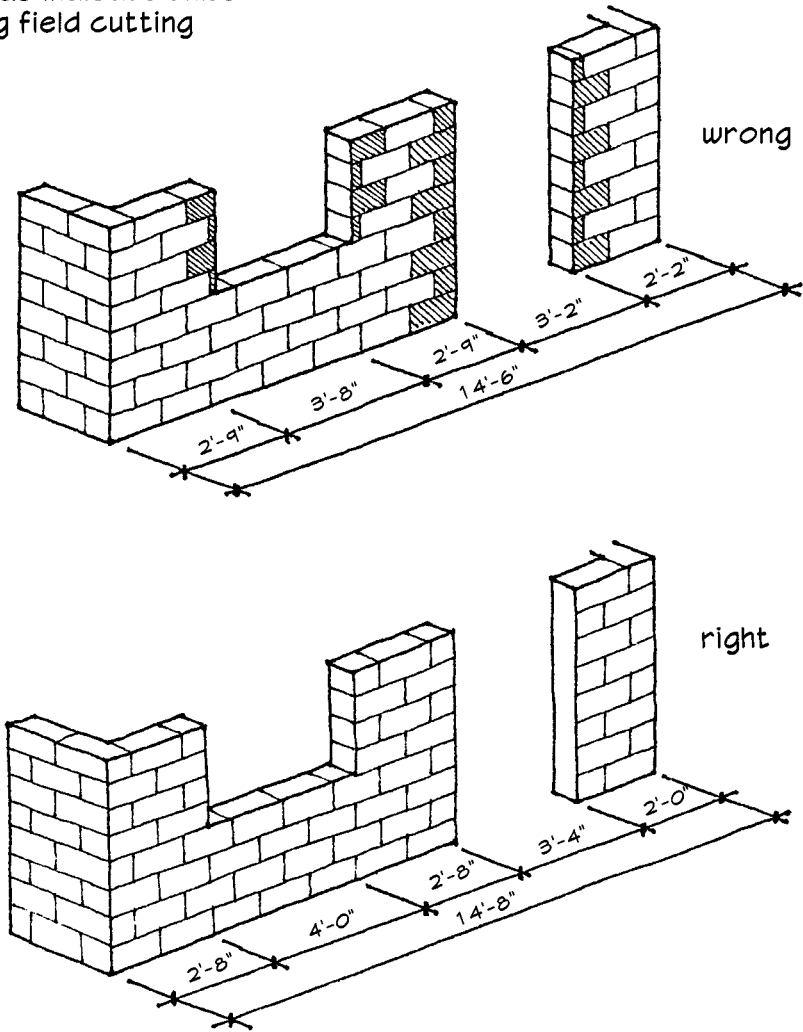


wall and corner layout

7.1.5 Modular Unit Layout at Openings



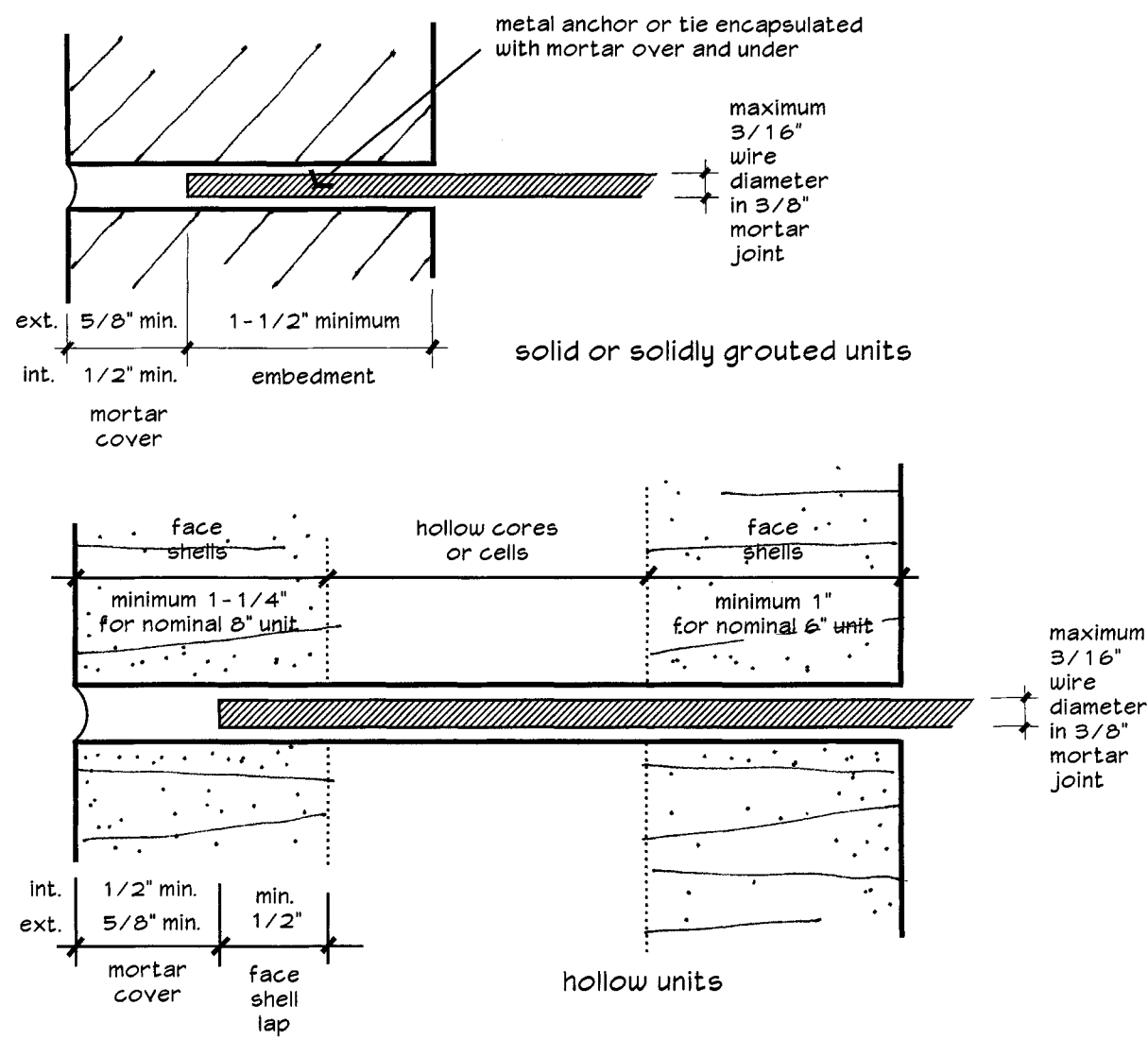
shaded areas indicate units requiring field cutting



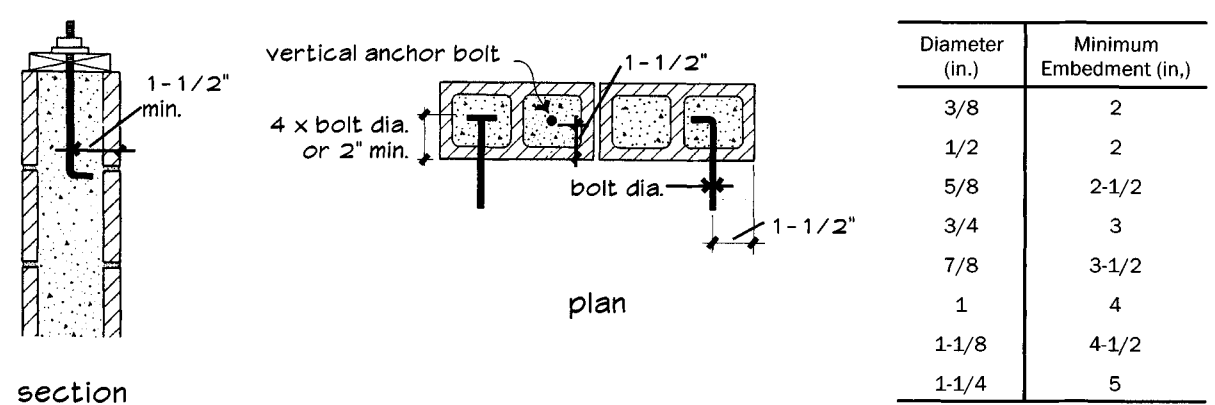
7.1.6 Modular Unit Coursing Tables

Vertical Coursing			Horizontal Coursing		
Number of Brick and Bed Joint Courses	Number of Concrete Block and Bed Joint Courses	Wall Height	Number of Brick and Head Joint Courses	Number of Concrete Block and Head Joint Courses	Wall Length
1		2'-11 1/16"	1		8"
2		5'-5/16"	2	1	1'-4"
3	1	8"	3		2'-0"
6	2	1'-4"	4	2	2'-8"
9	3	2'-0"	5		3'-4"
12	4	2'-8"	6	3	4'-0"
15	5	3'-4"	7		4'-8"
18	6	4'-0"	8	4	5'-4"
21	7	4'-8"	9		6'-0"
24	8	5'-4"	10	5	6'-8"
27	9	6'-0"	11		7'-4"
30	10	6'-8"	12	6	8'-0"
33	11	7'-4"	13		8'-8"
36	12	8'-0"	14	7	9'-4"
39	13	8'-8"	15		10'-0"
42	14	9'-4"	16	8	10'-8"
45	15	10'-0"	17		11'-4"
48	16	10'-8"	18	9	12'-0"
51	17	11'-4"	19		12'-8"
54	18	12'-0"	20	10	13'-4"
57	19	12'-8"	21		14'-0"
60	20	13'-4"	22	11	14'-8"
63	21	14'-0"	23		15'-4"
66	22	14'-8"	24	12	16'-0"
69	23	15'-4"	25		16'-8"
72	24	16'-0"	26	13	17'-4"
			27		18'-0"
			28	14	18'-8"
			29		19'-4"
			30	15	20'-0"
			36	18	24'-0"
			42	21	28'-0"
			48	24	32'-0"

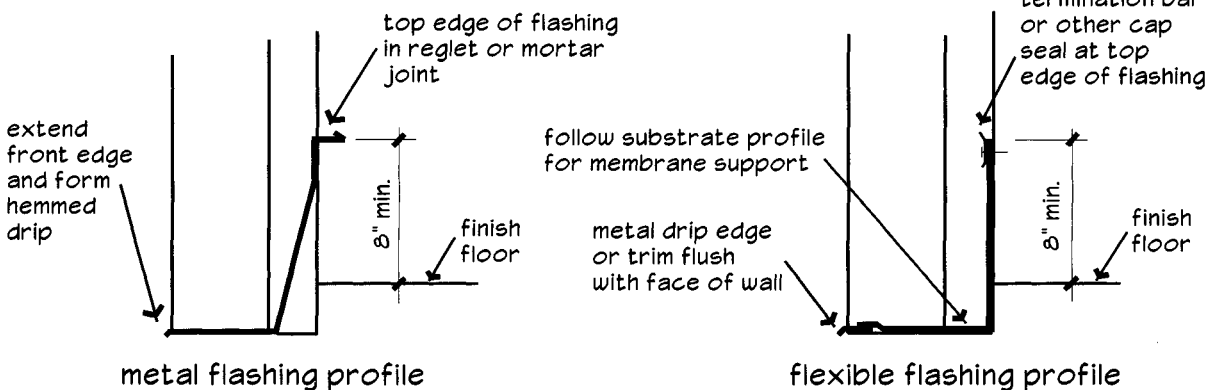
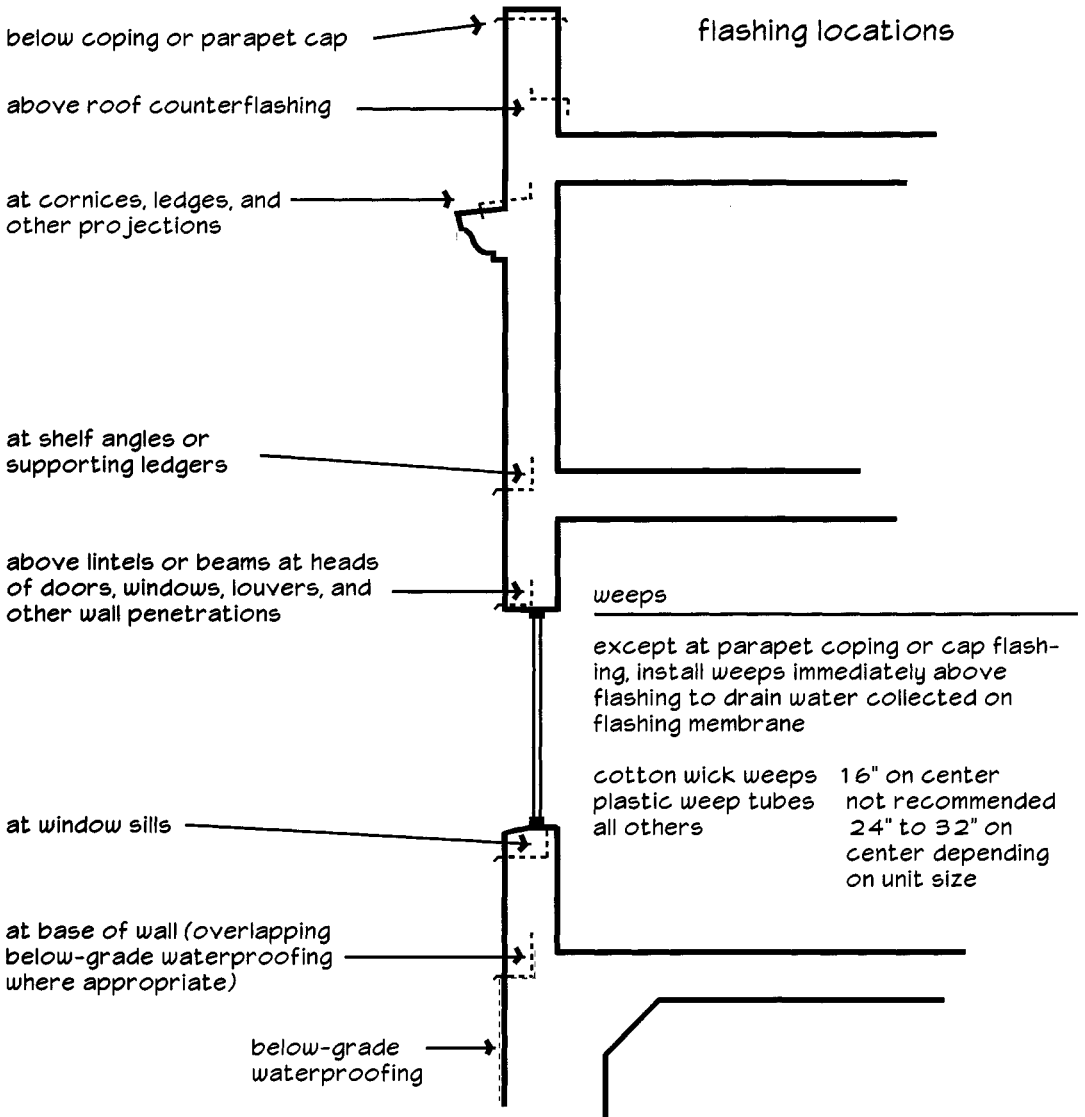
7.2.1
Masonry Tie and Anchor Placement



7.2.2
Masonry Anchor Bolt Placement

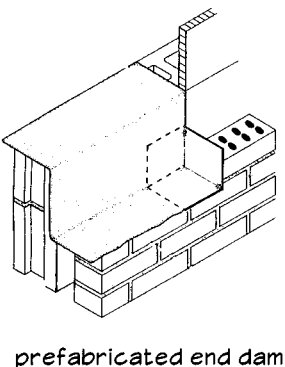
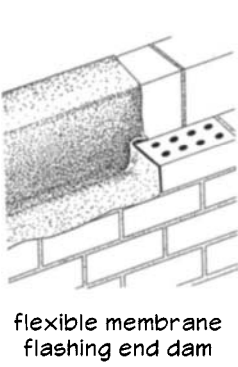
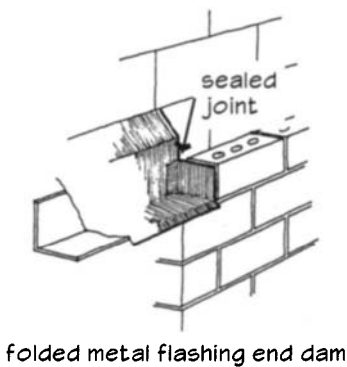
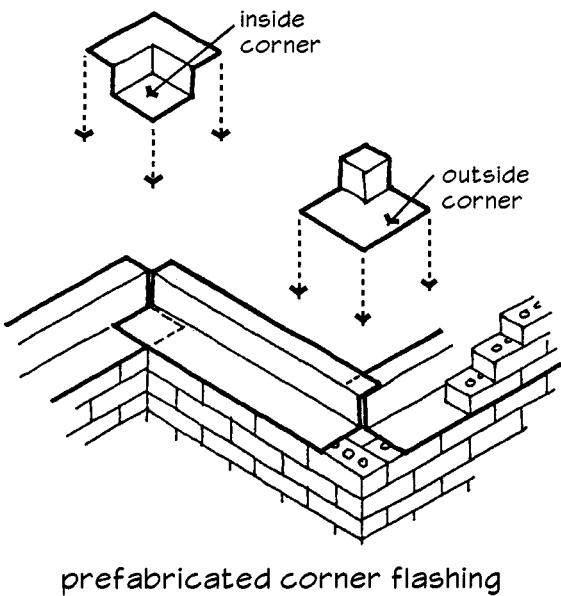
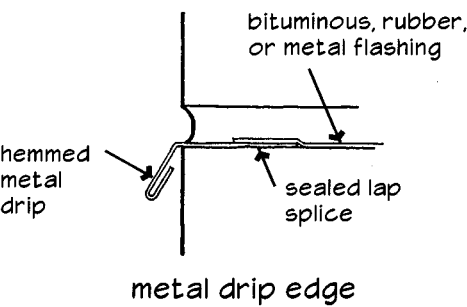


7.2.3 Masonry Flashing and Weep Placement



7.2.4 Masonry Flashing Details

Flashing should be continuous at building corners and offsets, and installation is greatly facilitated by the use of prefabricated metal or rubber corner flashing boots. Flashing must also be lapped and sealed at joints. A non-hardening butyl caulk or urethane sealant will provide better accommodation of thermal expansion and contraction of metal flashings than soldered joints. At terminations, flashing should be turned up to form an end dam. Where masonry abuts door jambs, curtain wall, storefront systems, or other cladding materials, stop flashing in first head joint adjacent to interface and form end dam. Where steel or concrete columns interrupt CMU backing in masonry cavity walls, flashing should be continued across the face of the column, and the gaps between the backing wall and columns should be sealed against air and moisture penetration.

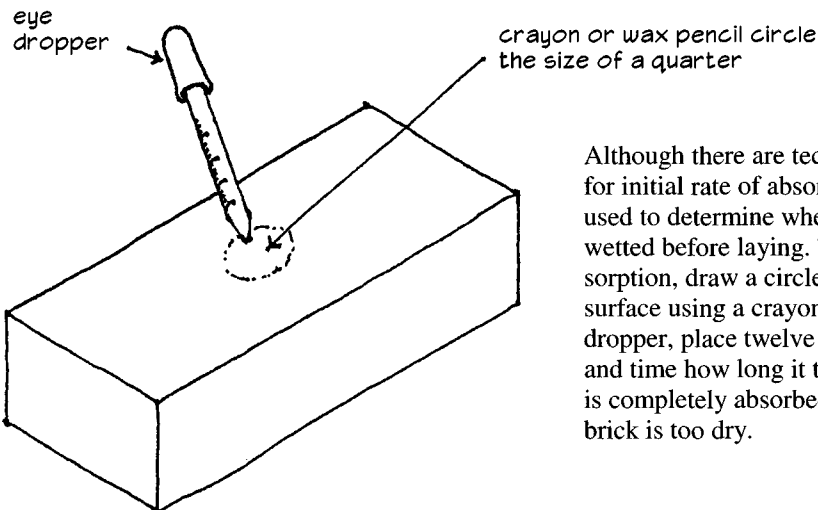
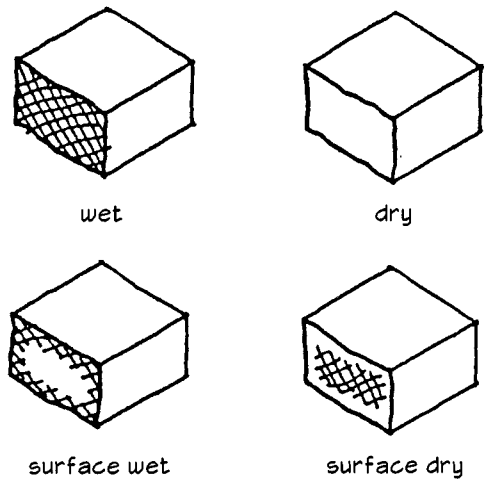
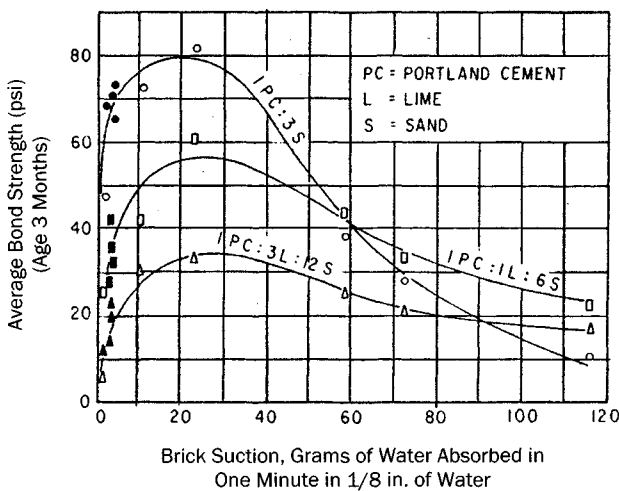


end dams at flashing terminations

7.2.5 Brick Suction

When brick is manufactured, it is fired in a high-temperature kiln which drives virtually all of the moisture out of the wet clay. Fired brick are extremely dry until they absorb enough moisture from the air to achieve a state of moisture equilibrium with their surroundings. Brick that is very dry when it is laid causes rapid and excessive loss of mixing water from the mortar which results in poor adhesion, incomplete bond, and water-permeable joints of low strength. Brick that is very dry and absorptive is said to have a high initial rate of absorption (IRA) or high suction. High-suction brick should be wetted with a garden hose the day before they will be used so that moisture is fully absorbed into the units but the surfaces are dry to the touch before being laid. Visual inspection of a broken brick will indicate whether moisture is evenly distributed throughout the unit. A surface film of water will cause the brick to float. Where prewetting of units is not possible, the time lapse between spreading the mortar and laying the unit should be kept to a minimum.

Some experts recommend that brick not be wetted in winter because some high-suction units produce better bond strength in cold weather than low-suction units. Even though it is very absorptive, concrete block should never be wetted before placement because this will increase unit shrinkage and the possibility of cracking in the finished wall.

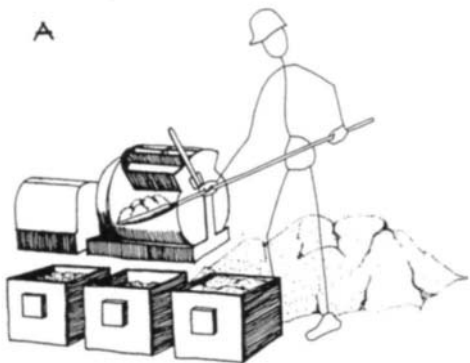


Although there are technical laboratory and field tests for initial rate of absorption, a simple field test can be used to determine whether or not the units need to be wetted before laying. To test a brick for excessive absorption, draw a circle the size of a quarter on the bed surface using a crayon or wax pencil. With a medicine dropper, place twelve drops of water inside the circle and time how long it takes to be absorbed. If the water is completely absorbed in less than one minute, the brick is too dry.

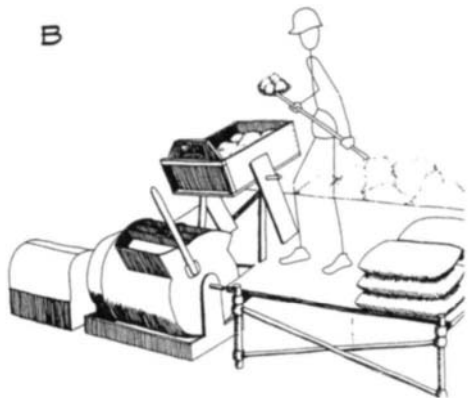
7.2.6 Masonry Mortar Mixing and Placement

Proper proportioning of mortar ingredients is critical to field quality control. While the volume of cement, lime, and admixtures is relatively easy to control, sand bulks with increases in moisture content, so the volume of a given quantity of sand may vary throughout the day and from day to day. Measuring sand by counting shovels is not an accurate method of batching and is not recommended. The illustrations below show two alternate methods for accurately measuring sand volume. Figure A shows measuring boxes being used to check the number of shovels of sand it takes for 1 cubic foot. Measuring boxes should be used at least twice a day to check sand volume, once in the morning and again after lunch. Figure B shows a batching box in which the sand is shoveled into a 1 cubic foot measure and then discharged into the mixer from the box. This method is more accurate and accounts for continuous volume changes in the sand as it dries or bulks with moisture changes.

All of the aggregate and cementitious materials (cement and lime) should be mixed for 3 to 5 minutes in a mechanical batch mixer with the maximum amount of water to produce a workable consistency. Within the first 2-1/2 hours of mixing, mortar that has begun to stiffen because of evaporation should be retempered by adding water as frequently as needed to restore the required consistency. This will assure better mortar bond by keeping workability at the optimum. No mortar should be used beyond 2-1/2 hours after mixing.

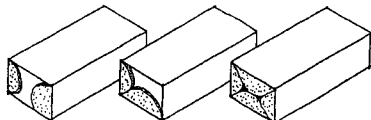
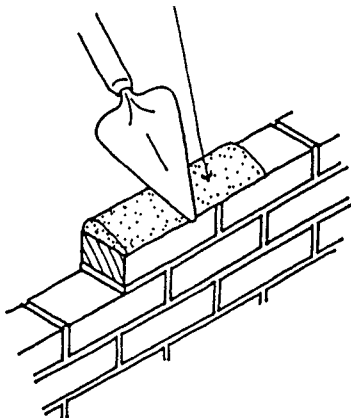


measuring boxes for checking sand volume during the work day



batching box for accurately and continuously measuring sand volume

bevel bed joints to minimize mortar droppings in cavity



fill head joints for better resistance to rain penetration

Hollow unit masonry is laid with mortar applied only to the vertical and horizontal face shell thickness (face-shell bedding). Webs are mortared only on piers, columns, and pilasters, in the starting course at foundations, and adjacent to unit cores which will be grouted.

7.2.7 Temporary Bracing for Masonry Walls

Bracing is used to stabilize masonry walls under construction. Before the mortar is cured and the wall has developed its full design strength, high wind loads can cause structural failures that endanger the lives of workers. If wind speeds are 20 mph or less, the *Standard Practice for Bracing Masonry Walls Under Construction* allows a maximum unbraced height for various types of masonry based on unit density and on the assumption that during the “Initial Period” after construction, the mortar is assumed to have no strength (see table below). The Initial Period is limited to a maximum of one working day after the wall is built, and the unbraced height may be the height above the base of the wall, or the height above the highest line of bracing. Wall stability is provided only by the dead weight of the materials. The heavier the units, the more stable the wall. Walls greater in height than the allowable must be braced against lateral loads.

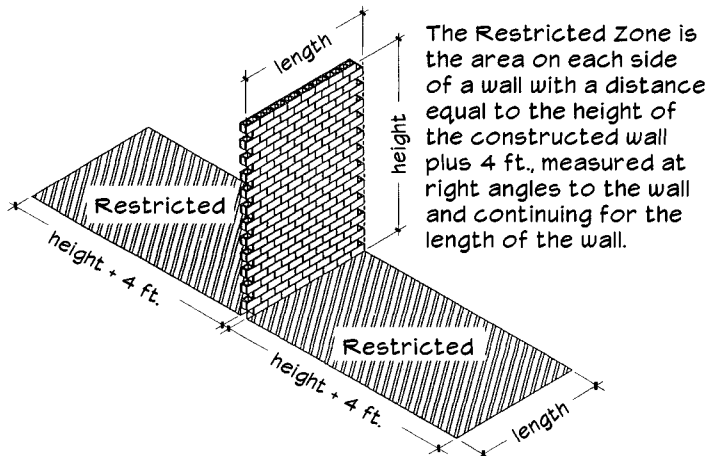
During the “Intermediate Period” before the mortar has attained its full strength and until the wall is permanently anchored for lateral stability, the wall is assumed to have half the 28-day design strength. The design of tall walls must take into account this period of reduced strength. Development length of reinforcement is increased by a factor of 1.67 over that required by code to account for uncured grout. Tables in the Standard identify required height and spacing for reinforced and unreinforced masonry built with various mortars (see following pages).

When wind speeds exceed 20 mph during the Initial Period or 35 mph during the Intermediate Period, the Standard requires that work stop and an area around the wall identified as the “Restricted Zone” be evacuated for safety. The Restricted Zone may remain occupied during the Initial Period if the wall is no more than 8 ft. above grade and wind speeds are not more than 35 mph.

Initial Period—Maximum Unbraced Height of Masonry Walls Above Grade or Above Highest Line of Lateral Support, Maximum 20 mph Wind Speed, Measured on Each Side of the Wall (ft.)

Nominal Wall Thickness (in.)	Lightweight Units (Density 95 to 115 pcf)		Medium Weight Units (Density 115 to 125 pcf)		Normal Weight Units (Density greater than 125 pcf)	
	Hollow Units	Solid or Solidly Grouted Units	Hollow Units	Solid or Solidly Grouted Units	Hollow Units	Solid or Solidly Grouted Units
4	8'-0"	8'-0"	8'-0"	8'-0"	8'-0"	8'-0"
6	8'-0"	8'-0"	8'-0"	10'-0"	8'-0"	10'-6"
8	10'-8"	15'-4"	12'-8"	18'-0"	14'-0"	20'-0"
10	16'-8"	24'-2"	20'-0"	29'-2"	21'-8"	31'-8"
12	23'-0"	35'-0"	28'-0"	35'-0"	30'-0"	35'-0"

For partially grouted masonry, weight of masonry shall be determined by linear interpolation between hollow ungrouted units and fully grouted units, based on the amount of grouting.



Maximum Allowable Observed 5-Second Wind Gust Speed (mph)

Period	Instrument [§]	Visual [†]
Initial	20	15
Intermediate	35	30

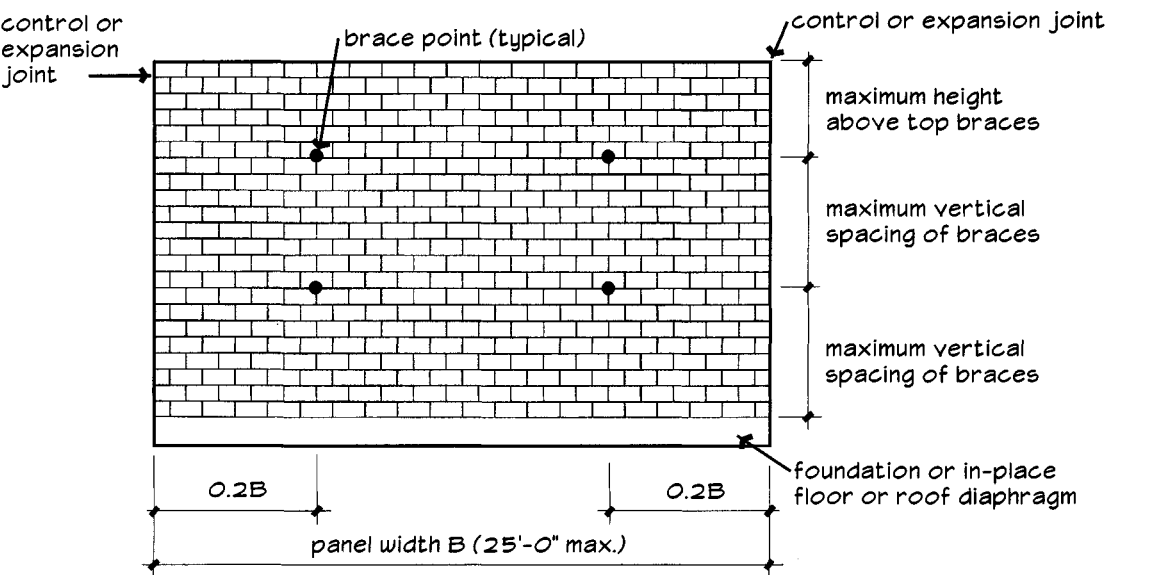
[§] Preferred method. Required accuracy of instrument ± 2 mph.

[†] The Standard identifies several visual methods for determining wind speed, all of which require experience for proficiency.

7.2.8 Temporary Brace Locations

Intermediate Period—Temporary Brace Locations ^s (ft.)					
Bracing Condition	Mortar Type →	PC-Lime or Mortar Cement		Masonry Cement	
		Type M or S	Type N	Type M or S	Type N
8 in. Unreinforced Wall					
Maximum unbraced height, unbonded condition [†]		3'-4" [‡]	3'-4" [‡]	3'-4" [‡]	3'-4" [‡]
Maximum height above top brace ^{§§}		6'-8"	6'-0"	5'-4"	4'-8"
Maximum vertical spacing of braces ^{§§}		14'-0"	12'-8"	11'-4"	10'-0"
12 in. Unreinforced Wall					
Maximum unbraced height, unbonded condition [†]		7'-4" [‡]	7'-4" [‡]	7'-4" [‡]	7'-4" [‡]
Maximum height above top brace ^{§§}		10'-8"	10'-0"	8'-8"	8'-0"
Maximum vertical spacing of braces ^{§§}		21'-4"	19'-4"	17'-4"	16'-0"
8 in. Reinforced Wall ^{††}					
Maximum unbraced height or height above top brace ^{‡‡}		10'-8"	10'-8"	10'-8"	10'-8"
Maximum vertical spacing of braces		21'-4"	21'-4"	21'-4"	21'-4"
12 in. Reinforced Wall ^{††}					
Maximum unbraced height or height above top brace ^{‡‡}		15'-4"	15'-4"	15'-4"	15'-4"
Maximum vertical spacing of braces		30'-0"	30'-0"	30'-0"	30'-0"

- ^s
Maximum height permitted without bracing for all hollow CMU 95 pcf and greater density, solid CMU, and hollow and solid clay masonry.
- [†]
Assumes an unbonded condition between the wall and foundation, such as at flashing.
- [‡]
Exception: walls 8 ft. tall and less above the ground do not need to be braced.
- ^{§§}
Assumes continuity of masonry other than at the base (i.e., no flashing other than at the base).
- ^{††}
Reinforced walls are considered unreinforced until grout is in place 12 hours. Minimum reinforcement for 8 in. walls is #5 vertical bars at 48 in. on center. Minimum lap splice for grout less than 24 hrs. old, 40 in.; for grout more than 24 hrs. old, 30 in. lap splice. Minimum reinforcement for 12 in. walls is #5 vertical bars at 72 in. on center. Minimum lap splice for grout less than 24 hrs. old, 40 in.; for grout more than 24 hrs. old, 30 in. lap splice.
- ^{‡‡}
Masonry may be bonded or unbonded (i.e., flashing located anywhere in wall) provided that vertical reinforcement is continuous throughout the wall and into the foundation. For reinforced walls not requiring bracing, check adequacy of foundation to prevent overturning.



- Notes:
- For maximum vertical spacing of braces, see table above.
 - For maximum height above braces during initial period see table on previous page, for intermediate period see table on next page.

(Adapted from Council for Masonry Bracing, Standard Practice for Bracing Masonry Walls Under Construction, 2001)

7.2.9 Maximum Unbraced Wall Height

Intermediate Period—Maximum Unbraced Heights for Masonry Walls [§]					
Wall Type	Mortar Type →	PC-Lime or Mortar Cement		Masonry Cement	
		Type M or S	Type N	Type M or S	Type N
35 mph Evacuation Wind Speed (40 mph Design Wind Speed)					
8 in. unreinforced, unbonded†		3'-4"‡	3'-4"‡	3'-4"‡	3'-4"‡
8 in. unreinforced, bonded§§		6'-8"	6'-0"	5'-4"	4'-8"
8 in. reinforced††, unbonded† or bonded§§					
#5 @ 10 ft. o.c.		12'-0"	12'-0"	12'-0"	12'-0"
#5 @ 4 ft. o.c.		19'-4"	19'-4"	19'-4"	19'-4"
12 in. unreinforced, unbonded†		7'-4"‡	7'-4"‡	7'-4"‡	7'-4"‡
12 in. unreinforced, bonded§§		10'-8"	10'-0"	8'-8"	8'-0"
12 in. reinforced††, unbonded† or bonded§§					
#5 @ 10 ft. o.c.		20'-0"	20'-0"	20'-0"	20'-0"
#5 @ 6 ft. o.c.		24'-0"	24'-0"	24'-0"	24'-0"
30 mph Evacuation Wind Speed (35 mph Design Wind Speed)					
8 in. unreinforced, unbonded†		4'-0"‡	4'-0"‡	4'-0"‡	4'-0"‡
8 in. unreinforced, bonded§§		8'-0"	7'-4"	6'-8"	6'-0"
8 in. reinforced††, unbonded† or bonded§§					
#5 @ 10 ft. o.c.		14'-8"	14'-8"	14'-8"	14'-8"
#5 @ 4 ft. o.c.		22'-0"	22'-0"	22'-0"	22'-0"
12 in. unreinforced, unbonded†		9'-0"‡	9'-0"‡	9'-0"‡	9'-0"‡
12 in. unreinforced, bonded§§		12'-8"	11'-4"	10'-8"	9'-4"
12 in. reinforced††, unbonded† or bonded§§					
#5 @ 10 ft. o.c.		23'-4"	23'-4"	23'-4"	23'-4"
#5 @ 6 ft. o.c.		28'-8"	28'-8"	28'-8"	28'-8"
25 mph Evacuation Wind Speed (30 mph Design Wind Speed)					
8 in. unreinforced, unbonded†		6'-0"‡	6'-0"‡	6'-0"‡	6'-0"‡
8 in. unreinforced, bonded§§		10'-0"	8'-8"	8'-0"	6'-8"
8 in. reinforced††, unbonded† or bonded§§					
#5 @ 10 ft. o.c.		16'-8"	16'-8"	16'-8"	16'-8"
#5 @ 4 ft. o.c.		25'-4"	25'-4"	25'-4"	25'-4"
12 in. unreinforced, unbonded†		12'-8"‡	12'-8"‡	12'-8"‡	12'-8"‡
12 in. unreinforced, bonded§§		15'-4"	14'-0"	12'-8"	11'-4"
12 in. reinforced††, unbonded† or bonded§§					
#5 @ 10 ft. o.c.		28'-8"	28'-8"	28'-8"	28'-8"
#5 @ 6 ft. o.c.		33'-4"	33'-4"	33'-4"	33'-4"
20 mph Evacuation Wind Speed (25 mph Design Wind Speed)					
8 in. unreinforced, unbonded†		8'-8"‡	8'-8"‡	8'-8"‡	8'-8"‡
8 in. unreinforced, bonded§§		12'-0"	10'-8"	10'-0"	8'-8"
8 in. reinforced††, unbonded† or bonded§§					
#5 @ 10 ft. o.c.		20'-0"	20'-0"	20'-0"	20'-0"
#5 @ 4 ft. o.c.		26'-0"	26'-0"	26'-0"	26'-0"
12 in. unreinforced, unbonded†		18'-0"‡	18'-0"‡	18'-0"‡	18'-0"‡
12 in. unreinforced, bonded§§		20'-0"	18'-0"	16'-8"	15'-4"
12 in. reinforced††, unbonded† or bonded§§					
#5 @ 10 ft. o.c.		28'-8"	28'-8"	28'-8"	28'-8"
#5 @ 6 ft. o.c.		33'-4"	33'-4"	33'-4"	33'-4"
15 mph Evacuation Wind Speed (20 mph Design Wind Speed)					
8 in. unreinforced, unbonded†		12'-8"‡	12'-8"‡	12'-8"‡	12'-8"‡
8 in. unreinforced, bonded§§		16'-0"	14'-8"	13'-4"	12'-0"
8 in. reinforced††, unbonded† or bonded§§					
#5 @ 10 ft. o.c.		20'-8"	20'-8"	20'-8"	20'-8"
#5 @ 4 ft. o.c.		26'-0"	26'-0"	26'-0"	26'-0"
12 in. unreinforced, unbonded†		28'-0"‡	28'-0"‡	28'-0"‡	28'-0"‡
12 in. unreinforced, bonded§§		27'-4"	25'-4"	23'-8"	22'-0"
12 in. reinforced††, unbonded† or bonded§§					
#5 @ 10 ft. o.c.		28'-8"	28'-8"	28'-8"	28'-8"
#5 @ 6 ft. o.c.		33'-4"	33'-4"	33'-4"	33'-4"

[§] Maximum height permitted without bracing for all hollow CMU 95 pcf and greater density, solid CMU, and hollow and solid clay masonry.

[†] Assumes an unbonded condition between the wall and foundation, such as at flashing.

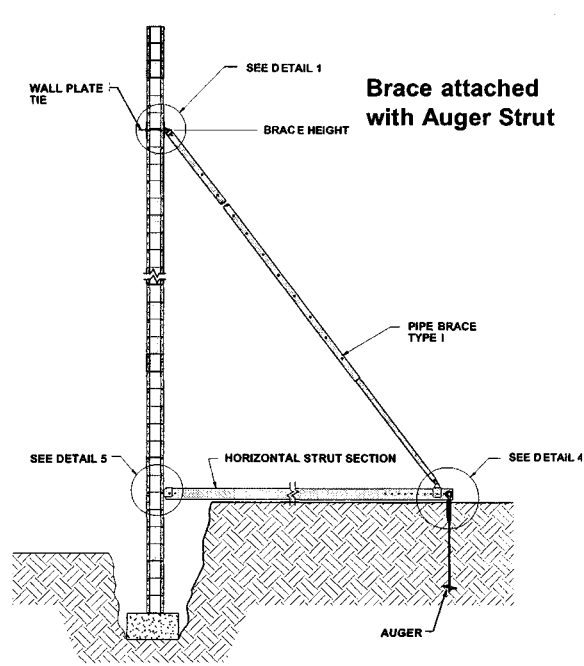
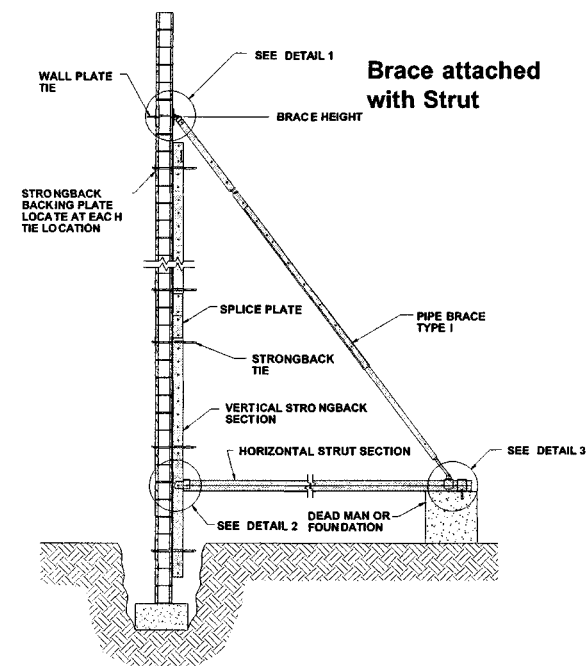
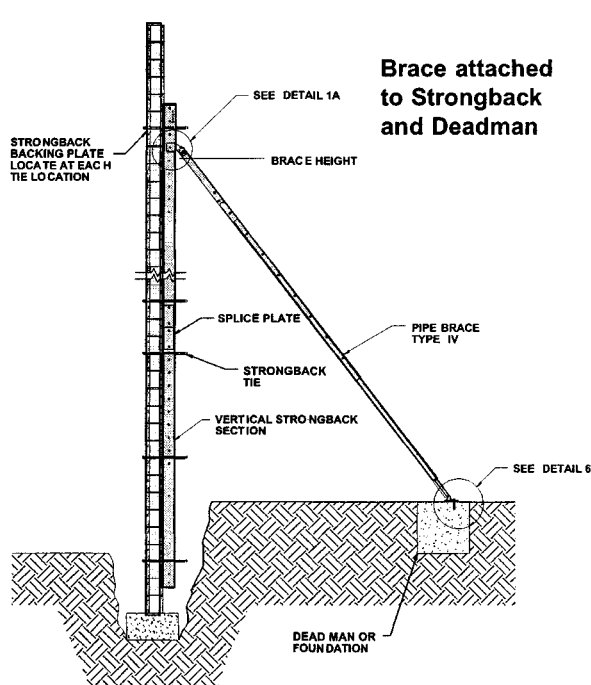
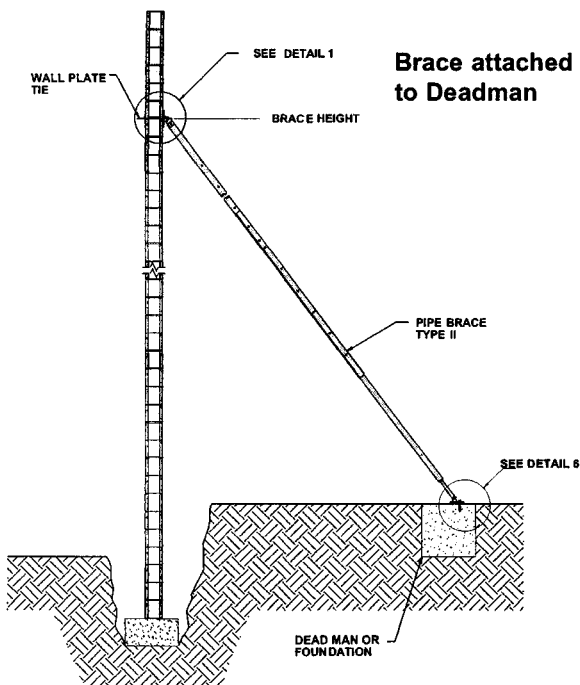
[‡] Exception: walls 8 ft. tall and less above the ground do not need to be braced.

^{§§} Bonded condition assumes continuity of masonry at the base (i.e., no flashing).

^{††} Reinforced walls are considered unreinforced until grout is in place 12 hours. Reinforcement indicated is minimum vertical reinforcement required and continuous into foundation. Minimum lap splice for grout less than 24 hrs. old, 40 in.; for grout more than 24 hrs. old, 30 in. lap splice. For reinforced walls not requiring bracing, check adequacy of foundation to prevent overturning.

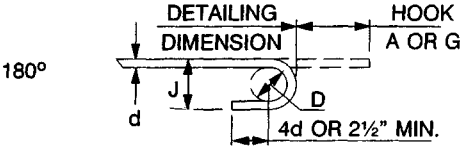
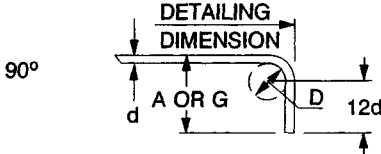
(Adapted from Council for Masonry Bracing, Standard Practice for Bracing Masonry Walls Under Construction, 2001)

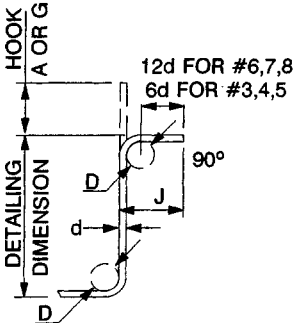
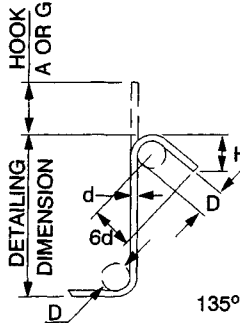
7.2.10 Examples of Masonry Bracing Methods



(From Dur-O-Wall Technical Bulletin 99-2, 1999)

7.3.1 Standard Hooks, Stirrups, and Tie-Hooks

Dimensions for Standard Hooks (in.)					
	Bar Size	D	180°		90°
			A or G	J	A or G
	#3	2-1/4	5	3	6
	#4	3	6	4	8
	#5	3-3/4	7	5	10
	#6	4-1/2	8	6	12
	#7	5-1/4	10	7	14
	#8	6	11	8	16
	#9	9-1/2	15	11-3/4	19
	#10	10-3/4	17	13-1/4	22
	#11	12	19	14-3/4	24
	#14	18-1/4	27	21-3/4	31
	#18	24	36	28-1/2	41

Dimensions for Stirrup and Tie-Hooks (in.)					
	Bar Size	D	90°	135°	
			A or G	A or G	H
	#3	1-1/2	4	4	2-1/2
	#4	2	4-1/2	4-1/2	3
	#5	2-1/2	6	5-1/2	3-3/4
	#6	4-1/2	12	8	4-1/2
	#7	5-1/4	14	9	5-1/4
	#8	6	16	10-1/2	6
	#3	1-1/2	4	4	2-1/2
	#4	2	4-1/2	4-1/2	3
	#5	2-1/2	6	5-1/2	3-3/4
	#6	4-1/2	12	8	4-1/2
	#7	5-1/4	14	9	5-1/4
	#8	6	16	10-1/2	6

(From PCI Design Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)

7.3.2
Minimum Tension Embedment Lengths, ℓ_{dh} , for Standard Hooks (in.)

General use (non-seismic)

Bar size	Normal weight concrete, f'_c (psi)							
	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
#3	6	6	6	6	6	6	6	6
#4	8	7	6	6	6	6	6	6
#5	10	9	8	7	7	6	6	6
#6	12	10	9	8	8	7	7	6
#7	14	12	11	10	9	9	8	7
#8	16	14	12	11	10	10	9	8
#9	18	15	14	13	12	11	10	9
#10	20	17	15	14	13	12	11	11
#11	22	19	17	16	14	14	13	12

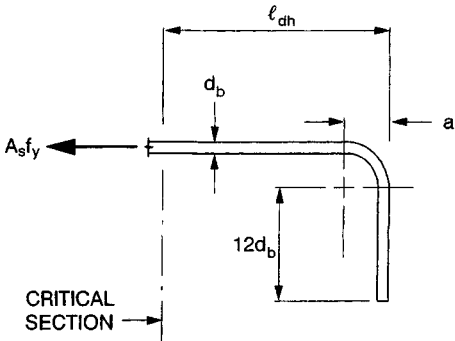
- NOTES: 1. SIDE COVER $\geq 2\frac{1}{2}$ in.
2. END COVER (90° HOOKS) ≥ 2 in.

Special confinement (non-seismic) (See ACI 318-95, Sec. 12.5.3.3)

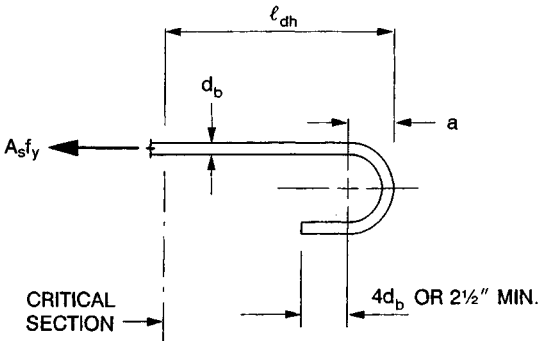
Bar size	Normal weight concrete, f'_c (psi)							
	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
#3	6	6	6	6	6	6	6	6
#4	6	6	6	6	6	6	6	6
#5	8	7	6	6	6	6	6	6
#6	10	8	7	7	6	6	6	6
#7	11	10	9	8	7	7	6	6
#8	13	11	10	9	8	8	7	6
#9	14	12	11	10	9	9	8	7
#10	16	14	12	11	11	10	9	9
#11	18	15	14	13	12	12	10	10

- NOTES: 1. SIDE COVER $\geq 2\frac{1}{2}$ in.
2. END COVER (90° HOOKS) ≥ 2 in.

BARS WITH STANDARD HOOKS:



STANDARD 90° HOOK



STANDARD 180° HOOK

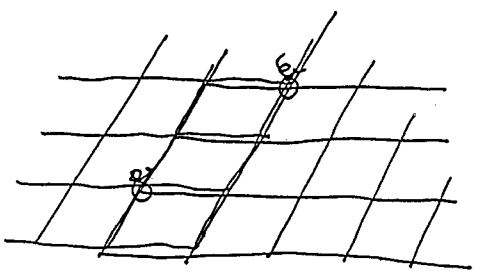
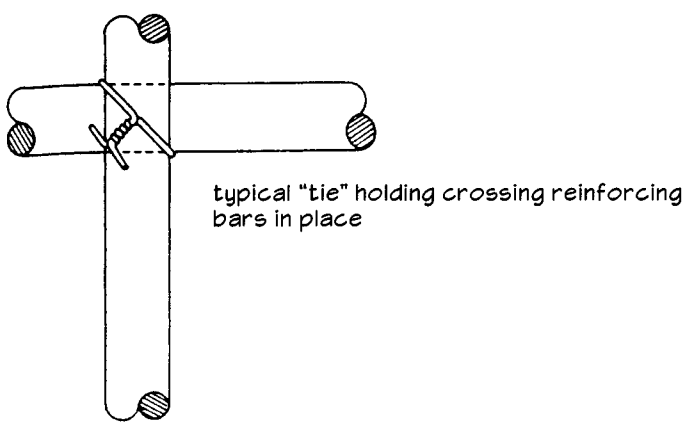
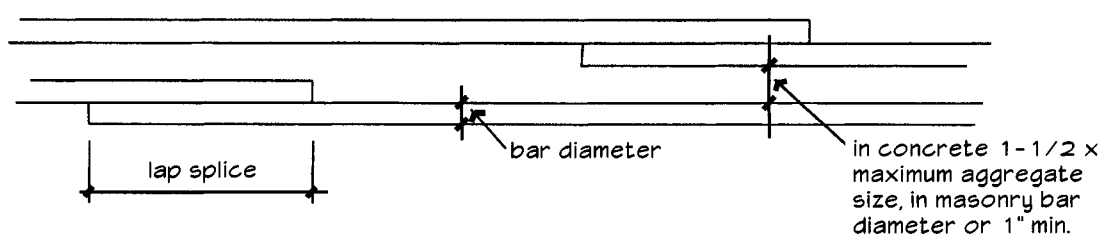
DIMENSION $a = 4d_b$ FOR #3 THROUGH #8,
 $= 5d_b$ FOR #9, #10 AND #11,

MODIFICATION FACTORS:
GRADE 40 BARS = 0.67
LIGHTWEIGHT CONCRETE = 1.3
EPOXY COATED REINFORCEMENT = 1.2

(From PCI Design Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)

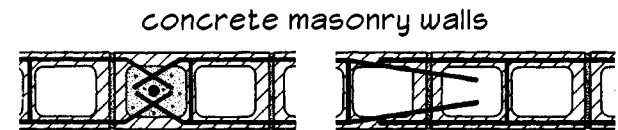
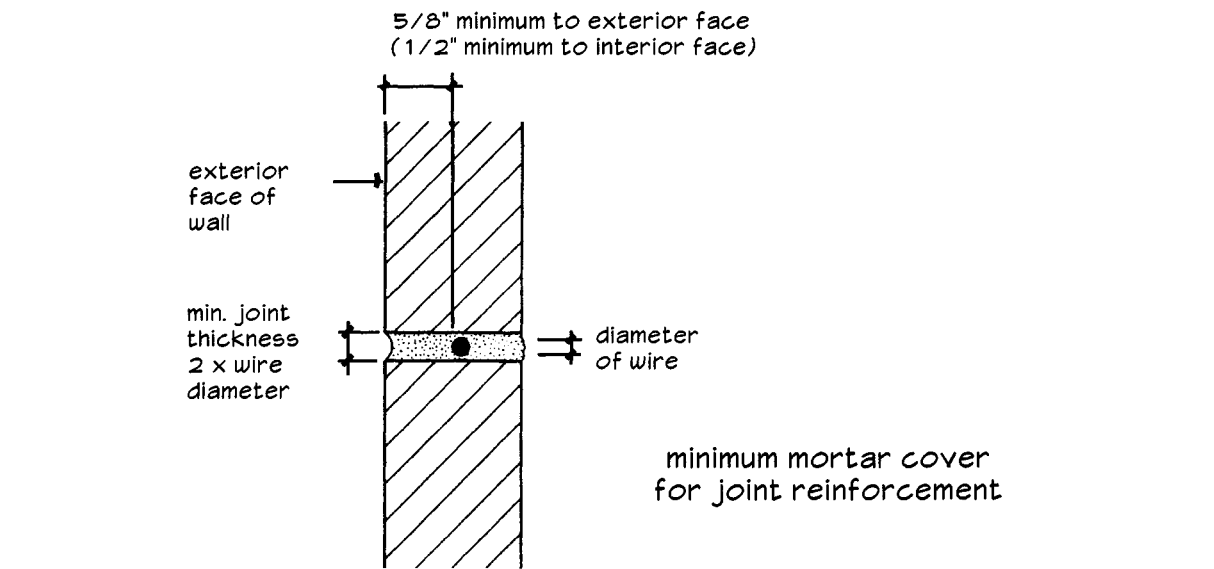
7.3.3 Splicing Reinforcing Bars

in masonry, lapped bars need not be in contact

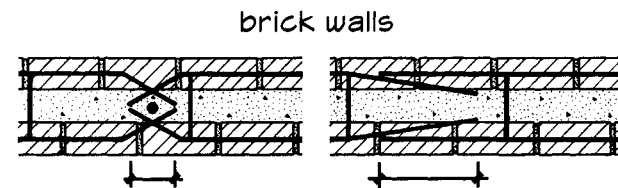


Lap welded wire mesh at least one square. Do not make lap splices at control joints.

7.3.4
Masonry Joint Reinforcement Splices and Minimum Mortar Cover



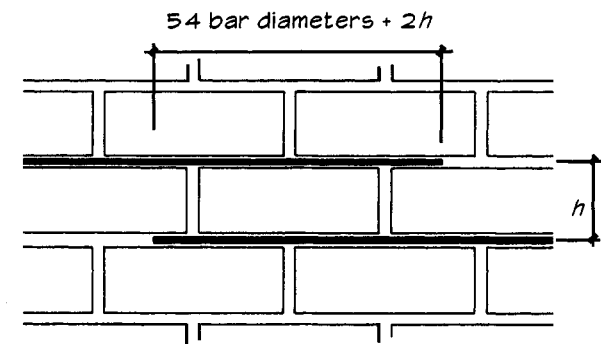
concrete masonry walls



brick walls

grouted cell splices
5 4 bar diameters

bed joint splices
7 5 bar diameters



alternate bed joint lap splice

UBC Requirements for Length of Ladder Type Joint Reinforcement Splices (in.)

Reinforcement		Grouted Cell Splices	Bed Joint Splices	Vertical Spacing of Joint Reinforcement for Alternate Bed Joint Lap	
				h 8 in.	h 16 in.
Size	Dia. (in.)	54 Dia. Lap [§]	75 Dia. Lap [†]		
9 ga.	.1483	8	11	24	40
3/16"	.1875	10	14	26	42

[§] Joint reinforcement lapped at grouted cell.
[†] Joint reinforcement lapped in mortared bed joint

(Table and drawings at left adapted from Amhrein, Reinforced Masonry Engineering Handbook, 5th ed.)

7.3.5 Supporting Reinforcement

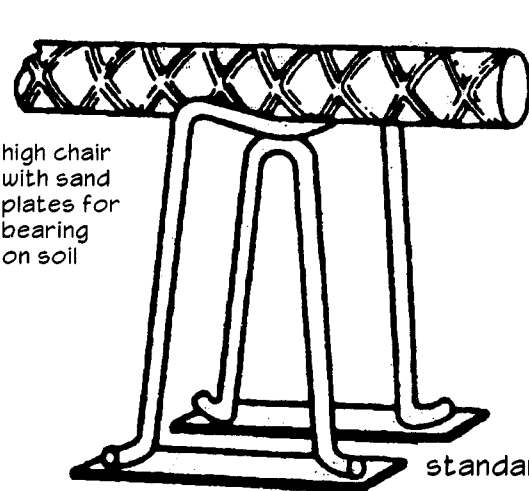
Reinforcement properly located at the top of the slab helps keep surface cracks closed. There are two ways to position the reinforcement near the top of the slab. The preferred method is to use blocks or standard bar supports (chairs) to hold reinforcement at the proper elevation. A second method involves a three-step procedure.

- strike off the concrete 2 in. low
- place the mesh (or other reinforcement) on the surface
- then cast the top 2 in. immediately

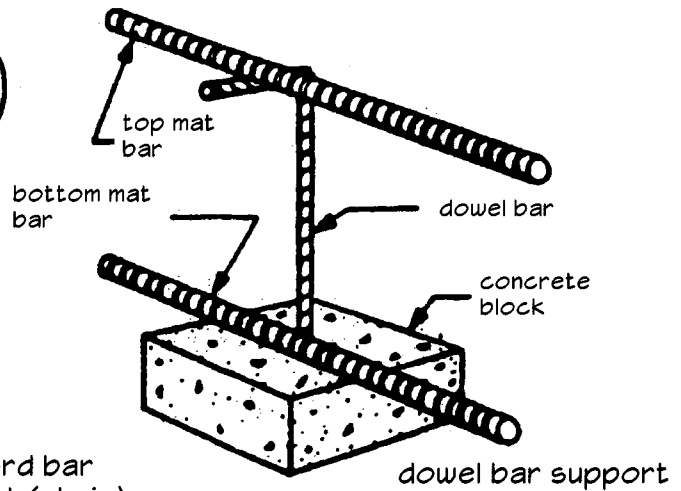
Do not “hook” or lift reinforcement from the subgrade as the concrete is being placed, and don’t walk on the steel after it has been placed on supports at the proper elevation.



worker setting 3-in. concrete blocks under reinforcing mat to hold it at the proper elevation in the slab

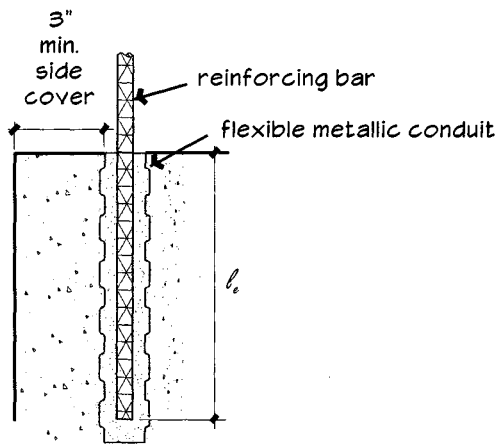


standard bar support (chair)



dowel bar support

7.3.6
Reinforcing Bar Embedded in Grouted Conduit



Minimum Embedment of Reinforcing Bar in Grout-Filled Conduit	
Bar Size No.	Bar Embedment Length, ℓ_e (in.) [§]
3	12
4	12
5	12
6	15
7	21
8	27

[§] For grout strengths higher than 5000 psi, multiply embedment length by $\sqrt{5000/f'_c}$ (where f'_c = specified compressive strength of grout).

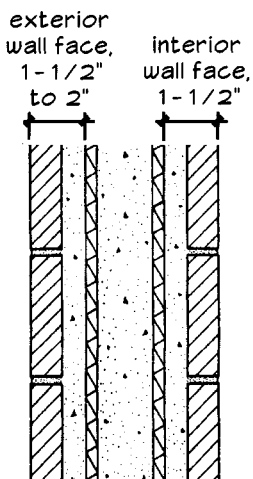
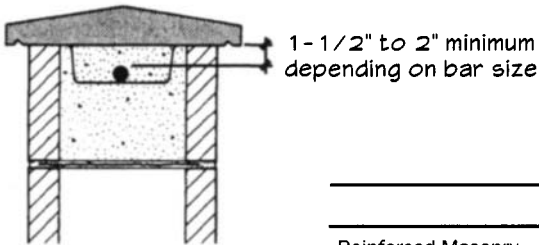
7.3.7 Minimum Concrete or Masonry Cover for Reinforcement

Reinforcement must be properly embedded for protection against corrosion and fire. ACI 318 *Building Code Requirements for Concrete Structures* lists minimum cover for cast-in-place concrete as shown in the table below. The *International Building Code* minimum requirements for reinforcement cover in masonry construction are listed in the second table. In corrosive atmospheres or severe exposure conditions, the amount of protective cover should be suitably increased, or corrosion-resistant reinforcement used. When a covering greater than that shown below is required for fire protection, the fire protection requirements should govern.

Cast-In-Place Concrete (Non-Prestressed)	Minimum Cover (in.) [§]
Cast against and permanently exposed to earth (such as footings or a slab-on-grade)	3
Exposed to earth or weather (but not placed directly on earth)	
No. 6 through No. 18 bars	2
No. 5 bars, W31 or D31 wire and smaller	1-1/2
Not exposed to weather or in contact with the ground	
Slabs, walls, joists	
No. 14 and No. 18 bars	1-1/2
No. 11 and smaller	3/4
Beams, girders, columns	1-1/2
principal reinforcement, ties, stirrups, or spirals	
Shells and folded plate members	
No. 6 bars and larger	3/4
No. 5 bars, 5/8-in. wire and smaller	1/2

[§] Specified cover is to outside of bar, not to centerline.

(From ACI 318 Building Code Requirements for Concrete Structures, American Concrete Institute)



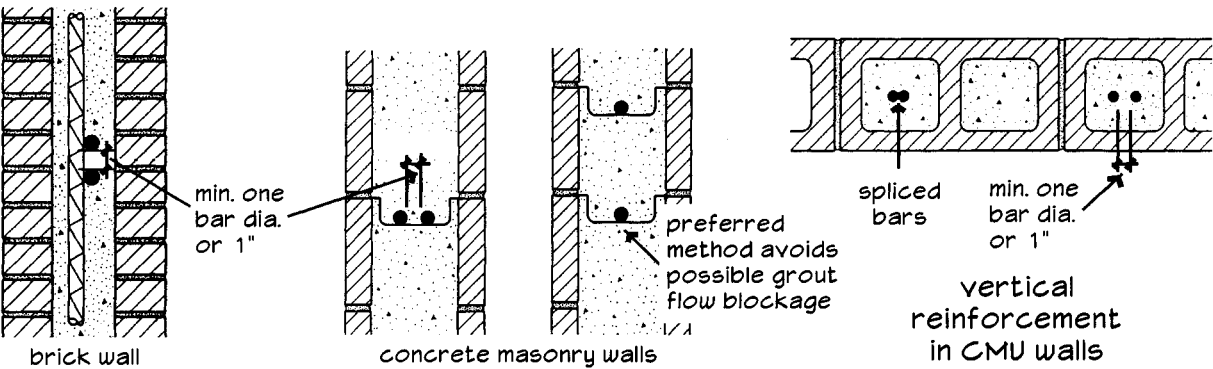
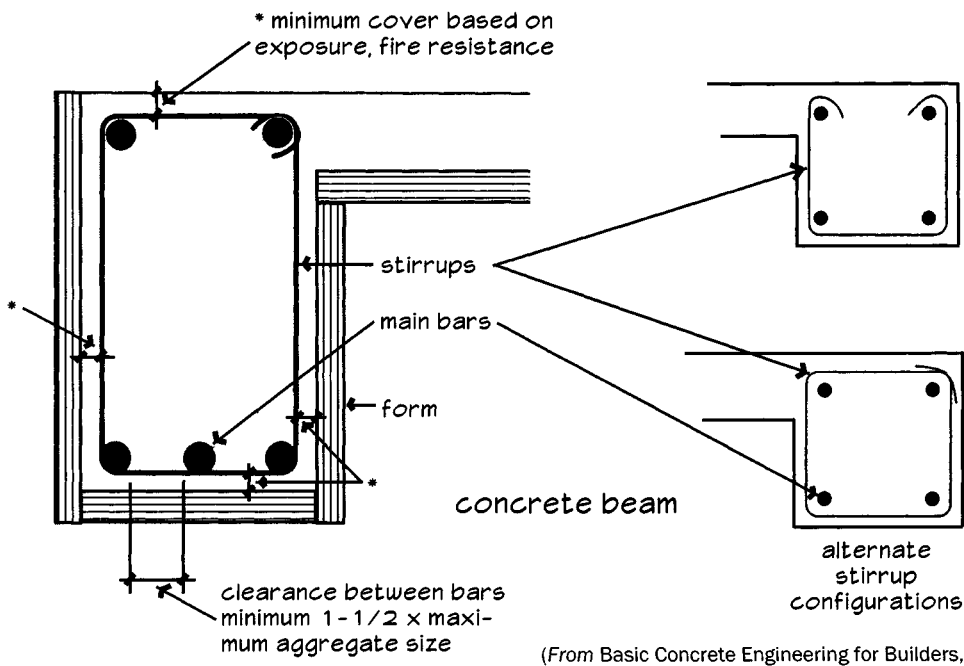
Reinforcement Cover for Strength Design	
Reinforced Masonry	Minimum Cover (in.) [§]
Masonry exposed to earth or weather	
No. 6 and larger	2-1/2 x bar diameter, but not less than 2
No. 5 and smaller	2-1/2 x bar diameter, but not less than 1-1/2
Masonry not exposed to earth or weather	2-1/2 x bar diameter, but not less than 1-1/2

[§] Minimum cover includes thickness of masonry unit.

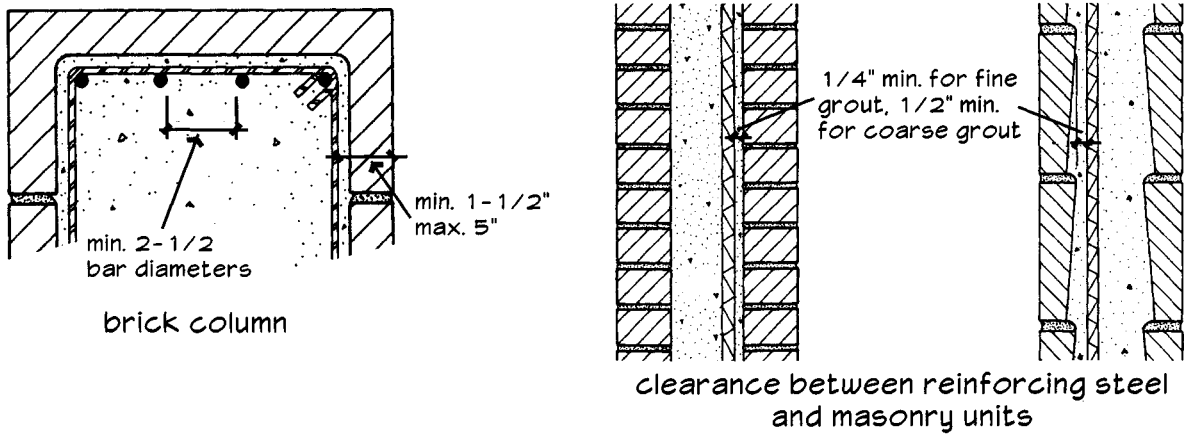
(From *International Building Code*, 2000)

(From *Reinforced Masonry Engineering Handbook*, 5th ed., Amrhein)

7.3.8 Minimum Clearances for Concrete and Masonry Reinforcement



horizontal reinforcing bars



(From Reinforced Masonry Engineering Handbook, 5th ed., Amrhein)

7.3.9 Reinforcing Bar Size Limitations for Hollow Unit Masonry Construction

Reinforcing bars in masonry construction must be fully embedded in grout for effective structural function. Because the cavity or collar joint between masonry wythes and the cores or cells of CMU and hollow brick are small, the MSJC and International Building Codes impose bar size limitations to assure adequate grout flow and embedment of the reinforcing steel. These limitations may be based on the nominal wall thickness or the clear dimension of the cell or collar joint, and are summarized as follows:

- Maximum bar size
No. 11 (MSJC and IBC)
- Maximum bar size based on nominal wall thickness
1/8 nominal wall thickness (IBC)
- Maximum bar size based on clear dimension of unit cell
1/2 clear cell or collar joint thickness (MSJC)
1/4 clear cell or collar joint thickness (IBC)

The following tables list code limitations imposed by the MSJC *Building Code Requirements for Masonry Structures* (ACI 530/ASCE 5/TMS 402-99) and the *International Building Code 2000*.

Note: Compare limitations based on 1/4 or 1/2 of clear grout space dimension and based on 1/8 of wall thickness (see tables on this page) with limitations based on percent of grout space area (see table on next page) to determine which governs.

Maximum Reinforcing Bar Size Based on 1/8 Wall Thickness, t					
Nominal Wall Thickness, t (in.) →	4 [§]	6	8	10	12
Max. Bar Diameter (in.)	0.5 in.	0.75 in.	1.0 in.	1.25 in.	1.5 in.
Bar Size Designation	No. 4	No. 6	No. 8	No. 9	No. 11

[§] While 4-in. nominal hollow clay masonry units are available, most 4-in. nominal hollow concrete masonry is nearly solid and cannot be reinforced and grouted.

Bar Diameter Limitations Based on Clear Cell or Collar Joint Thickness			
Nominal Unit Thickness (in.)	Probable Maximum Clear Cell or Collar Joint Dimension (in.) [§]	Maximum Bar Diameter Based on 1/2 Clear Cell or Collar Joint	Maximum Bar Diameter Based on 1/4 Clear Cell or Collar Joint
Hollow Clay Masonry			
4 [†]	1.0	0.5	0.25
5	1.5	0.75	0.38
6	2.5	1.25	0.63
8	4	3.0	1.0
10	5.75	2.88	1.44
12	7.5	3.75	1.88
Hollow Concrete Masonry			
4	1.125	0.56	0.28
6	2.625	1.31	0.66
8	4.125	2.06	1.03
10	5.875	2.94	1.47
12	7.625	3.81	1.91

[§] Based on minimum face shell thickness from ASTM C652 for hollow clay units and ASTM C90 for concrete units, and assuming maximum allowable mortar protrusions of 1/2" both sides, reducing clear dimension by 1" total.

[†] While 4-in. nominal hollow clay masonry units are available, most 4-in. nominal hollow concrete masonry is nearly solid and cannot be reinforced and grouted.

7.3.10
Maximum Area of Vertical Steel for Hollow Unit Masonry Construction

The maximum area of vertical steel permitted in hollow unit cores or cells is based on the area of the grout space. The limitations imposed by the *MSJC Building Code Requirements for Masonry Structures* and the *International Building Code 2000* are slightly different for working stress and strength design.

- 6% of grout space area (MSJC and IBC working stress design)
- 4% of grout space area, except where splices occur (IBC strength design)

The following table lists maximum area limitations based on the approximate area of hollow cells in concrete masonry units of various nominal thicknesses. The area of cells in hollow clay units may be slightly larger or smaller depending on face shell thickness, web thickness, core shape, etc.

Note: Compare limitations based on percent of grout space area (see table on this page) with limitations based on 1/4 or 1/2 of clear grout space dimension and based on 1/8 of wall thickness (see tables on previous page) to determine which governs.

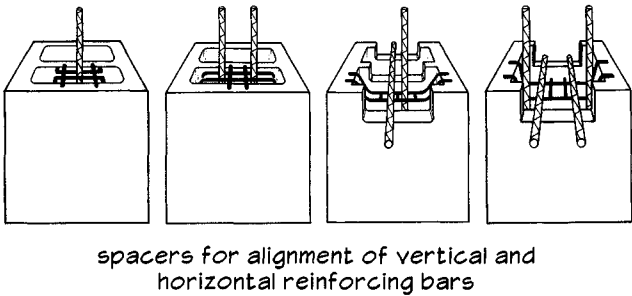
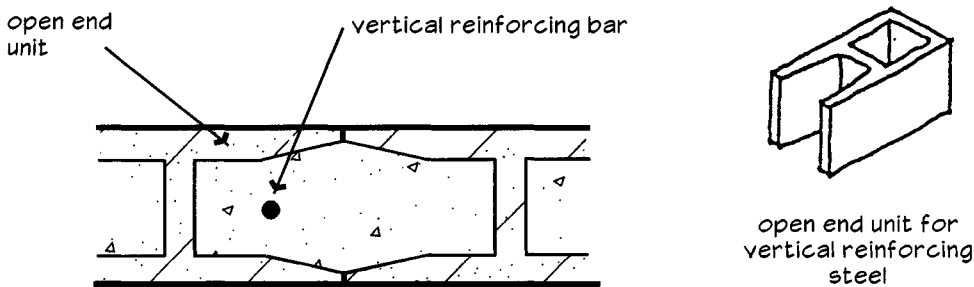
Maximum Area of Reinforcing Steel Based on Percentage of Grout Space Area			
Nominal CMU Wall Thickness, t (in.)	Approximate Area of CMU Cell (sq.in.) [§]	Maximum Area of Vertical Reinforcement Based on MSJC 6% Limit	Maximum Area of Vertical Reinforcement Based on IBC 4% Limit
4†	12.5	0.75	0.50
6	21	1.26	0.84
8	30	1.80	1.20
10	42	2.52	1.68
12	54	3.24	2.16

[§] Cell area will vary based on actual face shell thickness, web thickness, core shape, etc. Check with local manufacturers to verify actual cell area.
[†] Many nominal 4-in. CMU are nearly solid and cannot be reinforced and grouted.

7.3.11 MSJC Placement Tolerances for Masonry Reinforcement

Element	Distance From Centerline of Steel to the Opposite Face of Masonry		
	≤ 8 in.	> 8 in. but ≤ 24 in.	> 24 in.
Walls and Flexural Elements	$\pm 1/2$ in.	± 1 in.	$\pm 1-1/4$ in.
Walls	For vertical bars, within 2 in. of location along length of wall		

Reinforcement may be placed in masonry walls in one of two ways. Vertical reinforcing bars may be placed before the units are laid or as the walls are being constructed. In single-wythe walls, installing reinforcement first is most efficiently accomplished using open end blocks which can be placed around the vertical steel. Double-wythe walls are simply laid up around the reinforcement in the cavity. When reinforcement is installed after the units are laid, spacers must be placed at intervals in the wall to assure proper alignment of vertical steel.



7.3.12 ACI Placement Tolerances for Concrete Reinforcement

Concrete Reinforcement Placement Tolerances

Item	Condition	Tolerance (in.)
Clear distance to side forms and resulting concrete surfaces, and clear distance to formed and resulting concrete soffits in direction of tolerance	When member size is 4 in. or less When member size is over 4 in. but not over 12 in. When member size is over 12 in. but not over 2 ft. When member size is over 2 ft.	+ 1/4, - 3/8 3/8 1/2 1
Concrete cover ^s measured perpendicular to concrete surface in direction of tolerance	When member size is 12 in. or less When member size is over 12 in. Reduction in cover shall not exceed one-third specified concrete cover. Reduction in cover to formed soffits shall not exceed	- 3/8 - 1/2 1/4
Distance between reinforcement	One-quarter specified distance not to exceed Providing that distance between reinforcement shall not be less than the greater of the bar diameter or 1 in. for unbundled bars. For bundled bars, the distance between bundles shall not be less than the greater of 1 in. or 1.4 times the individual bar diameter for 2 bar bundles, 1.7 times the individual bar diameter for 3 bar bundles and 2 times the individual bar diameter for 4 bar bundles.	1
Spacing of non-prestressed reinforcement, deviation from specified location	In slabs and walls other than stirrups and ties Stirrups—depth of beam in inches/12 x Ties—least width of column in inches/12 x However, total number of bars shall not be less than that specified.	3 1 1
Placement of prestressing reinforcement or prestressing steel ducts	Lateral placement: Member depth (or thickness) 24 in. or less Member depth (or thickness) over 24 in. Vertical placement: Member depth (or thickness) 8 in. or less Member depth (or thickness) over 8 in. but not over 24 in. Member depth (or thickness) more than 24 in.	 1/2 1 1/4 3/8 1/2
Longitudinal location of bends and ends of bars	At discontinuous ends of members At other locations	1 2
Embedded length of bars and length of bar laps	#3 through #11 bar sizes #14 through #18 bar sizes (embedment only)	- 1 - 2
Bearing plate for prestressing tendons	Deviation from specified plane	1 degree
Placement of embedded items	Clearance to reinforcement the greater of the bar diameter or Vertical, lateral and level alignment	1 1

^s Tolerances shall not permit a reduction in cover except as set forth in this section.

(From ACI 117-90, Standard Specifications for Tolerances for Concrete Construction and Materials, American Concrete Institute)

7.4.1 Methods and Equipment for Transporting and Handling Concrete

Equipment	Type and Range of Work	Advantages	Cautions/Limitations
Belt conveyors	For moving concrete horizontally or to a higher or lower level. Usually used between main and secondary discharge points.	Adjustable reach, traveling diverter, and variable speed both forward and reverse. Can place large volume of concrete quickly when access is limited.	End-discharge arrangements needed to prevent segregation and leave no mortar on return belt. In hot, windy weather, long reaches of belt need cover to prevent drying.
Buckets	Used with cranes, cableways and helicopters. Convey directly from central discharge point to formwork or secondary discharge.	Enable full versatility of cranes, cableways and helicopters to be exploited. Clean discharge. Wide range of capacities.	Select bucket capacity to conform to size of concrete batch and capacity of placing equipment. Discharge should be controllable.
Chutes	For conveying concrete to lower level, usually below ground level.	Low cost and easy to maneuver. No power required, gravity does most of the work.	Slopes from 1:2 and 1:3 must be adequately supported in all positions. Arrange for discharge at end (downpipe) to prevent segregation.
Cranes	For work above grade.	Can handle concrete, reinforcing steel, formwork, and other items in high-rise buildings.	Has only one hook. Careful scheduling between trades and operations required for efficient use.
Dropchutes	Used for placing concrete in vertical forms.	Direct concrete into formwork and carry it to bottom of forms without segregation. Avoids spillage on form sides and prevents segregation of coarse particles.	Must have sufficiently large, splayed-top openings into which concrete can be discharged without spillage. Choose section shape to permit insertion into formwork without interfering with reinforcing steel.
Mobile Batcher Mixers	Used for intermittent production of concrete at job site.	Combined materials transporter and mobile batching / mixing for quick, precise proportioning of specified mix. One person operation.	Requires good preventive maintenance. Materials must be identical to those in original mix design.
Pneumatic Guns	Used when concrete placed in difficult locations and where thin sections and large areas are needed.	Ideal for placing in free-form shapes, for repairing and strengthening buildings, protective coatings, and thin linings.	Quality of work depends on skill of those using equipment. Only experienced nozzle operators should be employed.
Pumps	Used to convey concrete directly from central discharge point to formwork or secondary discharge.	Pipelines take up little space and can be readily extended. Delivers concrete in continuous stream. Can move concrete both vertically and horizontally. Mobile or stationary pumps available for small, large, or high-rise projects.	Constant supply of freshly mixed concrete needed with average consistency and without tendency to segregate. Care must be taken to assure even flow. Must clean pump at conclusion of each operation. Vertical lifts, bends in pipe and flexible hose reduces maximum pumping distance.
Tremies	Used to place concrete under water.	Can be used to funnel concrete through water into foundation or other part of structure being cast.	Ensure that tremie discharge end is always buried in fresh concrete so a seal is preserved between water and concrete mass. Minimum 10-12 in. diameter needed unless pressure is available. Concrete mix needs more cement (7-8 bags/cu.yd.) and greater slump (6-9 in.) because concrete must flow and consolidate without any vibration.
Truck Agitators	Used to transport concrete for all uses.	Usually operate from central mixing plants where concrete is produced under controlled conditions. Discharge is well controlled. Uniformity and homogeneity of concrete on discharge.	Haul distances must allow discharge of concrete within 1-1/2 hours of mixing. Must time deliveries to suit job schedule, with crew and equipment ready on site to handle concrete.
Wheelbarrows and Buggies	For short, flat hauls, especially where accessibility is restricted.	Versatile and therefore ideal inside and on job sites where placing conditions are constantly changing.	Slow and labor intensive.

(From Design and Control of Concrete Mixes, 13th ed., Portland Cement Association, 1990)

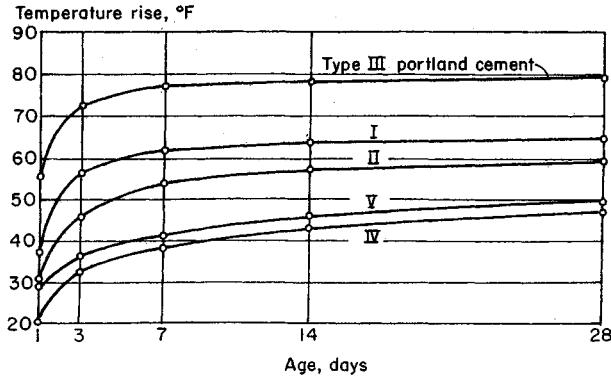
7.4.2
Maximum Lateral Pressure on Forms During Concrete Pour

Column Forms							
Rate of filling forms. ft per hr	Maximum Lateral Pressure, lb per sq ft for the temperature indicated						
	40° F	50° F	60° F	70° F	80° F	90° F	100° F
1							
2	600	600 lb per sq ft minimum governs					
3	825	690	600				
4	1,050	870	750	664	600		
5	1,275	1,050	900	793	713	650	600
6	1,500	1,230	1,050	921	825	750	690
7	1,725	1,410	1,200	1,050	938	850	780
8	1,950	1,590	1,350	1,179	1,050	950	870
9	2,175	1,770	1,500	1,307	1,163	1,050	960
10	2,400	1,950	1,650	1,436	1,275	1,150	1,050
11	2,625	2,130	1,800	1,564	1,388	1,250	1,140
12	2,850	2,310	1,950	1,693	1,500	1,350	1,230
13	3,075*	2,490	2,100	1,821	1,613	1,450	1,320
14		2,670	2,250	1,950	1,725	1,550	1,410
15		2,850	2,400	2,079	1,838	1,650	1,500
16		3,030*	2,550	2,207	1,950	1,750	1,590
17			2,700	2,336	2,063	1,850	1,680
18			2,850	2,464	2,175	1,950	1,770
19			3,000	2,593	2,288	2,050	1,860
20			3,150*	2,721	2,400	2,150	1,950
21				2,850	2,513	2,250	2,040
22				2,979	2,625	2,350	2,130
23				3,107*	2,738	2,450	2,220
24					2,850	2,550	2,310
25					2,963	2,650	2,400
26					3,075*	2,750	2,490
27						2,850	2,580
28						2,950	2,670
29						3,050*	2,760
30							2,850
Wall Forms							
1							
2	600	600 lb per sq ft minimum governs					
3	825	690	600				
4	1,050	870	750	664	600		
5	1,275	1,050	900	793	713	650	600
6	1,500	1,230	1,050	921	825	750	690
7	1,725	1,410	1,200	1,050	938	850	780
8	1,795	1,466	1,247	1,090	973	881	808
9	1,865	1,522	1,293	1,130	1,008	912	836
10	1,935	1,578	1,340	1,170	1,043	943	864

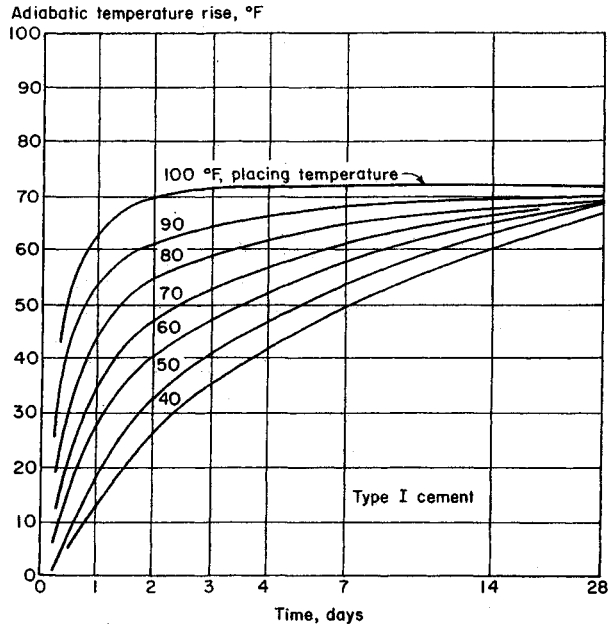
Pressures based on 150 pcf density concrete with 4-in. slump.

(From Peurifoy and Oberlender, Formwork for Concrete Structures, 3rd ed., 1996)

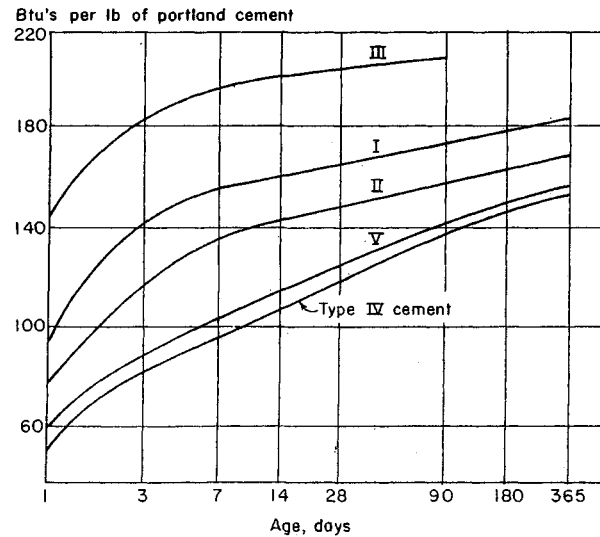
7.4.3 Heat of Hydration and Temperatures Rise In Concrete



Temperature rise for mass concrete with 4-1/2 in. maximum size aggregate and 376 lbs. of cement per cubic yard. Specimens were 17 x 17 in. cylinders, sealed and cured in adiabatic calorimeter rooms. The temperature rise for higher cement content concretes would be proportionately higher.



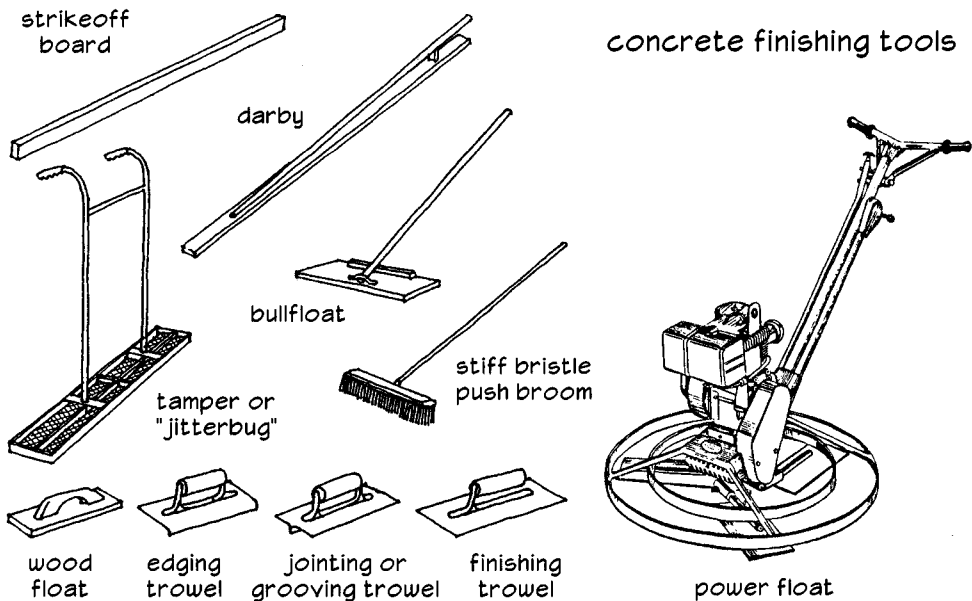
The effect of concrete placing temperature on temperature rise in mass concrete with 376 lbs. of cement per cubic yard. Higher placing temperatures accelerate temperature rise.



Typical heat of hydration curves for various types of cement.

7.4.4 Concrete Finishing on Grade

- Strike off or screed excess concrete so the surface is level with the top of the forms. Fill hollow areas with shovels of concrete mix, and then strike them off again.
- Wide elements like slabs and driveways next require a bull float with a long handle to begin smoothing the screeded concrete. For smaller elements like sidewalks, a wooden darby can be used instead. Do not do any more finishing until the water sheen is gone from the surface, and the concrete will hold your weight without your foot sinking more than 1/4". The time that this will take will vary depending on the temperature, wind and humidity, and the type of cement used.
- For sidewalks, driveways and patios, begin finishing operations by edging the slab. First, use the point of a small trowel to cut the top inch or so of concrete away from the face of the form, then edge the slab with an edging trowel. Edging is not necessary on slabs which will be covered by other construction.
- Use a jointing or grooving trowel to form tooled control joints. For saw-cut control joints, wait until the concrete has hardened for about 3 hours. On small jobs, use a circular saw with a masonry blade, and on large jobs use a commercial concrete saw. Saw joints to a depth of one-fourth the slab thickness.
- After forming the control joints, use a float to smooth the concrete surface and bring a sand and water mixture to the top of the slab. Hold the float nearly flat and move it in wide sweeping motions. *If water comes to the surface, stop and wait a while before trying again. Premature finishing can cause scaling, crazing or dusting of the concrete surface. For outdoor concrete, this is particularly harmful because the concrete is less durable and less wear resistant.* After floating the surface, touch up edges and control joints with the edger and jointing tool. Where tile or pavers will be used as a flooring, leave the concrete with this float finish so that it will provide a good bond with the setting bed. Where carpet or hardwood floors will be laid, a float finish provides an adequate substrate without any further finishing work. A float finish also provides moderate slip resistance for exterior surfaces. Power floats can be used to reduce finishing time on large slabs, and by changing blades, the same equipment can be used for troweling.
- For a non-slip finish on exterior sidewalks, patios, steps or driveways, pull a damp broom across the floated concrete surface perpendicular to the direction of traffic. For a fine texture, use a soft bristled brush. For a coarser texture, use a broom with stiffer bristles.
- Where resilient flooring will be applied, the concrete surface must be very smooth so that imperfections will not "telegraph" through the flooring. Where the concrete will be left exposed, the surface must be smooth so that cleaning or waxing is easier. For a smooth dense surface, a trowel finish is applied with a steel finishing trowel. Hold the blade nearly flat against the surface sweeping back and forth in wide arcs. For an even smoother finish, go back over the surface again after you have finished the initial troweling. Touch up edges and control joints in outdoor work with the edger and jointing tool after troweling.



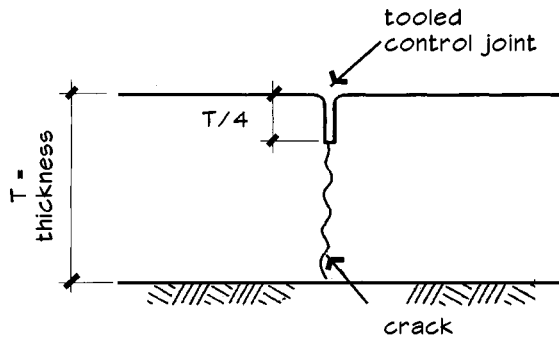
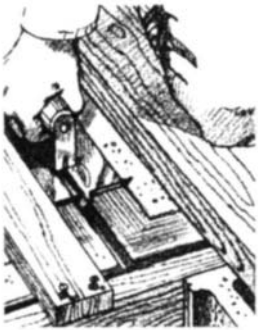
7.4.5 Forming Concrete Control Joints

Control joints should be cut to $1/4$ of the slab depth, but not less than 1 inch deep. Shallower joints will permit cracking to occur elsewhere. Deeper joints will result in less aggregate interlock, which will permit the adjacent concrete sections to slip past each other vertically. Wire mesh and other steel reinforcement are (generally) discontinued on both sides of the joint. Control joints are made by sawing, hand-tooling, or by forming with pressure-treated lumber, asphalt-impregnated fiberboard, or plastic strips that are left in place.

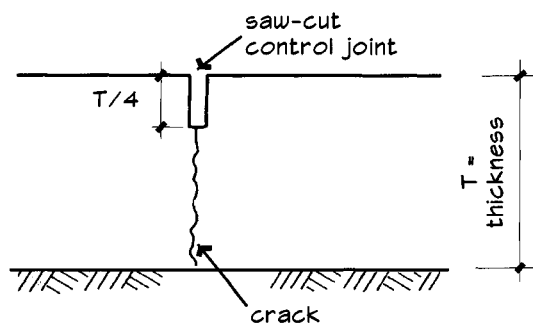
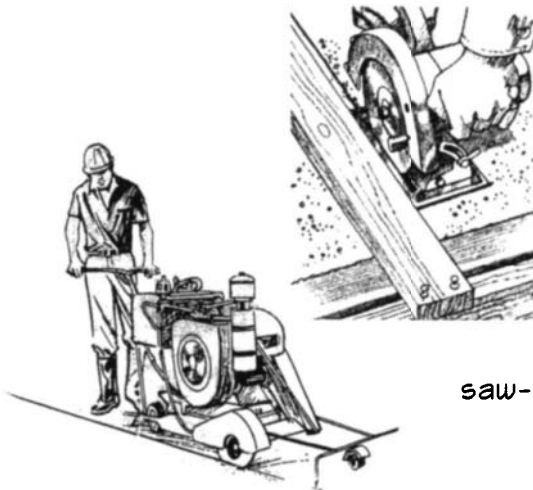
Sawing control joints should be performed as soon as the concrete is firm enough to be worked without tearing the surface, usually between 4 and 24 hours after placement. Weather conditions will affect the required wait time. Slight raveling of aggregate at the edge is acceptable. An abrasive, non-diamond saw blade should be used on concrete that has set but not yet hardened, because loose particles in the green concrete may tear the diamonds off a diamond blade. Diamond blades are preferred on harder concrete or concrete with very hard aggregate. With a diamond blade, water cooling of the blade is required.

A grooving tool that is deep enough may be used to make control joints. As soon as possible after bullfloating, use a trowel to dislodge aggregate along the path of the groove. Then use a special grooving tool to score the concrete surface. The groover may be used both before and after floating and troweling. However, the concrete should not be worked when bleed water is present.

In walls, control joints should be placed at openings, within 10 feet of corners, and at a maximum spacing of 20 feet.



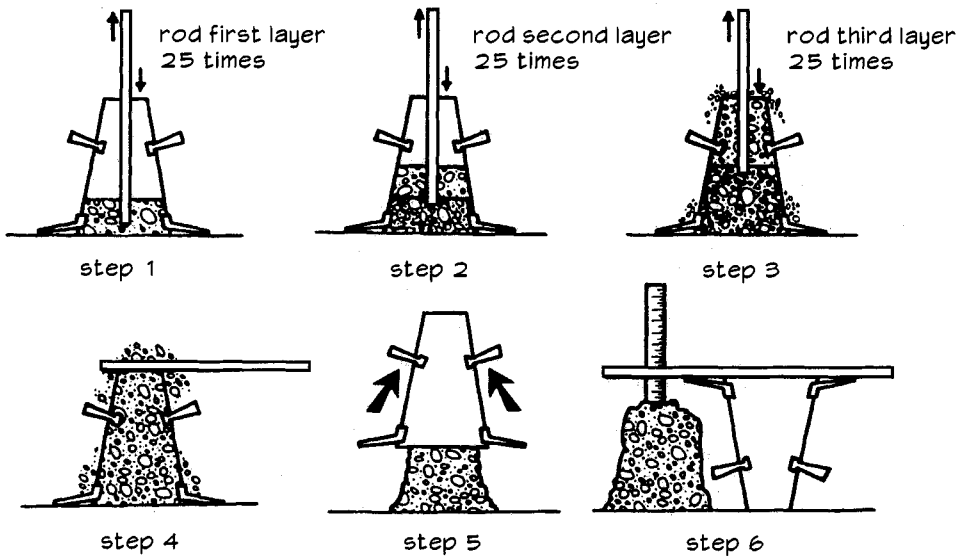
grooved or tooled control joint



saw-cut control joint

7.4.6 Concrete Slump Test and Cylinder Molds

concrete slump test



- Step 1 Fill the bottom 3 in. of the cone and rod 25 times to remove air pockets.
 Step 2 Fill the middle 4 in. of the cone and rod 25 times to remove air pockets. (The rod should penetrate into the previous layer about 1 in.)
 Step 3 Fill the top 5 in. of the cone and rod 25 times to remove air pockets.
 Step 4 Strike off excess concrete from the top of the cone.
 Step 5 Remove the cone slowly with an even motion, taking from 5 to 12 seconds. Do not jar the mixture or tilt the cone in the process.
 Step 6 Measure the slump with the tamping rod and a ruler.

The slump test should not take longer than 1-1/2 minutes from start to finish. Do not use the same batch of concrete for any other test.

making concrete test cylinder molds

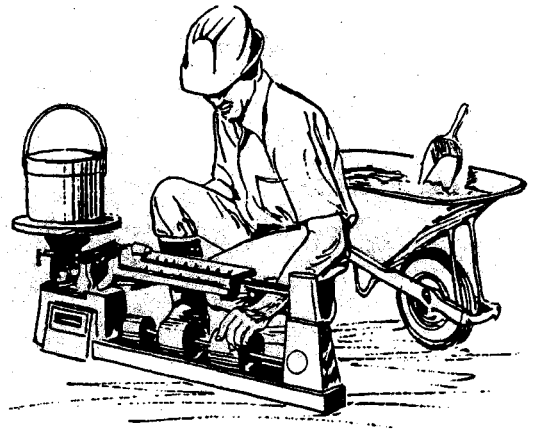
- Step 1 Place cleaned and oiled cylinder molds on a solid level base such as a concrete slab.
 Step 2 For concrete with slumps greater than 3 in., fill each mold in 3 equal layers. Rod each layer 25 times with a standard tamping rod. (The rod should penetrate into the previous layer about 1 in.) Tap the sides of the mold lightly to close any voids left by rodding.
 For concrete with slumps less than 1 in., fill the mold in 2 equal layers. Insert an internal vibrator with a diameter of 3/4 to 1-1/2 in. into the concrete at 3 locations. Leave the vibrator in the concrete long enough each time to allow entrapped air to escape, then raise the vibrator slowly. Tap the sides of the mold lightly to close any voids left by vibrating.
 For slumps between 1 and 3 in., fill the mold and compact either by rodding or vibrating as described above.
 Step 3 Strike off and smooth the concrete surface. Cover the top surface of the cylinders with a plate or sheet of impervious plastic.



7.4.7 Tests for Concrete Unit Weight and Air Content

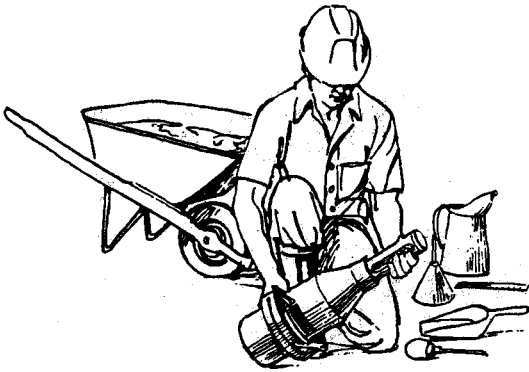
testing concrete unit weight

To determine the unit weight of concrete, weigh a level-full container of concrete, subtract weight of empty container, and divide by volume of container.

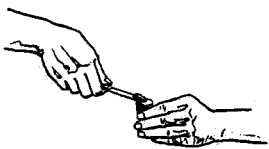


testing concrete air content with a volumetric air meter

Fill the bowl with freshly mixed concrete, clamp the top assembly on and fill with water to the zero mark on the water column. Roll the meter and agitate it until the air bubbles are removed from the concrete. The amount that the water column goes down is a measure of the air content.

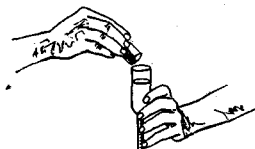


estimating concrete air content with an air indicator test



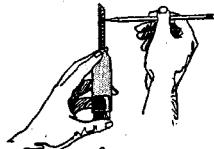
step 1

Fill the open-top cup with mortar from the concrete, being careful to avoid any pieces of gravel or rock.



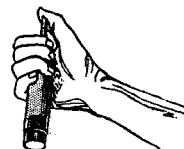
step 2

Insert the stopper which contains the cup into the glass tube.



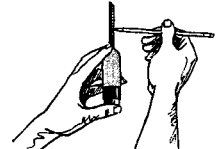
step 3

Fill the glass tube with alcohol to the zero mark.



step 4

Shake the tube (with thumb over open end) until the mortar is mixed with the alcohol.



step 5

The drop in alcohol level is a measure of the concrete air content.

7.4.8 Construction Practices and Concrete Air Content

Effect of Production Procedures, Construction Practices, and Environmental Factors on Control of Air Content in Concrete

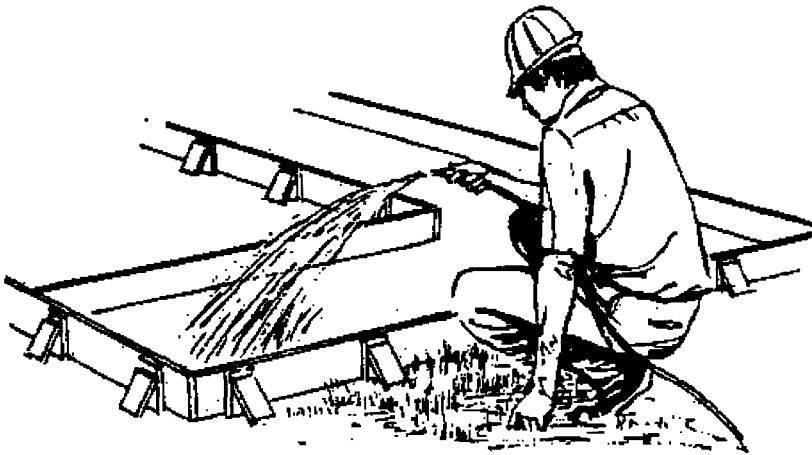
Variable	Effect on Air Content	Corrective Action
Admixture metering	Accuracy, reliability of metering system affect uniformity of air content.	Avoid manual-dispensing, gravity-feed systems and timers. Positive displacement devices preferred. Establish frequent maintenance and calibration program.
Batching sequence	Simultaneous batching lowers air content. Late addition of air-entraining admixture raises air content.	Avoid slurry-mix addition of air-entraining admixture.
Concrete consolidation	Air content decreases under prolonged vibration or at high frequencies.	Do no overvibrate. Avoid high-frequency vibrators. Avoid multiple passes of vibratory screeds.
Concrete finishing	Air content reduced in surface layer by excessive finishing.	Avoid finishing with bleed water still on surface. Avoid overfinishing. Do not sprinkle water on surface prior to finishing.
Haul time	Long hauls reduce air content, especially in hot weather.	Optimize delivery schedules. Maintain concrete temperature in recommended range.
Mixer capacity	Air content increases as capacity is approached.	Run mixer close to full capacity, avoid overloading, and clean mixer frequently.
Mixing speed	Air content increases up to approximately 20 rpm, and then decreases at higher speeds.	Avoid high drum speeds.
Mixing time	For central mixers, air content increases up to 90 seconds. For truck mixers, air content increases up to 10 minutes. Air content decreases after optimum time is reached for any type mixer.	Establish optimum mixing time for particular mixer. Avoid overmixing.
Retempering	Air content decreases after retempering. Retempering is ineffective beyond 4 hours.	Retemper only enough to restore workability. Avoid addition of excess water.
Temperature	Air content decreases with increase in temperature.	Increase air-entraining admixture dosage as temperature increases.
Transport	Some air (1 to 2%) normally lost in transport. Air also lost in pumping and on belt conveyors, especially at higher air content.	Avoid high air contents in pumped concrete. Do not use dump trucks or aluminum pipelines.

Note: Information may not apply to all situations.

(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

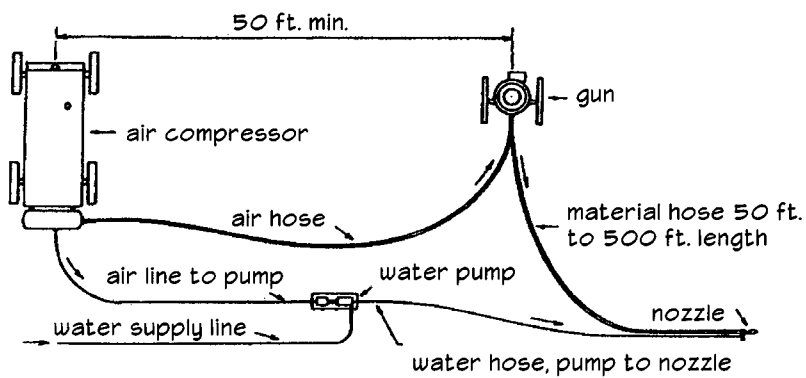
7.4.9 Constructing a Slab-On-Grade

- SITE PREPARATION
 1. Prepare subgrade
 2. Establish grade elevations
 3. Set edge forms, temporary bulkheads, and screed guides
 4. Install vapor retarder, if any
 5. Install reinforcement, if any
 6. Get tools and materials ready
- PLACING CONCRETE
 1. Deliver concrete to proper location(s)
 2. Spread or distribute concrete
 3. Vibrate concrete
 4. Strike off slab surface
- FINISHING CONCRETE
 1. Bull float *or* darby *or* use highway straightedge
 2. WAIT for bleed water to disappear
 3. Edge and joint as needed
 4. Float
 5. Trowel, if required
 6. Saw joints as needed
 7. Cure

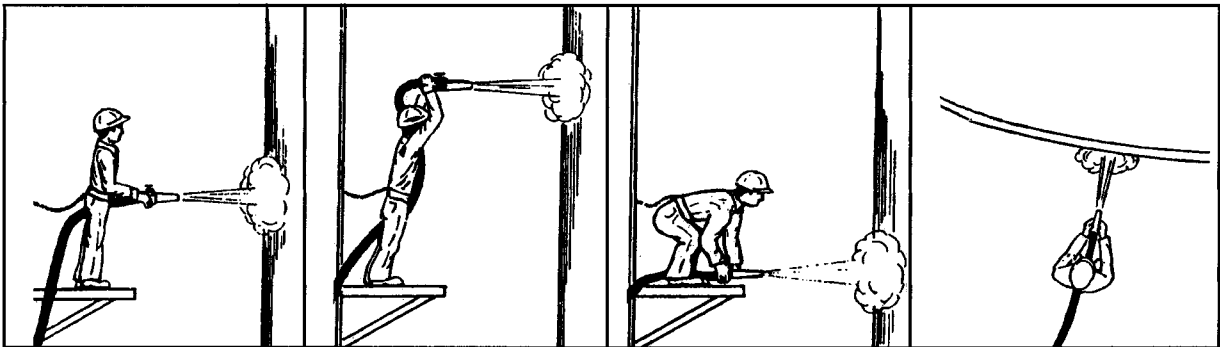
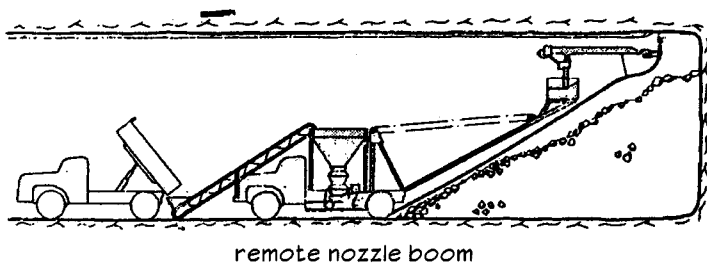


Dampen subgrade or subbase before concrete is deposited **ONLY** if needed to prevent plastic shrinkage or other severe problems. Allow water to penetrate so that there is no standing water at time of concrete placement.

7.4.10 Shotcrete Placement



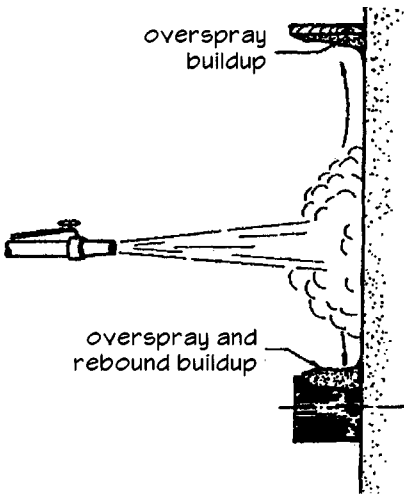
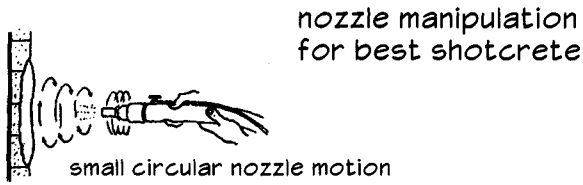
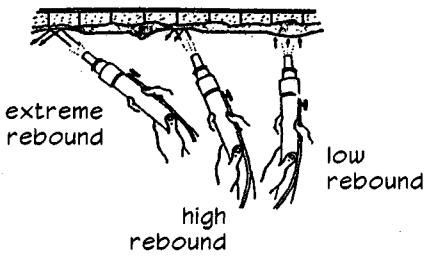
plan view showing typical arrangement of equipment for shotcreting



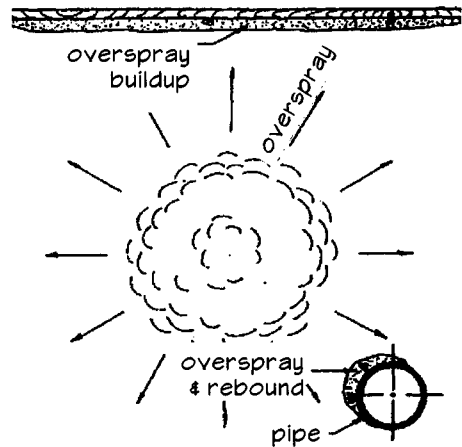
correct shooting or gunning positions—with nozzle perpendicular to wall

(From ACI 506R-90, Guide to Shotcrete, American Concrete Institute, Reapproved 1995)

7.4.11 Shotcrete Placement Techniques



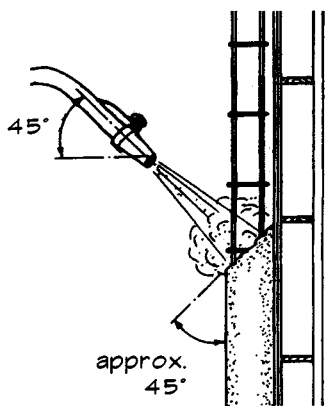
section



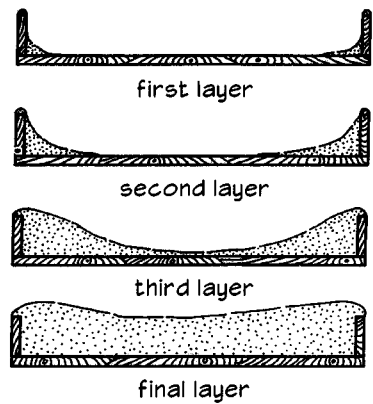
nozzle operator's view

Rebound Losses (%)		
Surface	Dry Mix	Wet Mix
Floor or slabs	5–15	0–5
Sloping and vertical walls	15–25	5–10
Overhead work	25–50	10–20

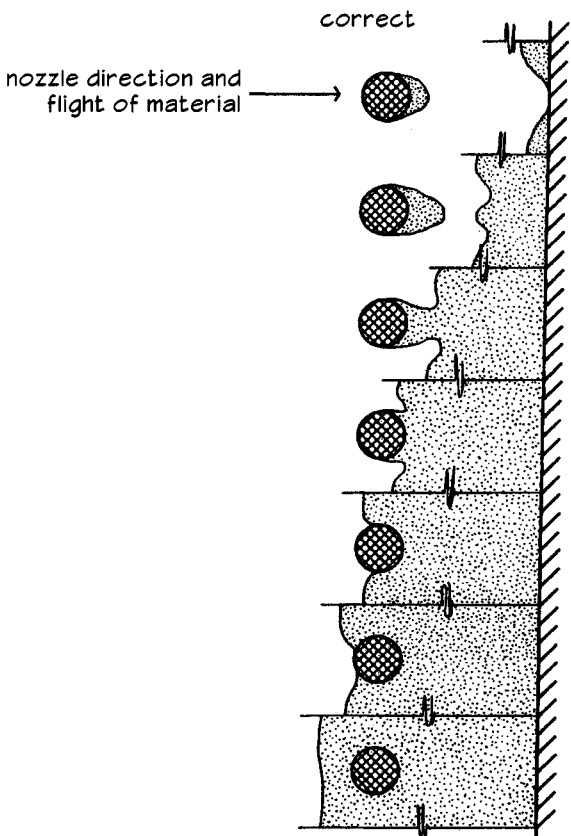
7.4.12 Shotcrete Placement Methods



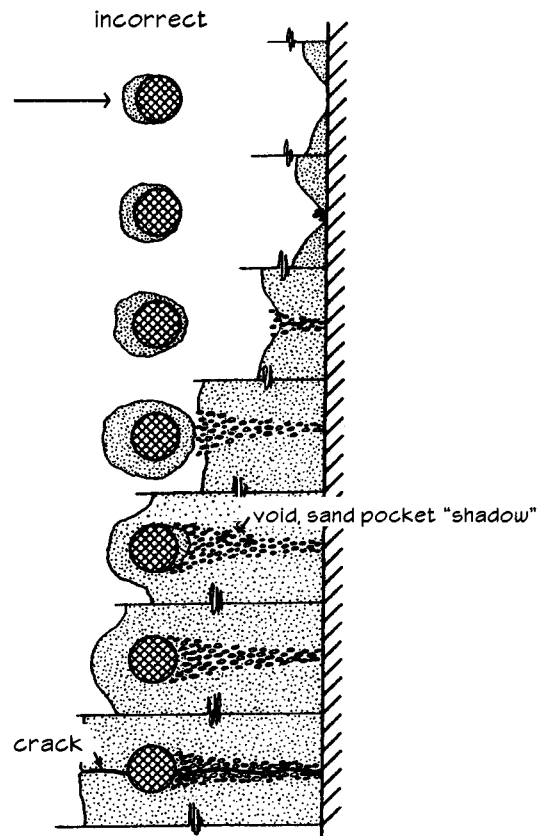
correct method for shooting thick applications



correct method for shooting corners

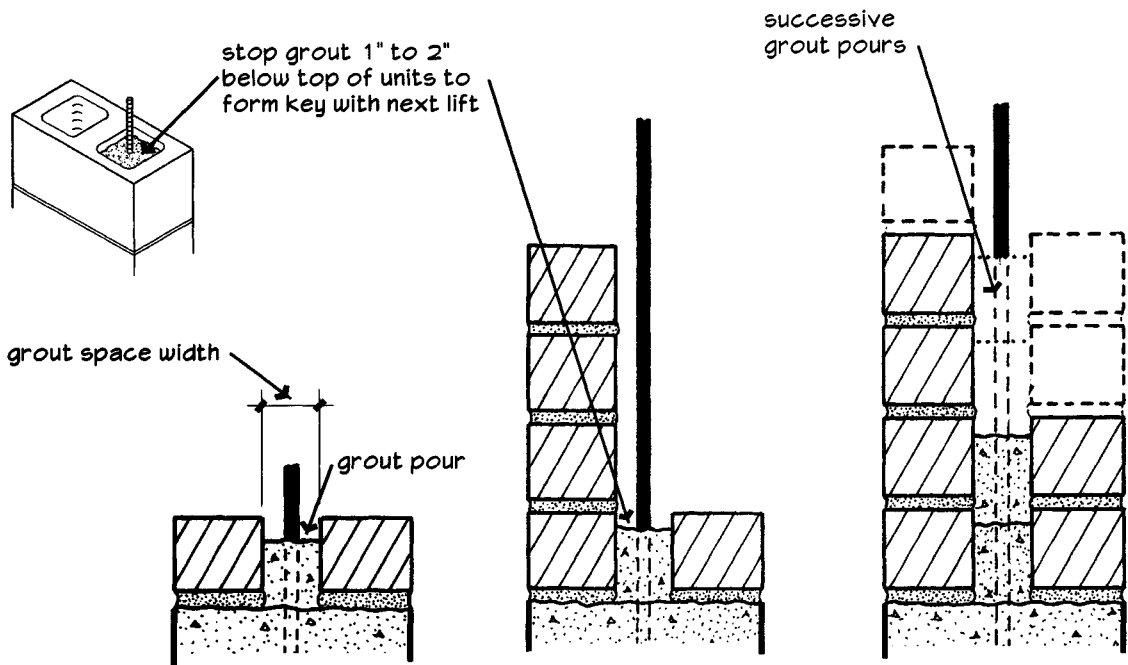


correct method of encapsulating reinforcement

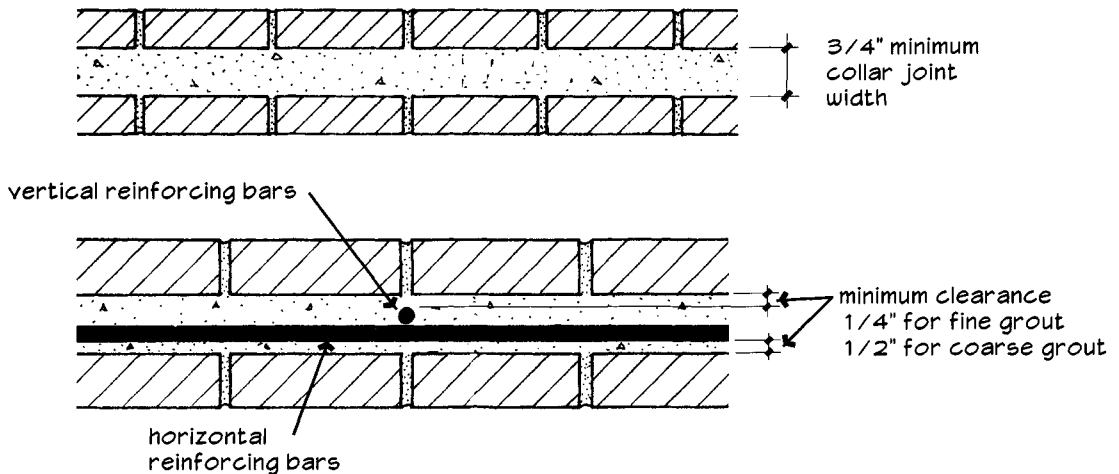


(From ACI 506R-90, Guide to Shotcrete, American Concrete Institute, Reapproved 1995)

7.5.1 Low-Lift Masonry Grouting, 12" or Less

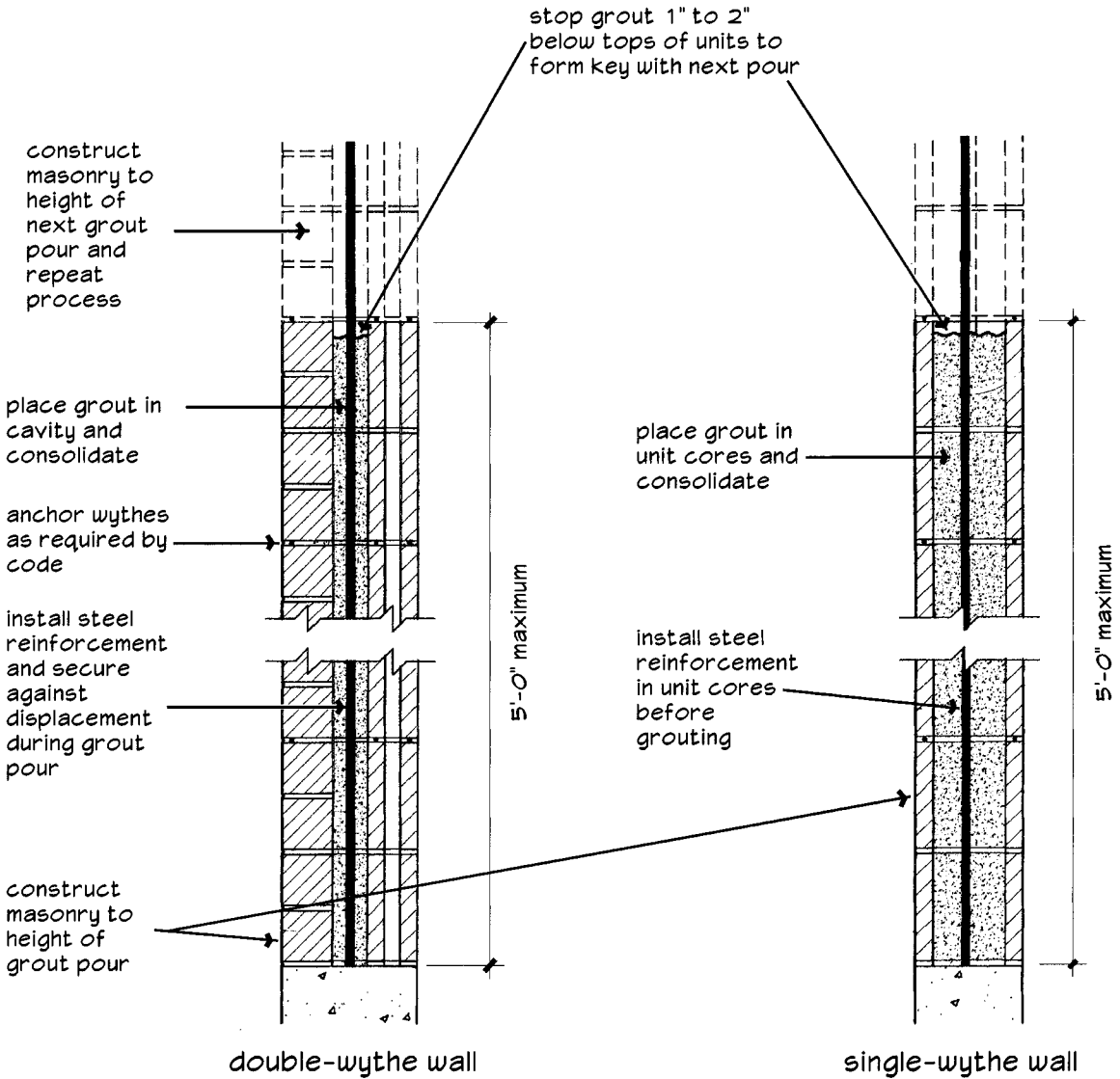


for small projects, grout may be placed as the masonry is laid in lifts not to exceed 12" in height



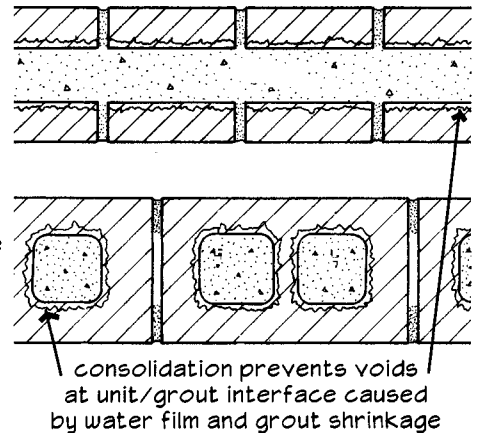
minimum grout space widths and clearances
for low-lift grouting

7.5.2 Low-Lift Masonry Grout Pours Up to 5 Ft. in Height



grout consolidation and re-consolidation

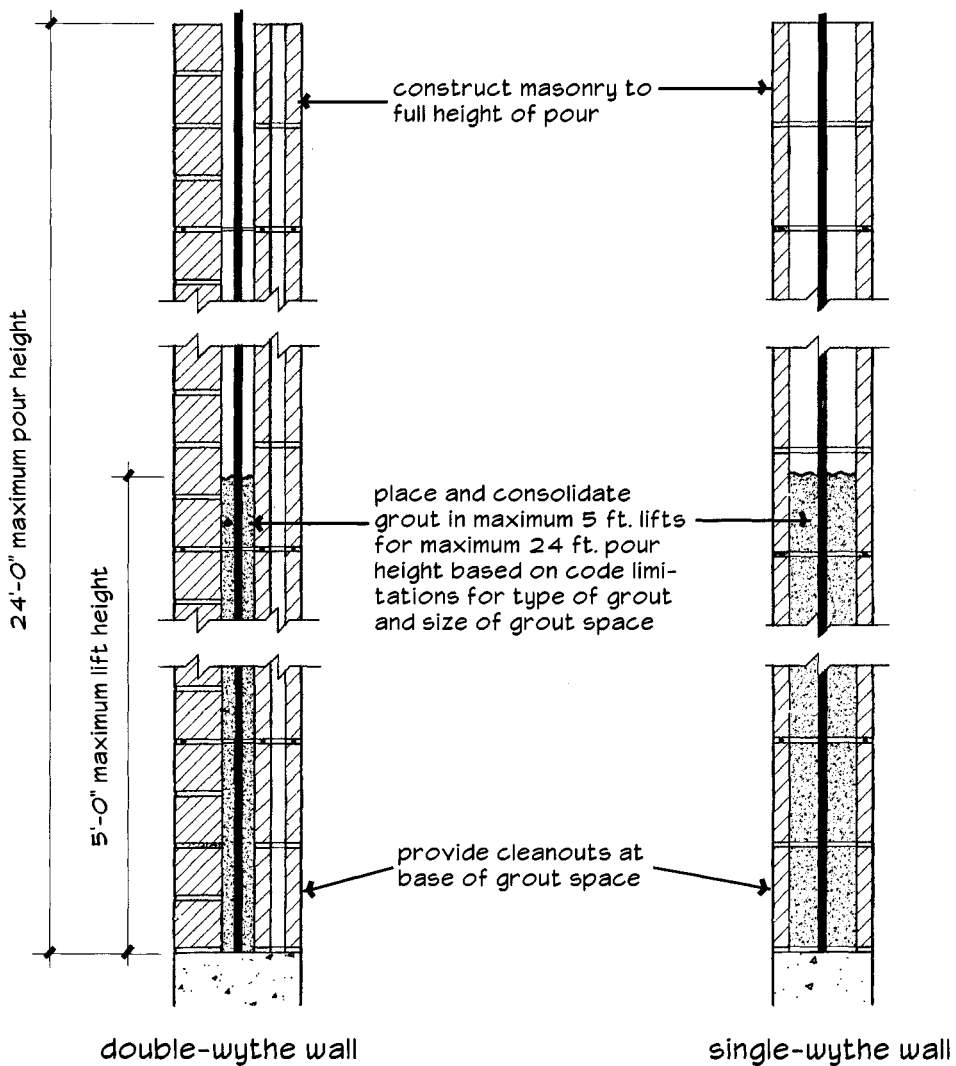
Grout must be consolidated by vibration as it is being placed to minimize voids that are left when water from the grout mix is absorbed by the masonry. Grout consolidation can be accomplished by puddling with a piece of reinforcing bar if the lifts do not exceed 12 in., but for higher lifts, a mechanical vibrator with a 3/4- to 1-in. diameter head must be used. Five to ten minutes after the grout is placed, the vibrator should be inserted into the grout cavity or cores for a few seconds in each location. Within 30 minutes of consolidation, the grout must be re-consolidated to assure proper bond to the units and reinforcement. Re-consolidation prevents separations from developing between the grout and the masonry by eliminating water build-up between the two materials.



7.5.3 High-Lift Masonry Grouting

High-lift grouting is more efficient for large projects than low-lift grouting. The full height of the pour must be accomplished in a single day, working in lifts that are a maximum of 5 ft. high. A delay of 30 to 60 minutes between lifts allows time for consolidation and re-consolidation after initial water loss and settlement have occurred. Each lift should be consolidated by mechanical vibration, with the vibrator head inserted completely through the new lift and extending 12 to 24 in. into the previous lift. This will bond the two lifts together without cold joints. Double-wythe walls should be allowed to cure for 3 days in warm weather or 5 days in cold weather before high-lift grouting. Single-wythe walls should cure 12 to 18 hours.

Grout fluidity is critical in high-lift grouting to assure complete filling of unit cores or wall cavities, and mortar protrusions into the grout space should be limited to a maximum of 1/2 in. Cleanouts at the base of the wall facilitate removal of debris and inspection prior to grouting operations.



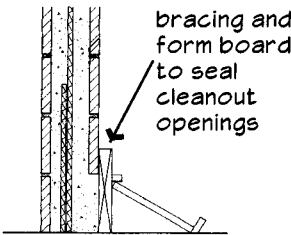
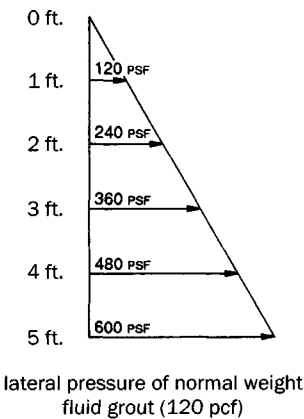
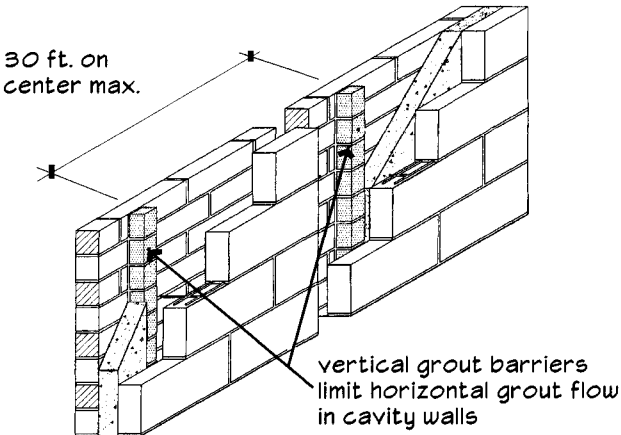
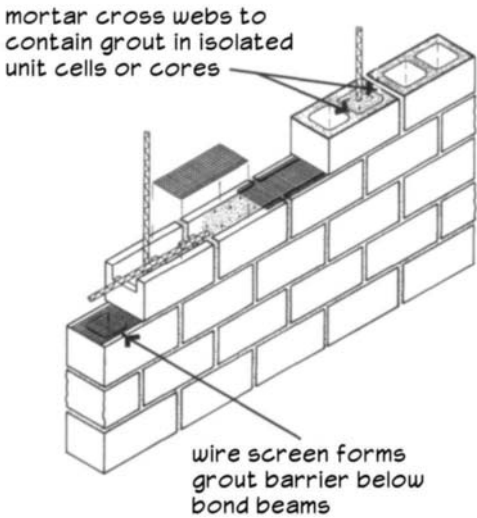
7.5.4 Grouting Requirements

Acceptable grout pour heights are based on the type of grout and the size of the grout space as indicated in the table below. Maximum lift and pour heights should take into account the ability of the wall, with and without temporary bracing, to withstand the fluid grout pressures without damage to the wall. In cavity walls, vertical grout barriers should be constructed to limit horizontal grout flow to 30 feet. In single-wythe walls, grout barriers are provided by mortaring the cross webs of the units. If grouting is stopped for more than 1 hour, a grout key should be formed by terminating the grout lift 1 to 2 in. below the top of the uppermost grouted unit. Cleanout openings at least 3 in. x 3 in. at the base of the wall should be located a maximum of 32 in. on center in double-wythe walls, and at every cell of single-wythe walls where vertical reinforcing occurs.

Minimum Grout Space Requirements for ASTM C476 Grout (with tolerance of +3/8" or -1/4")			
Grout Type	Maximum Grout Pour Height (ft.)	Minimum Width of Grout Space Between Wythes of Masonry [§] (in.)	Minimum Grout Space Dimensions for Grouting Cells or Cores of Hollow Units [†] (in. x in.)
Fine	1	¾	1½ x 2
Fine	5	2	2 x 3
Fine	12	2½	2½ x 3
Fine	24	3	3 x 3
Coarse	1	1½	1½ x 3
Coarse	5	2	2½ x 3
Coarse	12	2½	3 x 3
Coarse	24	3	3 x 4

- [§] Grout space dimension is the clear dimension between any masonry protrusion and shall be increased by the diameters of the horizontal bars within the cross section of the grout space.
[†] Area of vertical reinforcement not to exceed 6% of the area of the grout space.

(From Masonry Standards Joint Committee, Building Code Requirements for Masonry Structures, ACI 530/ASCE 5/TMS 402 and Specifications for Masonry Structures, ACI 530.1/ASCE 6/TMS 602).



7.6.1 Curing Concrete

Curing is critical to production of good concrete. Without good curing, concrete may attain only 40% of its design strength (see graph below). Although concrete will continue to gain strength as long as it is cured, most of the strength gain stops shortly after curing is stopped. Other undesirable effects of inadequate curing are cracking, curling, reduced watertightness, reduced abrasion resistance, reduced resistance to freezing and thawing, and greater tendencies toward efflorescence and discoloration.

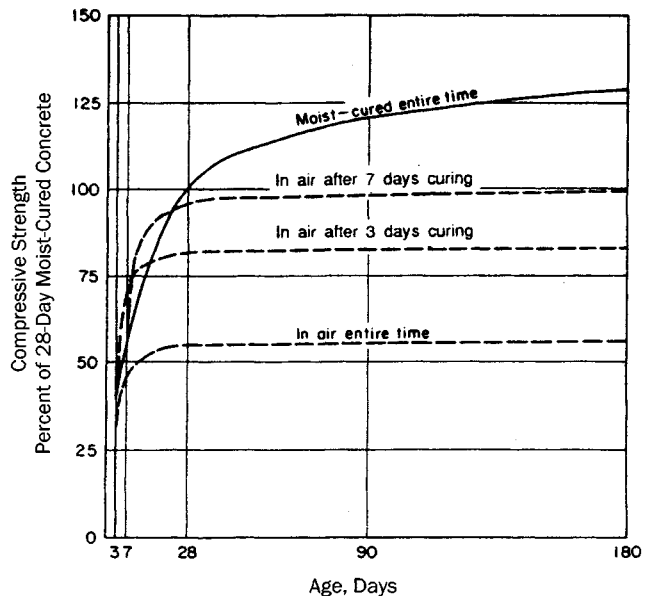
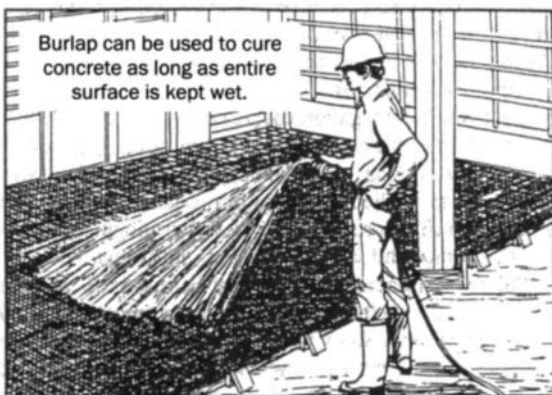
Enough water is in concrete, even with a low water-to-cement ratio, for curing the concrete. Precautions are required to keep the moisture in the concrete (prevent rapid evaporation). Basic curing takes a minimum of :

- 5 days at 70° F or higher, or
- 7 days at 50 to 70° F.

Other curing considerations are:

- Thinner sections of concrete should be cured longer.
- Keep the curing uniform across the surface.
- Taper off the curing (do not let a wet-cured concrete surface dry rapidly and do not abruptly lower the temperature of a heat-cured surface).
- After curing, let the concrete surface air-dry for a few days before using it unless a curing compound is applied.
- Allow 4 weeks of air-drying for air-entrained concrete that will be exposed to deicers.
- Curing compounds that do not allow air drying should not be used when cold weather is approaching.

Curing methods seal the concrete surface to retain the moisture, either with water or without using water. Curing products that do not require water application include polyethylene, waterproof paper, or liquid membrane.



Concrete strength increases with age as long as moisture and favorable temperatures are present for cement hydration. Proper curing more than doubles the strength of concrete.

(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

(From Building Movements and Joints, PCA, 1982)

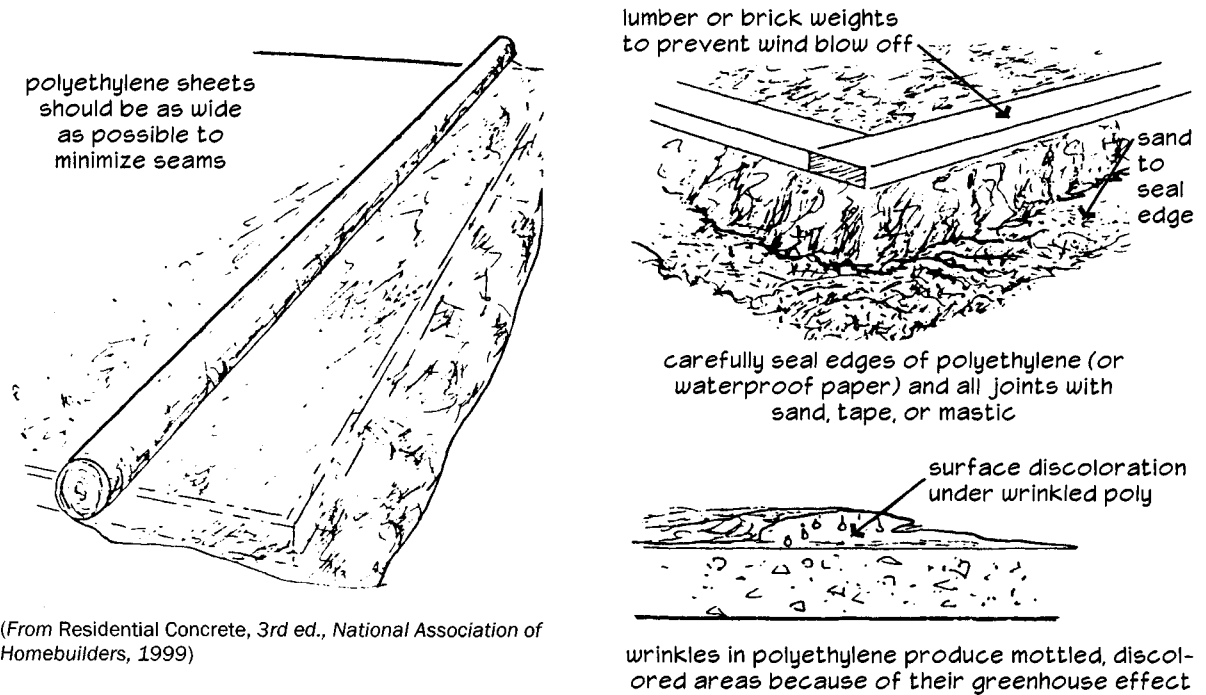
7.6.2 Curing Concrete With Sheet Membranes

In the polyethylene cure, wide sheets of clear, white, or black polyethylene are laid on the concrete surface. White is good in hot weather because it reflects light and heat. Black is good in cool weather because it absorbs heat. It is good practice to wet the concrete before applying the polyethylene. Edges and laps of the sheets must be sealed to prevent escape of water vapor. Advantages include:

- Easy placement, except in windy weather
- Does not prevent bond with floor coverings
- Low cost
- Can be reused

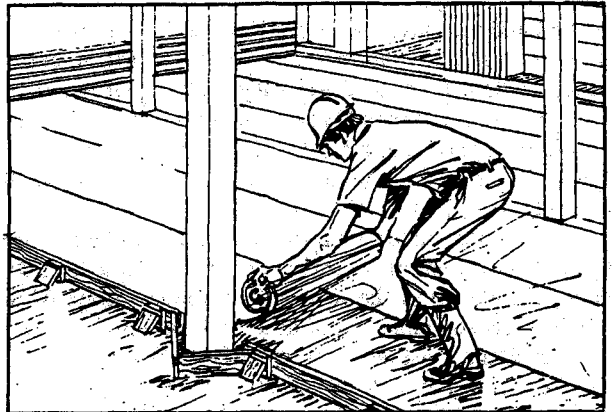
Disadvantages include:

- Easily punctured
- Laps can open, resulting in uneven cure
- Can leave a blotchy or mottled surface (greenhouse effect) due to wrinkles



Waterproof paper cure is similar to polyethylene, in that wide sheets should be used and edges and laps must be sealed. The paper must be vaporproof, strong, nonstaining, and nonshrinking. Ordinary building paper is not vaporproof and, therefore, is not appropriate. Advantages of using waterproof paper for curing are similar to using polyethylene. Greenhouse effect is less likely because the material is less easily wrinkled. Sheets should be lapped and edges weighted down to prevent wind damage.

(From Building Movement and Joints, Portland Cement Association, 1982)



7.6.3 Curing Concrete With Liquid Membranes

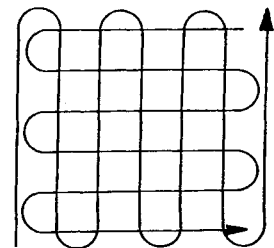
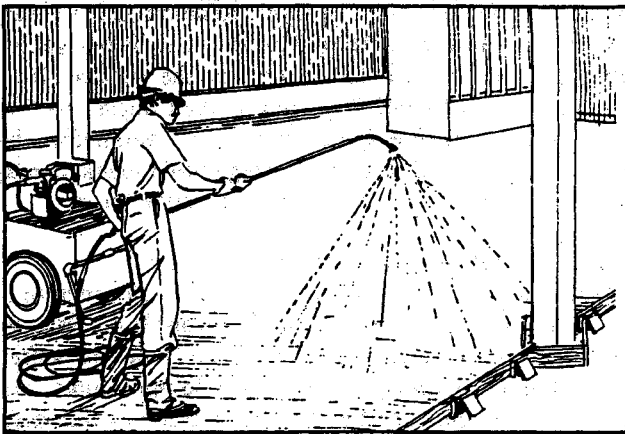
There are many types of liquid membrane curing compounds. Some only cure, while others also seal, harden, or dustproof. The compound may seal the surface for about a month and then gradually dissipate or wear off. Manufacturer's labels should be carefully studied before using a liquid membrane curing compound. Good coverage of the compound is essential to good curing. Two lighter spraying passes at right angles are preferred to one heavy pass. A compound that is colored will allow missed spots to be readily located. Some products contain a fugitive (vanishing) dye.

A clear wax-base or wax-resin-base membrane curing compound is relatively inexpensive and is effective for about 28 days. This type of product is not recommended if the concrete is to be painted, tiled, or treated, because the wax base leaves a gummy residue that attracts dirt. The wax may take a year or more to fully disintegrate.

A resin-base curing membrane is more expensive than a clear wax-resin-base membrane, but may permit painting or other surface treatment. Some resin cures may not allow surface treatment until they disintegrate, in 30 to 60 days or more. The resin cure typically results in a harder and more abrasion-resistant film than the wax cure, and is less likely to wear off under traffic.

White pigmented compounds are special formulations of wax-base or resin-base compounds. Their advantage is the ability to lower heat buildup and evaporation, in addition to indicating coverage.

Black and grey compounds have a partial or complete asphaltic base and are usually inexpensive. They are good waterproofers. These products may be used on a slab surface since they can provide a good base for tile, linoleum, and other materials that are compatible with asphalt. Because black or grey compounds absorb heat from the sun, they are desirable in cold weather.



spraying pattern for applying curing compound

applying curing compound with pressurized sprayer

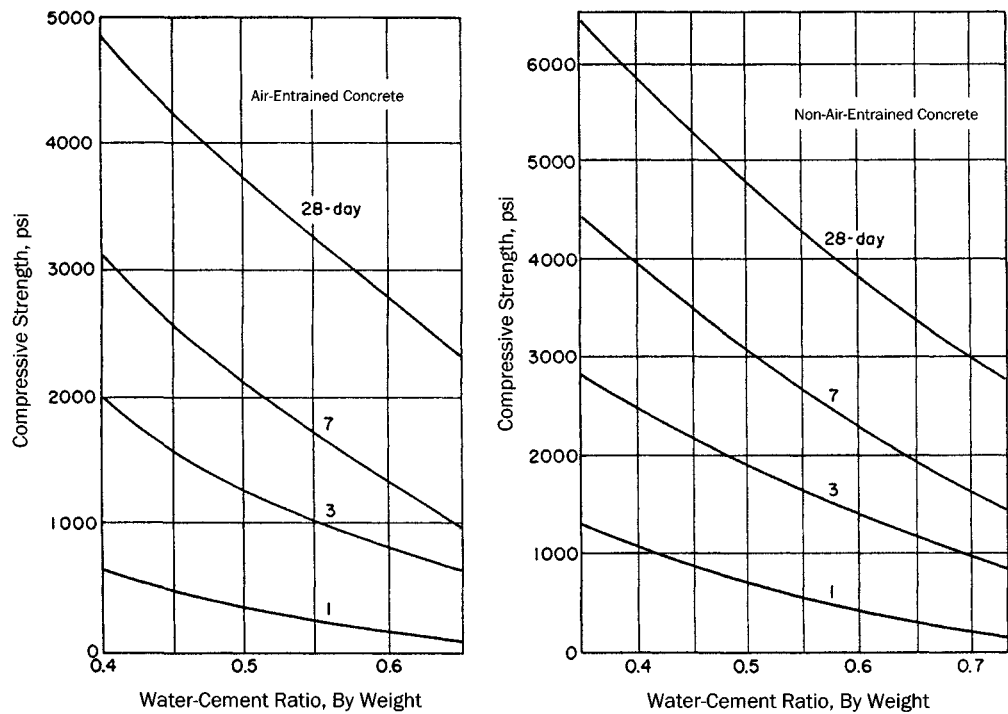
(From Building Movement and Joints, Portland Cement Association, 1982)

7.6.4 Comparison of Concrete Curing Methods

Method	Advantages	Disadvantages
Polyethylene	Easy to handle, inexpensive	Can be punctured, may leave blotchy surface
Waterproof paper	Leaves surface clean	Deteriorates with traffic
Wax based, clear	Least expensive	Leaves gummy residue
Wax-resin based	Inexpensive	Leaves gummy residue
Resin based, clear	Allows painting	More expensive
White-pigmented	Reflects heat	Must be stirred before use
Black/grey mix	Asphalt tile sticks, inexpensive, absorbs heat	Leaves surface colored
Wet burlap	Economical, reusable, leaves surface clean	Must be kept wet, restricts traffic
Sprinkling, fogging	Leaves surface clean	Costly in labor, quality control difficult, restricts traffic, not good in cold weather
Ponding	Best quality control, economical, little supervision required, leaves surface clean, acts as temperature buffer	Pond may leak, restricts traffic, not good in cold weather

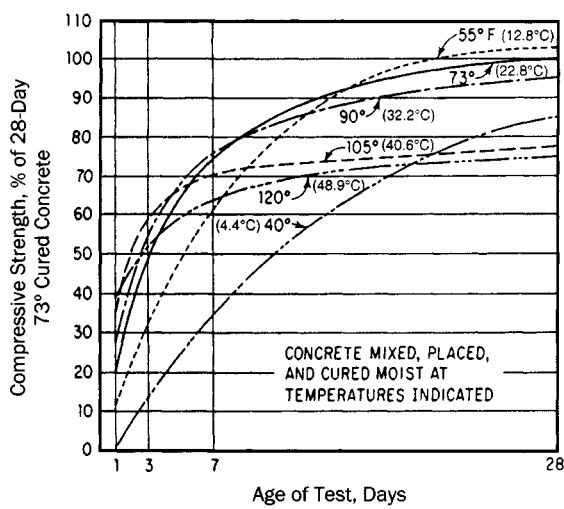
(From Residential Concrete, 3rd ed., National Association of Home Builders, 1999)

7.6.5 Age-Strength Relationships in Concrete

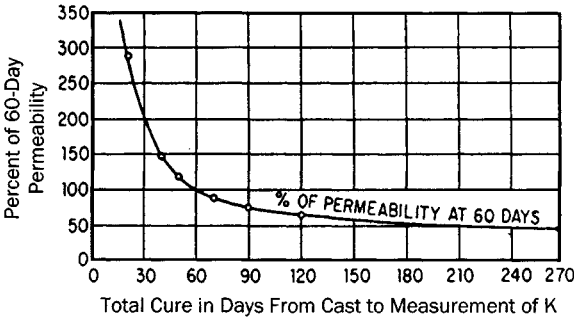


(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

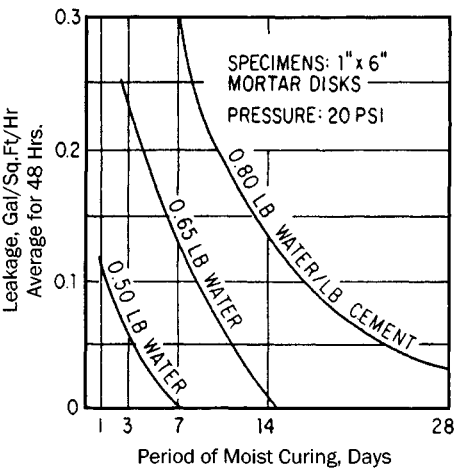
7.6.6 Effects of Curing on Concrete Properties



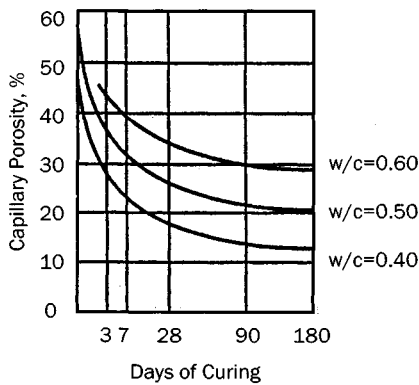
Effect of Curing Temperature on the Compressive Strength of Concrete



Effect of Length of Curing Period on Concrete Permeability



Effect of Water-Cement Ratio and Curing on Concrete Permeability



Development of Capillary Porosity as a Function of Concrete Curing

(From Dobrowolski, Concrete Construction Handbook, McGraw-Hill, 1998)

7.6.7 Concrete Form Removal

Item	Time Until Form Removal	
Walls [§]	12 hours	
Columns [§]	12 hours	
Sides of Beams and Girders [§]	12 hours	
Pan Joist Forms [†]		
30 in. wide or less	3 days	
over 30 in. wide	4 days	
	Where Structural Live Load Is	
	Less Than Structural Dead Load	Greater Than Structural Dead Load
Arch Centers	14 days	7 days
Joist, Beam, or Girder Soffits		
Under 10 ft. clear span between structural supports [‡]	7 days*	4 days
10 to 20 ft. clear span between structural supports	14 days*	7 days
Over 20 ft. clear span between structural supports	21 days *	14 days
One-Way Floor Slabs		
Under 10 ft. clear span between structural supports	4 days*	3 days
10 to 20 ft. clear span between structural supports	7 days*	4 days
Over 20 ft. clear span between structural supports	10 days*	7 days
Two-Way Slab Systems	Removal times are contingent on reshores, where required, being placed as soon as practicable after stripping operations are complete but not later than the end of the working day in which stripping occurs. Where reshores are required to implement early stripping while minimizing sag or creep, the capacity and spacing of such reshores should be specified by the engineer/architect.	
Post-Tensioned Slab Systems	As soon as full post-tensioning has been applied	

[§] Where such forms also support formwork for slab or beam soffits, the removal time of the latter should govern.

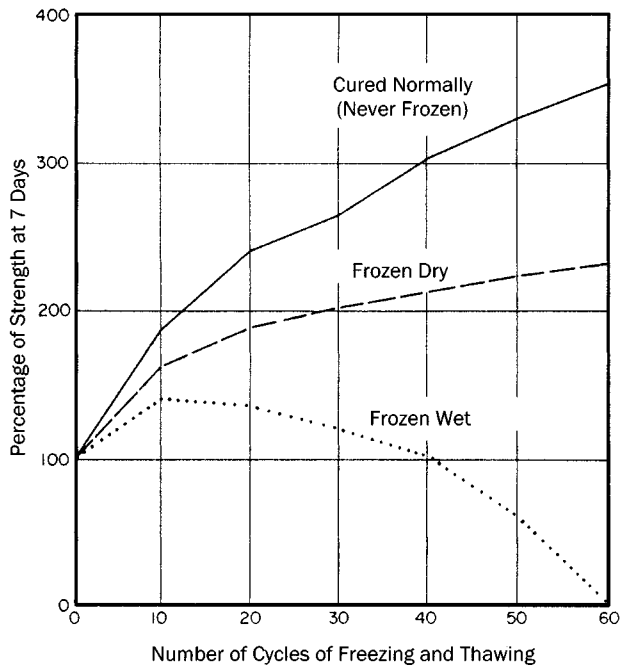
[†] Of the type which can be removed without disturbing form or shores.

[‡] Distances between supports refer to structural supports and not to temporary formwork or shores.

* Where forms may be removed without disturbing shores, use half of values shown, but not less than 3 days.

(From ACI Committee 347, Guide to Formwork for Concrete, American Concrete Institute)

7.7.1 Effect of Freezing on Non-Air-Entrained Concrete



(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

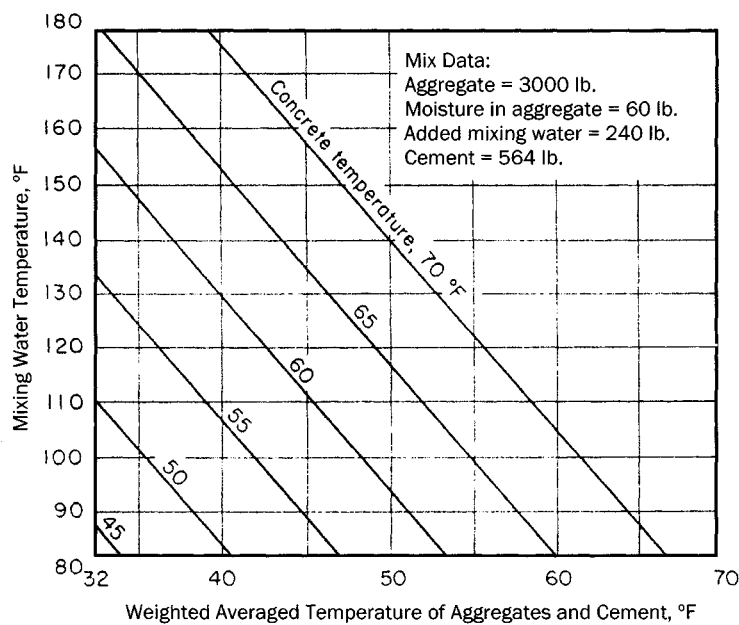
7.7.2 Recommended Concrete Temperatures for Cold Weather Construction

Recommended Concrete Temperature for Air-Entrained Concrete For Cold Weather Construction					
Condition		Thickness of Concrete Section (in.)			
		Less than 12	12 to 36	36 to 72	Over 72
Minimum temperature of fresh concrete as mixed in weather indicated	Above 30°F	60	55	50	45
	0°F to 30°F	65	60	55	50
	Below 0°F	70	65	60	55
Minimum temperature of fresh concrete as placed and maintained during protection period (°F) [§]		55	50	45	40
Maximum allowable gradual drop in temperature during first 24 hours after protection is removed (°F)		50	40	30	20

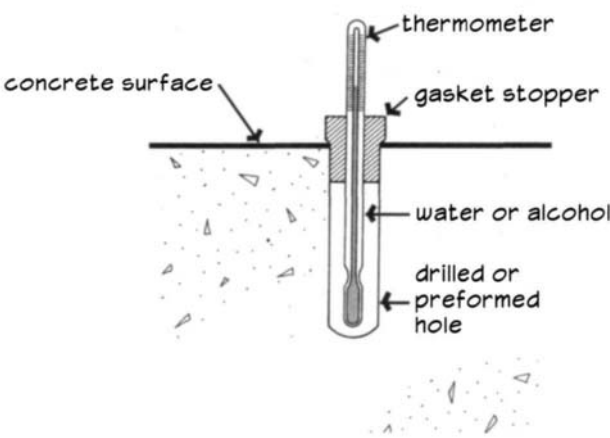
[§] Placement temperatures listed are for normal weight concrete. Lower temperatures can be used for lightweight concrete if justified by tests. For recommended duration of protection period, see table in Section 7.7.4.

(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

7.7.3 Mixing Water Temperatures for Heated Concrete



Temperature of mixing water required to produce heated concrete of required temperature. Water temperatures are based on the concrete mix shown, but are reasonably accurate for other typical mixes.



method of measuring concrete temperatures below the surface with a glass thermometer

(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

7.7.4 Recommended Protection Period for Cold-Weather Concreting

Cold weather is defined as that in which the average daily temperature is less than 40°F for 3 successive days except that if temperatures above 50°F occur during at least 12 hours in any day, the concrete should no longer be regarded as cold weather concrete and normal curing practices should apply. For concrete that is not air-entrained, ACI recommends that protection for durability should be at least twice the number of days listed in the table below.

Recommended Period of Protection for Air-Entrained Concrete
During Cold Weather

Service category††	For durability		For safe stripping strength	
	Conventional concrete,** days	High-early-strength concrete,† days	Conventional concrete,** days	High-early-strength concrete,† days
No load, not exposed, favorable moist-curing	2	1	2	1
No load, exposed, but later has favorable moist-curing	3	2	3	2
Partial load, exposed	3	2	6	4
Fully stressed, exposed	3	2	See Table Below	

†† "Exposed" means subject to freezing and thawing.

** Made with ASTM C150, Type I or Type II portland cement.

† Made with ASTM C150, Type III portland cement, or a set accelerator, or an extra 100 lbs. of cement per cu.yd.

(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

Recommended Period of Protection for
Fully Stressed, Exposed, Air-Entrained Concrete

Required percentage of design strength, f_c'	Days at 50°F			Days at 70°F		
	Type of portland cement			Type of portland cement		
	I	II	III	I	II	III
50	6	9	3	4	6	3
65	11	14	5	8	10	4
85	21	28	16	16	18	12
95	29	35	26	23	24	20

Values shown are approximate and will vary according to the thickness of the concrete, mix proportions, etc. They are not intended to represent the ages at which supporting forms can be removed.

(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

Protection Period Required to Prevent Damage to Air-Entrained Concrete from Early-Age Freezing

Exposure	Protection Period at Recommended Concrete Temperatures (See Section 7.7.5)	
	Type I or II Cement	Type III Cement, or Set Accelerating Admixture, or 100 lbs/cu.yd. of Additional Cement
Not exposed	2	1
Exposed	3	1

(From ACI Manual of Concrete Practice 306R-16, American Concrete Institute)

7.7.5 Recommended Concrete Temperatures, and Heat of Hydration

Recommended Concrete Temperatures at Various Stages					
Line	Air Temperature (°F)	Section Size, Minimum Dimension (in.)			
		< 12 in.	12—36 in.	36—72 in.	> 72 in.
Minimum Concrete Temperature as Placed and Maintained					
1	—	55	50	45	40
Minimum Concrete Temperature as Mixed for Indicated Air Temperatures ^s					
2	Above 30	60	55	50	45
3	0 to 30	65	60	55	50
4	Below 0	70	65	60	55
Maximum Allowable Gradual Temperature Drop in First 24 hr. After End of Protection					
5	—	50	40	30	20

^s For colder weather, a greater margin in temperature is provided between concrete as mixed and required minimum temperature of fresh concrete in place.

(From ACI Manual of Concrete Practice 306R-16, American Concrete Institute)

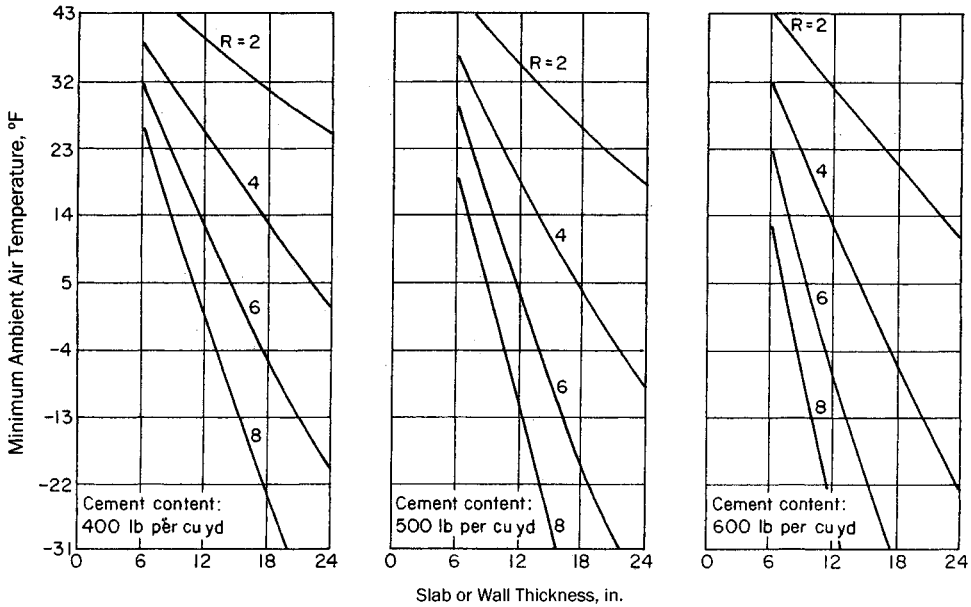
Time Required to Dissipate Heat of Hydration	
Concrete Thickness (in.)	Approximate Heat Dissipation Time (hrs.)
6	2
8	3
12	7
18	15
24	27
60	168

(From Building Movements and Joints,
Portland Cement Association, 1982)

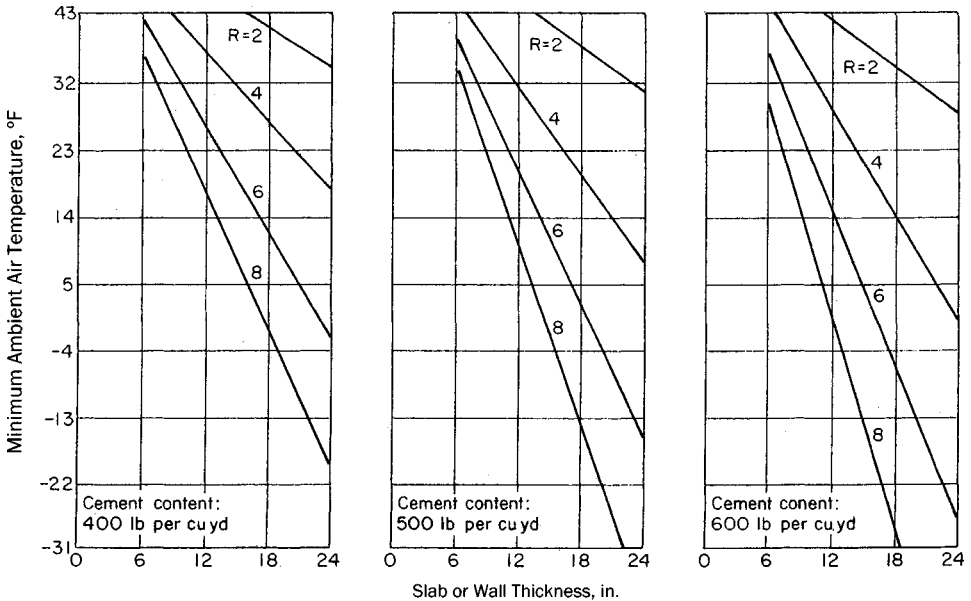
7.7.6 Insulation Required to Maintain Concrete Temperature Above 50°F

Thermal Resistance of Insulation Required to Maintain Concrete Surface Temperature of Walls and Slabs Above Ground at 50°F or Above for 3 Days and 7 Days
(Concrete Temperature as Placed 50°F, Maximum Wind Velocity 15 mph)

Requirements for Maintaining Temperature for 3 Days

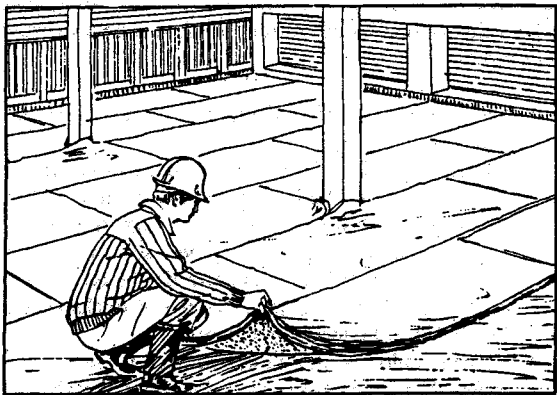


Requirements for Maintaining Temperature for 7 Days



(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

7.7.7
Insulation Blankets for Cold-Weather Concrete Protection



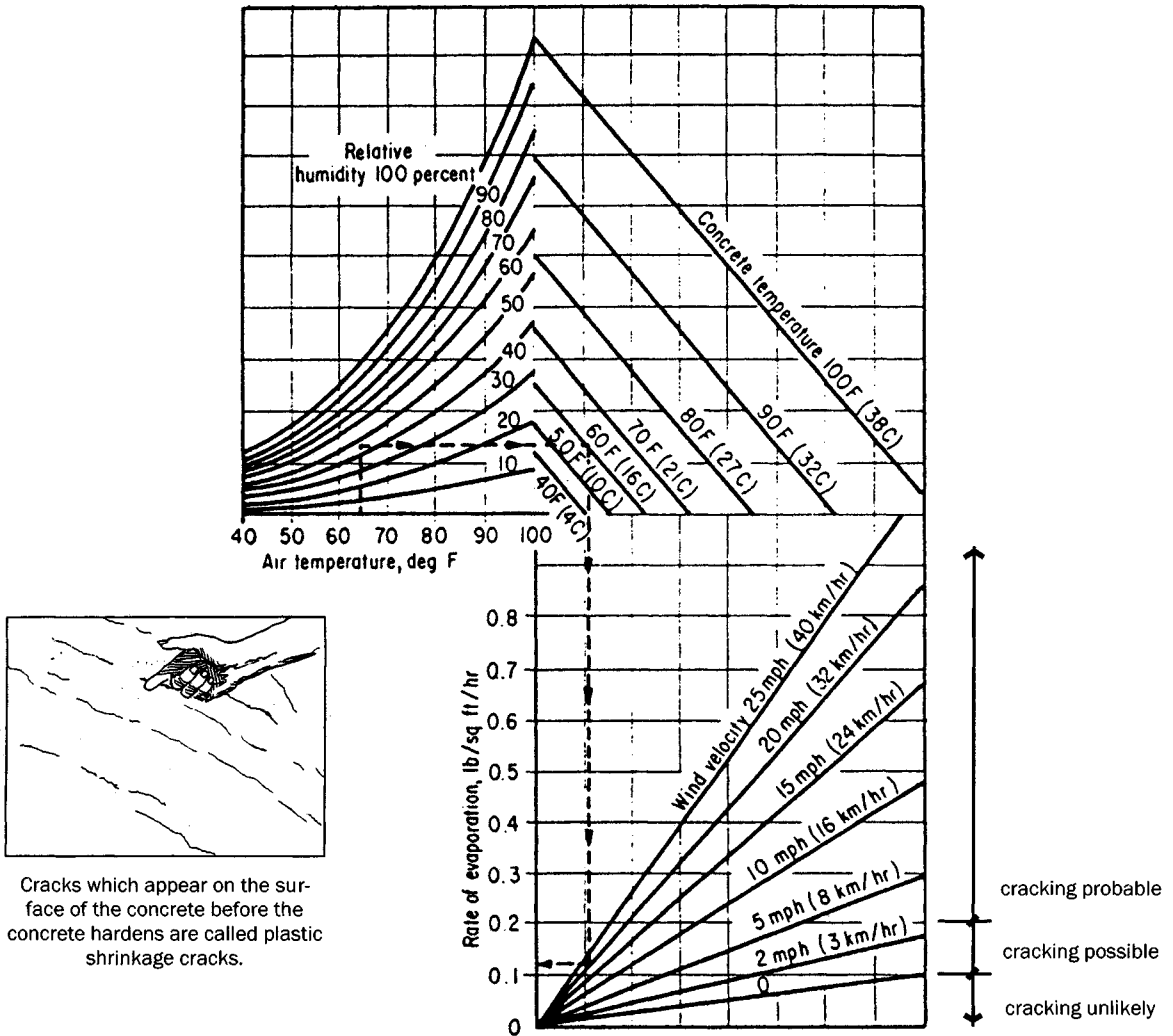
Insulation blankets are used during the curing period to protect concrete in cold weather.

(From Building Movements and Joints, Portland Cement Association, 1982)

Thermal Resistance for Various Types of Insulation	
Material	Thermal Resistance, R-Value, for 1-in. Thickness
Boards and Slabs	
expanded polyurethane	6.25
extruded polystyrene	5.00
expanded polystyrene	3.85
glass fiber	4.00
mineral fiber with resin binder	3.45
mineral fiberboard, wet felted	2.94
particle board, low density	1.85
plywood	1.24
Loose Fill	
wood fiber	3.33
perlite, expanded	2.70
vermiculite, exfoliated	2.27
sawdust or shavings	2.22
Blankets	
mineral fiber, fibrous form	R-7 for 2 to 2.75 in. thk.
mineral fiber, loose fill	R-11 for 3.75 to 5 in. thk.

(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

7.7.8 Moisture Evaporation in Hot Weather Concreting



7.7.9 Cold Weather Masonry Construction

MSJC Cold Weather Construction Requirements	
Temperature	Action Required
During Construction	
Ambient Temperature	32 to 40°F or When temperature of masonry units is less than 40°F
	Do not lay glass unit masonry. Do not lay units that have a temperature below 20°F. Remove visible ice on units before laying. Heat mortar sand or mixing water to produce mortar temperature between 40°F and 120°F at time of mixing. Maintain mortar above freezing until used in masonry.
	20 to 25°F Perform actions required when ambient temperature is 32 to 40°F. Provide heat sources on both sides of the masonry. When wind velocity exceeds 15 mph, install wind breaks.
Less than 20°F	Perform actions required when ambient temperature is 32 to 40°F. Enclose masonry under construction. Provide supplementary heat to maintain temperature within enclosure above 32°F.
For 24 Hours After Construction	
Mean Daily Temperature	32 to 40°F
	25 to 32°F
	20 to 25°F
	Less than 20°F
	Cover completed masonry with weather-resistive membrane to protect from rain and snow. Completely cover completed masonry with weather-resistive membrane. Completely cover completed masonry with insulating blankets or equal protection. Enclose masonry. Provide supplementary heat to maintain temperature of masonry within enclosure above 32°F.
For 48 Hours After Construction	
All	Maintain temperature of glass unit masonry above 40°F.

(From Masonry Standards Joint Committee Specification for Masonry Structures, ACI 530.1/ASCE 6/TMS 602)

7.7.10 Hot Weather Masonry Construction

MSJC Hot Weather Construction Requirements	
Temperature	Action Required
Preparation	
Ambient temperature above 100°F, or 90°F with wind velocity greater than 8 mph	Maintain sand piles in a damp, loose condition. Provide necessary conditions and equipment to produce mortar having a temperature below 120°F.
Ambient temperature above 115°F, or 105°F with wind velocity greater than 8 mph	Maintain sand piles in a damp, loose condition. Provide necessary conditions and equipment to produce mortar having a temperature below 120°F. Shade materials and mixing equipment from direct sunlight.
During Construction	
Ambient temperature above 100°F, or 90°F with wind velocity greater than 8 mph	Maintain temperature of mortar and grout below 120°F. Flush mixer, mortar transport container, and mortar boards with cool water before they come into contact with mortar ingredients or mortar. Maintain mortar consistency by retempering with cool water. Use mortar within 2 hrs. of initial mixing.
Ambient temperature above 115°F, or 105°F with wind velocity greater than 8 mph	Maintain temperature of mortar and grout below 120°F. Flush mixer, mortar transport container, and mortar boards with cool water before they come into contact with mortar ingredients or mortar. Maintain mortar consistency by retempering with cool water. Use mortar within 2 hrs. of initial mixing. Use cool mixing water for mortar and grout. Ice is permitted in the mixing water prior to use. Do not permit ice in the mixing water when added to the other mortar ingredients or grout materials.
Protection	
Mean daily temperature above 100°F or 90°F with wind velocity greater than 8 mph	Fog spray all newly constructed masonry until damp, at least three times a day until the masonry is 3 days old.

(From Masonry Standards Joint Committee Specification for Masonry Structures, ACI 530.1/ASCE 6/TMS 602)

Site and Landscape Elements

8.1 Concrete Paving

- 8.1.1 Concrete Driveways
- 8.1.2 Concrete Driveway Slope
- 8.1.3 Concrete Curbs and Gutters
- 8.1.4 Concrete Sidewalks
- 8.1.5 Sand Fill for Concrete Sidewalks
- 8.1.6 Joints in Concrete Paving
- 8.1.7 Concrete Joint Locations
- 8.1.8 Patterned Concrete Flatwork
- 8.1.9 Concrete Steps

8.2 Masonry Paving

- 8.2.1 Masonry Paving
- 8.2.2 Installing Flexible Masonry Paving
- 8.2.3 Alternative Masonry Paving Edge Restraints
- 8.2.4 Masonry Paving Patterns
- 8.2.5 Expansion Joints in Rigid Brick Paving
- 8.2.6 Concrete Masonry Grid Pavers
- 8.2.7 Brick Steps

8.3 Traditional Retaining Walls

- 8.3.1 Types of Retaining Walls
- 8.3.2 Concrete Retaining Wall Terminology and Guidelines
- 8.3.3 Concrete Retaining Wall Design Basics
- 8.3.4 Notation for Structural Reinforcement for Concrete Retaining Walls ≤ 10 ft.
- 8.3.5 Notation for Structural Reinforcement for Concrete Retaining Walls > 10 ft.
- 8.3.6 Concrete Crib Wall
- 8.3.7 Concrete Masonry Retaining Walls
- 8.3.8 Double-Wythe Brick Retaining Walls
- 8.3.9 Retaining Wall Drainage and Weeps

8.4 Segmental CMU Retaining Walls

- 8.4.1 Segmental Retaining Wall Types
- 8.4.2 Maximum Height of Segmental Retaining Walls

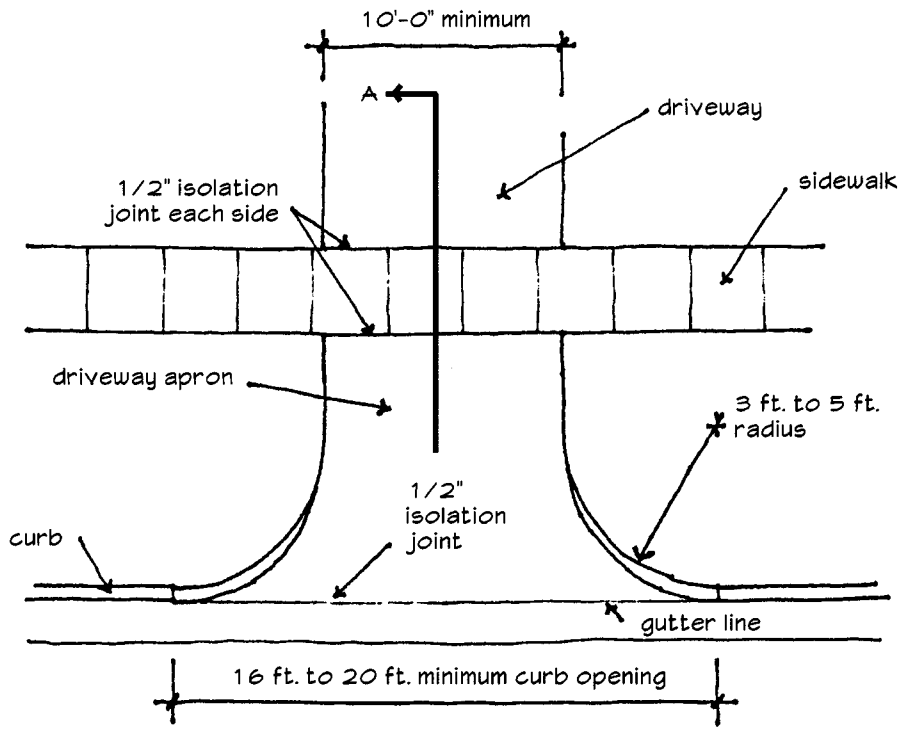
8.5 Freestanding Walls

- 8.5.1 Masonry Screen Wall Patterns

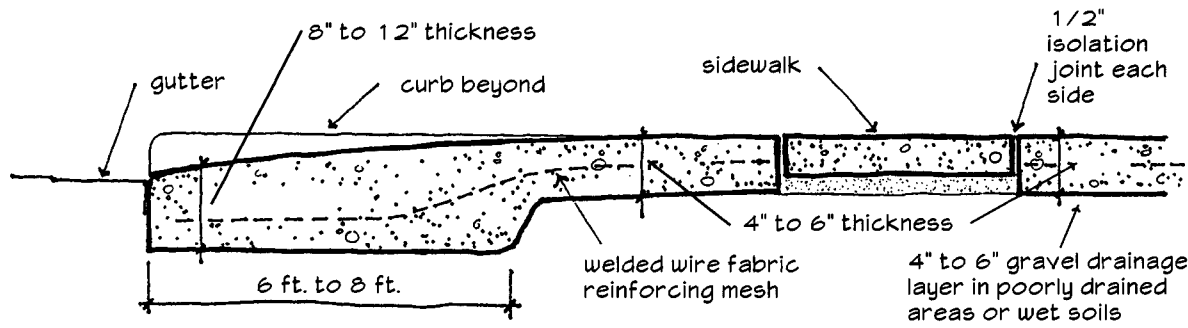
- 8.5.2 Methods of Supporting Masonry Screen Walls

- 8.5.3 Masonry Bonded Garden Walls
- 8.5.4 Metal-Tie Bonded Garden Walls
- 8.5.5 CMU Garden Walls
- 8.5.6 Garden Wall Footings
- 8.5.7 Brick Garden Wall Columns and Pilasters
- 8.5.8 CMU Garden Wall Pilasters
- 8.5.9 Garden Wall Caps and Flashing
- 8.5.10 Single-Wythe Brick Pier and Panel Garden Walls
- 8.5.11 Brick Pier and Panel Wall Design Tables
- 8.5.12 CMU Pier and Panel Wall Design Tables
- 8.5.13 CMU Garden Wall Design Tables

8.1.1 Concrete Driveways



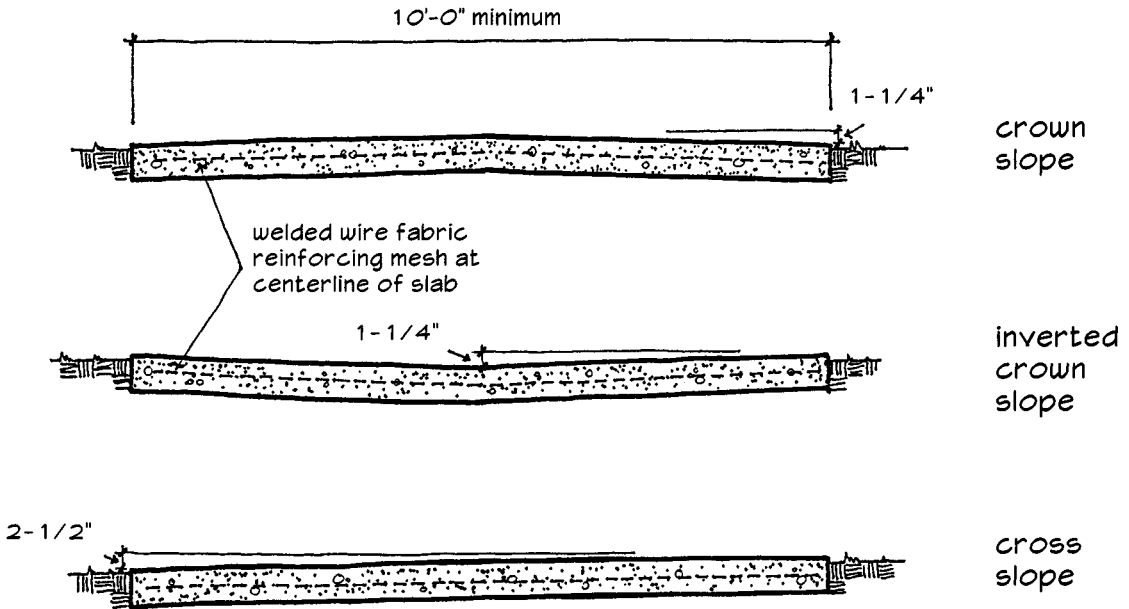
driveway plan



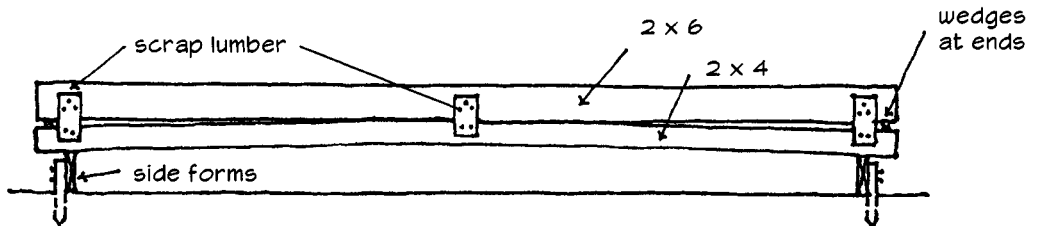
driveway section A

(From The Homeowner's Guide to Building With Concrete, Brick and Stone, Portland Cement Association)

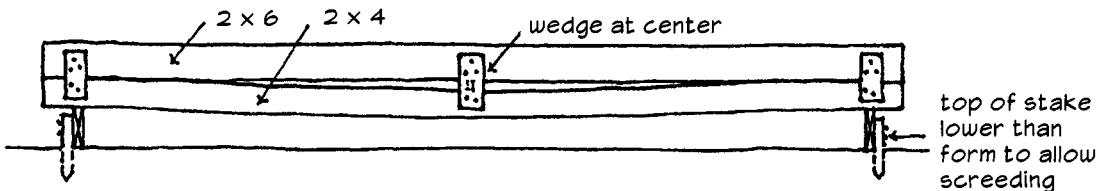
8.1.2 Concrete Driveway Slope



if there is no ground slope along the length of the drive, slope driveways laterally a minimum of 1/4" per foot to drain water from surface

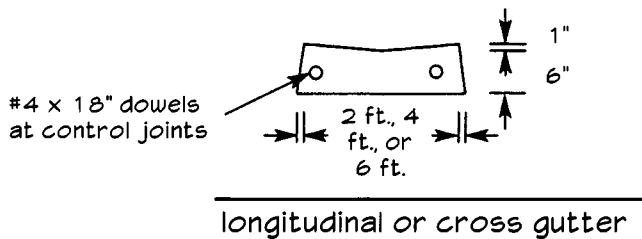
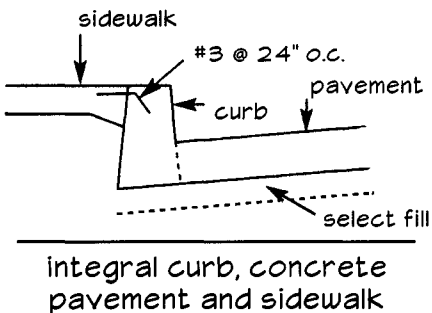
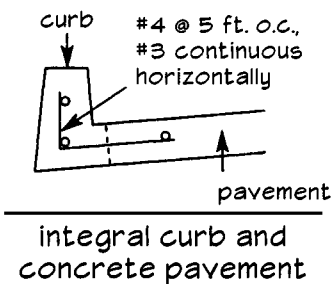
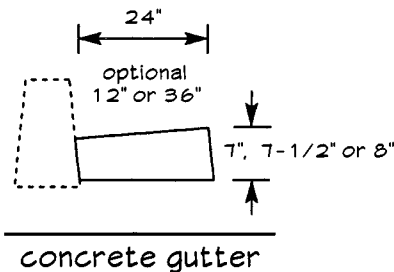
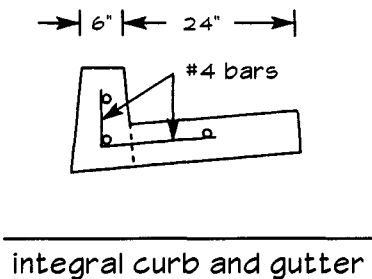
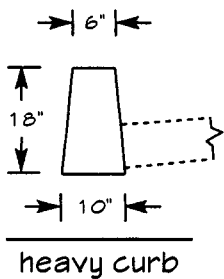
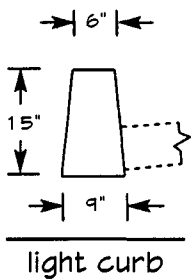


strikeoff board for crown sloped driveway



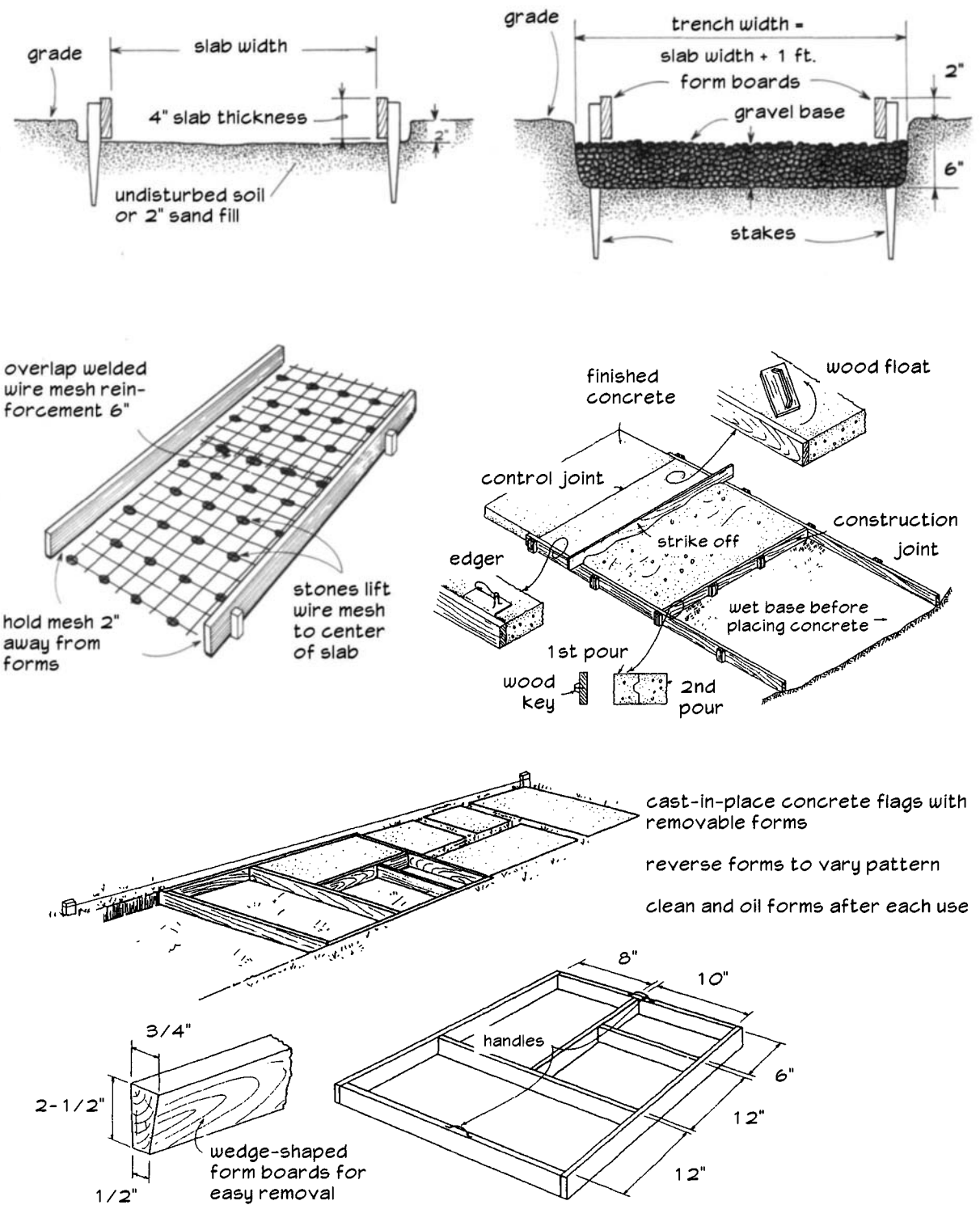
strikeoff board for inverted crown sloped driveway

8.1.3 Concrete Curbs and Gutters



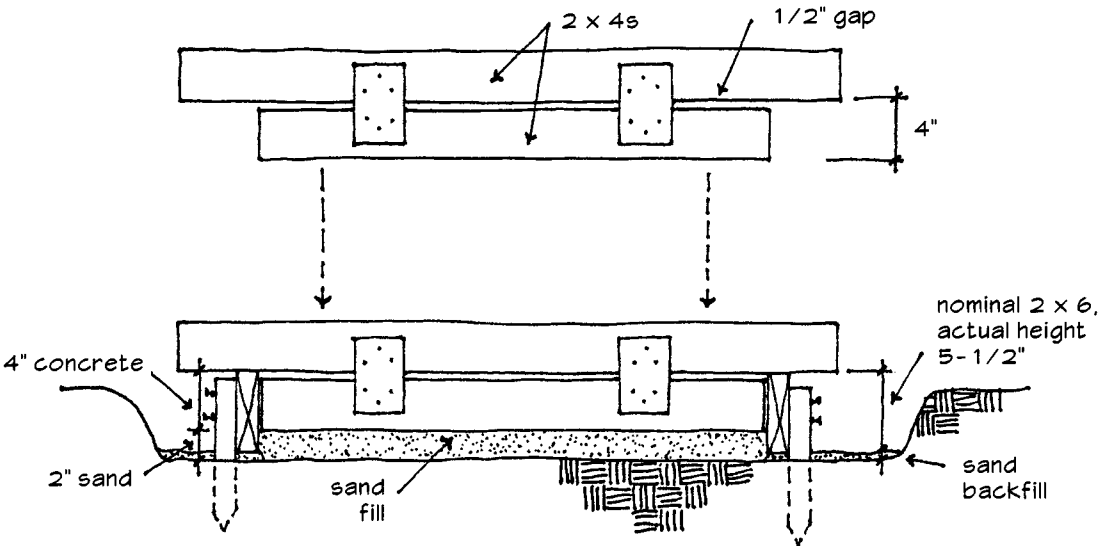
(From Schwartz, Basic Concrete Engineering for Builders, Craftsman Book Company, 2000)

8.1.4 Concrete Sidewalks

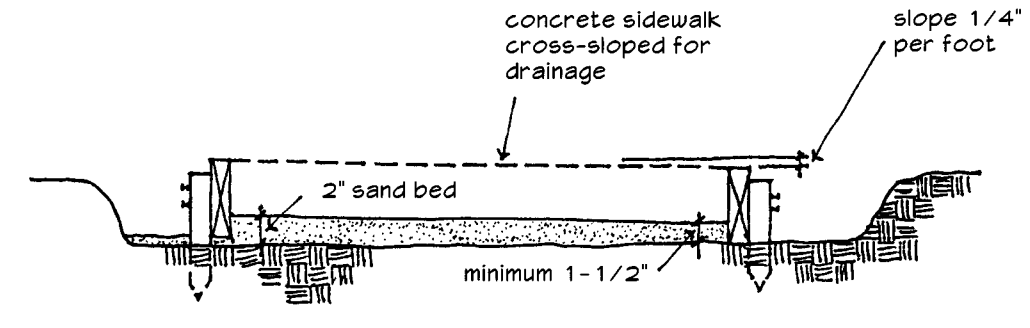


(From Alth, Masonry and Concrete Work, Popular Science Books, 1978; and Residential Concrete, 3rd ed., NAHB, 1999)

8.1.5 Sand Fill for Concrete Sidewalks



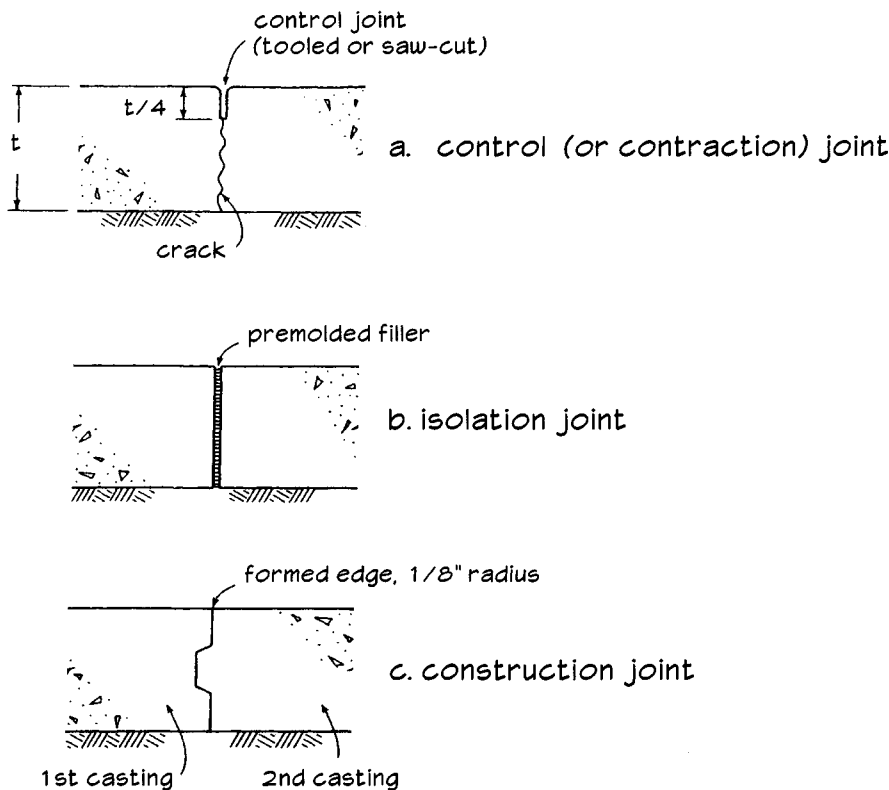
screed for leveling sand bed



sloped sand bed, uniform concrete thickness, for sloped sidewalk

(From Beall, Masonry and Concrete for Residential Construction, McGraw-Hill Complete Construction Series, 2001)

8.1.6 Joints in Concrete Paving

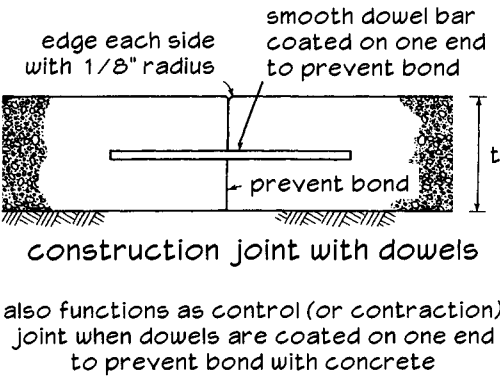


three types of joints for concrete pavements

Dowels for Concrete Joints in Parking Lots, Streets, and Highways				
Pavement Type	Slab Thickness (in.)	Dowel Diameter (in.)	Dowel Embedment [§] (in.)	Total Dowel Length [†] (in.)
Parking lots	5 [‡]	5/8	5	12
	6 [‡]	3/4	6	14
	7 [‡]	7/8	6	14
	8	1	6	14
	9	1-1/8	7	16
City streets (jointed, reinforced concrete with joint spacings greater than 20 ft.)	6 [‡]	3/4	5	14
	6-1/2 [‡]	7/8	5	14
	7 [‡]	1	6	16
	7-1/2	1-1/8	7	16
Highways	8	1-1/4	8	17
	<10	1-1/4	7-1/2	18
	≥10	1-1/2	9	20

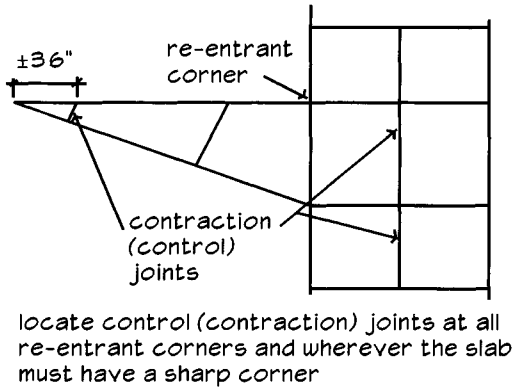
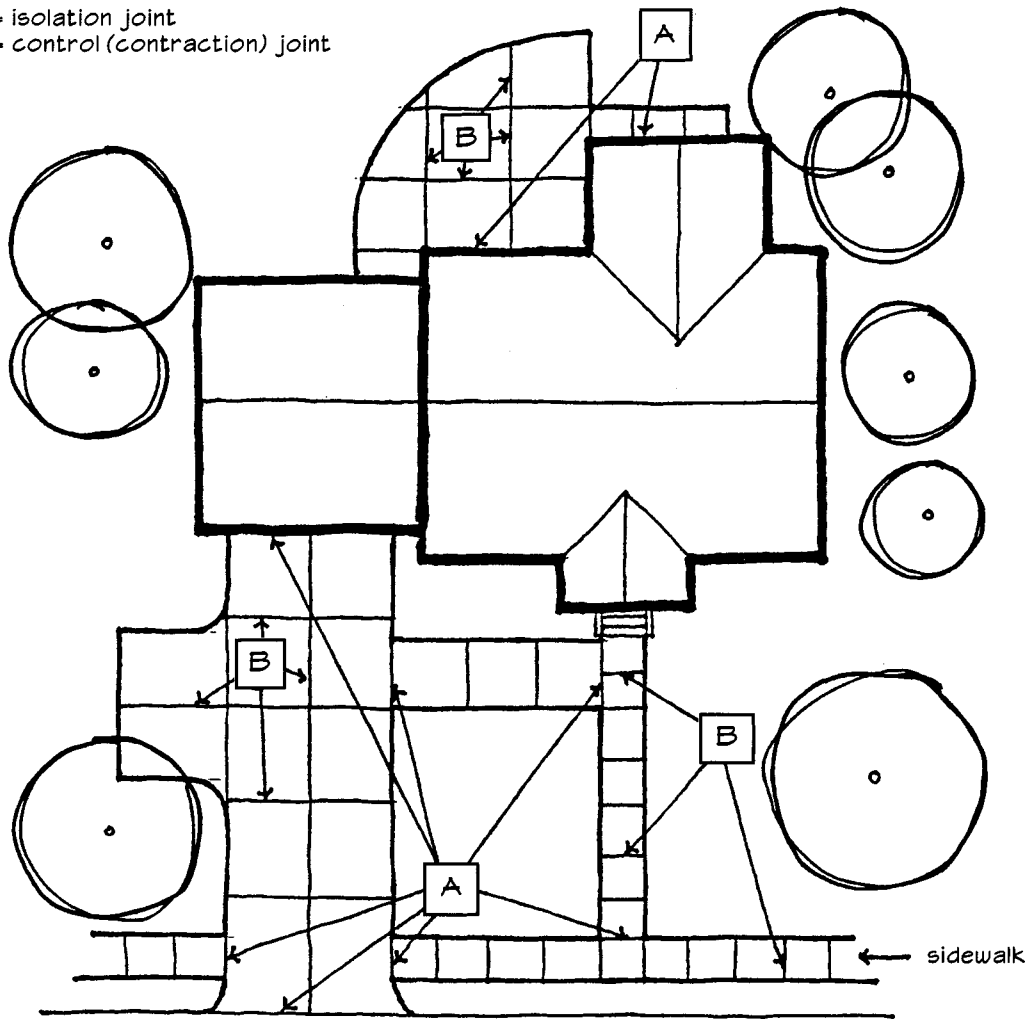
[§] For load transfer, embed dowel each side 6 x dowel diameter.
[†] Includes allowance for joint opening and minor errors in positioning (2 x embedment length + 2 to 3 in.)
[‡] Dowels may be impractical in thinner pavements.

(From ACI 224.3R-95 Joints in Concrete Construction)



8.1.7 Concrete Joint Locations

A = isolation joint
B = control (contraction) joint

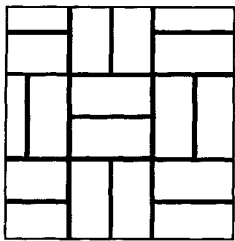


Minimum Cement Requirements for Normal-Weight Concrete Used in Flatwork	
Maximum Size of Aggregate (in.)	Cement (lb/cu.yd)*
1-1/2	470
1	520
3/4	540
1/2	590
3/8	610

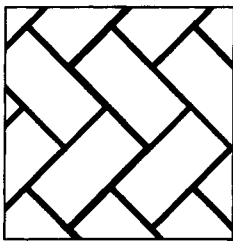
* Cement quantities may need to be greater for severe exposures.

(From Beall, Masonry and Concrete for Residential Construction, McGraw-Hill Complete Construction Series, 2001)

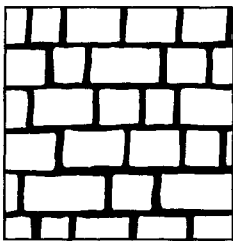
8.1.8 Patterned Concrete Flatwork



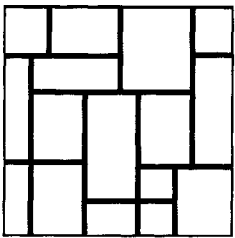
basket weave



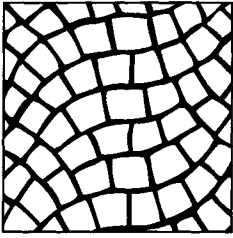
herringbone



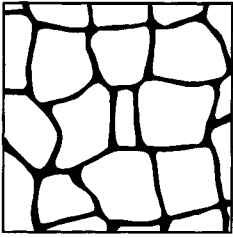
Norman cobbles



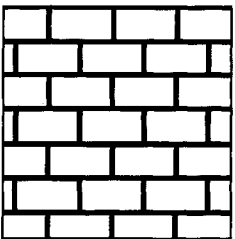
king's slate



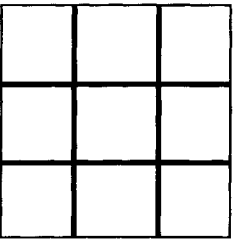
serpentine



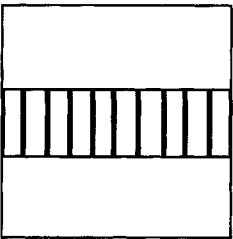
American flagstone



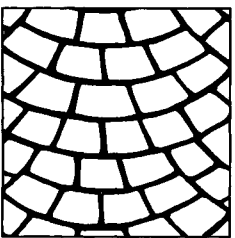
Baltimore brick



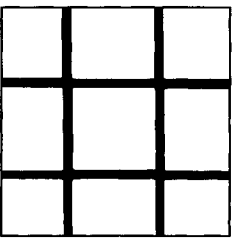
Santa Fe



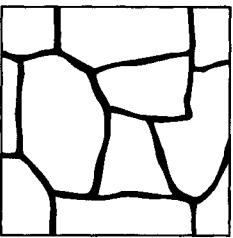
brick ribbon
soldier course



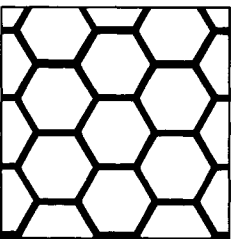
fanfare



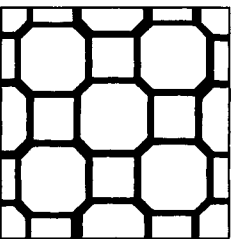
Saltillo tile



Palos Verde stone



hexagon

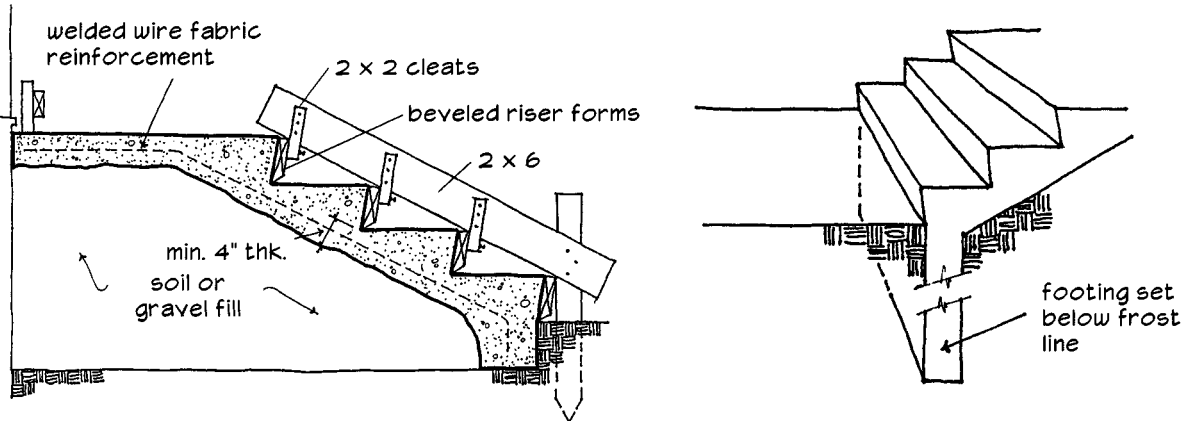


runner

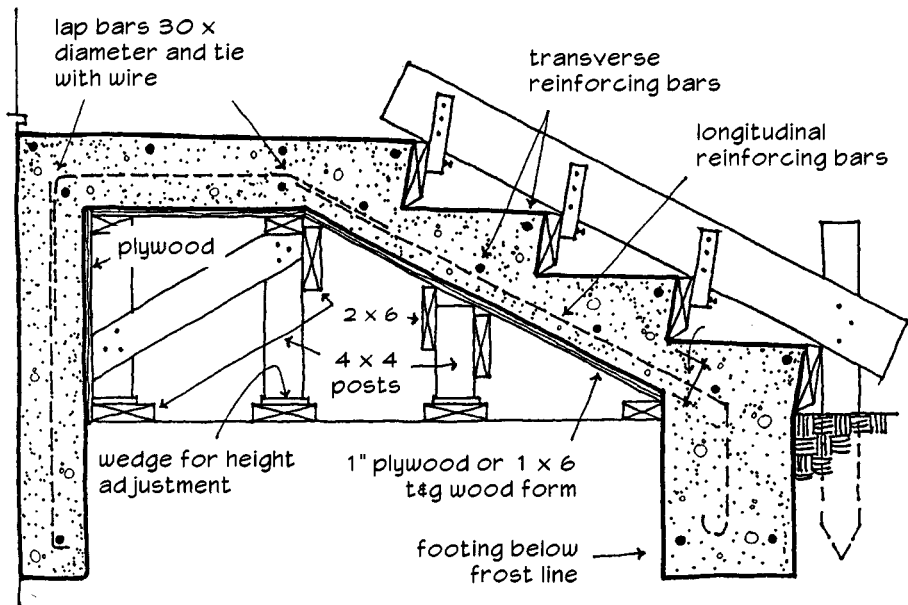
Color and texture can be added to both interior and exterior concrete flatwork using proprietary systems or generic mats to impress a relief pattern into the wet concrete surface. Patterned concrete can be applied directly to the concrete slab or to a topping slab of colored concrete. Pigments can be used to simulate mortar joints. The wide variety of patterns shown at left are offered by one proprietary system. Other patterns are available from other manufacturers.

(From The Euclid Chemical Company)

8.1.9 Concrete Steps



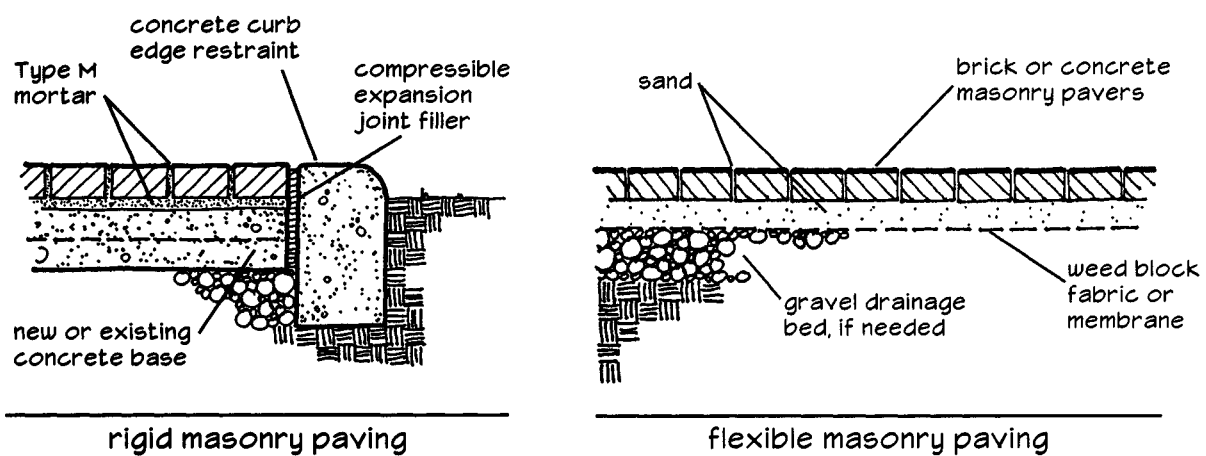
(From Beall, Masonry and Concrete for Residential Construction, McGraw-Hill Complete Construction Series, 2001)



Reinforcement for Self-Supporting Steps					
Concrete Dimensions		Longitudinal Reinforcing		Transverse Reinforcing	
Length (ft.)	Thickness (in.)	Bar Size	Spacing (in.)	Bar Size	Spacing (in.)
2 to 3	4	#2	10	#2	12 to 18
3 to 4	4	#2	5-1/2	#2	12 to 18
4 to 5	5	#2	4-1/2	#2	12 to 18
5 to 6	5	#3	7	#2	18 to 24
6 to 7	6	#3	6	#2	18 to 24
7 to 8	6	#3	4	#2	18 to 24
8 to 9	7	#4	7	#2	18 to 24

(From Dezettel, Masons and Builders Library, MacMillan, 1986)

8.2.1 Masonry Paving



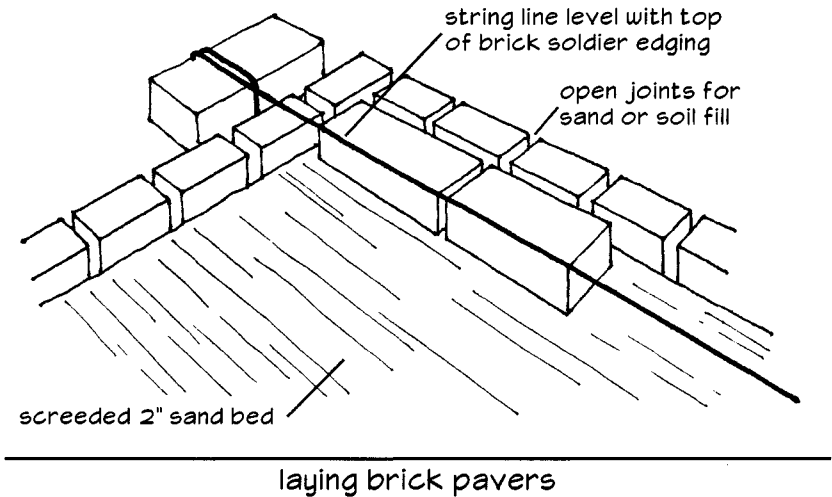
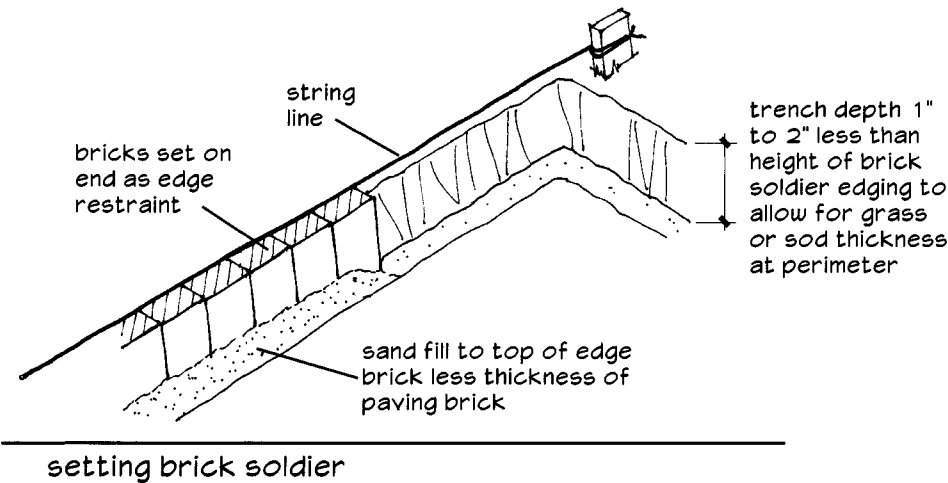
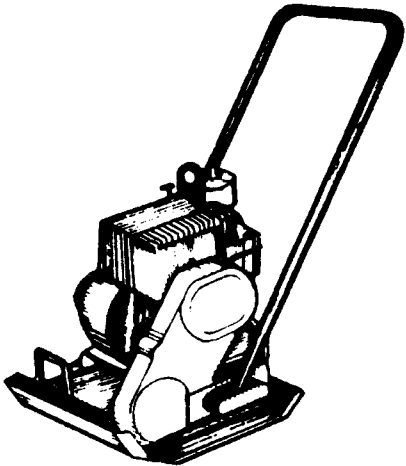
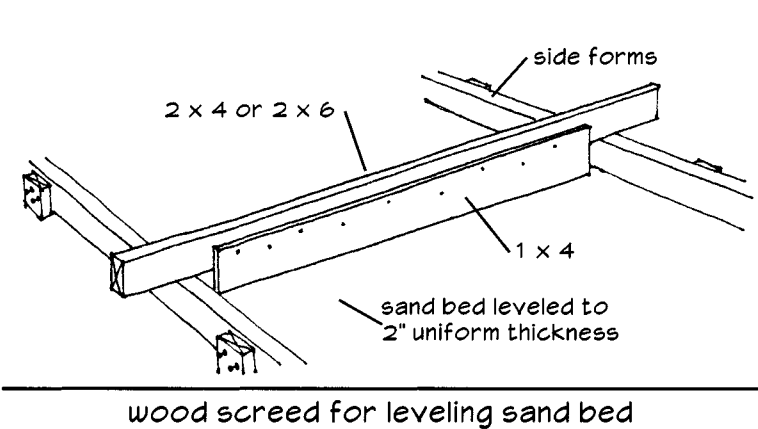
(From Beall, Masonry and Concrete for Residential Construction, McGraw-Hill Complete Construction Series, 2001)

Concrete Masonry Paving Base and Paver Thickness

Application	Aggregate Sub-Base Thickness (in.)		Thickness of Concrete Masonry Paving Units (in.)
	Well-Drained, Dry Areas	Low, Wet Areas	
Light duty Residential driveways, patios, pool decks, walkways, parking, bicycle paths, erosion control, temporary paving	0–3	4–8	2-1/2–3
Medium duty Sidewalks, shopping malls, residential streets, public parking, bus stops, service roads, cross walks, parking lots, camping areas, mobile home parks, canal lining, safety zones, maintenance areas, farm equipment storage	4–6	10	3–4
Heavy duty City streets, intersections, gas stations, loading docks, loading ramps, industrial floors, stables	8	12	4–6

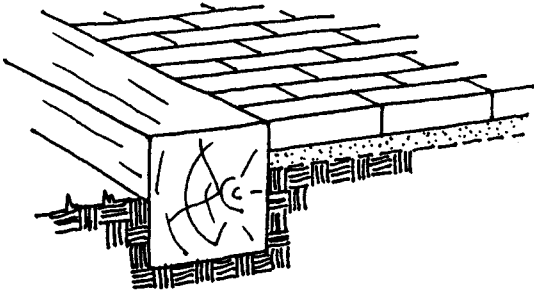
Note: The sand bed between the sub-base and the concrete pavers is always 2 in. thick.
(From NCMA TEK Bulletin 75, National Concrete Masonry Association)

8.2.2 Installing Flexible Masonry Paving

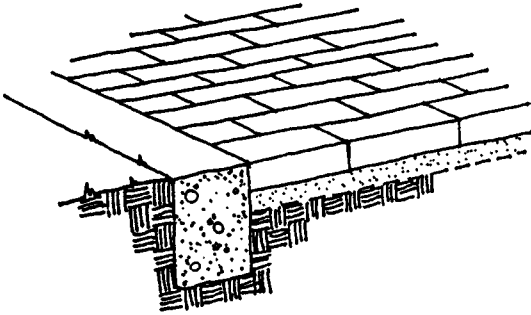


(From Beall, Masonry and Concrete for Residential Construction, McGraw-Hill Complete Construction Series, 2001.)

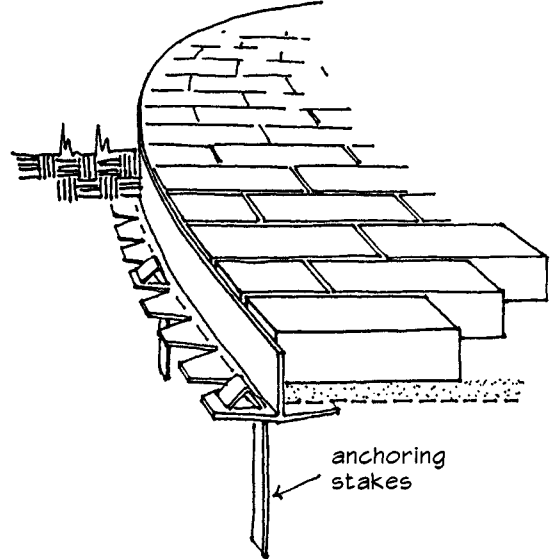
8.2.3 Alternative Masonry Paving Edge Restraints



railroad ties for straight or angled edges



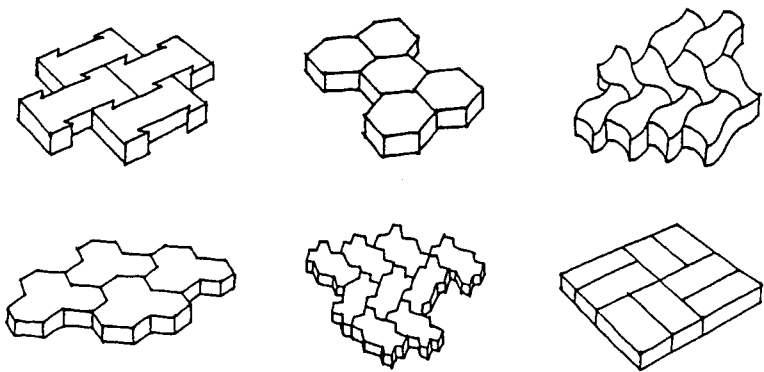
concrete curb for straight, curved,
or angled edges



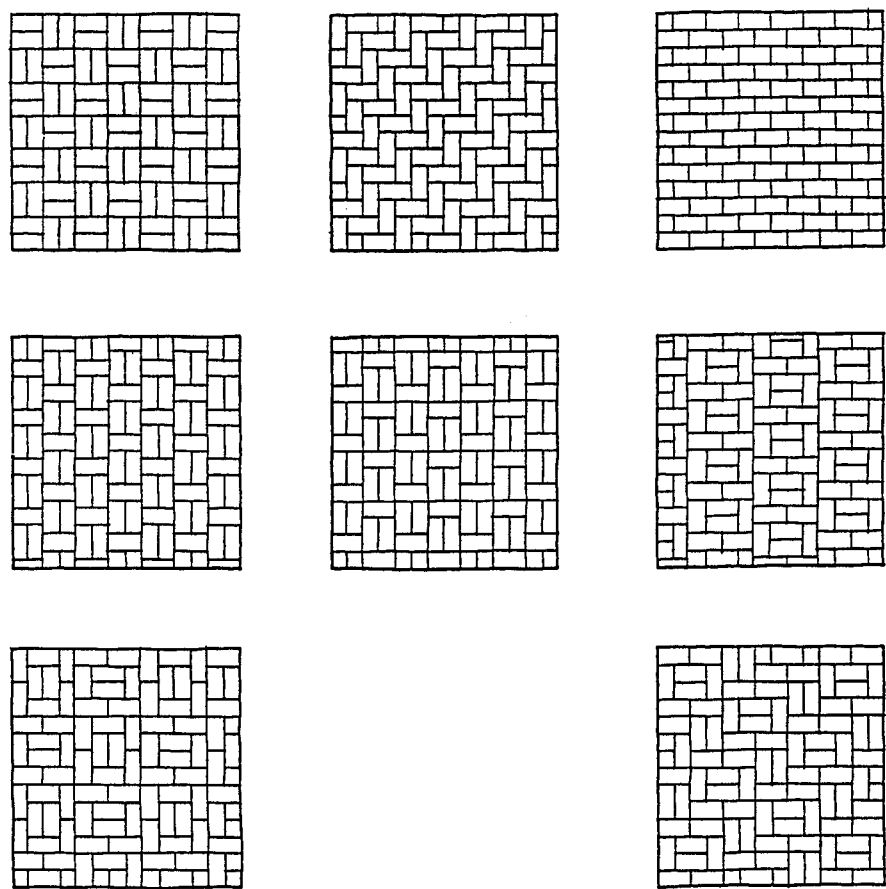
anchoring
stakes

proprietary metal or plastic systems
for straight or curved edges

8.2.4 Masonry Paving Patterns



examples of concrete masonry paving patterns

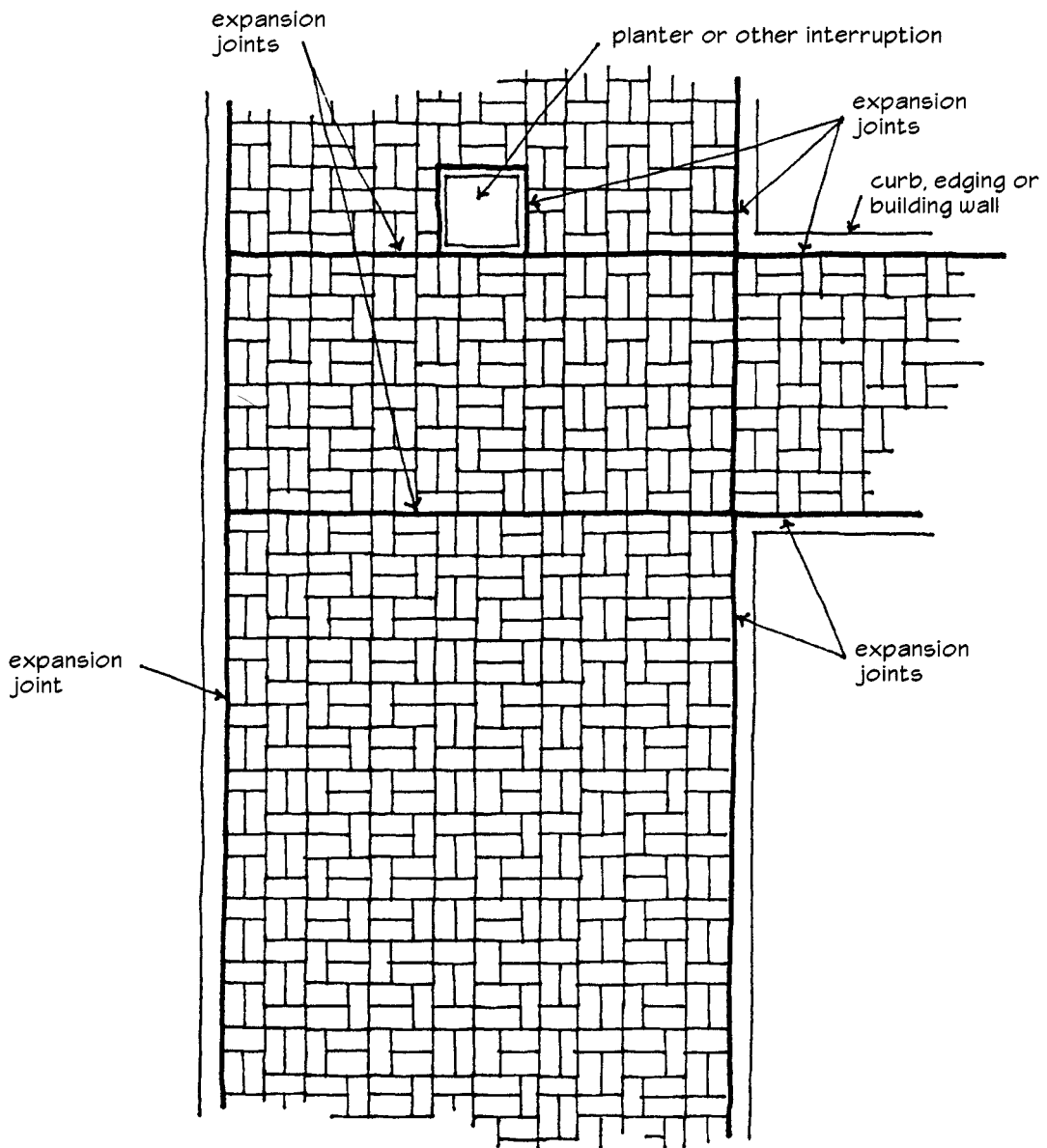


brick paving patterns

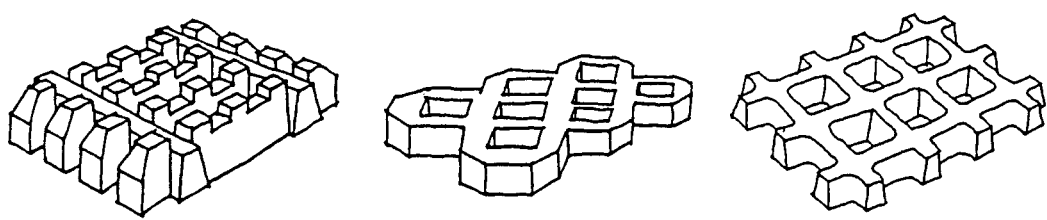
For vehicular traffic on flexible sand bed paving, long continuous joints should be oriented perpendicular to the direction of travel. Patterns without long continuous joints are more stable against sliding, displacement, and the formation of ruts from the repeated braking and acceleration of vehicles.

(From Beall, Masonry Design and Detailing, 4th ed., McGraw-Hill, 1997)

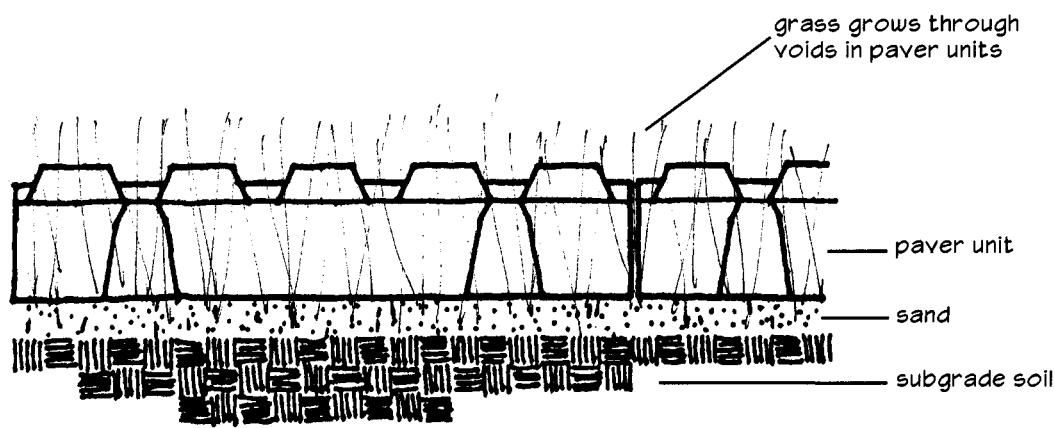
8.2.5 Expansion Joints in Rigid Brick Paving



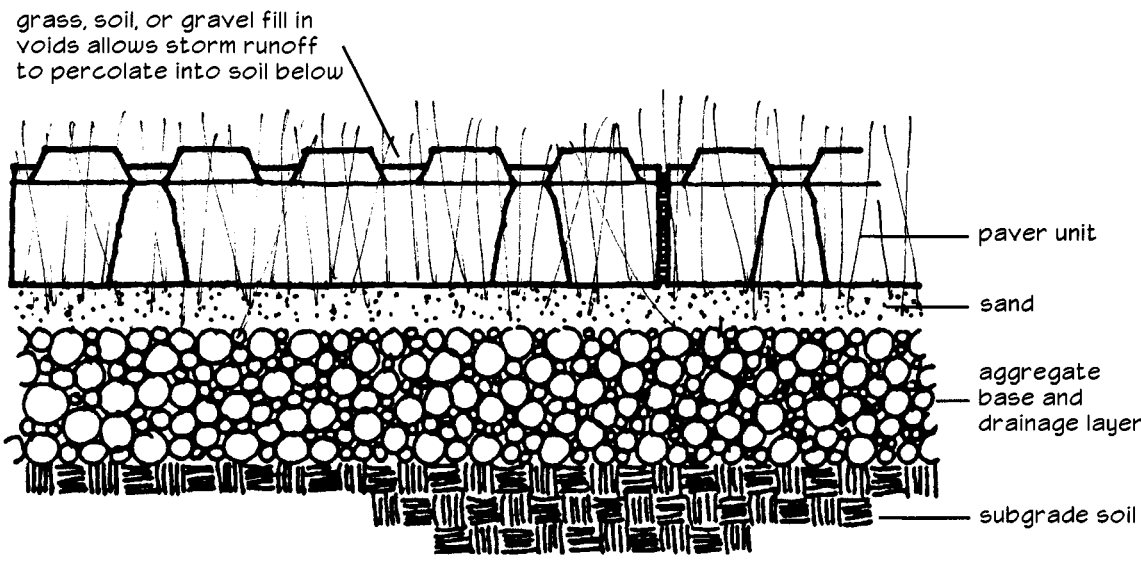
8.2.6 Concrete Masonry Grid Pavers



examples of concrete masonry grid pavers



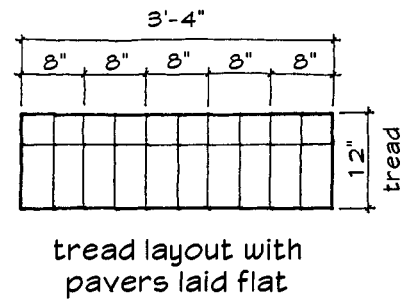
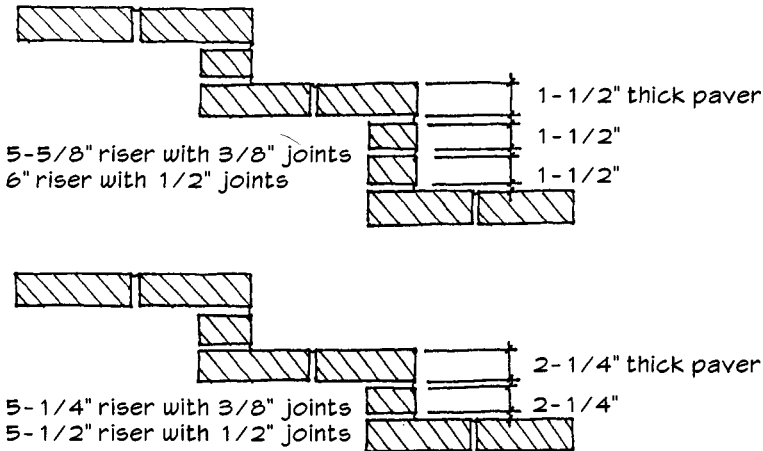
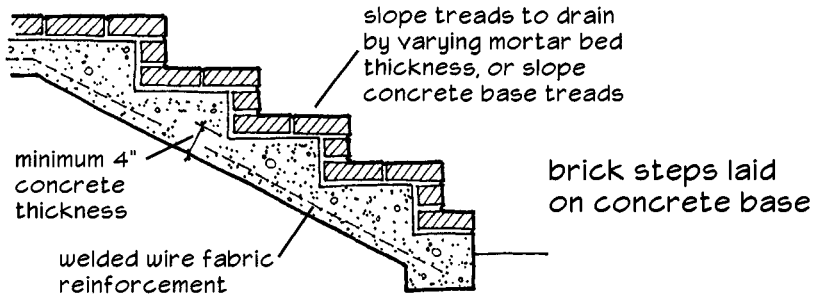
light vehicular traffic installation



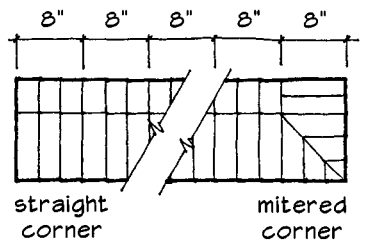
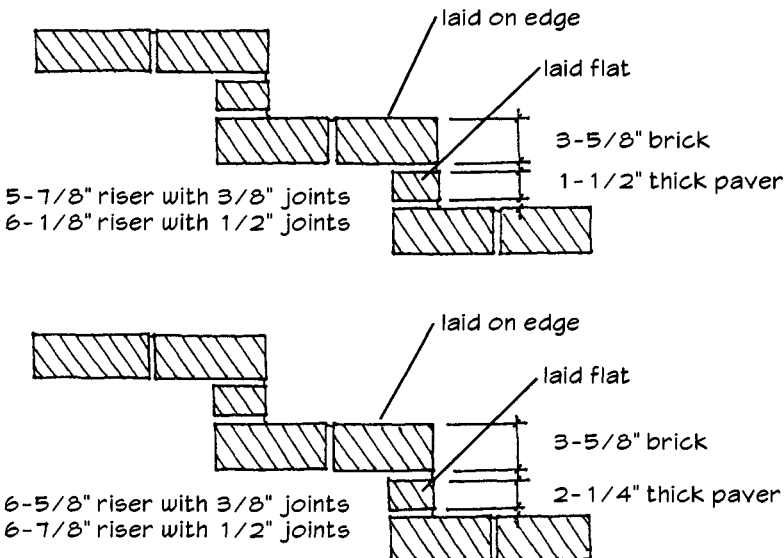
heavy vehicular traffic installation

(From NCMA TEK Bulletin 91, National Concrete Masonry Association)

8.2.7 Brick Steps



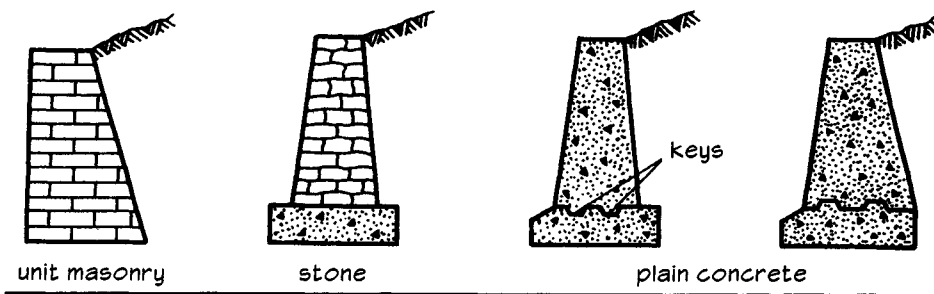
pavers laid flat



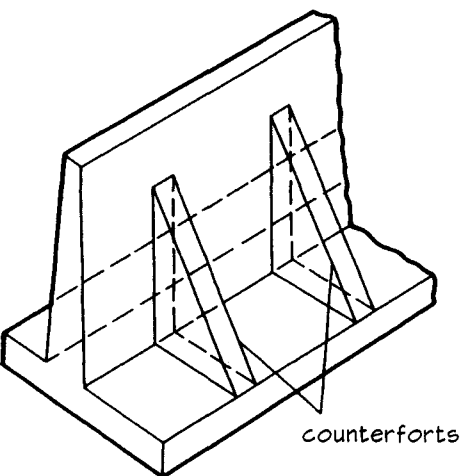
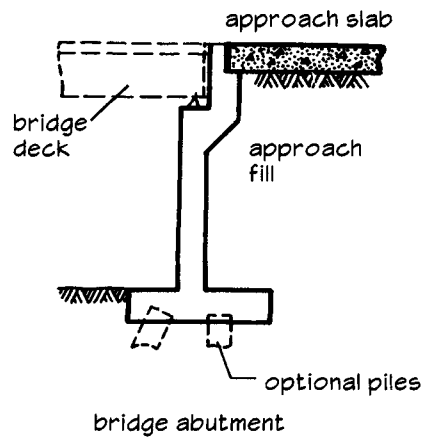
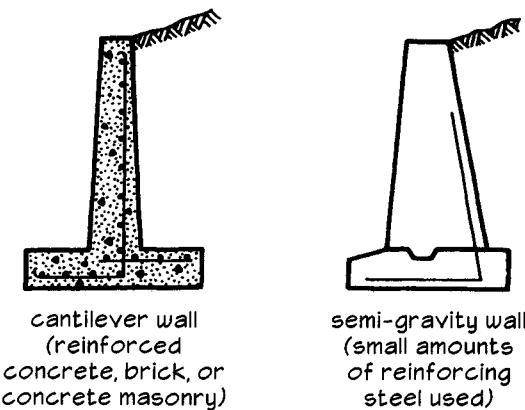
tread layout with bricks laid on edge

flat pavers and bricks on edge

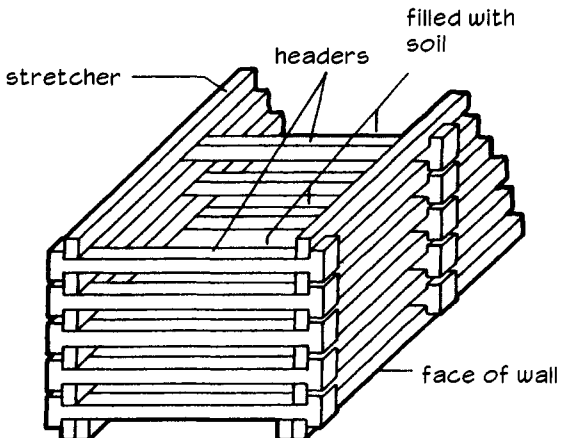
8.3.1 Types of Retaining Walls



gravity retaining walls
(weight provides stability against overturning and sliding)



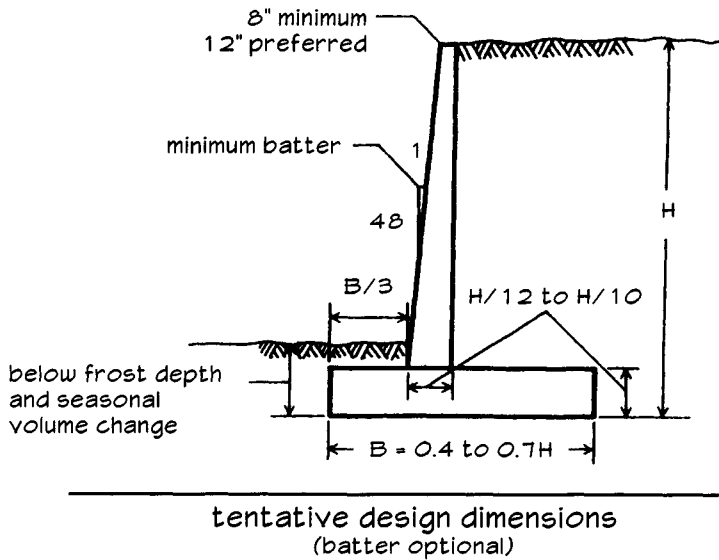
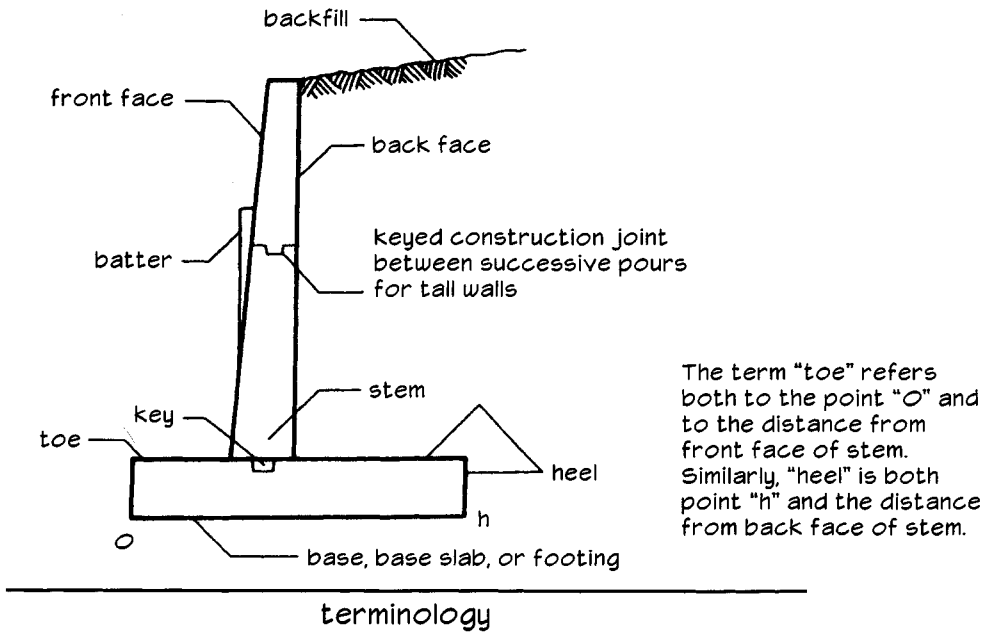
counterfort wall if soil covers counterforts
(buttress wall if soil is on opposite side)



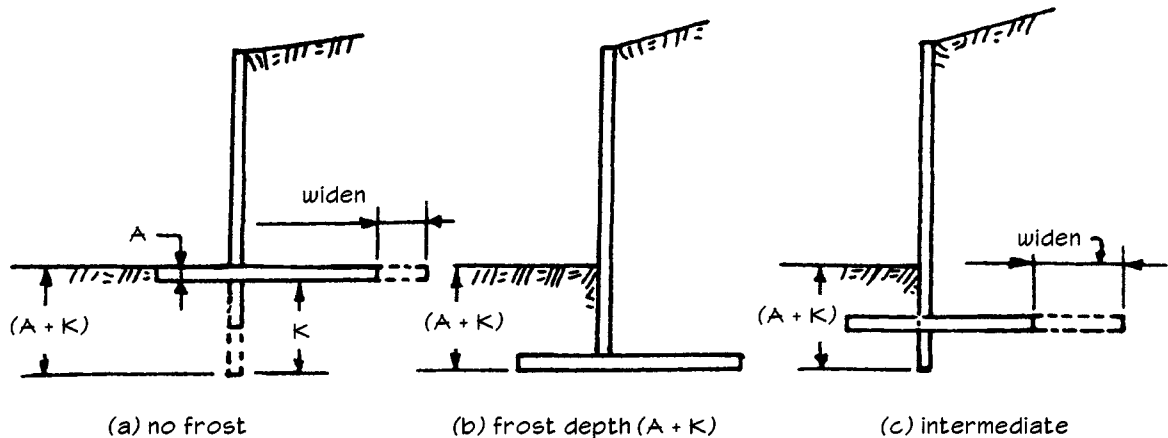
crib wall

(From Bowles, Foundation Analysis and Design, 4th ed., McGraw-Hill, 1988)

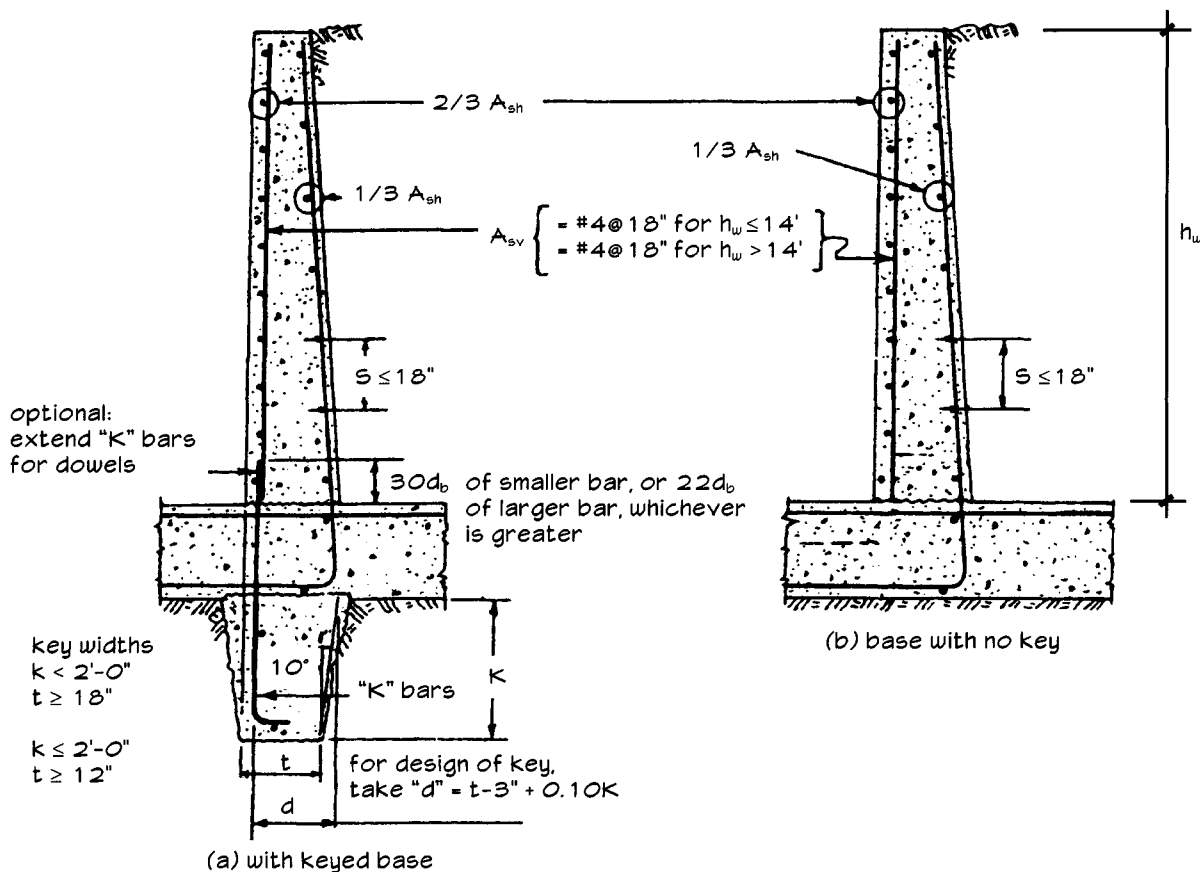
8.3.2 Concrete Retaining Wall Terminology and Guidelines



8.3.3 Concrete Retaining Wall Design Basics



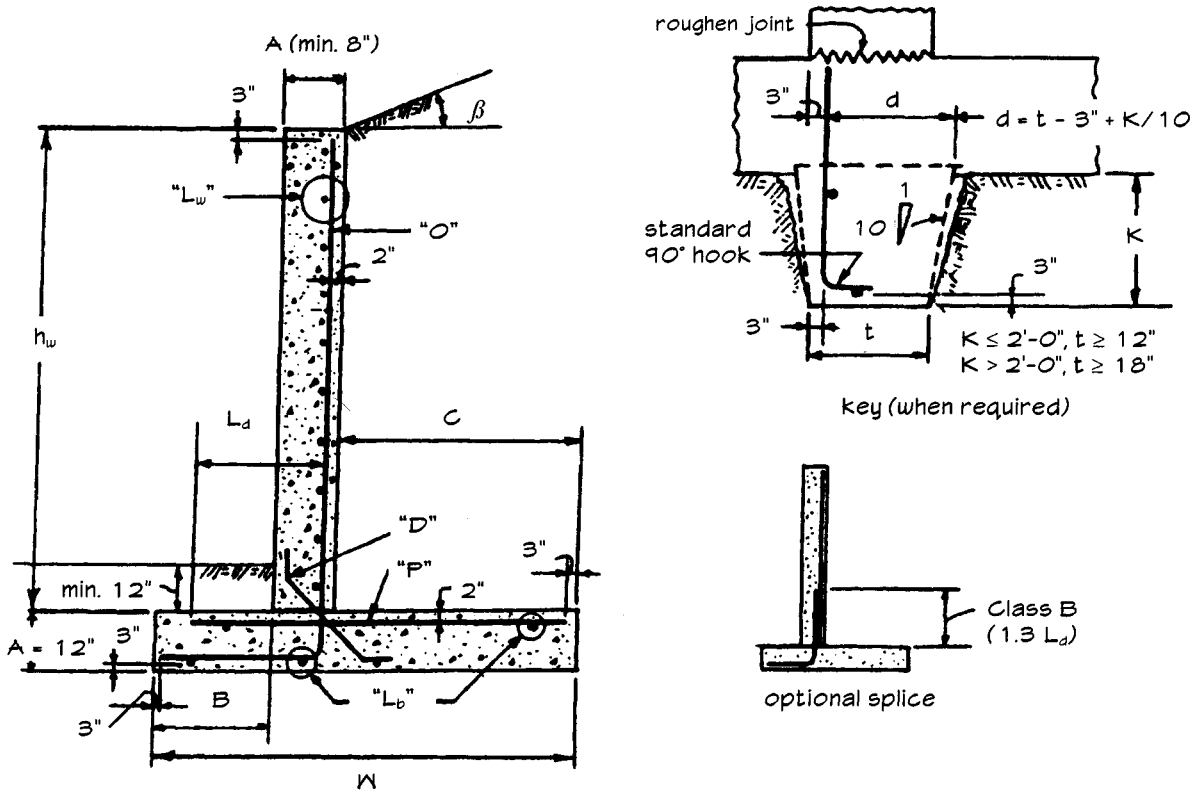
designs to prevent horizontal sliding



shrinkage and temperature bars in exposed face (when used)

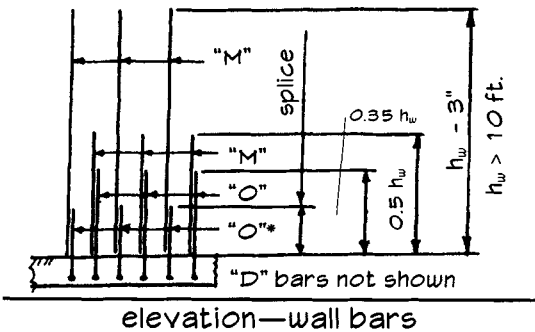
(From CRSI Handbook, Concrete Reinforcing Steel Institute, 1992)

8.3.4 Notation for Structural Reinforcement for Concrete Retaining Walls ≤ 10 ft.



8.3.5 Notation for Structural Reinforcement for Concrete Retaining Walls > 10 ft.

* larger of: Class B for "M" and L_d for "O"

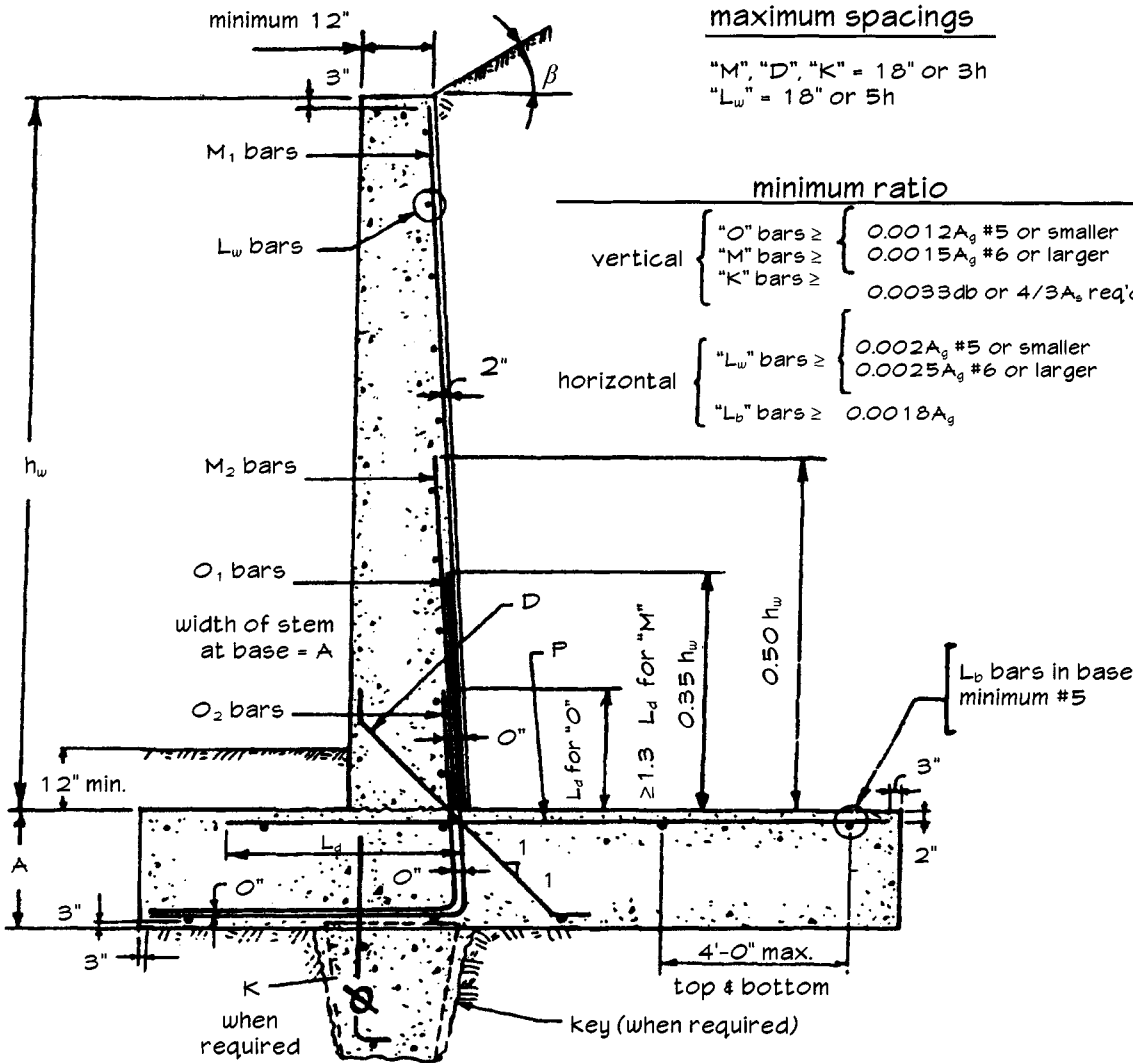


maximum spacings

"M", "D", "K" = 18" or 3h
 "L_w" = 18" or 5h

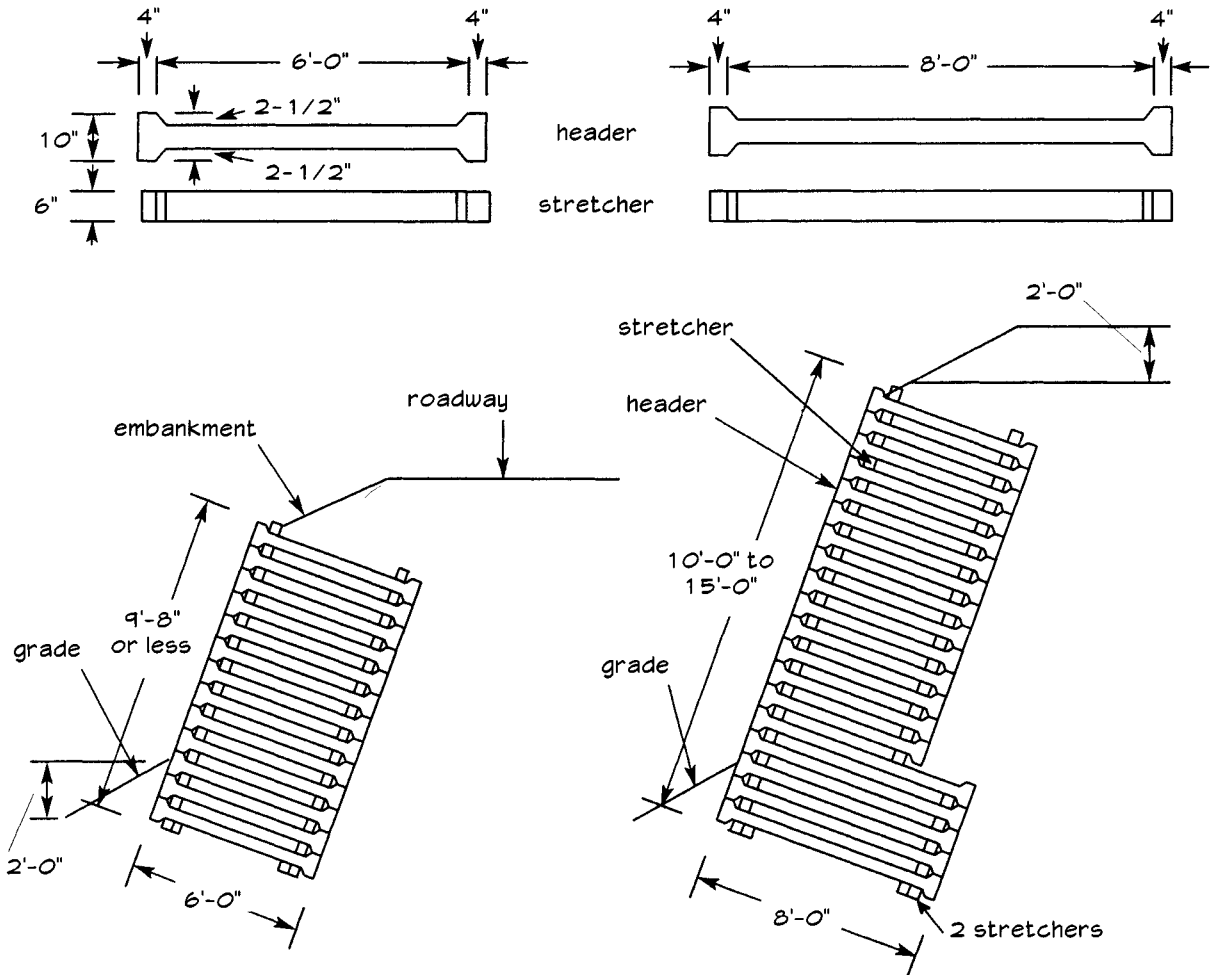
minimum ratio

vertical	"O" bars ≥	0.0012A _g #5 or smaller
	"M" bars ≥	0.0015A _g #6 or larger
	"K" bars ≥	0.0033db or 4/3A _s req'd.
horizontal	"L _w " bars ≥	0.002A _g #5 or smaller
	"L _b " bars ≥	0.0025A _g #6 or larger
		0.0018A _g



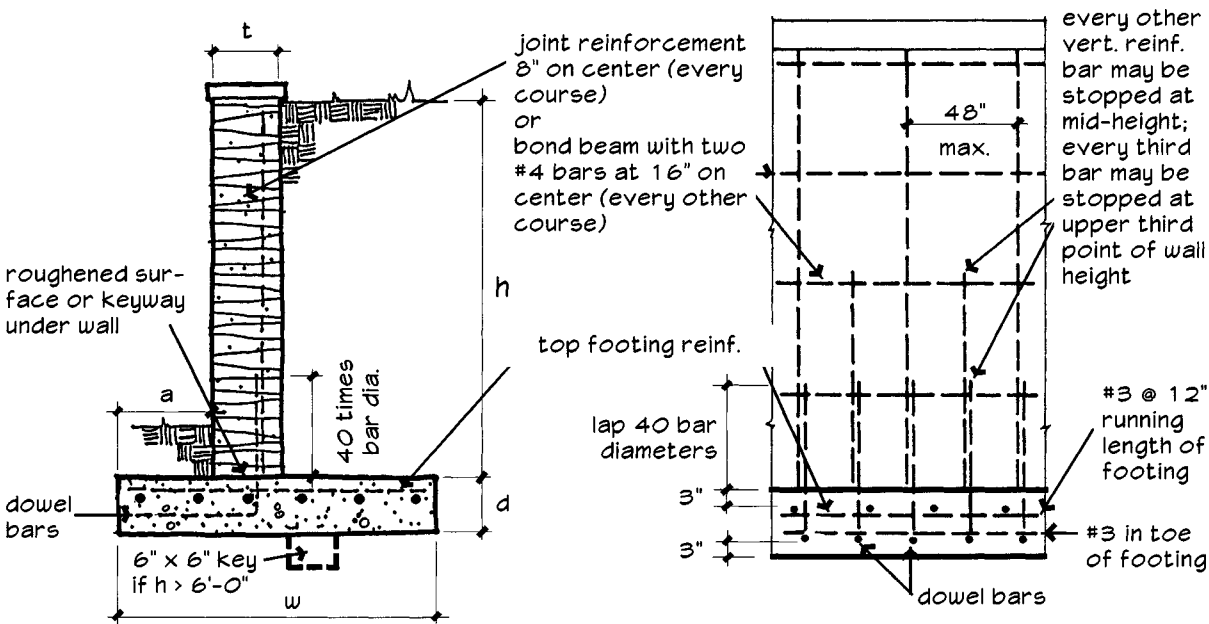
(From CRSI Handbook, Concrete Reinforcing Steel Institute, 1992)

8.3.6 Concrete Crib Wall



Crib walls are usually started about 2 ft. below grade at the toe of an embankment. Two pairs of stretchers are used to support the first header, and the face of the wall is set on a batter of 1:6. Headers are reinforced with four #3 longitudinal bars and hooks in the flanges and are 6 ft. to 8 ft. long. Longer headers are used in the lower portion of walls 10 ft. to 15 ft. high.

8.3.7 Concrete Masonry Retaining Walls

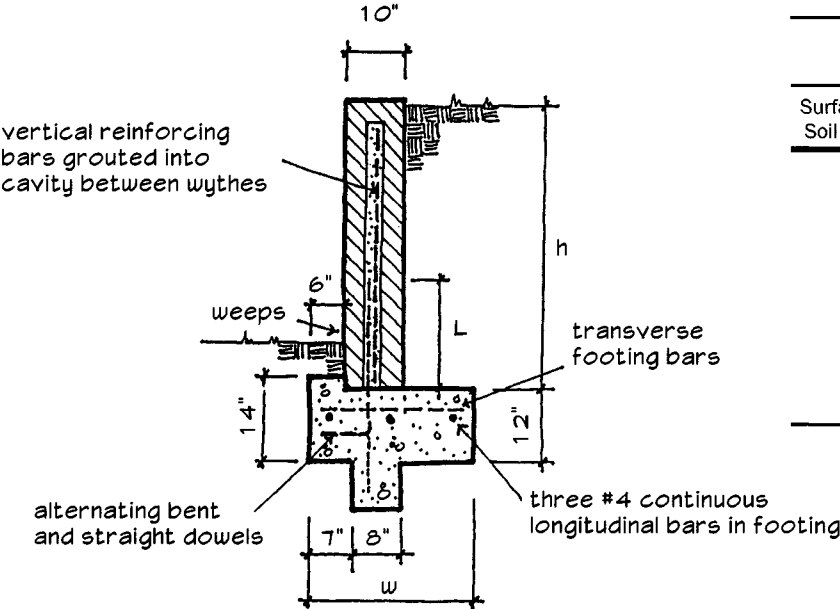


Dimensions and Reinforcement for CMU Cantilever Retaining Wall*						
Nominal Wall Thickness, <i>t</i> (in.)	Wall Stem Height, <i>h</i> (ft.-in.)	Toe Length, <i>a</i> (in.)	Footing Width, <i>w</i> (ft.-in.)	Footing Depth, <i>d</i> (in.)	Dowels and Vertical Reinforcement	Top Footing Reinforcement
8	3'-4"	12	2'-8"	9	#3 @ 32" o.c.	#3 @ 27" o.c.
	4'-0"	12	3'-0"	9	#4 @ 32" o.c.	#3 @ 27" o.c.
	4'-8"	12	3'-3"	10	#5 @ 32" o.c.	#3 @ 27" o.c.
	5'-4"	14	3'-8"	10	#4 @ 16" o.c.	#4 @ 27" o.c.
	6'-0"	15	4'-2"	12	#6 @ 24" o.c.	#4 @ 27" o.c.
12	3'-4"	12	2'-8"	9	#3 @ 32" o.c.	#3 @ 27" o.c.
	4'-0"	12	3'-0"	9	#3 @ 32" o.c.	#3 @ 27" o.c.
	4'-8"	12	3'-3"	10	#4 @ 32" o.c.	#3 @ 27" o.c.
	5'-4"	14	3'-8"	10	#4 @ 24" o.c.	#3 @ 25" o.c.
	6'-0"	15	4'-2"	12	#4 @ 16" o.c.	#4 @ 30" o.c.
	6'-8"	16	4'-6"	12	#6 @ 24" o.c.	#4 @ 22" o.c.
	7'-4"	18	4'-10"	12	#7 @ 32" o.c.	#5 @ 26" o.c.
	8'-0"	20	5'-4"	12	#7 @ 24" o.c.	#5 @ 21" o.c.
	8'-8"	22	5'-10"	14	#7 @ 16" o.c.	#6 @ 26" o.c.
	9'-4"	24	6'-4"	14	#8 @ 8" o.c.	#6 @ 21" o.c.

* Design based on zero slope soil backfill weighing 100 pcf with an equivalent fluid pressure of 45 pcf and a soil bearing pressure 1,500 psf, with no surcharge load. Reinforcing steel is deformed bars with a yield strength of 40,000 psi.

(Adapted from Randall and Panarese, Concrete Masonry Handbook, Portland Cement Association)

8.3.8 Double-Wythe Brick Retaining Walls



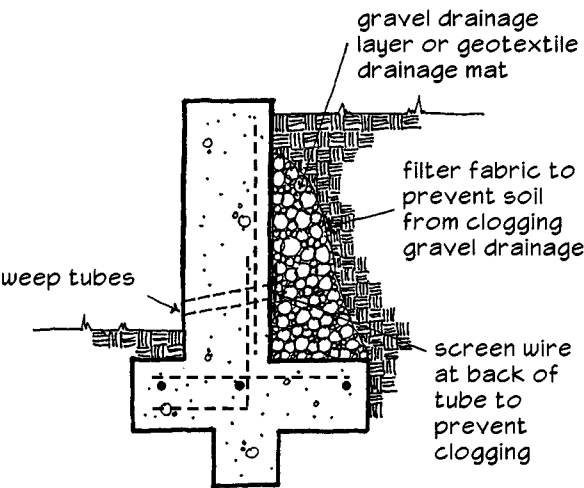
Equivalent Fluid Pressure for Retained Slopes	
Surface Slope of Retained Soil (vertical : horizontal)	Equivalent Fluid Pressure (pcf)
Level	30
1 : 5	32
1 : 4	35
1 : 3	38
1 : 2	43
1 : 1-1/2	55
1 : 1	80

Dimensions and Reinforcement for Double-Wythe Brick Retaining Walls*					
Wall Stem Height, h (ft.-in.)	Footing Width, w (ft.-in.)	Reinforcing Dowels	Length of Dowel Lap, L (ft.-in.)	Vertical Reinforcement	Transverse Footing Reinforcement
2'-0"	1'-9"	#3 @ 40" o.c.	1'-10"	—	#3 @ 40" o.c.
2'-6"	1'-9"	#3 @ 40" o.c.	2'-4"	—	#3 @ 40" o.c.
3'-0"	2'-0"	#3 @ 40" o.c.	2'-10"	—	#3 @ 40" o.c.
3'-6"	2'-0"	#3 @ 40" o.c.	3'-4"	—	#3 @ 40" o.c.
4'-0"	2'-4"	#3 @ 27" o.c. or #4 @ 40" o.c.	1'-4"	#3 @ 27" o.c. or #3 @ 40" o.c.	#3 @ 27" o.c. or #3 @ 40" o.c.
4'-6"	2'-8"	#3 @ 19" o.c. or #4 @ 35" o.c.	1'-6"	#3 @ 38" o.c. or #3 @ 35" o.c.	#3 @ 19" o.c. or #3 @ 35" o.c.
5'-0"	3'-0"	#3 @ 14" o.c. or #4 @ 25" o.c. or #5 @ 40" o.c.	1'-8"	#3 @ 28" o.c. or #3 @ 25" o.c. or #4 @ 40" o.c.	#3 @ 14" o.c. or #3 @ 25" o.c. or #4 @ 40" o.c.
5'-6"	3'-3"	#3 @ 1" o.c. or #4 @ 20" o.c. or #5 @ 31" o.c.	1'-10"	#3 @ 22" o.c. or #4 @ 40" o.c. or #4 @ 31" o.c.	#3 @ 11" o.c. or #3 @ 20" o.c. or #4 @ 31" o.c.
6'-0"	3'-6"	#3 @ 8" o.c. or #4 @ 14" o.c. or #5 @ 20" o.c.	2'-0"	#3 @ 16" o.c. or #4 @ 28" o.c. or #5 @ 40" o.c.	#3 @ 8" o.c. or #3 @ 14" o.c. or #4 @ 20" o.c.

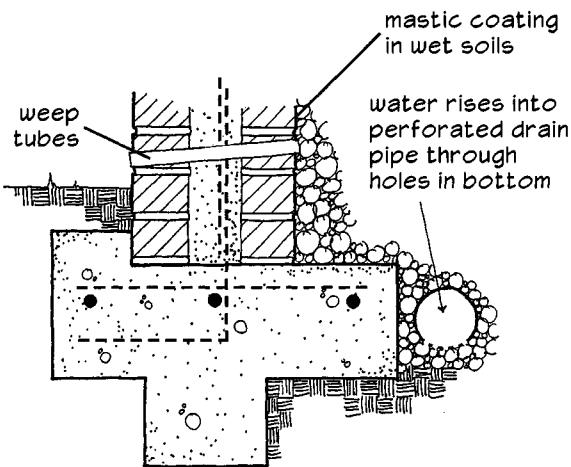
* Design based on zero slope soil backfill with equivalent fluid pressure of 30 psf, with no surcharge load. Masonry is fully grouted, and reinforcing steel has a yield strength of 40,000 psi.

(Adapted from BIA Technical Note 17N, Brick Industry Association)

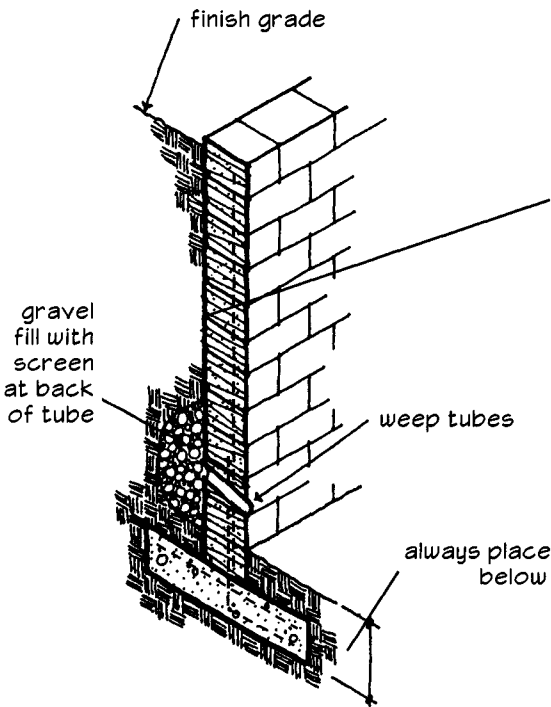
8.3.9 Retaining Wall Drainage and Weeps



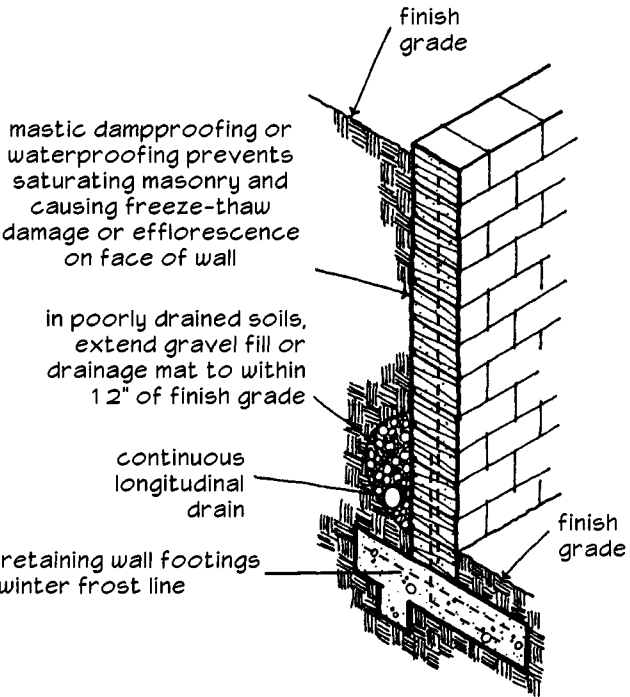
weep tubes



weep tubes and perforated drain

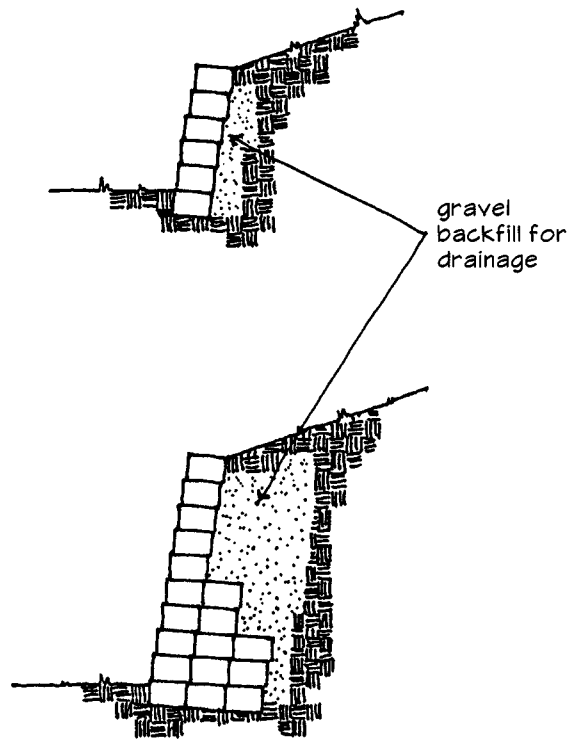


weep tubes

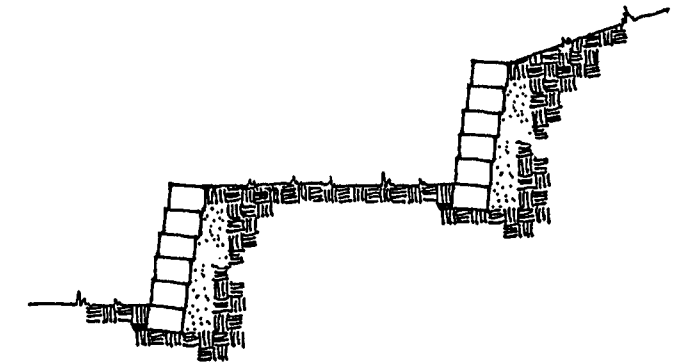
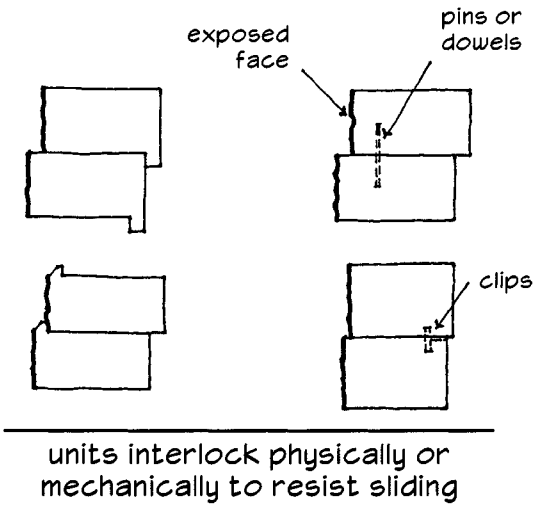


perforated subgrade drain

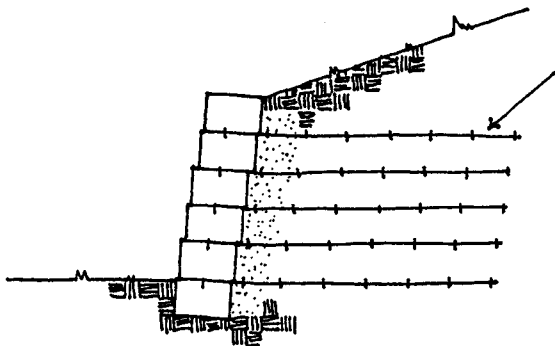
8.4.1 Segmental Retaining Wall Types



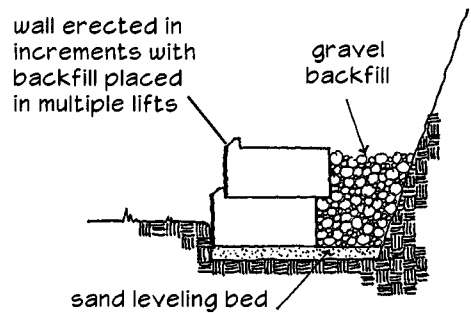
single- and multiple-depth walls



two-level terraced wall



soil-reinforced wall



segmental wall installation

8.4.2 Maximum Height of Segmental Retaining Walls

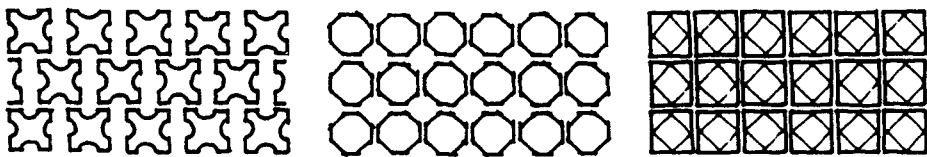
Maximum Exposed Wall Height*							
Segmental Unit Height (in.)	Segmental Unit Depth (in.)	Angle of Internal Friction of Soil, ϕ (See Table Below)					
		$\phi = 28^\circ$			$\phi = 34^\circ$		
		Wall Battered 5°	Wall Battered 10°	Wall Battered 15°	Wall Battered 5°	Wall Battered 10°	Wall Battered 15°
6	12	2'-0"	2'-6"	3'-0"	2'-6"	3'-6"	3'-6"
	24	5'-0"	5'-6"	6'-0"	6'-6"	7'-6"	7'-6"
8	12	2'-3"	2'-3"	2'-10"	2'-10"	3'-6"	3'-6"
	24	4'-10"	5'-6"	6'-3"	6'-3"	7'-6"	7'-6"

* Design based on non-critical case walls without soil reinforcing, zero slope backfill at top of wall, no surcharge load, required 6 in. wall embedment in ground at toe, soil and block unit weight 120 pcf.

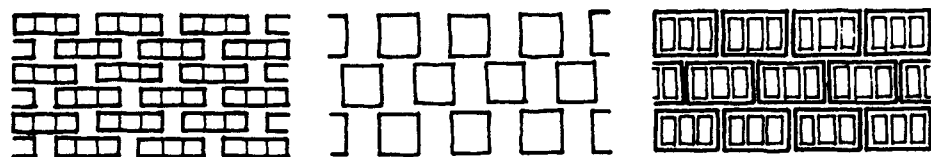
Angle of Internal Friction (ϕ) for Various Soil Types		
Soil Type		Angle of Internal Friction (Degrees)
GW	Well-graded gravels, gravel sand mixtures, little or no fines	37 to 42
GP	Poorly graded gravels or gravel sand mixtures, little or no fines	
SW	Well-graded sands, gravelly sands, little or no fines	33 to 40
SP	Poorly graded sands or gravelly sands, little or no fines	
GM	Silty gravels, gravel-sand-silt mixtures	28 to 35
SM	Silty sand, sand-silt mixtures	
GC	Clayey gravels, gravel-sand-clay mixtures	
SC	Clayey sands, sand-clay mixtures	
ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	25 to 32
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, and lean clays	

(From NCMA Design Manual for Segmental Retaining Walls, National Concrete Masonry Association)

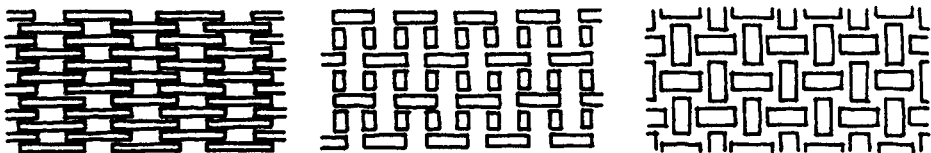
8.5.1 Masonry Screen Wall Patterns



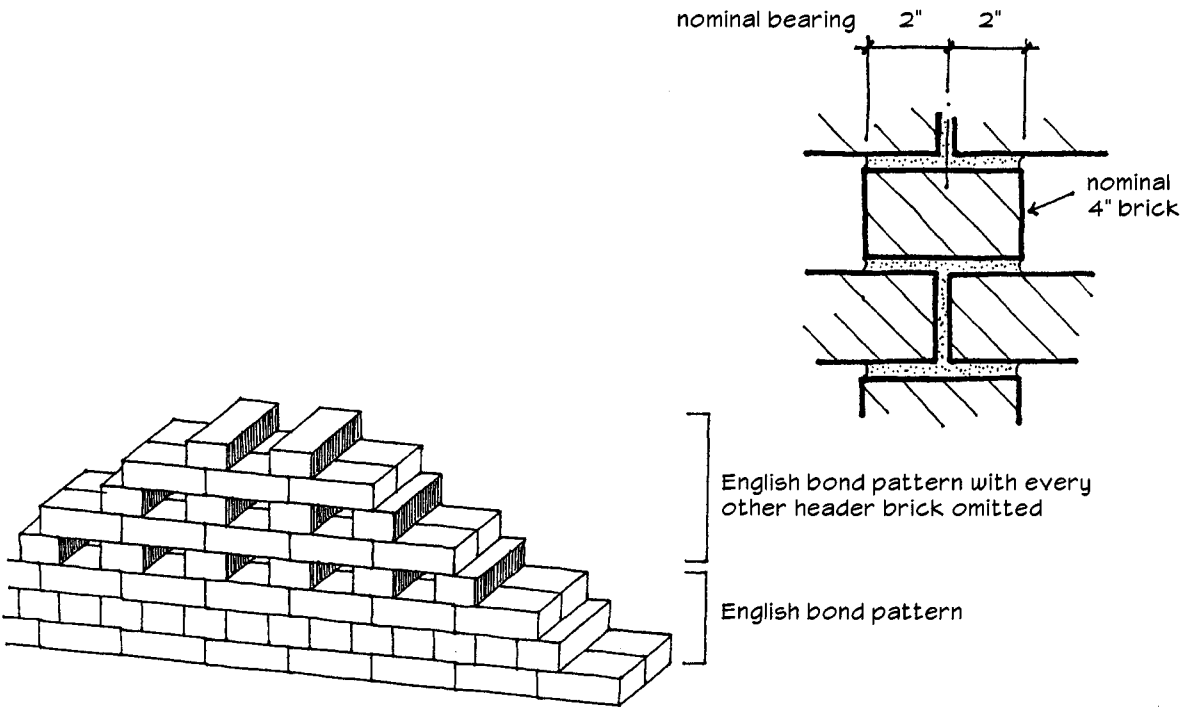
patterns created using screen tile or screen block



patterns created by turning hollow units on edge

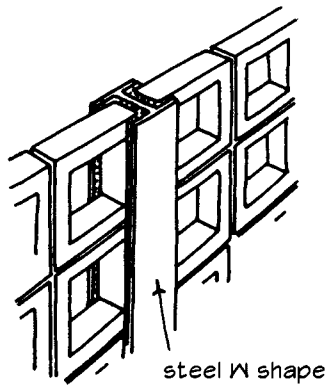
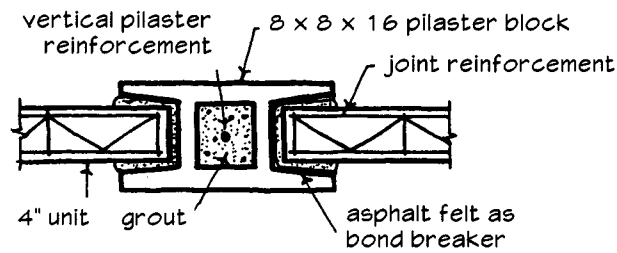


patterns created with solid units and alternating void spaces

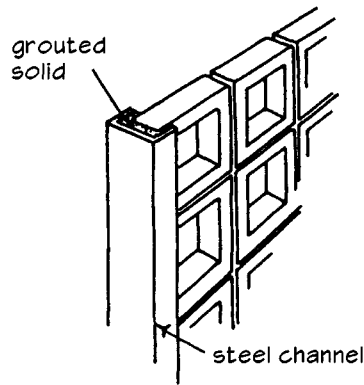
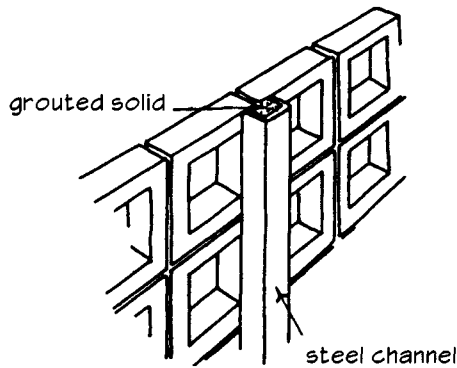


(From BIA Technical Note Vol. 11, No. 11, Brick Industry Association)

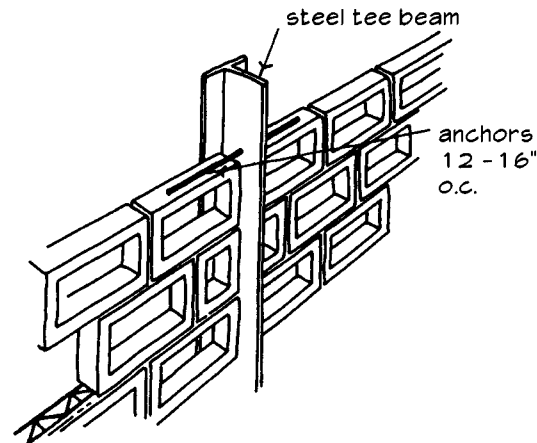
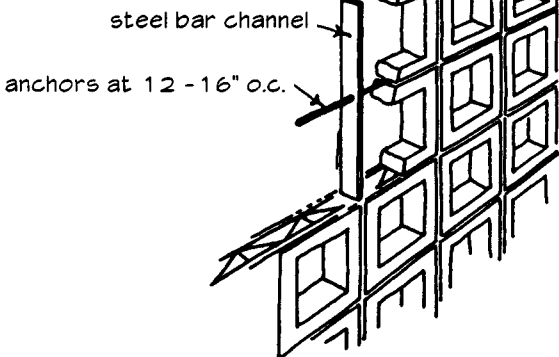
8.5.2 Methods of Supporting Masonry Screen Walls



Maximum Distance Between Lateral Supports (height or length, but not both)					
Wall Type	Nominal Wall Thickness (in.)				
	4	6	8	12	Other
Non-loadbearing exterior	6'-0"	9'-0"	12'-0"	18'-0"	18t
interior	12'-0"	18'-0"	24'-0"	36'-0"	36t

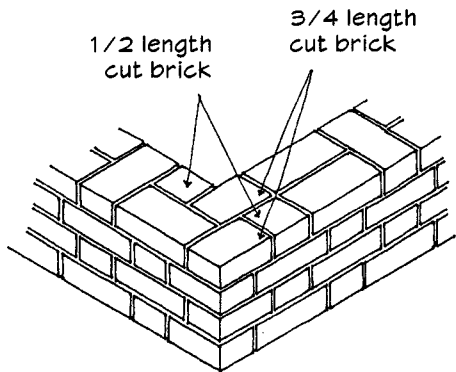


note: wire anchors in mortar joints welded to steel channel

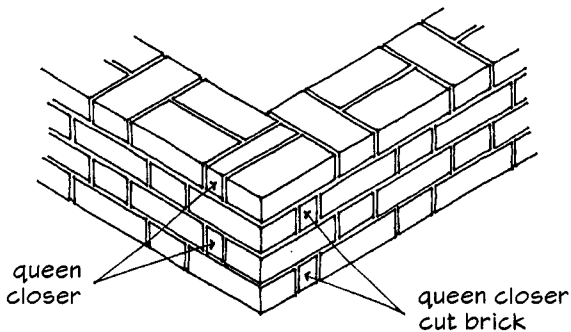


(From NCMA TEK Bulletin 5, National Concrete Masonry Association)

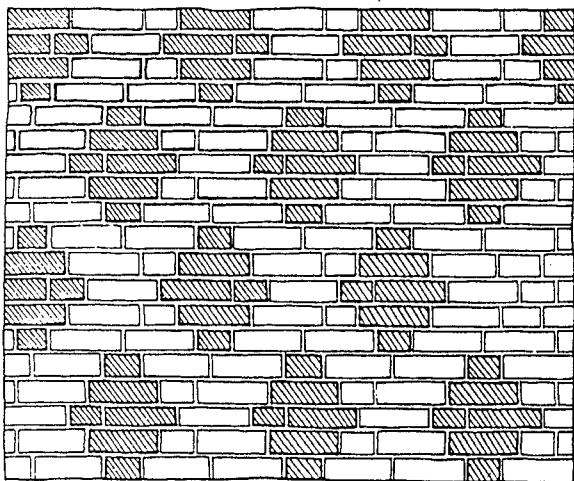
8.5.3 Masonry Bonded Garden Walls



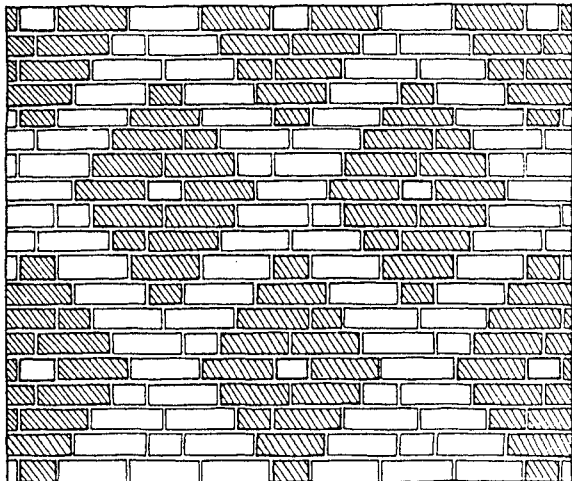
Dutch corner bond



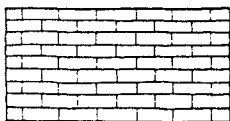
English corner bond



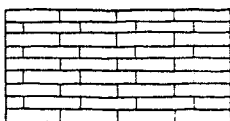
double stretcher garden wall bond
with units in diagonal lines



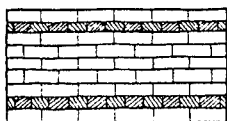
garden wall bond with units
in dovetail pattern



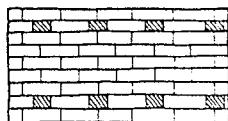
running bond



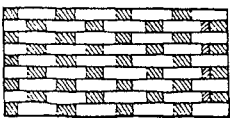
1/3 running bond



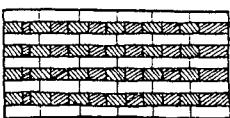
common bond or
American bond
6th course headers



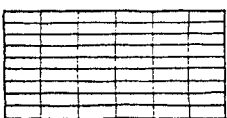
common bond or
American bond
6th course Flemish headers



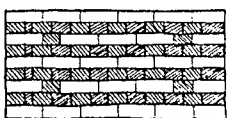
Flemish bond



English bond



stack bond



English cross or
Dutch bond

Dutch
corner

English
corner

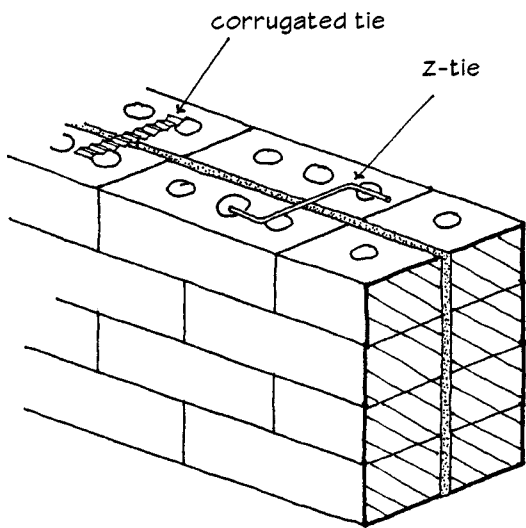
English
corner

Dutch
corner

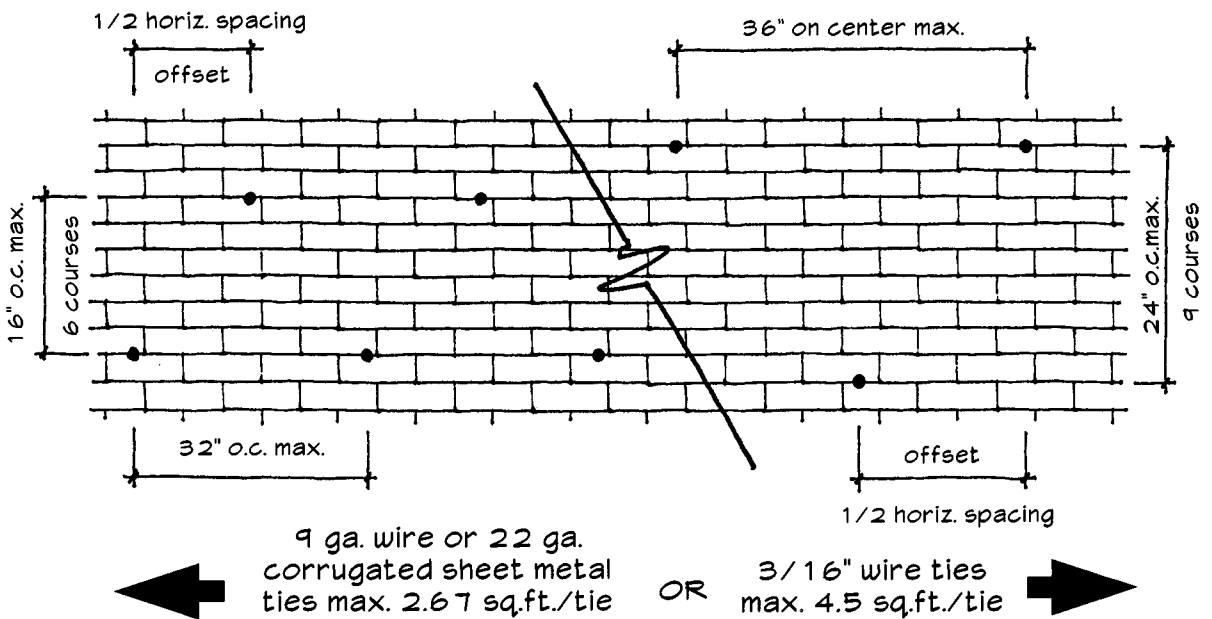
English
corner

Dutch
corner

8.5.4 Metal-Tie Bonded Garden Walls

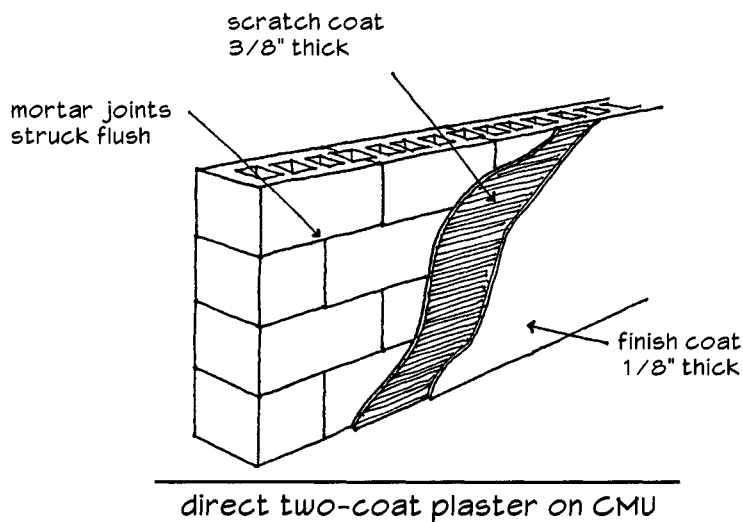
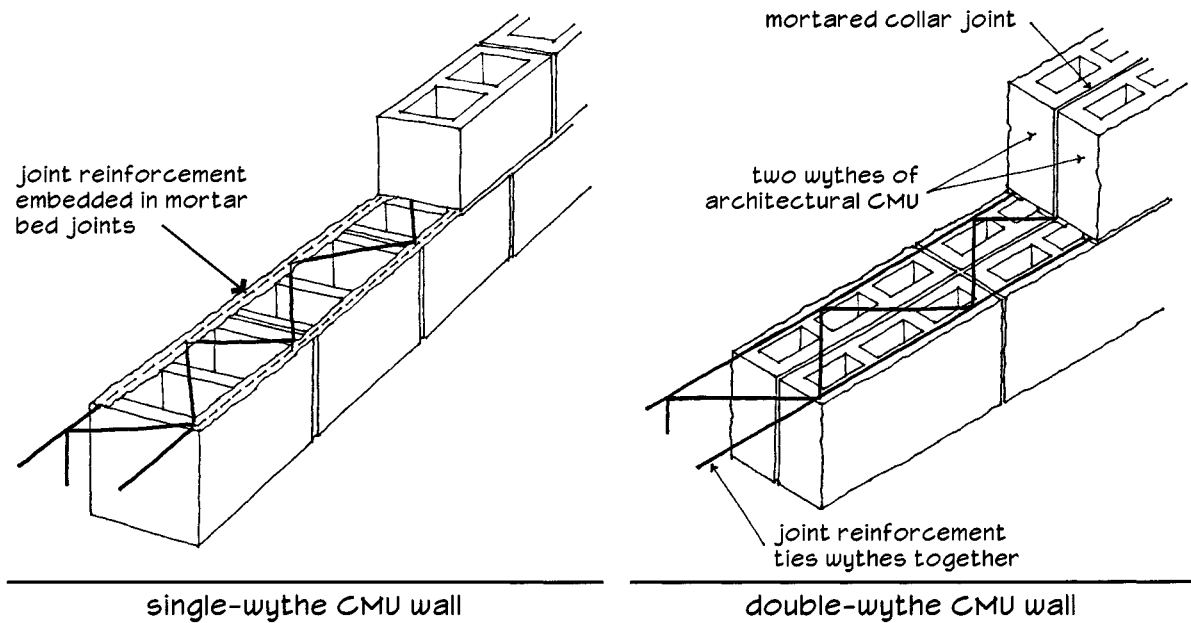


double-wythe garden wall with metal ties



recommended tie spacing for garden walls
(based on CABO One and Two Family Dwelling Code requirements
for spacing of veneer anchors)

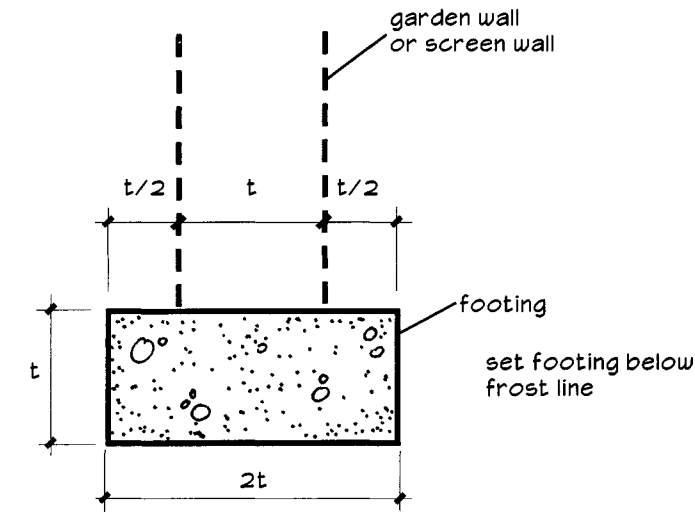
8.5.5 CMU Garden Walls



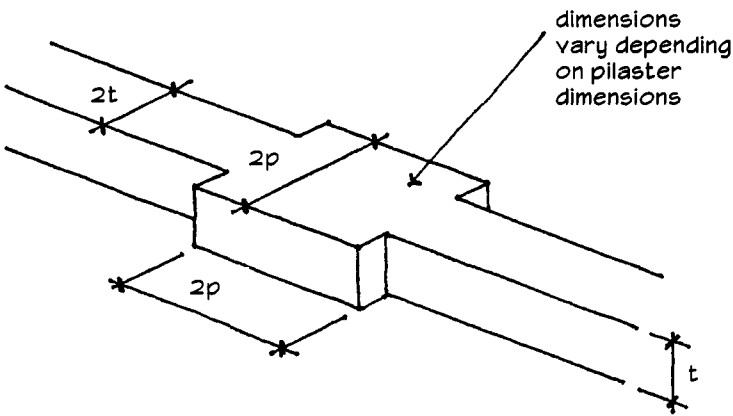
Control Joint Spacing for CMU Garden Walls		
Joint Reinforcement Spacing (in. on center vertically)	Control Joint Spacing Expressed as Ratio of Wall Panel Length to Panel Height, L/H	Maximum Control Joint spacing (ft.)
None	2	40
8	2-1/2	45
16	3	50
32	4	60

(From NCMA TEK Bulletin 10-1, National Concrete Masonry Assoc.)

8.5.6 Garden Wall Footings



rule of thumb proportions for masonry garden or screen wall footings

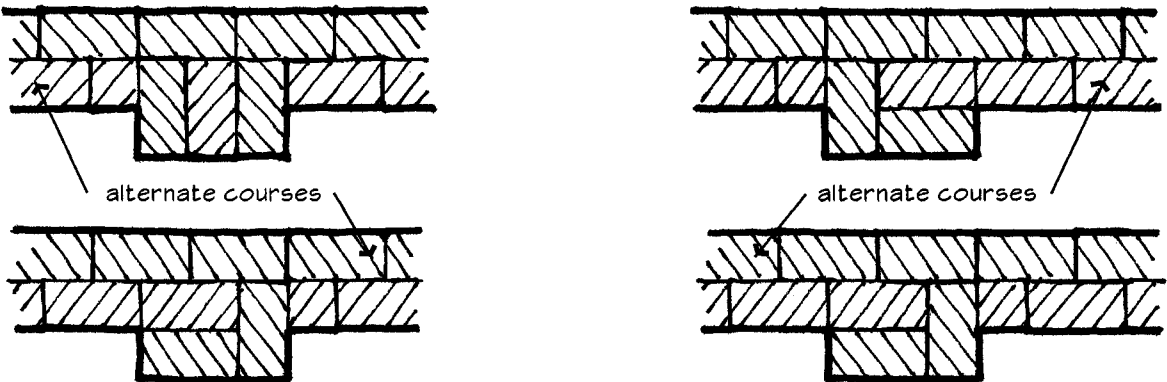


wider footings are required at supporting pilasters

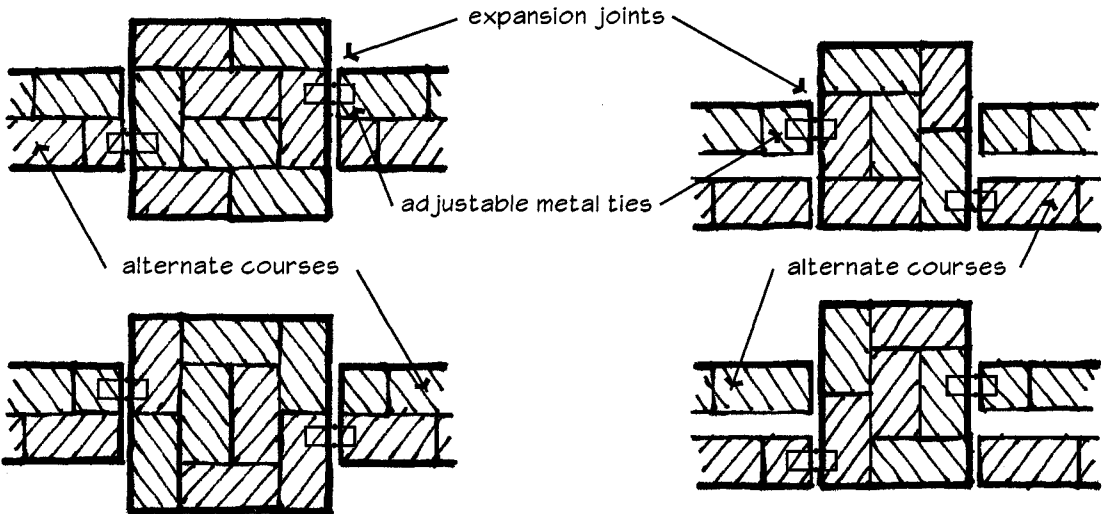
Recommended Pilaster Spacing for Masonry Garden and Screen Walls	
Nominal Wall Thickness (in.)	Maximum Distance Between Pier or Pilasters, 18 x t (ft.)
4	6
6	9
8	12
12	18

(From Beall, Masonry and Concrete for Residential Construction, McGraw-Hill Complete Construction Series, 2001)

8.5.7 Brick Garden Wall Columns and Pilasters



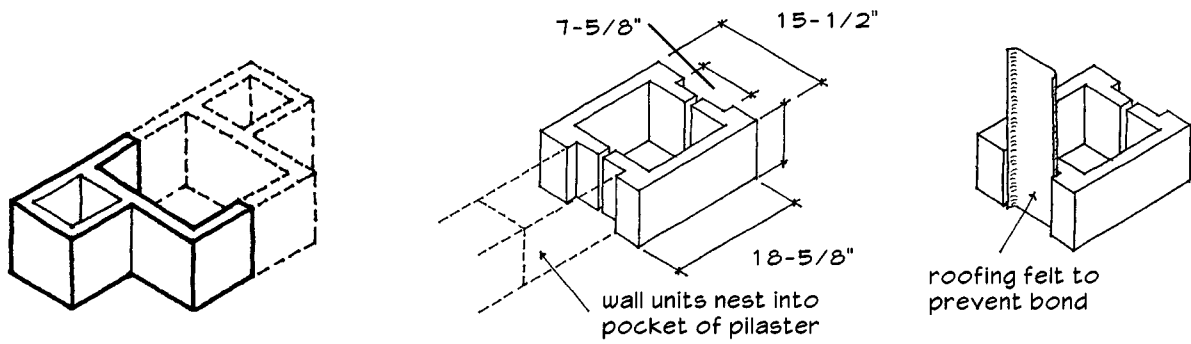
masonry unit bonded pilasters



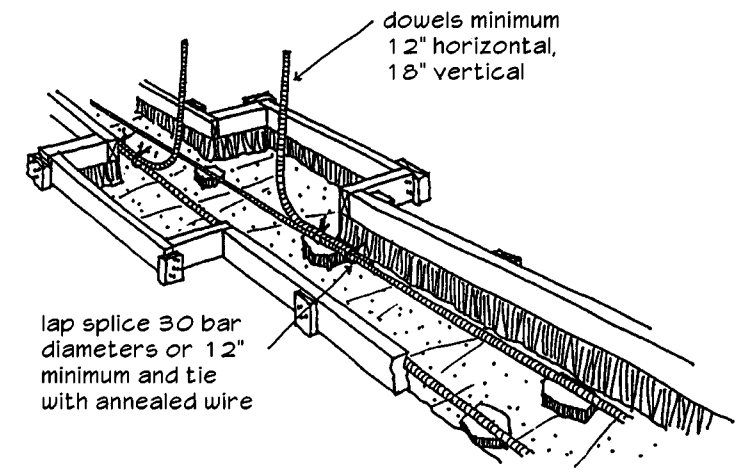
columns and metal tied walls

(Adapted from Harry C. Plummer, Brick and Tile Engineering, BIA, 1962)

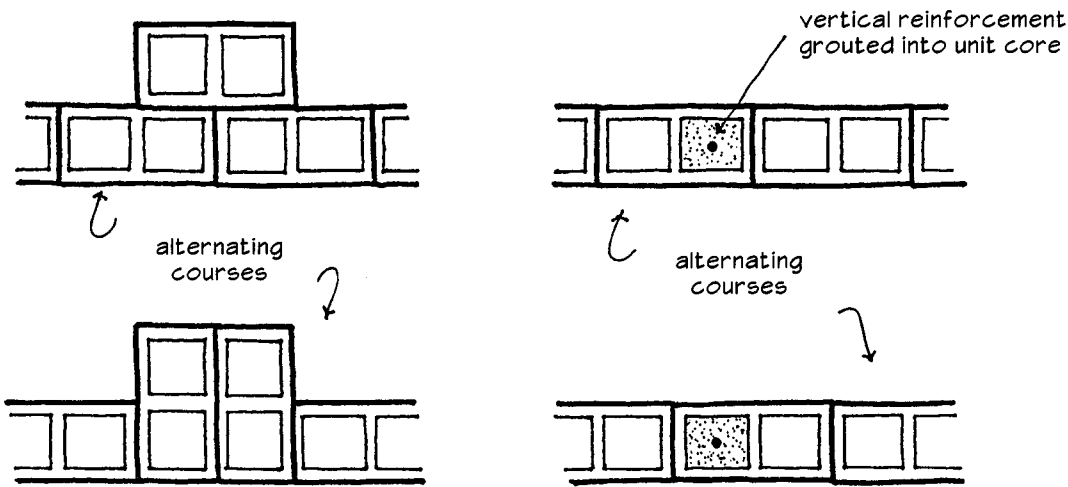
8.5.8 CMU Garden Wall Pilasters



CMU pilaster units



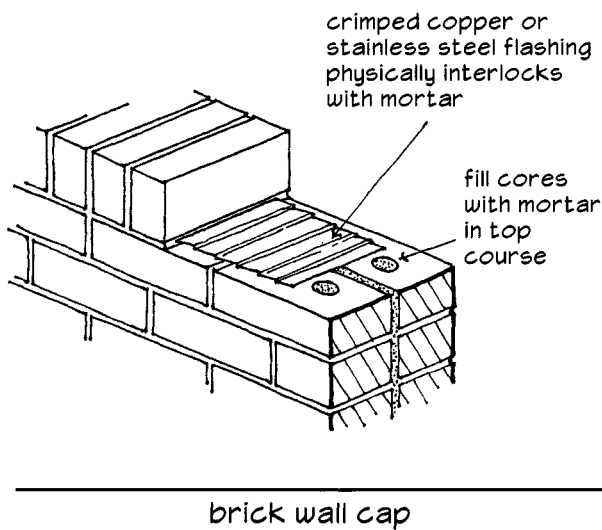
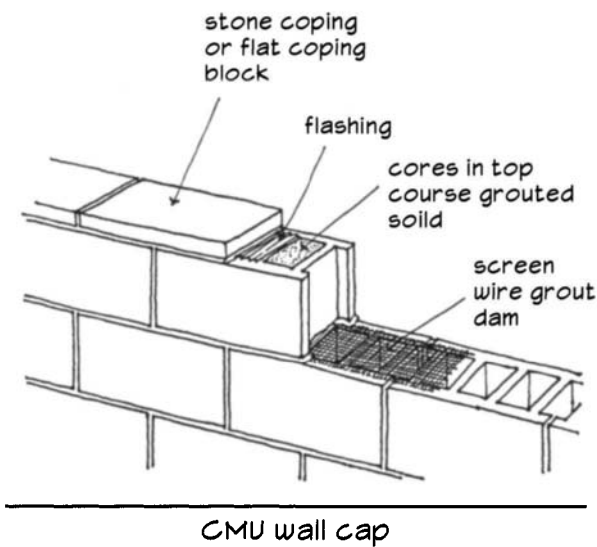
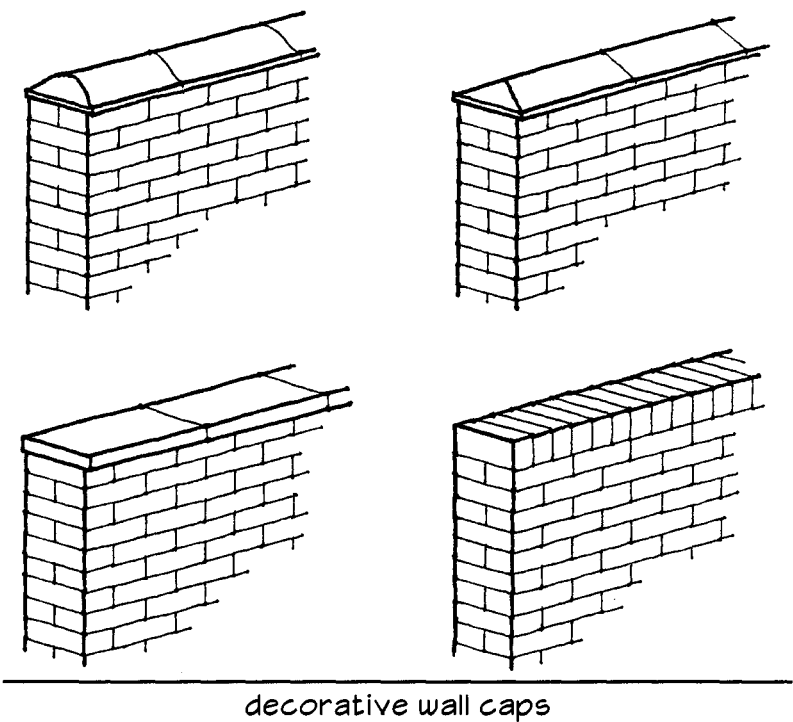
pilaster reinforcing (if any) doweled into footing



pilaster made of stretcher units in projected, interlocking bond pattern

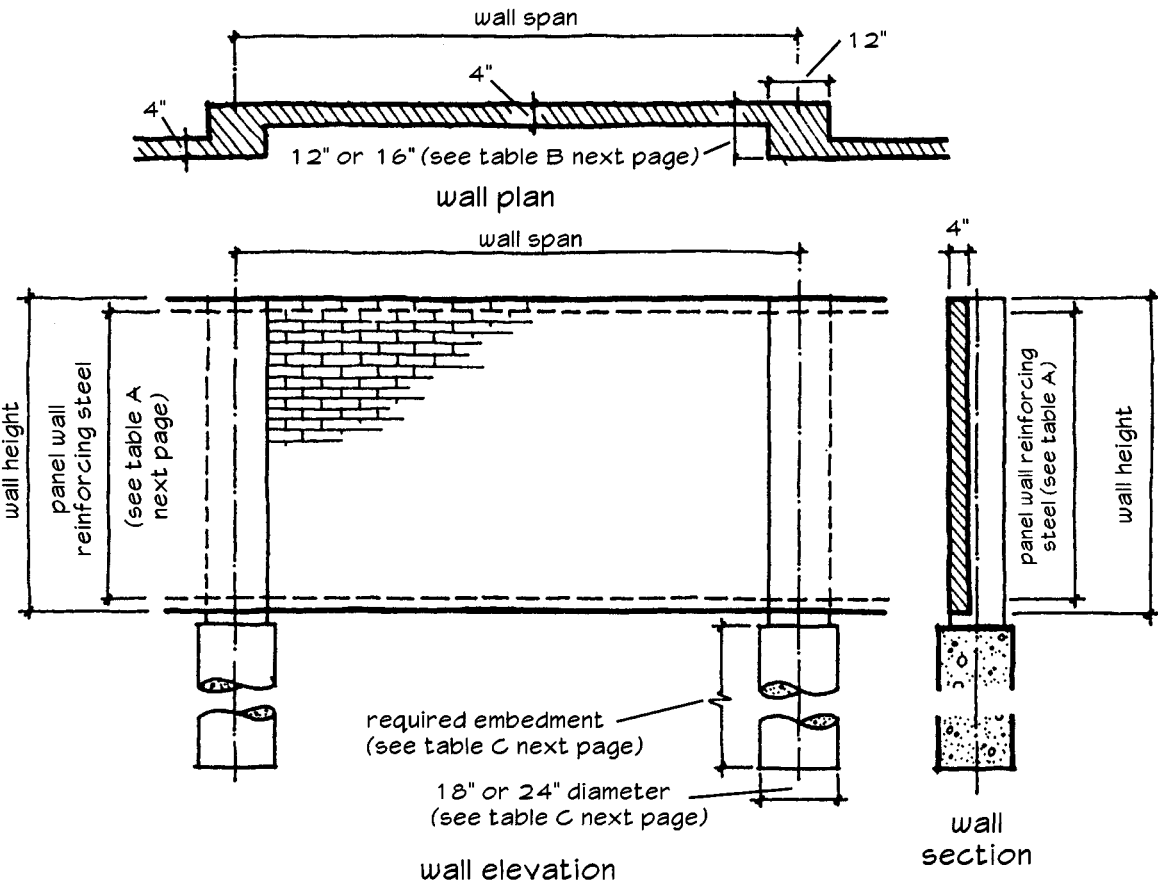
integral "pilaster" in reinforced vertical core

8.5.9 Garden Wall Caps and Flashing

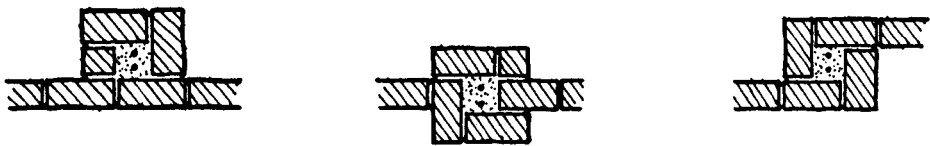


(From Beall, Masonry and Concrete for Residential Construction, McGraw-Hill Complete Construction Series, 201)

8.5.10 Single-Wythe Brick Pier and Panel Garden Walls



pier and panel wall details



alternate methods of constructing piers
(see table B for reinforcing steel)

(From BIA Technical Note 29A, Brick Industry Association)

8.5.11 Brick Pier and Panel Wall Design Tables

TABLE A PANEL WALL REINFORCING STEEL

Wall span (ft)	Vertical Spacing* (in.)								
	Wind load 10 psf			Wind load 15 psf			Wind load 20 psf		
	A	B	C	A	B	C	A	B	C
8	45	30	19	30	20	12	23	15	9.5
10	29	19	12	19	13	8.0	14	10	6.0
12	20	13	8.5	13	9.0	5.5	10	7.0	4.0
14	15	10	6.5	10	6.5	4.0	7.5	5.0	3.0
16	11	7.5	5.0	7.5	5.0	3.0	6.0	4.0	2.5

*A, two - No. 2 bars; B, two - $\frac{3}{16}$ -in. diam wires; C, two - 9 gauge wires.

TABLE B PIER REINFORCING STEEL*

Wall span (ft)	Wind load 10 psf			Wind load 15 psf			Wind load 20 psf		
	Wall height (ft)			Wall height (ft)			Wall height (ft)		
	4	6	8	4	6	8	4	6	8
8	2#3	2#4	2#5	2#3	2#5	2#6	2#4	2#5	2#5
10	2#3	2#4	2#5	2#4	2#5	2#7	2#4	2#6	2#6
12	2#3	2#5	2#6	2#4	2#6	2#6	2#4	2#6	2#7
14	2#3	2#5	2#6	2#4	2#6	2#6	2#5	2#5	2#7
16	2#4	2#5	2#7	2#4	2#6	2#7	2#5	2#6	2#7

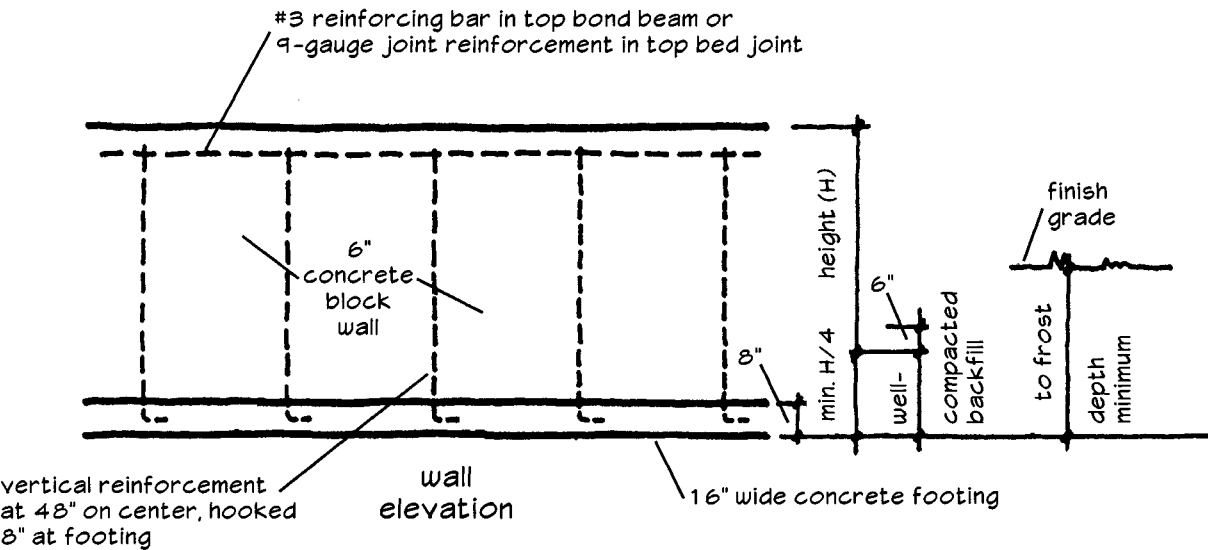
*Within heavy lines 12 by 16-in. pier required. All other values obtained with 12 by 12-in. pier.

TABLE C REQUIRED EMBEDMENT FOR PIER FOUNDATION*

Wall span (ft)	Wind load 10 psf			Wind load 15 psf			Wind load 20 psf		
	Wall height (ft)			Wall height (ft)			Wall height (ft)		
	4	6	8	4	6	8	4	6	8
8	2'-0"	2'-3"	2'-9"	2'-3"	2'-6"	3'-0"	2'-3"	2'-9"	3'-0"
10	2'-0"	2'-6"	2'-9"	2'-3"	2'-9"	3'-3"	2'-6"	3'-0"	3'-3"
12	2'-3"	2'-6"	3'-0"	2'-3"	3'-0"	3'-3"	2'-6"	3'-3"	3'-6"
14	2'-3"	2'-9"	3'-0"	2'-6"	3'-0"	3'-3"	2'-9"	3'-3"	3'-9"
16	2'-3"	2'-9"	3'-0"	2'-6"	3'-3"	3'-6"	2'-9"	3'-3"	4'-0"

*Within heavy lines 24-in. diam. foundation required. All other values obtained with 18-in. diam. foundation.

8.5.13 CMU Garden Wall Design Tables



CMU garden wall without pilasters

H	Reinforcement for wind pressure			
	5 psf	10 psf	15 psf	20 psf
4'-0"	1—No. 3	1—No. 3	1—No. 4	1—No. 4
5'-0"	1—No. 3	1—No. 4	1—No. 5	1—No. 5
6'-0"	1—No. 3	1—No. 4	1—No. 5	2—No. 4

(From Randall and Panarese, Concrete Masonry Handbook, Portland Cement Association)

Residential Foundations

9.1 Soils, Footings, and Foundations

- 9.1.1 Soil Classification and Allowable Bearing Pressures
- 9.1.2 Frost Depth Requirements
- 9.1.3 Basic Residential Foundation Types
- 9.1.4 Minimum Width of Concrete Footings
- 9.1.5 Unreinforced Foundation Wall Requirements
- 9.1.6 Reinforced Foundation Wall Requirements
- 9.1.7 Concrete Strength Requirements
- 9.1.8 Concrete Foundation Wall Details
- 9.1.9 Sill Plates and Masonry Ledges
- 9.1.10 Concrete and Masonry Basement/Foundation Walls
- 9.1.11 Capillary Moisture/Rising Damp
- 9.1.12 Waterproofing for Hydrostatic Pressure Relief
- 9.1.13 Soil Moisture Vapor
- 9.1.14 Heat Flow and Insulation
- 9.1.15 Basement and Foundation Insulation Details
- 9.1.16 Frost-Protected Shallow Foundations
- 9.1.17 Frost-Protected Shallow Foundation Requirements
- 9.1.18 Air-Freezing Index
- 9.1.19 Radon Protection

9.2 Insulating Concrete Forms (ICF)

- 9.2.1 Insulating Concrete Forms and Applicability Limits
- 9.2.2 ICF Flat Wall System
- 9.2.3 ICF Waffle-Grid Wall System
- 9.2.4 ICF Screen-Grid Wall System
- 9.2.5 ICF Foundations
- 9.2.6 ICF Walls With Slabs-On-Grade
- 9.2.7 ICF Crawl Space Walls
- 9.2.8 Vertical Reinforcement for ICF Crawl Space Walls
- 9.2.9 ICF Basement Walls
- 9.2.10 Reinforcement for ICF Basement Walls
- 9.2.11 Vertical Reinforcement for 7.5-in. Thick Flat ICF Basement Walls
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- 9.2.13 Vertical Reinforcement for 6-in. Waffle-Grid ICF Basement Walls
- 9.2.14 Vertical Reinforcement for 8-in. Waffle-Grid ICF Basement Walls
- 9.2.15 Vertical Reinforcement for 6-in. Screen-Grid ICF Basement Walls
- 9.2.16 Above-Grade ICF Walls
- 9.2.17 Above-Grade ICF Wall With 2nd Story Light Frame Construction
- 9.2.18 Horizontal Reinforcement for Above-Grade ICF Walls
- 9.2.19 Vertical Reinforcement for Flat ICF Above-Grade Walls
- 9.2.20 Vertical Reinforcement for Waffle-Grid ICF Above-Grade Walls
- 9.2.21 Vertical Reinforcement for Screen-Grid ICF Above-Grade Walls
- 9.2.22 ICF Wall Opening Requirements
- 9.2.23 Minimum Percentage of Solid Wall Length in ICF Walls
- 9.2.24 Base Percentage of Solid Wall Length in ICF Walls
- 9.2.25 ICF Foundation Wall-To-Footing Connection
- 9.2.26 Top-Bearing Floor Connections to ICF Walls
- 9.2.27 Anchor Bolts for Side Connection of Floor to ICF Walls
- 9.2.28 Side-Bearing Floor Connections to ICF Walls
- 9.2.29 Through-Bolt Floor Connections to ICF Walls
- 9.2.30 Roof Anchorage Requirements to ICF Walls
- 9.2.31 Roof Framing Connections to ICF Walls

9.1.1 Soil Classification and Allowable Bearing Pressures

Properties of Soils Classified According to the Unified Soil Classification System					
Soil Group	Unified Soil Classification Symbol	Soil Description	Drainage Properties§	Frost Heave Potential	Volume Change Potential Expansion†
Group I	GW	Well-graded gravels, gravel sand mixtures, little or no fines	Good	Low	Low
	GP	Poorly graded gravels or gravel sand mixtures, little or no fines	Good	Low	Low
	SW	Well-graded sands, gravelly sands, little or no fines	Good	Low	Low
	SP	Poorly graded sands or gravelly sands, little or no fines	Good	Low	Low
	GM	Silty gravels, gravel-sand-silt mixtures	Good	Medium	Low
	SM	Silty sand, sand-silt mixtures	Good	Medium	Low
Group II	GC	Clayey gravels, gravel-sand-clay mixtures	Medium	Medium	Low
	SC	Clayey sands, sand-clay mixtures	Medium	Medium	Low
	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Medium	High	Low
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, and lean clays	Medium	Medium	Medium to Low
Group III	CH	Inorganic clays of high plasticity	Poor	Medium	High
	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor	High	High
Group IV	OL	Organic silts and organic silty clays of low plasticity	Poor	Medium	Medium
	OH	Organic clays of medium to high plasticity, and organic silts	Unsatisfactory	Medium	High
	Pt	Peat and other highly organic soils	Unsatisfactory	Medium	High

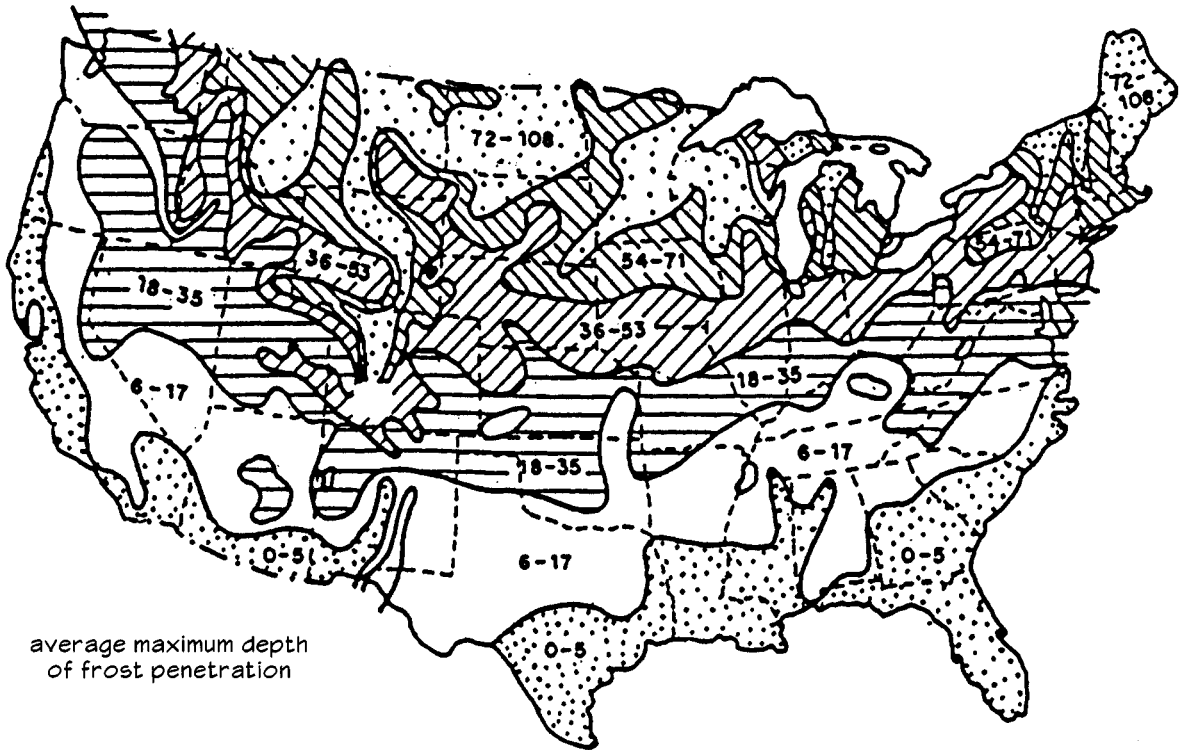
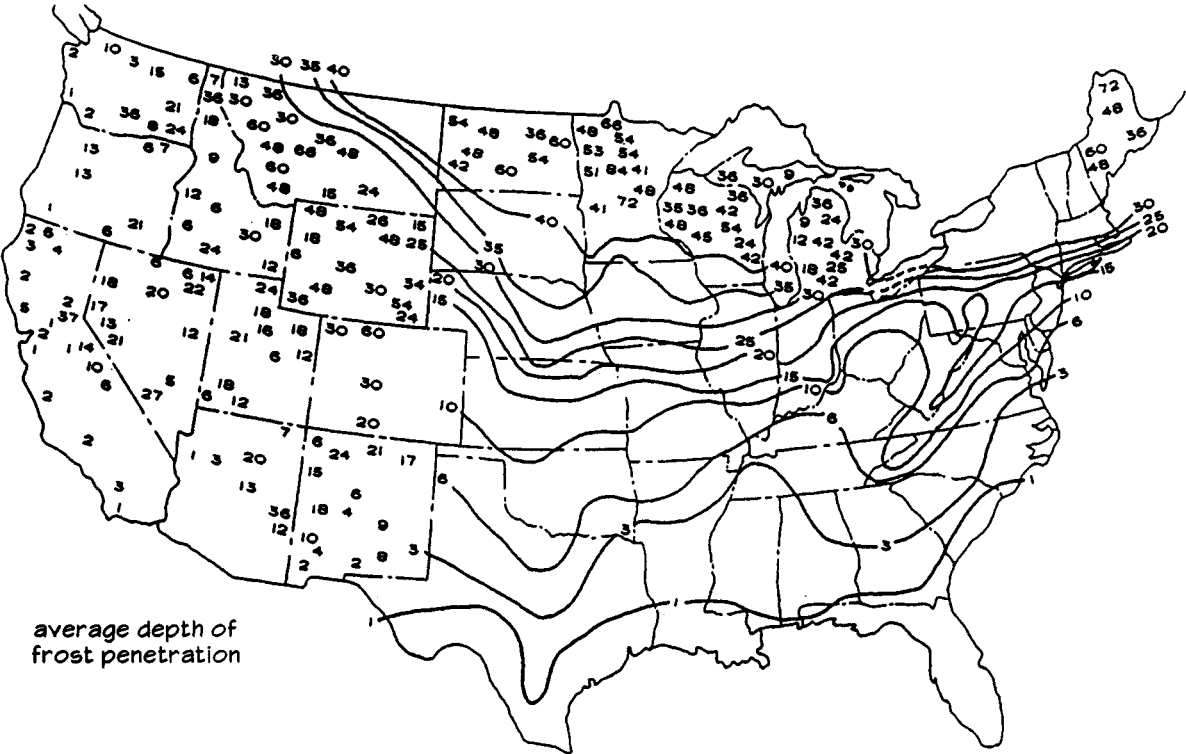
§ The percolation rate for good drainage is over 4 in. per hour. Medium drainage is 2-4 in. per hour. Poor drainage is less than 2 in. per hour.

† Soils with a low potential expansion have a plasticity index (PI) of 0 to 15. Soils with a medium potential expansion have a PI of 10 to 35. Soils with a high potential expansion have a PI greater than 20.

Allowable Bearing Pressures for Various Types of Soil	
Class of Material	Allowable Bearing Pressure (psi)
Crystalline bedrock	12,000
Sedimentary rock	6,000
Sandy gravel or gravel	5,000
Sand, silty sand, clayey sand, silty gravel, and clayey gravel	3,000
Clay, sandy clay, silty clay, and clayey silt	2,000

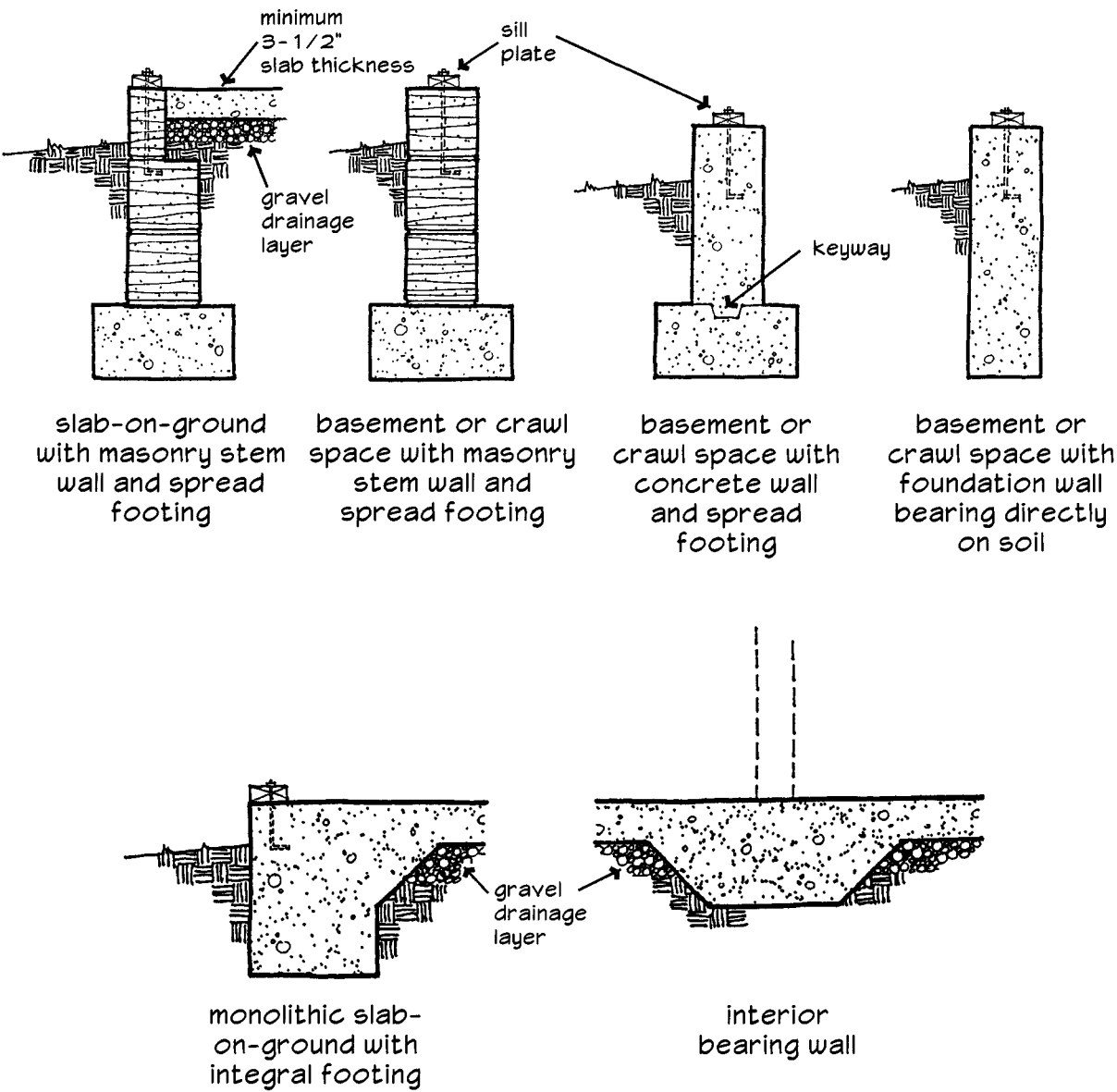
(From CABO One and Two Family Dwelling Code)

9.1.2 Frost Depth Requirements

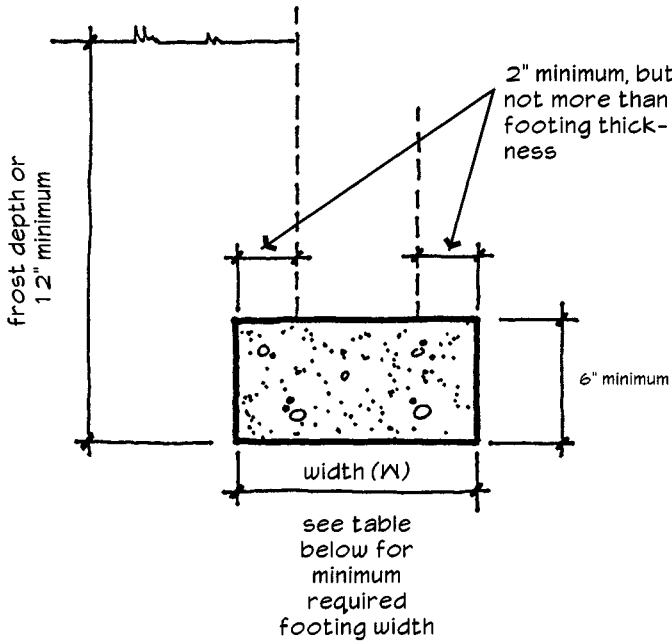


(From U.S. Weather Bureau)

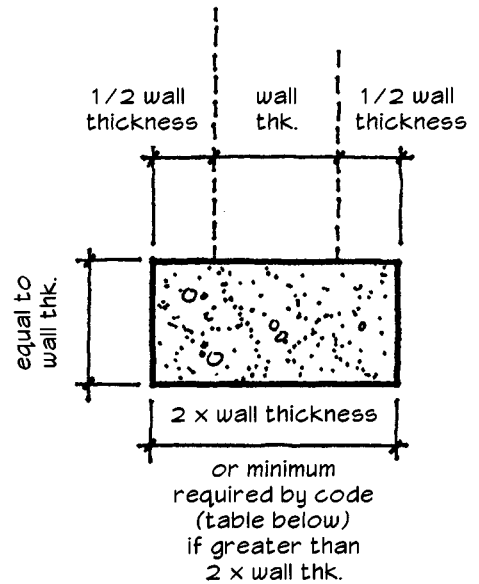
9.1.3 Basic Residential Foundation Types



9.1.4 Minimum Width of Concrete Footings



minimum dimensions required by code



rule of thumb footing dimensions

Minimum Width (W) of Concrete Footings (in.)						
Load Bearing Value of Soil (psf) →	1,500	2,000	2,500	3,000	3,500	4,000
Conventional Wood Frame Construction						
1 story	16	12	10	8	7	6
2 story	19	15	12	10	8	7
3 story	22	17	14	11	10	9
4-in Brick Veneer Over Wood Frame or 8-in. Hollow Concrete Masonry						
1 story	19	15	12	10	8	7
2 story	25	19	15	13	11	10
3 story	31	23	19	16	13	12
8-in. Solid or Fully Grouted Masonry						
1 story	22	17	13	11	10	9
2 story	31	23	19	16	13	12
3 story	40	30	24	20	17	15

(From CABO One and Two Family Dwelling Code)

9.1.5
Unreinforced Foundation Wall Requirements

Requirements for Unreinforced Concrete and Unreinforced Masonry Foundation Walls ¹							
Maximum Wall Height (ft.)	Maximum Unbalanced Backfill Height ⁴ (ft.)	Plain Concrete Minimum Nominal Wall Thickness (in.)			Plain Masonry ² Minimum Nominal Wall Thickness (in.)		
		Soil Classes ³					
		GW, GP, SW and SP	GM, GC, SM, SM-SC and ML	SC, MH, ML-CL and Inorganic CL	GW, GP, SW and SP	GM, GC, SM, SM-SC and ML	SC, MH, ML-CL and Inorganic CL
5	4	6	6	6	6 solid ⁵ or 8	6 solid ⁵ or 8	6 solid ⁵ or 8
	5	6	6	6	6 solid ⁵ or 8		
6	4	6	6	6	6 solid ⁵ or 8	6 solid ⁵ or 8	6 solid ⁵ or 8
	5	6	6	6	6 solid ⁵ or 8	8	10
	6	6	8	8	8	10	12
7	4	6	6	6	6 solid ⁵ or 8	8	8
	5	6	6	8	6 solid ⁵ or 8	10	10
	6	6	8	8	10	12	10 solid ⁵
	7	8	8	10	12	10 solid ⁵	12 solid ⁵
8	4	6	6	6	6 solid ⁵ or 8	6 solid ⁵ or 8	8
	5	6	6	8	6 solid ⁵ or 8	10	12
	6	8 ⁸	8	10	10	12	12 solid ⁵
	7	8	10	10	12	12 solid ⁵	Note 6
	8	10	10	12	10 solid ⁵	12 solid ⁵	Note 6
9	4	6	6	6	6 solid ⁵ or 8	6 solid ⁵ or 8	8
	5	6	8	8	8	10	12
	6	8	8	10	10	12	12 solid ⁵
	7	8	10	10	12	12 solid ⁵	
	8	10	10	12	12 solid ⁵	Note 6	Note 6
	9	10	12	Note 7	Note 6	Note 6	Note 6

- Notes: 1. Use of this table for sizing concrete and masonry foundation walls in Seismic Zones 3 and 4 shall be limited to the following conditions:
- a. Walls shall not support more than 4 ft. of unbalanced backfill.
 - b. Walls shall not exceed 8 ft. in height.
2. Mortar shall be Type M or Type S and masonry shall be laid in running bond. UngROUTed hollow masonry units are permitted except where otherwise indicated.
3. Soil classes are in accordance with Unified Soil Classification System.
4. Unbalanced backfill height is the difference in height of the exterior and interior finish ground levels. Where an interior concrete slab is provided, the unbalanced backfill height shall be measured from the exterior finish ground level to the top of the interior concrete slab.
5. Solid grouted hollow units or solid masonry units (i.e. having core area less than 25%).
6. Wall construction shall be reinforced as required by CABO Table for Requirements for Reinforced Concrete and Masonry Foundation Walls.
7. Engineered design is required.
8. Thickness may be 6 in., provided minimum specified compressive strength of concrete is 4,000 psi.

(From CABO One and Two Family Dwelling Code)

MSJC Code Requirements for Minimum Masonry Foundation Wall Thickness for Empirically Designed Masonry		
Foundation Wall Construction	Min. Nominal Thickness (in.)	Maximum Depth of Unbalanced Backfill (ft.)
UngROUTed hollow masonry units	8	5
	10	6
	12	7
Solid masonry units	8	5
	10	7
	12	7
Hollow or solid masonry units fully grouted	8	7
	10	8
	12	8

(From Masonry Standards Joint Committee Building Code Requirements for Masonry Structures, ACI 530/ASCE 5/TMS 402)

9.1.6 Reinforced Foundation Wall Requirements

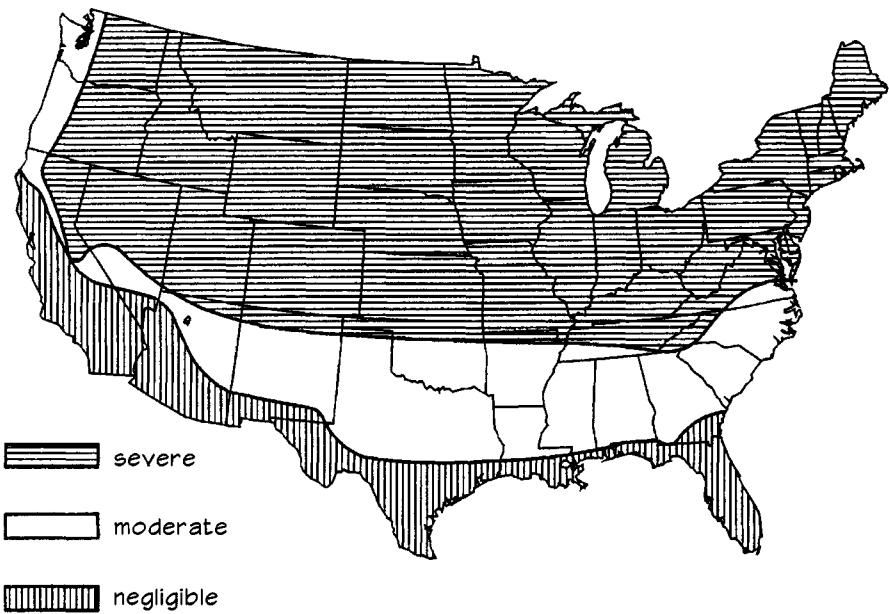
Minimum Vertical Reinforcement Size and Spacing ^{1,2} for 8-in. Nominal Concrete or Masonry ³ Foundation Wall Thickness				
Maximum Wall Height (ft.)	Maximum Unbalanced Backfill Height ⁵ (ft.)	Soil Classes ⁴		
		GW, GP, SW, and SP	GM, GC, SM, SM-SC, and ML	SC, MH, ML-CL, and Inorganic CL
6	5	#4 @ 48" o.c.	#4 @ 48" o.c.	#4 @ 48" o.c.
	6	#4 @ 48" o.c.	#4 @ 40" o.c.	#5 @ 48" o.c.
7	4	#4 @ 48" o.c.	#4 @ 48" o.c.	#5 @ 48" o.c.
	5	#4 @ 48" o.c.	#4 @ 48" o.c.	#4 @ 40" o.c.
	6	#4 @ 48" o.c.	#5 @ 48" o.c.	#5 @ 40" o.c.
	7	#4 @ 48" o.c.	#5 @ 40" o.c.	#6 @ 48" o.c.
8	5	#4 @ 48" o.c.	#4 @ 48" o.c.	#4 @ 40" o.c.
	6	#4 @ 48" o.c.	#5 @ 48" o.c.	#5 @ 40" o.c.
	7	#5 @ 48" o.c.	#6 @ 48" o.c.	#6 @ 40" o.c.
	8	#5 @ 40" o.c.	#6 @ 40" o.c.	#6 @ 24" o.c.
9	5	#4 @ 48" o.c.	#4 @ 48" o.c.	#5 @ 48" o.c.
	6	#4 @ 48" o.c.	#5 @ 48" o.c.	#6 @ 48" o.c.
	7	#5 @ 48" o.c.	#6 @ 48" o.c.	#6 @ 32" o.c.
	8	#5 @ 40" o.c.	#6 @ 32" o.c.	#6 @ 24" o.c.
	9	#6 @ 40" o.c.	#6 @ 24" o.c.	#6 @ 16" o.c.

- Notes: 1. Alternative reinforcing bar sizes and spacings having an equivalent cross-sectional area of reinforcement per lineal foot of wall are permitted provided the spacing of the reinforcement does not exceed 72 in.
2. Vertical reinforcement must be Grade 60 minimum. The distance from the face of the soil side of the wall to the center of the vertical reinforcement must be at least 5 in.
3. Mortar shall be Type M or Type S and masonry shall be laid in running bond.
4. Soil classes are in accordance with Unified Soil Classification System.
5. Unbalanced backfill height is the difference in height of the exterior and interior finish ground levels. Where an interior concrete slab is provided, the unbalanced backfill height shall be measured from the exterior finish ground level to the top of the interior concrete slab.

9.1.7 Concrete Strength Requirements

Minimum Specified Compressive Strength of Concrete			
Type or Location of Concrete	Weathering Potential*		
	Negligible	Moderate	Severe
Basement walls and foundations not exposed to weather	2500	2500	2500§
Basement slabs and interior slabs-on-grade, except garage floor slabs	2500	2500	2500§
Basement walls, foundation walls, exterior walls and other vertical concrete work exposed to weather	2500	3000†	3000†
Porches, carport slabs, and steps exposed to weather, and garage slabs	2500	3000‡	3500‡

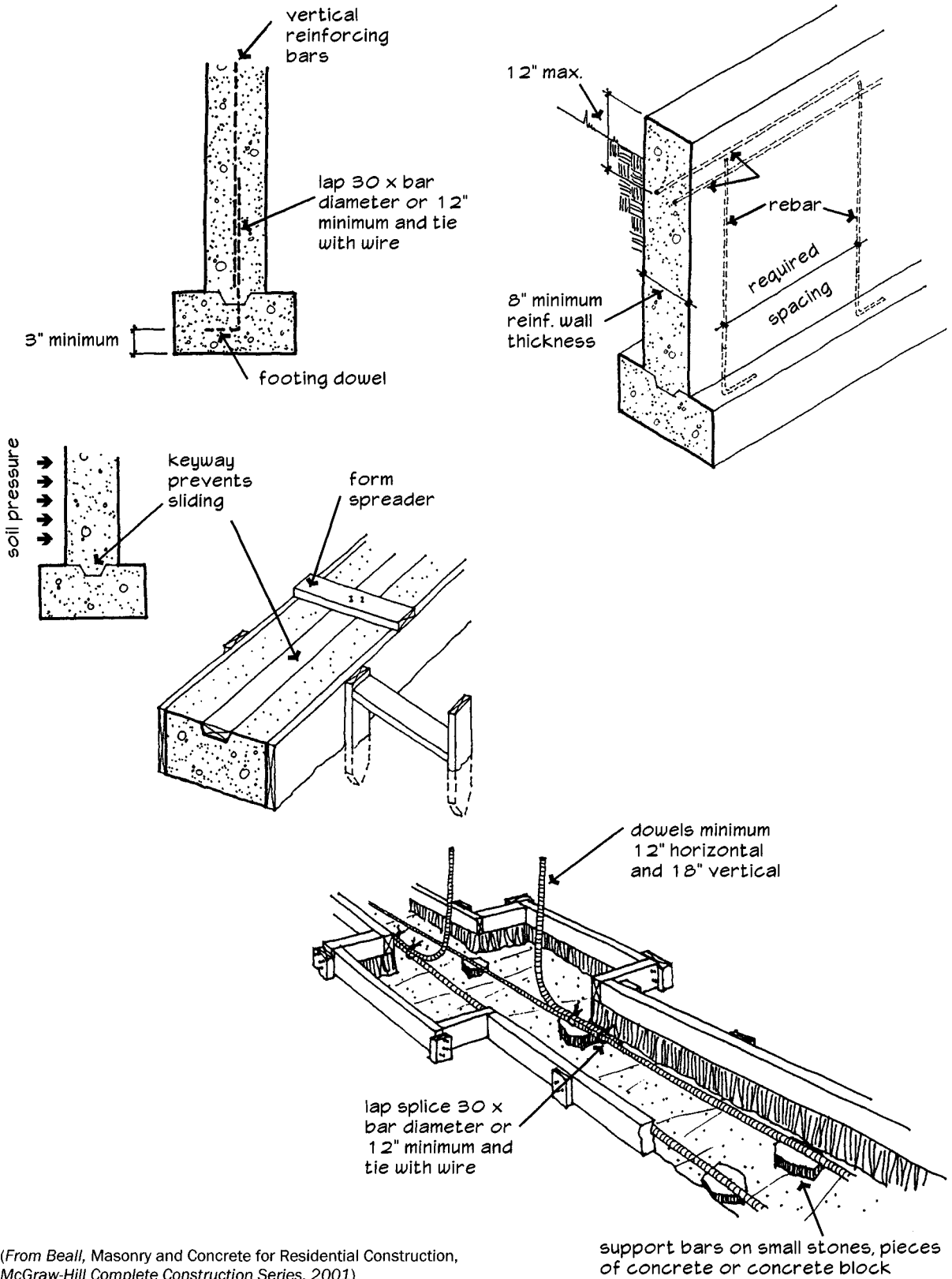
- * See map below for weathering potential.
- † Use air-entrained cement.
- § Use air-entrained cement if concrete will be subject to freezing and thawing during construction.
- ‡ Minimum cement content 5-1/2 bags per cubic yard.



- Lines defining areas are approximate only. Local areas can be more or less severe than indicated by the region classification.
- A “severe” classification is where weather conditions result in significant snowfall combined with extended periods during which there is little or no natural thawing causing deicing salts to be used extensively.
- Alaska and Hawaii are classified as severe and negligible, respectively.

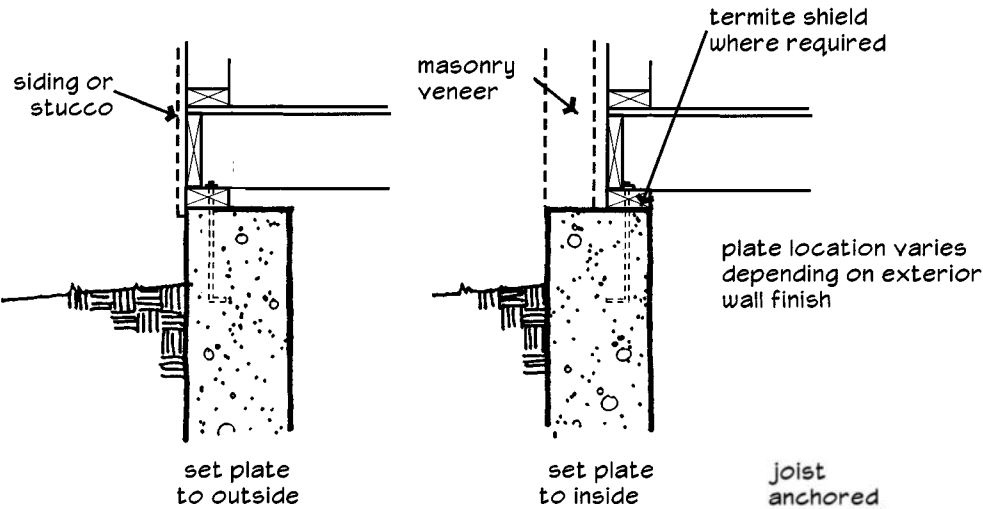
(From CABO One and Two Family Dwelling Code)

9.1.8 Concrete Foundation Wall Details

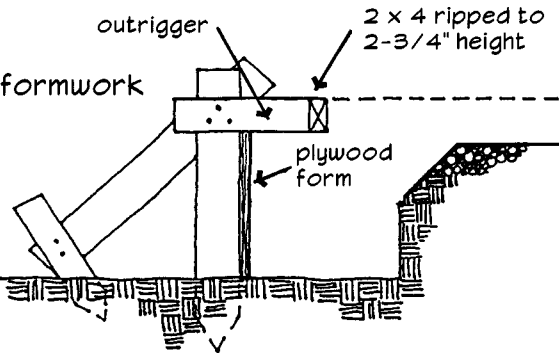
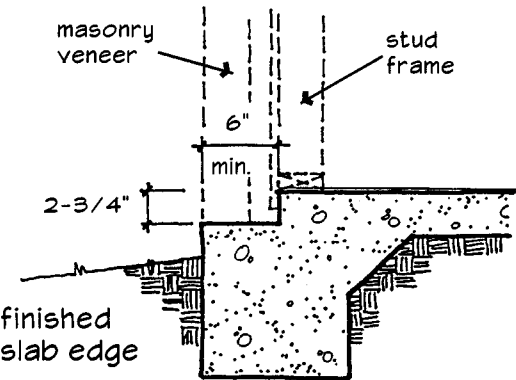


(From Beall, Masonry and Concrete for Residential Construction, McGraw-Hill Complete Construction Series, 2001)

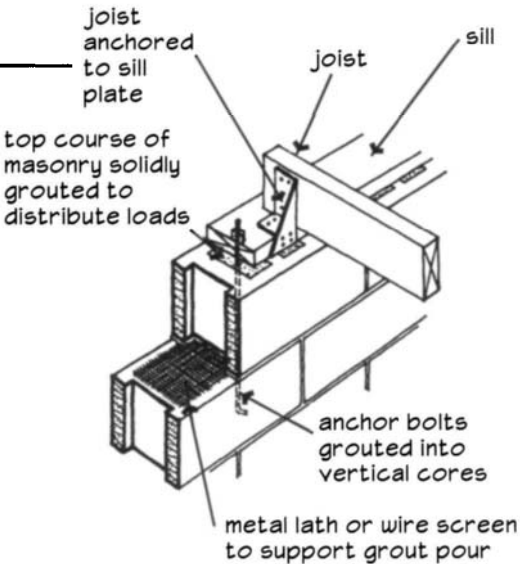
9.1.9 Sill Plates and Masonry Ledges



sill plates at foundation



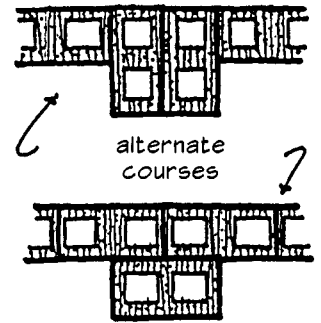
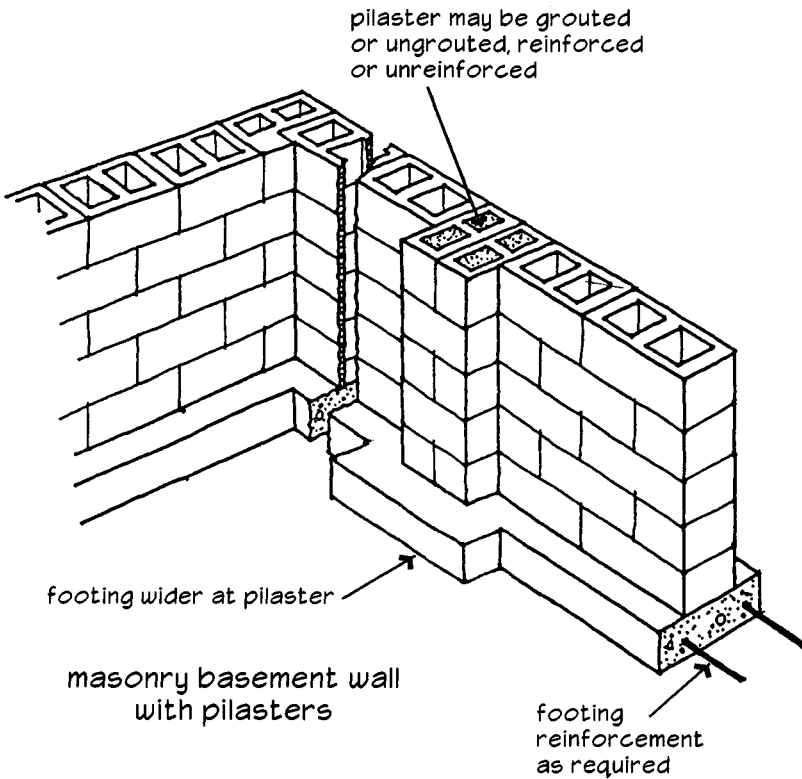
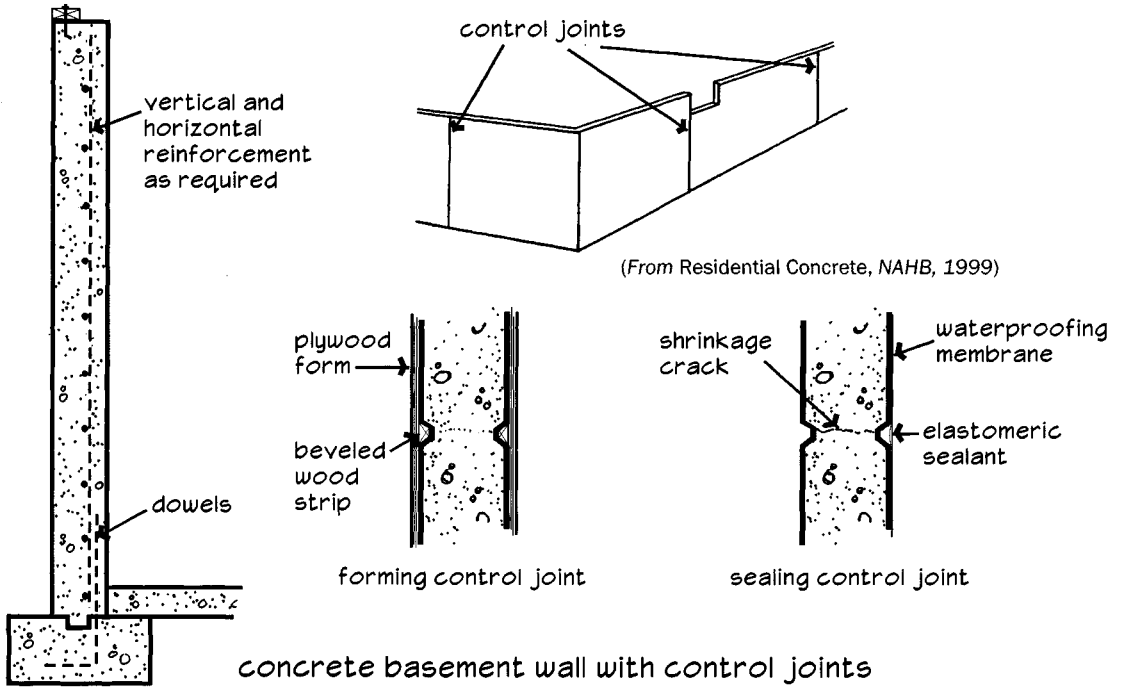
masonry ledge at edge of floor slab



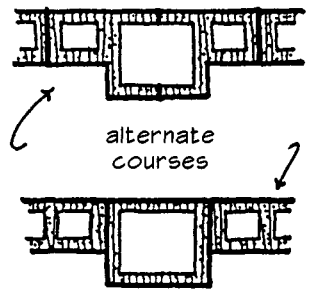
top course of masonry walls grouted to support anchored sill plates and floor loads

(From Beall, Masonry and Concrete for Residential Construction, McGraw-Hill Complete Construction Series, 2001)

9.1.10 Concrete and Masonry Basement/Foundation Walls

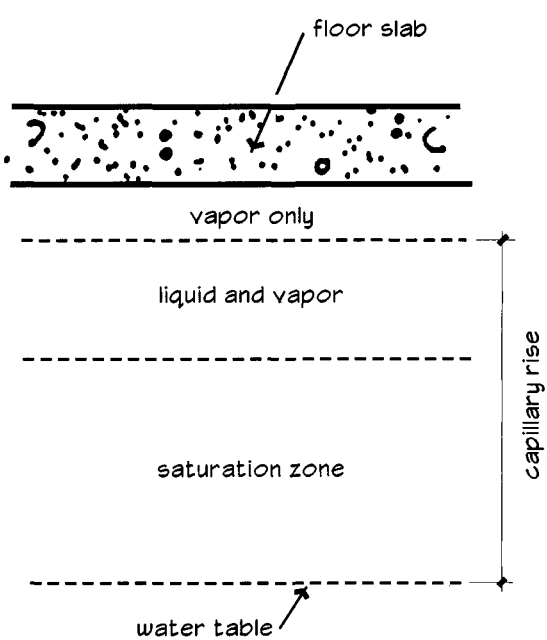
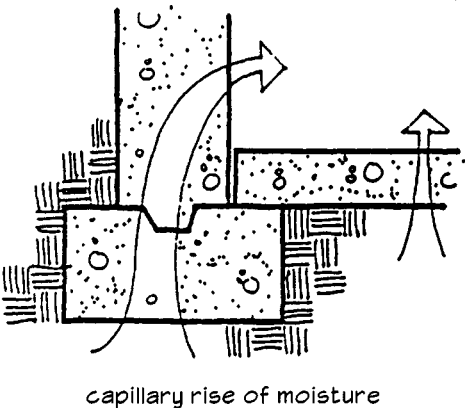


pilaster built with stretcher units



pilaster built with half-pilaster units

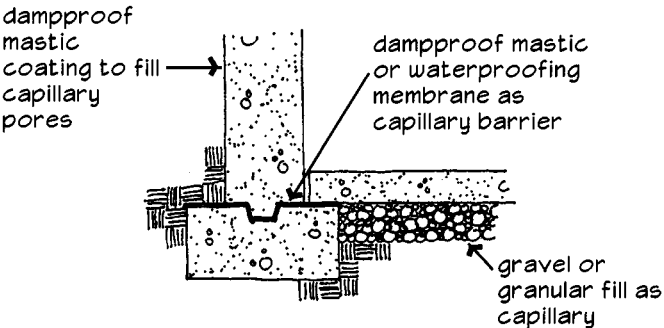
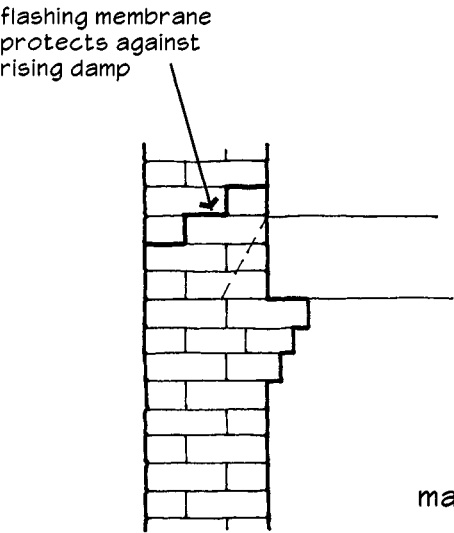
9.1.11 Capillary Moisture/Rising Damp



Height of Capillary Moisture Rise Above Water Table
for Various Soils

Soil Type	Saturation Zone (ft.)	Capillary Rise (ft.)
Clay	5+	8+
Silt	5+	8+
Fine sand	1 to 5	3 to 8
Coarse sand	0 to 1	1 to 3
Gravel	0	0

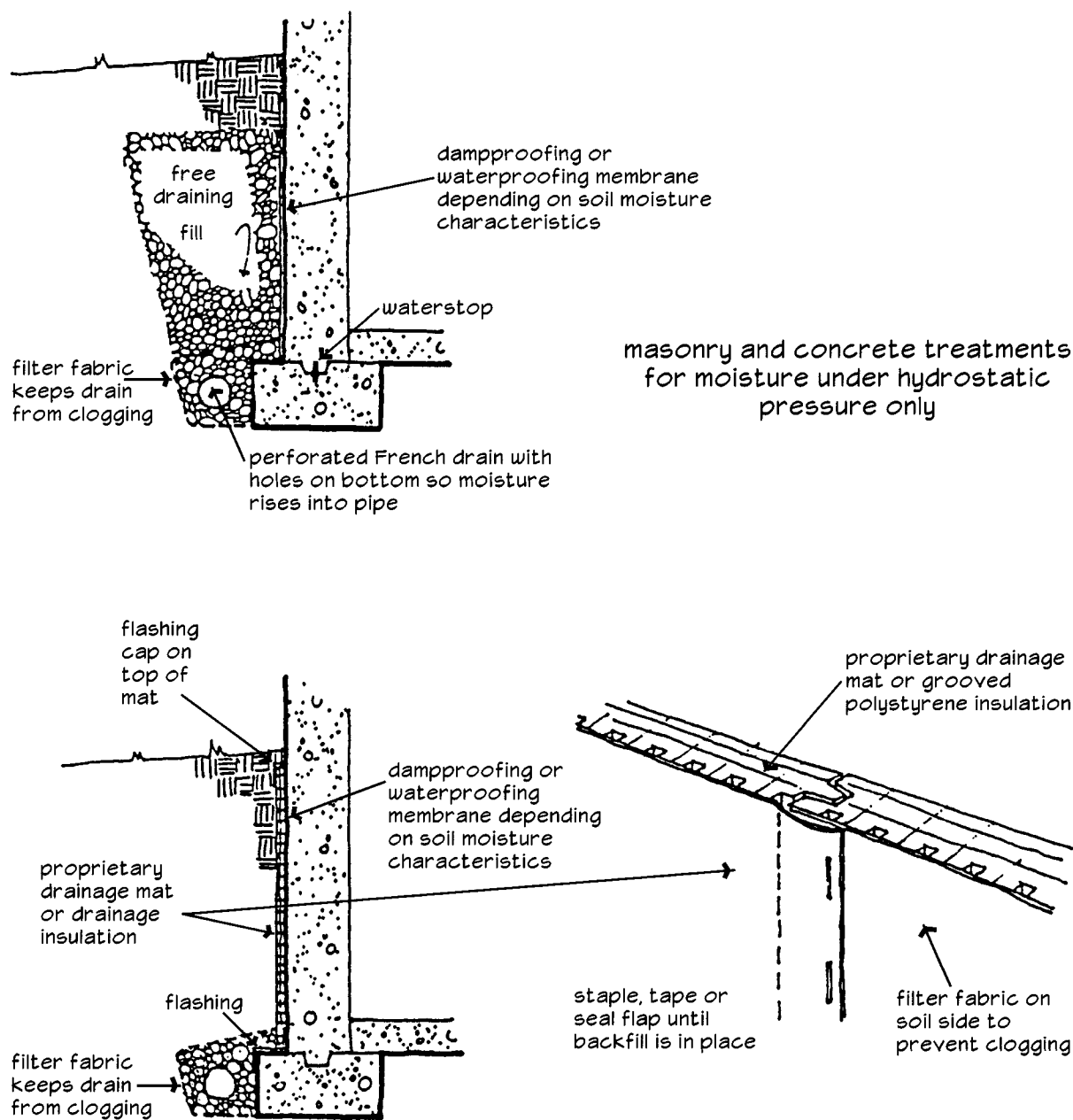
(From Olin, Construction Principles, Materials and Methods, 5th ed., Van Nostrand Reinhold, 1990)



masonry and concrete treatments
for capillary moisture only

(From Beall, Thermal and Moisture Protection Manual, McGraw-Hill, 1999)

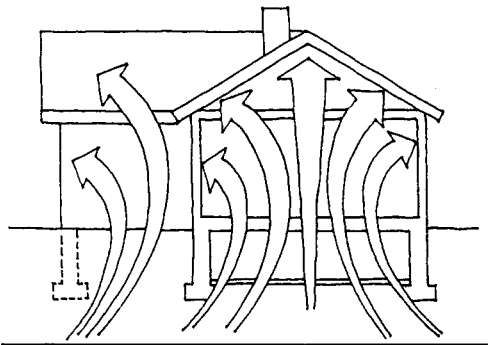
9.1.12 Waterproofing for Hydrostatic Pressure Relief



(From Lstiburek and Carmody, Moisture Control Handbook)

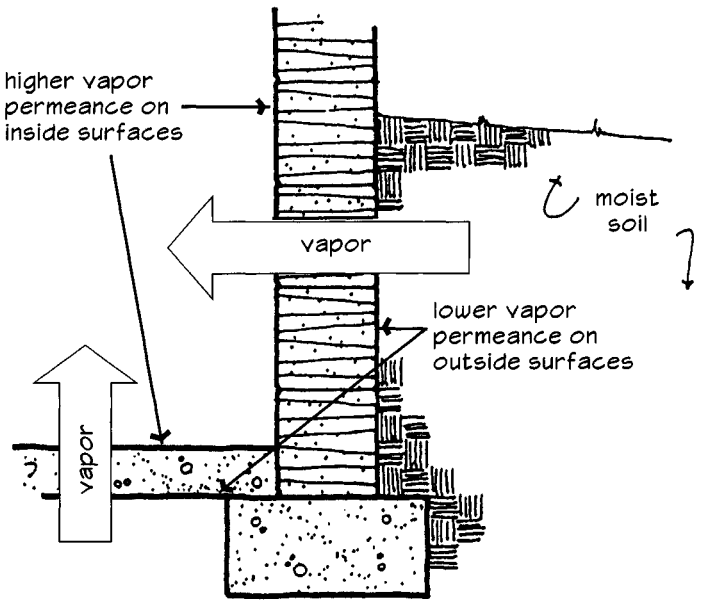
9.1.13 Soil Moisture Vapor

Moist soil has higher a vapor pressure than interior spaces, so vapor will migrate through the walls and slab. Excessive vapor migration may cause interior paint to peel and flooring to buckle or delaminate as well as possible condensation on cold surfaces. Materials with a vapor permeance less than 1.0 will reduce and materials with a vapor permeance less than 0.5 will virtually eliminate vapor penetration if they are properly installed and continuous. Interior finishes should have higher vapor permeance than outside materials to allow construction moisture to dry and to prevent trapping moisture within the walls or slab.



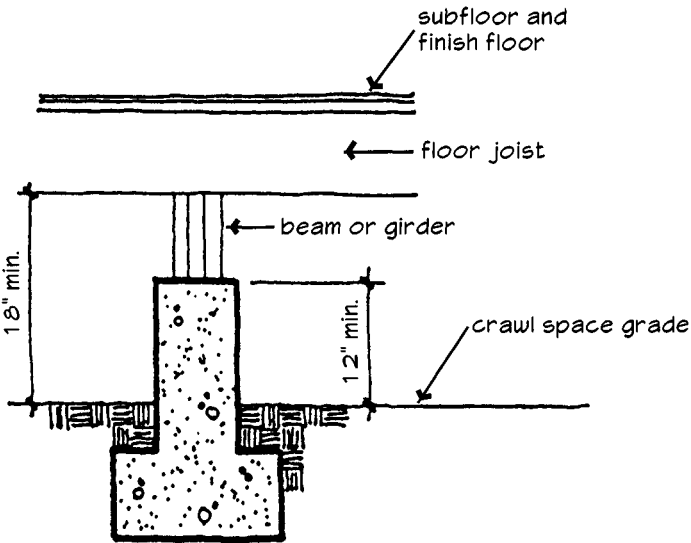
vapor flow from soil

(From W.R. Meadows, Inc., The Hydrologic Cycle and Moisture Migration)



vapor migration through basement walls & slabs

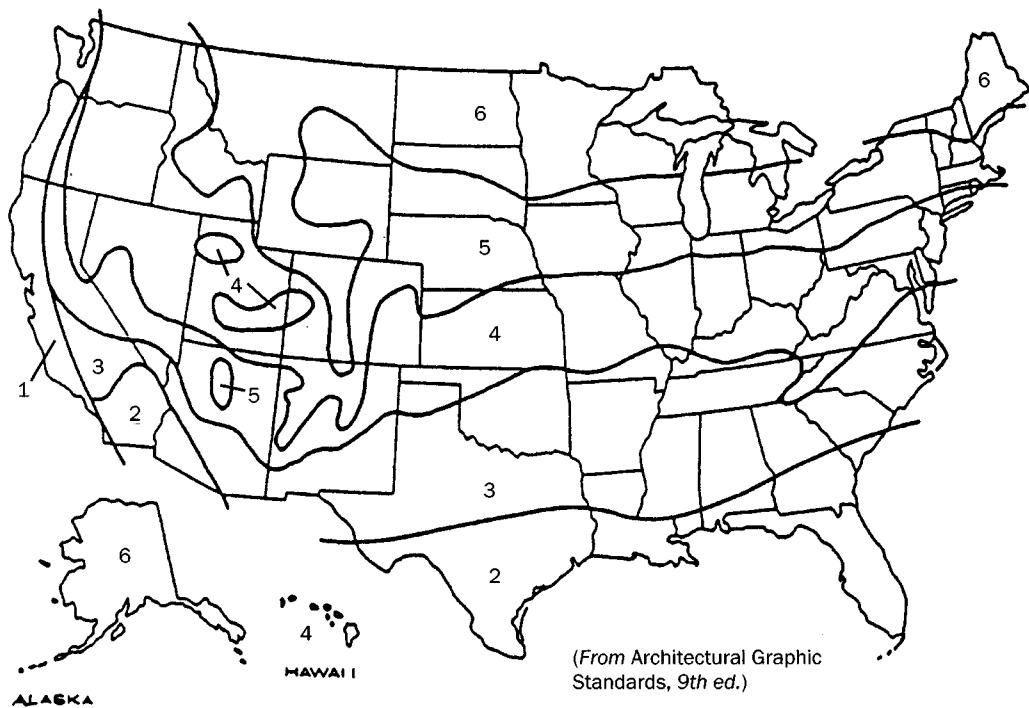
(From Beall, Thermal and Moisture Protection Manual, McGraw-Hill, 1999)



minimum height of wood framing above crawl space soil to allow adequate ventilation of soil moisture vapor and access for periodic inspection and maintenance

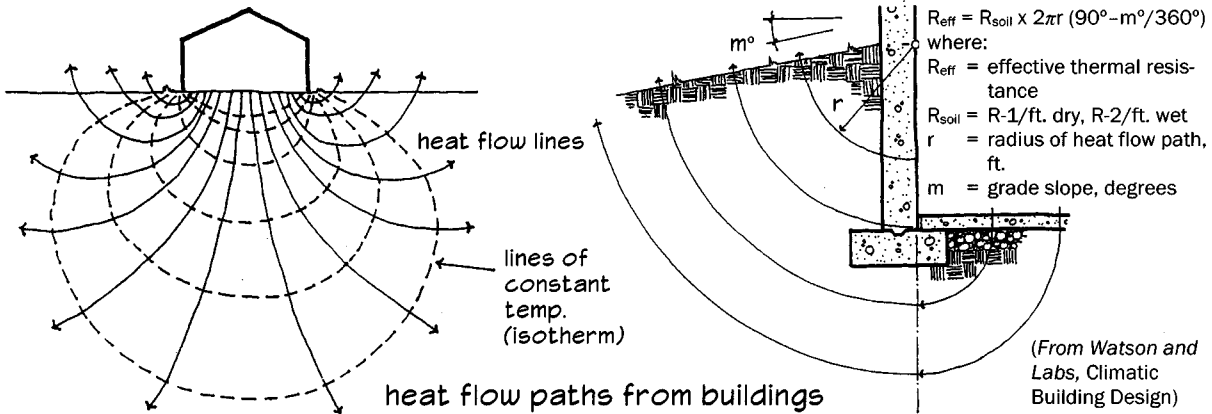
(From, Olin, Construction Principles, Materials and Methods, 5th ed., Van Nostrand Rheinhold, 1990)

9.1.14 Heat Flow and Insulation

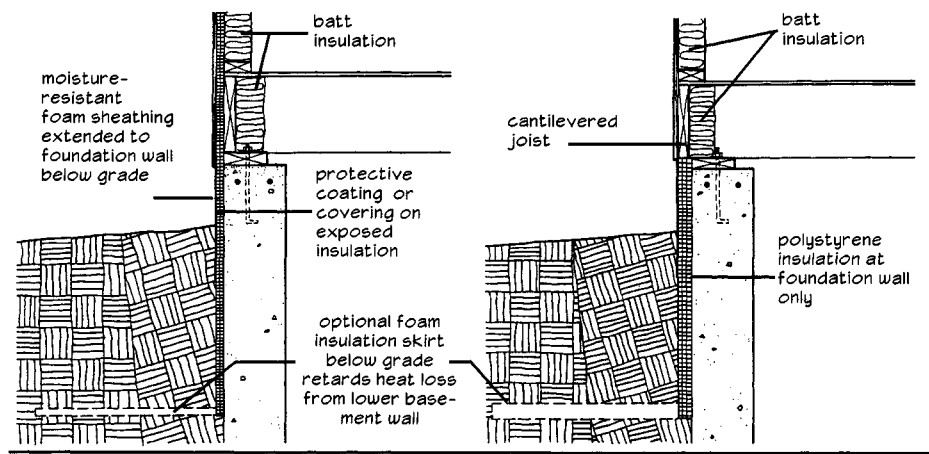


RECOMMENDED MINIMUM THERMAL RESISTANCE (R) OF INSULATION			
ZONE	CEILING	WALL	FLOOR
1	19	11	11
2	26	13	11
3	26	19	13
4	30	19	19
5	33	19	22
6	38	19	22

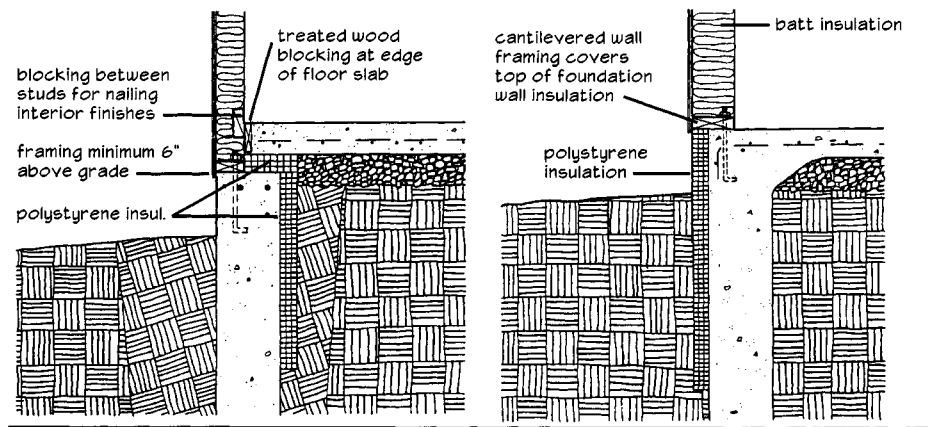
NOTE: The minimum insulation R-values recommended for various parts of the United States as delineated on the map of insulation zones.



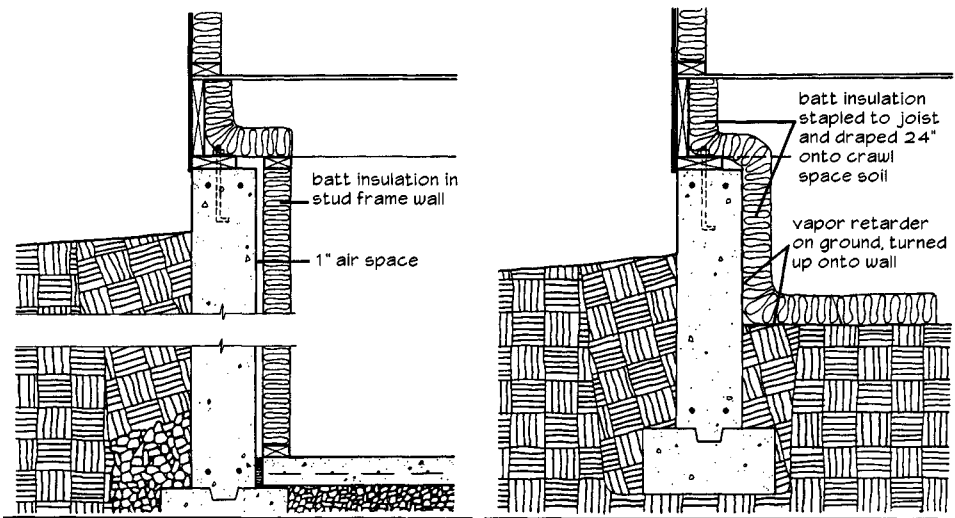
9.1.15 Basement and Foundation Insulation Details



basement or crawl space with wood frame floor



slabs-on-grade with foundation stem wall

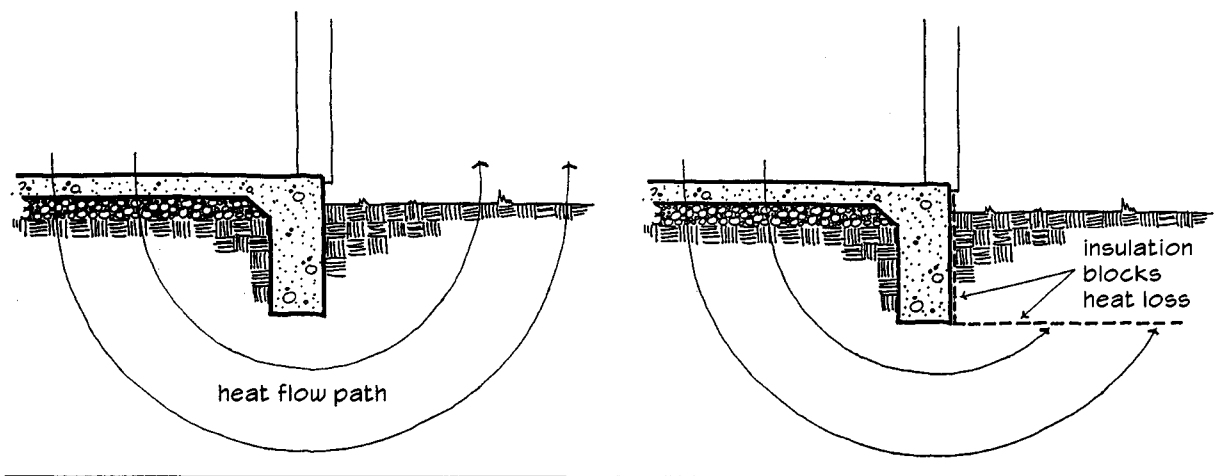


basement / wood frame floor

crawl space

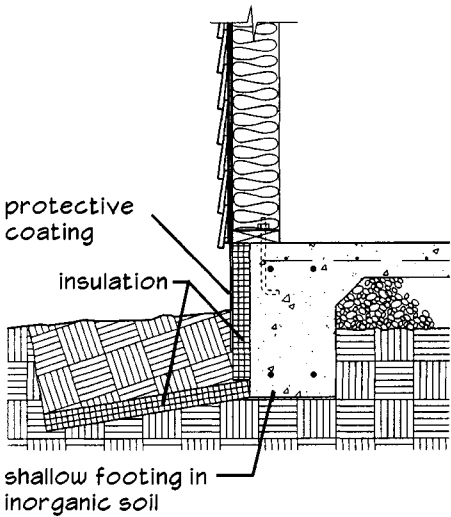
(From Allen, Fundamentals of Building Construction)

9.1.16 Frost-Protected Shallow Foundations



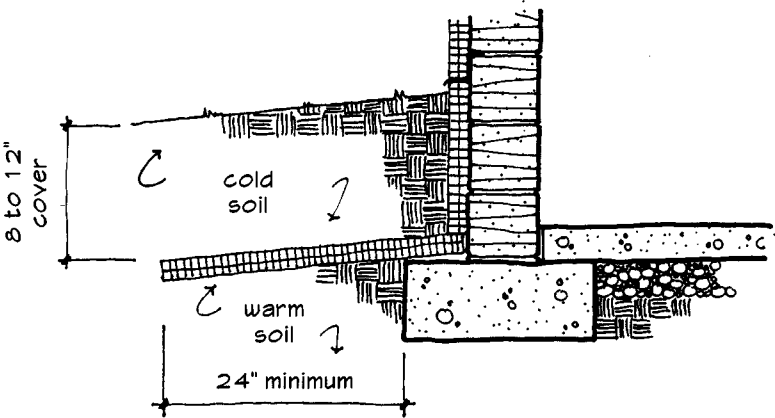
heat flow path at slab edge

(From Watson and Labs, Climatic Building Design)



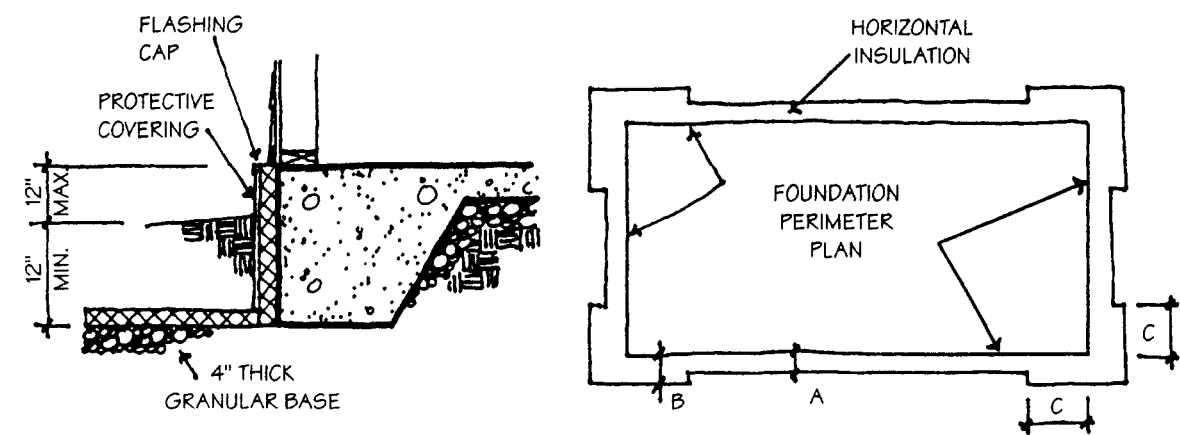
examples of frost-protected shallow foundation details

(From Allen, Fundamentals of Building Construction)



(From Beall, Thermal and Moisture Protection Manual)

9.1.17 Frost-Protected Shallow Foundation Requirements

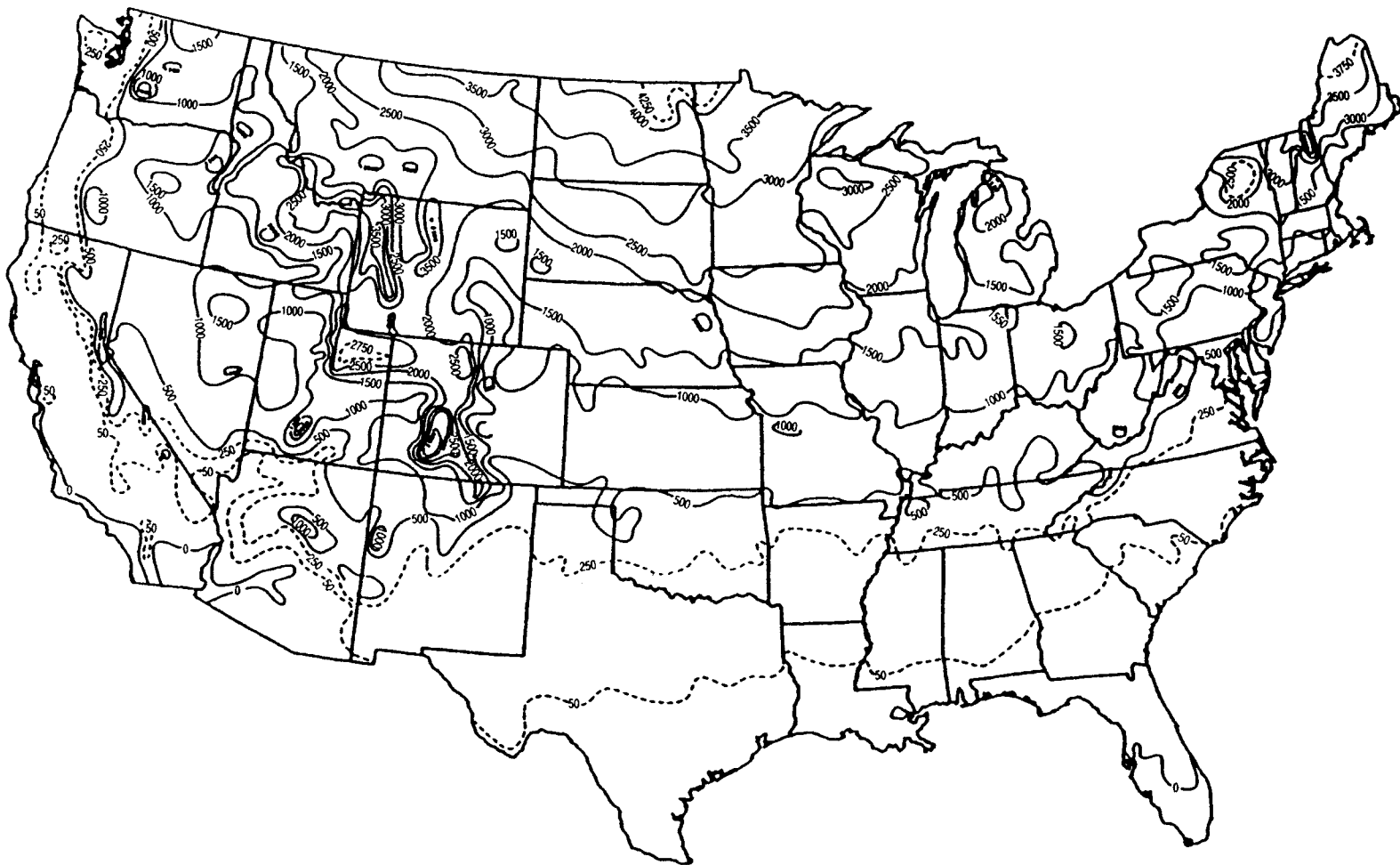


Minimum Insulation Requirements for Frost-Protected Footings in Heated Buildings¹

Air Freezing Index (° F Days) ²	Vertical Insulation R-Value ^{3,4}	Horizontal Insulation R-Value ^{3,5}		Horizontal Insulation Dimensions Inches		
		along walls	at corners	A	B	C
1,500 or less	4.5	Not Required	Not Required	Not Required	Not Required	Not Required
2,000	5.6	Not Required	Not Required	Not Required	Not Required	Not Required
2,500	6.7	1.7	4.9	12	24	40
3,000	7.8	6.5	8.6	12	24	40
3,500	9.0	8.0	11.2	24	30	60
4,000	10.0	10.5	13.1	24	36	60

- NOTES:**
1. Insulation requirements are for protection against frost damage in heated buildings. Greater values may be required to meet energy conservation standards. Interpolation between values is permitted.
 2. See next page for Air-Freezing Index values.
 3. Insulation materials shall provide the stated minimum R-values under long-term exposure to moist, below-ground conditions in freezing climates. The following R-values shall be used to determine insulation thickness required for this application: Type II expanded polystyrene 2.4 R per inch; Type IV extruded polystyrene 4.5 R per inch; Type VI extruded polystyrene 4.5 R per inch; Type IX expanded polystyrene 3.2 R per inch; Type X extruded polystyrene 4.5 R per inch.
 4. Vertical insulation shall be expanded polystyrene insulation or extruded polystyrene insulation, and the exposed portions shall have a rigid, opaque and weather-resistant protective covering to prevent the degradation of thermal performance. Protective covering shall cover the exposed portion of the insulation and extend to a minimum of 6 in. below grade.
 5. Horizontal insulation shall be extruded polystyrene insulation.

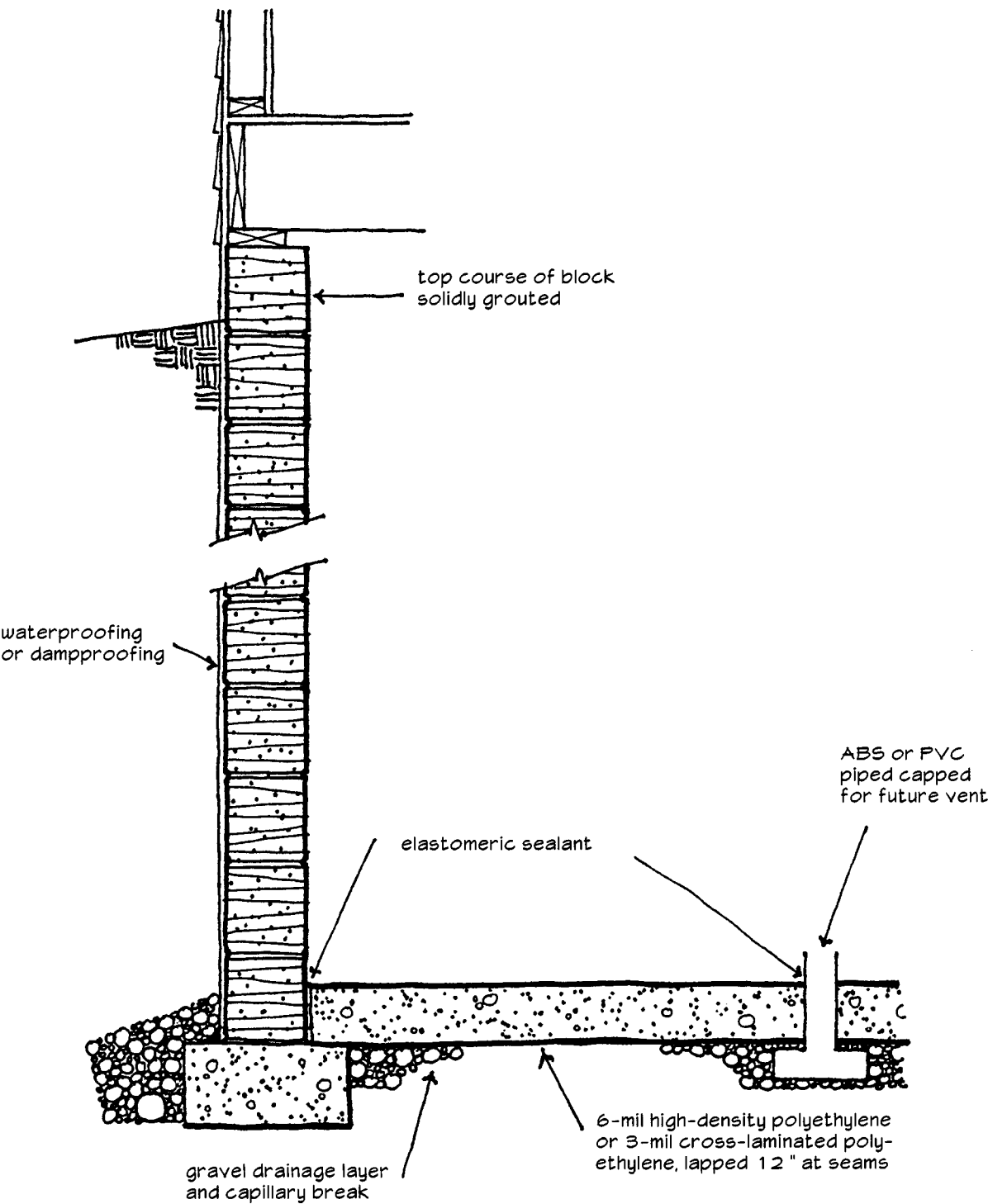
(From CABO One and Two Family Dwelling Code)



The air-freezing index is defined as cumulative degree days below 32°F. It is used as a measure of the combined magnitude and duration of air temperature below freezing. The index was computed over a 12-month period (July-June) for each of the 3,044 stations used in the above analysis. Data from the 1951 to 1980 period were fitted to a Weibull probability distribution to produce an estimate of the 100-year period.

(From CABO One and Two Family Dwelling Code)

9.1.19 Radon Protection



(From NCMA TEK 6-15, National Concrete Masonry Association)

9.2.1 Insulating Concrete Forms and Applicability Limits

Insulating concrete forms utilize stay-in-place insulating materials to form cast-in-place concrete walls. These walls may be used as basement or crawlspace walls, or as the above-grade enclosure walls for a residence. They may also be loadbearing.

Limitations: The prescriptive requirements presented herein for using insulating concrete form (ICF) systems in residential structures are limited by the following:

- 1. Applicable structures are limited to detached one- and two-family homes, townhouses, and other attached single-family dwellings.
- 2. Applicable ICF systems include flat, waffle-grid, and screen-grid systems.
- 3. The post-and-beam ICF system must be engineered. Prescriptive design does not apply to these systems.
- 4. ICF systems for dwellings located along the immediate, hurricane-prone coastline subjected to storm surge (such as beach front property) must be engineered. Prescriptive design does not apply to those structures.
- 5. Additional applicability limits are given in the table below.

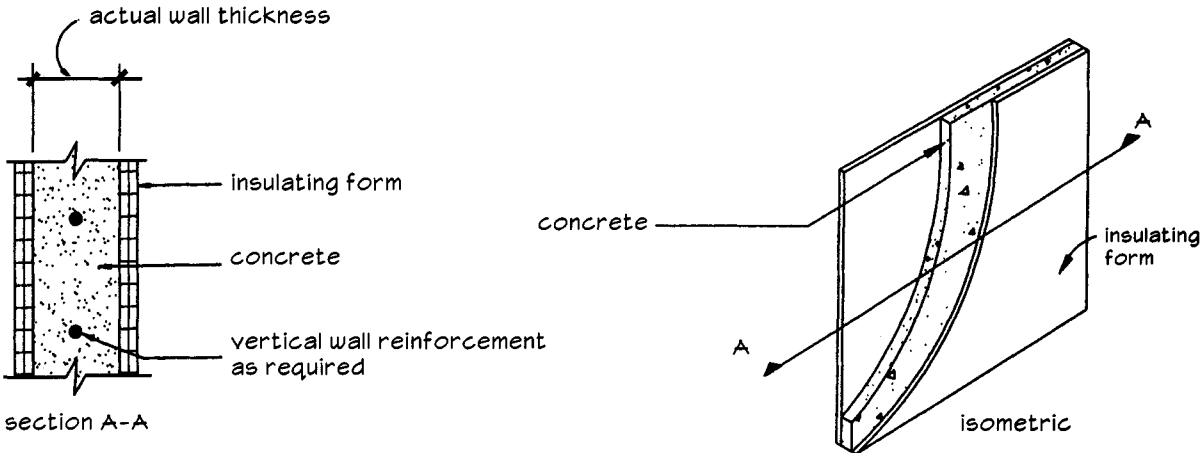
Material requirements for ICF systems are as follows:

- Ready-Mixed Concrete: ASTM C94, maximum slump 6 inches, maximum aggregate 3/4 inch, minimum compressive strength, f'_c , 2500 psi at 28 days.
- Reinforcing Steel: ASTM A615, ASTM A616, ASTM A617, or ASTM A706, Grade 40 minimum, with minimum 3/4-inch concrete cover.
- Place horizontal and vertical reinforcement in middle third of beams, columns, lintels, horizontal and vertical cores, and flat walls. Exception: horizontal and vertical reinforcement in basement and crawlspace walls may be placed closer to the inside face of the wall provided that the minimum concrete cover is maintained.
- Provide lap splices of minimum length $40 d_b$ and maximum gap between noncontact parallel bars at a lap splice of $d_b/8$, where d_b is the diameter of the smaller bar.
- Form Material: Rigid foam plastic meeting ASTM C578, composite cement and foam insulation, composite cement and wood chips, or other approved material. Flame spread rating less than 75 and smoke developed rating less than 450.

Applicability Limits	
Attribute	Maximum Limitation
General	
maximum building plan dimension	60 ft.
number of stories	2 stories above grade + basement
story height	10 ft.
design wind speed	110 mph fastest mile wind speed
ground snow load	70 psf
seismic zone	0, 1 and 2 only
Foundations	
unbalanced backfill height	9 ft.
equivalent fluid density of soil	60 pcf
minimum presumed soil bearing value	2,000 psf
Walls	
unit weight of concrete	150 pcf
loadbearing wall height	10 ft.
Floors	
floor dead load	15 psf
first floor live load	40 psf
second floor live load (sleeping rooms)	30 psf
floor clear span (unsupported)	32 ft.
Roofs	
roof slope	12:12
roof and ceiling dead load	15 psf
roof live load (ground snow load)	70 psf
attic live load	20 psf
roof clear span (unsupported)	40 ft.

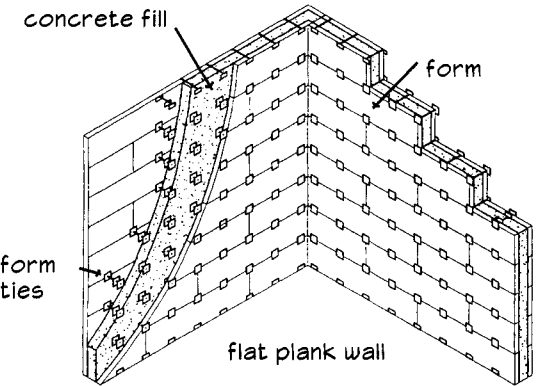
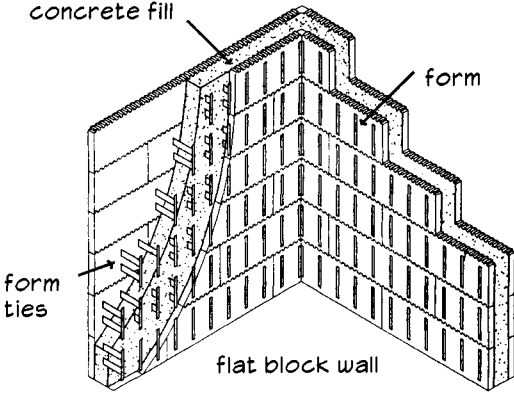
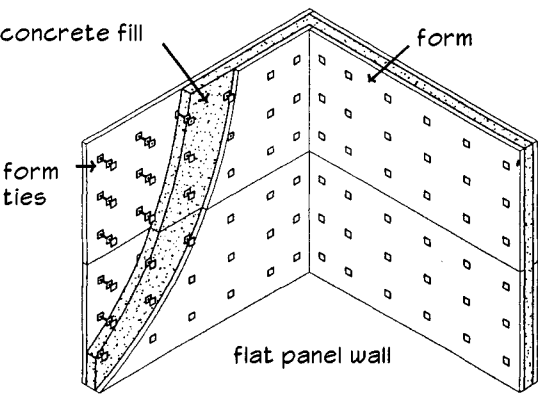
(From NAHB Research Center Prescriptive Method for Insulating Concrete Forms in Residential Construction, Portland Cement Association, 1998)

9.2.2 ICF Flat Wall System



Flat Wall: A solid concrete wall of uniform thickness produced by ICFs or other forming systems. Minimum concrete thickness is 5.5 inches (140 mm) for basement walls and 3.5 inches (89 mm) for above-grade walls.

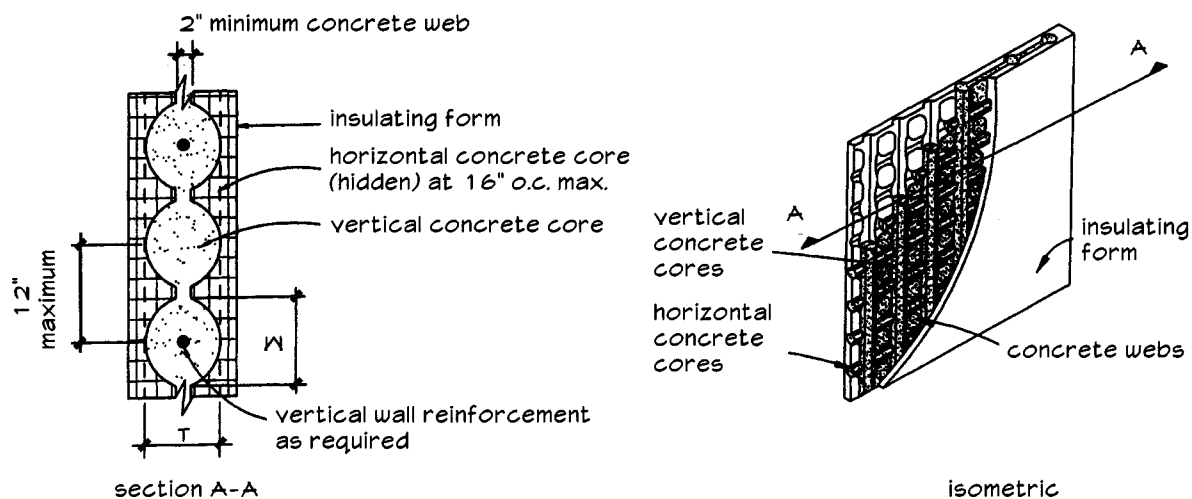
(From NAHB Research Center Prescriptive Method for Insulating Concrete Forms in Residential Construction, Portland Cement Association, 1998)



three types of ICF flat wall systems

(From VanderWerk, Insulating Concrete Forms, McGraw-Hill, 1997.)

9.2.3 ICF Waffle-Grid Wall System

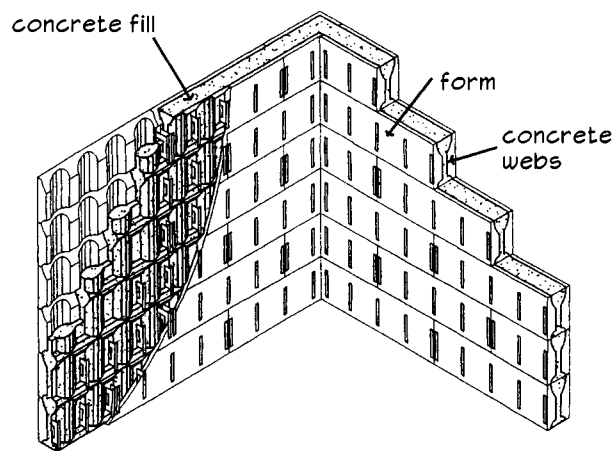


Waffle-Grid Wall: A solid concrete wall with closely spaced vertical and horizontal concrete members (cores) with a concrete web between the members created by the ICF form. The thicker vertical and horizontal concrete cores and the thinner concrete webs create the appearance of a breakfast waffle. Minimum dimensions for 6-inch and 8-inch waffle-grid ICF walls are given in the table below.

(From NAHB Research Center Prescriptive Method for Insulating Concrete Forms in Residential Construction, Portland Cement Association, 1998)

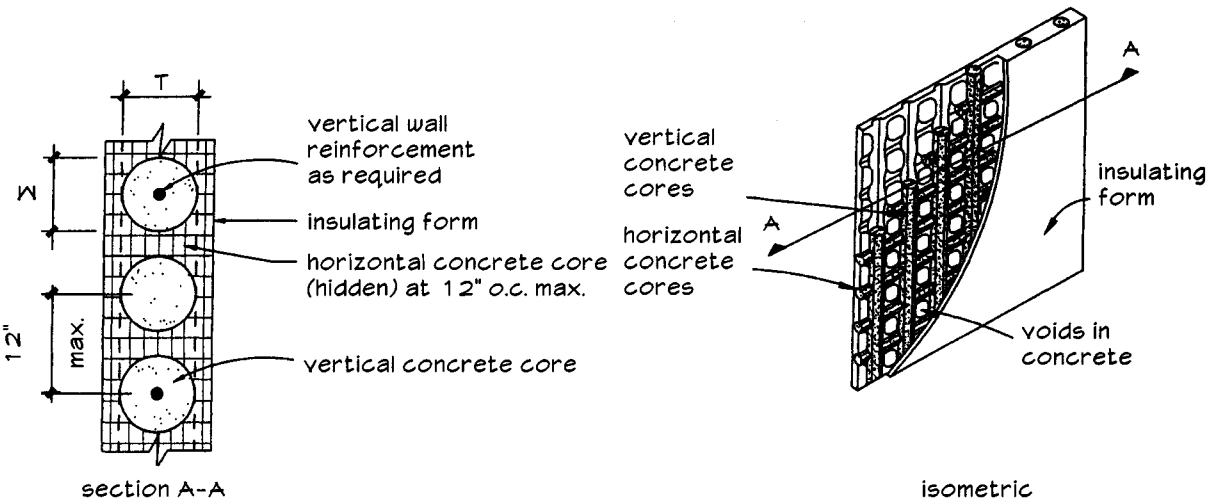
Dimensional Requirements for Cores and Webs in Waffle-Grid ICF Walls					
Nominal Size (in.)	Minimum Width (W) of Vertical Core (in.)	Minimum Thickness (T) of Vertical Core (in.)	Maximum Spacing of Vertical Cores (in.)	Maximum Spacing of Horizontal Cores (in.)	Minimum Web Thickness (in.)
6	6.25	5	12	16	2
8	7	7	12	16	2

(From NAHB Research Center Prescriptive Method for Insulating Concrete Forms in Residential Construction, Portland Cement Association, 1998)



(From VanderWerk, Insulating Concrete Forms, McGraw-Hill, 1997)

9.2.4 ICF Screen-Grid Wall System

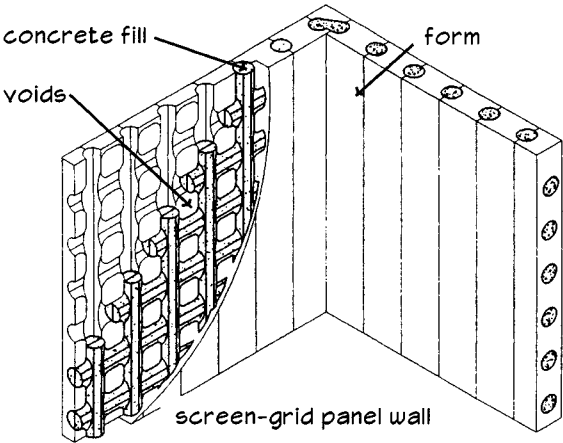


Screen-Grid Wall: A perforated concrete wall with closely spaced vertical and horizontal concrete members (cores) with voids in the concrete between the members created by the ICF form. Minimum dimensions for 6-inch screen-grid ICF walls are given in the table below.

(From NAHB Research Center Prescriptive Method for Insulating Concrete Forms in Residential Construction, Portland Cement Association, 1998)

Dimensional Requirements for Cores and Webs in Screen-Grid ICF Walls				
Nominal Size (in.)	Minimum Width (W) of Vertical Core (in.)	Minimum Thickness (T) of Vertical Core (in.)	Maximum Spacing of Vertical Cores (in.)	Maximum Spacing of Horizontal Cores (in.)
6	5.5	5.5	12	16

(From NAHB Research Center Prescriptive Method for Insulating Concrete Forms in Residential Construction, Portland Cement Association, 1998)



(From VanderWerk, Insulating Concrete Forms, McGraw-Hill, 1997)

9.2.5 ICF Foundations

ICF walls must be supported on continuous footings of ICF, solid masonry, or concrete. The footing must extend below the frost line or be protected from frost and be placed a minimum of 12 inches below grade. The footing must bear on undisturbed natural soil or approved fill with a minimum bearing capacity of 2000 psf. Minimum footing sizes are given in the table below.

ICF foundation walls shall be greater than or equal in thickness to the wall above. Place one No. 4 bar at 24 inches on center across all cold joints, with minimum embedment of 12 inches on both sides of the cold joint (or use the minimum wall reinforcement specified herein). Where vertical wall reinforcement is interrupted by wall openings, provide one vertical bar within 12 inches of each side of the opening.

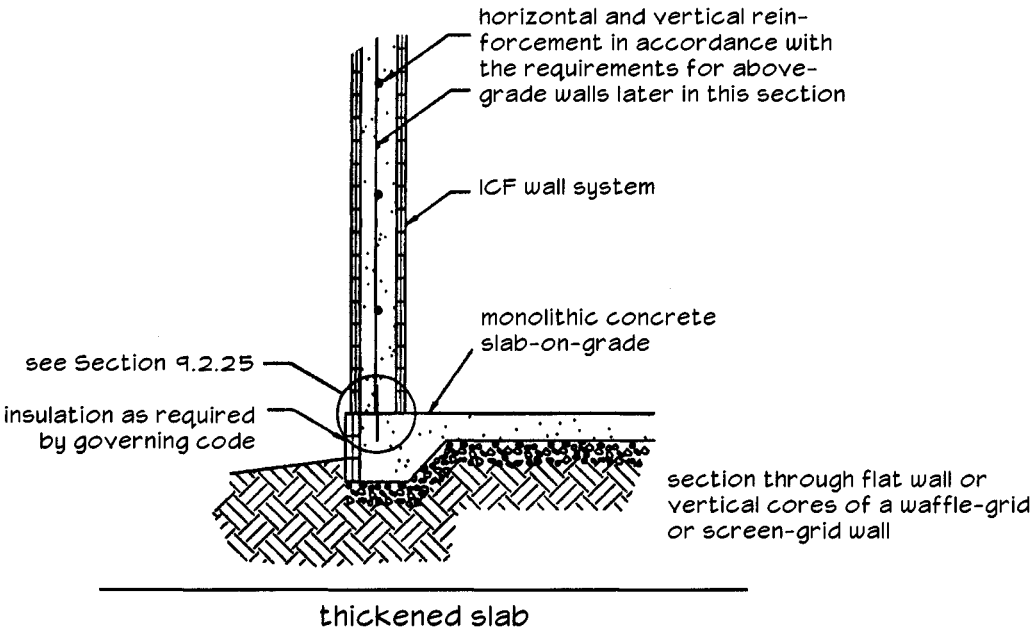
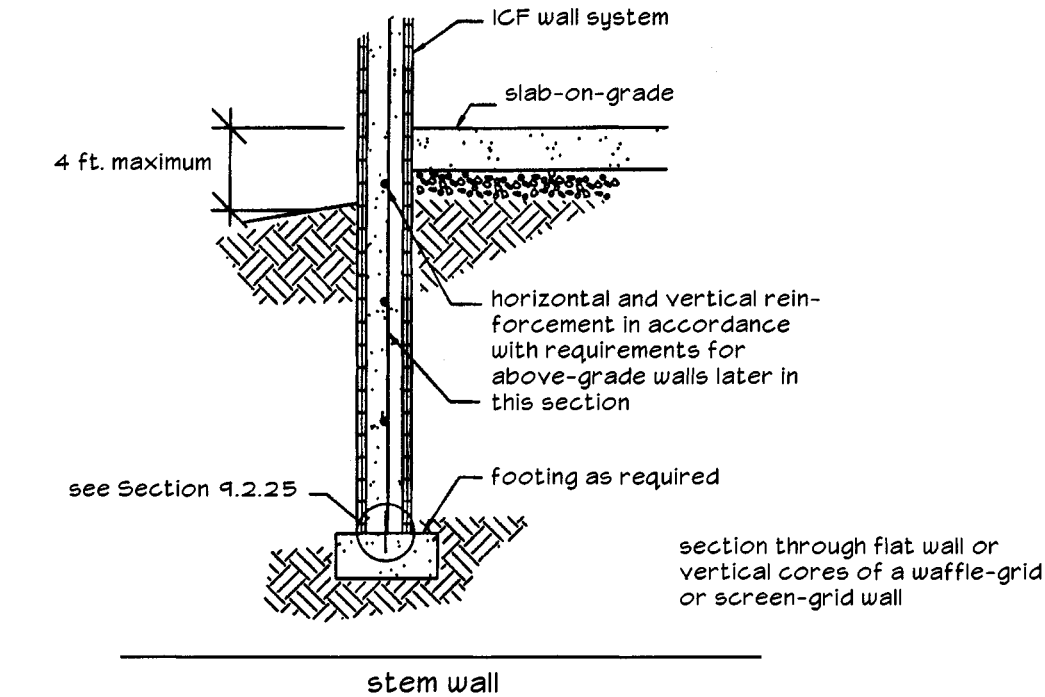
MINIMUM WIDTH OF ICF AND CONCRETE FOOTINGS FOR ICF WALLS^{1,2} (inches)

Maximum Number of Stories	Minimum Load-Bearing Value of Soil (psf)				
	2,000	2,500	3,000	3,500	4,000
5.5-Inch Flat, 6-Inch Waffle-Grid, or 6-Inch Screen-Grid ICF Wall Thickness³					
One Story	11	9	8	6	6
Two Story	20	15	13	11	10
Three Story ⁴	31	23	18	15	13
7.5-Inch Flat or 8-Inch Waffle-Grid ICF Wall Thickness³					
One Story	13	10	9	8	8
Two Story	22	18	15	13	11
Three Story ⁵	36	27	21	18	15
9.5-Inch Flat ICF Wall Thickness³					
One Story	15	12	10	10	10
Two Story	26	21	17	15	13
Three Story	41	31	24	20	17

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 psf = 47.8804 Pa

- ¹ Minimum footing thickness shall be the greater of 11 inches (279 mm) when a dowel is required in accordance with Section 9.2.25, one-third of the footing width, or 6 inches (152 mm).
- ² Required minimum footing widths that are greater than the ICF wall thickness shall be increased as required to allow for a minimum 2-inch (51-mm) footing width projection on both sides of the ICF wall. The footing width projection shall be measured from the face of the concrete in the ICF wall to the edge of the footing.
- ³ Actual thickness is shown for flat walls while nominal thickness is given for waffle- and screen-grid walls. Refer to Section 9.2.3 and 9.2.4 for actual waffle- and screen-grid thickness and dimensions.
- ⁴ Applicable also for 7.5-inch- (191-mm-) thick or 9.5-inch- (241-mm-) thick flat ICF story supporting two 3.5-inch-thick flat ICF stories.
- ⁵ Applicable also for 9.5-inch- (241-mm-) thick flat ICF wall story supporting two 5.5-inch- (140-mm-) thick flat ICF stories.

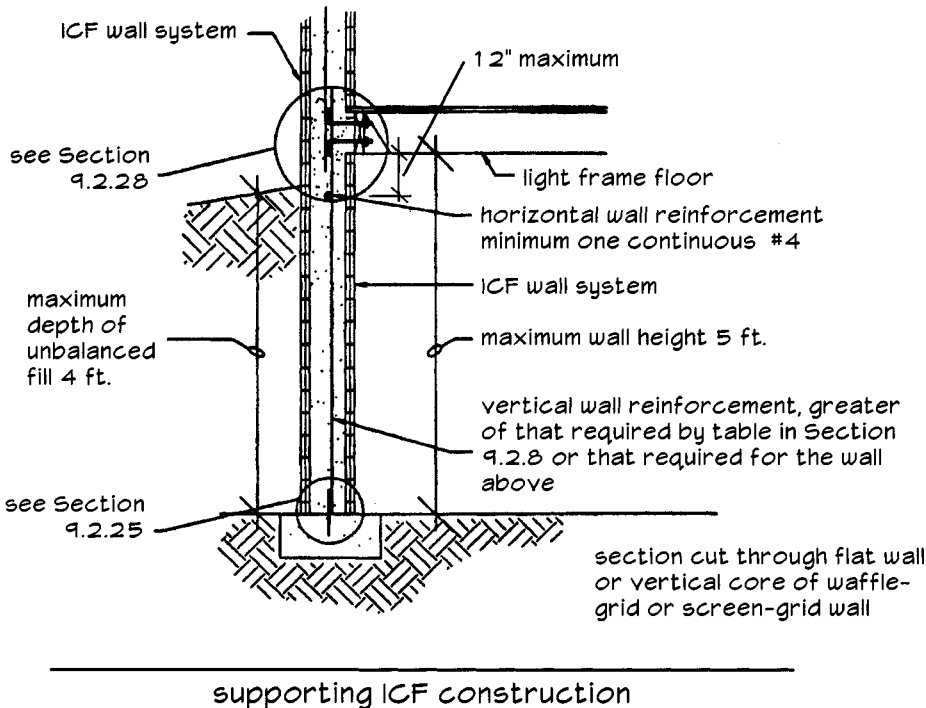
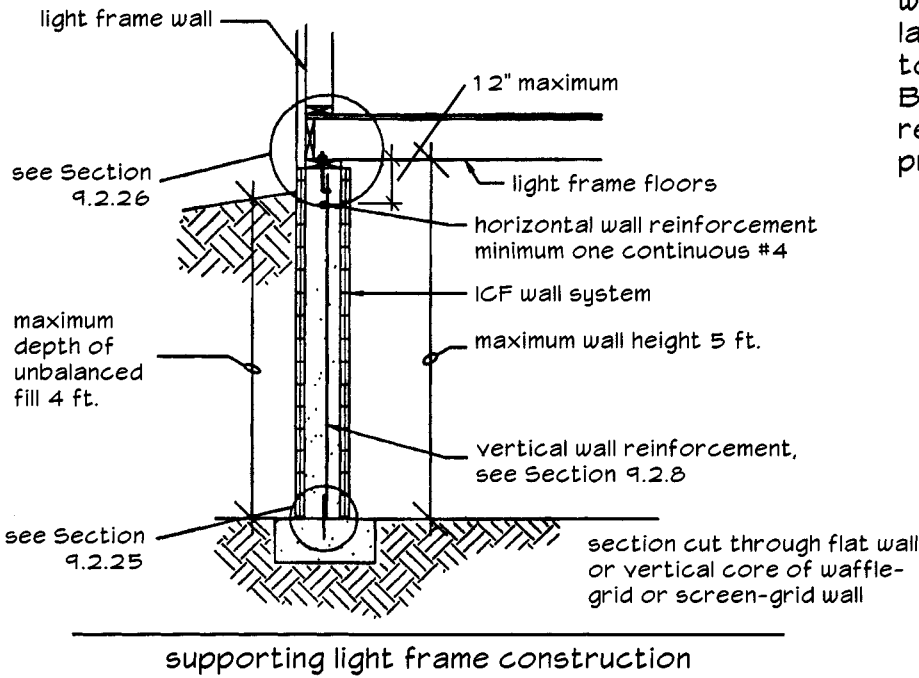
9.2.6 ICF Walls With Slabs-On-Grade



(From NAHB Research Center Prescriptive Method for Insulating Concrete Forms in Residential Construction, Portland Cement Association, 1998)

9.2.7 ICF Crawl Space Walls

ICF crawl space walls must be laterally supported top and bottom. Building codes may require termite protection.



(From NAHB Research Center Prescriptive Method for Insulating Concrete Forms in Residential Construction, Portland Cement Association, 1998)

9.2.8 Vertical Reinforcement for ICF Crawl Space Walls

MINIMUM VERTICAL WALL REINFORCEMENT FOR
 ICF CRAWLSPACE WALLS^{1,2,3,4}

Shape of Concrete Walls	Wall Thickness ⁵ (inches)	Maximum Unbalanced Backfill Height (feet)	Minimum Vertical Reinforcement		
			Maximum Equivalent Fluid Density 30 pcf	Maximum Equivalent Fluid Density 45 pcf	Maximum Equivalent Fluid Density 60 pcf
Flat	3.5 ⁶	4	#4@32"	#3@18"; #4@28"; #5@38"	#3@12"; #4@22"; #5@28"
	5.5	4	#4@48"	#4@48"	#4@48"
	7.5	4	N/R	N/R	N/R
Waffle-Grid	6	4	#4@48"	#4@48"	#3@12"; #4@24"; #5@36"
	8	4	N/R	N/R	N/R
Screen-Grid	6	4	#4@48"	#4@48"	#3@12"; #4@24"; #5@36"

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 pcf = 16.0179 kg/m³

¹ N/R indicates no vertical wall reinforcement is required.

² Applicable only to crawlspace walls 5 feet (1.5 m) or less in height.

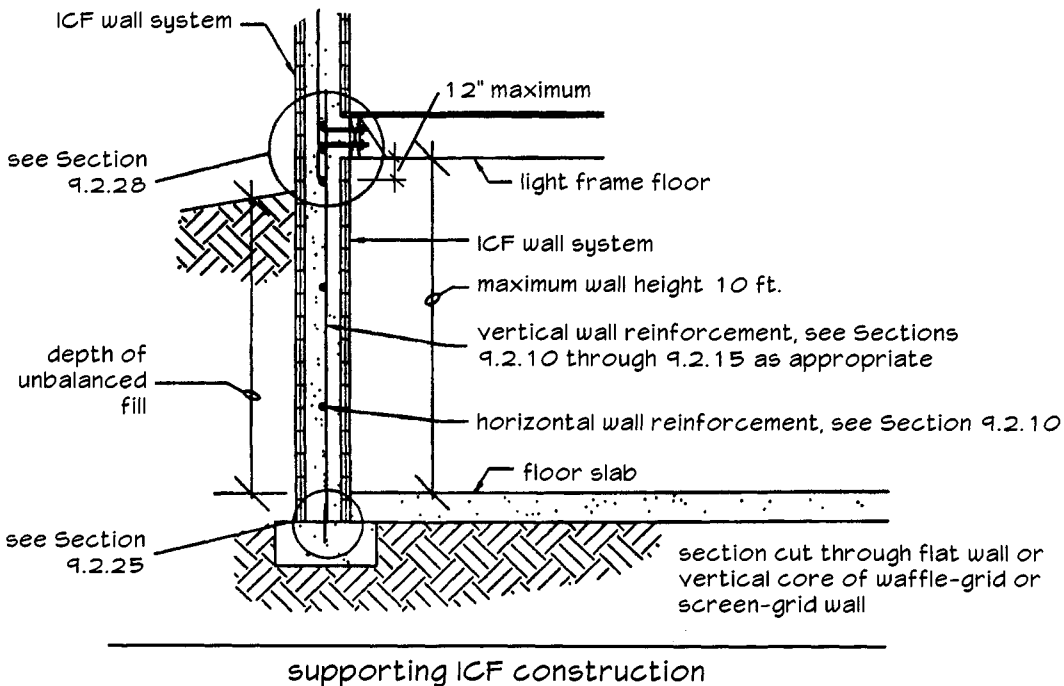
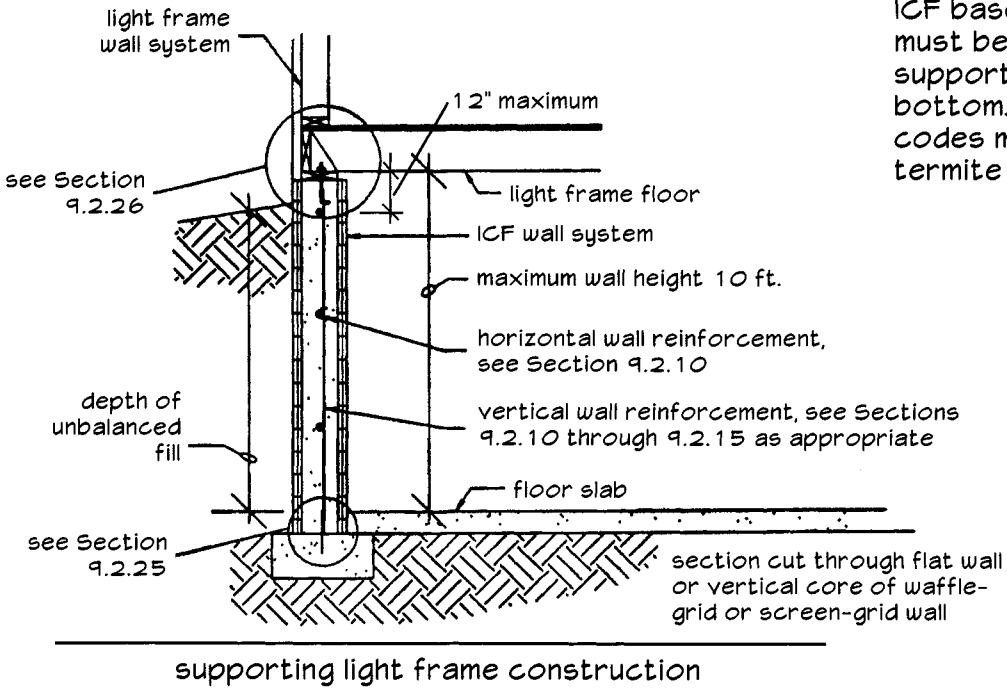
³ Interpolation shall not be permitted.

⁴ Walls shall be laterally supported at the top before backfilling.

⁵ Actual thickness is shown for flat walls while nominal thickness is given for waffle- and screen-grid walls. Refer to Sections 9.2.3 and 9.2.4 for actual waffle- and screen-grid thickness and dimensions.

⁶ Applicable only to one-story construction with floor bearing on top of crawlspace wall.

9.2.9 ICF Basement Walls



(From NAHB Research Center Prescriptive Method for Insulating Concrete Forms in Residential Construction, Portland Cement Association, 1998)

9.2.10 Reinforcement for ICF Basement Walls**MINIMUM HORIZONTAL WALL REINFORCEMENT FOR
ICF BASEMENT WALLS**

Maximum Height of Basement Wall feet (meters)	Location of Horizontal Reinforcement
8 (2.4)	One No. 4 bar within 12 inches (305 mm) of the top of the wall story and one No. 4 bar near mid-height of the wall story
9 (2.7)	One No. 4 bar within 12 inches (305 mm) of the top of the wall story and one No. 4 bar near third points in the wall story
10 (3.0)	One No. 4 bar within 12 inches (305 mm) of the top of the wall story and one No. 4 bar near third points in the wall story

**MINIMUM VERTICAL WALL REINFORCEMENT FOR
5.5-INCH- (140-MM-) THICK FLAT ICF BASEMENT WALLS ^{1,2,3}**

Max. Height of Basement Wall (feet)	Maximum Unbalanced Backfill Height (feet)	Minimum Vertical Reinforcement		
		Maximum Equivalent Fluid Density 30 pcf	Maximum Equivalent Fluid Density 45 pcf	Maximum Equivalent Fluid Density 60 pcf
8	4	#4@48"	#4@48"	#4@48"
	5	#4@48"	#3@12"; #4@22"; #5@32"; #6@40"	#3@8"; #4@14"; #5@20"; #6@26"
	6	#3@12"; #4@22"; #5@30"; #6@40"	#3@8"; #4@14"; #5@20"; #6@24"	#3@6"; #4@10"; #5@14"; #6@20"
	7	#3@8"; #4@14"; #5@22"; #6@26"	#3@5"; #4@10"; #5@14"; #6@18"	#3@4"; #4@6"; #5@10"; #6@14"
9	4	#4@48"	#4@48"	#4@48"
	5	#4@48"	#3@12"; #4@20"; #5@28"; #6@36"	#3@8"; #4@14"; #5@20"; #6@22"
	6	#3@10"; #4@20"; #5@28"; #6@34"	#3@6"; #4@12"; #5@18"; #6@20"	#4@8"; #5@14"; #6@16"
	7	#3@8"; #4@14"; #5@20"; #6@22"	#4@8"; #5@12"; #6@16"	#4@6"; #5@10"; #6@12"
	8	#3@6"; #4@10"; #5@14"; #6@16"	#4@6"; #5@10"; #6@12"	#4@4"; #5@6"; #6@8"
10	4	#4@48"	#4@48"	#4@48"
	5	#4@48"	#3@10"; #4@18"; #5@26"; #6@30"	#3@6"; #4@14"; #5@18"; #6@20"
	6	#3@10"; #4@18"; #5@24"; #6@30"	#3@6"; #4@12"; #5@16"; #6@18"	#3@4"; #4@8"; #5@12"; #6@14"
	7	#3@6"; #4@12"; #5@16"; #6@18"	#3@4"; #4@8"; #5@12"	#4@6"; #5@8"; #6@10"
	8	#3@4"; #4@8"; #5@12"; #6@14"	#4@6"; #5@8"; #6@12"	#4@4"; #5@6"; #6@8"
	9	#3@4"; #4@6"; #5@10"; #6@12"	#4@4"; #5@6"; #6@8"	#5@4"; #6@6"

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 pcf = 16.0179 kg/m³¹ Deflection criterion is $L/240$, where L is the height of the basement wall in inches.² Interpolation shall not be permitted.³ Walls shall be laterally supported at the top before backfilling.

(From NAHB Research Center Prescriptive Method for Insulating Concrete Forms in Residential Construction, Portland Cement Association, 1998)

9.2.11 Vertical Reinforcement for 7.5-in. Thick Flat ICF Basement Walls

**MINIMUM VERTICAL WALL REINFORCEMENT FOR
7.5-INCH- (191-MM-) THICK FLAT ICF BASEMENT WALLS^{1,2,3,4}**

Max. Height of Basement Wall (feet)	Maximum Unbalanced Backfill Height (feet)	Minimum Vertical Reinforcement		
		Maximum Equivalent Fluid Density 30 pcf	Maximum Equivalent Fluid Density 45 pcf	Maximum Equivalent Fluid Density 60 pcf
8	4	N/R	N/R	N/R
	5	N/R	N/R	N/R
	6	N/R	N/R	N/R
	7	N/R	#3@8"; #4@14"; #5@20"; #6@28"	#3@6"; #4@10"; #5@16"; #6@20"
9	4	N/R	N/R	N/R
	5	N/R	N/R	N/R
	6	N/R	N/R	#3@8"; #4@14"; #5@20"; #6@28"
	7	N/R	#3@6"; #4@12"; #5@18"; #6@26"	#3@4"; #4@8"; #5@14"; #6@18"
	8	#3@8"; #4@14"; #5@22"; #6@28"	#3@4"; #4@8"; #5@14"; #6@18"	#3@4"; #4@6"; #5@10"; #6@14"
10	4	N/R	N/R	N/R
	5	N/R	N/R	N/R
	6	N/R	N/R	#3@6"; #4@12"; #5@18"; #6@26"
	7	N/R	#3@6"; #4@12"; #5@18"; #6@24"	#3@4"; #4@8"; #5@12"; #6@18"
	8	#3@6"; #4@12"; #5@20"; #6@26"	#3@4"; #4@8"; #5@12"; #6@16"	#3@4"; #4@6"; #5@8"; #6@12"
	9	#3@6"; #4@10"; #5@14"; #6@20"	#3@4"; #4@6"; #5@10"; #6@12"	#4@4"; #5@6"; #6@10"

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 pcf = 16.0179 kg/m³

¹ N/R indicates no reinforcement is required.

² Deflection criterion is $L/240$, where L is the height of the basement wall in inches.

³ Interpolation shall not be permitted.

⁴ Walls shall be laterally supported at the top before backfilling.

9.2.12 Vertical Reinforcement for 9.5-in. Thick Flat ICF Basement Walls**MINIMUM VERTICAL WALL REINFORCEMENT FOR
9.5-INCH- (241-MM-) THICK FLAT ICF BASEMENT WALLS^{1,2,3,4}**

Max. Height of Basement Wall (feet)	Maximum Unbalanced Backfill Height (feet)	Minimum Vertical Reinforcement		
		Maximum Equivalent Fluid Density 30 pcf	Maximum Equivalent Fluid Density 45 pcf	Maximum Equivalent Fluid Density 60 pcf
8	4	N/R	N/R	N/R
	5	N/R	N/R	N/R
	6	N/R	N/R	N/R
	7	N/R	N/R	N/R
9	4	N/R	N/R	N/R
	5	N/R	N/R	N/R
	6	N/R	N/R	N/R
	7	N/R	N/R	#3@6"; #4@12"; #5@18"; #6@26"
	8	N/R	#3@6"; #4@12"; #5@18"; #6@26"	#3@4"; #4@8"; #5@14"; #6@18"
10	4	N/R	N/R	N/R
	5	N/R	N/R	N/R
	6	N/R	N/R	#3@10"; #4@18"; #5@26"; #6@36"
	7	N/R	N/R	#3@6"; #4@10"; #5@18"; #6@24"
	8	N/R	#3@6"; #4@12"; #5@16"; #6@24"	#3@4"; #4@8"; #5@12"; #6@16"
	9	N/R	#3@4"; #4@8"; #5@12"; #6@18"	#3@4"; #4@6"; #5@10"; #6@12"

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 pcf = 16.0179 kg/m³

- ¹ N/R indicates no vertical wall reinforcement is required.
- ² Deflection criterion is $L/240$, where L is the height of the basement wall in inches.
- ³ Interpolation shall not be permitted.
- ⁴ Walls shall be laterally supported at the top before backfilling.

9.2.13 Vertical Reinforcement for 6-in. Waffle-Grid ICF Basement Walls**MINIMUM VERTICAL WALL REINFORCEMENT FOR
6-INCH (152-MM) WAFFLE-GRID ICF BASEMENT WALLS^{1,2,3,4,5}**

Max. Height of Basement Wall (feet)	Maximum Unbalanced Backfill Height (feet)	Minimum Vertical Reinforcement		
		Maximum Equivalent Fluid Density 30 pcf	Maximum Equivalent Fluid Density 45 pcf	Maximum Equivalent Fluid Density 60 pcf
8	4	#4@48"	#3@12"; #4@24"; #5@24"	#3@12"; #4@12"
	5	#3@12"; #4@12"; #5@24"	#4@12"; #5@12"	#7@12"
	6	#4@12"; #5@12"	#7@12"	#7@12"
	7	#6@12"	Design Required	Design Required
9	4	#4@48"	#3@12"; #4@12"; #5@24"	#3@12"; #4@12"
	5	#3@12"; #4@12"	#4@12"; #5@12"	#7@12"
	6	#5@12"; #6@12"	Design Required	Design Required
	7	Design Required	Design Required	Design Required
	8	Design Required	Design Required	Design Required
10	4	#4@48"	#4@12"; #5@12"	#5@12"; #6@12"
	5	#3@12"; #4@12"	#7@12"	Design Required
	6	#7@12"	Design Required	Design Required
	7	Design Required	Design Required	Design Required
	8	Design Required	Design Required	Design Required
	9	Design Required	Design Required	Design Required

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 pcf = 16.0179 kg/m³

¹ N/R indicates no vertical wall reinforcement is required.

² Deflection criterion is $L/240$, where L is the height of the basement wall in inches.

³ Interpolation shall not be permitted.

⁴ Nominal thickness is given. Refer to Section 9.2.3 for actual wall thickness.

⁵ Walls shall be laterally supported at the top before backfilling.

9.2.14 Vertical Reinforcement for 8-in. Waffle-Grid ICF Basement Walls**MINIMUM VERTICAL WALL REINFORCEMENT FOR
8-INCH (203-MM) WAFFLE-GRID ICF BASEMENT WALLS^{1,2,3,4,5}**

Max. Height of Basement Wall (feet)	Maximum Unbalanced Backfill Height (feet)	Minimum Vertical Reinforcement		
		Maximum Equivalent Fluid Density 30 pcf	Maximum Equivalent Fluid Density 45 pcf	Maximum Equivalent Fluid Density 60 pcf
8	4	N/R	N/R	N/R
	5	N/R	#3@12"; #4@24"; #5@36"	#3@12"; #4@12"; #5@24"
	6	#3@12"; #4@24"; #5@36"	#4@12"; #5@24"	#4@12"; #5@12"
	7	#3@12"; #4@12"; #5@12"; #6@24"	#4@12"; #5@12"	#5@12"; #6@12"
9	4	N/R	N/R	N/R
	5	N/R	#3@12"; #4@12"; #5@24"	#3@12"; #4@12"; #5@24"
	6	#3@12"; #4@24"; #5@24"	#4@12"; #5@12"	#4@12"; #5@12"
	7	#4@12"; #5@24"; #6@24"	#5@12"; #6@12"	#5@12"; #6@12"
	8	#4@12"; #5@12"	#5@12"; #6@12"	#8@12"
10	4	N/R	#3@12"; #4@24"; #5@24"; #6@36"	#3@12"; #4@12"; #5@24"
	5	N/R	#3@12"; #4@24"; #5@24"; #6@36"	#4@12"; #5@24"
	6	#3@12"; #4@12" #5@24"	#4@12"; #5@12"	#5@12"; #6@12"
	7	#4@12"; #5@12"	#5@12"; #6@12"	#6@12"; #7@12"
	8	#4@12"; #5@12"	#6@12"; #7@12"	#8@12"
	9	#5@12"; #6@12"	#8@12"	#8@12"

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 pcf = 16.0179 kg/m³

¹ N/R indicates no vertical wall reinforcement is required.

² Deflection criterion is $L/240$, where L is the height of the basement wall in inches.

³ Interpolation shall not be permitted.

⁴ Nominal thickness is given. Refer to Section 9.2.3 for actual wall thickness.

⁵ Walls shall be laterally supported at the top before backfilling.

9.2.15 Vertical Reinforcement for 6-in. Screen-Grid ICF Basement Walls**MINIMUM VERTICAL WALL REINFORCEMENT FOR
6-INCH (152-MM) SCREEN-GRID ICF BASEMENT WALLS^{1,2,3,4}**

Max. Height of Basement Wall (feet)	Maximum Unbalanced Backfill Height (feet)	Minimum Vertical Reinforcement		
		Maximum Equivalent Fluid Density 30 pcf	Maximum Equivalent Fluid Density 45 pcf	Maximum Equivalent Fluid Density 60 pcf
8	4	#4@48"	#3@12"; #4@24"; #5@36"	#3@12"; #4@12"; #5@24"
	5	#3@12"; #4@24"; #5@24"	#3@12"; #4@12"	#4@12"; #5@12"
	6	#4@12"; #5@12"	#5@12"; #6@12"	#7@12"
	7	#4@12"; #5@12"	#7@12"	Design Required
9	4	#4@48"	#3@12"; #4@24"; #5@24"	#3@12"; #4@12"; #5@12"; #6@24"
	5	#3@12"; #4@12"; #5@24"	#4@12"; #5@12"	#7@12"
	6	#4@12"; #5@12"	#7@12"	#7@12"
	7	#7@12"	Design Required	Design Required
	8	#7@12"	Design Required	Design Required
10	4	#4@48"	#3@12"; #4@12"; #5@24"; #6@24"	#3@12"; #4@12"
	5	#3@12"; #4@12"	#4@12"; #5@12"	#7@12"
	6	#4@12"; #5@12"	Design Required	Design Required
	7	#7@12"	Design Required	Design Required
	8	Design Required	Design Required	Design Required
	9	Design Required	Design Required	Design Required

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 pcf = 16.0179 kg/m³

¹ Deflection criterion is $L/240$, where L is the height of the basement wall in inches.

² Interpolation shall not be permitted.

³ Nominal thickness is given. Refer to Section 9.2.4 for actual wall thickness.

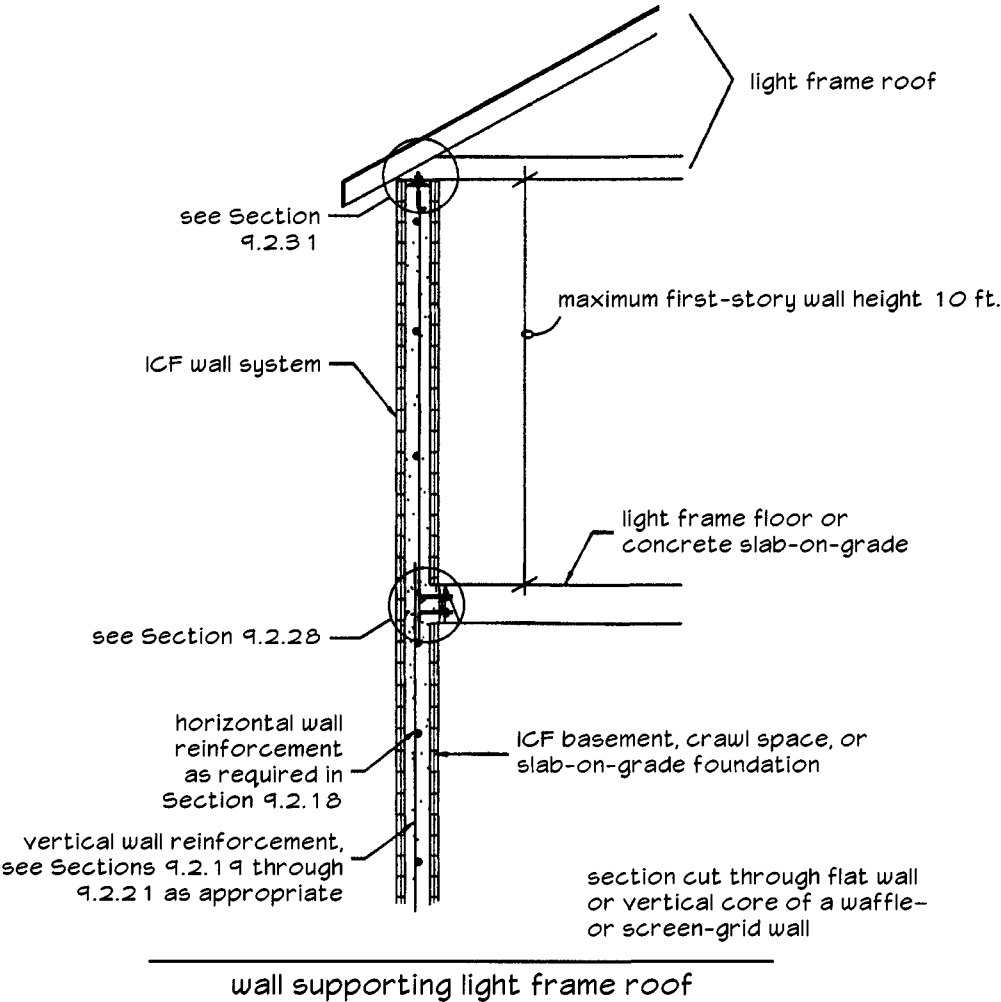
⁴ Walls shall be laterally supported at the top before backfilling.

9.2.16 Above-Grade ICF Walls

Above-grade walls formed with ICF are shown below and on the following page. These walls must be laterally supported by floor and roof framing. The minimum wall thickness is at least that of the wall story above. Reinforcement across cold joints and adjacent to openings is required as for ICF foundation walls.

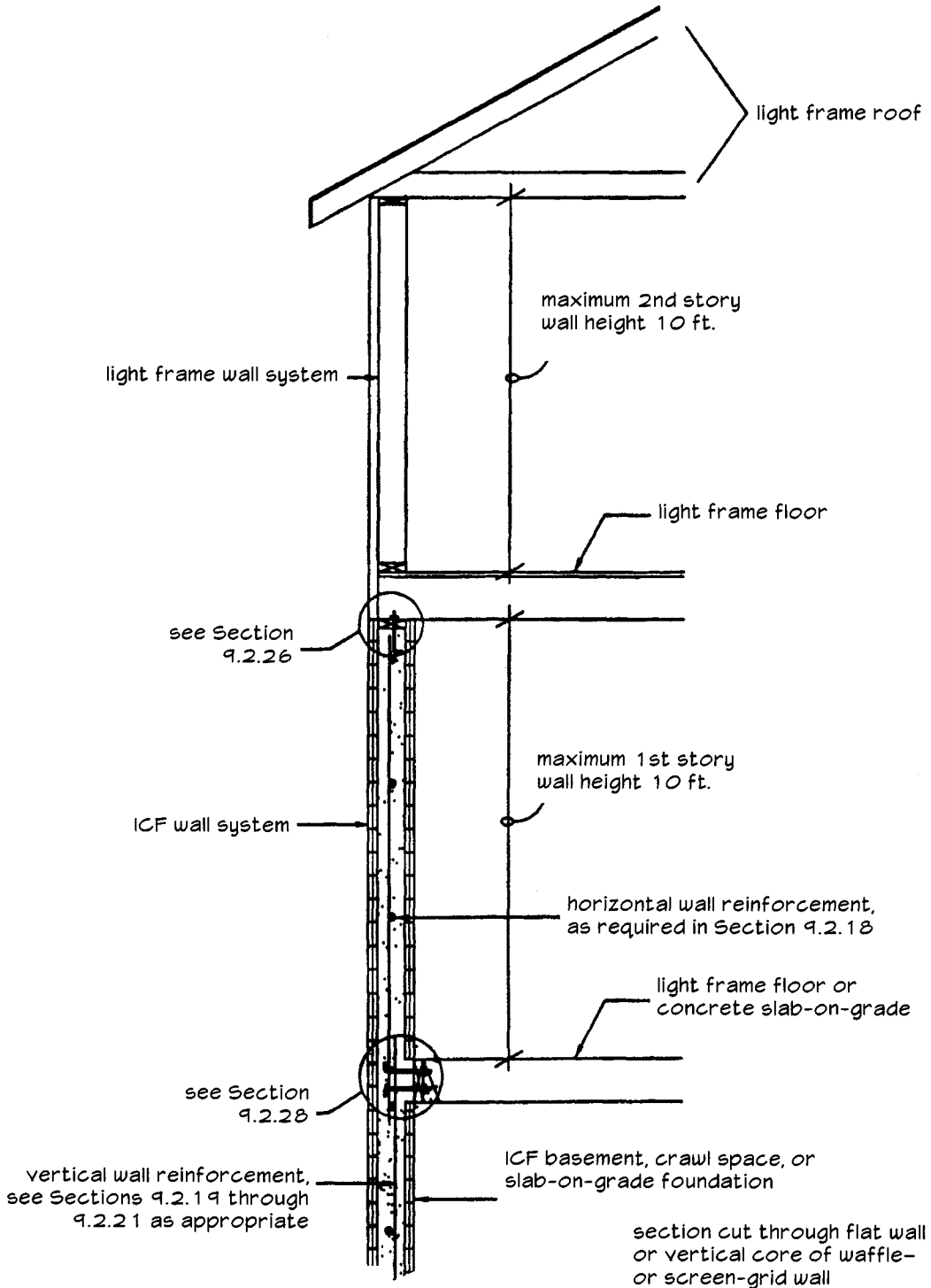
Where wind speeds exceed 90 mph, all vertical wall reinforcement in the top-most ICF story shall be terminated with a 90-degree bend with minimum 24-inch length parallel to the horizontal wall reinforcement and within 4 inches of the top surface of ICF. Also, all horizontal wall reinforcement shall be terminated at building corners with a bend resulting in a minimum 24-inch long embedment into the intersecting wall. Standard 90-degree hooks may be used in lieu of bending the wall reinforcement if a minimum 24-inch long lap splice is provided.

Where ICF foundation walls or above-grade walls enclose habitable space, the interior surface of rigid foam plastic shall be covered with minimum of 1/2-inch gypsum board. Building codes may also require a vapor retarder. The exterior surface of rigid foam plastic shall be protected from sunlight and physical damage by covering with an approved material. The exterior surface of all ICFs shall be covered to provide an adequate barrier against weather. Building codes may require an air barrier.



(From NAHB Research Center Prescriptive Method for Insulating Concrete Forms in Residential Construction, Portland Cement Association, 1998)

9.2.17 Above-Grade ICF Wall With 2nd Story Light Frame Construction



wall supporting light frame 2nd story and roof

(From NAHB Research Center Prescriptive Method for Insulating Concrete Forms in Residential Construction, Portland Cement Association, 1998)

9.2.18
Horizontal Reinforcement for Above-Grade ICF Walls

MINIMUM HORIZONTAL WALL REINFORCEMENT FOR
 ICF ABOVE-GRADE WALLS

ICF Wall Type and Minimum Wall Thickness inches (mm) ¹	Maximum Height of Wall Story feet (meters)	Location of Horizontal Reinforcement
Flat 3.5 (89)	8 (2.4)	One No. 4 bar within 12 inches (305 mm) of the top of the wall story and one No. 4 bar near third points in the wall story
	9 (2.7)	One No. 4 bar within 12 inches (305 mm) of the top of the wall story and one No. 4 bar near third points in the wall story
	10 (3.0)	One No. 4 bar within 12 inches (305 mm) of the top of the wall story and one No. 4 bar near fourth points in the wall story
Flat 5.5 (140) or Waffle-Grid 6 (152) or Screen-Grid 6 (152)	8 (2.4)	One No. 4 bar within 12 inches (305 mm) of the top of the wall story and one No. 4 bar near mid-height of the wall story
	9 (2.7)	One No. 4 bar within 12 inches (305 mm) of the top of the wall story and one No. 4 bar near third points in the wall story
	10 (3.0)	One No. 4 bar within 12 inches (305 mm) of the top of the wall story and one No. 4 bar near third points in the wall story

¹ Actual thickness is shown for flat walls while nominal thickness is given for waffle- and screen-grid walls. Refer to Sections 9.2.3 and 9.2.4 for actual waffle- and screen-grid thickness and dimensions.

(From NAHB Research Center Prescriptive Method for Insulating Concrete Forms in Residential Construction, Portland Cement Association, 1998)

9.2.19 Vertical Reinforcement for Flat ICF Above-Grade Walls

**MINIMUM VERTICAL WALL REINFORCEMENT
FOR FLAT ICF ABOVE-GRADE WALLS^{1,2,3}**

Max. Wind Speed (mph)	Maximum Wall Height per Story (feet)	Minimum Vertical Reinforcement					
		Supporting Light-Frame Roof Only		Supporting Light-Frame Second Story and Roof		Supporting ICF Second Story and Light-Frame Roof	
		Minimum Wall Thickness (inches)					
		3.5	5.5	3.5	5.5	3.5	5.5
70	8	#4@32"	N/R	#4@32"	N/R	#4@32"	N/R
	9	#4@32"	N/R	#4@32"	N/R	#3@20"; #4@24"; #5@26"	N/R
	10	#4@32"	N/R	#4@32"	N/R	#3@20"; #4@24"; #5@26"	N/R
80	8	#4@32"	N/R	#4@32"	N/R	#4@32"	N/R
	9	#4@32"	N/R	#3@28"; #4@32"; #5@34"	N/R	#3@14"; #4@18"; #5@20"	N/R
	10	#3@16"; #4@26"; #5@34"	N/R	#3@16"; #4@26"; #5@34"	N/R	Design Required	N/R
90	8	#4@32"	#4@96"	#4@32"	#4@96"	#4@32"	#4@96"
	9	#3@16"; #4@26"; #5@34"	#4@96"	#3@18"; #4@20"; #5@22"	#4@96"	Design Required	#4@96"
	10	Design Required	#4@96"	#3@10"; #4@12"; #5@14"	#4@96"	Design Required	#4@96"
100	8	#3@18"; #4@30"; #5@40"	#4@96"	#3@18"; #4@30"; #5@40"	#4@96"	#4@32"	#4@96"
	9	#3@12"; #4@22"; #5@30"	#4@96"	#3@12"; #4@16"; #5@16"	#4@96"	Design Required	#4@96"
	10	Design Required	#4@96"	Design Required	#4@96"	Design Required	#4@96"
110	8	#3@14"; #4@20"; #5@24"	#4@96"	#3@14"; #4@18"; #5@20"	#4@96"	Design Required	#4@96"
	9	Design Required	#4@96"	Design Required	#4@96"	Design Required	#4@96"
	10	Design Required	#4@96"	Design Required	#4@96"	Design Required	#4@96"

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 mph = 1.6093 km/hr

¹ N/R indicates no vertical wall reinforcement is required.

² Deflection criterion is $L/240$, where L is the height of the wall story in inches.

³ Interpolation shall not be permitted.

9.2.20 Vertical Reinforcement for Waffle-Grid ICF Above-Grade Walls

**MINIMUM VERTICAL WALL REINFORCEMENT
FOR WAFFLE-GRID ICF ABOVE-GRADE WALLS ^{1,2,3}**

Max. Wind Speed (mph)	Maximum Wall Height per Story (feet)	Minimum Vertical Reinforcement					
		Supporting Light-Frame Roof Only		Supporting Light-Frame Second Story and Roof		Supporting ICF Second Story and Light-Frame Roof	
		Minimum Wall Thickness ⁴ (inches)					
		6	8	6	8	6	8
70	8	N/R	N/R	N/R	N/R	N/R	N/R
	9	N/R	N/R	N/R	N/R	N/R	N/R
	10	N/R	N/R	N/R	N/R	N/R	N/R
80	8	N/R	N/R	N/R	N/R	N/R	N/R
	9	N/R	N/R	N/R	N/R	N/R	N/R
	10	N/R	N/R	N/R	N/R	N/R	N/R
90	8	#4@96"	#4@96"	#4@96"	#4@96"	#4@96"	#4@96"
	9	#4@96"	#4@96"	#4@96"	#4@96"	#4@96"	#4@96"
	10	#3@12"; #4@24"; #5@36"	#4@96"	#3@12"; #4@24"; #5@24"	#4@96"	#3@12"; #4@24"; #5@24"	#4@96"
100	8	#4@96"	#4@96"	#4@96"	#4@96"	#4@96"	#4@96"
	9	#3@12"; #4@24"; #5@36"	#4@96"	#3@12"; #4@24"; #5@36"	#4@96"	#3@12"; #4@24"; #5@24"	#4@96"
	10	#3@12"; #4@24"; #5@24"	#4@96"	#3@12"; #4@24"; #5@24"	#4@96"	#3@12"; #4@12"	#4@96"
110	8	#3@12"; #4@24"; #5@36"	#4@96"	#3@12"; #4@24"; #5@36"	#4@96"	#3@12"; #4@24"; #5@24"	#4@96"
	9	#3@12"; #4@24"; #5@24"	#4@96"	#3@12"; #4@24"; #5@24"	#4@96"	#3@12"; #4@12"	#4@96"
	10	#3@12"; #4@12"; #5@24"	#4@96"	Design Required	#4@96"	Design Required	#4@96"

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 mph = 1.6093 km/hr

¹ N/R indicates no vertical wall reinforcement is required.

² Deflection criterion is $L/240$, where L is the height of the wall story in inches.

³ Interpolation shall not be permitted.

⁴ Nominal thickness is given. Refer to Section 9.2.3 for actual thickness.

9.2.21 Vertical Reinforcement for Screen-Grid ICF Above-Grade Walls**MINIMUM VERTICAL WALL REINFORCEMENT
FOR SCREEN-GRID ICF ABOVE-GRADE WALLS^{1,2,3}**

Max. Wind Speed (mph)	Maximum Wall Height per Story (feet)	Minimum Vertical Reinforcement		
		Supporting Light-Frame Roof Only	Supporting Light-Frame Second Story and Roof	Supporting ICF Second Story and Light-Frame Roof
		Minimum Wall Thickness ⁴ (inches)		
		6	6	6
70	8	N/R	N/R	N/R
	9	N/R	N/R	N/R
	10	N/R	N/R	N/R
80	8	N/R	N/R	N/R
	9	N/R	N/R	N/R
	10	N/R	N/R	N/R
90	8	#4@96"	#4@96"	#4@96"
	9	#4@96"	#4@96"	#4@96"
	10	#3@12"; #4@24"; #5@36"	#3@12"; #4@24"; #5@36"	#4@96"
100	8	#4@96"	#4@96"	#4@96"
	9	#3@24"; #4@36"	#3@24"; #4@36"; #5@36"	#4@96"
	10	#3@12"; #4@24"; #5@36"	#4@24"; #5@24"	#3@12"; #4@24"; #5@24"
110	8	#3@24"; #4@36"; #5@48"	#3@24"; #4@36"; #5@48"	#4@96"
	9	#3@12"; #4@24"; #5@36"	#3@12"; #4@24"; #5@36"	#3@12"; #4@24"; #5@24"
	10	#3@12"; #4@12"	#4@24"; #5@24"	#3@12"; #4@12"; #5@24"

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 mph = 1.6093 km/hr

¹ N/R indicates no vertical wall reinforcement is required.

² Deflection criterion is $L/240$, where L is the height of the wall story in inches.

³ Interpolation shall not be permitted.

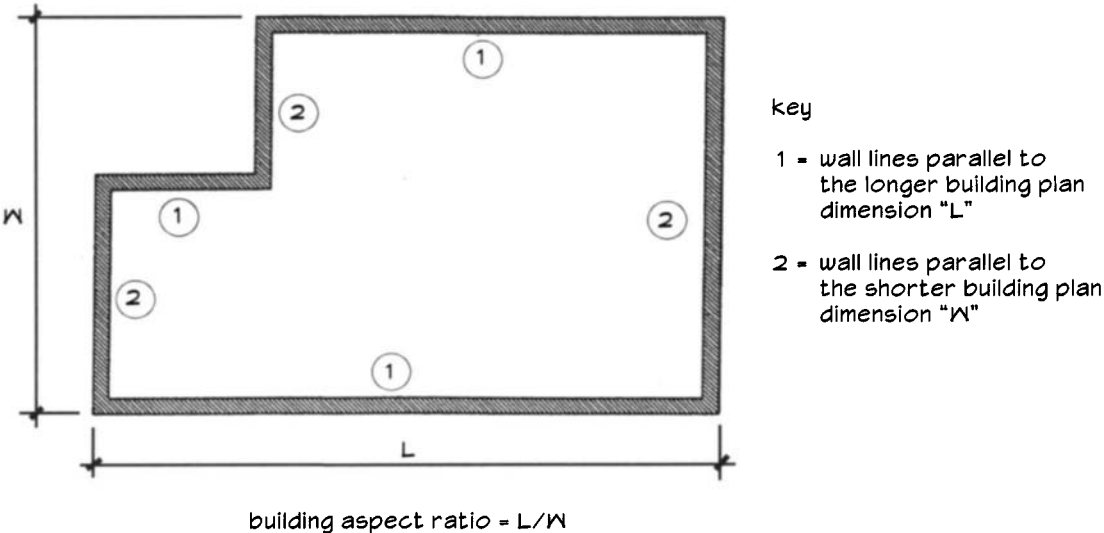
⁴ Nominal thickness is shown. Refer to Section 9.2.4 for actual wall thickness.

(From NAHB Research Center Prescriptive Method for Insulating Concrete Forms in Residential Construction, Portland Cement Association, 1998)

9.2.22 ICF Wall Opening Requirements

Exterior ICF walls must have a minimum percentage of solid wall length, as defined by Sections 9.2.23 and 9.2.24. Only wall segments of minimum length 24 inches may be included toward satisfying the minimum solid wall length requirement. The maximum spacing of wall segments at least 24 inches in length shall be 18 feet on center, with a minimum wall segment of 24 inches in length occurring at all interior and exterior corners of exterior walls.

Wall openings shall have a minimum depth of concrete above the opening of 8 inches in flat and waffle-grid ICF systems and 12 inches in screen-grid ICF walls. In waffle- and screen-grid walls, the openings shall be located so that concrete vertical cores of minimum cross section equal to $T \times 0.5W$ occur along each side of the opening. Openings in ICF walls require special reinforcement in addition to the wall reinforcement. Those requirements are outside the scope of this manual, but may be found in *Prescriptive Method for Insulating Concrete Forms in Residential Construction*, Portland Cement Association, 1998.



(From NAHB Research Center Prescriptive Method for Insulating Concrete Forms in Residential Construction, Portland Cement Association, 1998)

9.2.23 Minimum Percentage of Solid Wall Length in ICF Walls**MINIMUM PERCENTAGE OF SOLID WALL LENGTH
ALONG EXTERIOR WALL LINES¹**

Exterior Wall Line Category	Site Wind and Seismic Conditions ^{2,3}	
	All Wind Speeds and Seismic Zones 0 and 1	All Wind Speeds and Seismic Zone 2
Parallel to the shorter building dimension or end wall, W	<p>The minimum percentage of solid wall length shall be the larger of the following:</p> <ul style="list-style-type: none"> - The base percentage of solid wall length based on wind speed in Section 9.2.24 multiplied by the factor from the table below - 15% for walls supporting a light frame roof, or 20% for walls supporting a ICF or light-frame second story and light frame roof 	<p>The minimum percentage of solid wall length shall be the larger of the following:</p> <ul style="list-style-type: none"> - The base percentage of solid wall length based on wind speed in Section 9.2.24 multiplied by the factor from the table below - The base percentage of solid wall length for Seismic Zone 2 in Section 9.2.24 without adjustment - 15% for walls supporting a light frame roof, or 20% for walls supporting a ICF or light frame second story and light frame roof
Parallel to the longer building dimension or sidewall, L	<p>The minimum percentage of solid wall length shall be the larger of the following:</p> <ul style="list-style-type: none"> - The base percentage of solid wall length based on wind speed in Section 9.2.24 multiplied by the factor from the table below - 15% for walls supporting a light frame roof, or 20% for walls supporting a ICF or light frame second story and light frame roof 	<p>The minimum percentage of solid wall length shall be the larger of the following:</p> <ul style="list-style-type: none"> - The base percentage of solid wall length based on wind speed in Section 9.2.24 multiplied by the factor from the table below - The base percentage of solid wall length for Seismic Zone 2 in Section 9.2.24 without adjustment - 15% for walls supporting a light frame roof, or 20% for walls supporting a ICF or light frame second story and light-frame roof

1 Refer to Section 9.2.22 for definitions of L, W, and building aspect ratio.

2 The percent of solid wall in Seismic Zones 3 and 4, regardless of wind speed, shall be determined by an approved design.

3 In no case shall the spacing of wall segments at least 24 in. in length exceed 18 ft. on center.

**ADJUSTMENT FACTORS FOR USE
WITH SECTION 9.2.24¹**

Building Aspect Ratio ²	Adjustment Factor	
	Parallel to the Shorter Building Dimension or Endwall, W	Parallel to the Longer Building Dimension or Sidewall, L
2.0	1.0	0.25
1.8	0.9	0.30
1.6	0.8	0.35
1.4	0.7	0.40
1.2	0.6	0.45
1.0	0.5	0.50

¹ Linear interpolation between building aspect ratios is permitted.

² Refer to Section 9.2.22 for definition of building aspect ratio.

9.2.24 Base Percentage of Solid Wall Length in ICF Walls

BASE PERCENTAGE OF SOLID WALL LENGTH
ALONG EXTERIOR WALL LINES^{1,2,3}

ICF Wall Type and Minimum Wall Thickness (inches) ⁴	Max. Roof Slope	Base Solid Wall Length (percent)									
		Wall Supporting Light-Frame Roof Only					Wall Supporting ICF or Light-Frame Second Story and Light-Frame Roof				
		Maximum Wind Speed (mph)									
		70	80	90	100	110	70	80	90	100	110
Flat 3.5	3:12	15	15	15	15	20	30	35	40	50	55
	6:12	15	15	20	20	25	30	40	50	55	60
	9:12	20	25	30	40	45	45	60	70	85	95
	12:12	25	35	40	50	60	50	65	80	95	100
Flat 5.5	3:12	15	15	15	15	15	20	25	30	40	40
	6:12	15	15	15	15	20	20	30	35	40	45
	9:12	15	15	20	25	30	35	45	50	60	70
	12:12	20	20	25	35	40	35	50	55	70	75
Flat 7.5	3:12	15	15	15	15	15	20	20	25	30	30
	6:12	15	15	15	15	15	20	20	25	30	35
	9:12	15	15	15	20	25	25	30	40	45	50
	12:12	15	20	20	25	30	30	35	40	50	55
Waffle-Grid 6	3:12	15	15	15	15	20	25	30	35	45	50
	6:12	15	15	20	20	25	25	35	45	50	55
	9:12	20	20	25	35	40	40	55	60	75	85
	12:12	25	30	35	45	50	45	60	70	85	90
Waffle-Grid 8	3:12	15	15	15	15	15	20	25	30	35	35
	6:12	15	15	15	15	20	20	25	30	35	40
	9:12	15	15	20	25	30	30	40	45	55	60
	12:12	20	20	25	30	35	35	40	50	60	65
Screen-Grid 6	3:12	15	15	20	20	25	30	40	45	55	60
	6:12	15	20	25	30	35	30	40	50	60	70
	9:12	25	30	45	50	65	50	65	80	90	100
	12:12	35	40	55	65	80	55	70	85	100	100
Seismic Zone 2											
Flat, 3.5	N/A	20					35				
Flat, 5.5	N/A	15					30				
Flat, 7.5	N/A	15					25				
Waffle-Grid, 6	N/A	20					35				
Waffle-Grid, 8	N/A	20					30				
Screen-Grid, 6	N/A	25					45				

For SI: 1 inch = 25.4 mm; 1 mph = 1.6093 km/hr

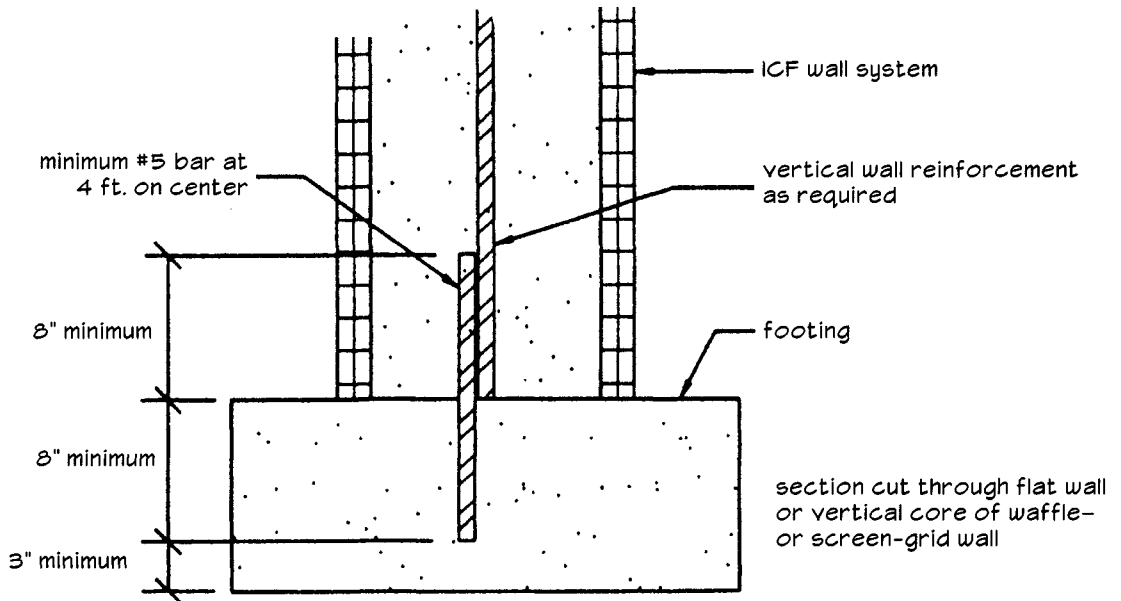
¹ Linear interpolation between roof slopes shall be permitted.
² Base percentages are applicable for maximum 10-foot (3.0-m) wall story heights.
³ N/A indicates not applicable.
⁴ Actual thickness is shown for flat walls while nominal thickness is given for waffle- and screen-grid walls.
Refer to Sections 9.2.3 and 9.2.4 for actual waffle- and screen-grid wall thickness and dimensions.

(From NAHB Research Center Prescriptive Method for Insulating Concrete Forms in Residential Construction, Portland Cement Association, 1998)

9.2.25 ICF Foundation Wall-To-Footing Connection

Dowels are required between ICF foundation wall and footing in accordance with the detail below, unless one of the following conditions exists:

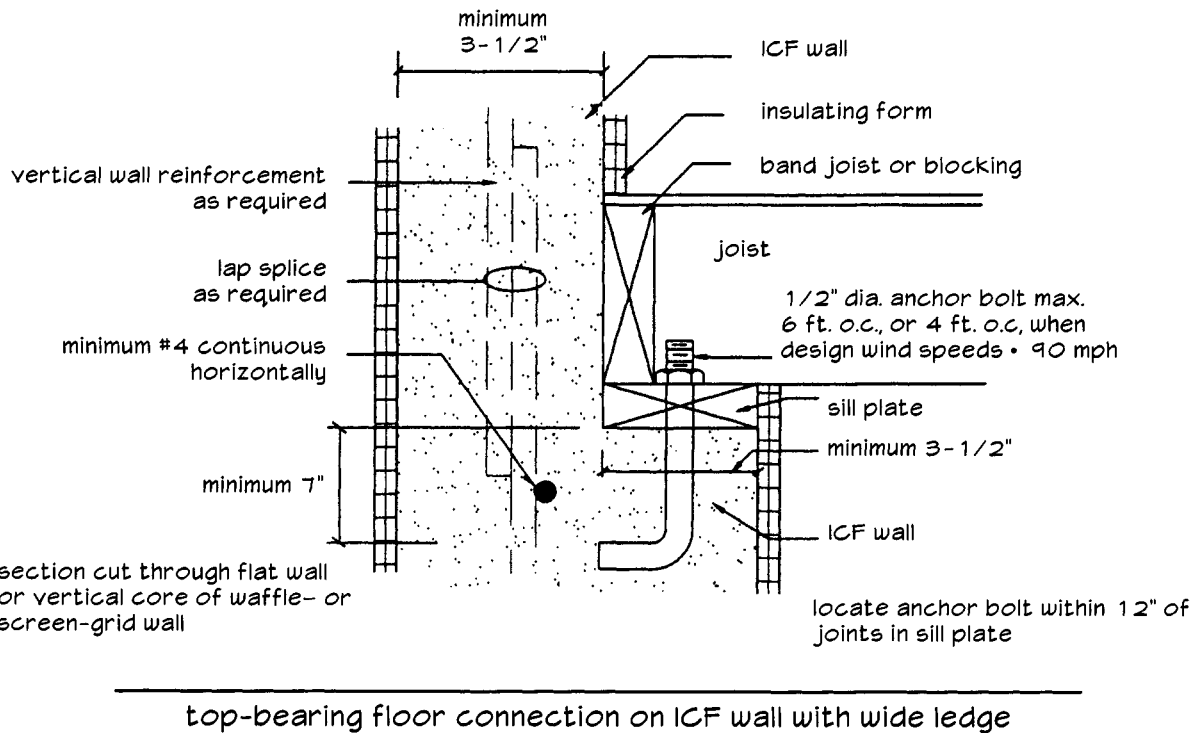
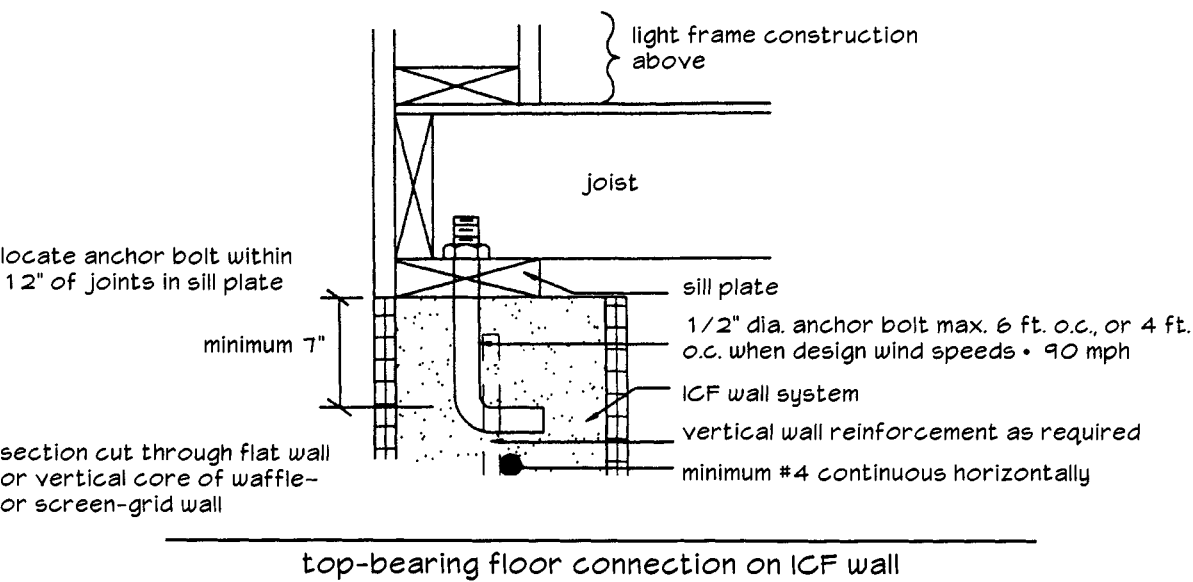
- Unbalanced backfill height does not exceed 4 feet.
- Interior floor slab is installed in accordance with Section 9.2.9 prior to backfilling.
- Temporary bracing is provided at the bottom of the foundation wall prior to backfilling and remains in place during construction until either the interior floor slab is installed in accordance with Section 9.2.9 or the wall is backfilled on both sides.



note: dowel may be omitted when the vertical wall reinforcement extends into the footing at least 8 in. at a maximum spacing of 4 ft. on center

foundation wall-to-footing connection

9.2.26 Top-Bearing Floor Connections on ICF Wall



(From NAHB Research Center Prescriptive Method for Insulating Concrete Forms in Residential Construction, Portland Cement Association, 1998)

9.2.27 Anchor Bolts for Side Connection of Floor to ICF Walls

The table below provides the required anchor bolt sizes and spacing for side-bearing floor connections to ICF walls. Section 9.2.28 illustrates side-bearing connections for flat ICF walls (5.5-inches thick minimum) and waffle- or screen-grid walls (6 inches minimum thickness). Section 9.2.29 applies to flat ICF walls of minimum thickness 3.5 inches.

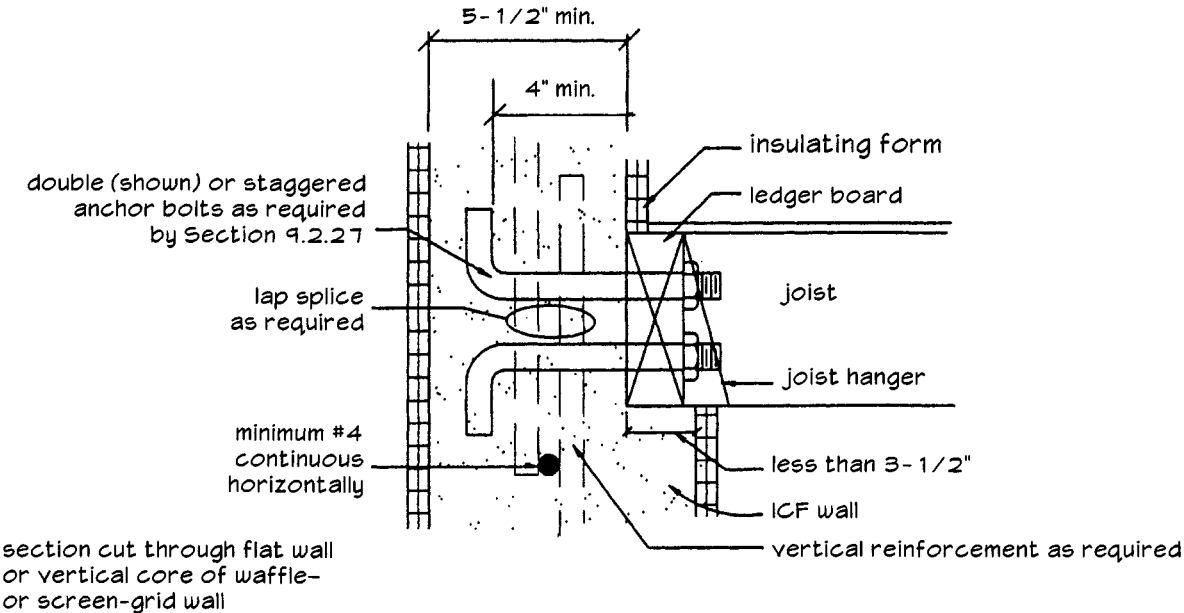
FLOOR LEDGER-ICF WALL CONNECTION (SIDE-BEARING CONNECTION) REQUIREMENTS^{1,2,3}

Maximum Floor Clear Span ⁴ (feet)	Maximum Anchor Bolt Spacing ⁵ (inches)			
	Staggered 1/2-Inch- Diameter Anchor Bolts	Staggered 5/8-Inch- Diameter Anchor Bolts	Two 1/2-Inch- Diameter Anchor Bolts ⁶	Two 5/8-Inch- Diameter Anchor Bolts ⁶
8	18	20	36	40
10	16	18	32	36
12	14	18	28	36
14	12	16	24	32
16	10	14	20	28
18	9	13	18	26
20	8	11	16	22
22	7	10	14	20
24	7	9	14	18
26	6	9	12	18
28	6	8	12	16
30	5	8	10	16
32	5	7	10	14

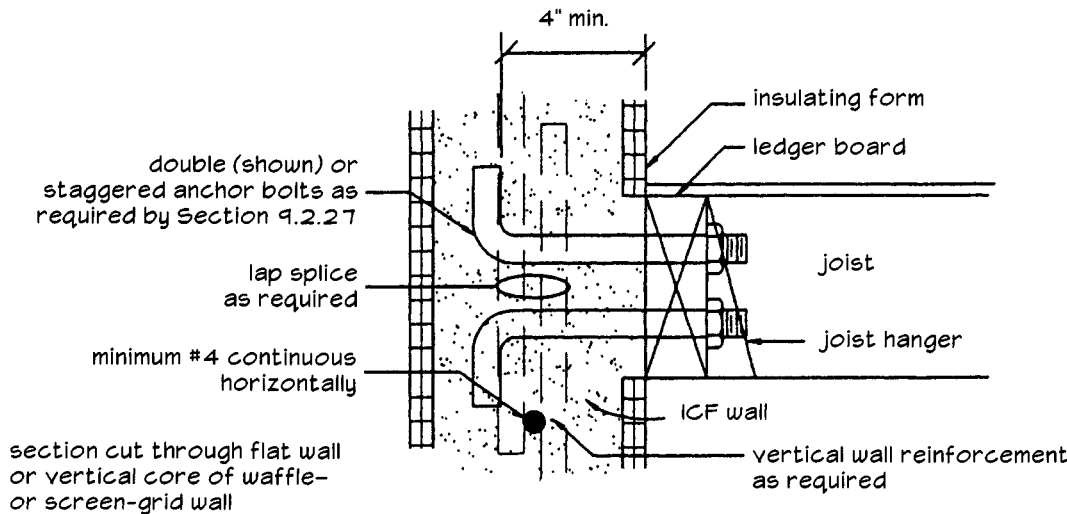
For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm

- ¹ Minimum ledger board nominal depth shall be 8 inches (203 mm). The thickness of the ledger board shall be a minimum of 2 inches (51 mm). Thickness of ledger board is in nominal lumber dimensions. Ledger board shall be minimum No. 2 Grade.
- ² Minimum edge distance shall be 2 inches (51 mm) for 1/2-inch- (13-mm-) diameter anchor bolts and 2.5 inches (64 mm) for 5/8-inch- (16-mm-) diameter anchor bolts.
- ³ Interpolation is permitted between floor spans.
- ⁴ Floor span corresponds to the clear span of the floor structure (i.e., joists or trusses) spanning between load-bearing walls or beams.
- ⁵ Anchor bolts shall extend through the ledger to the center of the flat ICF wall thickness or the center of the horizontal or vertical core thickness of the waffle-grid or screen-grid ICF wall system.
- ⁶ Minimum vertical distance between bolts shall be 1.5 inches (38 mm) for 1/2-inch- (13-mm-) diameter anchor bolts and 2 inches (51 mm) for 5/8-inch- (16-mm-) diameter anchor bolts.

9.2.28 Side-Bearing Floor Connections to ICF Walls



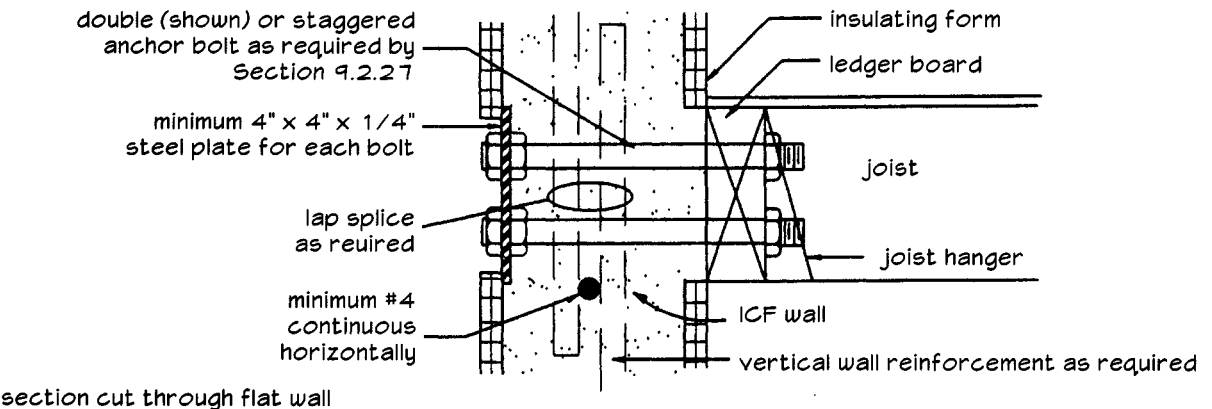
side-bearing floor connection to ICF wall with narrow ledge



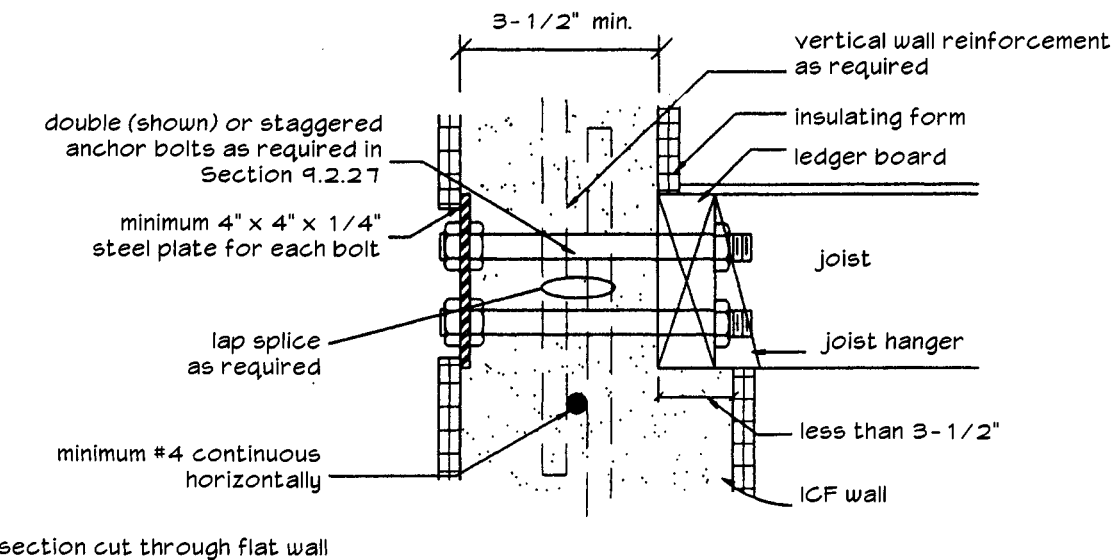
side-bearing floor connection to ICF wall

(From NAHB Research Center Prescriptive Method for Insulating Concrete Forms in Residential Construction, Portland Cement Association, 1998)

9.2.29 Through-Bolt Floor Connections to ICF Walls



through-bolt floor connection to ICF wall



through-bolt floor connection to ICF wall with narrow ledge

(From NAHB Research Center Prescriptive Method for Insulating Concrete Forms in Residential Construction, Portland Cement Association, 1998)

9.2.30 **Roof Anchorage Requirements to ICF Walls**

The detail at the top of Section 9.2.31 shows the connection between the sill plate for the roof framing and the ICF wall, where the anchor bolt size and spacing is given by the table immediately below. When design wind speeds are 90 mph or greater, uplift connectors are also needed. Requirements for the uplift connectors illustrated in Section 9.2.31 are given in the table at the bottom of this page. Embedment of strap connectors shall be in accordance with the manufacturer’s recommendations and attachment of the roof framing to the sill plate shall be in accordance with the applicable building code.

TOP SILL PLATE-ICF WALL CONNECTION REQUIREMENTS

Maximum Wind Speed (mph)	Maximum Anchor Bolt Spacing ¹	
	1/2-Inch-Diameter Anchor Bolt	5/8-Inch-Diameter Anchor Bolt
70	6'-0"	8'-0"
80	6'-0"	8'-0"
90	6'-0"	8'-0"
100	4'-0"	6'-0"
110	4'-0"	4'-0"

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 mph = 16.09344 km/hr

¹ Minimum anchor bolt embedment length shall be 4 inches (102 mm).

ROOF STRAP UPLIFT REQUIREMENTS^{1,2}

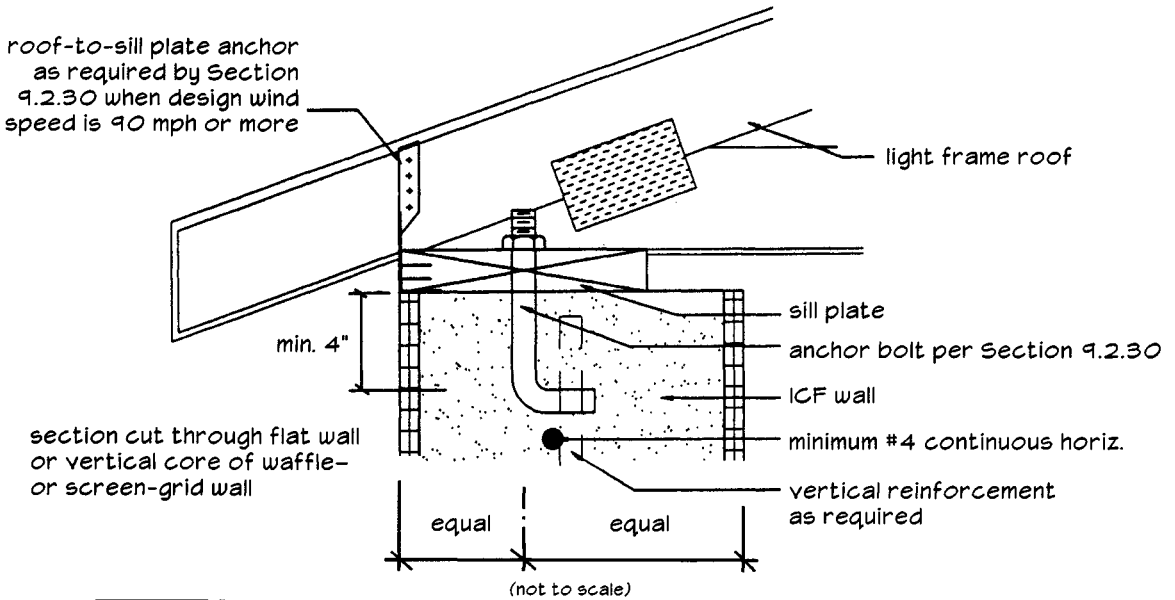
Maximum Roof Clear Span (feet)	Maximum Number of Stories Above Grade	Minimum Strap Uplift Load (lb)			
		Maximum Wind Speed (mph)			
		80 ³	90	100	110
24	One	240	400	570	760
	Two	320	490	680	900
28	One	270	450	640	860
	Two	350	550	770	1010
32	One	310	500	720	960
	Two	390	600	850	1120
36	One	340	560	800	1080
	Two	430	670	940	1240
40	One	380	620	890	1190
	Two	470	740	1030	1360

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 mph = 16.09344 km/hr

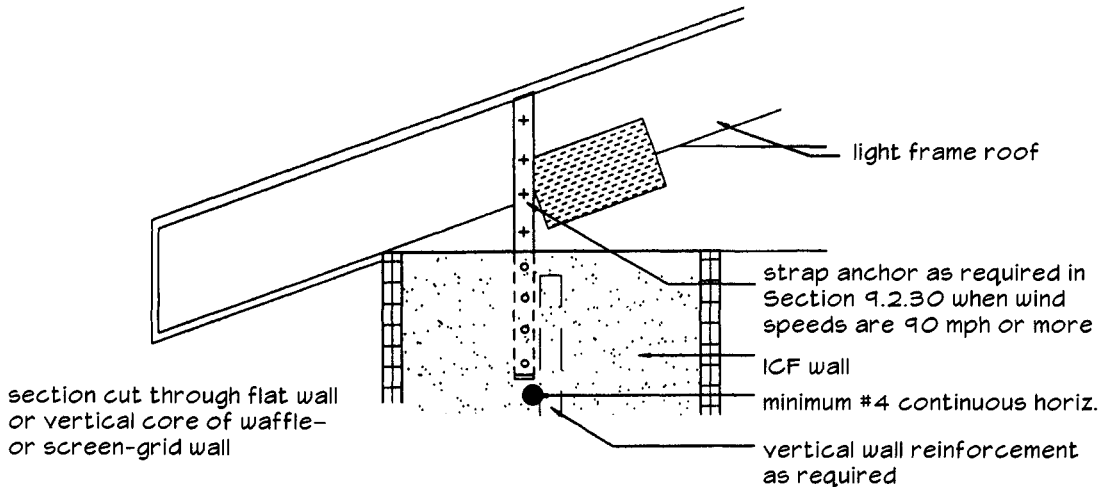
¹ Maximum roof overhang shall be 2 feet (1.2 m).
² Maximum roof truss or rafter spacing shall be 2 feet (1.2 m) on center. For 16-inch (406-mm) and 12-inch (305-mm) truss or rafter spacing, the required loads shall be multiplied by 0.67 and 0.5, respectively.
³ Strap is not required when roof framing is connected to a wood sill plate in accordance with the local building code and the wood sill plate is anchored to the wall in accordance with the table above.

(From NAHB Research Center Prescriptive Method for Insulating Concrete Forms in Residential Construction, Portland Cement Association, 1998)

9.2.31 Roof Framing Connections to ICF Walls



roof connection to ICF wall with anchor bolt and strap anchor



roof connection to ICF wall with strap anchor

Cast-In-Place Concrete

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- 10.1.1 Tolerances on Concrete Batching, Slump and Air Content
- 10.1.2 Concrete Placement Tolerances
- 10.1.3 Tolerances on Concrete Floor Finishes
- 10.1.4 Recommended Concrete Air Contents
- 10.1.5 Required Concrete Properties
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- 10.3.20 Waterstops for Concrete Slabs-On-Ground and Foundation Walls
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10.4 Shotcrete

- 10.4.1 Shotcrete Strength and Characteristics
- 10.4.2 Dry-Process Shotcrete Guns
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10.1.1 Tolerances on Concrete Batching, Slump and Air Content

Concrete Batching Tolerances	
Material	Tolerance
Cementitious materials	
≥ 30% of scale capacity	1% of cumulative weight
< 30% of scale capacity	-0% to +4% of required cumulative weight
Water	
added water or ice	1% of total water content (which includes added water, ice, and water on aggregates)
total water content	3% of total water content
Aggregates	
cumulative batching	
> 30% of scale capacity	1% of required cumulative weight
≤ 30% of scale capacity	0.3% of scale capacity or 3% of required cumulative weight, whichever is less
individual material batching	2% of required weight
Admixtures	3% of required amount

Tolerances on Concrete Slump and Air Content	
Property	Tolerance
Slump	
where specified as "maximum" or "not to exceed"	
specified slump 3 in. or less	-1-1/2 in., +0 in.
specified slump more than 3 in.	-2-1/2 in., +0 in.
where specified as a single value	
specified slump 4 in. or less	-1 in., +0 in.
specified slump more than 4 in.	-1-1/2 in., +0 in.
where range is specified	no tolerance
Air content	
where no range is specified and specified air content by volume is 4% or greater	1-1/2%
where range is specified	no tolerance

(From ACI 117-90 Standard Specifications for Tolerances for Concrete Construction and Materials)

10.1.2 Concrete Placement Tolerances

Placement Tolerances for Cast-In-Place Concrete for Buildings	
Item	Tolerance
Vertical alignment	
for heights 100 ft. or less	
lines, surfaces, and arrises	1 in.
outside corner of exposed corner columns and control joint grooves in concrete exposed to view	1/2 in.
for heights greater than 100 ft.	
lines, surfaces, and arrises	1/1000 times the height but not more than 6 in.
outside corner of exposed corner columns and control joint grooves in concrete exposed to view	1/2000 times the height but not more than 3 in.
Lateral alignment	
members	1 in.
in slabs, centerline location of openings 12 in. or smaller and edge location of larger openings	1/2 in.
sawcuts, joints, and weakened plane embedments in slabs	3/4 in.
Level alignment	
tops of slabs	
elevation of slabs-on-grade	3/4 in.
elevation of top surfaces of formed slabs before removal of supporting shores	3/4 in.
elevation of formed surfaces before removal of shores	3/4 in.
lintels, sills, parapets, horizontal grooves, and other lines exposed to view	1/2 in.
Cross-sectional dimensions	
members such as columns, beams, piers, walls (thickness only), and slabs (thickness only)	
12 in. dimension or less	+3/8 in., -1/4 in.
more than 12 in. dimension but not over 3 ft. dimension	+1/2 in., -3/8 in.
over 3 ft. dimension	+1 in., -3/4 in.
Relative alignment	
stairs	
difference in height between adjacent risers	1/8 in.
difference in width between adjacent treads	1/4 in.
grooves	
specified width 2 in. or less	1/8 in.
specified width more than 2 in. but not more than 12 in.	1/4 in.
formed surfaces may slope with respect to the specified plane at a rate not to exceed the following amounts in 10 ft.	
vertical alignment of outside corner of exposed corner columns and control joint grooves in concrete exposed to view	1/4 in.
all other conditions	3/8 in.
the offset between adjacent pieces of formwork facing material shall not exceed	
Class of surface:	
Class A	1/8 in.
Class B	1/4 in.
Class C	1/2 in.
Class D	1 in.
Openings through members	
cross-sectional size of opening	-1/4 in., + 1 in.
location of centerline of opening	1/2 in.

(From ACI 117-90 Standard Specifications for Tolerances for Concrete Construction and Materials)

10.1.3 Tolerances on Concrete Floor Finishes

Concrete floor finish tolerances shall meet the requirements of

EITHER

Floor Finish Tolerances as Measured in Accordance With ASTM E1155 Standard Test Method for Determining Floor Flatness and Levelness Using the F-Number System				
Floor Profile Quality Classification	Minimum F_F F_L Required			
	Test Area		Minimum Local F Number	
	Flatness (F_F)	Level (F_L)	Flatness (F_F)	Level (F_L)
Conventional				
Bulldozer	15	13	13	10
Straightdozer	20	15	15	10
Flat	30	20	15	10
Very flat	50	30	25	15

Note: The F_L levelness tolerance shall not apply to slabs placed on unshored form surfaces and/or shored form surfaces after the removal of shores. F_L levelness tolerances shall not apply to cambered or inclined surfaces and shall be measured within 72 hr. after slab concrete placement.

OR

Floor Finish Tolerance as Measured With a 10-ft. Straightedge	
Floor Profile Quality Classification	Tolerance
Conventional bulldozer straightdozer	1/2 (in.) 5/16 (in.)
Flat	3/16 (in.)
Very flat	1/8 (in.)

Note: Floor finish tolerances as measured by placing a freestanding (unleveled) 10-ft. straightedge anywhere on the slab and allowing it to rest upon two high spots within 72 hr. after slab concrete placement. The gap at any point between the straightedge and the floor (and between the high spots) shall not exceed the values given in the table.

(From ACI 117-90 Standard Specifications for Tolerances for Concrete Construction and Materials)

10.1.4 Recommended Concrete Air Contents

Recommended Air Contents for Frost-Resistant Concrete		
Nominal Maximum Aggregate Size (in.)	Average Air Content (%) [‡]	
	Severe Exposure [†]	Moderate Exposure [§]
3/8	7-1/2	6
1/2	7	5-1/2
3/4	6	5
1	6	5
1-1/2	5-1/2*	4-1/2*
3	4-1/2*	3-1/2*
6	4	3

[‡] A reasonable tolerance for air content in field construction is $\pm 1\text{-}1/2\%$.

[†] Outdoor exposure in a cold climate where the concrete may be in almost continuous contact with moisture prior to freezing, or where deicing salts are used. Examples are pavements, bridge decks, sidewalks, and water tanks.

[§] Outdoor exposure in a cold climate where the concrete will be only occasionally exposed to moisture prior to freezing, and where no deicing salts will be used. Examples are certain exterior walls, beams, girders, and slabs not in direct contact with soil.

* These air contents apply to the whole as for the preceding aggregate sizes. When testing these concretes, however, aggregate larger than 1-1/2 in. is removed by hand picking or sieving and the air content is determined on the minus 1-1/2 in. fraction of the mixture. (The field tolerance applies to this value.) From this the air content of the whole mixture is computed.

Note: There are conflicting opinions on whether air contents lower than those given in the table should be permitted for high-strength (more than 5500 psi) concrete. Committee 201.2 believes that where supporting experience and experimental data exist for particular combinations of materials, construction practices and exposures, the air content may be reduced by approximately 1%. (For nominal maximum aggregate sizes over 1-1/2 in., this reduction applies to the minus 1-1/2 in. fraction of the mixture.)

(From ACI 201.2R-92 Guide to Durable Concrete)

Air Content [§] of Concrete for Various Sizes of Coarse Aggregate			
Nominal Maximum Size of Aggregate (in.)	Air Content* (%)		
	Severe Exposure	Moderate Exposure	Mild Exposure
Less than 3/8	9	7	5
3/8	7.5	6	4.5
1/2	7	5.5	4
3/4	6	5	3.5
1	6	4.5	3
1-1/2	5.5	4.5	2.5
2	5	4	2
3	4.5	3.5	1.5
6	4	3	1

[§] Measured in accordance with ASTM C231, C173, or C138.

* Air content tolerance is $\pm 1\text{-}1/2\%$.

(From ACI 301-99 Specifications for Structural Concrete)

10.1.5 Required Concrete Properties

Minimum Cover for Concrete Reinforcement (Except for Extremely Corrosive Atmospheres, Other Severe Exposures, or Fire Protection)	
Element	Minimum Cover (in.)
Slabs and joists top and bottom bars for dry conditions No. 11 bars and smaller No. 14 and 18 bars formed concrete surfaces exposed to earth, water, or weather, and over or in contact with sewage, and for bottoms bearing on work mat, or slabs supporting earth cover No. 5 bars and smaller, W31 or D31 wire and smaller No. 6 through 18 bars, W45 or D45 wire	3/4 in. 1-1/2 in. 1-1/2 in. 2 in.
Beams and columns, formed, for dry conditions stirrups, spirals and ties principal reinforcement	1-1/2 in. 2 in.
Beams and columns, formed, exposed to earth, water, sewage, or weather stirrups, spirals and ties principal reinforcement	2 in. 2-1/2 in.
Walls, for dry conditions No. 11 bars and smaller No. 14 and 18 bars formed concrete surfaces exposed to earth, water, sewage, weather, or in contact with ground	3/4 in. 1-1/2 in. 2 in.
Footings and base slabs at formed surfaces and bottoms bearing on concrete work mat at unformed surfaces and bottoms in contact with earth top of footings over top of piles	2 in. 3 in. same as slabs 2 in.

Required Average Compressive Strength f'_{cr} §	
Specified Strength f'_c (psi)	Average Compressive Strength f'_{cr} (psi)
Less than 3,000	$f'_c + 1,000$
3,000 to 5,000	$f'_c + 1,200$
Over 5,000 to 10,000	$f'_c + 1,400$
Over 10,000 to 15,000	$f'_c + 1,800$

§ When data are not available to establish standard deviation.

k-Factor for Increasing Standard Deviation for Number of Tests Considered	
Total Number of Tests Considered	k-Factor
15	1.16
20	1.08
25	1.03
30 or more	1.00

Note: Linear interpolation for intermediate number of tests is acceptable.

Maximum Allowable Chloride Ion Content	
Type of Member	Maximum Water-Soluble Chloride Ion in Concrete (% by Weight of Cement)
Prestressed concrete	0.06
Reinforced concrete exposed to chloride in service	0.15
Reinforced concrete that will be dry or protected from moisture in service	1.00
Other reinforced concrete construction	0.30

(From ACI 301-99 Specifications for Structural Concrete)

10.1.6 Effect of Chemicals on Concrete

Effect of Commonly Used Chemicals on Concrete					
Rate of Attack at Ambient Temperature	Inorganic Acids	Organic Acids	Alkaline Solutions	Salt Solutions	Miscellaneous
Rapid	hydrochloric hydrofluoric Nitric sulfuric	acetic formic lactic	—	aluminum chloride	—
Moderate	phosphoric	tannic	sodium* hydroxide > 20%§	ammonium nitrate ammonium sulfate sodium sulfate magnesium sulfate calcium sulfate	bromide (gas) sulfate liquor
Slow	carbonic	—	sodium* hydroxide 10-20%§ sodium hypochlorite	ammonium chloride magnesium chloride sodium cyanide	chlorine (gas) seawater soft water
Negligible	—	oxalic tartaric	sodium* hydroxide < 10%§ sodium hypochlorite ammonium hydroxide	calcium chloride sodium chloride zinc nitrate sodium chromate	ammonia (liquid)

* The effect of potassium hydroxide is similar to that of sodium hydroxide.

§ Avoid siliceous aggregates because they are attacked by strong solutions of sodium hydroxide.

Factors Influencing Chemical Attack on Concrete	
Factors Which Accelerate or Aggravate Attack	Factors Which Mitigate or Delay Attack
High porosity due to high water absorption permeability voids	Dense concrete achieved by proper mix proportioning* reduced unit water content increased cementitious material content air entrainment adequate consolidation effective curing†
Cracks and separations due to stress concentrations thermal shock	Reduce tensile stress in concrete by† using tensile reinforcement of adequate size, correctly located inclusion of pozzolan (to suppress temperature rise) provision of adequate contraction joints
Leaching and liquid penetration due to flowing liquids§ ponding hydraulic pressure	Structural design minimize areas of contact and turbulence provide membranes and protective-barrier system(s)** to reduce penetration

* Mix proportions and initial mixing and processing of fresh concrete determine its homogeneity and density.

† Poor curing procedures result in flaws and cracks.

‡ Resistance to cracking depends on strength and strain capacity.

§ Movement of water-carrying deleterious substances increases reactions which depend on both the quantity and velocity of flow.

** Concrete which will be frequently exposed to chemicals known to produce rapid deterioration should be protected with a chemically resistant protective-barrier system.

(From ACI 201.2R-92 Guide to Durable Concrete)

10.1.7 Protecting Concrete from Chemical Attack

Requirements for Concrete Exposed to Deicing Chemicals

Cementitious Materials	Maximum Percent of Total Cementitious Materials by Weight*
Fly ash or other pozzolans conforming to ASTM C618	25
Slag conforming to ASTM C989	50
Silica fume conforming to ASTM C1240	10
Total of fly ash or other pozzolans, slag, and silica fume	50 [§]
Total of fly ash or other pozzolans and silica fume	35 [§]

* Total cementitious material also includes ASTM C150, C595, and C845 cements. The maximum percentages above shall include:

- fly ash or other pozzolans present in Type IP or I (PM) blended cement, ASTM C595;
- slag used in manufacture of an IS or I(SM) blended cement, ASTM C595; and
- silica fume, ASTM C1240, present in blended cement.

[§] Fly ash or other pozzolans and silica fume shall constitute no more than 25% and 10% respectively, of the total weight of cementitious materials.

(From ACI 301-99 Specifications for Structural Concrete)

Recommendations for Normal Weight Concrete Subject to Sulfate Attack

Exposure	Water-Soluble Sulfate* in Soil (%)	Sulfate* in Water (ppm)	Cement	Maximum Water-Cement Ratio†
Mild	0.00 to 0.10	0 to 150	—	—
Moderate†	0.10 to 0.20	150 to 1500	Type II, IP(MS) IS(MS)‡	0.50
Severe	0.20 to 2.00	1500 to 10,000	Type V [§]	0.45
Very Severe	over 2.00	over 10,000	Type V + pozzolan or slag††	0.45

* Sulfate expressed as SO₄ is related to sulfate expressed as SO₃, as SO₃ × 1.2 = SO₄.

† When chlorides or other depassivating agents are present in addition to sulfate, a lower water-cement ratio may be necessary to reduce corrosion potential of embedded items.

‡ Or a blend of Type I cement and a ground granulated blast furnace slag or a pozzolan determined by tests to give equivalent sulfate resistance.

[§] Or a blend of Type II cement and a ground granulated blast furnace slag or a pozzolan determined by tests to give equivalent sulfate resistance.

†† Use a pozzolan or slag determined by tests to improve sulfate resistance when used in concrete with Type V cement.

(From ACI 201.2R-92 Guide to Durable Concrete)

General Categories of Protective Barrier Systems

Severity of Chemical Environment	Total Nominal Thickness Range (mils)	Typical Protective Barrier Systems	Typical But Not Exclusive Uses of Protective Systems in Order of Severity
Mild	under 40	polyvinyl butyral, polyurethane, epoxy, acrylic, chlorinated rubber, styrene-acrylic copolymer asphalt, coal tar, chlorinated rubber, epoxy, polyurethane, vinyl, neoprene, coal-tar epoxy, coal-tar urethane	<ul style="list-style-type: none"> protect against deicing salts improve freeze-thaw resistance prevent staining high-purity water service protect concrete in contact with chemical solutions having a pH as low as 4, depending on the chemical
Intermediate	125 to 375	sand-filled epoxy, sand-filled polyester, sand-filled polyurethane, bituminous materials	<ul style="list-style-type: none"> protect concrete from abrasion and intermittent exposure to dilute acids in chemical, dairy, and food processing plants
Severe	20 to 250	glass-reinforced epoxy, glass-reinforced polyester, pre-cured neoprene sheet, plasticized PVC sheet	<ul style="list-style-type: none"> protect concrete tanks and floors during continuous exposure to dilute mineral, (pH below 3) organic acids, salt solutions, strong alkalis
Severe	20 to 280	composite systems	<ul style="list-style-type: none"> protect concrete tanks during continuous or intermittent immersion, exposure to water, dilute acids, strong alkalis, and salt solutions
	over 250	<ol style="list-style-type: none"> sand-filled epoxy system top-coated with a pigmented but unfilled epoxy asphalt membrane covered with acid-proof brick using a chemical-resistant mortar 	<ul style="list-style-type: none"> protect concrete from concentrated acids or combinations of acids and solvents

(From ACI 201.2R-92 Guide to Durable Concrete)

10.1.8 Estimating Individual Ingredients for Concrete

Proportions by Weight to Make One Cubic Foot of Concrete								
Maximum Size Coarse Aggregate (in.)	Air-Entrained Concrete				Concrete Not Air-Entrained			
	Cement (lb.)	Wet Sand [§] (lb.)	Coarse Aggregate [†] (lb.)	Water (lb.)	Cement (lb.)	Wet Sand [§] (lb.)	Coarse Aggregate [†] (lb.)	Water (lb.)
3/8	29	53	46	10	29	59	46	11
1/2	27	46	55	10	27	53	55	11
3/4	25	42	65	10	25	47	65	10
1	24	39	70	9	24	45	70	10
1-1/2	23	38	75	9	23	43	75	9

§ Proportions are based on wet sand. If sand is damp rather than wet, decrease the quantity of sand by one pound and increase the water by one pound. If sand is very wet, increase the quantity of sand by one pound and decrease water by one pound.

† If crushed stone is used rather than gravel, decrease coarse aggregate by three pounds and increase sand by three pounds.

(From Portland Cement Association Homeowner's Guide to Building With Concrete, Brick and Stone)

portland cement 94 lbs/bag
 sand 90 lbs/cu.ft.
 coarse aggregate 100 lbs/cu.ft.
 water 62.4 lbs/cu.ft.
 (1 gallon of water weighs 8.34 lbs.)

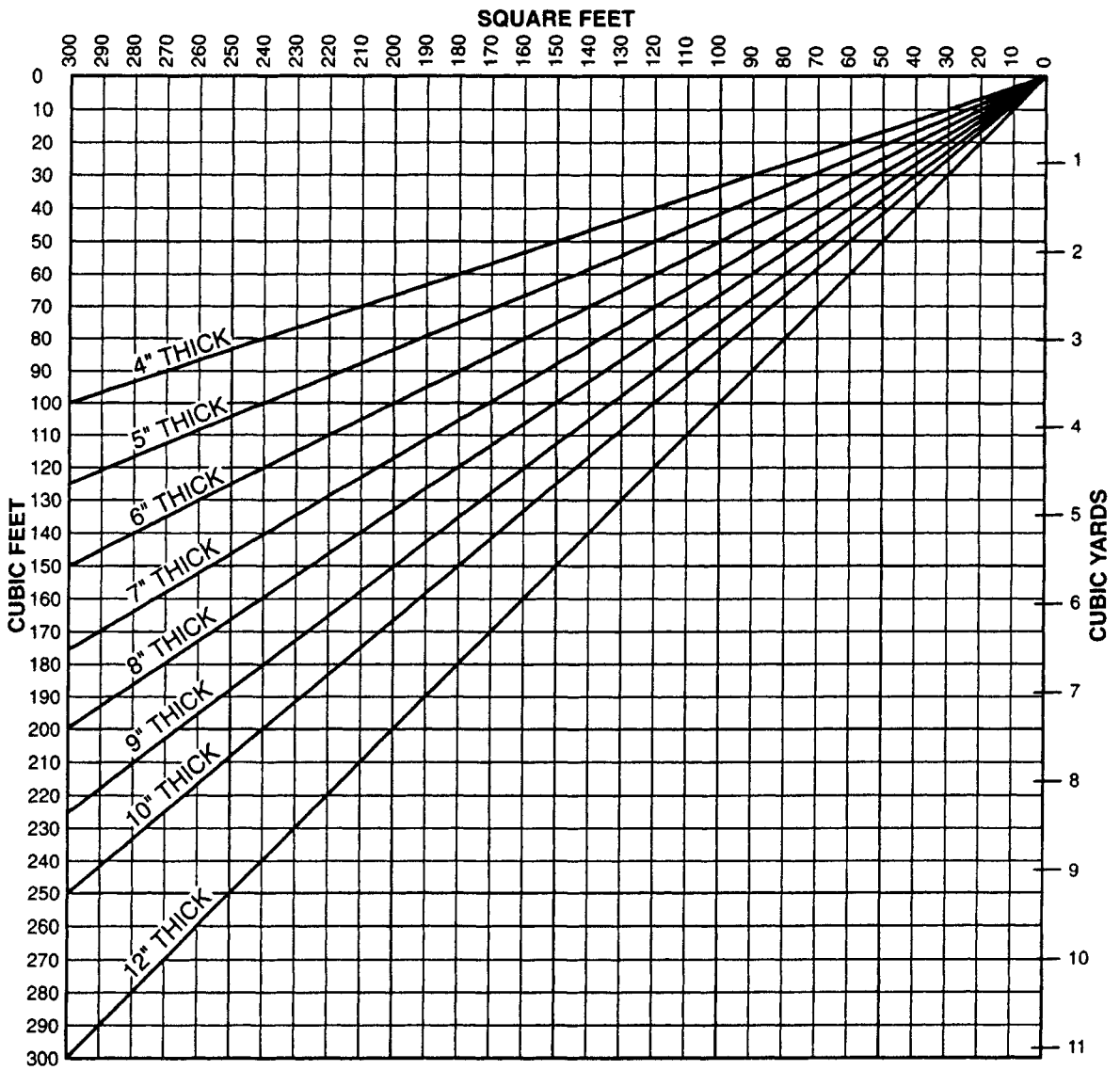
Proportions by Volume to Make One Cubic Foot of Concrete								
Maximum Size Coarse Aggregate (in.)	Air-Entrained Concrete				Concrete Not Air-Entrained			
	Cement	Sand	Coarse Aggregate	Water [§]	Cement	Sand	Coarse Aggregate	Water [§]
3/8	1	2-1/4	1-1/2	1/2	1	2-1/2	1-1/2	1/2
1/2	1	2-1/4	2	1/2	1	2-1/2	2-1/2	1/2
3/4	1	2-1/4	2-1/2	1/2	1	2-1/2	2-1/2	1/2
1	1	2-1/4	2-3/4	1/2	1	2-1/2	2-3/4	1/2
1-1/2	1	2-1/4	3	1/2	1	2-1/2	3	1/2

The combined volume of concrete is approximately 2/3 of the sum of the original bulk volumes of the ingredients. Proportions are only a guide and may need adjustment to produce a workable mix with locally available aggregates.

§ One cubic foot of water is 7.48 gallons. One gallon of water is 0.134 cu.ft.

(From Portland Cement Association Homeowner's Guide to Building With Concrete, Brick and Stone)

10.1.9 Calculating Concrete Quantities



Find the area in square feet along the top of the graph. Follow the vertical line down until it intersects the diagonal line for the appropriate thickness. Read horizontally to the left to find the volume in cubic feet. Read horizontally to the right to find the volume in cubic yards.

(From Beall, Masonry and Concrete for Residential Construction, McGraw-Hill Complete Construction Series, 2001)

10.1.10 Concrete Aggregate Volume and Weight of Fresh Concrete

Volume of Oven-Dry-Rodded Coarse Aggregate ^s per Unit Volume of Concrete				
Maximum Size of Aggregate (in.)	Fineness Moduli of Fine Aggregate			
	2.40	2.60	2.80	3.00
3/8	0.50	0.48	0.46	0.44
1/2	0.59	0.57	0.55	0.53
3/4	0.66	0.64	0.62	0.60
1	0.71	0.69	0.67	0.65
1-1/2	0.75	0.73	0.71	0.69
2	0.78	0.76	0.74	0.72
3	0.82	0.80	0.78	0.76
6	0.87	0.85	0.83	0.81

^s Bulk volumes are based on aggregates in oven-dry-rodded condition as described in ASTM C29. These volumes are selected from empirical relationships to produce concrete with a degree of workability suitable for usual reinforced construction. For less workable concrete such as required for concrete pavement construction, they may be increased about 10%.

(From ACI 211.1-91 Reapproved 1997, Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete)

First Estimate of Concrete Weight* (lb/cu.yd.)		
Nominal Maximum Size of Aggregate (in.)	Non-Air-Entrained Concrete	Air-Entrained Concrete
3/8	3840	3710
1/2	3890	3760
3/4	3960	3840
1	4010	3850
1-1/2	4070	3910
2	4120	3950
3	4200	4040
6	4260	4110

* Values are calculated for concrete of medium richness (550 lb. of cement per cu.yd.) and medium slump with aggregate specific gravity of 2.7. Water requirements based on values for 3- to 4-in. slump and air content for air-entrained concrete on severe exposure as listed in table on following page.

Estimated weight may be refined as follows:

- For each 10 lb. difference in mixing water for 3- to 4-in. slump concrete from table on following page, correct the weight 15 lb. in the opposite direction.
- For each 100-lb. difference in cement content from 550 lb., correct the weight 15 lb. in the same direction.
- For each 0.1 by which aggregate specific gravity deviates from 2.7, correct the concrete weight 100 lb. in the same direction.
- For air-entrained concrete, weight can be increased 1% for each percent reduction in air content from amount listed for severe exposure in the table on the following page.

(From ACI 211.1-91 Reapproved 1997, Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete)

10.1.11 Concrete Slump, Mixing Water, and Air Content

Recommended Maximum and Minimum Slump*		
Type of Construction	Maximum Slump (in.) [§]	Minimum Slump (in.)
Reinforced foundation walls and footings	3	1
Plain footings, caissons and sub-structure walls	3	1
Beams and reinforced walls	4	1
Building columns	4	1
Pavements and slabs	3	1
Mass concrete	2	1

* Slump may be increased when chemical admixtures are used, provided the admixture-treated concrete has the same or lower water-cement or water-cementitious material ratio and does not exhibit segregation potential or excessive bleeding.

§ May be increased 1 in. for methods of consolidation other than vibration.

Approximate Mixing Water (lb./cu.yd.) and Target Air Content Requirements for Different Concrete Slumps and Maximum Sizes of Aggregate [§]								
Maximum Aggregate Size →	3/8 in.	1/2 in.	3/4 in.	1 in.	1-1/2 in.	2 in. [†]	3 in. [†]	6 in. [†]
Non-Air-Entrained Concrete								
Slump 1 to 2 in.	350	335	315	300	275	260	220	190
Slump 3 to 4 in.	385	365	340	325	300	285	245	210
Slump 6 to 7 in.	410	385	360	340	315	300	270	—
Approximate amount of entrapped air in non-air-entrained concrete (%)	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-Entrained Concrete								
Slump 1 to 2 in.	305	295	280	270	250	240	205	180
Slump 3 to 4 in.	340	325	305	295	275	265	225	200
Slump 6 to 7 in.	365	345	325	310	290	280	260	—
Recommended average total air content for level of exposure (%) [‡]								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5 ^{§§}	1.0 ^{§§}
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5 ^{§§}	3.0 ^{§§}
Severe exposure [*]	7.5	7.0	6.0	6.0	5.5	5.0	4.5 ^{§§}	4.0 ^{§§}

§ Mixing water quantities are for use in computing cement factors for trial batches. They are maximums for reasonably well shaped angular coarse aggregates graded within limits of accepted specifications.

† Slump values for concrete containing aggregate larger than 1-1/2 in. are based on slump tests made after removal of particles larger than 1-1/2 in. by wet screening.

‡ The air content in project specifications should be specified to be delivered within -1 to +2 percentage points of the table target value for moderate and severe exposures.

* These values are based on 9% air needed in mortar phase of concrete. If mortar volume will be substantially different from that determined in this recommended practice, it may be desirable to calculate needed air by taking 9% of actual mortar volume.

§§ For concrete with large aggregates that will be wet-screened over the 1-1/2-in. sieve before testing, the percentage of air in the 1-1/2-in. minus material should be as shown in the 1-1/2-in. column, but initial proportioning calculations should include air content as a percent of the whole. When using large aggregate in low-cement-factor concrete, air content requirements for extreme exposure should be considered for all exposures to reduce water requirement and avoid strength reduction caused by air-entrainment.

10.1.12 Water-Cement Ratio in Concrete

Typical Relationship Between Water-Cement Ratio and Concrete Compressive Strength		
Compressive Strength* at 28 Days (psi)	Water-Cement Ratio by Weight	
	Non-Air-Entrained Concrete	Air-Entrained Concrete
6000	0.41	—
5000	0.48	0.40
4000	0.57	0.48
3000	0.68	0.59
2000	0.82	0.74

- * Strength values estimated for concrete with not more than 2% air for non-air-entrained concrete and 6% total air content for air-entrained concrete. For a constant water-cement ratio, concrete strength is reduced as air content increases. 28-day strengths may be conservative. Strengths and rates at which strengths develop may change when various cementitious materials are used.
- Strength is based on 6 x 12 cylinders moist cured 28 days at 73.4°F ± 3°F prior to testing in accordance with Section 9b of ASTM C31.
- Relationship assumes maximum aggregate size of about 3/4 to 1 inch. For a given source of aggregate, strength produced at a given water-cement ratio will increase as nominal maximum size of aggregate decreases.

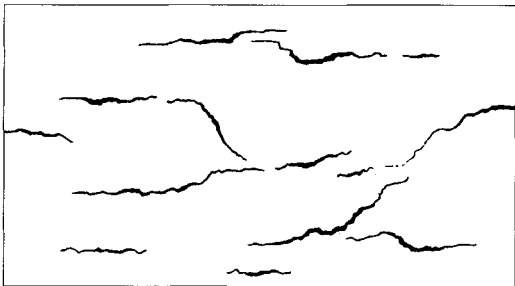
Maximum Permissible Water-Cement or Water-Cementitious Materials Ratios for Concrete in Severe Exposures [§]		
Type of Structure	Structure Wet Continuously or Frequently and Exposed to Freezing and Thawing [†]	Structure Exposed to Sea Water or Sulfates
Thin sections (railings, curbs, sills, ledges, ornamental work) and sections with less than 1 in. cover over steel reinforcement	0.45	0.40 [‡]
All other structures	0.50	0.45 [‡]

[§] Based on report of ACI Committee 201. Cementitious materials other than cement should conform to ASTM C618 and C989.

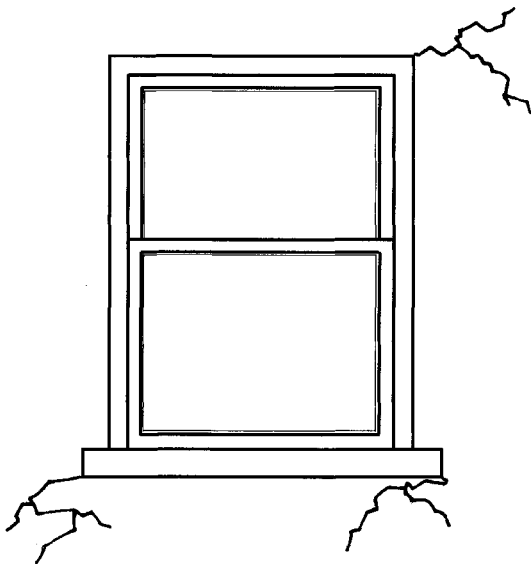
[†] Concrete should also be air-entrained.

[‡] If sulfate-resisting cement (ASTM C150 Type II or Type V) is used, permissible water-cement or water-cementitious materials ratio may be increased by 0.05.

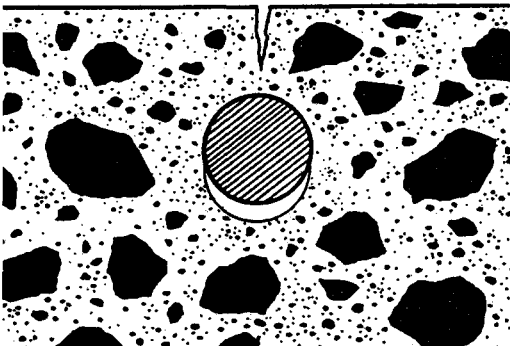
10.1.13 Cracking in Concrete



typical plastic shrinkage cracking



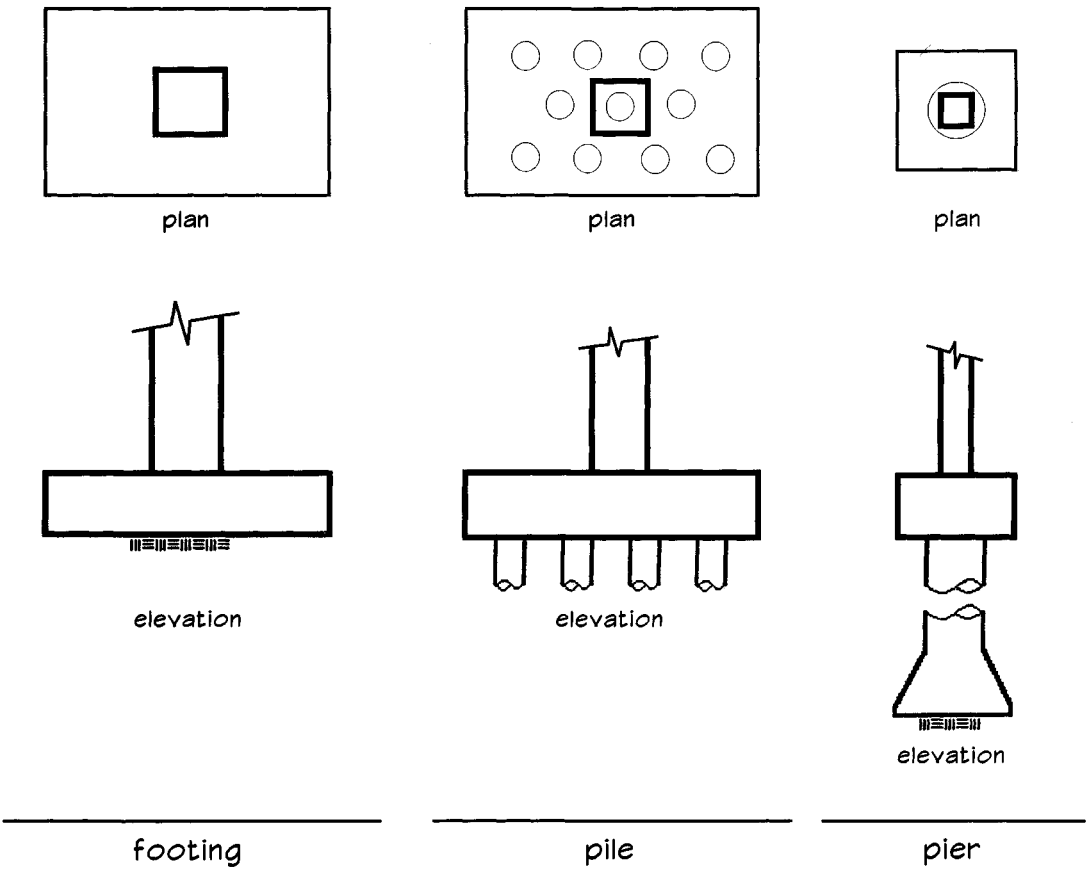
typical crack patterns at re-entrant corners



crack formed due to obstructed settlement

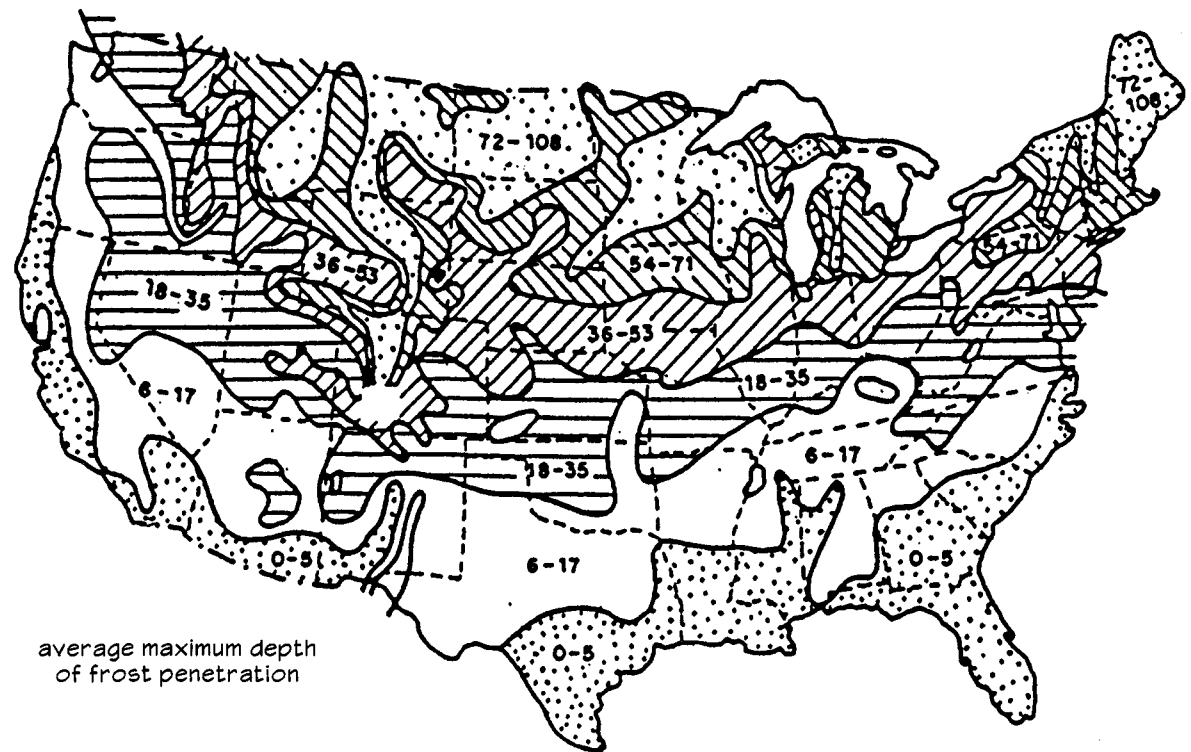
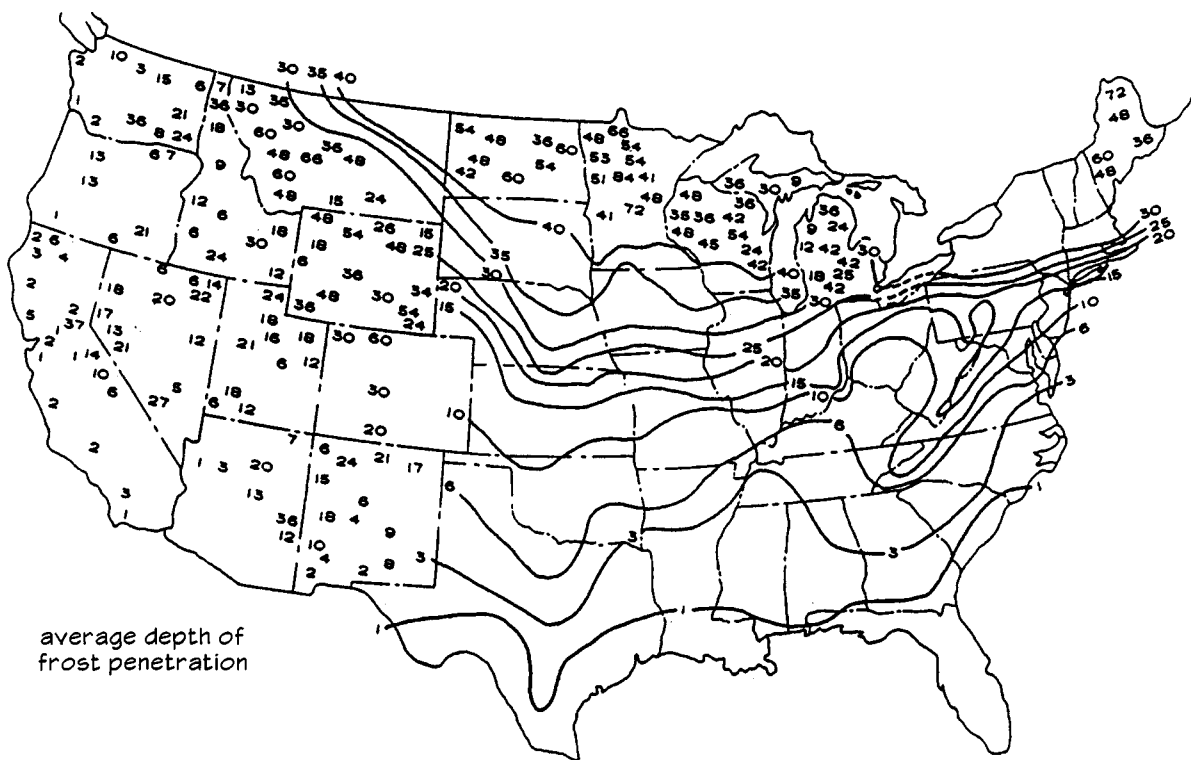
(From ACI 224.1R-93 Reapproved 1998, Causes, Evaluation and Repair of Cracks in Concrete Structures)

10.2.1 Concrete Foundation Systems



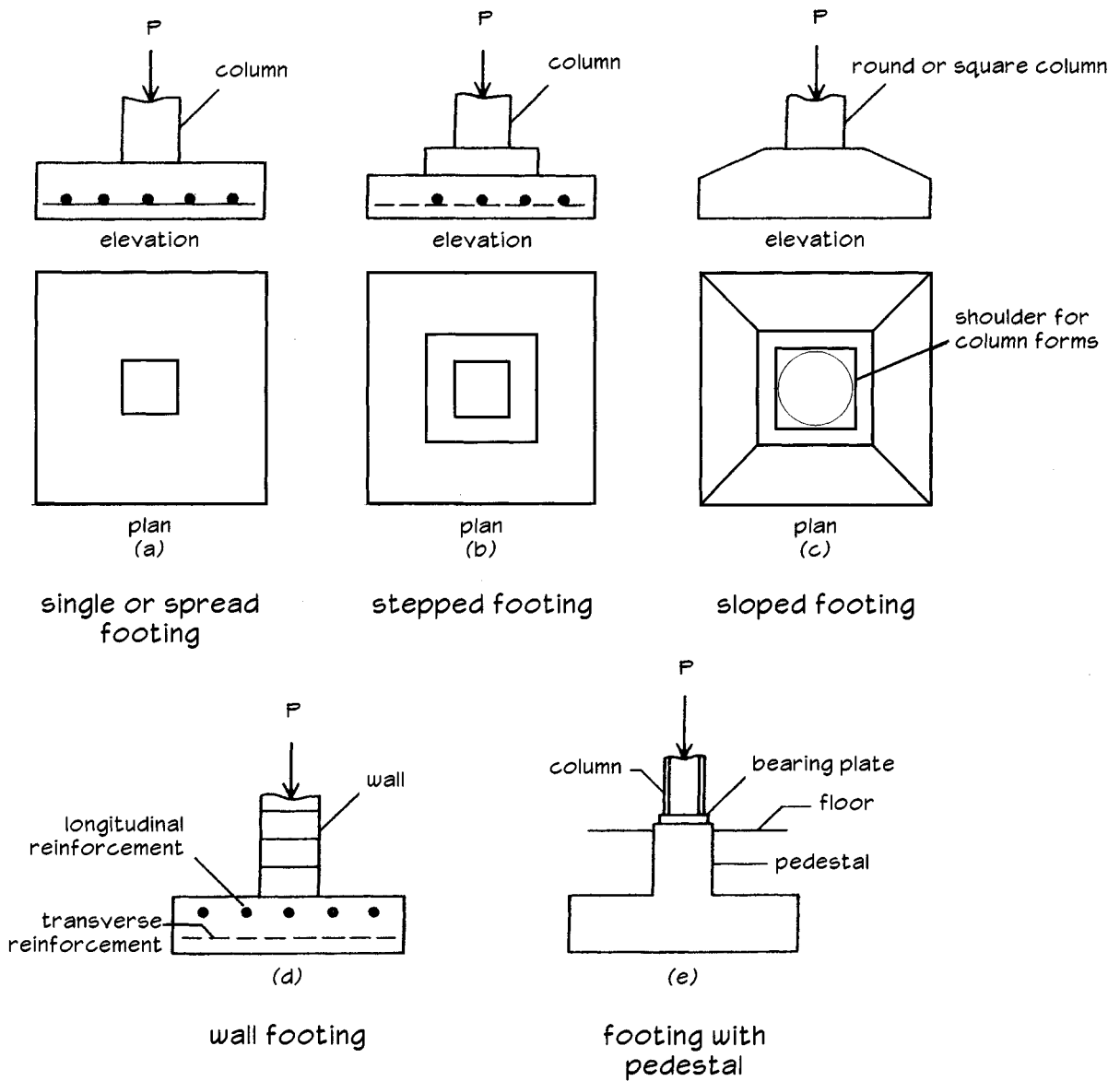
Reinforced concrete dominates the foundation industry because it is naturally resistant to the elements, has high compressive strength, and is extremely durable. Footings, piles (or pilings) and piers are all made of reinforced concrete.

10.2.2 Frost Depth in Continental United States

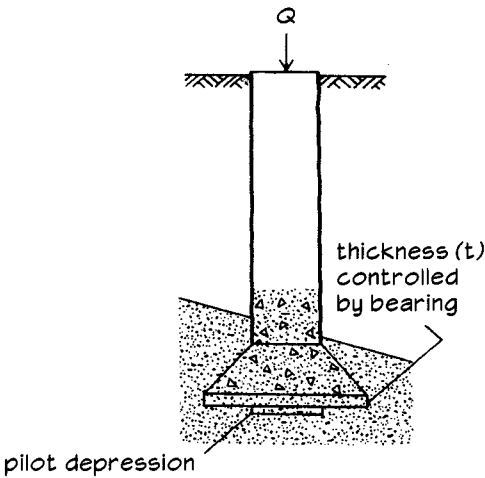


(From U.S. Weather Bureau)

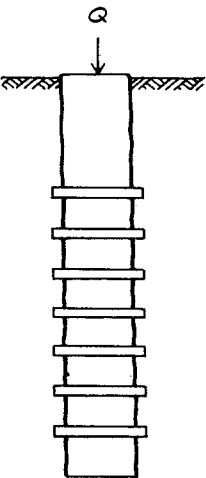
10.2.3 Typical Concrete Footings



10.2.4 Drilled Concrete Piers

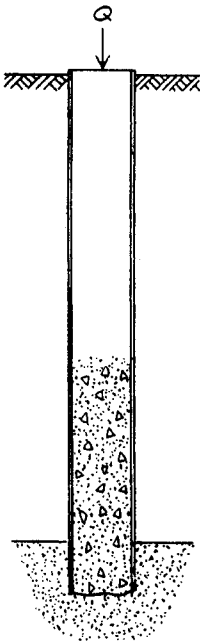


(a) angled bell pier
(usually between 30 and
45 degree) end bearing

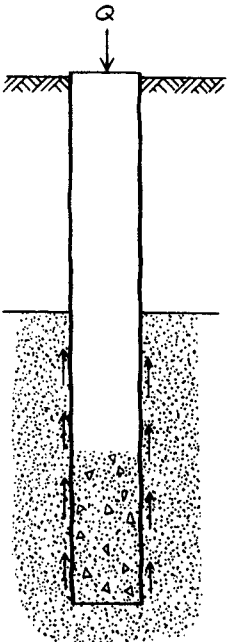


(b) friction caisson
using shear rings cut by
auger during drilling to
improve shear resistance

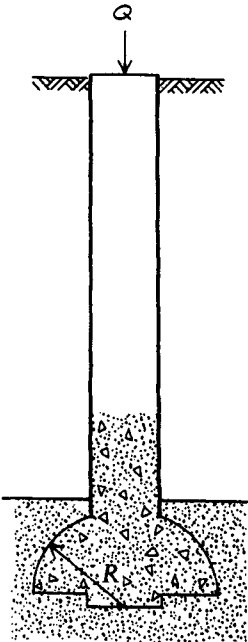
common drilled
pier configurations



(c) end-bearing
cased pier



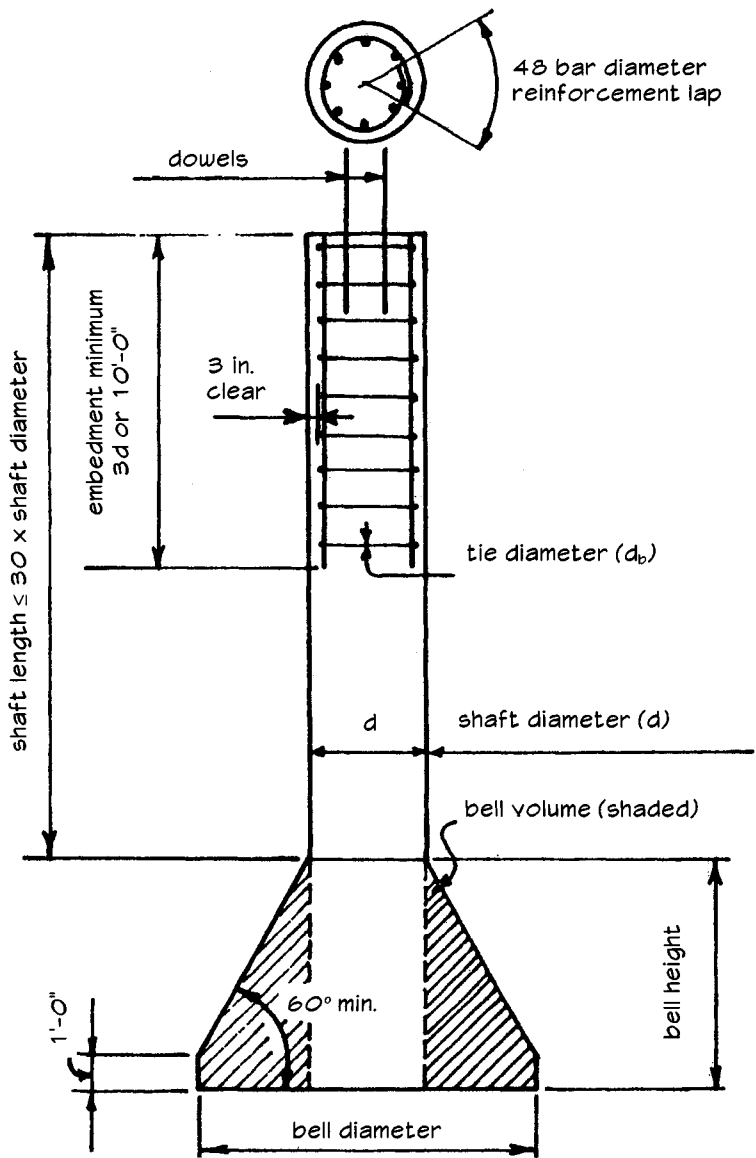
(d) end-bearing
uncased pier with
some skin resistance



(e) domed bell
end-bearing pier

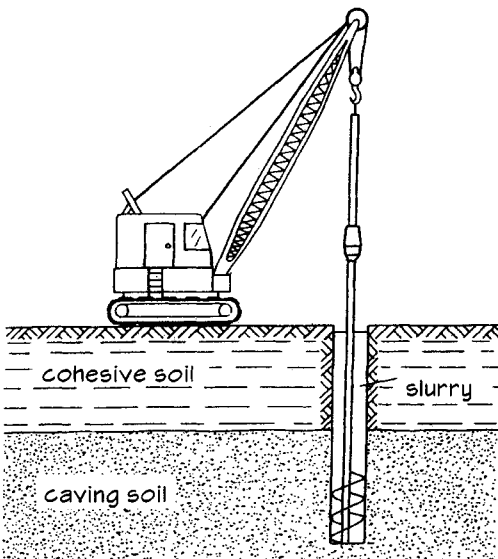
(From Bowles, Foundation Analysis and Design, McGraw-Hill, 1988)

10.2.5 Typical Drilled Concrete Pier

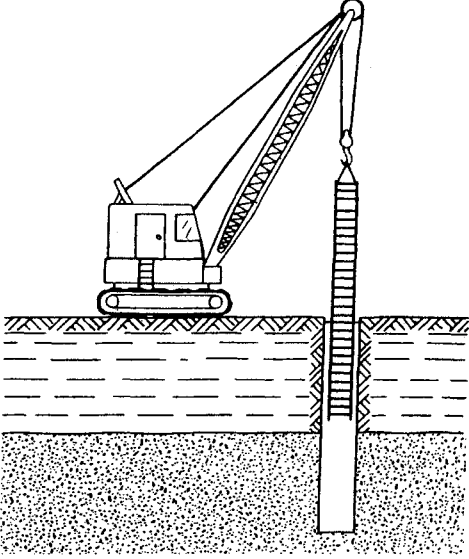


(From CRSI Handbook, Concrete Reinforcing Steel Institute, 1992)

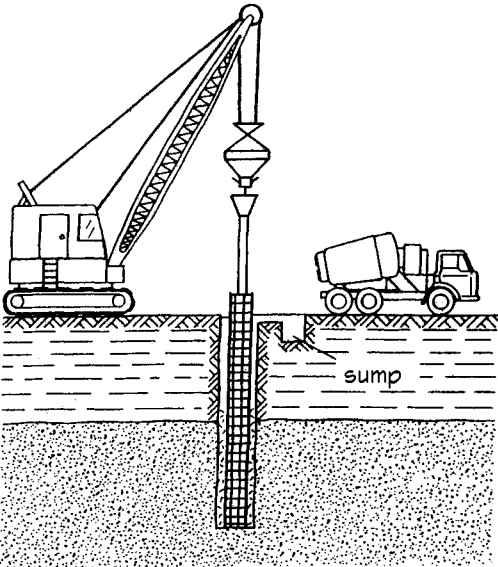
10.2.6 Slurry Method of Drilled Pier Construction



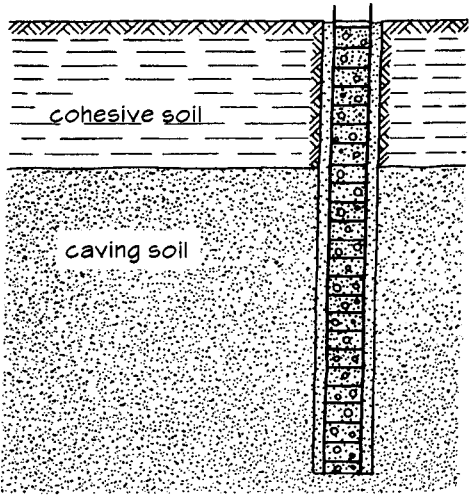
1. drill into caving soil and add slurry as necessary for adequate head and to required depth



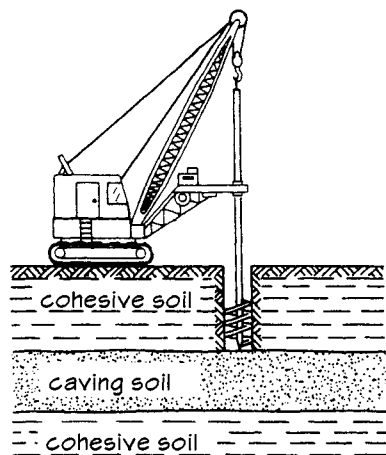
2. remove drill and insert reinforcing bar cage



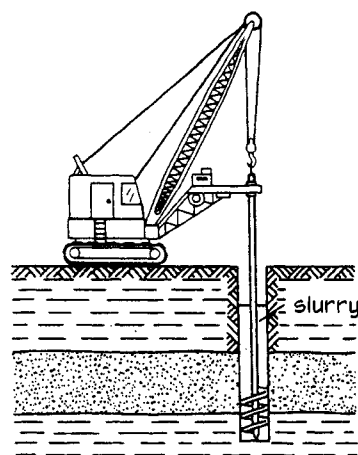
3. add tremie and pump cement, catching displaced slurry in sump pit



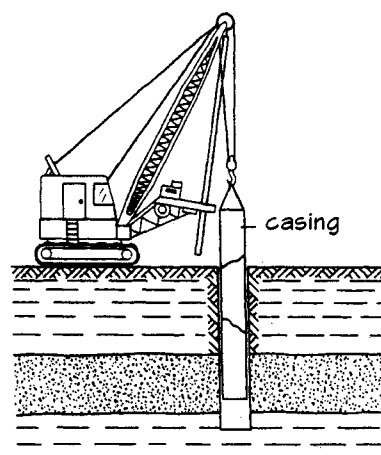
4. completed shaft



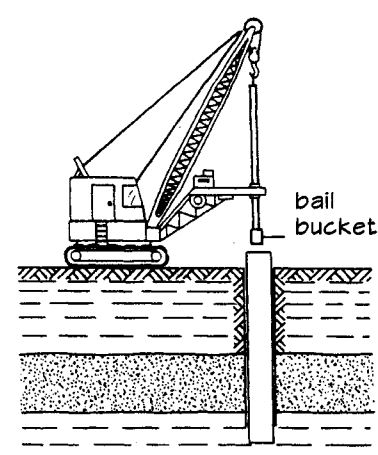
1. start drilling



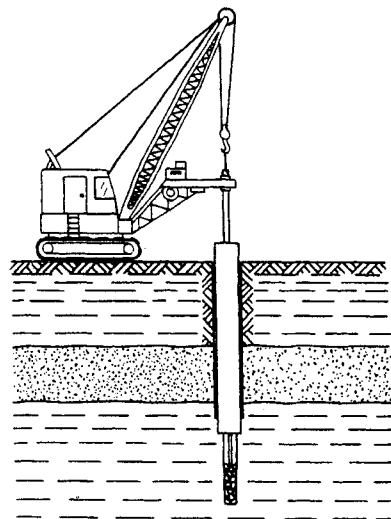
2. add slurry



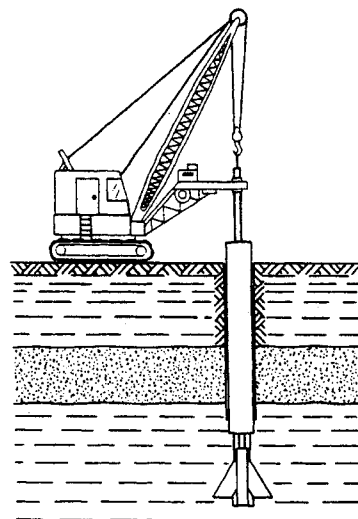
3. insert casing



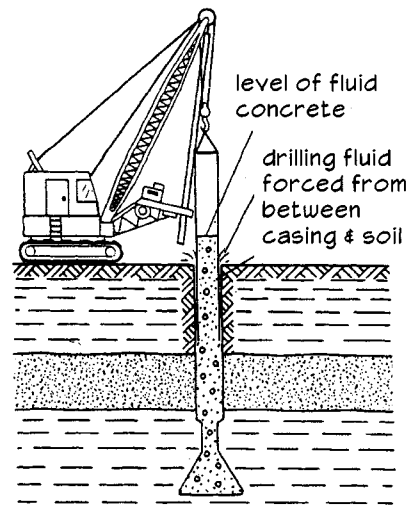
4. bail slurry



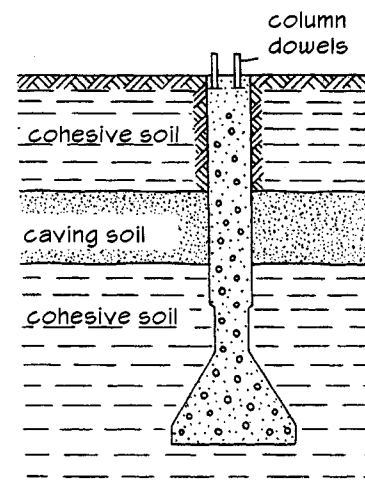
5. resume drilling



6. under-ream for bell



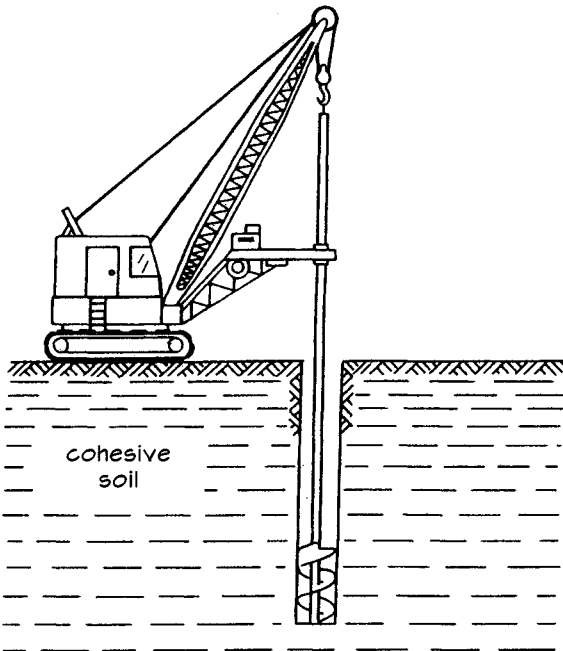
7. place concrete/pull casing



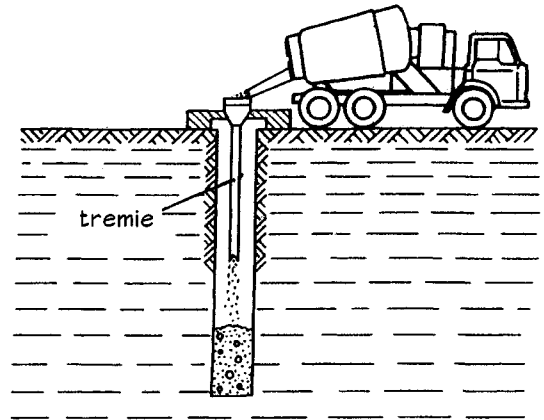
8. completed pier

(From Bowles, Foundation Analysis and Design, McGraw-Hill, 1988)

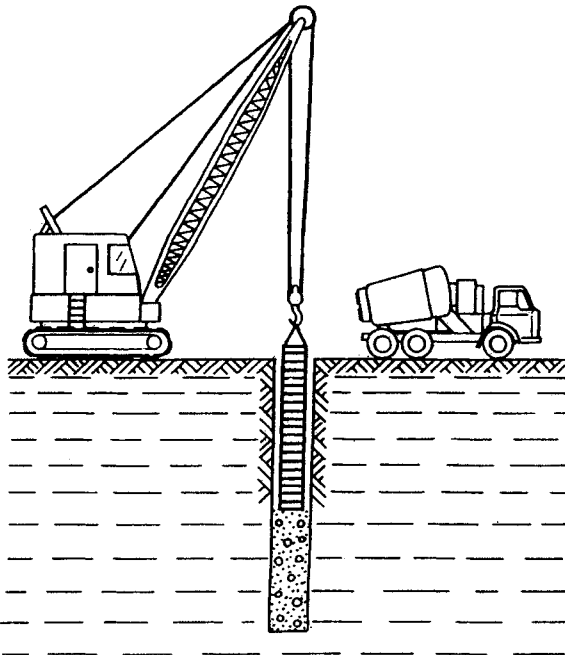
10.2.8 Dry Method of Drilled Pier Construction



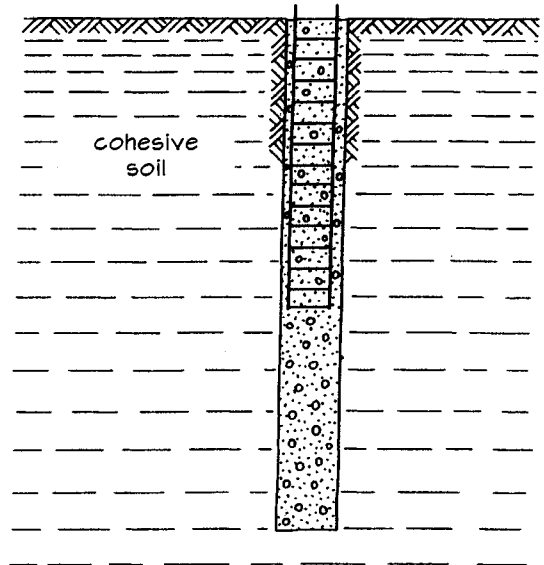
1. drill shaft to required depth



2. place concrete through tremie (and use limited free fall)

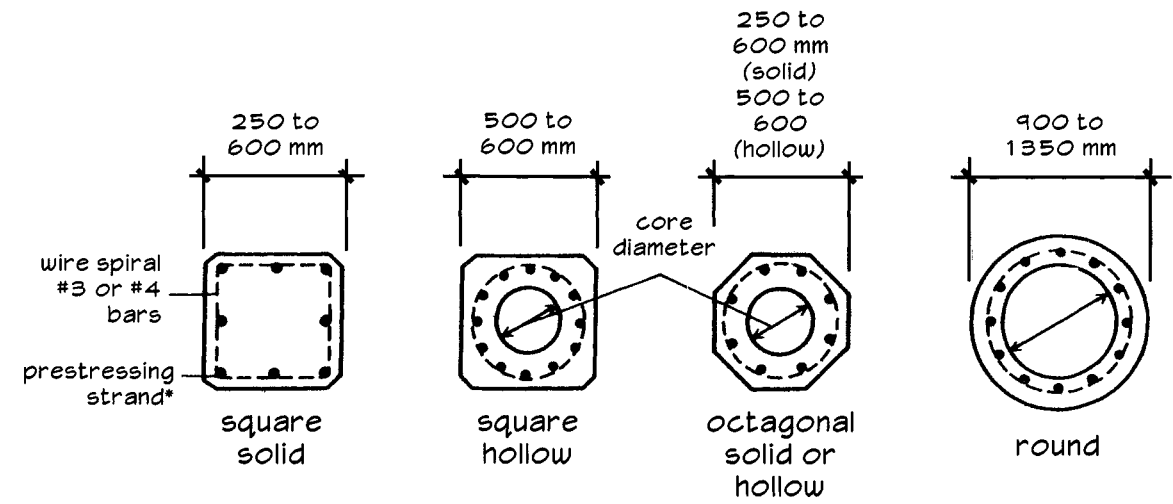


3. pull out tremie and set reinforcing bar cage to depth required

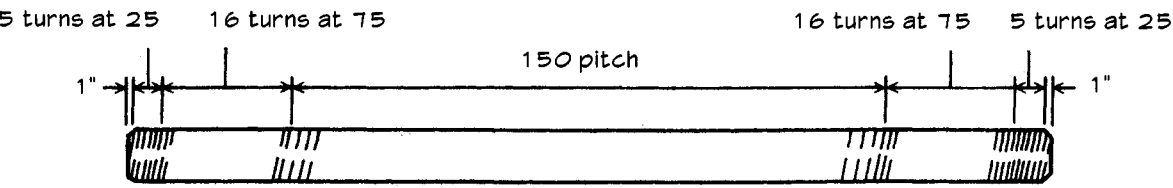


4. completed shaft

10.2.9 Typical Prestressed Concrete Piles

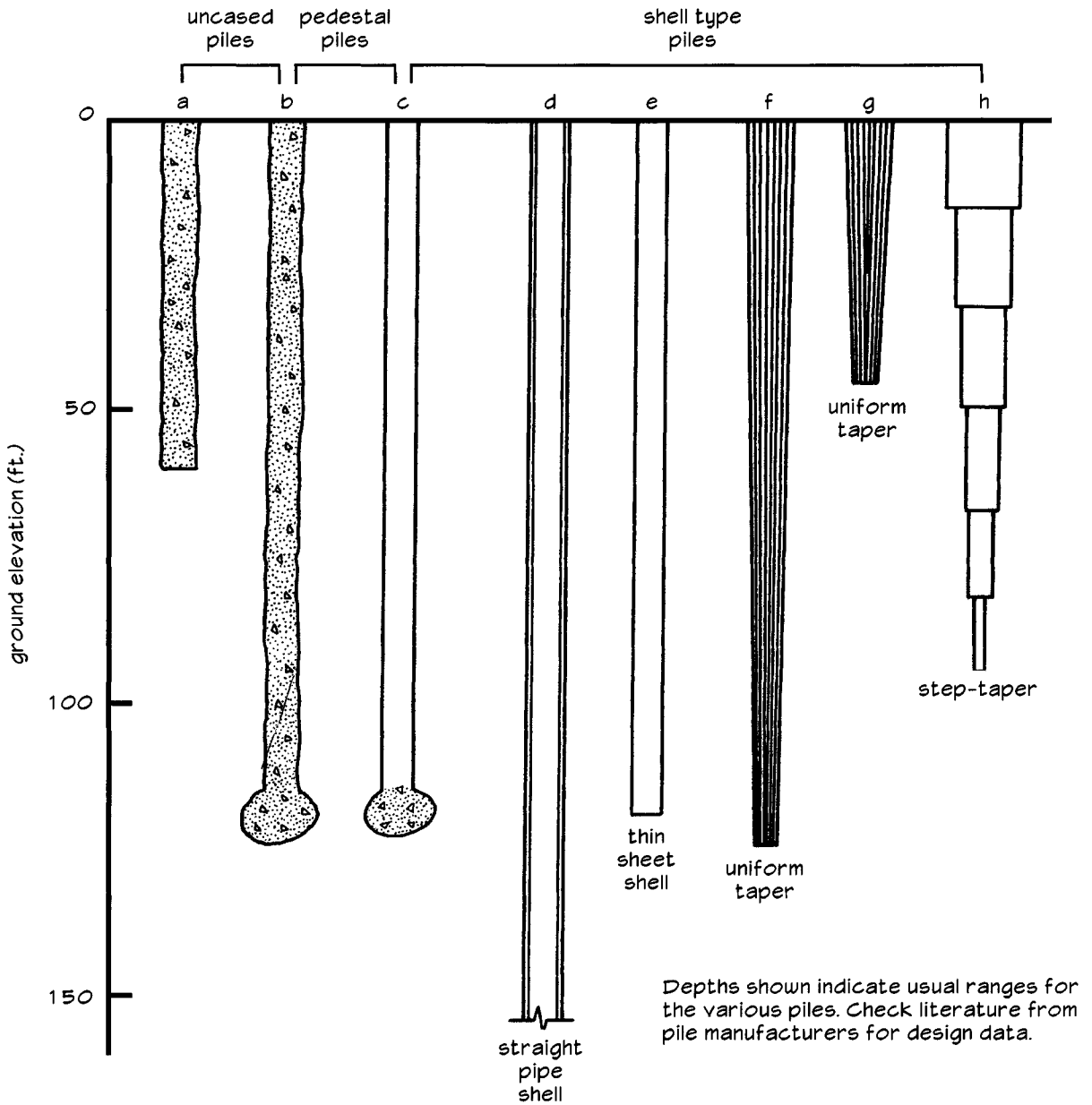


* strand 3/8 to 1/2 in. nominal diameter, $f_u = 1860$ MPa



(From Bowles, Foundation Analysis and Design, McGraw-Hill, 1988)

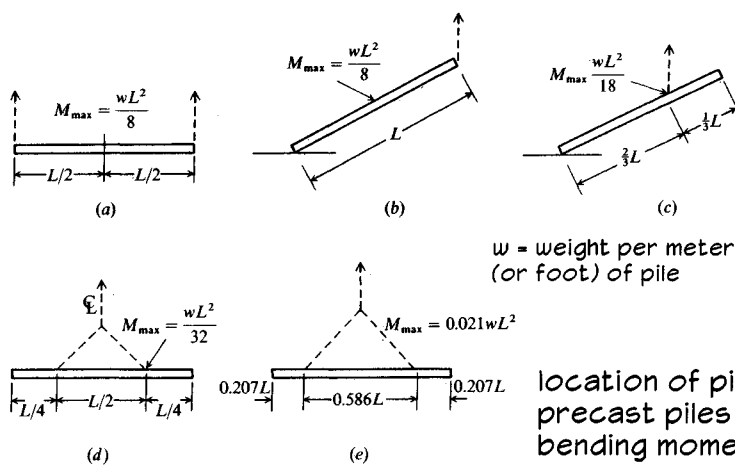
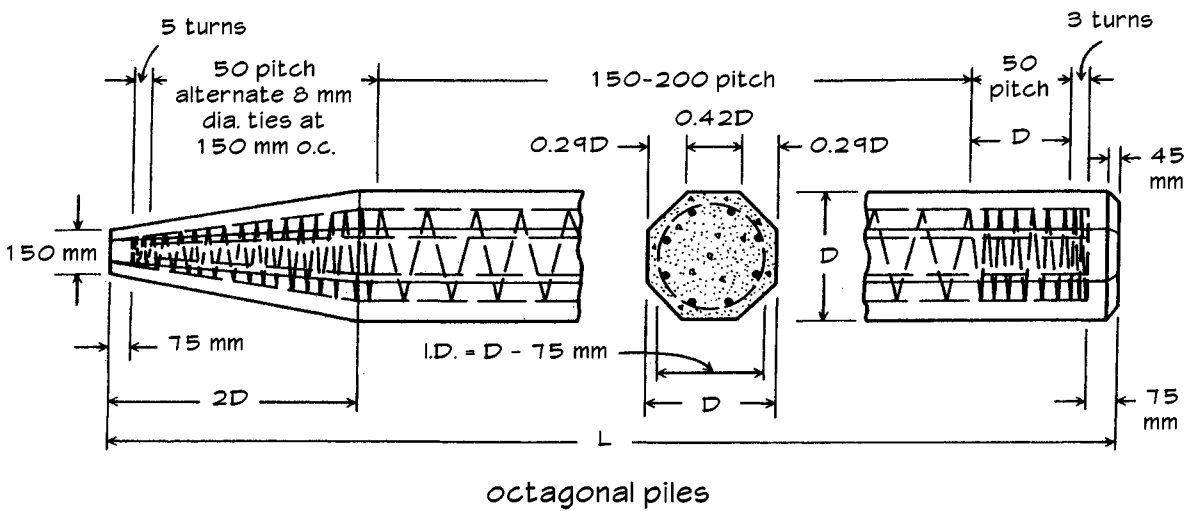
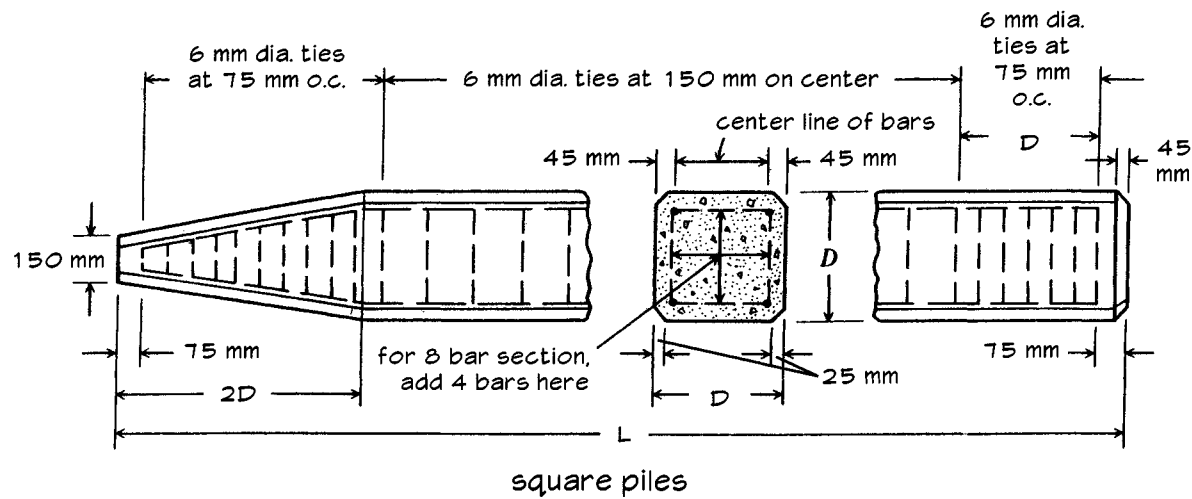
10.2.10 Cast-In-Place Concrete Piles



some common types of patented cast-in-place piles

- a Western uncased pile
- b Franki uncased-pedestal pile
- c Franki cased-pedestal pile
- d welded or seamless pipe
- e Western cased pile
- f Union or Monotube pile
- g Raymond standard
- h Raymond step-taper pile

10.2.11 Precast Concrete Piles

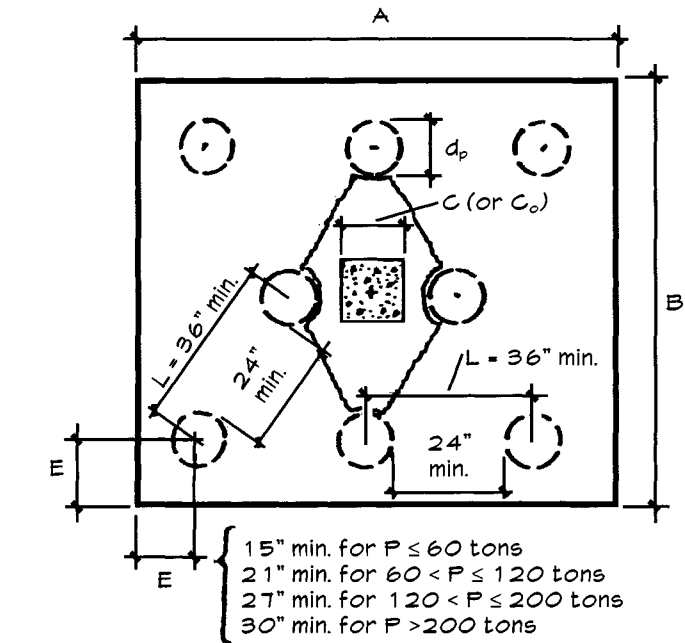


Spiral Wire			
D (mm)	400	500	600
US bar	#5	#4	#3
SI bar	15	10	10

w = weight per meter (or foot) of pile

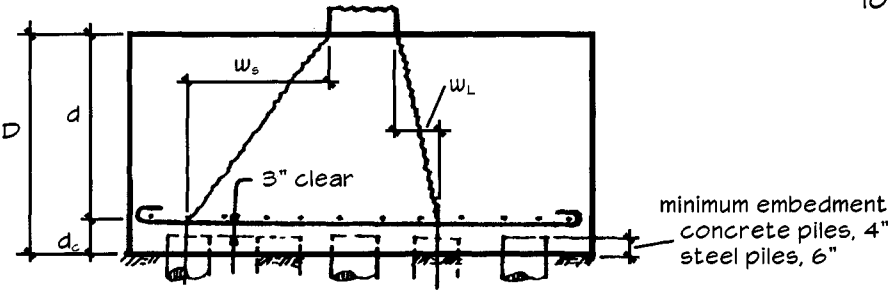
location of pickup points for precast piles with resultant bending moments indicated

10.2.12 Concrete Pile Caps

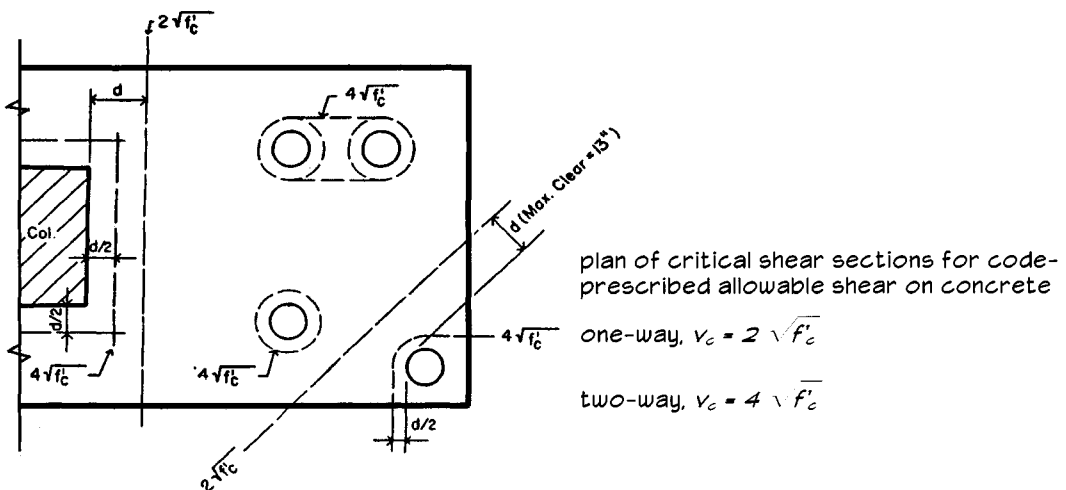


notation

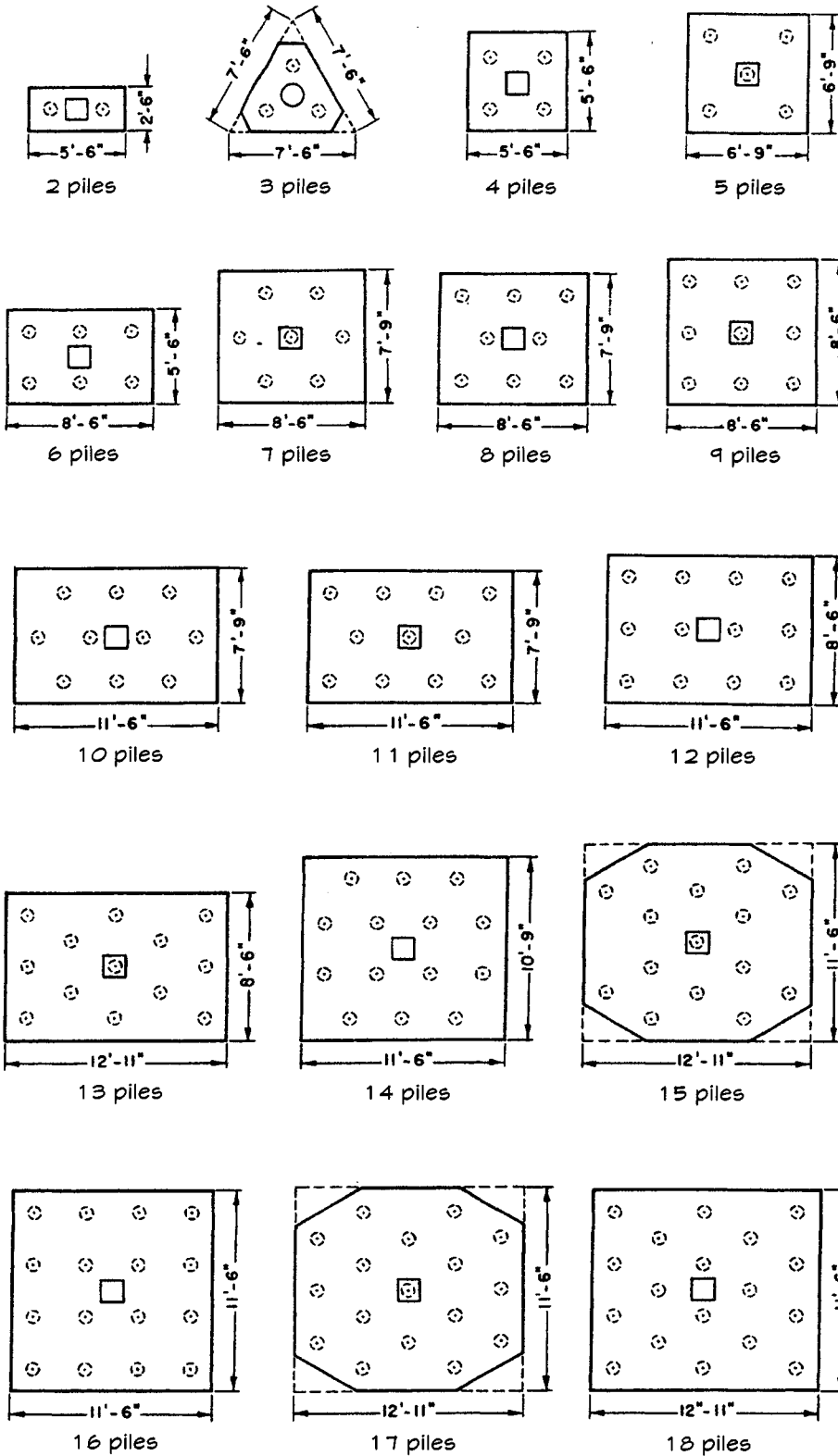
- D = total depth $d + d_c$
- d = effective depth
- d_c = average depth to center of steel reinf.
- C (or C_o) = column side (diameter)
- d_p = pile diameter
- E = edge to centerline of pile
- L = center-to-center pile spacing
- A = long side
- B = short side
- P = pile capacity ($D+L$) in tons
- w = horizontal component column face-to-bottom crack (sub "s" = short side, sub "L" = long side)



pile cap nomenclature, dimensions and details

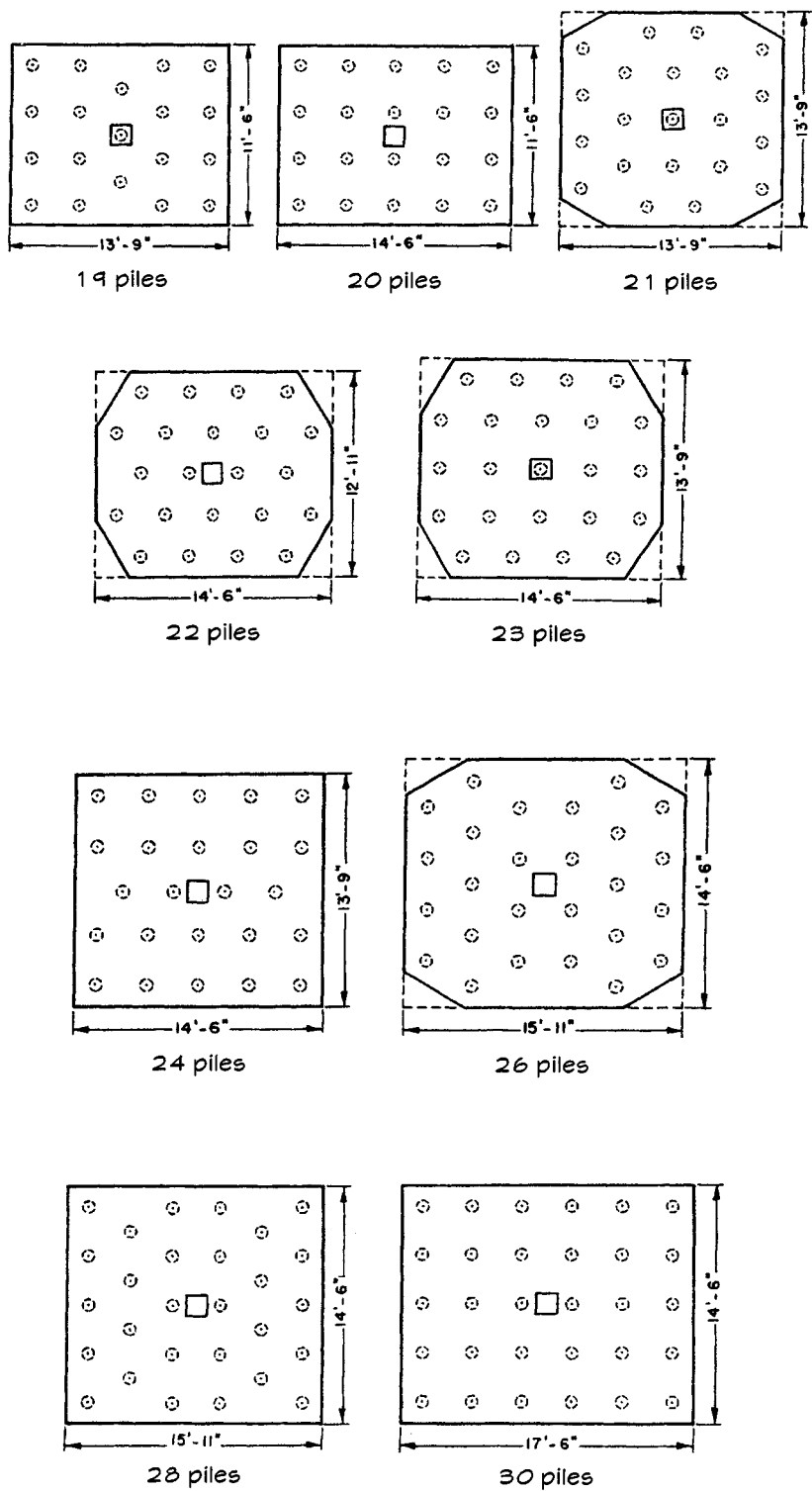


10.2.13 Pile Cap Layout Patterns



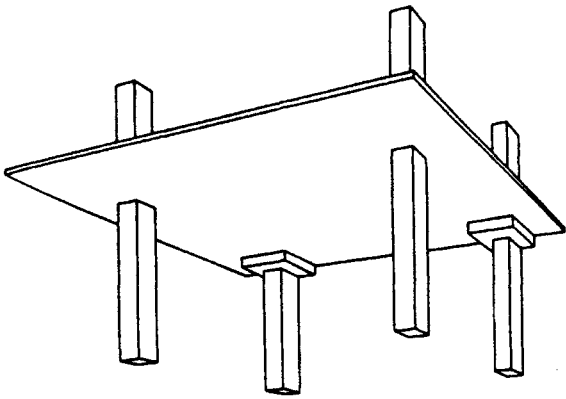
(From CRSI Handbook, Concrete Reinforcing Steel Institute, 1992)

10.2.13 Continued

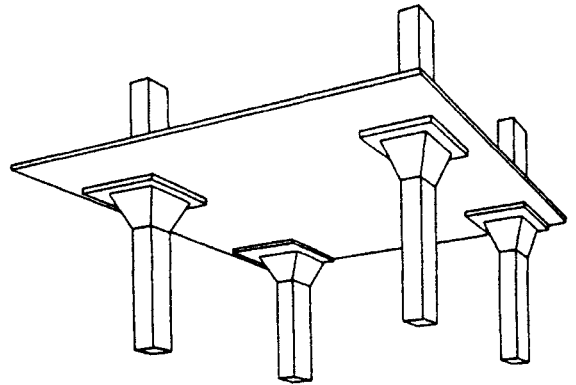


(From CRSI Handbook, Concrete Reinforcing Steel Institute, 1992)

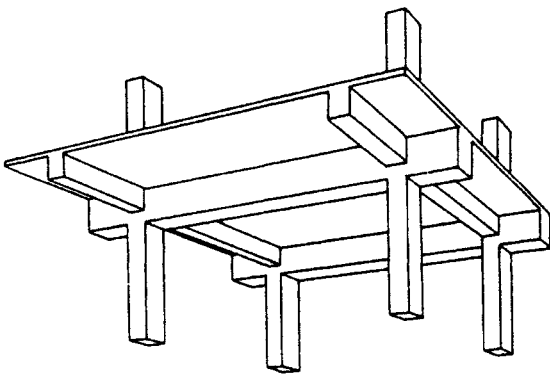
10.3.1 Concrete Column and Floor Framing



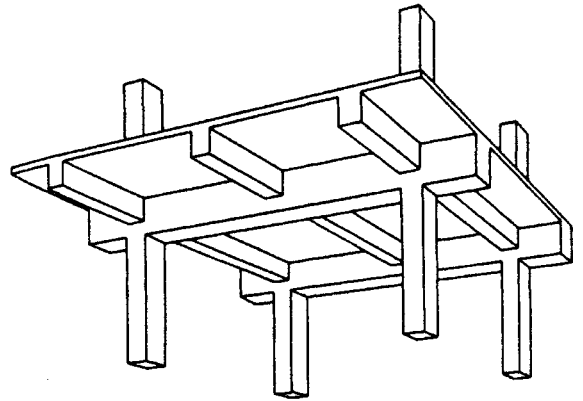
flat plate



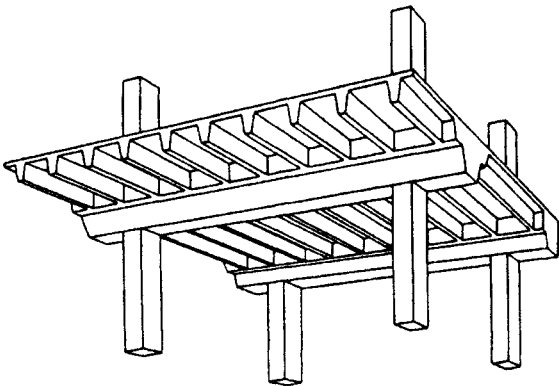
flat slab without beams



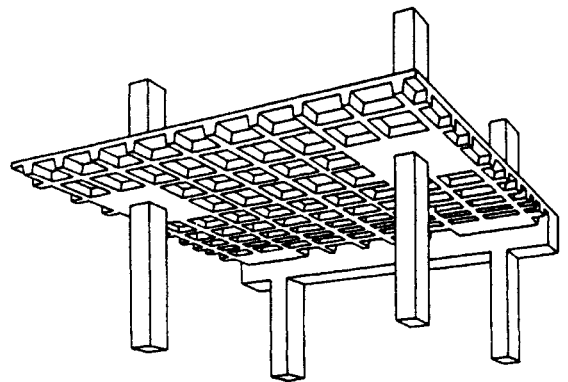
flat slab with beams



one-way slab with beams



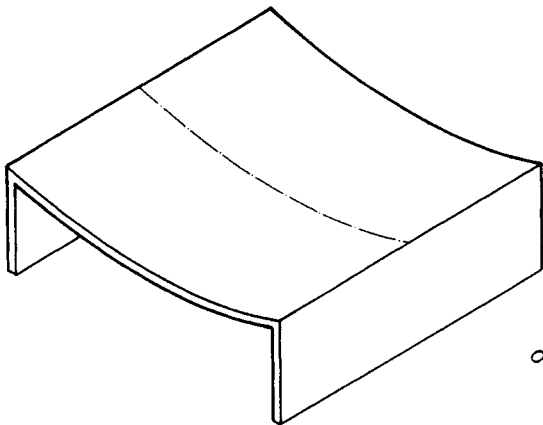
one-way joists with beams



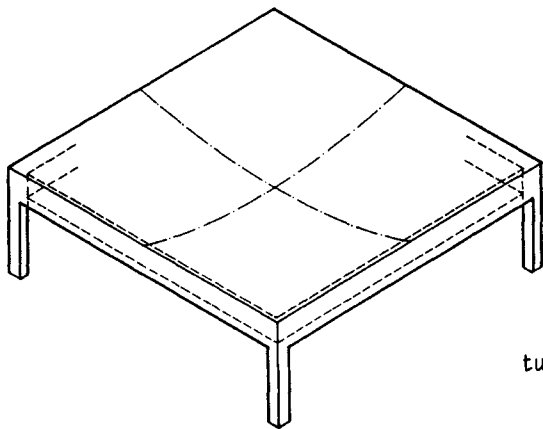
two-way joists without beams (waffle slab)

(From Architectural Graphic Standards, 9th ed., John Wiley & Sons, 1994)

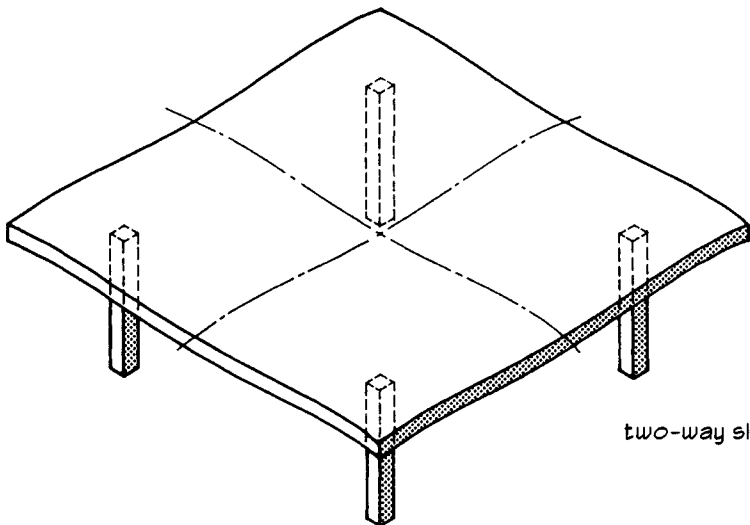
10.3.2 One-Way and Two-Way Concrete Slab Action



one-way slab action



two-way slab action with beams

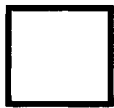


two-way slab action without beams

(From Allen, Fundamentals of Building Construction, 3rd ed., John Wiley & Sons, 1999)

10.3.3 Concrete Columns

columns can be almost any shape, but most are square, rectangular or round because of practical requirements in the layout of building walls and partitions, and ease of forming



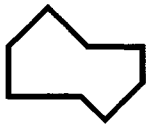
square



rectangular



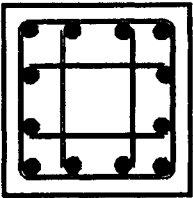
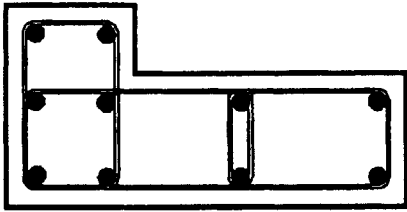
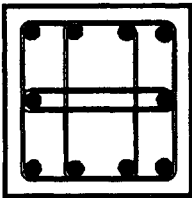
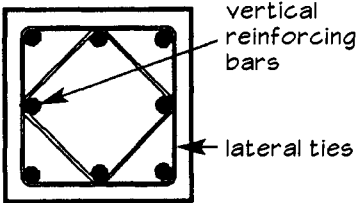
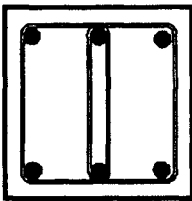
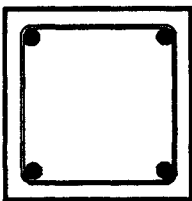
round



irregular

column shapes

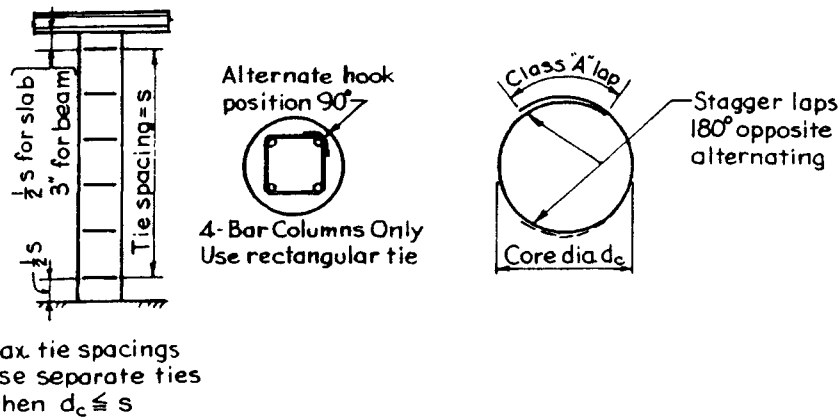
(From Workbook for Evaluating Concrete Building Designs, Concrete Reinforcing Steel Institute, 1995)



examples of vertical column reinforcement and ties

(From Schwartz, Basic Concrete Engineering for Builders, Craftsman Books, 2000)

10.3.4 Concrete Column Tie Spacing



suggested column ties

Minimum Column Tie Sizes and Spacings (in. on center)										
Column Diameter (in.)	Vertical Bar Size									
	With #3 Ties					With #4 Ties			#5 Ties	
	#5	#6	#7	#8	#9	#10	#11	#14	#18	#18
12	10	12	12	12	12	12	12	12	12	12
14	10	12	14	14	14	14	14	14	14	14
16	10	12	14	16	16	16	16	16	16	16
18	10	12	14	16	18	18	18	18	18	18
20	10	12	14	16	18	18	20	20	20	20
22	10	12	14	16	18	18	22	22	22	22
24	10	12	14	16	18	18	22	24	24	24
26	10	12	14	16	18	18	22	24	24	26
28	10	12	14	16	18	18	22	24	24	28
30	10	12	14	16	18	18	22	24	24	30
32	10	12	14	16	18	18	22	24	24	30
34	10	12	14	16	18	18	22	24	24	30
36	10	12	14	16	18	18	22	24	24	30
38	10	12	14	16	18	18	22	24	24	30
40	10	12	14	16	18	18	22	24	24	30
42	10	12	14	16	18	18	22	24	24	30
44	10	12	14	16	18	18	22	24	24	30
46	10	12	14	16	18	18	22	24	24	30
48	10	12	14	16	18	18	22	24	24	30

Maximum Column Tie Spacing*			
Vertical Bar Size	Tie Size and Spacing (in.)		
	#3	#4	#5
#5	10	—	—
#6	12	—	—
#7	14	—	—
#8	16	16	—
#9	18	18	—
#10	18	20	—
#11	**	22	22
#14	**	24	27
#18	**	24	30

* Maximum spacing not to exceed least column dimension.
** Not allowed.

(From CRSI Handbook, Concrete Reinforcing Steel Institute, 1992)

The diagram illustrates the nomenclature for flat plate panels in a 4x4 grid. The top-left corner is labeled 'A' in a circle, and the first column is labeled '1' in a circle. The grid is divided by 'edge column centerline' lines. The panels are labeled as follows:

C	EC	E	E
EC	IC	IE	IE
E	IE	I	I
E	IE	I	I

Legend:

- E: edge
- EC: edge-corner
- C: corner
- I: interior
- IC: interior corner
- IE: interior edge

panel types - location plan

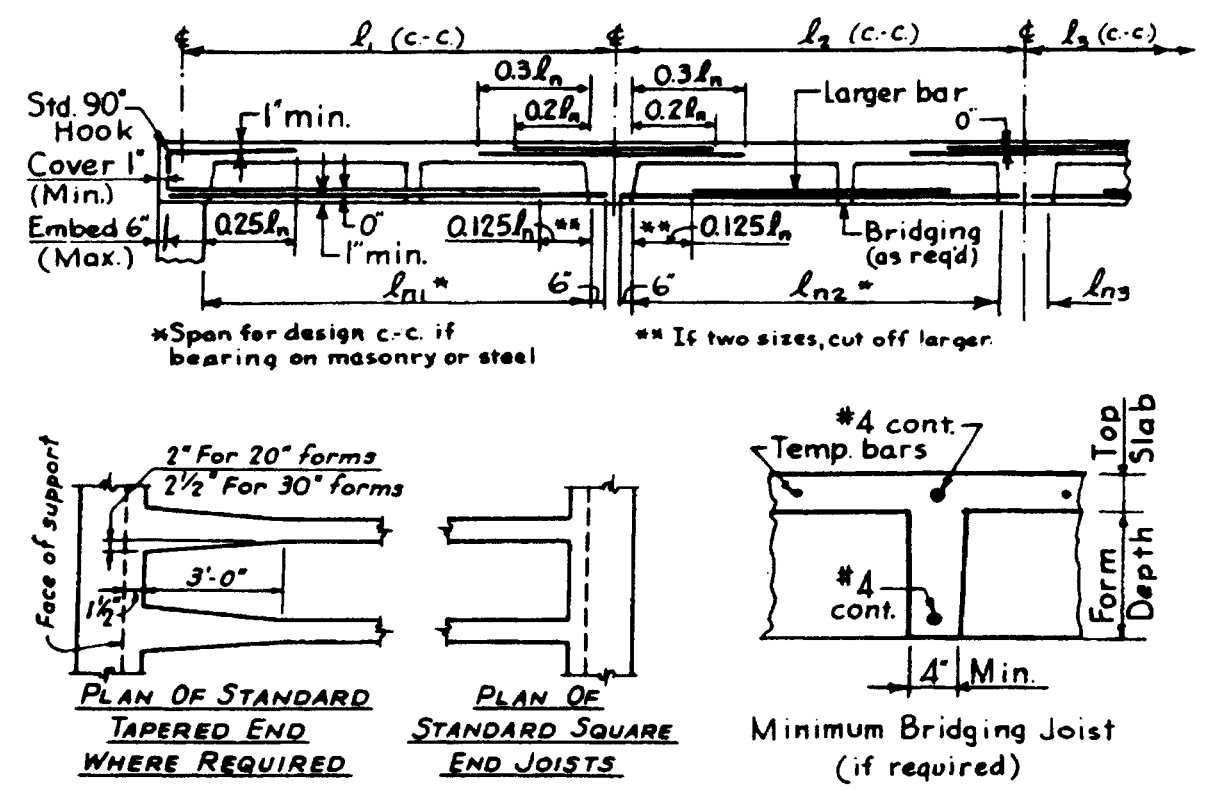
flat plate panel nomenclature

Diagram illustrating the reinforcement details for a continuous beam over two supports. The beam is divided into three segments: two outer segments of length $0.30l_n$ and a central segment of length $0.30l_n$. The total length is $1.00l_n$. The clear span is labeled $l_n = \text{Clear Span}$. The reinforcement is provided in two layers. The top layer has a maximum spacing of $0.125l'$ and a minimum of $3"$. The bottom layer has a maximum spacing of $0.125l'$ and a minimum of $3"$. The clear span is labeled $l_n = \text{Clear Span}$. The face of the supports is indicated by dashed lines.

Diagram illustrating the development length of reinforcement bars in a continuous beam over a support. The diagram shows two adjacent spans, l_n and l'_n , with clear spans. The reinforcement bars are shown with lap joints. The required lap length is indicated as $0.15l$ and $0.15l'$. The development length is indicated as $0.22l_n$ and $0.22l'_n$. The diagram also shows the 'Face' of the support and the 'Clear' distance from the support face to the start of the development length.

Note: Top bars must be concentrated within 1.5h width over the column. Integrity steel is required.

10.3.7 Concrete Slabs With One-Way Joists and Multiple Spans



recommended bar details for one-way joists with multiple spans

Temperature and Shrinkage Reinforcement for One-Way Joists			
Top Slab Thickness (in.)	Grade 60 Bars	Welded Wire Fabric [§]	
		One-Way [†]	Square
2-1/2	#3 @ 12 in. o.c. [‡]	4 x 12-W2.1 x W1.4	6 x 6-W2.9 x W2.9
3	#3 @ 15 in. o.c. [‡]	4 x 12-W2.1 x W1.4	6 x 6-W4 x W4
3-1/2	#3 @ 17 in. o.c.	4 x 12-W2.5 x W1.4	6 x 6-W4 x W4
4	#3 @ 15 in. o.c.	4 x 12-W3 x W2	4 x 4-W2.9 x W2.9
4-1/2	#3 @ 12 in. o.c.	4 x 12-W3.5 x W2	4 x 4-W3.5 x W3.5

§ Commonly available wire sizes.
† Larger diameter wires placed normal to span of joists.
‡ Maximum spacing permitted by ACI (five times slab thickness ≤ 18 in.).

10.3.8 Reinforcement and Deflection Limits for One-Way Slabs

Maximum Bar Spacings for One-Way Slabs						
Bar Size	Interior Exposure				Exterior Exposure	
	3/4 in. Cover d_c (in.)	Maximum Spacing, s (in.)	1 in. Cover d_c (in.)	Maximum Spacing, s (in.)	1-1/2 in. Cover, d_c (in.)	Maximum Spacing, s (in.)
#3	0.94	45*	1.19	28*	1.68	8
#4	1.00	40*	1.25	25*	1.75	7
#5	1.06	35*	1.31	23*	1.81	6
#6	1.13	31*	1.38	21*	—	—
#7	1.19	28*	1.44	19*	—	—
#8	1.25	25*	1.50	17	—	—
#9	1.31	23*	1.56	16	—	—
#10	1.39	21*	1.64	15	—	—
#11	1.46	19*	1.71	13	—	—

* Maximum spacings limited to 18 in. or 3 x thickness, whichever is smaller.

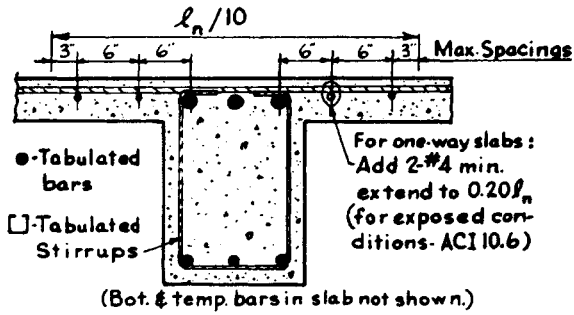
Minimum Thickness* of One-Way Slabs				
Member	Simply Supported	One End Continuous	Both Ends Continuous	Cantilever
Solid slabs	$\ell/20$	$\ell/24$	$\ell/28$	$\ell/10$
Beams or joists	$\ell/16$	$\ell/18.5$	$\ell/21$	$\ell/8$

* Members not supporting or attached to partitions or other construction likely to be damaged by large deflections.

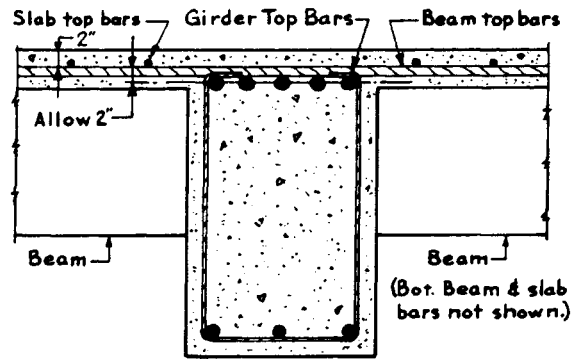
Notes: Values are for normal weight concrete and Grade 60 reinforcement.

ℓ = center-to-center spans.

10.3.9 Concrete Beams and Girders



typical beam section at support



Note: Top bars of beam & slab form two-way mat for exposure (ACI 10.6).

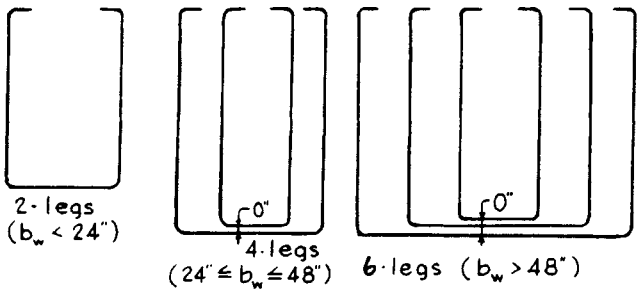
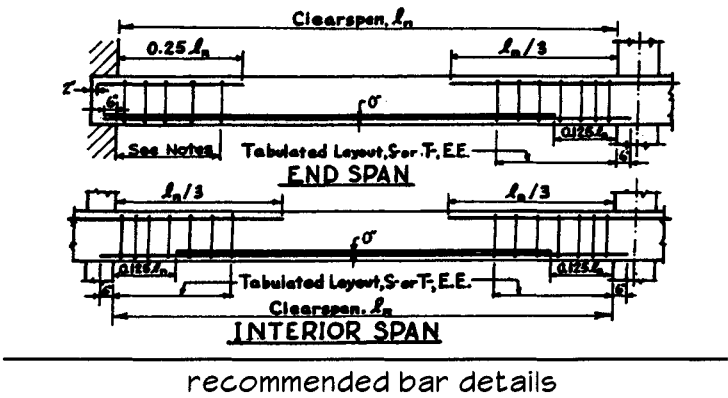
typical girder section at support

Clear Spans for Various Beam Dimensions

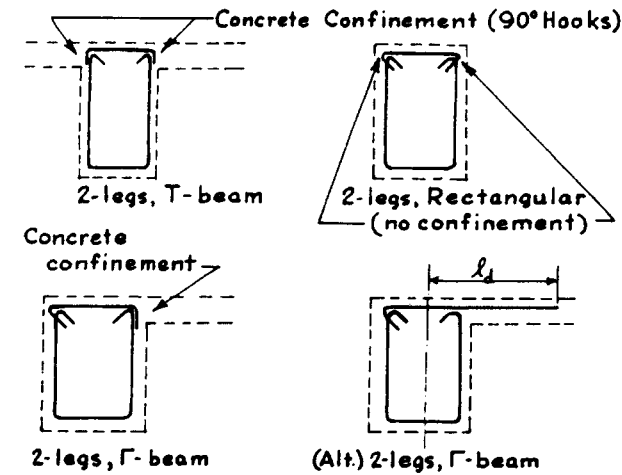
Depth, h (in.)	Widths, b (in.)	Clear Spans (ft.)
Regular Beams		
12	8, 10, 12	12, 14, 16, 18, 20, 22, 24
14	8, 10, 12	12, 14, 16, 18, 20, 22, 24
16	10, 12, 14	16, 18, 20, 22, 24, 26, 28
18	10, 12, 14	16, 18, 20, 22, 24, 26, 28
20	10, 12, 14, 16	20, 22, 24, 26, 28, 30, 32
22	12, 14, 16, 18	20, 22, 24, 26, 28, 30, 32
24	12, 14, 16, 18	24, 26, 28, 30, 32, 34, 36
26	14, 16, 18, 20	24, 26, 28, 30, 32, 34, 36
28	14, 16, 18, 20	26, 28, 30, 32, 34, 36, 38
30	14, 16, 18, 20	26, 28, 30, 32, 34, 36, 38
32	16, 18, 20, 24	32, 34, 36, 38, 40, 42, 44
34	16, 18, 20, 24	32, 34, 36, 38, 40, 42, 44
36	16, 18, 20, 24	36, 38, 40, 42, 44, 46, 48
42	20, 24, 30, 36	36, 38, 40, 42, 44, 46, 48
48	24, 30, 36, 42	40, 42, 44, 46, 48, 50, 52
Joist-Band (Wide) Beams		
12-1/2	24, 36, 48	12, 14, 16, 18, 20, 22, 24
14-1/2	24, 36, 48	12, 14, 16, 18, 20, 22, 24
16-1/2	24, 36, 48	12, 14, 16, 18, 20, 22, 24
18-1/2	24, 36, 48	18, 20, 22, 24, 26, 28, 30
20-1/2	24, 36, 48	18, 20, 22, 24, 26, 28, 30
24-1/2	24, 36, 48	18, 20, 22, 24, 26, 28, 30

(From CRSI Handbook, Concrete Reinforcing Steel Institute, 1992)

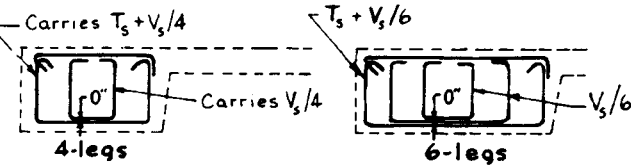
10.3.10 Reinforcement for Concrete Beams and Girders



(a) Open stirrups for shear plus torsion ($v_{tu} \leq 1.5\sqrt{f'_c}$)



In the absence of specific ACI Code limitations on maximum beam widths for 2-4-6 stirrup leg combinations, the limits shown at left were applied by CRSI. Users should apply their best judgment to set maximum width limits for their designs.

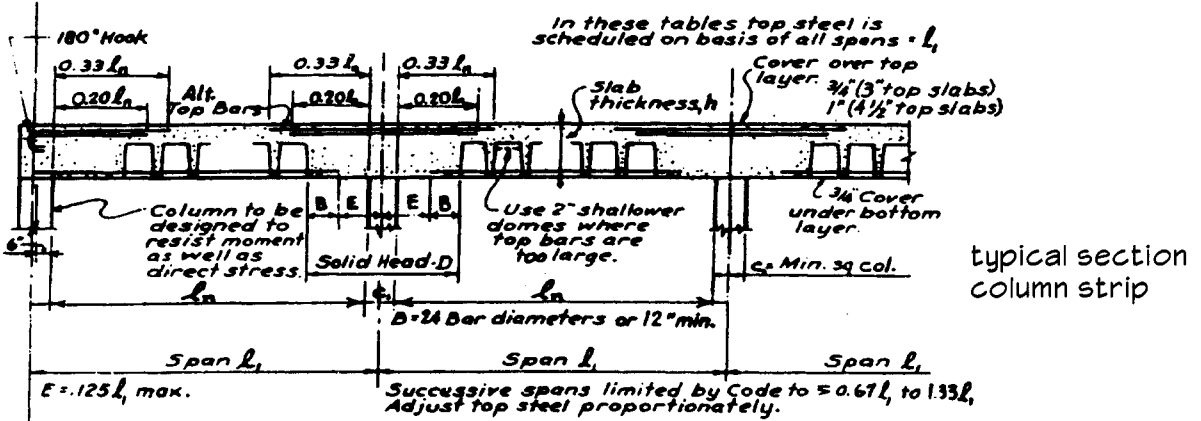
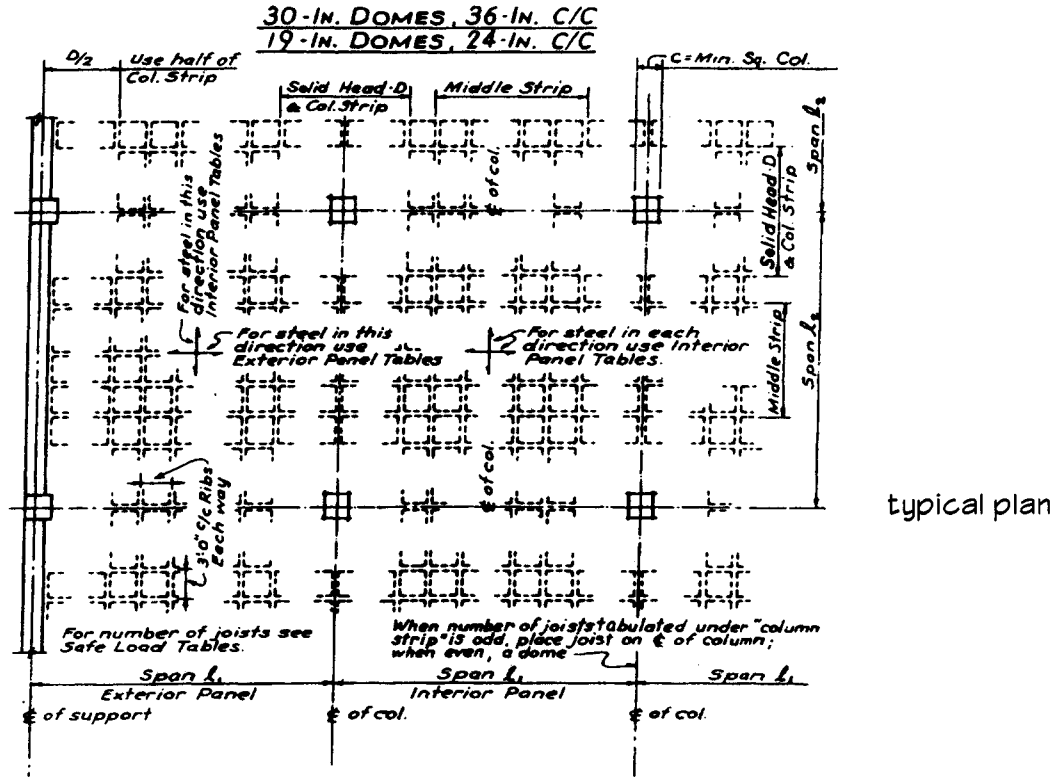


stirrups for concrete beams and girders

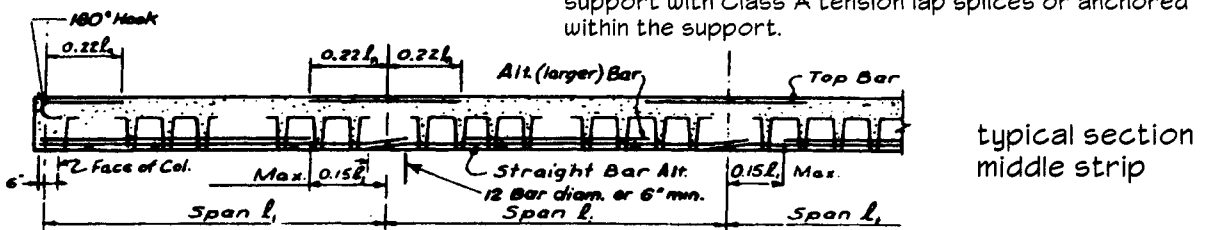
Multiple (interior) stirrups + (outside) Tie
(b) Various closed two-piece "stirrup-ties" (required only with torsion where $1.5\sqrt{f'_c} < v_{tu} \leq 4\sqrt{f'_c}$. For $b_w \geq 24''$, add interior open stirrups as req'd above

(From CRSI Handbook, Concrete Reinforcing Steel Institute, 1992)

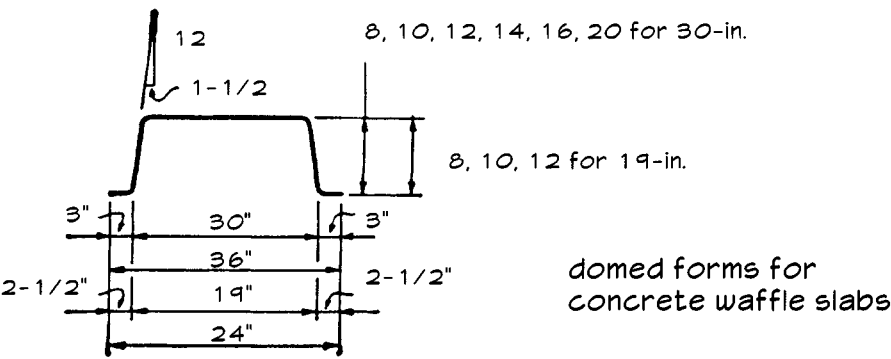
10.3.11 Reinforcement for Concrete Waffle Slabs



Integrity steel is required. At least two bottom bars in the column strip must be continuous or spliced at the support with Class A tension lap splices or anchored within the support.



10.3.12 Dome Forms for Concrete Waffle Slabs



Data on Dome Forms						
Depth (in.)	Volume (cu.ft./dome)	Weight of Displaced Concrete (lb/dome)	3-in. Top Slab		4-1/2-in. Top Slab	
			Equivalent Slab Thickness (in.)	Weight (psf)	Equivalent Slab Thickness (in.)	Weight (psf)
30-in. Wide Domes						
8	3.85	578	5.8	73	7.3	92
10	4.78	717	6.7	83	8.2	102
12	5.53	830	7.4	95	9.1	114
14	6.54	980	8.3	106	9.9	120
16	7.44	1116	9.1	114	10.6	133
20	9.16	1375	10.8	135	12.3	154
19-in. Wide Domes						
8	1.41	211	6.8	85	8.3	103
10	1.90	285	7.3	91	8.8	111
12	2.14	321	8.6	107	10.1	126

Note: Based on 150 pcf concrete weight.

(From CRSI Handbook, Concrete Reinforcing Steel Institute, 1992)

10.3.13 Concrete Floors

Floor Classifications					
Floor Type	Class	Usual Traffic	Use	Special Considerations	Concrete Finishing Technique
Single-Course	1	Light foot	Residential or tile covered	Grade for drainage; make plane for tile	Medium steel trowel
	2	Foot	Offices, churches, schools, hospitals	Nonslip aggregate; mix in surface	Steel trowel; special finish for non-slip
			Ornamental residential	Color shake, special	Steel trowel, color, exposed aggregate; wash if aggregate is to be exposed
	3	Light foot and pneumatic wheels	Drives, garage floors and sidewalks for residences	Crown; pitch; joints; air entrainment	Float, trowel and broom
	4	Foot and pneumatic wheels*	Light industrial commercial	Careful curing	Hard steel trowel and brush for non-slip
	5	Foot and wheels—abrasive wear*	Single-course industrial, integral topping	Careful curing	Special metallic or mineral aggregate, float and trowel
Two-Course	6	Foot and hard wheel vehicles—severe abrasion	Bonded two-course heavy industrial	Base: textured surface and bond Topping: special aggregate, and/or mineral or metallic surface treatment	Surface leveled by screeding Special power floats with repeated steel troweling
	7	Classes 3,4,5,6	Unbonded toppings	Mesh reinforcing; bond breaker on old concrete surface; minimum thickness 2-1/2 in.	

* Under abrasive conditions on floor surface, the exposure will be much more severe and a higher quality surface will be required for Class 4 and 5 floors. Under these conditions, a Class 6 two-course floor or a mineral or metallic aggregate monolithic surface treatment is recommended.

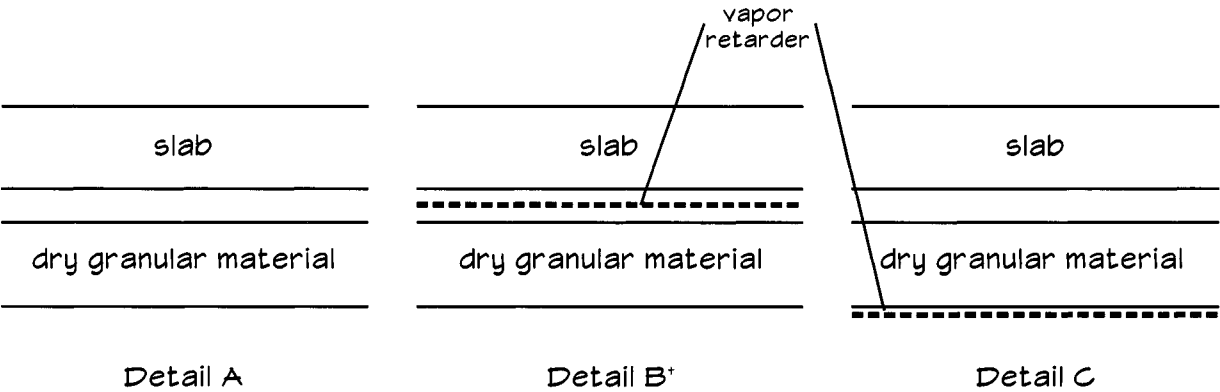
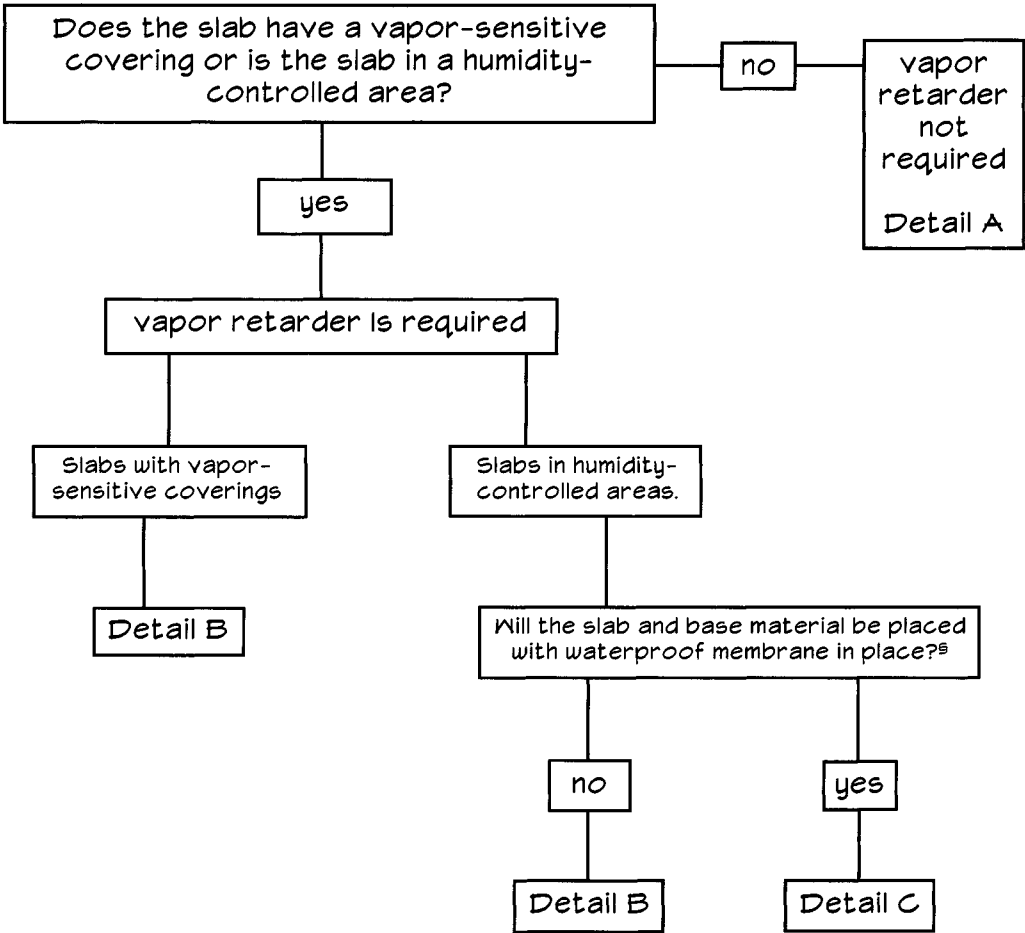
(From ACI 201.2R-92, Guide to Durable Concrete)

Minimum Cementitious-Materials Content Requirements for Concrete Floors	
Nominal Maximum Aggregate Size (in.)	Minimum Cementitious-Materials Content (lb/cu.yd)
1-1/2	470
1	520
3/4	540
3/8	610

Note: When fly ash is used, quantity shall not be less than 15% nor more than 25% by weight of total cementitious materials.

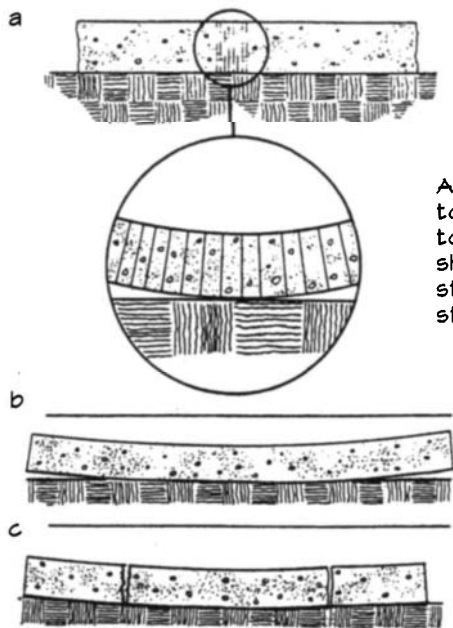
(From ACI 301-99, Specifications for Structural Concrete)

10.3.14 Vapor Retarder Placement for Concrete Slabs-On-Ground



§ If granular material is subject to future moisture infiltration, use Detail B.
+ If Detail B is used, reduced joint spacing and low-shrinkage mix design or other measures to minimize slab curl will likely be required.

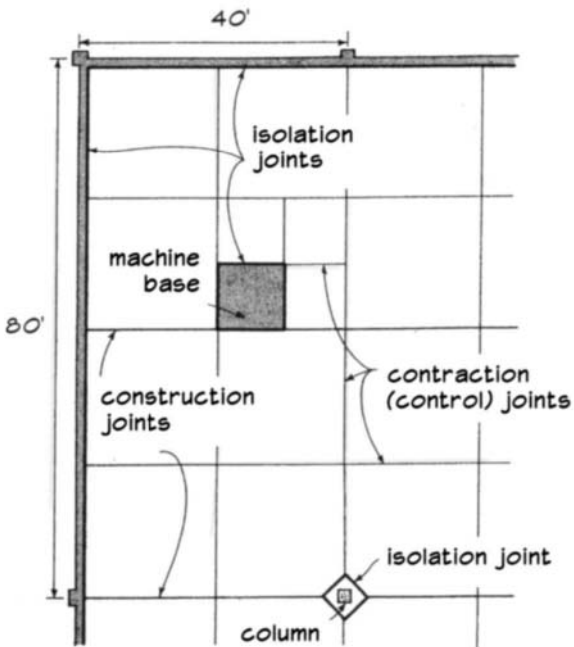
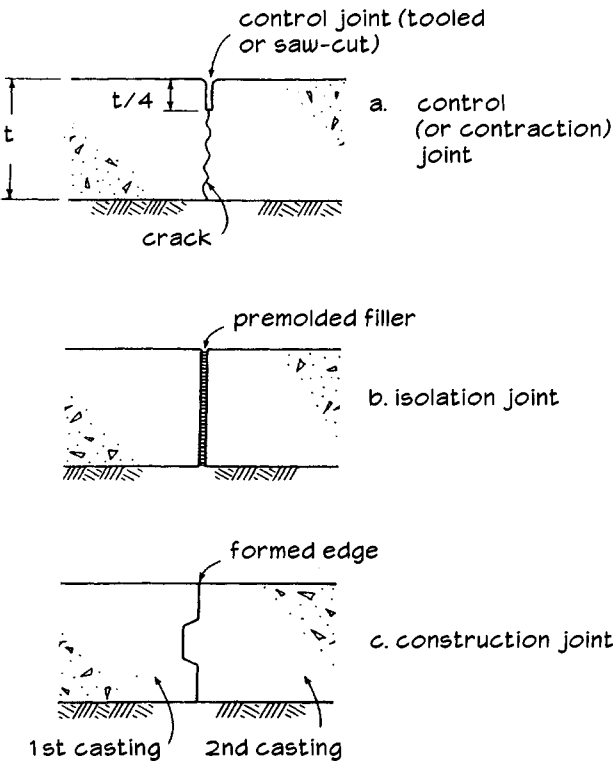
10.3.15 Joints in Concrete Slabs-On-Ground



After curing, a concrete slab-on-ground begins to dry at the top. Each vertical segment tends to narrow at the top and becomes wedge shaped (a). Then the slab curls (b). When curling stresses exceed the concrete's tensile strength, the slab cracks as shown in (c).

concrete slab curling

(From Building Movements and Joints, Portland Cement Association, 1982)

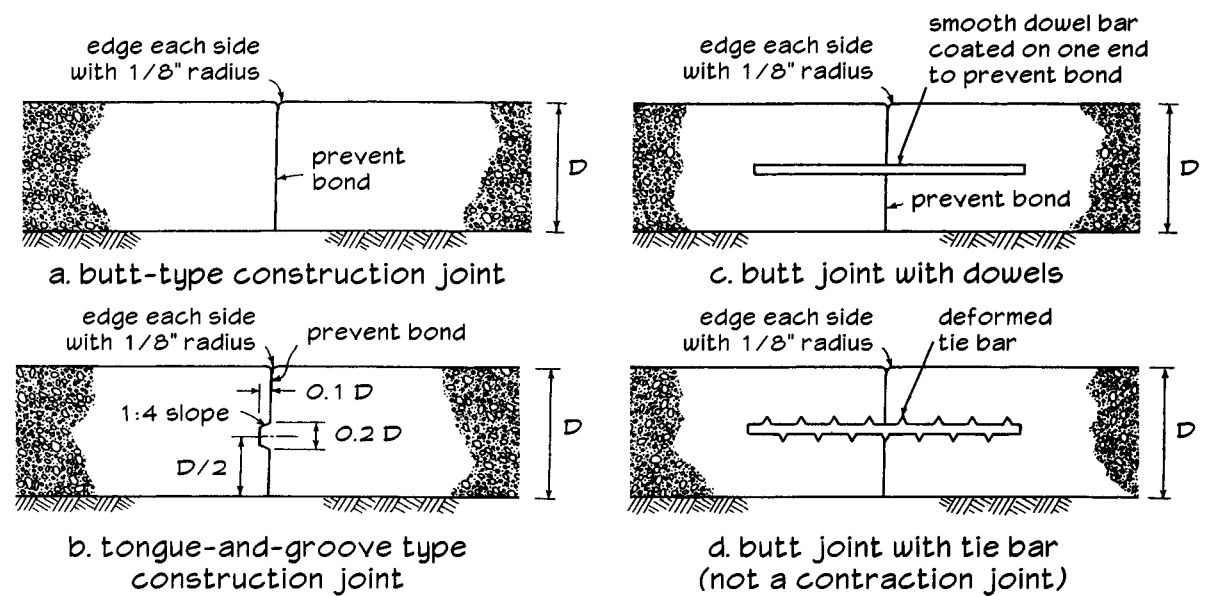


three basic types of joints

typical joint layout (8-in. slab)

(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

10.3.16 Concrete Construction Joints



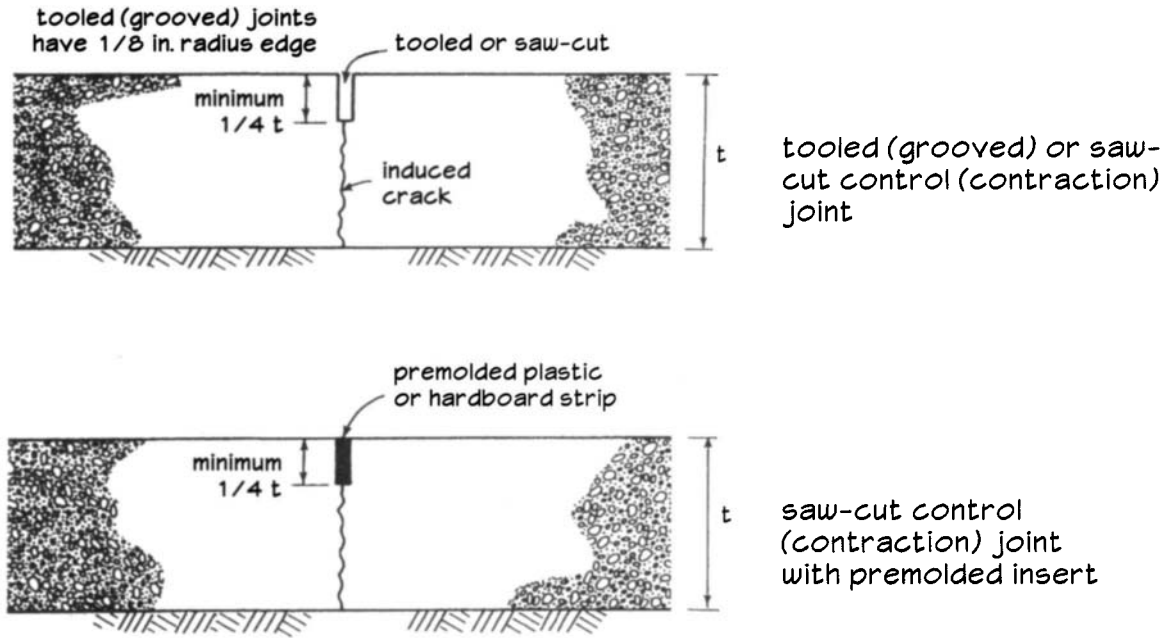
construction joints

Construction joints are stopping places in the process of construction. Construction joint types a, b, and c are also used as contraction (control) joints.

Dowel and Tie Bar Sizes and Spacings for Construction Joints			
Slab Depth (in.)	Dowel Diameter (in.) or Bar Size Number	Dowel or Bar Length (in.)	Center-To-Center Spacing (in.)
Dowels			
5	5/8	12	12
6	3/4	14	12
7	7/8	14	12
8	1	14	12
9	1-1/8	16	12
10	1-1/4	16	12
Tie Bars			
5	#4	30	30
6	#4	30	30
7	#4	30	30
8	#4	30	30
9	#5	30	30
10	#5	30	30

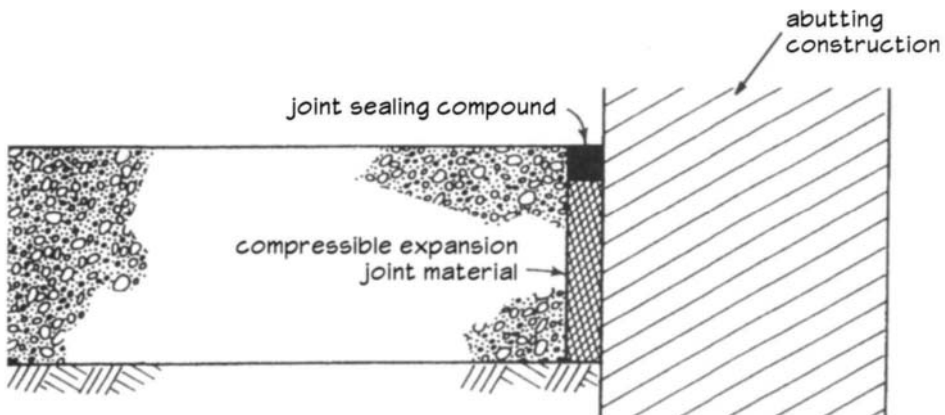
(From Design and Control of Concrete Mixtures, 13th ed., Portland Cement Association, 1990)

10.3.17 Concrete Control and Isolation Joints



control (contraction) joints

Control (contraction) joints provide for horizontal movement in the plane of a slab or wall and induce controlled cracking caused by drying shrinkage.



isolation joint

Isolation joints permit horizontal and vertical movements between abutting construction and concrete slabs.

10.3.18
Control Joint Spacing in Concrete Slabs-On-Ground

A rule of thumb for plain (unreinforced) slabs is that joint spacing should not exceed

- 24 slab thicknesses for concrete made with less than 3/4 in. maximum size coarse aggregate
- 30 slab thicknesses for concrete made with maximum size coarse aggregate larger than 3/4 in.
- 36 slab thicknesses for low-slump concrete

For reinforced slabs-on-ground, joint spacing normally varies from 30 to 80 ft. The percentage of reinforcement increases with an increase in joint spacing. In a continuously reinforced concrete slab that is without joints except for construction and isolation joints where needed, the percentage of distributed reinforcing steel is 0.6 and higher.

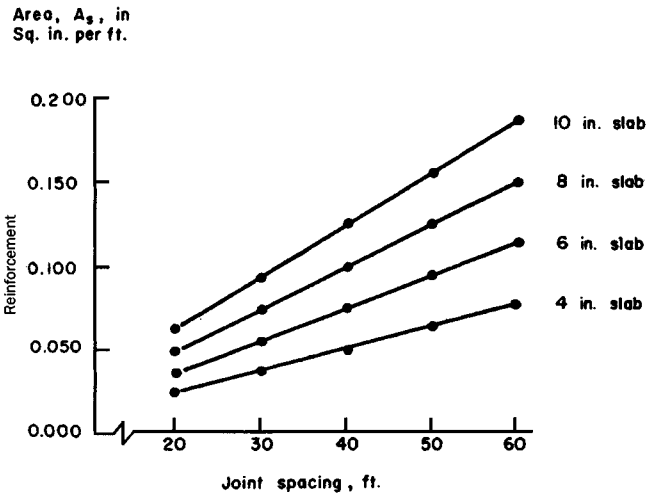
Slabs with joint spacings longer than those in the table usually will crack in the middle with the cracks generally held tightly closed by the reinforcement. The amount of steel (see graph) needed to hold a crack tight can be calculated using this subgrade-drag-method equation.

$$A_s = \frac{WFL}{2f_s}$$

- where A_s = required cross-sectional area of steel in square inches per foot of width of slab
- W = weight of slab only, psf
- F = coefficient of resistance to movement (generally assumed to be 1.5 but can vary from about 1.0 to 2.5)
- f_s = allowable stress in steel, commonly assumed to be 30,000 psi for welded wire fabric
- L = length of slab between free ends (a free end is any joint where horizontal movement is permitted)

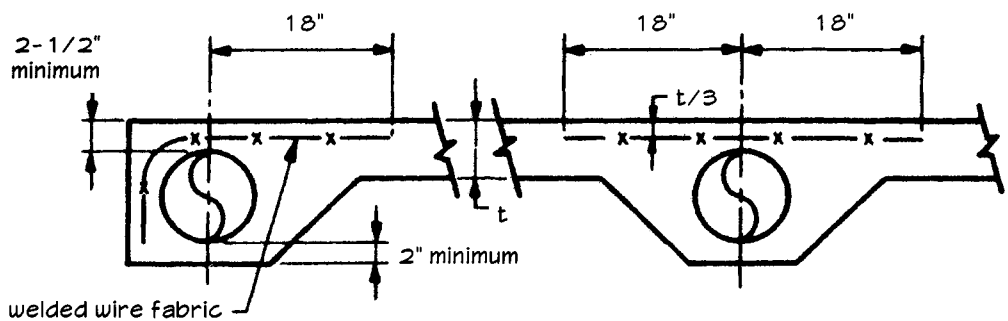
To be effective in controlling cracks, the steel must be positioned at or above the mid-depth of the slab. Distributed steel placed in a slab-on-ground for crack control does not increase significantly the load-carrying capacity of the floor.

Slab Thickness (in.)	Recommended Control Joint Spacing (Ft.)		
	Slump Greater Than 4 in.		Slump less than 4 in.
	Max. Agg. Size Less Than ¾ in.	Max. Agg. Size ¾ in. and larger	
4	8	10	12
5	10	13	15
6	12	15	18
7	14	18	21
8	16	20	24
9	18	23	27
10	20	25	30



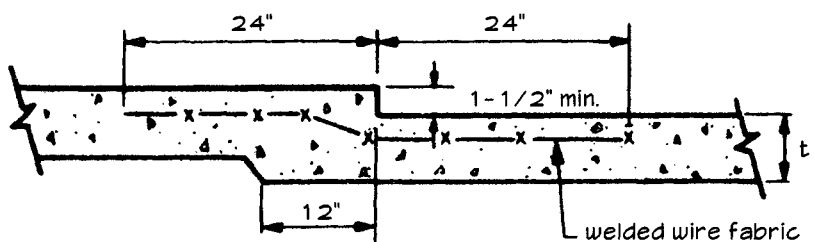
(From Building Movements and Joints, Portland Cement Association, 1982)

10.3.19 Concrete Slab-On-Ground Discontinuities

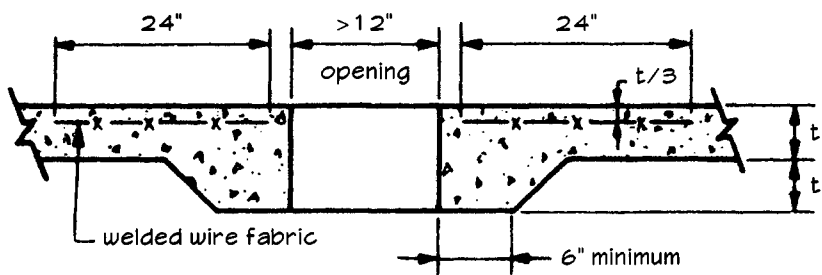


slab with reinforcement at ducts

Note: welded wire fabric or #3 bars at 18 in. on center each way

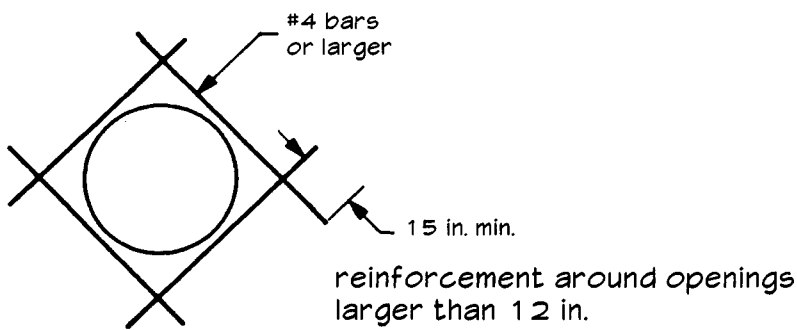


slab with reinforcement at depression



slab with reinforcement at openings

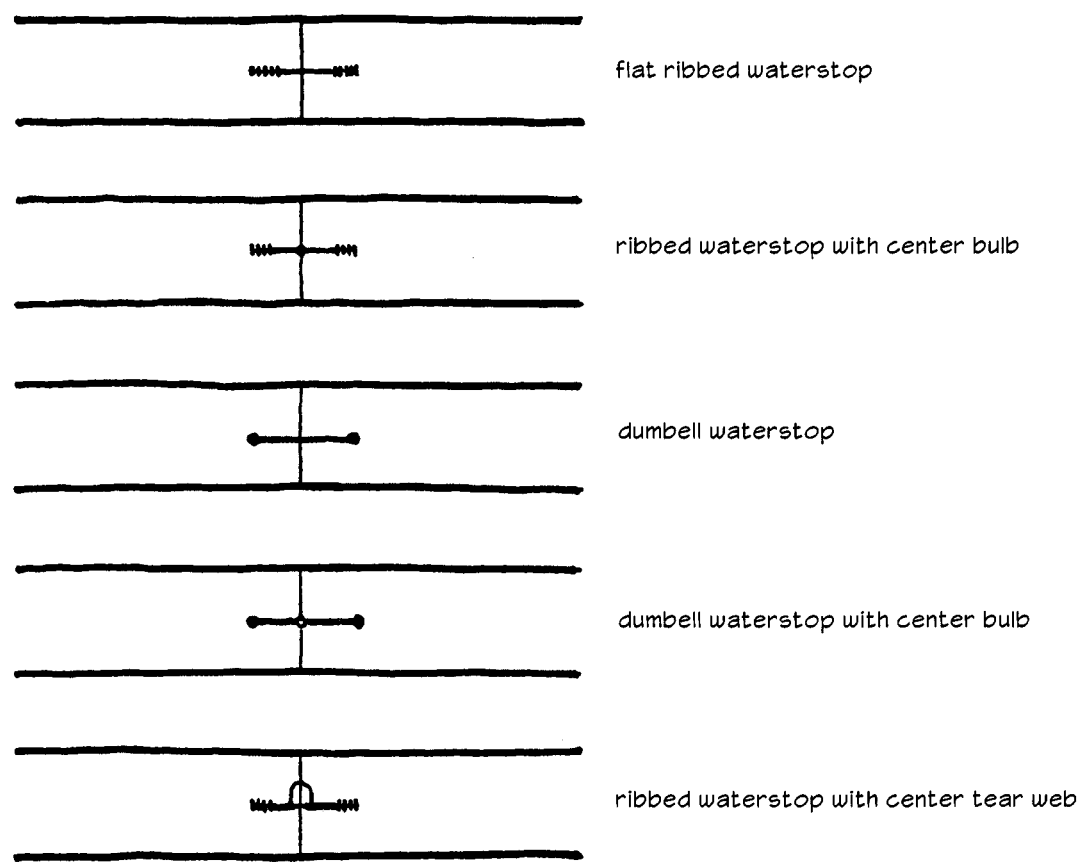
details for residential type slabs-on-ground



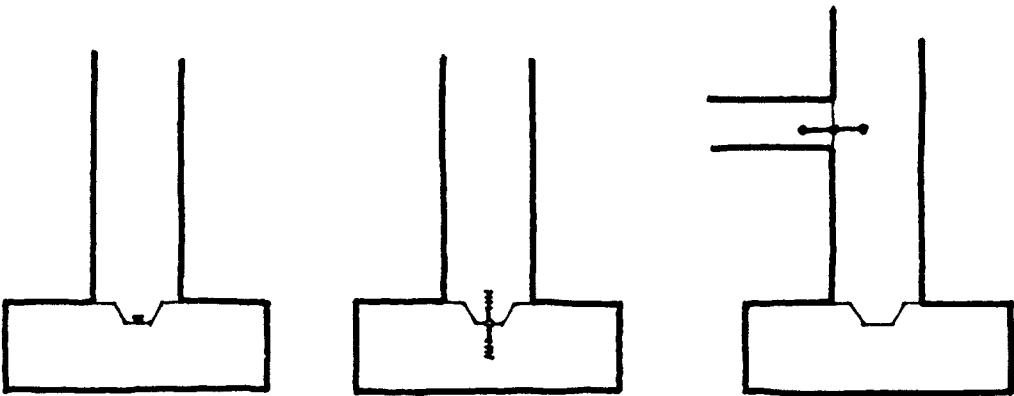
reinforcement around openings larger than 12 in.

(From ACI 332R-84 Reapproved 1999 Guide to Residential Cast-In-Place Concrete Construction)

10.3.20 Waterstops for Concrete Slabs-On-Ground and Foundation Walls



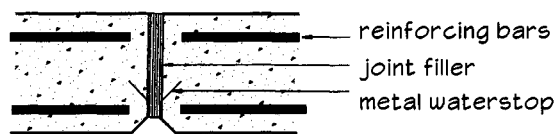
waterstops in slabs-on-ground



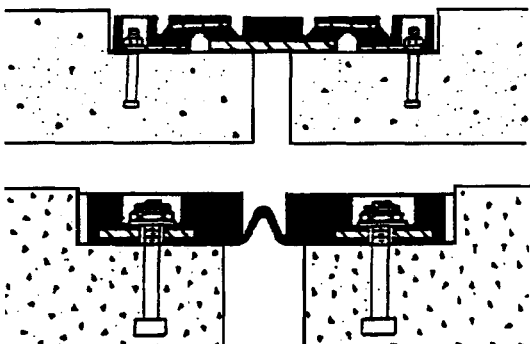
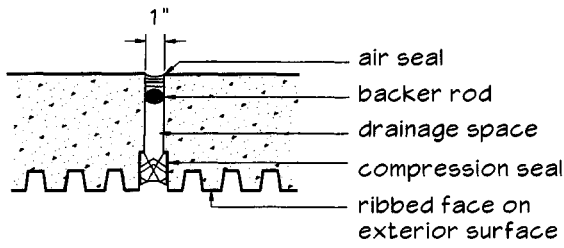
waterstops in concrete foundation walls

(From Beall, Thermal and Moisture Protection Manual, McGraw-Hill, 1999)

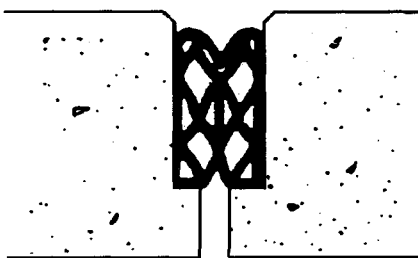
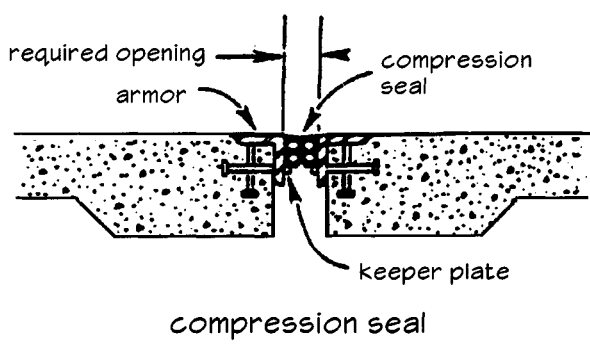
10.3.21 Expansion Joints in Concrete



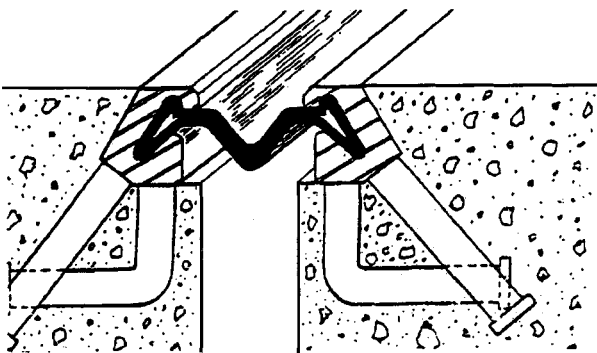
vertical expansion joints
in concrete walls



steel-reinforced modular seal



compression seal



strip or membrane seal

expansion joints in concrete slabs

(From ACI 224.3R-95 Joints in Concrete Construction)

10.4.1 Shotcrete Strength and Characteristics

Bond Strength of Shotcrete		
Sample Number	Compressive Strength of Shotcrete Cores (psi)	Bond Strength in Shear (psi)
A. Dry-Mix Shotcrete On Old Concrete		
1	5850	720
2	7140	598
3	5900	422
4	5410	520
5	7060	874
6	4620	411
7	4580	508
B. Dry-Mix Shotcrete On Old Wet-Mix Shotcrete		
8	4780	560
9	4360	530
10	4660	500
C. Wet-Mix Shotcrete On Old Wet-Mix Shotcrete		
11	4810	131
12		181
13	4420	243
14		220
15	4860	336

Notes: Data is from a single project. It is presented for illustrative purposes only. All tests on 6-in. diameter cores.
Concrete surface in Sections A and C prepared by sandblasting. No preparation in Section B.
Shear test conducted by "guillotine" method where load is applied parallel to the bonded surface.

Compressive Strength and Cement Factor	
Specified 28-Day Compressive Strength (psi)	Cement Factor (lb/cu.yd)
3000	500-650
4000	550-700
5000	650-850

Note: Data is for typical dry-mix shotcrete.

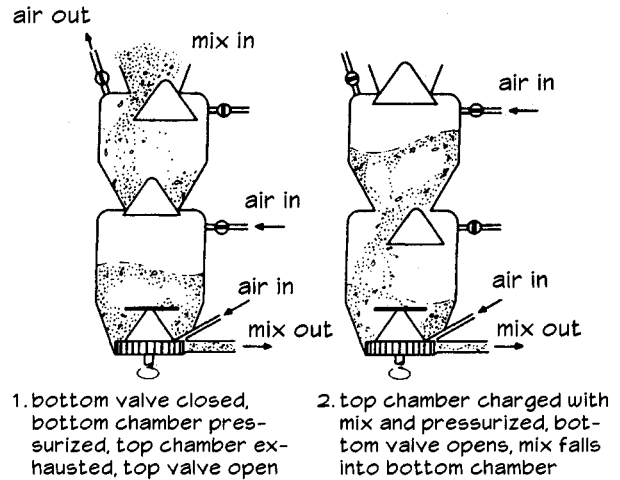
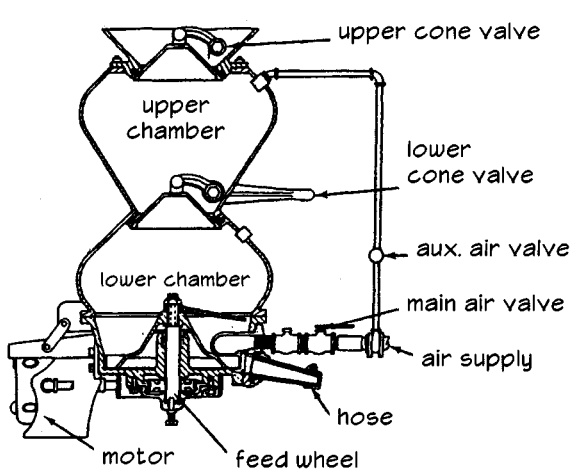
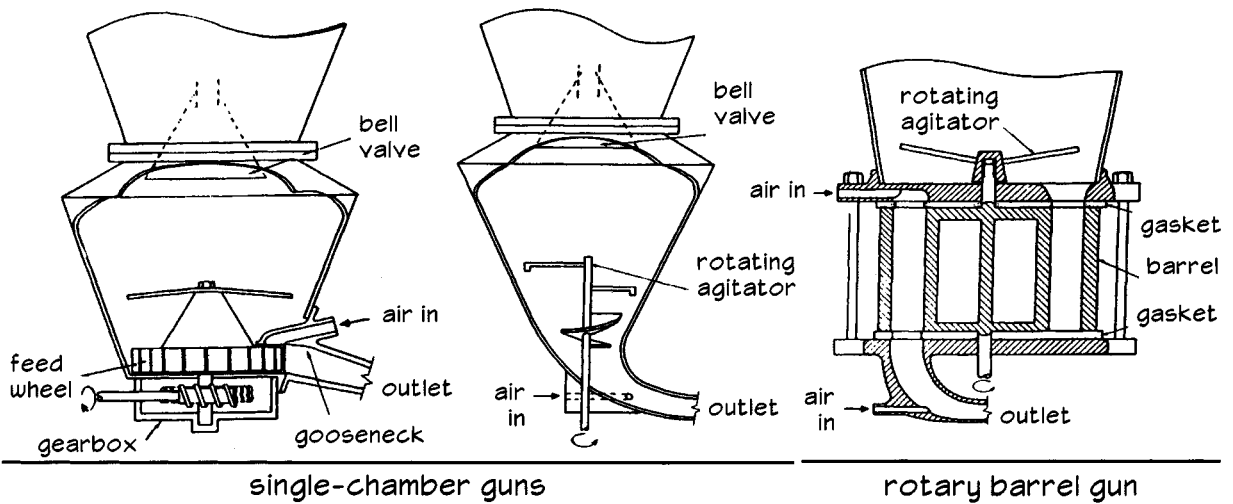
Gradation Limits for Combined Aggregates			
Sieve Size, U.S. Standard Square Mesh	Percent by Weight Passing Individual Sieves		
	Gradation No. 1	Gradation No. 2	Gradation No. 3
3/4 in.	—	—	100
1/2 in.	—	100	80–95
3/8 in.	100	90–100	70–90
No. 4	95–100	70–85	50–70
No. 8	80–100	50–70	35–55
No. 16	50–85	35–55	20–40
No. 30	25–60	20–35	10–30
No. 50	10–30	8–20	5–17
No. 100	2–10	2–10	2–10

Comparison of Dry-Mix and Wet-Mix Processes	
Dry-Mix Process	Wet-Mix Process
Instantaneous control over mixing water and mix consistency at nozzle to meet variable field conditions.	Mixing water is controlled at delivery equipment and can be accurately measured.
Better suited for placing mixes containing lightweight aggregates or refractory materials, and for shotcrete requiring early strength properties.	Better assurance that mixing water is thoroughly mixed with other ingredients.
Capable of being transported longer distances.	Less dusting and cement loss accompany the gunning operation.
Start and stop placement characteristics are better with minimal waste and greater placement flexibility.	Normally has lower rebound resulting in less material waste.
Capable of higher strengths.	Capable of greater production.

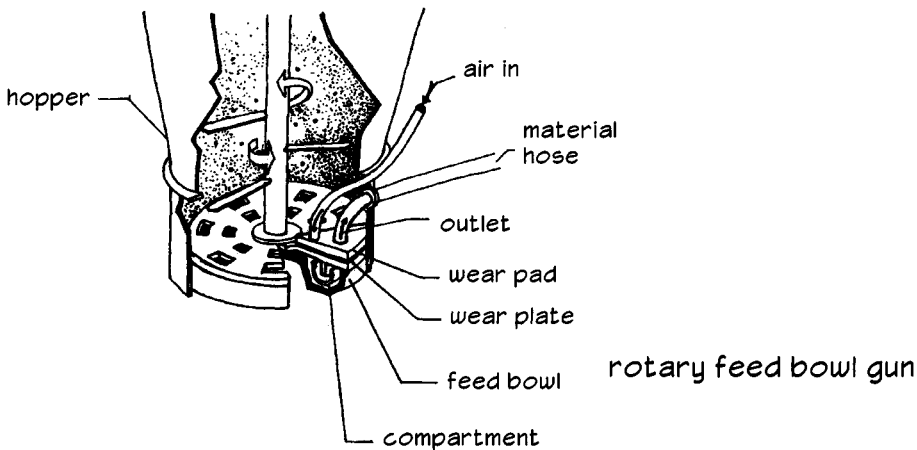
Typical Change in Ratio of Cement to Aggregate Proportions After Placement	
Nominal Mix Entering Gun	Mix In Place
1:3.0	1:2.0
1:3.5	1:2.8
1:4.0	1:3.25
1:4.5	1:3.6
1:5.0	1:3.8
1:6.0	1:4.1

(From ACI 506R-90 Reapproved 1995 Guide to Shotcrete)

10.4.2 Dry-Process Shotcrete Guns

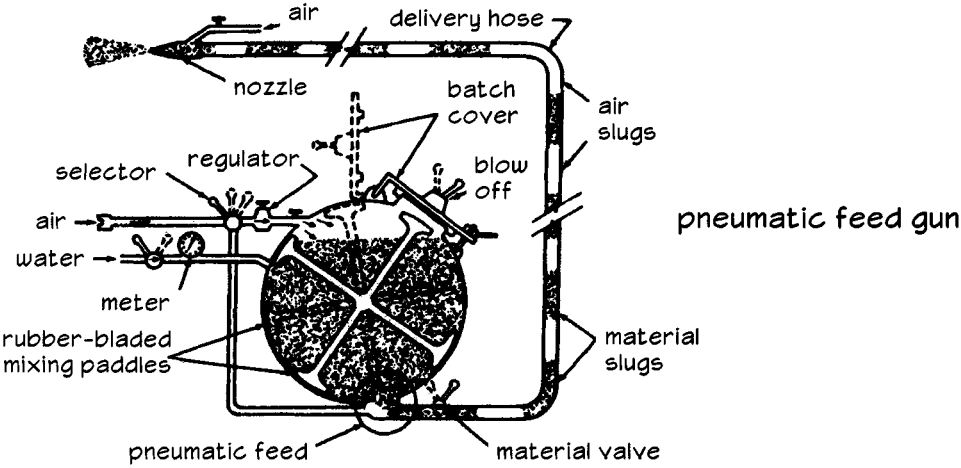


double-chamber guns

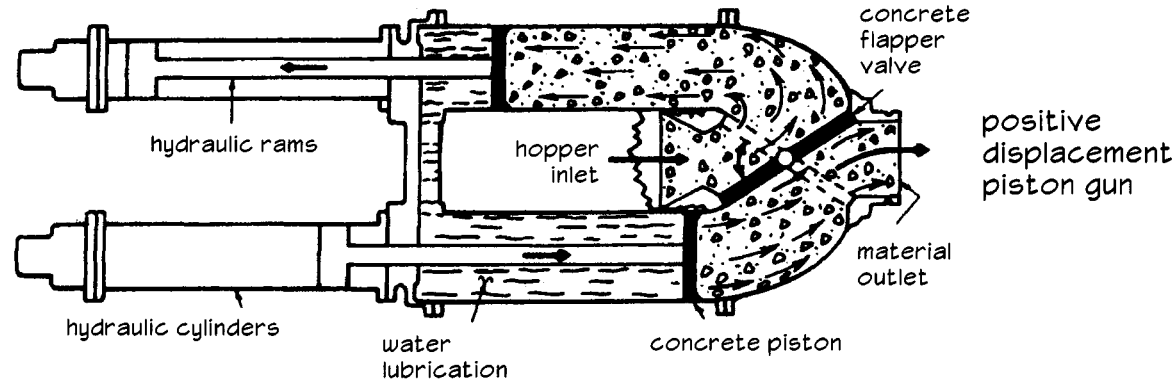
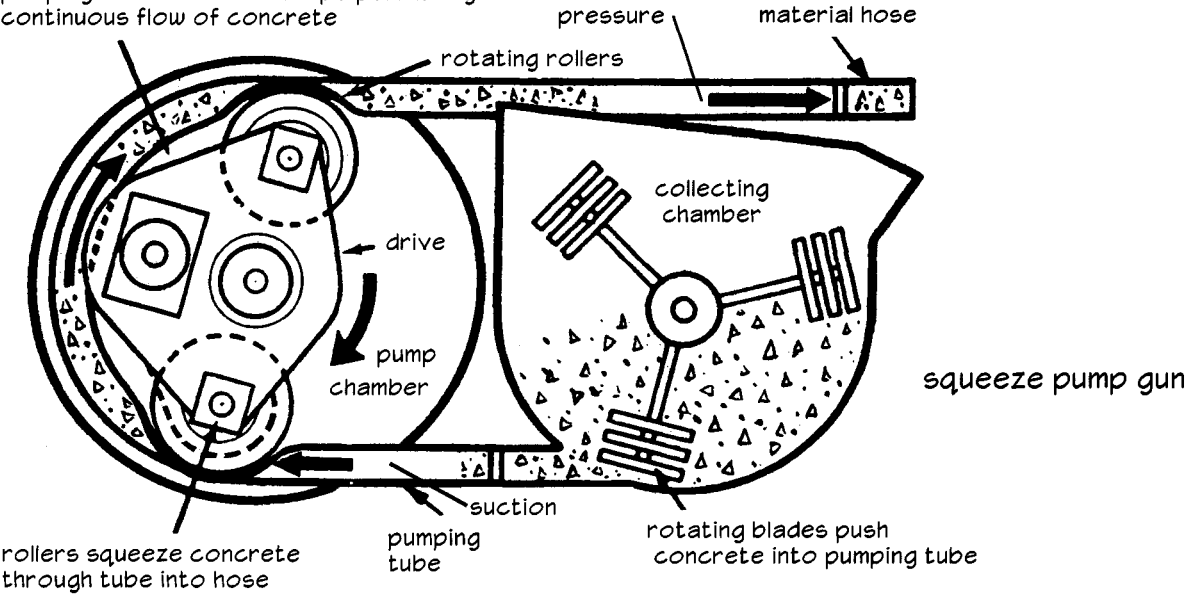


rotary feed bowl gun

10.4.3 Wet-Process Shotcrete Guns

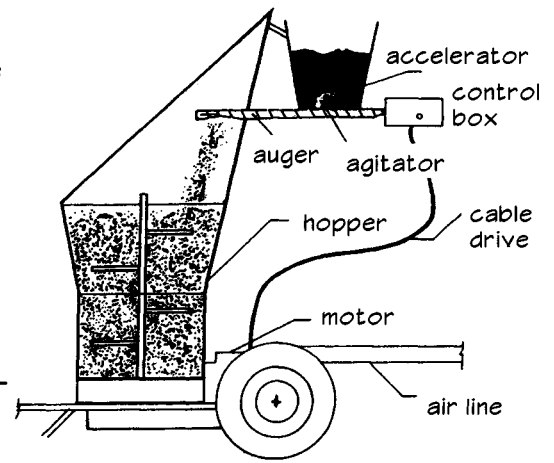
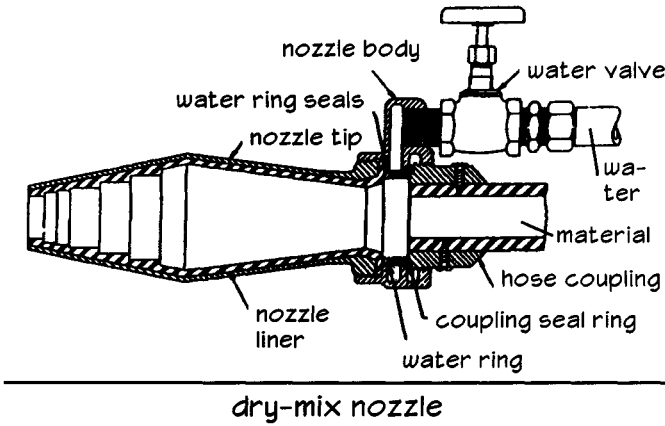


vacuum inside pump chamber restores
pumping tube to normal shape permitting
continuous flow of concrete

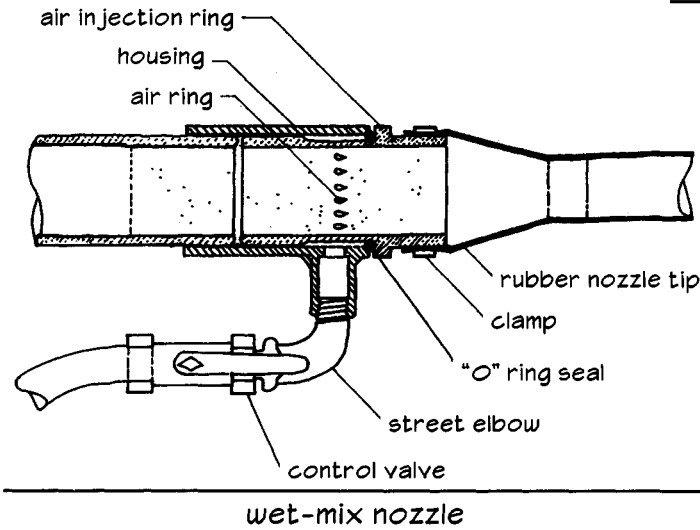


(From ACI 506R-90 Reapproved 1995 Guide to Shotcrete)

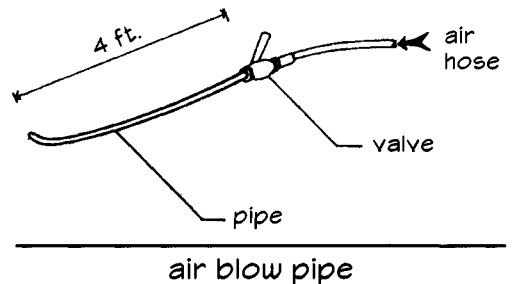
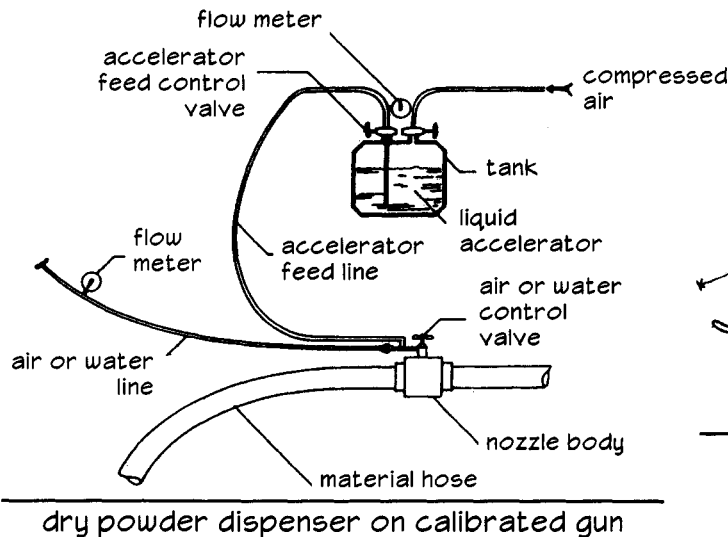
10.4.4 Shotcrete Hoses and Nozzles



liquid accelerator system
wet- or dry-mix process



Compressor Capacities and Hose Diameters	
Material Hose Inside Diameter (in.)	Compressor Capacity (cfm @ 100 psi)
1	350
1-1/4	450
1-1/2	600
2	750
2-1/2	1000



Precast and Prestressed Concrete

- | | | | |
|---------|--|---------|---|
| 11.1 | Precast Concrete Concepts | 11.2.8 | One-Stage Sealant Joints |
| 11.1.1 | Common Precast and Prestressed Concrete Products | 11.2.9 | Two-Stage Sealant Joints |
| 11.1.2 | Prestressed Concrete Concepts | 11.2.10 | Joint Sealants |
| 11.1.3 | Single-Story Precast Bearing Wall Construction | 11.2.11 | Fire-Resistant Joints |
| 11.1.4 | Multi-Story Precast Loadbearing Construction | 11.3 | Handling and Erection Concepts |
| 11.1.5 | Precast Beam-Column Construction | 11.3.1 | Handling Precast Concrete Panels |
| 11.1.6 | Terminology of Precast Concrete Units | 11.3.2 | Handling and Transporting Precast Panels |
| 11.1.7 | Precast Concrete Molds | 11.3.3 | Loading and Safety Factors for Handling Precast Concrete |
| 11.1.8 | Typical Precast Wall Systems | 11.4 | Reinforcing Concepts |
| 11.1.9 | Precast Panel Arrangement and Detailing | 11.4.1 | Precast/Prestressed Concrete Reinforcing Requirements |
| 11.1.10 | Precast and Prestressed Panel Shapes | 11.4.2 | Pretensioning Strand Requirements |
| 11.1.11 | Precast Panel Drafts, Transitions and Demarcations | 11.4.3 | Prestressing Tendons |
| 11.1.12 | Aggregate Facings for Precast Panels | 11.4.4 | Tendon Hold-Down Device |
| 11.1.13 | Mitered Corners on Precast Panels | 11.5 | Connection Concepts |
| 11.1.14 | Precast Panel Corner Details and Construction Tolerances | 11.5.1 | Precast Panel Connection Concepts |
| 11.1.15 | Typical Molds and Finishes for Backs of Precast Panels | 11.5.2 | Panel Connection Dimensions, Alignment and Adjustable Inserts |
| 11.1.16 | Precast/Prestressed Concrete Deflection and Camber | 11.5.3 | Force Transfers in Precast Panel Connections |
| 11.1.17 | Effective Thickness of Precast Panels | 11.5.4 | Deformations, Distortion and Cracking in Precast Panels |
| 11.1.18 | Prestressed Concrete Beams | 11.5.5 | Forces Required to Restrain Bowing |
| 11.1.19 | Precast Double Tee Beam with Deflected Tendons | 11.5.6 | Deflection Limits for Precast Wall Panels |
| 11.1.20 | Bridge Beam with Overhanging Span | 11.5.7 | Spandrel Connections |
| 11.2 | Environmental Performance Concepts | 11.5.8 | Double Tee Connections |
| 11.2.1 | Solar Shading With Precast Concrete Panels | 11.5.9 | Direct Bearing Connections |
| 11.2.2 | Rain Wetting and Marking Patterns | 11.5.10 | Eccentric Bearing Connections |
| 11.2.3 | Drips on Precast Panels | 11.5.11 | Bolted and Welded Tie-Back Connections |
| 11.2.4 | Directing Water Flow on Precast Panels | 11.5.12 | Welded Tie-Back Connections |
| 11.2.5 | Surface Sealers for Precast Concrete | 11.5.13 | Bolted and Welded Alignment Connections |
| 11.2.6 | Architectural Features of Precast Panel Joints | 11.5.14 | Column and Beam Cover Connections |
| 11.2.7 | Joints Accommodating Tolerances and Finishes | 11.5.15 | Soffit Hanger and Masonry Tie-Back Connections |
| | | 11.5.16 | Seismic Shear Plate Connections |
| | | 11.5.17 | Unique Conditions and Connections |

11.2 Section 11 Precast and Prestressed Concrete

- 11.5.18 Wall-To-Foundation Connections
- 11.5.19 Slab-To-Wall Connections
- 11.5.20 Wall-To-Wall Connections

11.6 Tolerance Concepts

- 11.6.1 Panel Warping and Bowing
- 11.6.2 Precast Panel Clearances, Smoothness and Bowing
- 11.6.3 Concrete and Steel Construction Tolerances
- 11.6.4 Precast Concrete Tolerances
- 11.6.5 Fabrication Tolerances for Precast Columns
- 11.6.6 Fabrication Tolerances for Hollow Core Slabs Used as Wall Panels
- 11.6.7 Fabrication Tolerances for Ribbed Precast Panels Used as Wall Panels
- 11.6.8 Fabrication Tolerances for Architectural Panels, Spandrels, and Column Covers
- 11.6.9 Erection Tolerances for Precast Beams and Spandrels
- 11.6.10 Erection Tolerances for Precast Floor and Roof Members

- 11.6.11 Erection Tolerances for Precast Columns
- 11.6.12 Erection Tolerances for Architectural Wall Panels
- 11.6.13 Erection Tolerances for Precast Structural Wall Panels
- 11.6.14 Unintended Mode of Support for Prestressed Concrete

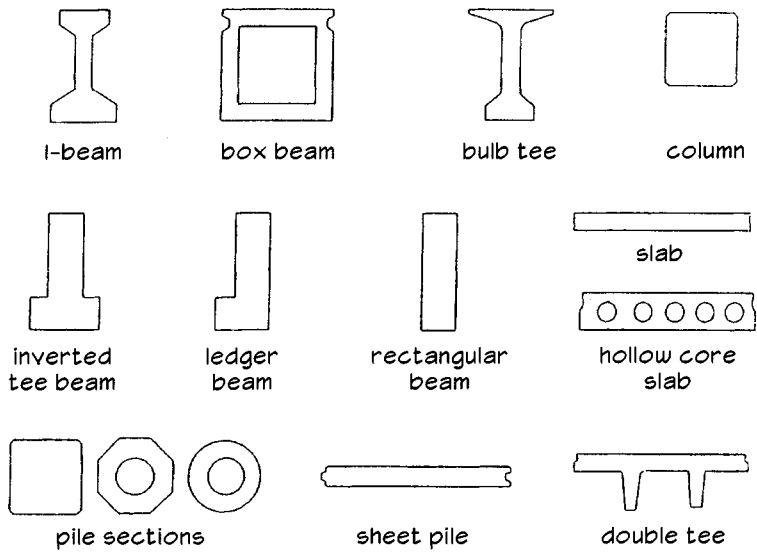
11.7 Insulated Concrete Panels

- 11.7.1 Insulation for Precast Wall Panels
- 11.7.2 Connectors for Insulated Precast Concrete Sandwich Panels
- 11.7.3 Connector Arrangement and Thermal Bridges

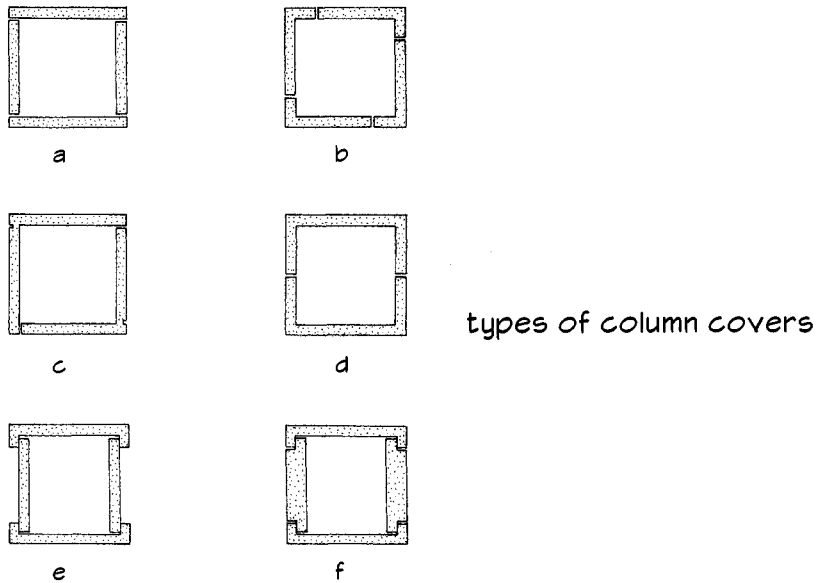
11.8 Composite Panels, GFRC, and Cast Stone

- 11.8.1 Veneer Faced Composite Precast Panels
- 11.8.2 Typical Anchor Details for Attaching Stone Veneer to Precast
- 11.8.3 GFRC Panels
- 11.8.4 Cast Stone

11.1.1 Common Precast and Prestressed Concrete Products

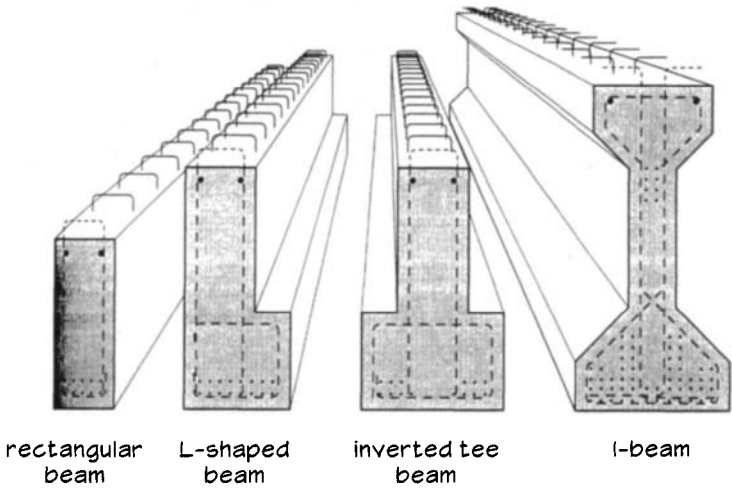
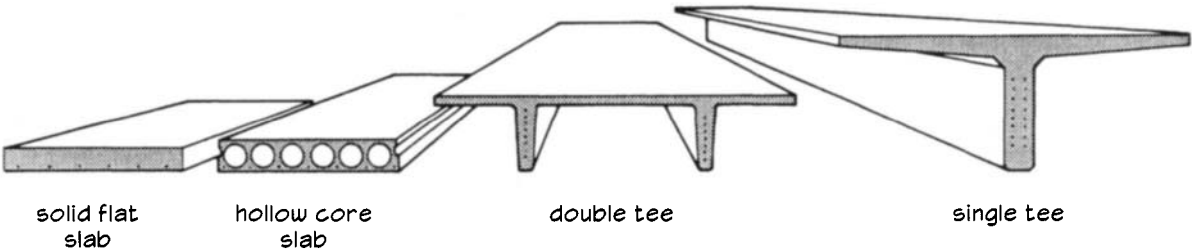


(From PCI Design Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)



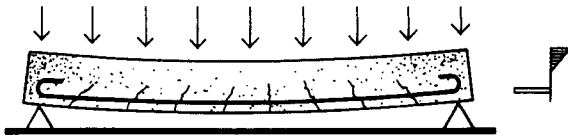
(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

11.1.1 Continued

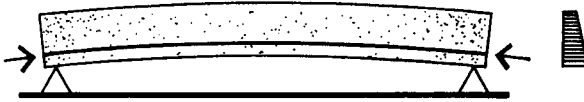


(From Allen, Fundamentals of Building Construction, 3rd ed., 1999)

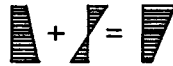
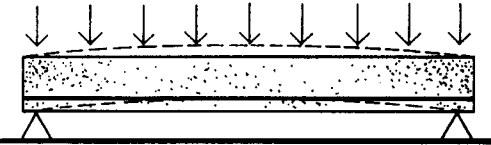
11.1.2 Prestressed Concrete Concepts



In a conventionally reinforced concrete beam, less than half the concrete is in compression and cracks will appear in the bottom of the beam under full load.



When a concrete beam is prestressed, all the concrete acts in compression. The off-center location of the prestressing steel causes a camber in the beam.



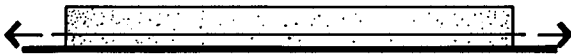
Under loading, the prestressed beam becomes flatter, but all the concrete still acts in compression, and no cracks appear.

In addition to the absence of cracks, the structural action in prestressed beams is more efficient than that of an ordinary reinforced beam, and therefore uses less material.

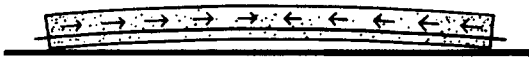
prestressed concrete



The first step in pretensioning is to stretch the steel prestressing strands tightly across the casting bed.



Concrete is then cast around the stretched strands and cured. The concrete bonds to the strands.

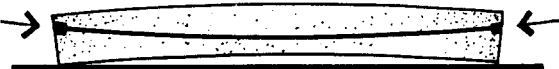


When the strands are cut, the concrete goes into compression and the beam takes on a camber.

pretensioned concrete



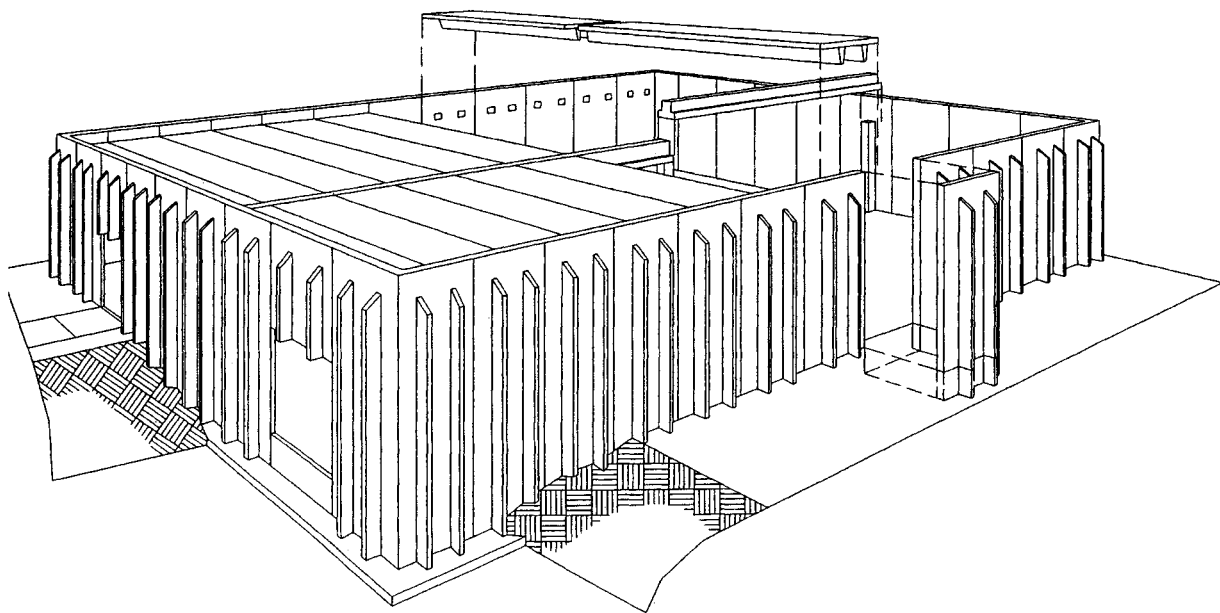
In post-tensioning, the concrete is not allowed to bond to the steel strands during curing.



After the concrete has cured, the strands are tensioned with a hydraulic jack and anchored to the ends of the beam. If the strands are draped, as shown here, higher structural efficiency is possible than with straight strands.

post-tensioned concrete

11.1.3 Single-Story Precast Bearing Wall Construction

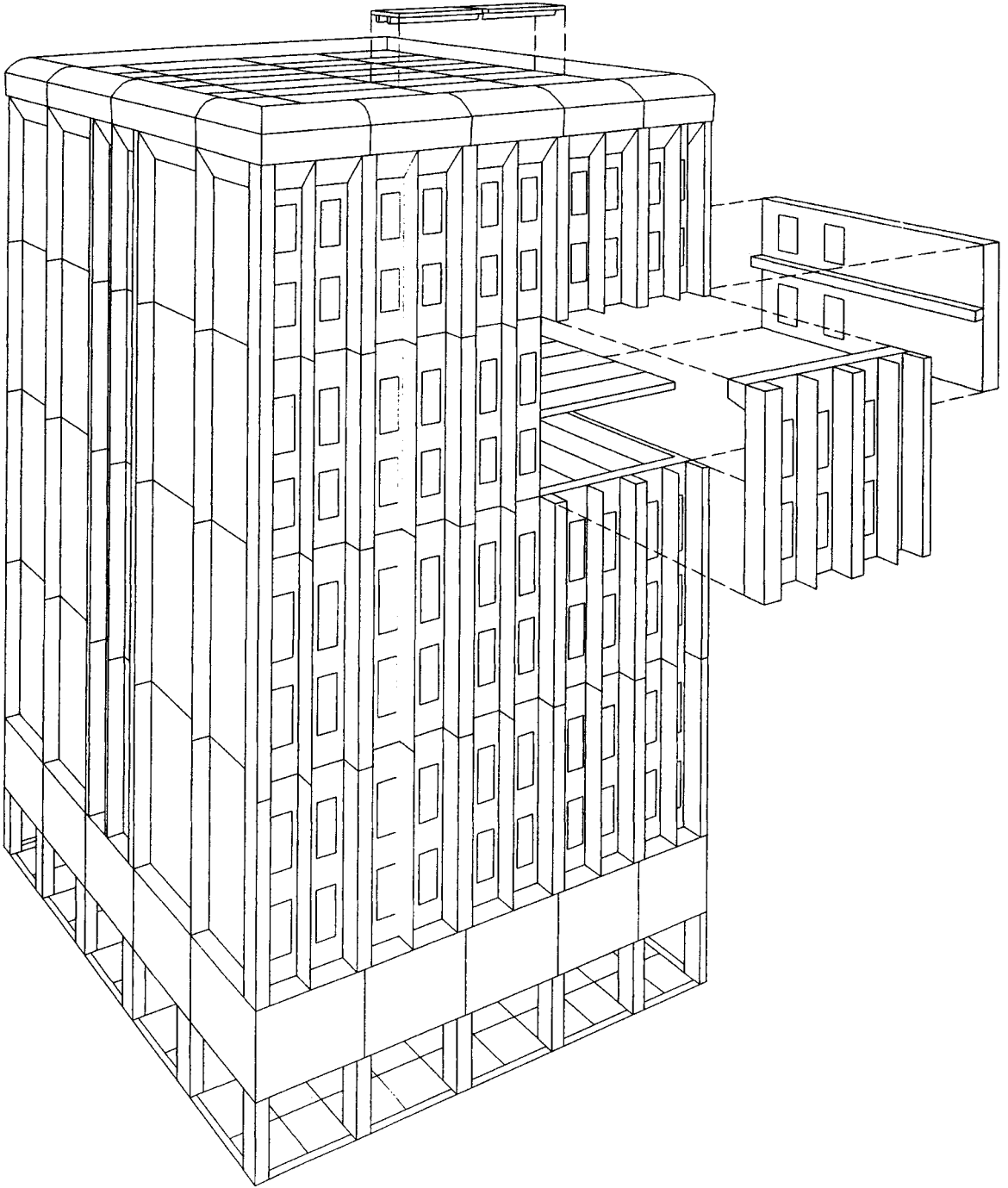


Provides economy by eliminating the need for a structural frame at the perimeter. The wall panels themselves can be selected from a variety of standard sections or flat panels, and specially formed architectural precast shapes. Any of the standard precast deck units can be used for roofs.

Typical Span-to-Depth Ratios of Flexural Precast, Prestressed Concrete Members	
Precast Member	Span-to-Depth Ratios*
Hollow-core floor slabs	30 to 40
Hollow-core roof slabs	40 to 50
Stemmed floor slabs	25 to 35
Stemmed roof slabs	35 to 40
Beams	10 to 20

* These values are intended as guidelines, not limits.

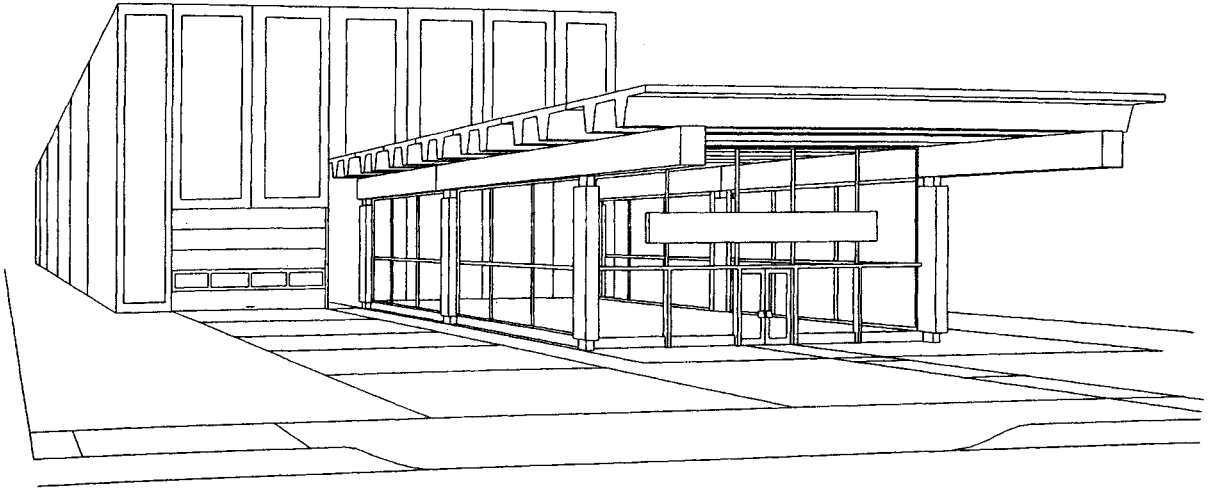
11.1.4 Multi-Story Precast Loadbearing Construction



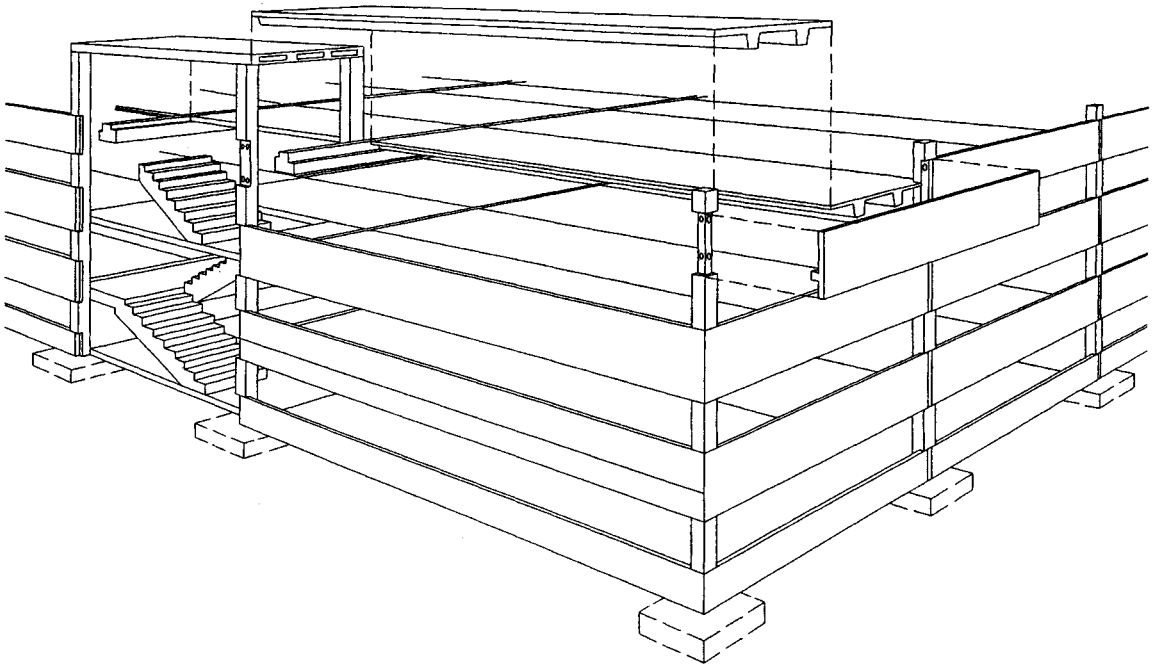
Precast bearing wall units can be cast in one-story or multi-story high units. The units may be started at the second floor level with the first floor framing consisting of beams and columns to obtain a more open space on the first level.

(From PCI Design Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)

11.1.5 Precast Beam-Column Construction

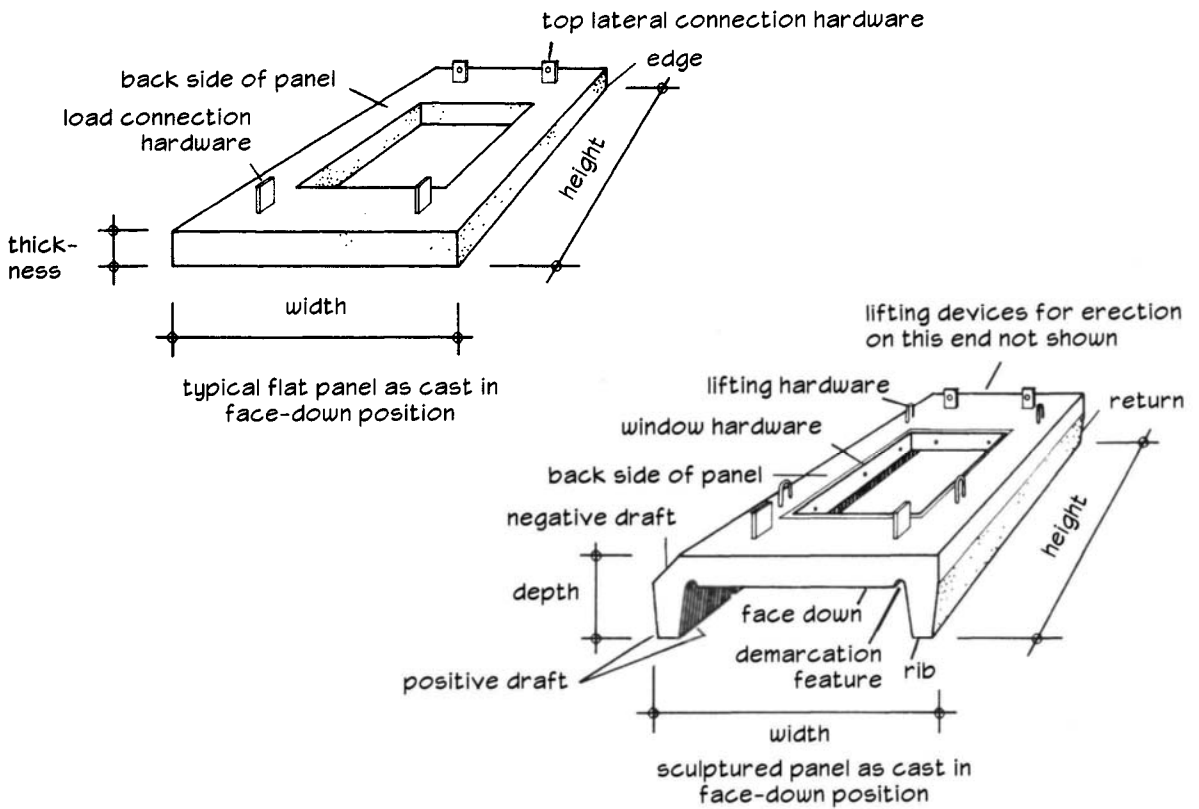


Any of the standard precast beam and column sections can be used for single-story structures. Selection of the type of beam to be used depends on considerations such as span length and level of superimposed loads, and also on depth of ceiling construction and desired architectural expression.



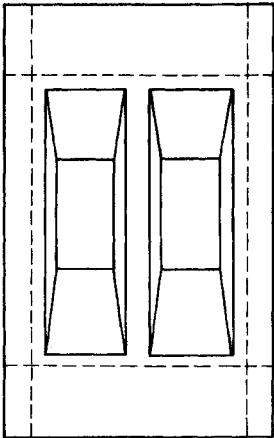
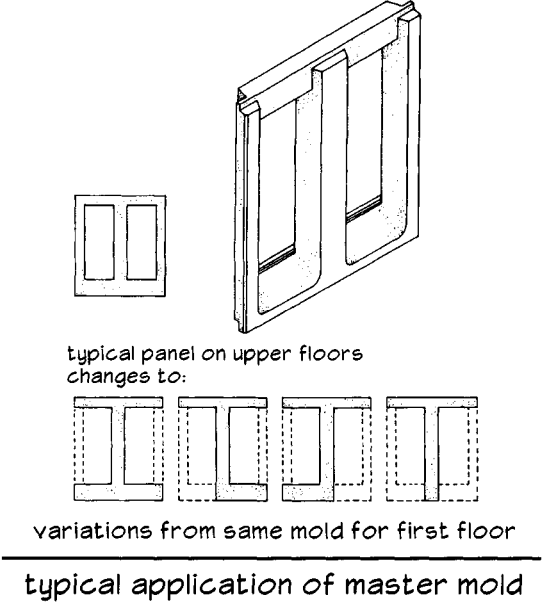
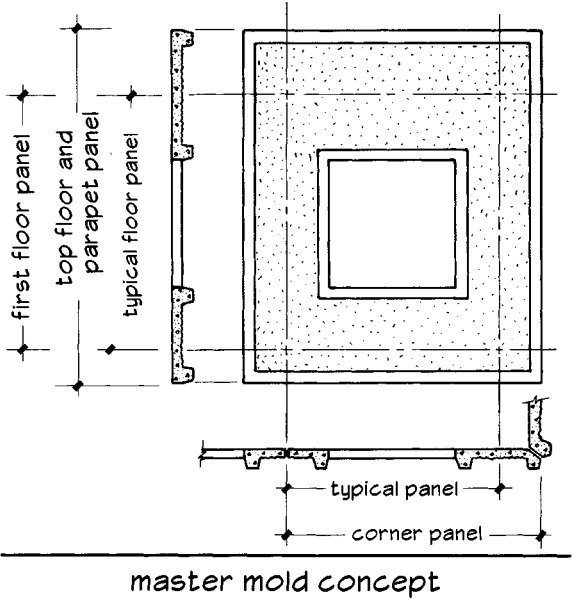
Beam-column framing is suitable for both low-rise and high-rise buildings. Architectural and engineering considerations dictate whether the beams are continuous with single-story columns, or whether multi-story columns are used with single span beams.

11.1.6 Terminology of Precast Concrete Units



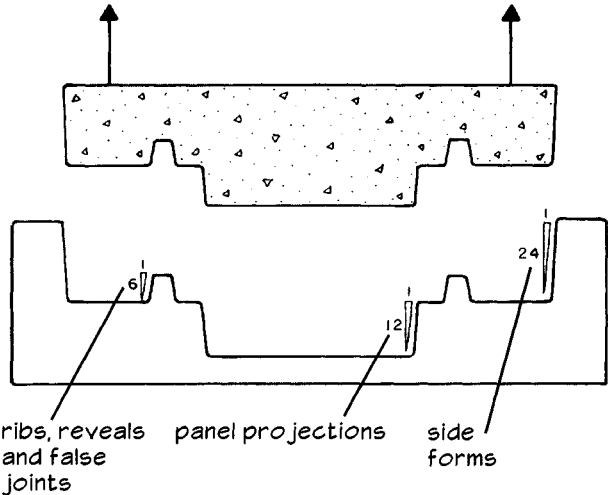
(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

11.1.7 Precast Concrete Molds



—— outline master mold
----- bulkhead locations

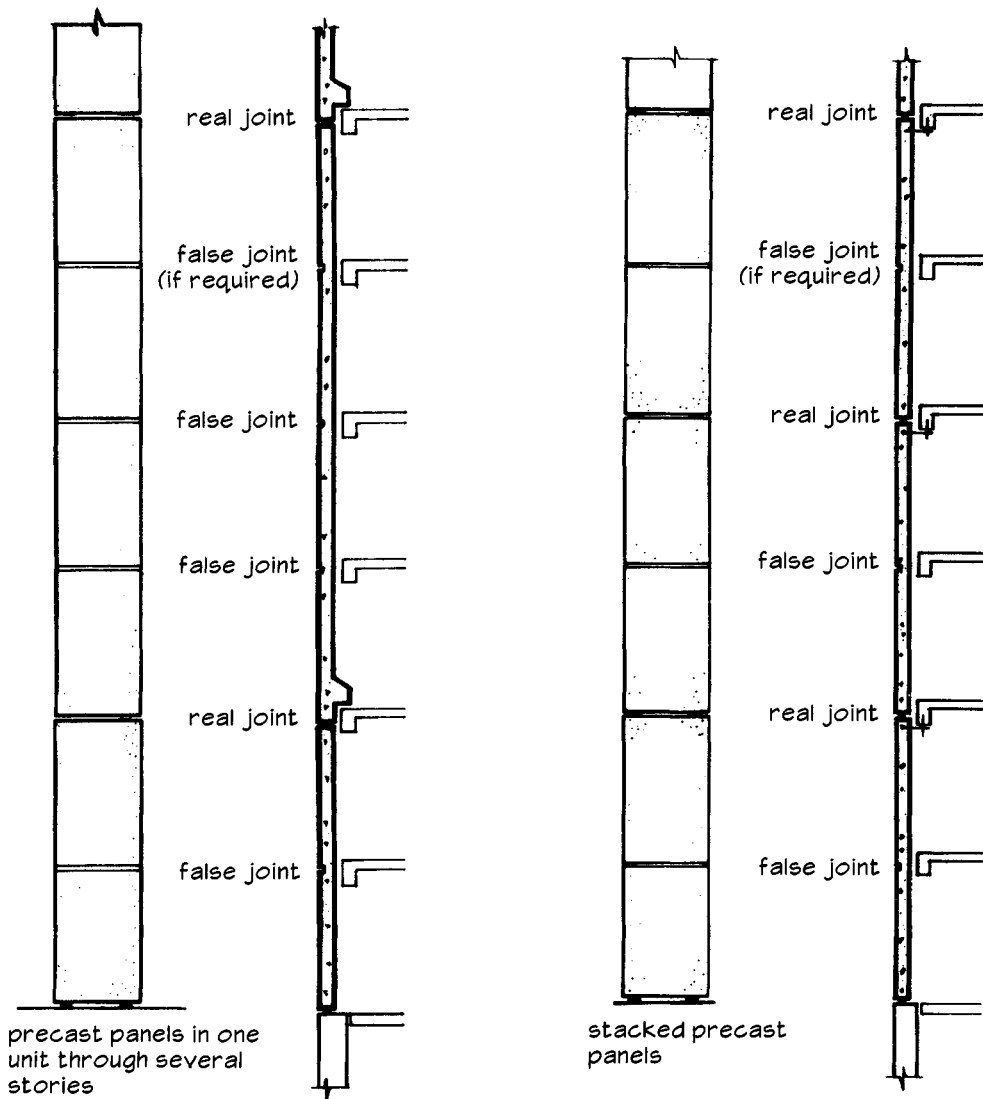
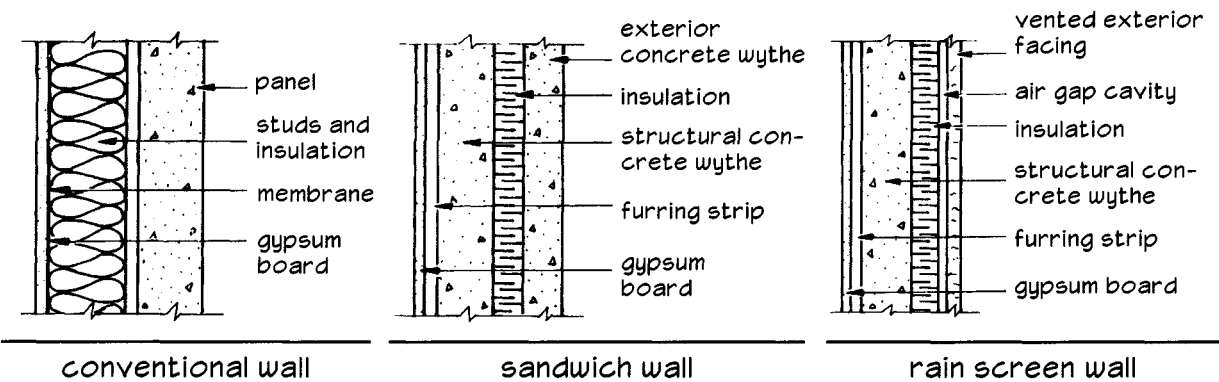
typical master mold for two-window wall unit



total envelope mold
minimum positive draft

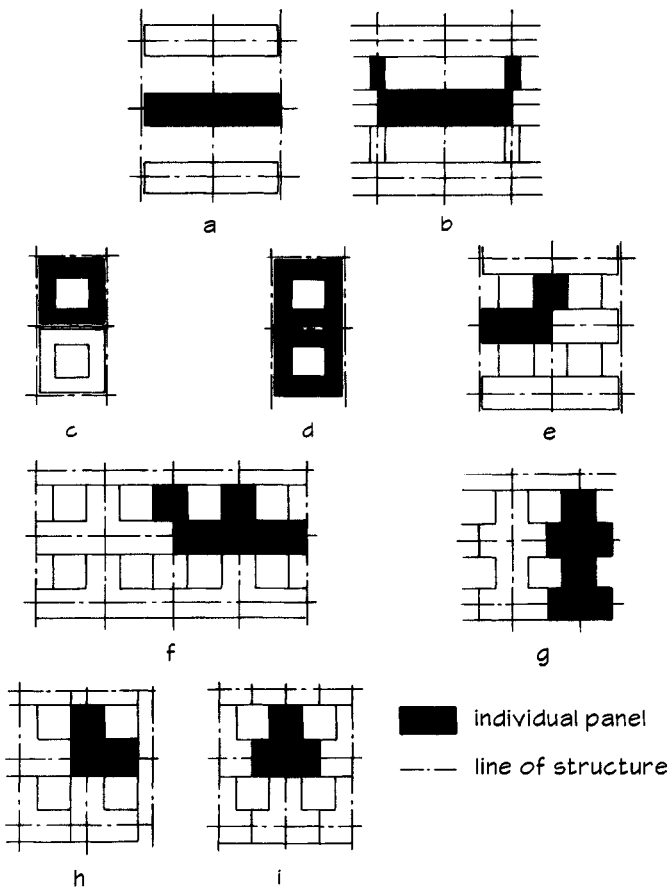
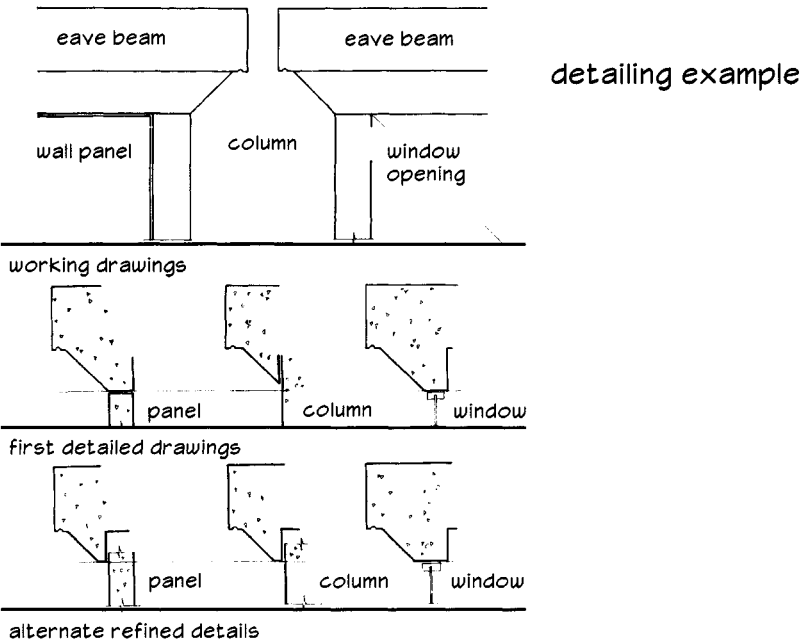
(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

11.1.8 Typical Precast Wall Systems



(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

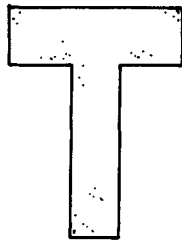
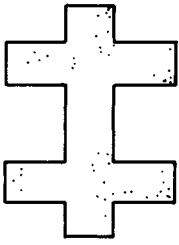
11.1.9 Precast Panel Arrangement and Detailing



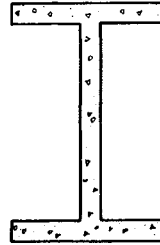
typical arrangements of
precast concrete panels

(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

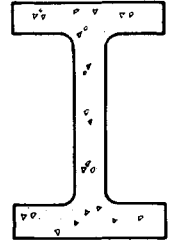
11.1.10 Precast and Prestressed Panel Shapes



open panel shapes

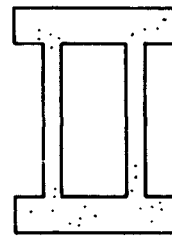
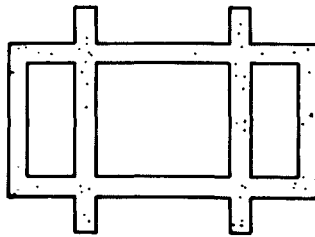


don't



do

proportioning of open units



combination of open and closed units



don't



don't



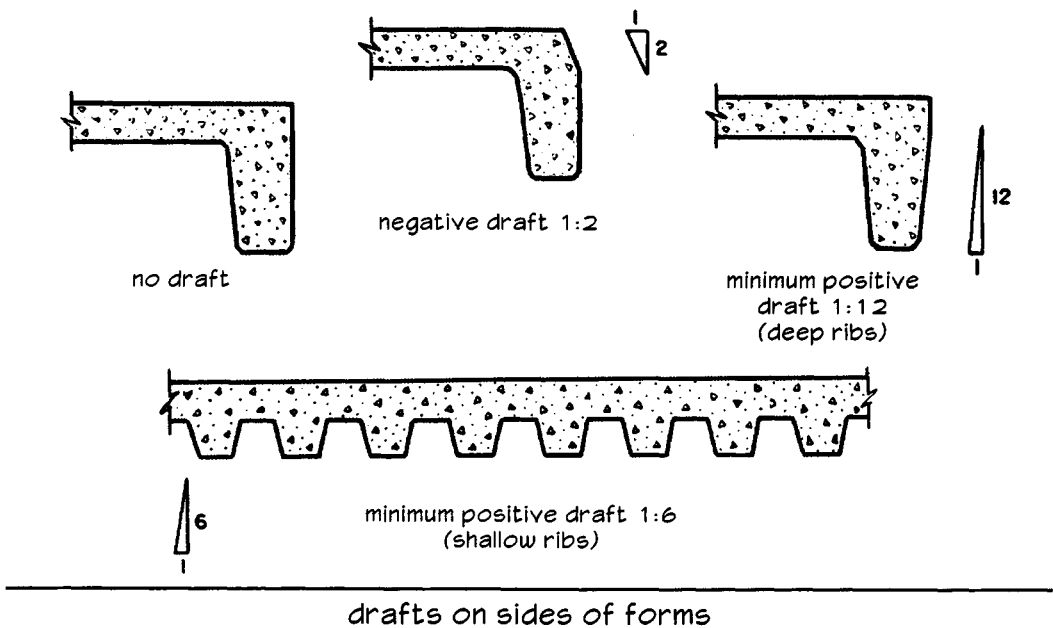
do



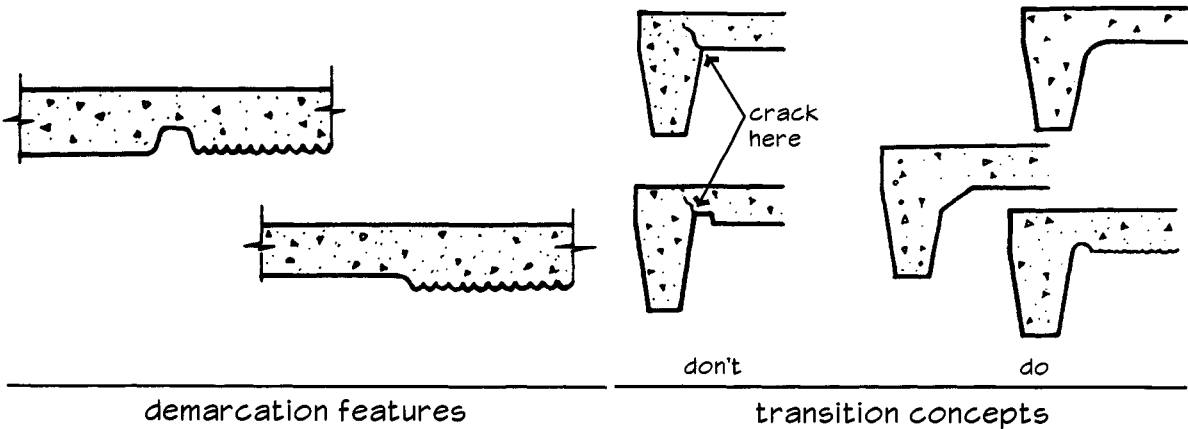
do

joining of open shaped units

11.1.11 Precast Panel Drafts, Transitions and Demarcations

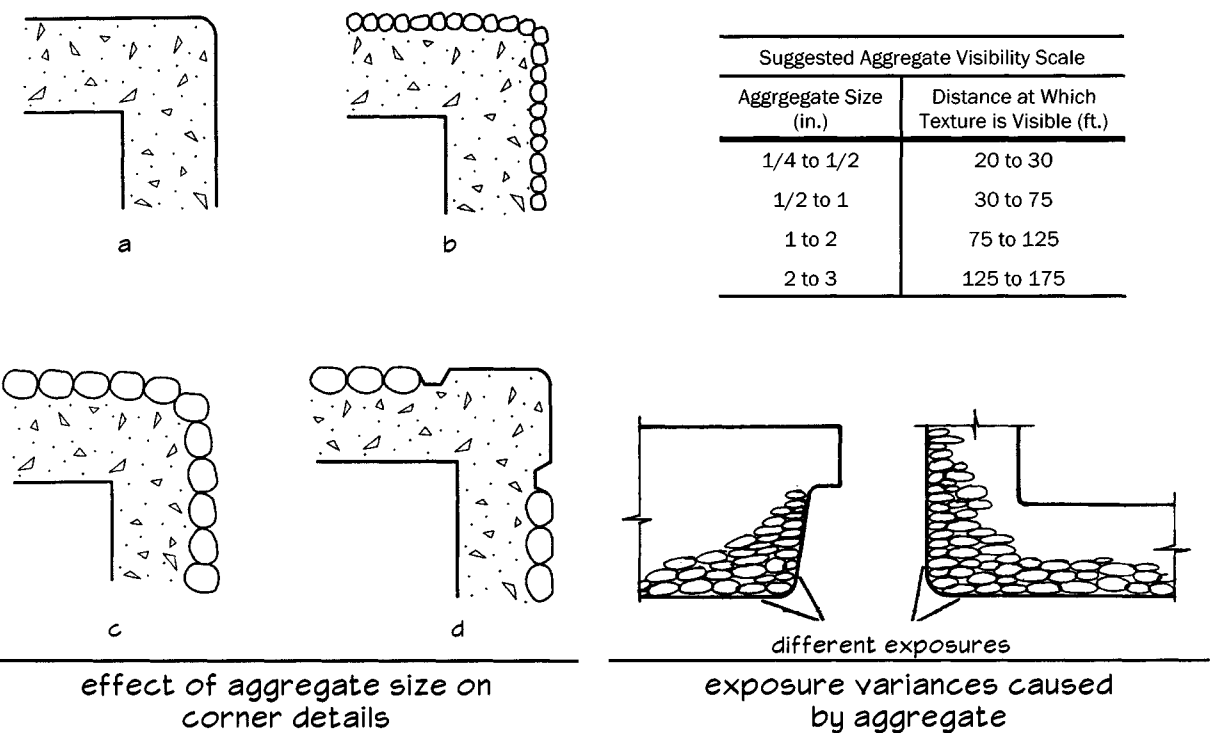


(From PCI Design Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)



(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

11.1.12 Aggregate Facings for Precast Panels

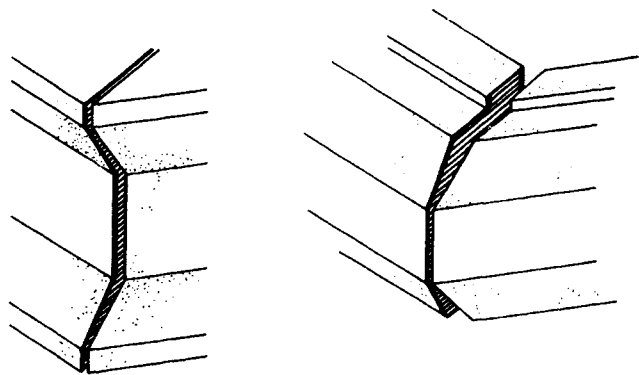


(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

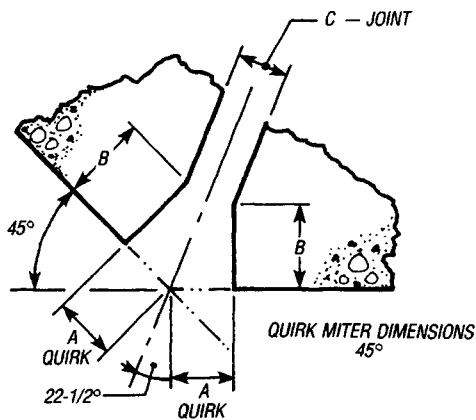
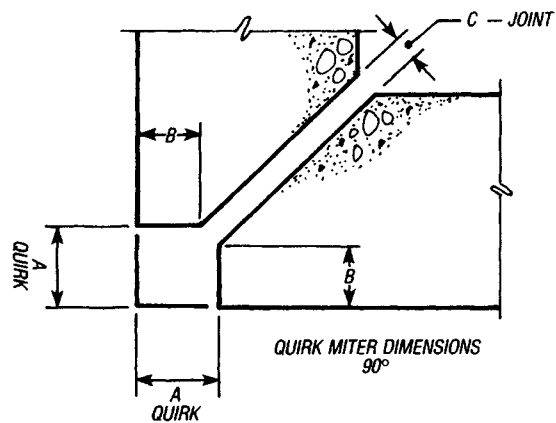
Typical Industry Size Specifications for Exposed Aggregate				
Sieve Opening (in.)	Percent of Indicated Size Aggregate Passing			
	Size D (1-3/8 to 7/8 in.)	Size C (7/8 to 1/2 in.)	Size B (1/2 to 1/4 in.)	Size A (1/4 to 3/32 in.)
1-1/2	100			
1-3/8	95-100			
1	30-60	100		
7/8	20-40	95-100		
5/8	0-10	30-50	100	
1/2		10-25	95-100	
3/8		0-10	40-70	100
1/4			5-20	95-100
1/8			0-10	15-35
3/32				0-10

(From ACI 533R-93 Guide For Precast Concrete Wall Panels, American Concrete Institute)

11.1.13 **Mitered Corners on Precast Panels**



poor mitered corner details



A	B	C
1 1/8	3/4	1/2
1 1/4	7/8	1/2
1 1/2	1 1/8	1/2
1 3/4	1 3/8	1/2
2	1 5/8	1/2

A	B	C
1 1/4	3/4	3/4
1 1/2	1	3/4
1 3/4	1 1/4	3/4
2	1 1/2	3/4
1 1/2	13/16	1
1 3/4	1 1/16	1
2	1 5/16	1

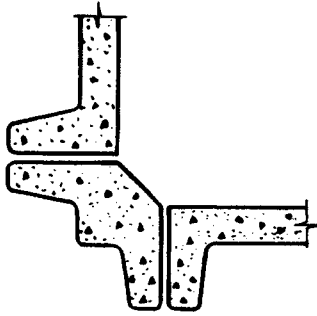
A	B	C
5/8	13/16	1/2
3/4	1 1/8	1/2
7/8	1 7/16	1/2

A	B	C
3/4	13/16	3/4
7/8	1 1/16	3/4
7/8	13/16	1
1	1 1/16	1

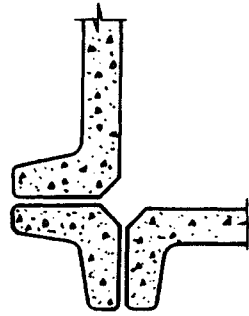
recommended quirk miter details and dimensions

(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

11.1.14 Precast Panel Corner Details and Construction Tolerances

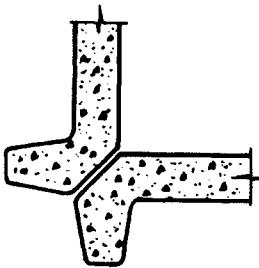


little adjustment possible
at corners

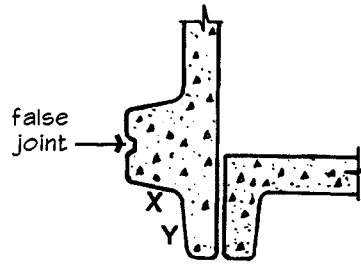


little adjustment possible
at corner

separate corner piece recommended for exposure reasons in case of difficult concrete mix



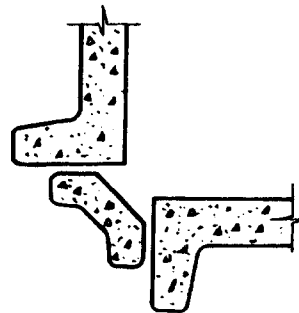
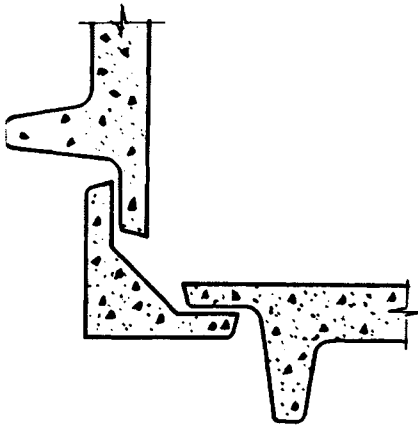
fairly easily mitered corner
since lines are vertical and
edges strong



alternative to corner above

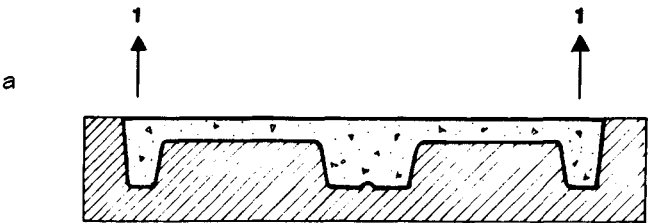
if faces "x" and "y" read similarly
in concrete mix, this is a more
economical solution

corner details which accommodate tolerances at joints

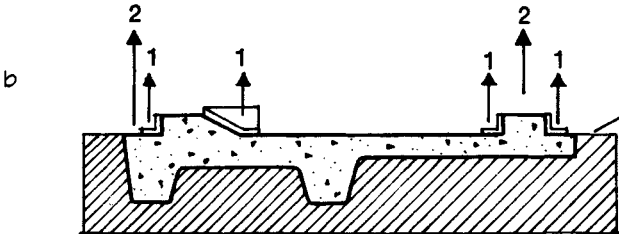


details with separate corner pieces for flexibility in
accommodating construction tolerances

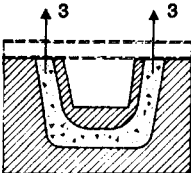
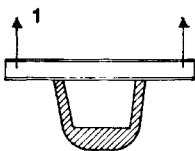
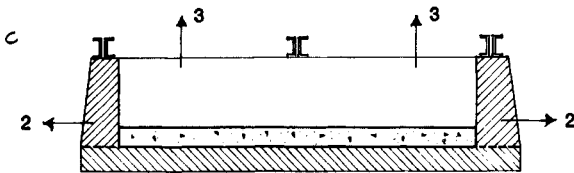
11.1.15 Typical Molds and Finishes for Backs of Precast Panels



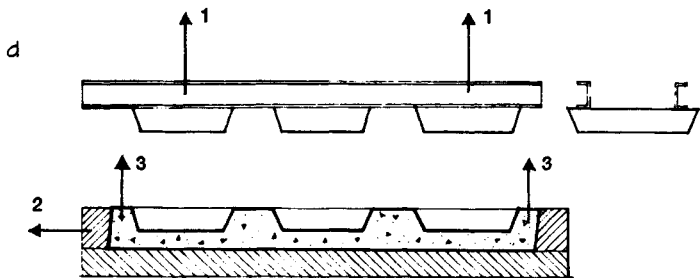
typical mold, easy finish of back



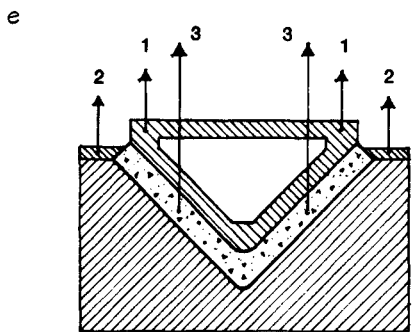
mold with haunch or beam projections on back



Interior finish will not be suitable for exposure in final location unless top form is removed and hand finishing started within hours of casting, demanding good draft on top form and often special lifting methods.

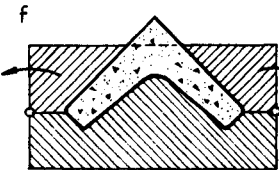


Top forms illustrated here should only be used where weight saving is important for design or erection reasons.



If finishing requirements are high, remove top forms as early as possible and hand finish these areas.

Mold pieces "2" are only necessary for carefully rounded edges, in which case they should be sealed between castings.



To avoid hand finishing on slope, back should be finished as shown by dashed line whenever possible.

corner molds

11.1.16 Precast/Prestressed Concrete Deflection and Camber

Maximum Permissible Computed Deflections

Type of member	Deflection to be considered	Deflection limitation
Flat roofs not supporting or attached to nonstructural elements likely to be damaged by large deflections	Immediate deflection due to live load	$\frac{\ell^a}{180}$
Floors not supporting or attached to nonstructural elements likely to be damaged by large deflections	Immediate deflection due to live load	$\frac{\ell}{360}$
Roof or floor construction supporting or attached to nonstructural elements likely to be damaged by large deflections	That part of the total deflection occurring after attachment of nonstructural elements (sum of the long-term deflection due to all sustained loads and the immediate deflection due to any additional live load) ^c	$\frac{\ell^b}{480}$
Roof or floor construction supporting or attached to nonstructural elements not likely to be damaged by large deflections		$\frac{\ell^d}{240}$

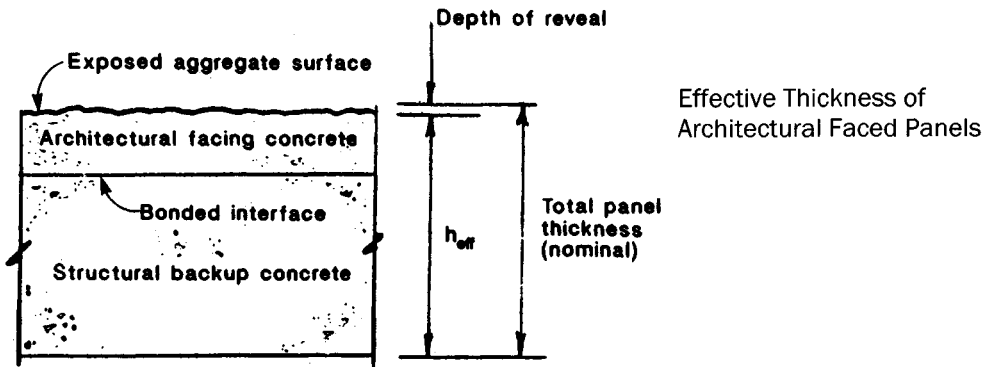
- a Limit not intended to safeguard against ponding. Ponding should be checked by suitable calculations of deflections, including added deflections due to ponded water and considering long-term effects of all sustained loads, camber, construction tolerances, and reliability of provisions for drainage.
- b Limit may be exceeded if adequate measures are taken to prevent damage to supported or attached elements.
- c Long-term deflection shall be determined in accordance with Sections 9.5.2.5 or 9.5.4.2 of ACI 318-95, but may be reduced by amount of deflection calculated to occur before attachment of nonstructural elements. This amount shall be determined on the basis of accepted engineering data relating to time-deflection characteristics of members similar to those being considered.
- d But not greater than tolerance provided for nonstructural elements. Limits may be exceeded if camber is provided so that total deflection minus camber does not exceed limit.

Suggested Simple Span Multipliers to be Used as a Guide in Estimating Long-Term Cambers and Deflections for Typical Prestressed Members

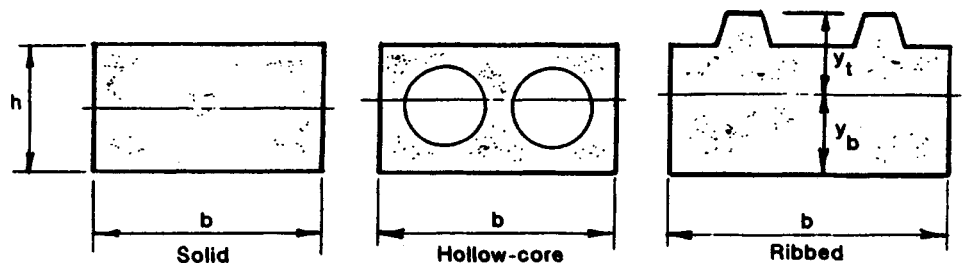
	Without Composite Topping	With Composite Topping
<i>At erection:</i>		
(1) Deflection (downward) component—apply to the elastic deflection due to the member weight at release of prestress	1.85	1.85
(2) Camber (upward) component—apply to the elastic camber due to prestress at the time of release of prestress	1.80	1.80
<i>Final:</i>		
(3) Deflection (downward) component—apply to the elastic deflection due to the member weight at release of prestress	2.70	2.40
(4) Camber (upward) component—apply to the elastic camber due to prestress at the time of release of prestress	2.45	2.20
(5) Deflection (downward)—apply to elastic deflection due to superimposed dead load only	3.00	3.00
(6) Deflection (downward)—apply to elastic deflection caused by the composite topping	—	2.30

(From PCI Design Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)

11.1.17 Effective Thickness of Precast Panels



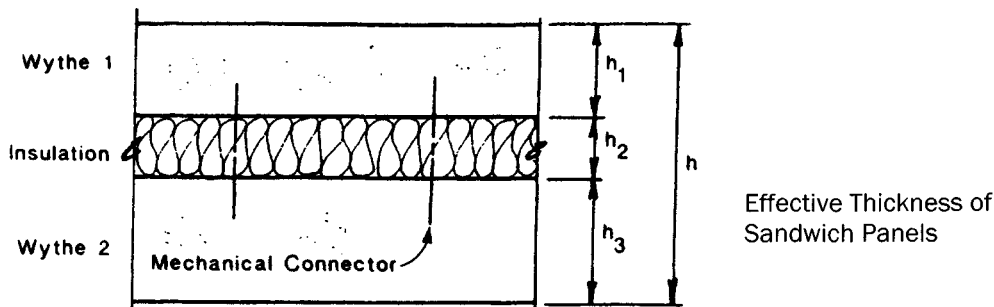
h_{eff} = Total panel thickness - depth of reveal (if depth of reveal exceeds 3% of nominal thickness)
or
 h_{eff} = Total panel thickness



I_g = Uncracked moment of inertia

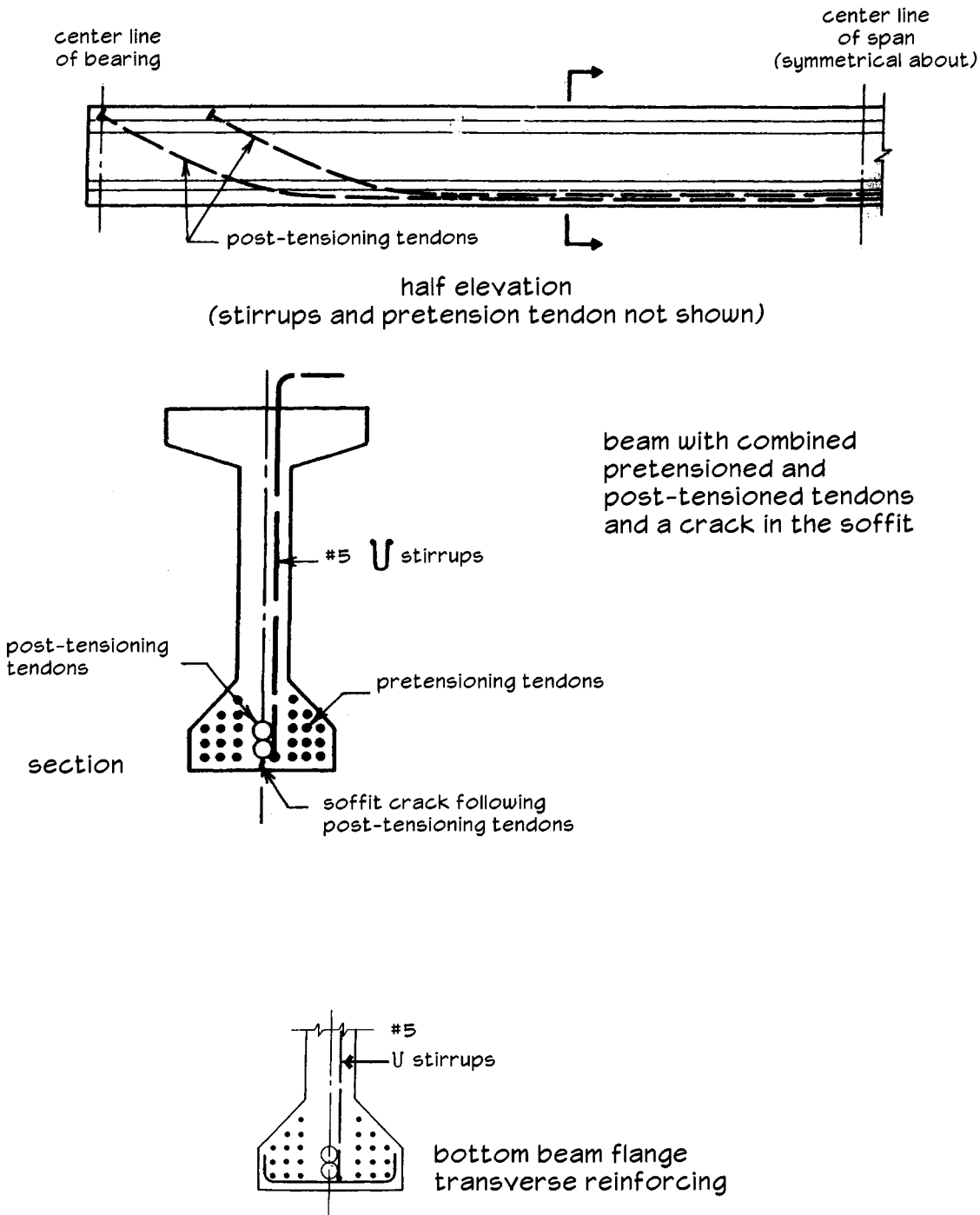
Effective Thickness of Solid, Hollow-Core, or Ribbed Panels

$$h_{eff} = \sqrt[3]{\frac{12 I_g}{b}}$$



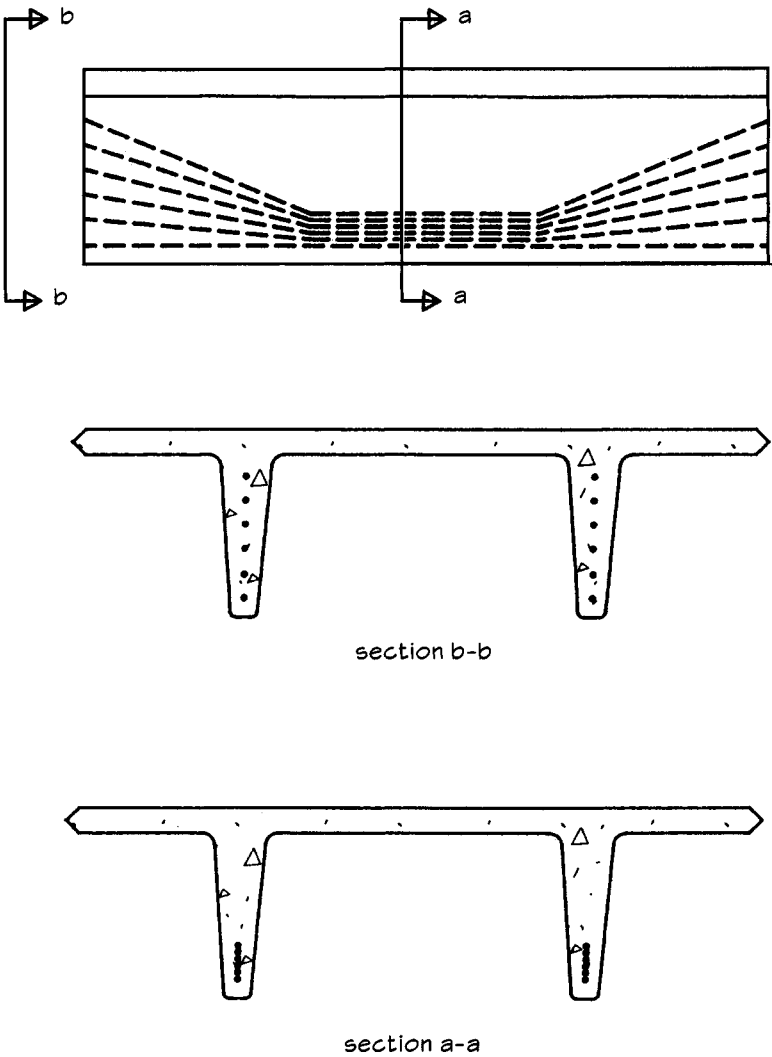
$h_{eff} = h_1 + h_2 + h_3$ (if wythes are fully composite)
 $h_{eff} = h_1$ or h_3 (if wythes are not considered composite)

11.1.18 Prestressed Concrete Beams



(From Libbey, Modern Prestressed Concrete Design Principles and Construction Methods, 4th ed.)

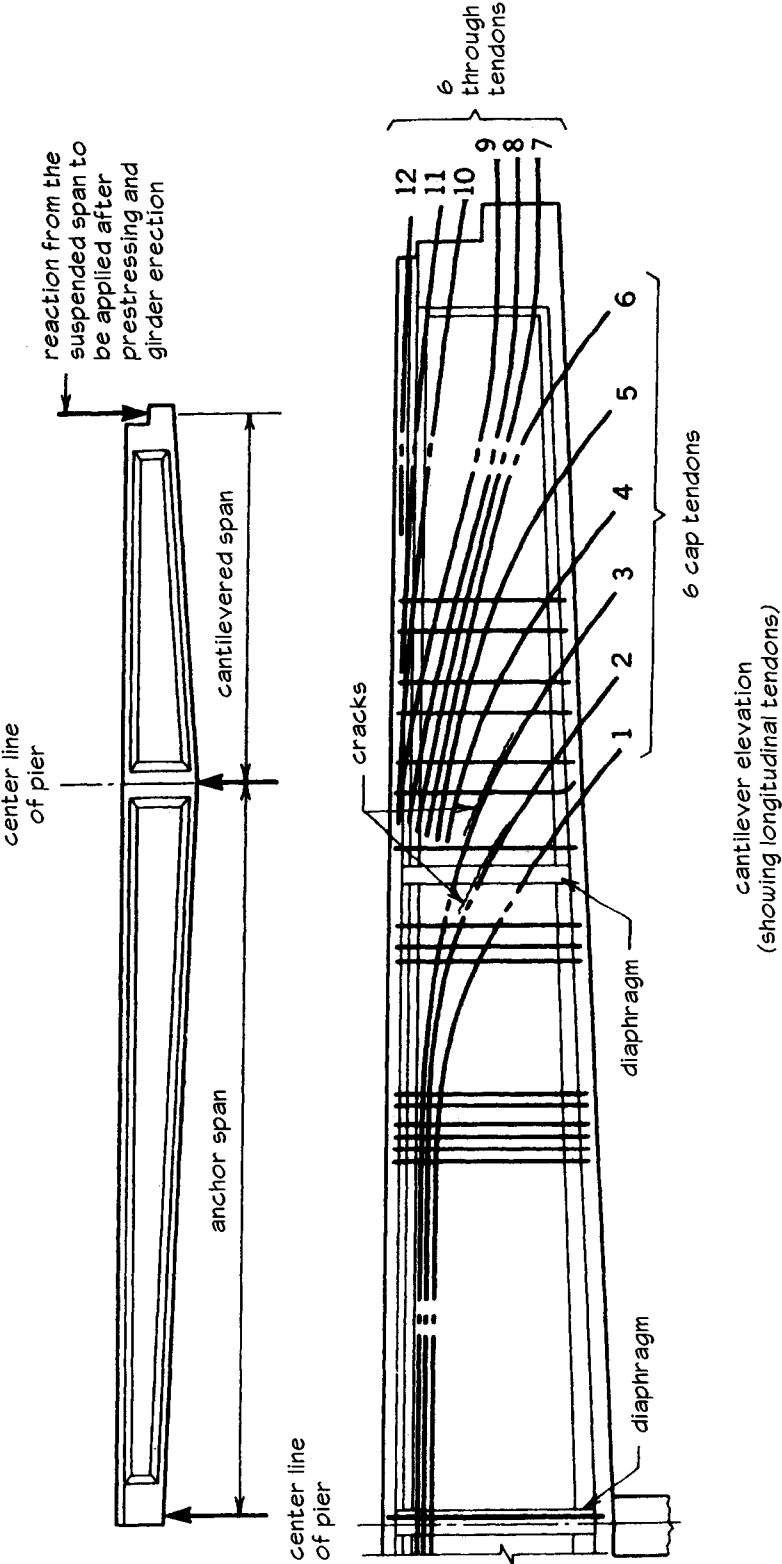
11.1.19 Precast Double Tee Beam with Deflected Tendons



(From Libbey, Modern Prestressed Concrete Design Principles and Construction Methods, 4th ed.)

11.1.20

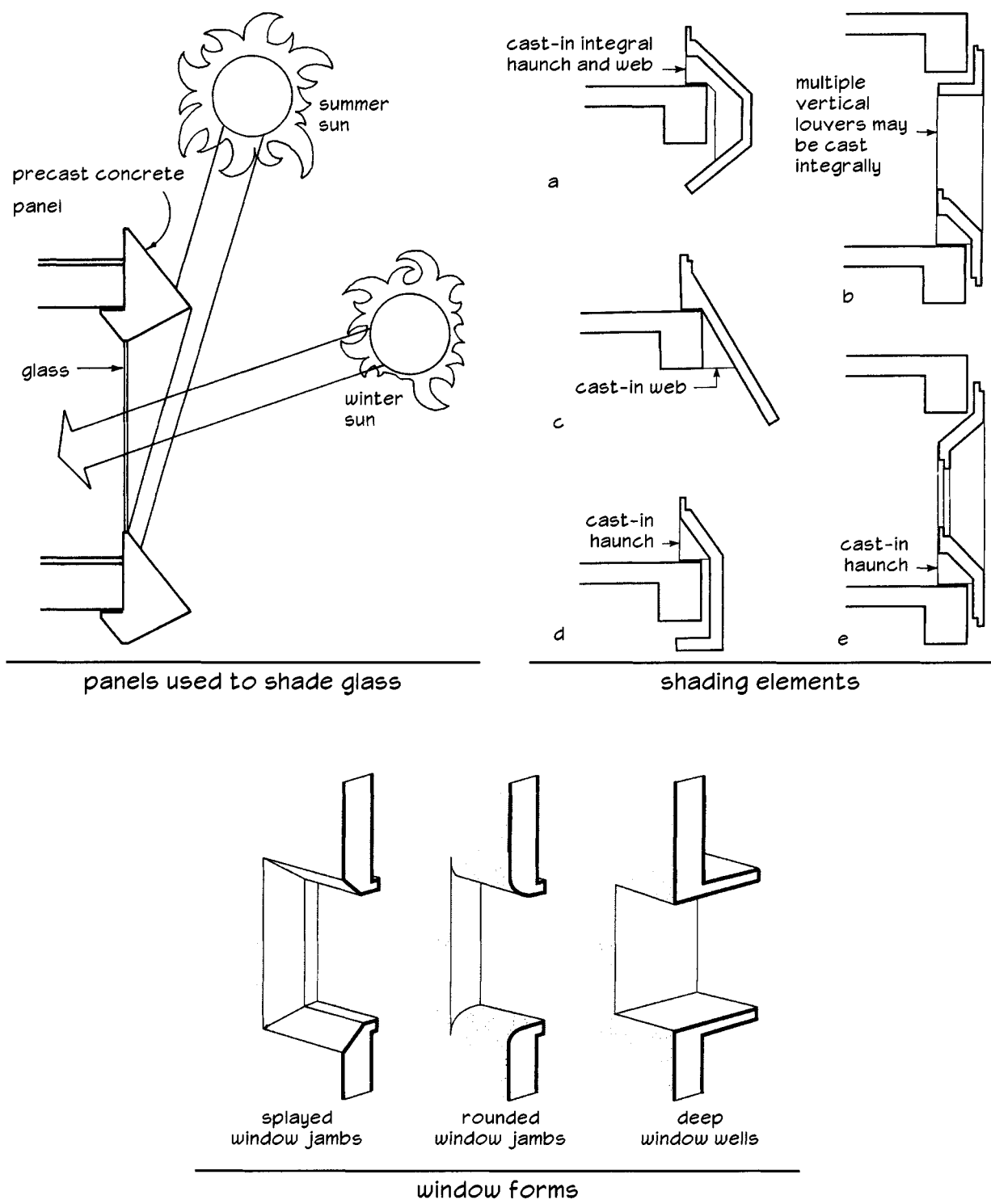
Bridge Beam with Overhanging Span



bridge beam with an overhanging end span
(elevation of beam and elevation of overhanging end span showing longitudinal tendons)

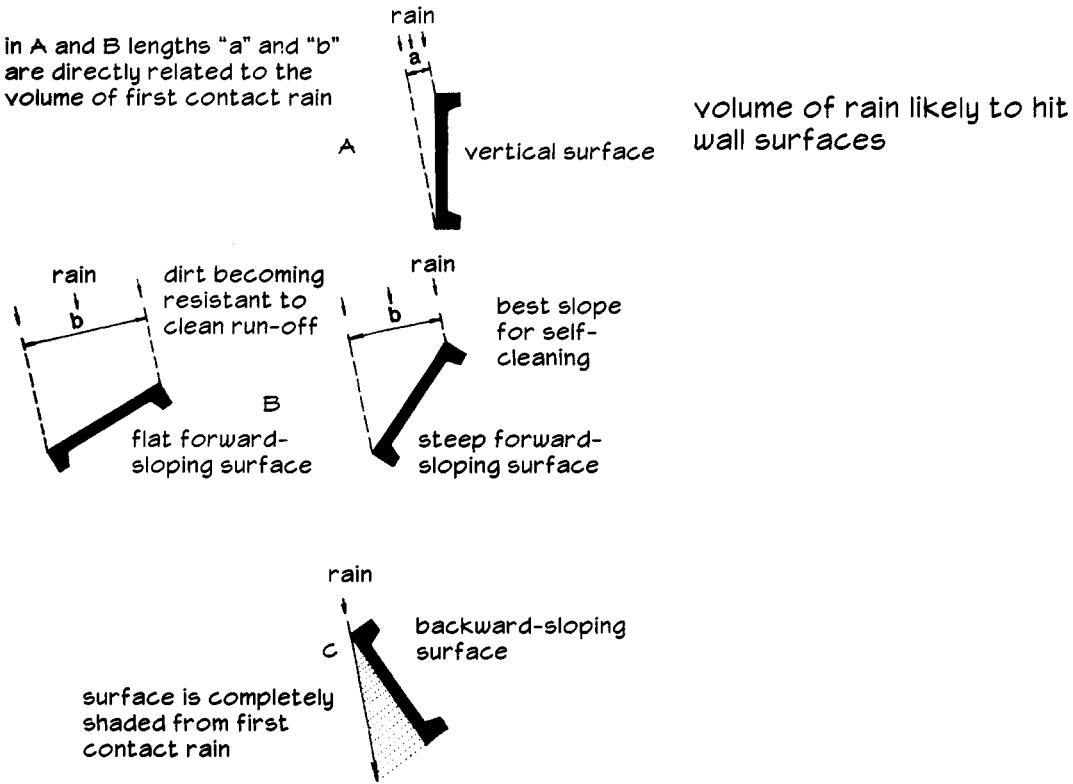
(From Libbey, Modern Prestressed Concrete Design Principles and Construction Methods, 4th ed.)

11.2.1 Solar Shading With Precast Concrete Panels

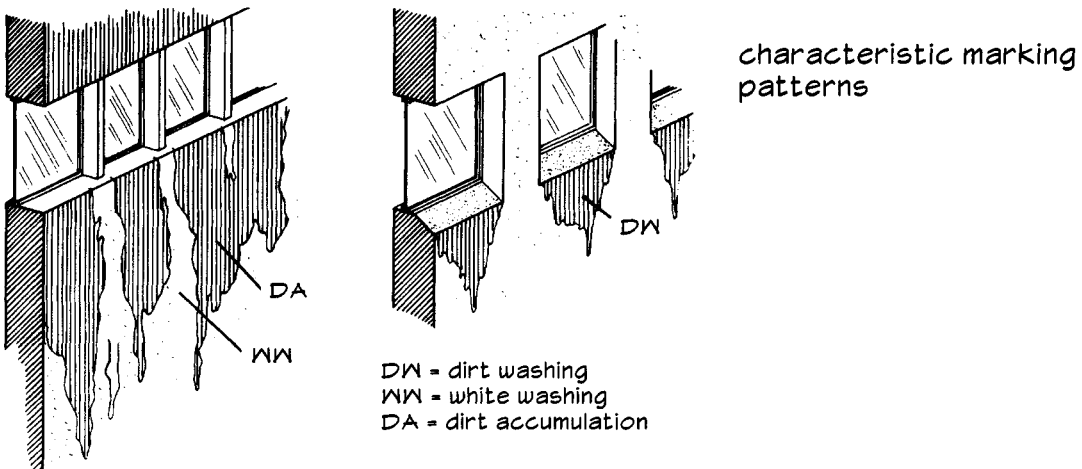


(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

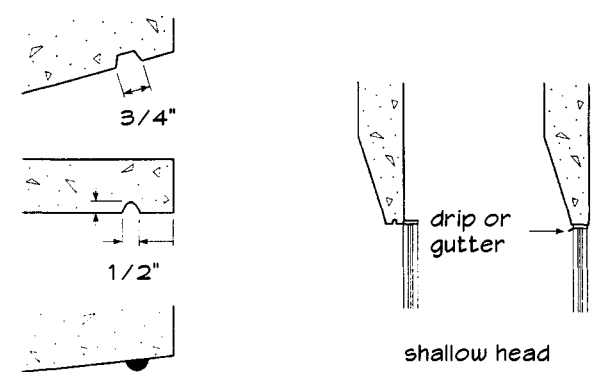
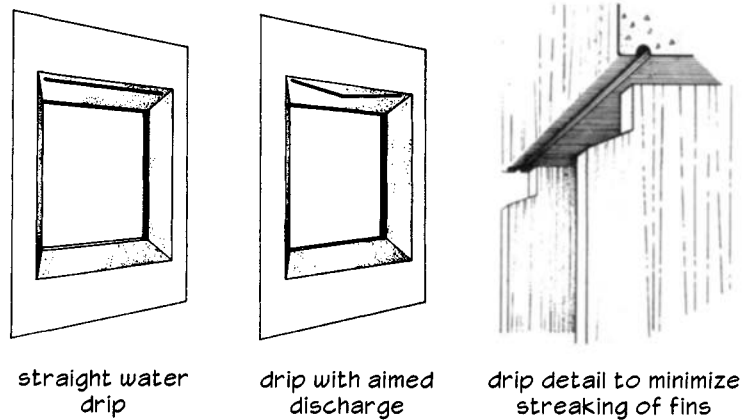
11.2.2 Rain Wetting and Marking Patterns



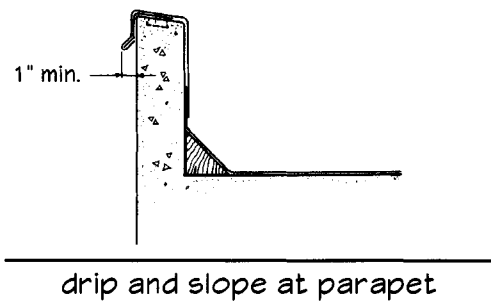
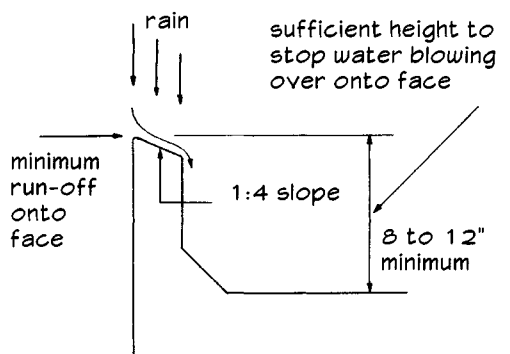
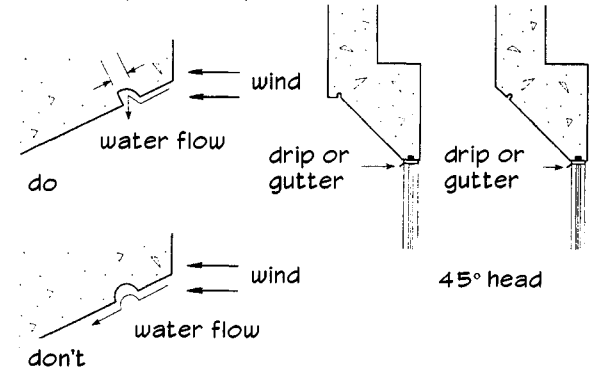
rain is assumed as 10° from vertical for diagrammatic purposes



11.2.3 Drips on Precast Panels

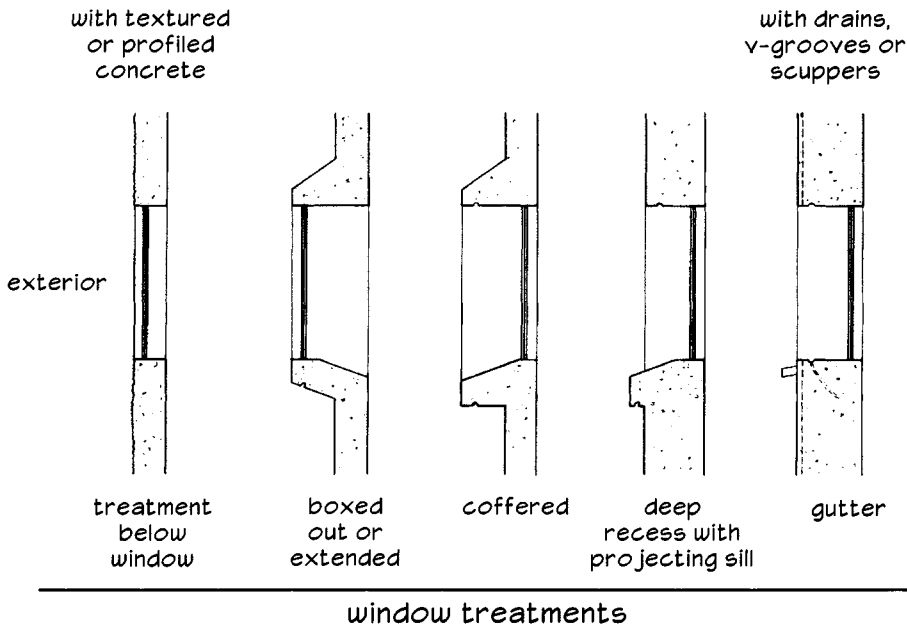


sealant or plastic drip

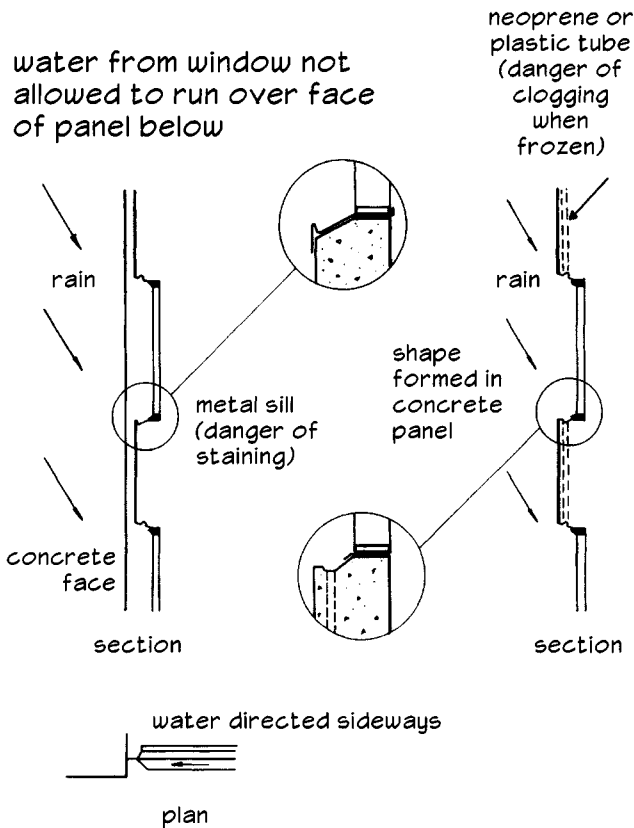


design of drip in relation to slope

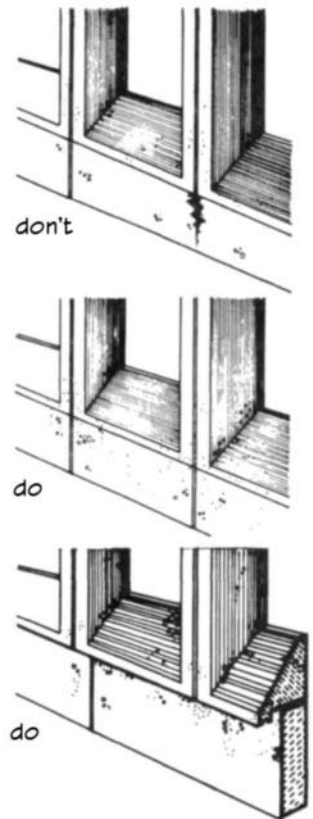
11.2.4 Directing Water Flow on Precast Panels



water from window not allowed to run over face of panel below



channeling of rain water hitting windows



proper channeling

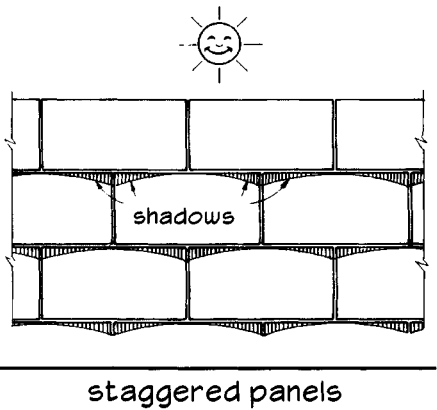
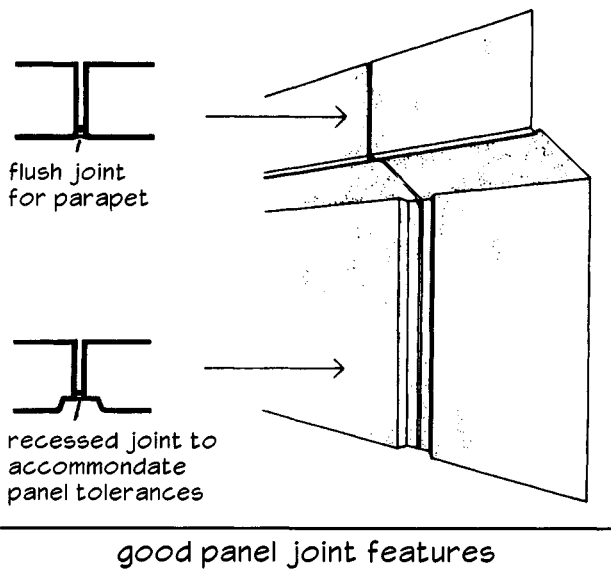
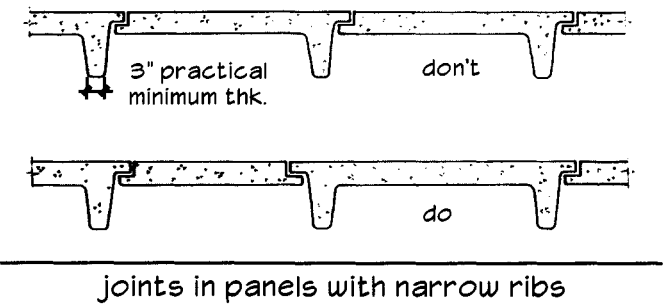
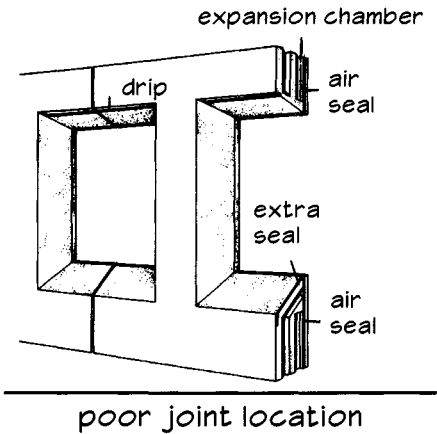
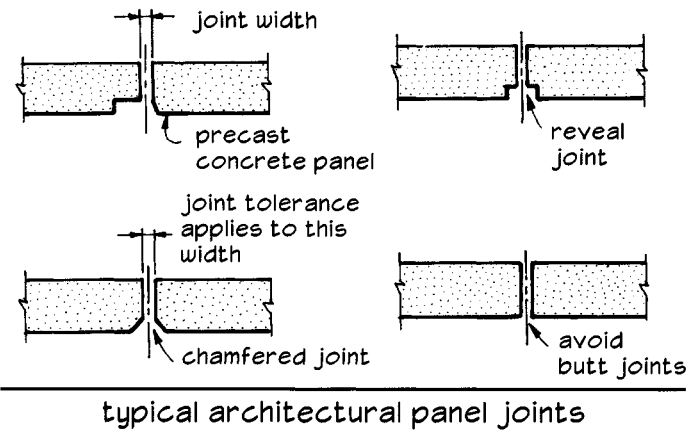
11.2.5 Surface Sealers for Precast Concrete

Sealer	Film Forming (F) or Penetrating (P)	Water Absorption Resistance	Carbonation Resistance	Breathability	Non-Yellowing
Acrylic	F	1	1	2	1
Butadiene-styrene	F	1	1	2	5
Chlorinated rubber	F	1	1	2	5
Epoxy	F	1	1	5	5
Oil	P	2	3	1	5
Polyurethane					
aliphatic	F	1	1	5	2
aromatic	F	1	1	5	5
Polyester	F	1	1	5	5
Siliconate	P	2	5	1	1
Silicone	P	2	5	1	1
Silane	P	1	5	1	1
Siloxane	P	1	5	1	1
Stearate	P	2	5	1	2
Vinyl	F	1	1	2	2

Rating: 1 to 5 where 1 = excellent and 5 = poor.

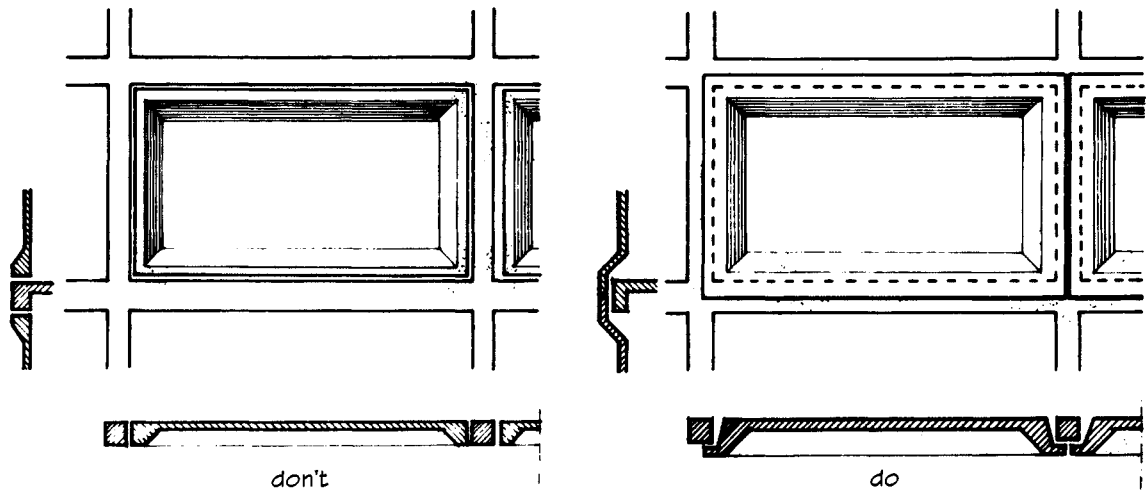
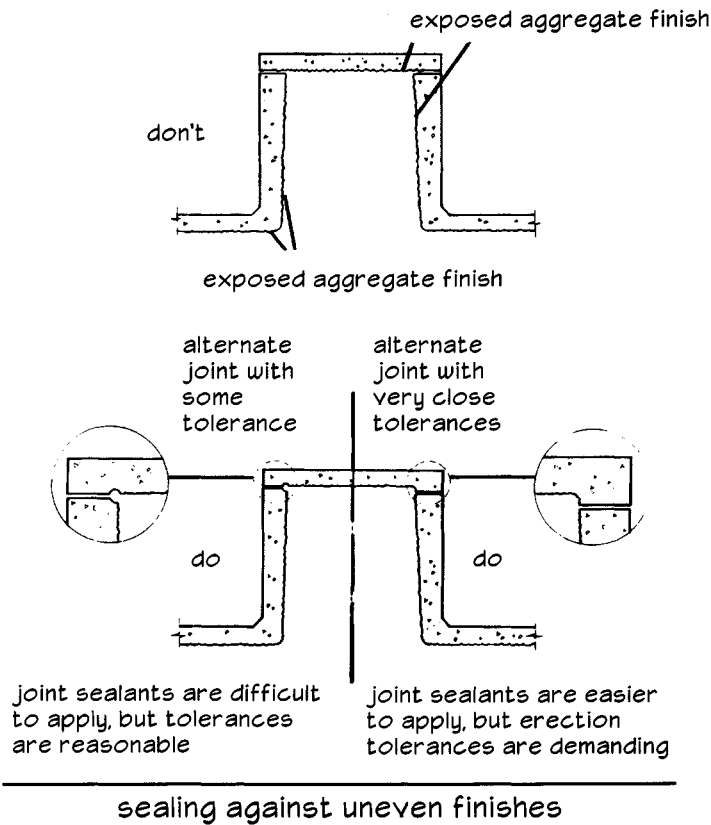
Note: This table represents average performance properties. There can be differences in performance in each generic group as many sealers are blends of various systems. Durability/longevity can also vary within each generic group. In all cases, the manufacturer should be consulted to obtain weatherometer results and field experiences.

11.2.6 Architectural Features of Precast Panel Joints



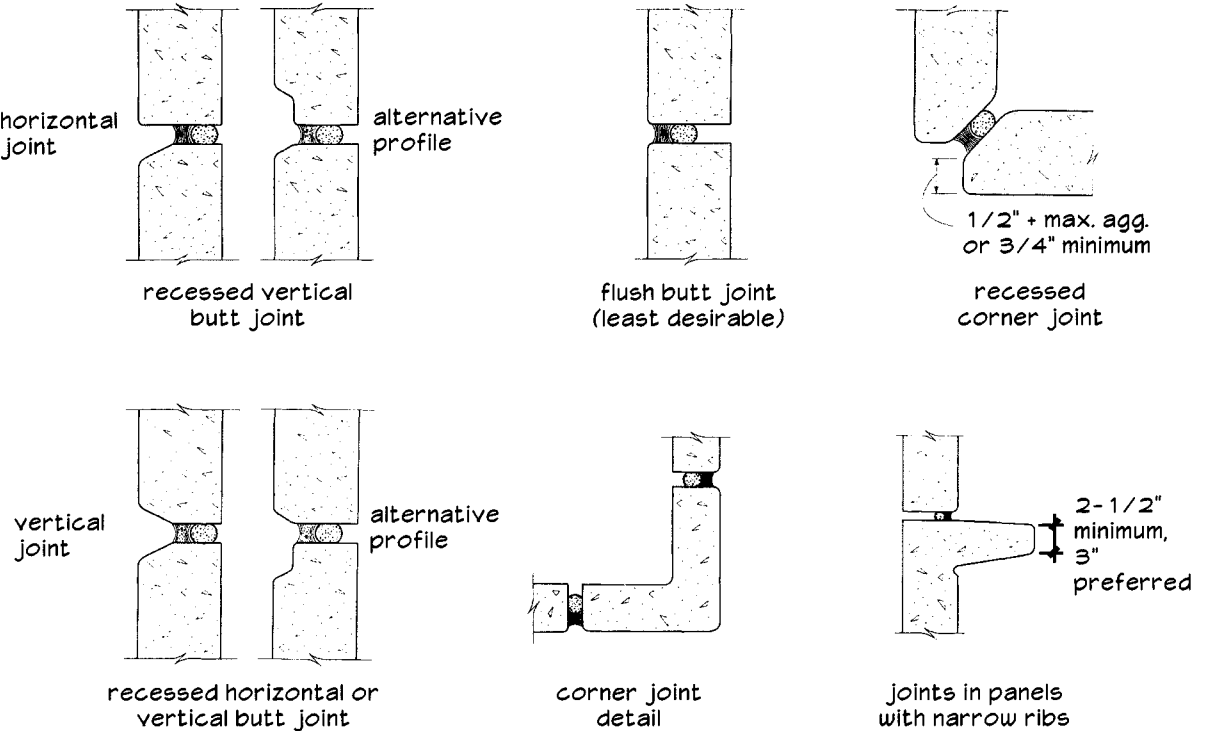
(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

11.2.7 Joints Accommodating Tolerances and Finishes



(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

11.2.8 One-Stage Sealant Joints



(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

11.2.10 Joint Sealants

Properties and Characteristics of Field-Molded Sealants

Property	Polysulfides		Polyurethanes		Silicones		
	1-Part	2-Part	1-Part	2-Part	1-Part Acetoxy	1-Part Non-Acid Cure	2-Part Non-Acid Cure
Primer required	usually	usually	usually	usually	usually	occasionally	occasionally
Curing process	chemical reaction with moisture in air and oxidation	chemical reaction with curing agent	chemical reaction with moisture in air	chemical reaction with curing agent	chemical reaction with moisture in air	chemical reaction with moisture in air	chemical reaction with curing agent
Tack-free time (hrs.) ASTM C679	24	36–48	24–36	24–72	1	1–2	1/2–5
Cure time [§] (days)	7–14	7	7–14	3–5	7–14	7–14	4–7
Maximum cured elongation (%)	300	600	300	500	300	400–1600	400–2000
Recommended maximum joint movement (%)	±25	±25	±15	±25	±25	±25 to +100, -50	±12-1/2 to ±50
Maximum joint width (in.)	3/4	1	1-1/4	2	3/4	1	1
Resiliency	high	high	high	high	high	moderate	high
Compression resistance	moderate	moderate	high	high	high	low	low
Extension resistance (modulus) [†]	moderate	moderate	medium	medium	high	low	low
Service temperature range (°F)	-40 to +200	-60 to +200	-40 to +180	-40 to +180	-60 to +350	-60 to +300	-60 to +300
Normal application temperature range (°F)	+40 to +120	+40 to +120	+40 to +120	+40 to +120	+20 to +160	+20 to +160	+20 to +160
Weather resistance	good	good	very good	very good	excellent	excellent	excellent
Direct UV resistance	good	good	poor to good	poor to good	excellent	excellent	excellent
Cut, tear and abrasion resistance	good	good	excellent	excellent	poor	poor to excellent	excellent knotty tear
Life expectancy [‡] (yrs.)	20+	20+	20+	20+	20+	20+	20+
Shore A hardness (ASTM C661)	25–35	25–45	25–45	25–45	30–45	15–35	15–40

[§] Cure time and pot life are greatly affected by temperature and humidity. Low temperatures and humidities create longer pot life and longer cure time. Conversely, high temperatures and humidities create shorter pot life and cure time.

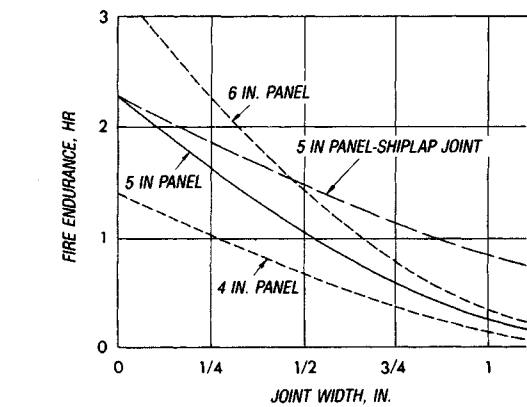
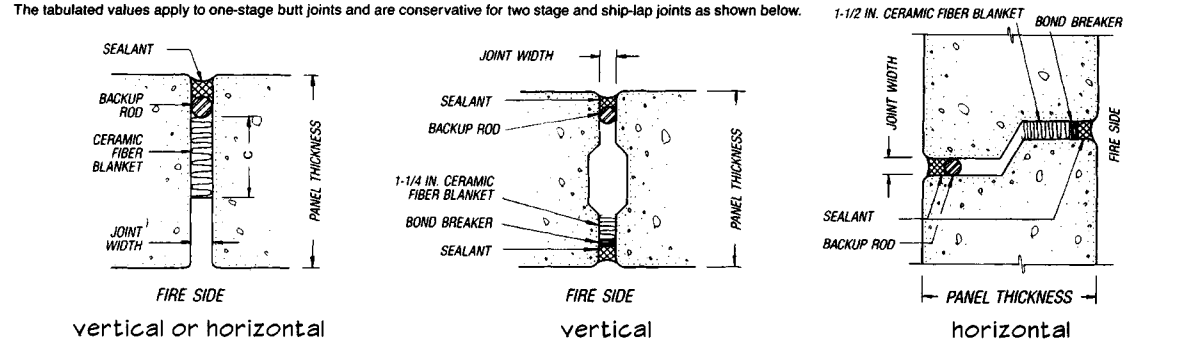
[†] Modulus is defined as the unit stress required to produce a given strain. It is not consistent but, rather, changes in value as the amount of elongation changes.

[‡] Life expectancy is directly related to joint design, workmanship and conditions imposed on any sealant. The length of time shown is based on joint design within the limitations outlined by the manufacturer and good workmanship based on accepted field practices and average job conditions. Variances of design, workmanship or conditions would shorten life expectancy to a degree. Total disregard for all would render any sealant useless within a very short period of time.

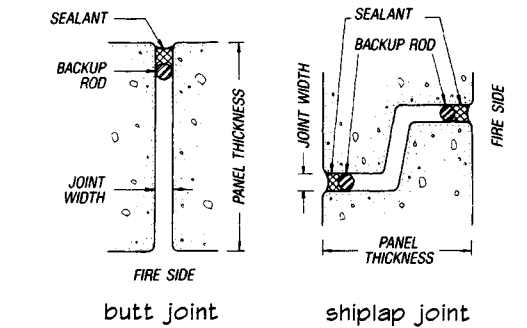
11.2.11 Fire-Resistant Joints

Panel thickness* (in.)	Thickness of ceramic fiber felt (in.) required for fire resistance ratings and joint widths shown							
	Joint width = 3/8 in.				Joint width = 1 in.			
	1 hr	2 hr	3 hr	4 hr	1 hr	2 hr	3 hr	4 hr
4	1/4	N.A.	N.A.	N.A.	3/4	N.A.	N.A.	N.A.
5	0	3/4	N.A.	N.A.	1/2	2 1/8	N.A.	N.A.
6	0	0	1 1/8	N.A.	1/4	1 1/4	3 1/2	N.A.
7	0	0	0	1	1/4	7/8	2	3 3/4

N.A. = Not application
Interpolation may be used for joint widths between 3/8 in. and 1 in.
*Panel equivalent thicknesses are for carbonate concrete. For siliceous aggregate concrete change "4, 5, 6, and 7" to "4.3, 5.3, 6.5, and 7.5". For sand-lightweight concrete change "4, 5, 6, and 7" to "3.3, 4.1, 4.9, and 5.7".
The tabulated values apply to one-stage butt joints and are conservative for two stage and ship-lap joints as shown below.

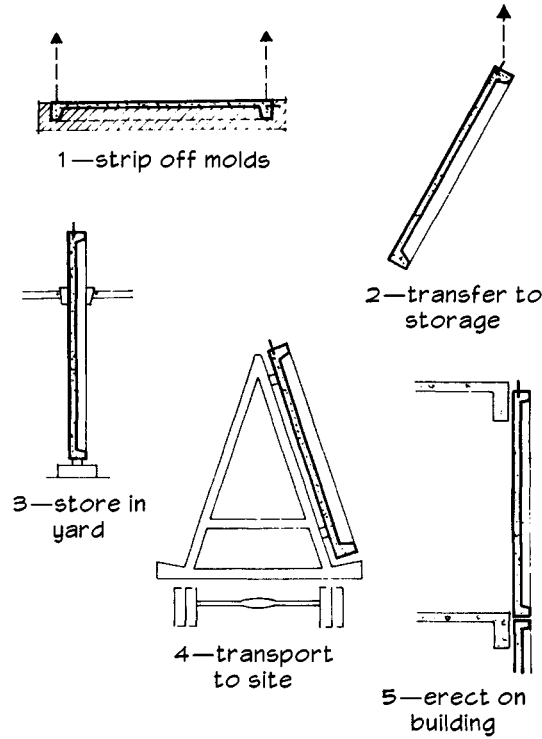


fire endurance of one-stage butt joints and two-stage shiplap joints

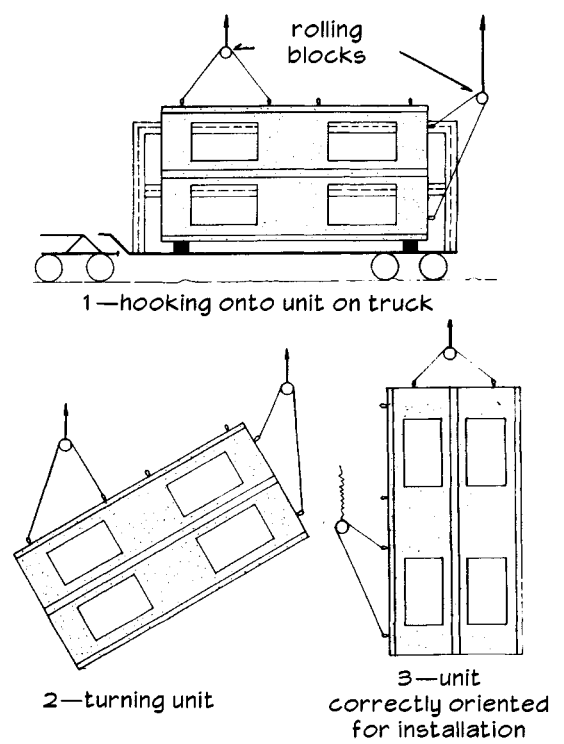


(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

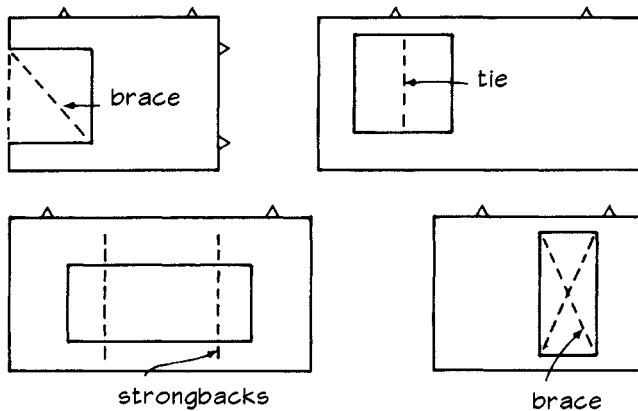
11.3.1 Handling Precast Concrete Panels



optimum handling sequence

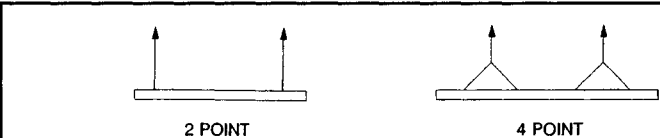
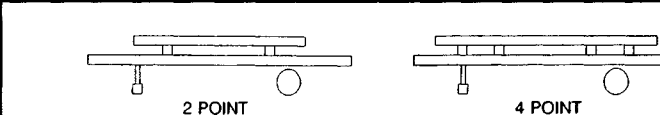
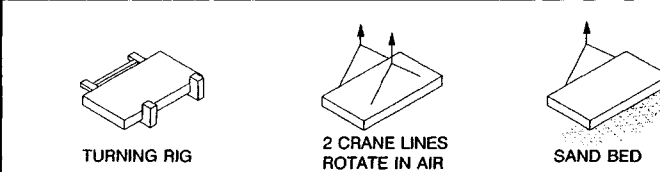

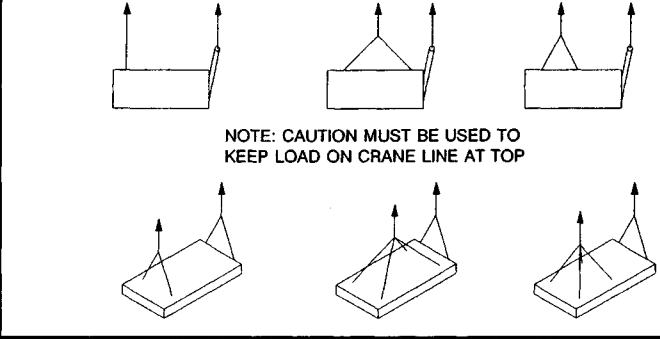


hoisting and turning multi-story units

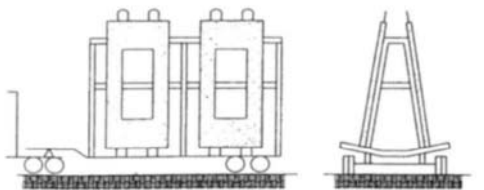


temporary strengthening of panels with large openings

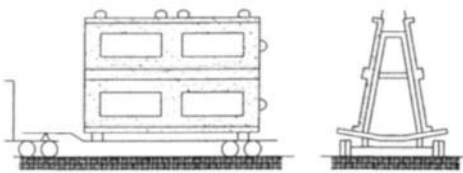
11.3.2 Handling and Transporting Precast Panels

STRIPPING	 2 POINT 4 POINT
YARDING	 2 POINT 4 POINT
ROTATING	 TURNING RIG 2 CRANE LINES ROTATE IN AIR SAND BED
STORAGE FOR SURFACE FINISHING, FINAL STORAGE, AND TRANSPORTATION	 "A" FRAME VERTICAL RACK
ERECTION	 NOTE: CAUTION MUST BE USED TO KEEP LOAD ON CRANE LINE AT TOP

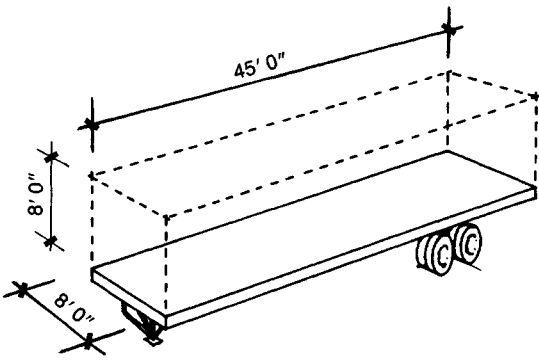
typical handling methods



transporting single-story panels



transporting multi-story panels



common overall truck volume

(From PCI Design Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)

11.3.3 Loading and Safety Factors for Handling Precast Concrete

Equivalent Static Load Multipliers to Account for Stripping and Dynamic Forces*		
Product Type	Finish	
	Exposed Aggregate With Retarder	Smooth Mold (Form Oil Only)
Stripping		
Flat, with removable side forms, no false joints or reveals	1.2	1.3
Flat, with false joints and/or reveals	1.3	1.4
Fluted, with proper draft‡	1.4	1.6
Sculptured	1.5	1.7
Yard Handling§ and Erection†		
All products	1.2	1.2
Travel§		
All products	1.5	1.5

* These factors are used in flexural design of panels and are not to be applied to required safety factors on lifting devices. At stripping, suction between product and form introduces forces which are treated here by introducing a multiplier on product weight. It would be more accurate to establish these multipliers based on the actual contact area and a suction factor independent of product weight.

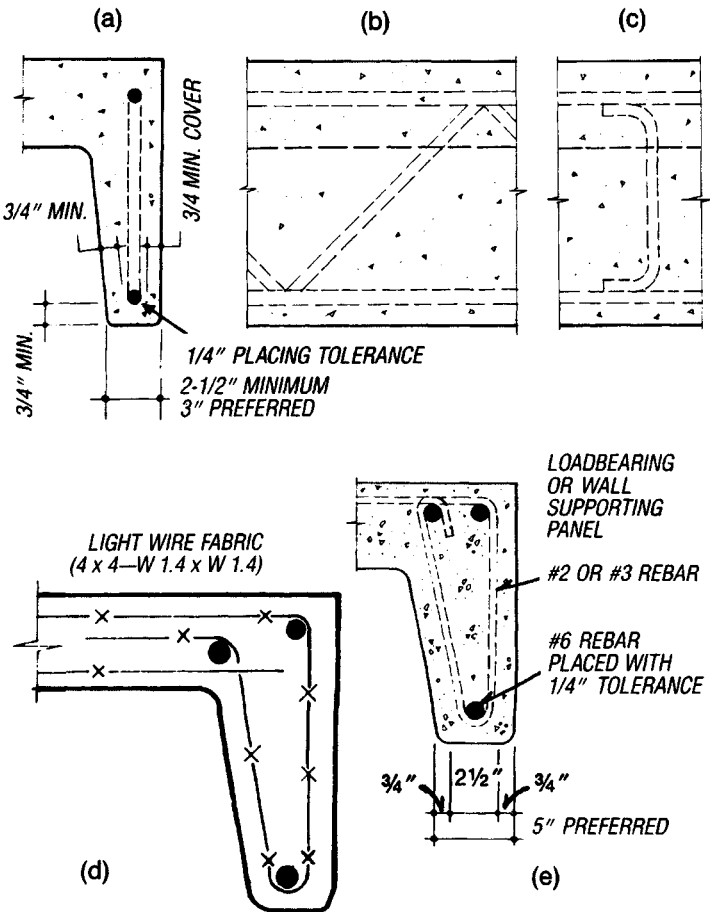
§ Certain unfavorable conditions in road surface, equipment, etc., may require use of higher values.

† Under certain circumstances, may be higher.

‡ For example, tees, channels, and fluted panels.

Suggested Safety Factors for Construction Loads	
Item/Condition	Safety Factor
Bracing for wind loads	2
Bracing inserts cast into precast members	3
Reusable hardware	5
Lifting inserts	4

11.4.1 Precast/Prestressed Concrete Reinforcing Requirements

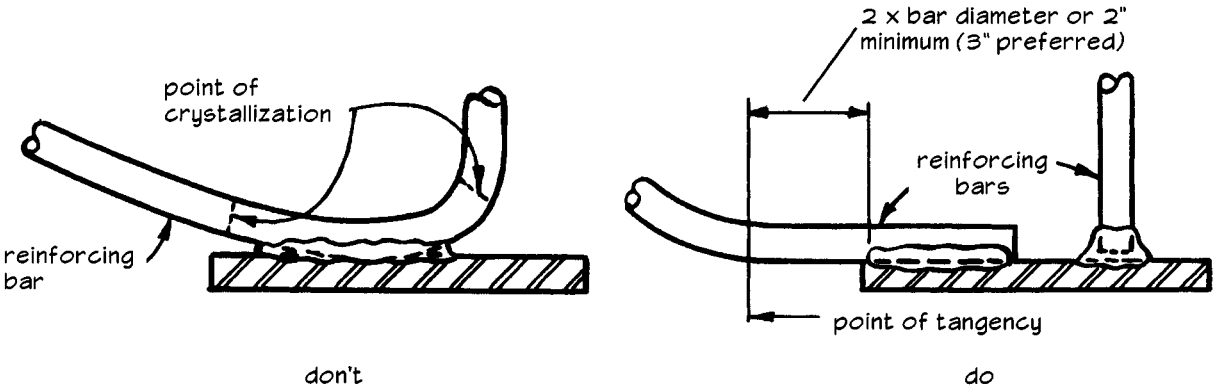


typical rib reinforcement

Minimum Cover for Reinforcement in Precast and Prestressed Concrete§†	
Condition	Minimum Cover
Exposed to earth or weather‡ - wall panels - other members	#11 and smaller, 3/4" #6 thru #11, 1-1/2" #5 bar or W31 wire and smaller, 1-1/4"
Not exposed to earth or weather - wall panels, slabs and joists - beams / columns - main steel	#11 and smaller, 5/8" diameter of bar, but not less than 5/8" and need not exceed 1-1/2" all sizes, 3/8"
- ties, stirrups or spirals	

§ Manufactured under plant control conditions.
‡ Increase cover by 50% if tensile stress of prestressed members exceeds $6 \sqrt{f'_c}$.
† Cover requirements for #5 bars and smaller apply to prestressing steel.

(From PCI Design Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)

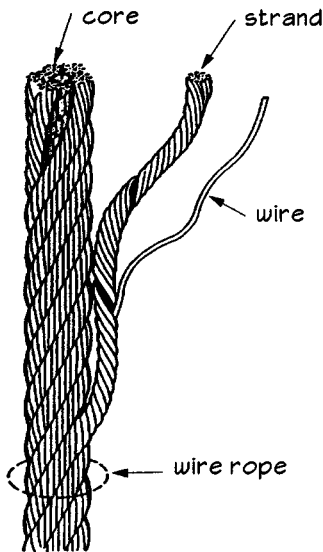


welding reinforcing bars

(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

11.4.2 Pretensioning Strand Requirements

To minimize the possibility of splitting cracks in thin pretensioned members, strand diameter should not exceed size shown in table.

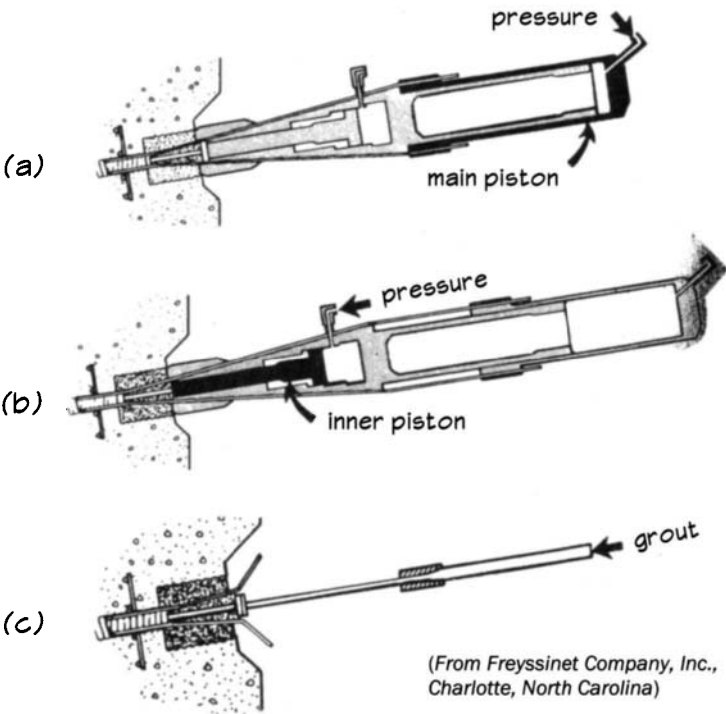


Maximum Strand Diameter in Thin Pretensioned Members	
Panel Thickness (in.)	Strand Diameter (in.)
2-1/2	3/8
2-1/2 to 3-1/2	7/16
3-1/2 and larger	1/2

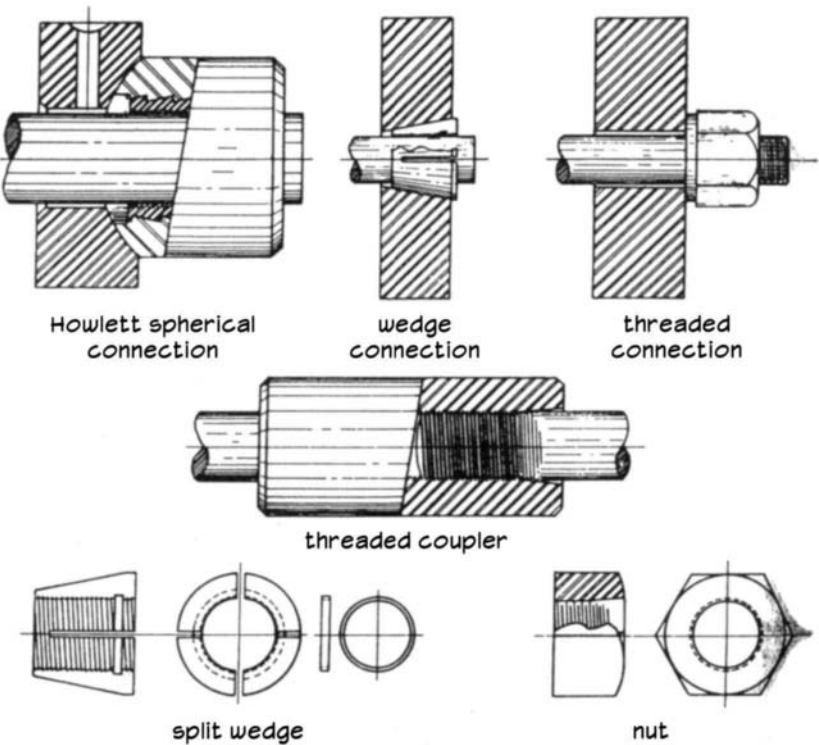
(From Architectural Precast Concrete, 2nd ed., Precast/
Prestressed Concrete Institute, 1989)

(From PCI Design Handbook, 5th ed.,
Precast/Prestressed Concrete Insti-
tute, 1999)

11.4.3 Prestressing Tendons

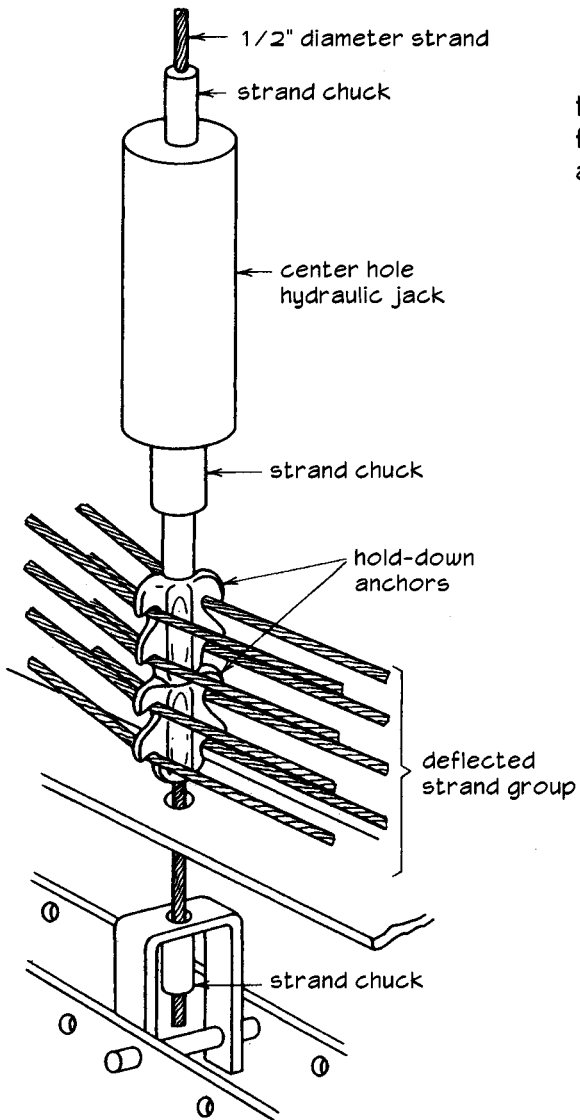


stressing sequence in the original Freyssinet system showing (a) the stressing, (b) the plugging, and (c) the grouting of the tendon



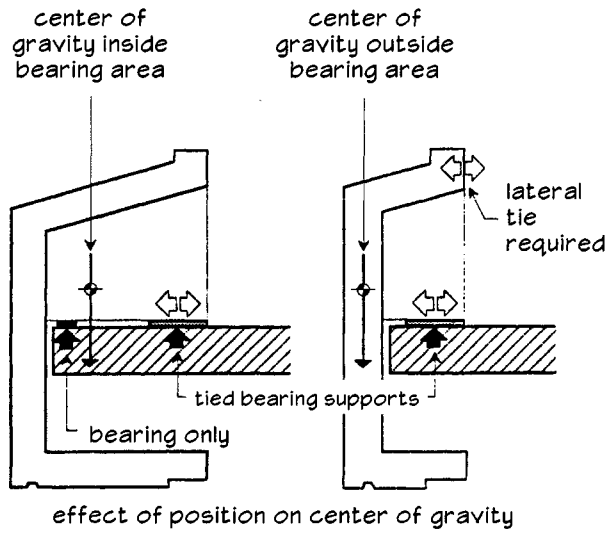
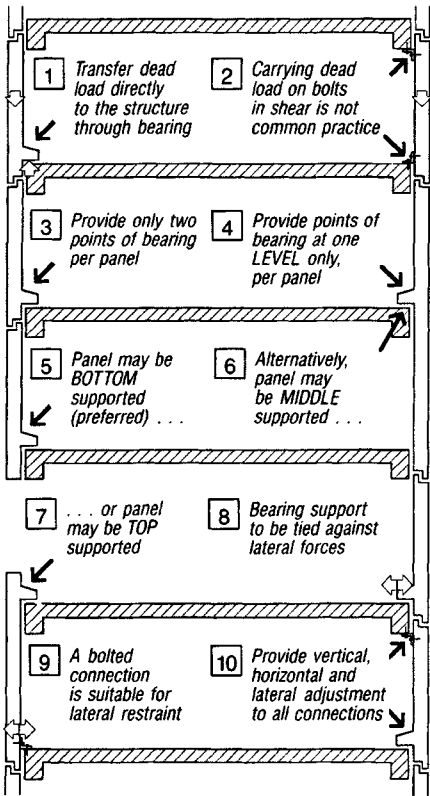
anchorages and couplers used with bar systems

(From Howlett Post-Tensioning Systems, Berkley, California)

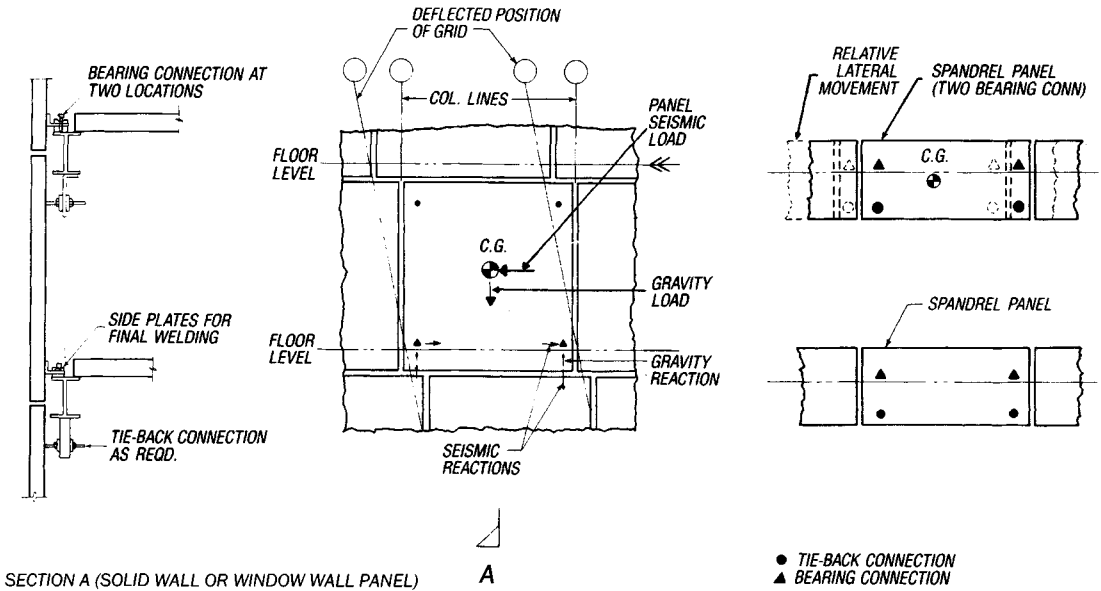
11.4.4 Tendon Hold-Down Device

tendon hold-down device
for use with jacking down
at the hold-down points

11.5.1 Precast Panel Connection Concepts



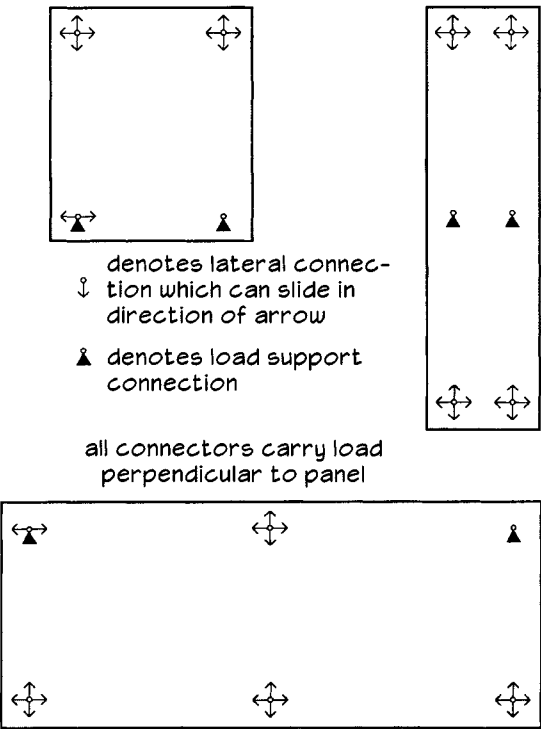
ten basic design principles for cladding panel connections



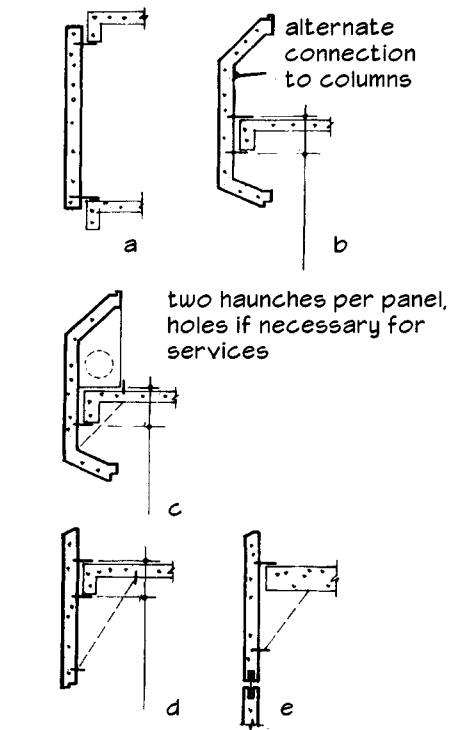
panel connection concepts

(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

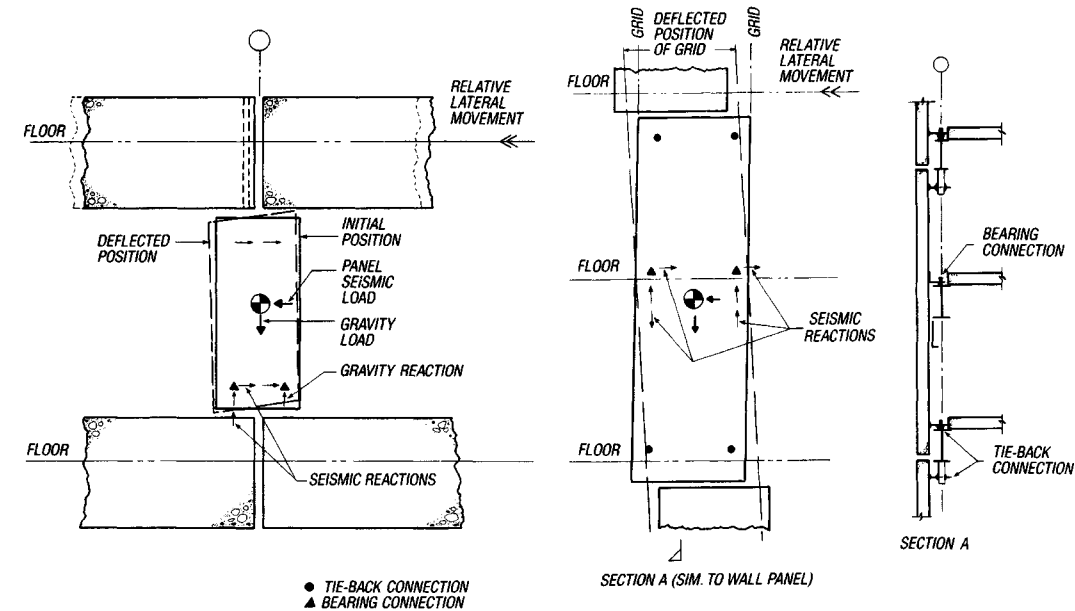
11.5.1 Continued



connections for cladding panels in low seismic risk areas



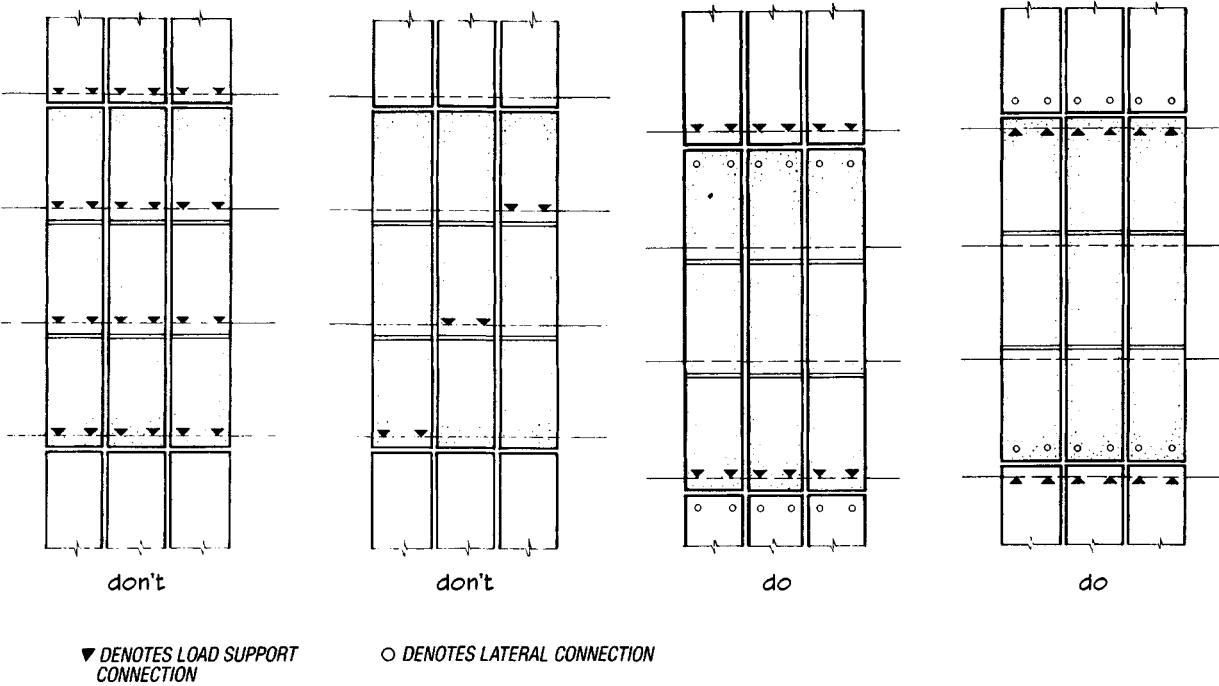
joint locations and corresponding connection concepts



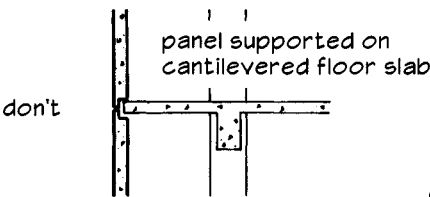
tall/narrow units

(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

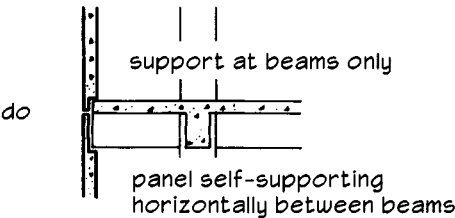
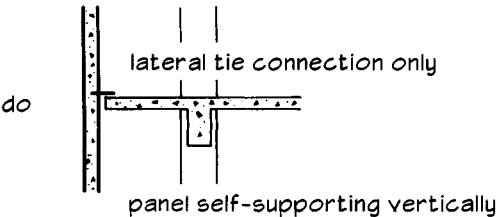
11.5.1 Continued



connections for wall-supporting precast concrete wall panels

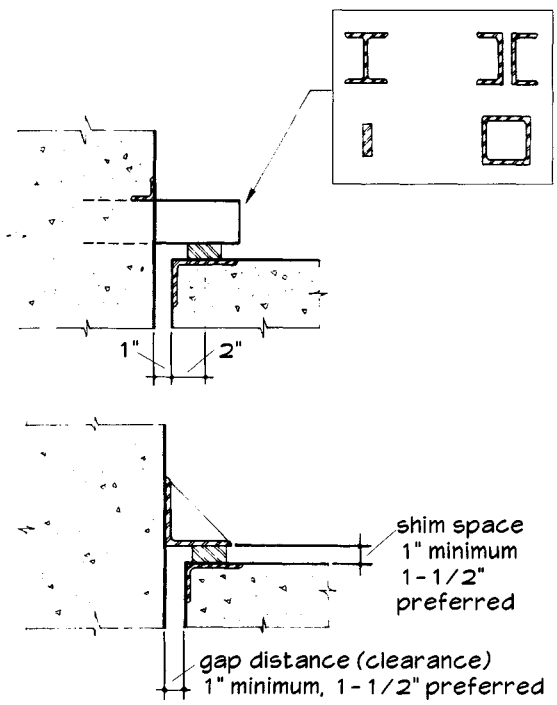


precast units for buildings with cantilevered floor slabs

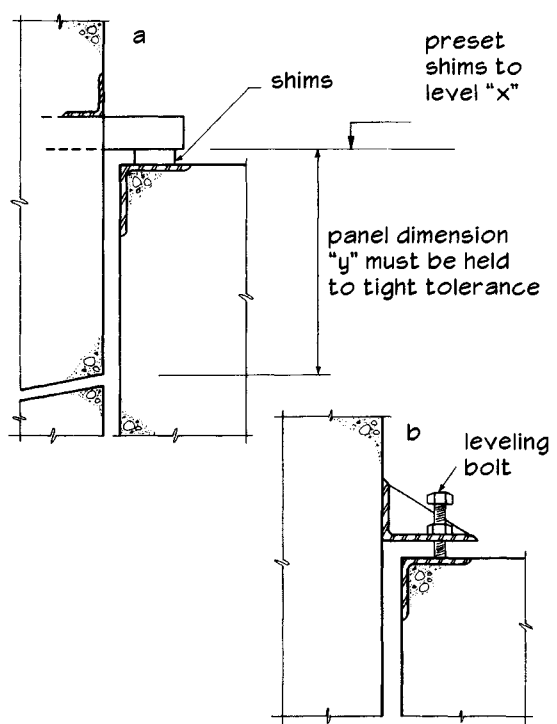


(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

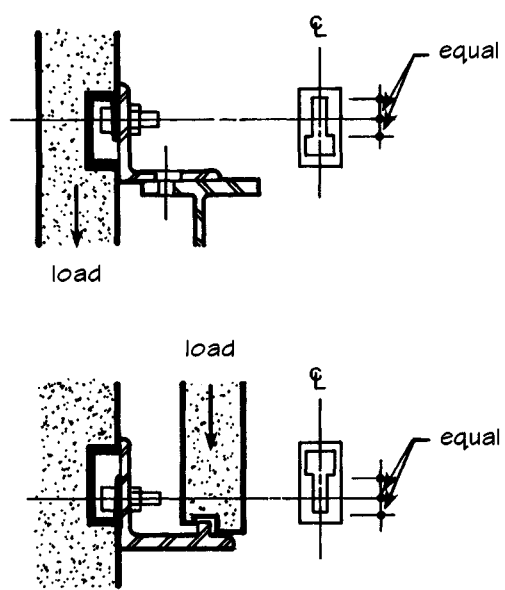
11.5.2 Panel Connection Dimensions, Alignment and Adjustable Inserts



dimensions for connection design



vertical alignment methods



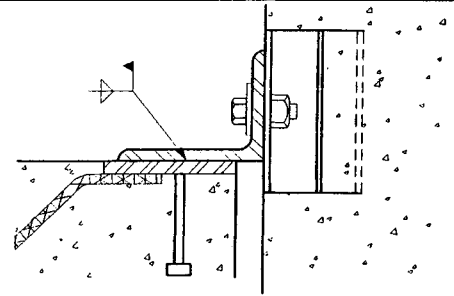
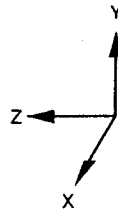
wedge inserts allow linear adjustment

(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

11.5.3 Force Transfers in Precast Panel Connections

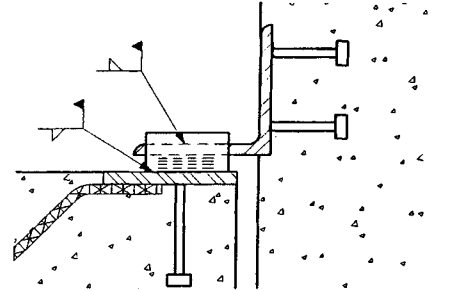
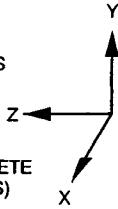
a. horizontal load transfer in x and z direction

- CONCRETE TO INSERT
- INSERT TO BOLT
- BOLT TO ANGLE
- ANGLE TO WELD
- WELD TO PLATE
- PLATE TO ANCHORS
- ANCHORS TO CONCRETE
(7 FORCE TRANSFERS)



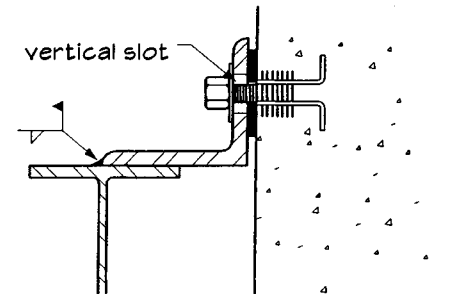
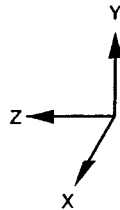
b. horizontal load transfer in z direction and vertical load transfer in y direction

- | | |
|---|---|
| <ul style="list-style-type: none"> (X) ▪ CONCRETE TO STUDS ▪ STUDS TO ANGLE ▪ ANGLE TO WELD ▪ WELD TO WING PLATE ▪ WING PLATE TO WELD ▪ WELD TO BRG PLATE ▪ BRG PLATE TO ANCHORS ▪ ANCHORS TO CONCRETE
(8 FORCE TRANSFERS) | <ul style="list-style-type: none"> (Y) ▪ CONCRETE TO STUDS ▪ STUDS TO ANGLE ▪ ANGLE TO SHIMS ▪ SHIMS TO PLATE ▪ PLATE TO ANCHORS ▪ ANCHORS TO CONCRETE
(6 FORCE TRANSFERS) |
|---|---|



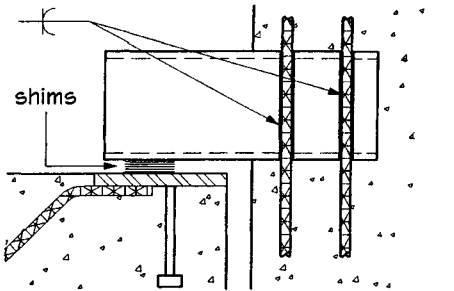
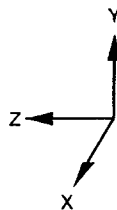
c. horizontal load transfer in x or z direction

- CONCRETE TO INSERT
- INSERT TO BOLT
- BOLT TO ANGLE
- ANGLE TO WELD
- WELD TO SUPPORT
(5 FORCE TRANSFERS)



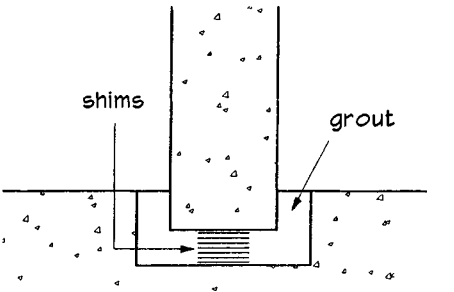
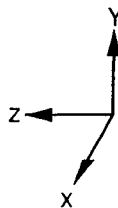
d. vertical load transfer

- CONCRETE TO REINFORCEMENT AND TUBE
- REINFORCEMENT TO WELDS
- WELDS TO TUBE
- TUBE TO SHIMS
- SHIMS TO BEARING PLATE
- BEARING PLATE TO ANCHORS
- ANCHORS TO CONCRETE
(7 FORCE TRANSFERS)

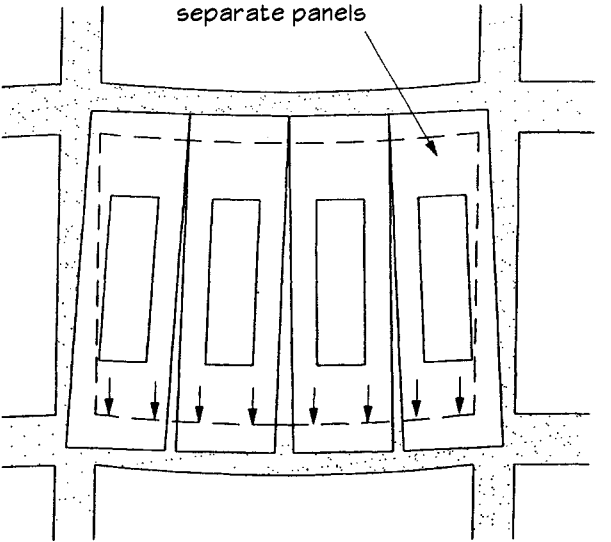


e. horizontal load transfer in x and z direction and vertical load transfer in y direction

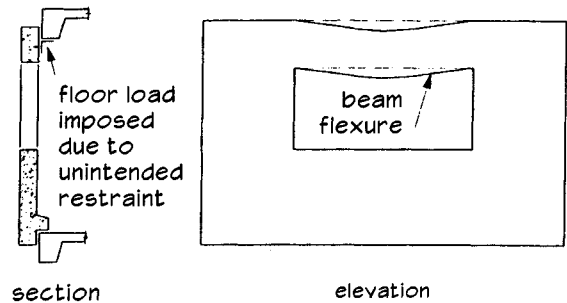
- CONCRETE TO GROUT AND SHIMS
- GROUT AND SHIMS TO SUPPORT
(2 FORCE TRANSFERS)



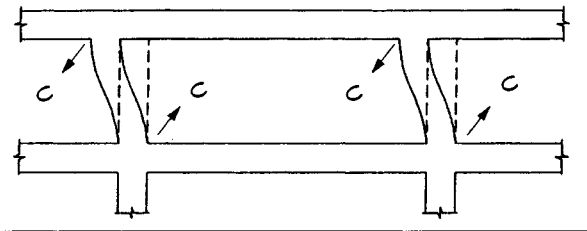
11.5.4 Deformation, Distortion and Cracking in Precast Panels



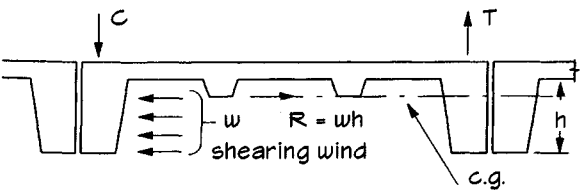
panel deformation on flexible beam



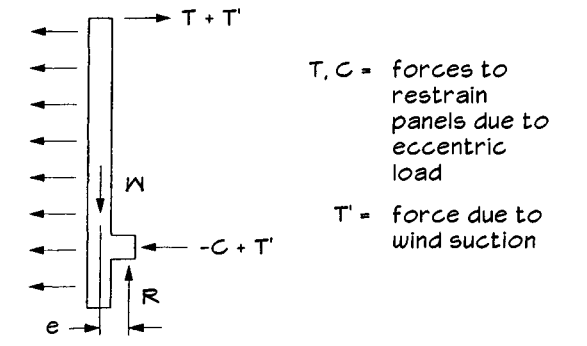
unanticipated loading on a non-loadbearing panel



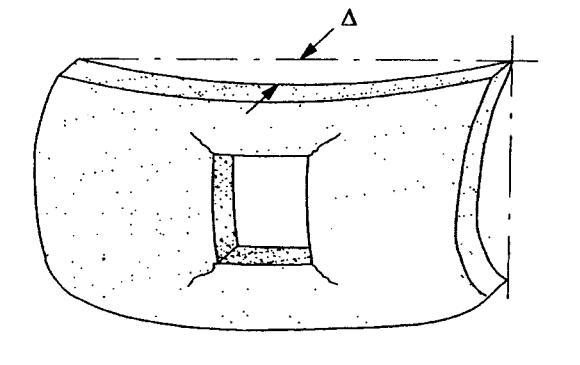
panel forces induced by frame distortion



shearing wind on ribbed panels



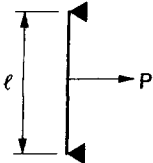
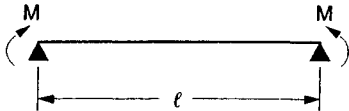
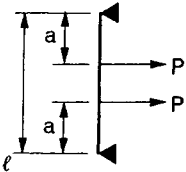
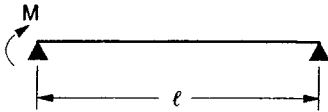
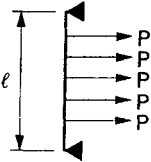
wind suction forces on panel



corner cracking due to unrestrained bowing

(From PCI Design Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)

11.5.5 Forces Required to Restrain Bowing

intermediate restraint (ends free to rotate)	end restraint
<p>case 1: single restraint at midspan</p>  $P = \frac{48 E_t I \Delta}{\ell^3}$ $\text{moment in panel} = \frac{P \ell}{4}$	<p>case 2: both ends restrained</p>  $M = \frac{8 E_t I \Delta}{\ell^2}$
<p>case 3: two restraint points</p>  $P = \frac{24 E_t I \Delta}{3a\ell^2 - 4a^3}$ $\text{moment in panel} = Pa$	<p>case 4: one end restrained</p>  $M = \frac{16 E_t I \Delta}{\ell^2}$
<p>case 5: three or more restraint points (approximate uniform continuous restraint)</p>  $\Sigma P = w \ell = \frac{77 E_t I \Delta}{\ell^3}$ $\text{moment in panel} = \frac{w \ell^2}{8} = \Sigma P \left(\frac{\ell}{8} \right)$	<p>for daily temperature change, use $E_t = 0.75 E_c$</p> <p>for seasonal temperature change, use $E_t = 0.50 E_c$</p>

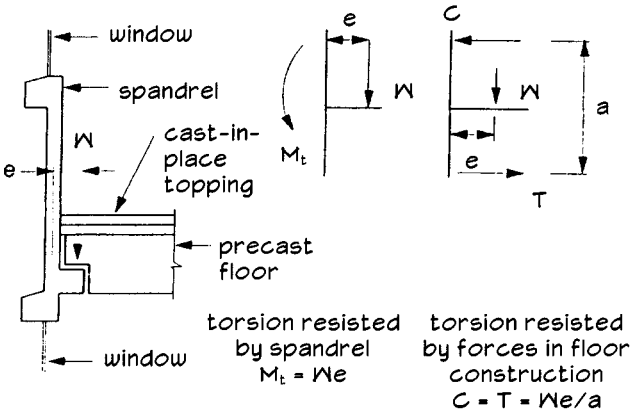
(From PCI Design Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)

11.5.6 Deflection Limits for Precast Wall Panels

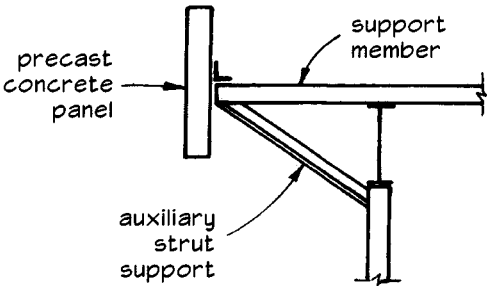
Type of Member	Deflection to be Considered	Deflection Limitation
Loadbearing precast wall panels	Immediate deflection due to combined effects of prestress, if any, self weight, and superimposed load	1/240 but not greater than 3/4 in.
	Immediate deflection due to live load	1/360 but not greater than 3/4 in.
Non-loadbearing precast wall panel elements likely to be damaged by large deflection	That part of the total deflection after the installation of the non-loadbearing element (the sum of the long time deflection due to all sustained loads and the immediate deflection due to live load)	1/480 but not greater than 3/4 in.

(From ACI 533R-93 Guide for Precast Concrete Wall Panels)

11.5.7 Spandrel Connections

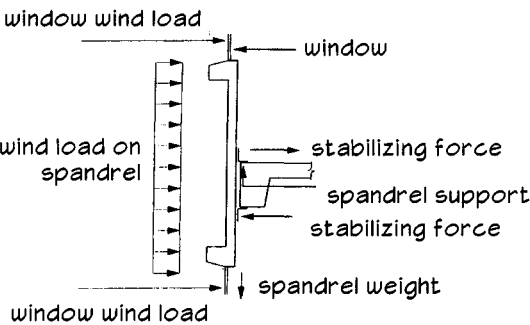


loadbearing spandrel

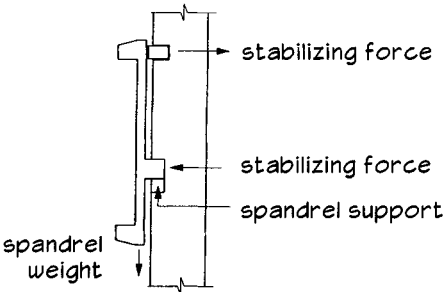


auxiliary strut support

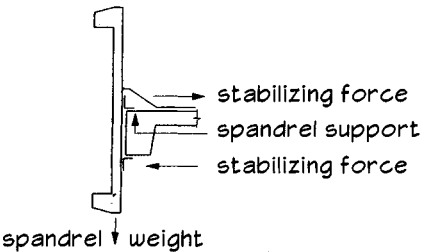
(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)



floor connection

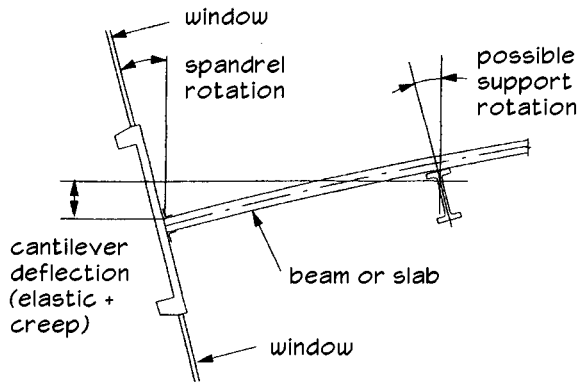


column connection



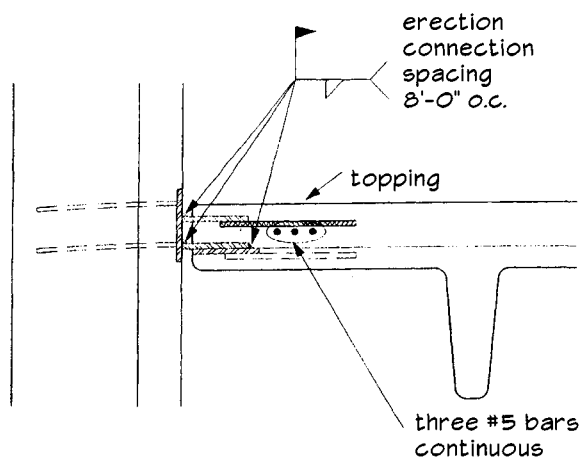
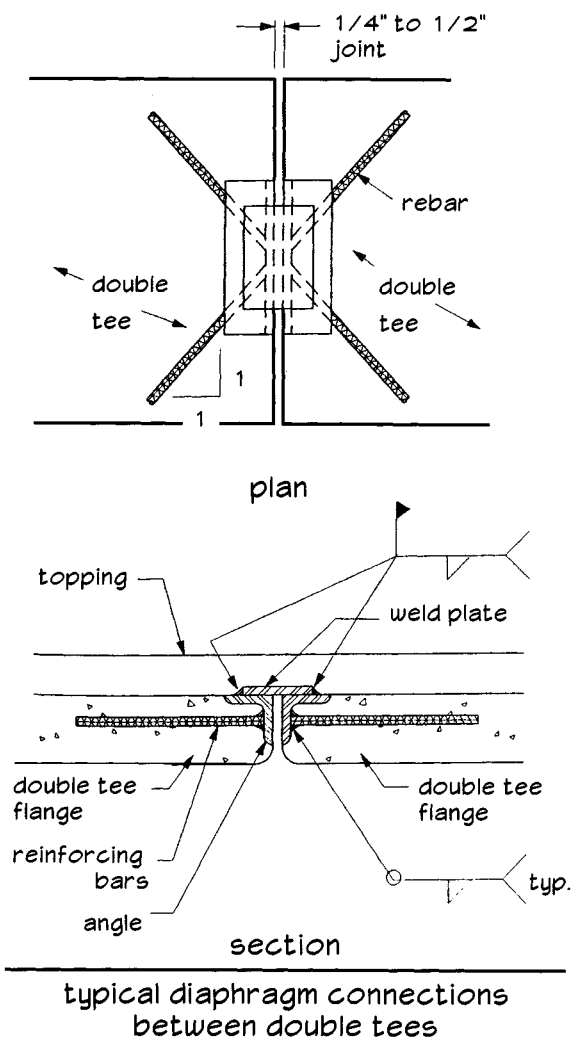
roof connection

typical spandrel connections

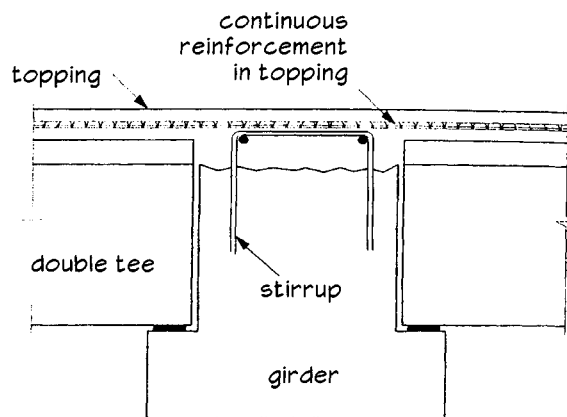


effect of cantilever supports

11.5.8 Double Tee Connections



typical connection between diaphragm and wall at side of double tee



typical end connection between double tees

(From PCI Design Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)

11.5.9 Direct Bearing Connections

Design

- more detailing
- provides lateral restraint
- shims must be placed to hold vertical alignment until grouting or drypacking is done
- realignment is not possible once connection has been completed

Production

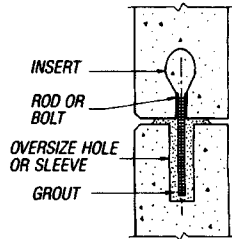
- more measuring
- reasonable tolerance each way

Erection

- wet placement requires care
- grout problem in cold weather
- may be best to field drill oversized hole into foundation

Variation

- grout could be injected through tubes allowing more time for alignment



SHIM STACKS OCCUR AT 2 POINTS PER PANEL ADJACENT TO CONNECTION

Design

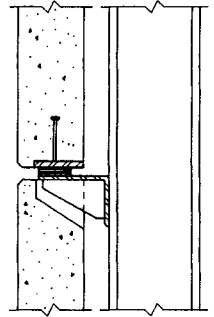
- preferable for bracket to be on contract drawing and shop installed
- may require restraint for shim stack

Production

- cost substantially more if column bracket field installed

Erection

- reasonable, if column bracket already there
- layout crew required if bracket not shop installed



Variations

- leveling bolt may be used in lieu of shims

Design

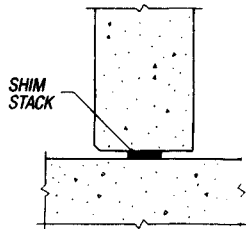
- simple
- lateral restraint not provided

Production

- simple

Erection

- simple
- does have large tolerance
- joint may be caulked or dry-packed



2 SHIM STACKS/PANEL

11.5.10 Eccentric Bearing Connections

Design

- hardware layout drawing required for General Contractor
- consider torque on projecting element if unsymmetrical section used
- panel must resist bending

Production

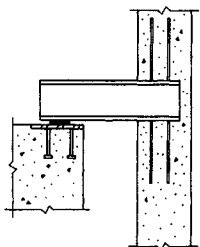
- simple
- requires early coordination with General Contractor
- requires additional space for storage and shipping

Erection

- simple

Variations

- W, I, channel, ST, flat bars, angle or TS may be used



Design

- weld all around may not be required
- keep bearing at centerline of beam to avoid torsion
- safety and sequence may dictate blockout to embed bracket in floor slab
- panel must resist bending

Production

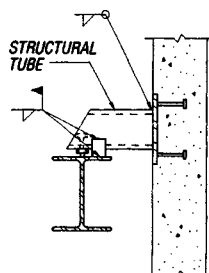
- simple
- substantial shop fabrication
- leveling bolt is costly

Erection

- simple
- leveling bolt saves time

Variations

- different tie-back connection may be used in lieu of weld plate
- shims may be used in lieu of leveling bolt
- location and configuration of weld plate may vary



Design

- hardware layout drwg. required for G.C.

Production

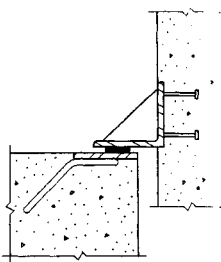
- simple
- requires early coordination with G.C.

Erection

- simple

Variations

- leveling bolt may be used in lieu of shims
- weld plate may be used in lieu of separate tie-back connection



Design

- important for shaped panels; can eliminate overturning moment from dead load when centerline of shim is at c.g. of panel

Production

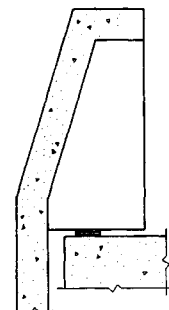
- complex forming especially if location of haunch changes

Erection

- simple

Variations

- forming made easier by substituting a bolt-on steel bracket especially if haunch location changes



Design

- hardware layout drwg. required for G.C.
- confinement steel around studs in panel may be required

Production

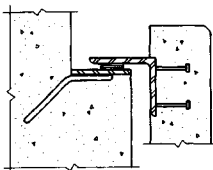
- simple
- requires early coordination with G.C.

Erection

- simple

Variations

- weld plate may be used in lieu of separate tie-back connection



11.5.11 Bolted and Welded Tie-Back Connections

Design

- slenderness ratio of rod must be considered for compression load

Production

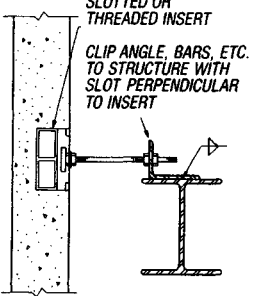
- simple
- adequate tolerance is provided when slotted insert set in opposite direction of slot in angle

Erection

- quick
- connection hardware is prewelded, thus panels are erected without welding
- panel alignment can be completed after release from crane

Variations

- if threaded insert is used, the in-plane movement may be achieved by flexibility of the rod, or by an oversized hole at the opposite end
- field weld angle to structure
- bolt angle to structure



SLOTTED OR THREADED INSERT
CLIP ANGLE, BARS, ETC. TO STRUCTURE WITH SLOT PERPENDICULAR TO INSERT

Design

- simple
- edge distance must be considered

Production

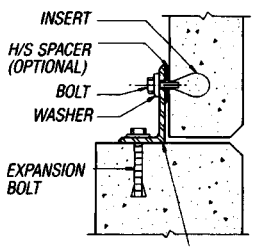
- simple

Erection

- simple
- must coordinate with steel in foundation
- accommodates large tolerance with exp. anchor

Variations

- if pre-set insert is used in place of exp. bolt, a slotted hole is necessary in the horizontal leg of the angle



INSERT
H/S SPACER (OPTIONAL)
BOLT
WASHER
EXPANSION BOLT
ANGLE WITH OVERSIZE HOLE ON VERTICAL LEG

Design

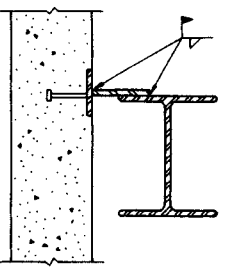
- volume change of panel and live load deflection of steel beam must be considered
- consider staggering studs to minimize magnification of the force on headed stud due to misalignment of plate
- rigid connection
- possible volume change restraint problems

Production

- simple

Erection

- requires bracing until welded; bracing may be achieved by another connection
- ample adjustment allowance



Design

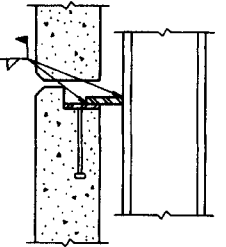
- rigid connection
- possible volume change restraint problems
- connection is difficult to inspect

Production

- simple

Erection

- requires bracing until welded; bracing may be achieved by another connection
- ample adjustment allowance
- alignment and welding must be completed before panel above is erected



11.5.12 Welded Tie-Back Connections

Design

- if strap is used, volume change restraint in the plane of panel must be considered
- slenderness ratio of rod must be considered for compression load

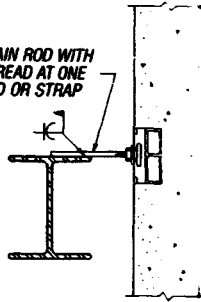
Production

- simple

Erection

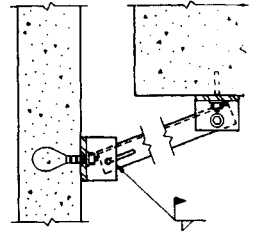
- requires bracing until welded; bracing may be achieved by another connection
- threaded rod should not be overtightened if future movement at slotted insert is expected

PLAIN ROD WITH
THREAD AT ONE
END OR STRAP



Design

- live load deflection of superstructure must be considered
- if bracing angle is designed as an axially loaded member, the vertical component of force must be accounted for in the design of other connections on the same panel



Production

- simple

Erection

- slots and bolts are used for temporary erection connection
- weld after final alignment

Design

- good solution to avoid problems caused by structure deflection

Production

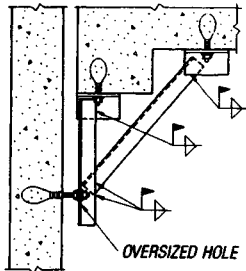
- simple

Erection

- if hardware is assembled prior to erection, oversized holes and plate washers are required

Variations

- use stiffer vertical members and eliminate the diagonal



OVERSIZED HOLE

Design

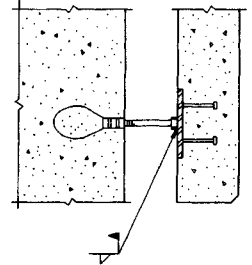
- a minimum bolt penetration into insert should be specified and ensured

Production

- simple

Erection

- quick
- adjustment allowance limited by ferrule and bolt lengths
- must have adequate clearance for welding



Variations

- weld may not be required if connection transfers only compression
- could be reversed

Design

- good for seismic parallel forces
- hardware layout drwg. required for G.C.

Production

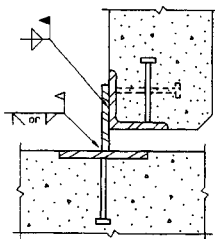
- simple
- requires early coordination with G.C.

Erection

- simple
- considerable adjustment

Variations

- change loose weld plate to loose angle



11.5.13 Bolted and Welded Alignment Connections

Design

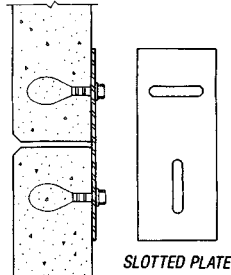
- can also serve as a tie-back connection for light loads

Production

- simple
- requires close thickness tolerances

Erection

- quick
- good adjustment allowance
- to avoid volume change restraint, bolts should not be overtightened
- may require horseshoe shim spacers



Design

- good shear transfer
- rigid connection
- possible volume change restraint problems

Production

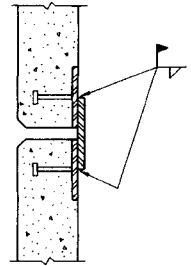
- simple
- face of panel to face of plate dimension is critical

Erection

- quick, easy
- ample adjustment allowance

Variations

- various embedded plates or shapes may be welded together
- one side could be bolted with slotted or oversized hole



Design

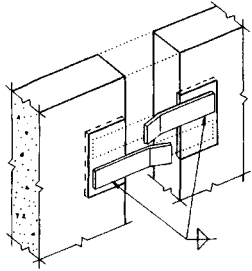
- can also serve as tie-back connection for light normal load

Production

- simple
- face of panel to face of plate dimension is critical

Erection

- quick
- good solution when connection is not accessible after erection
- plate can be shop welded prior to fabrication or field welded prior to erection
- erection sequence should be considered and may be governed by this connection



Design

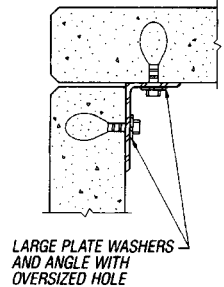
- volume change relief is provided unless necessary to weld plate washers for specific loads

Production

- simple

Erection

- quick
- good adjustment allowance
- to avoid volume change restraint bolts should not be overtightened



LARGE PLATE WASHERS AND ANGLE WITH OVERSIZED HOLE

11.5.14 Column and Beam Cover Connections

Design

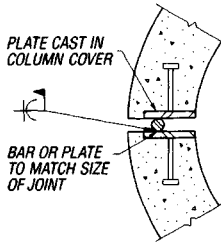
- provides a rigid connection between column cover segments
- can be used where connection to column or beam would be difficult due to limited access
- 3/4" minimum joint size is recommended

Production

- allows reasonable tolerances for alignment
- if the column section is thin, placement and coverage of plate is difficult

Erection

- panel joint must be sufficient to allow for welding
- care must be taken in preventing welding stain on exterior concrete
- care must be taken not to apply excess heat that would crack the concrete



Column Cover A

Design

- can be used only at top of column cover where access is available for welding
- used for lateral stability and alignment

Production

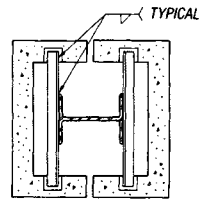
- the weld plates must be placed on the end form

Erection

- need access to top of column cover to make connections

Variations

- can be used on any shape column cover
- can be changed to bolted



Column Cover B

Design

- beam must be designed to prevent excessive rotation during erection
- rigidity provided by welded connections must be considered

Production

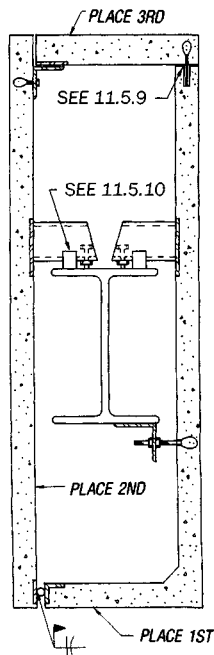
- requires careful casting to match finishes on faces
- requires a close casting tolerance on the doweled connections for the cap piece

Erection

- requires that the erector place pieces in proper sequence
- may require a combination of bolting, welding and grouting
- care must be taken to prevent staining of exposed surface during welding

Variations

- alternate top conditions are shown but only one type should be used (watertightness of top condition should be considered)



Notes
Refer to Column Cover A (above)
and to 11.5.10, 11.5.11

Beam Cover

11.5.15 Soffit Hanger and Masonry Tie-Back Connections

Design

- allows for adjustment and movement
- may require additional bracing for lateral loads

Production

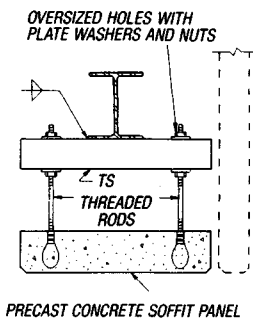
- ease in casting inserts into panel

Erection

- allows for final alignment after panel is released
- may be difficult to get to areas requiring bolting

Variations

- angles or other shapes maybe used instead of threaded rods



OVERSIZED HOLES WITH PLATE WASHERS AND NUTS

TS

THREADED RODS

PRECAST CONCRETE SOFFIT PANEL

Design

- the masonry may need to be reinforced

Production

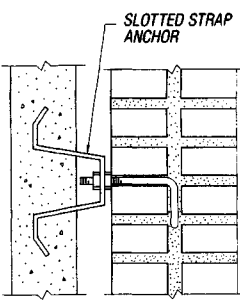
- the slotted insert with masonry tie-back allows for ease of casting and considerable tolerance

Erection

- precast concrete member must be set, aligned and braced prior to layup of masonry
- temporary bracing is required

Variations

- threaded or slotted inserts or dovetail anchor slots in masonry and precast concrete may be used in lieu of strap anchors



SLOTTED STRAP ANCHOR

11.5.16 Seismic Shear Plate Connections

Design

- normally one used at centerline of panel
- takes seismic force parallel to panel to minimize lateral load on bearing connections
- assume fixed at beam, pinned at panel
- particularly advantageous when panel to beam dimension is large
- also takes force perpendicular to panel
- thin plate allows some vertical movement

Production

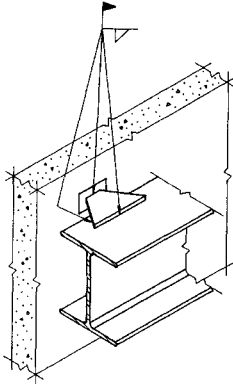
- panel plate tolerance large

Erection

- welding required
- cannot be installed until panel fully aligned
- large tolerance

Variations

- connection to panel can be made with angle and slot perpendicular to panel to allow movement perpendicular to panel
- is sometimes accomplished with a pair of angles or flat bars
- could be changed to bolted fastenings
- simplest version is small rectangular plate to floor slab embedment when panel is close to slab edge



Design

- shims carry full panel weight
- shims should be immediately adjacent to welded angle
- can not be installed until unit fully aligned so temporary tie may be required during erection
- orientation of angle provides maximum capacity both parallel and perpendicular to wall

Production

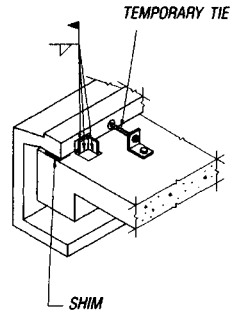
- simple
- large tolerance
- separate embedment may be required for temporary tie

Erection

- can not be installed until panel fully aligned

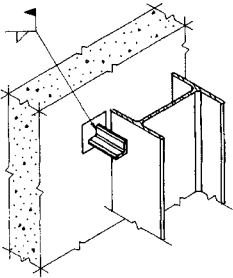
Variations

- any type of plate, angle or T may be used for field plate
- leveling bolt could be recessed in sill for ease of alignment in lieu of shims



Design

- at mid-height of column covers to eliminate inertial overturn
- if not welded to column, must be used in pairs and column cover rotates in plane of wall with story drift so bearing connections must allow lift off
- if welded to column, the column cover translates in plane of wall which other connections must tolerate
- items above require careful integration of entire connection system and panel joint widths for inter-story displacements



Production

- panel plate tolerance large

Erection

- welding required
- large tolerance
- can not be installed until panel fully aligned

11.5.17 Unique Conditions and Connections

Design

- use when tie-back well above beam bottom
- requires oversize hole in beam web and channel
- preferable for channel to be on contract drwg. and shop installed

Production

- insert location and beam bracket can be held at constant distance to floor (greater panel standardization)

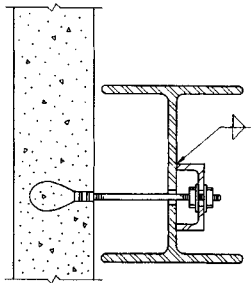
Erection

- where no access between beam flange and panel

Variations

- use MC, L or split TS

TIE-BACK WITH NO ACCESS BETWEEN PANEL & BEAM



Design

- requires oversize hole in beam web and angle
- preferable for angle to be on contract drwg. and shop installed

Production

- insert location must vary with beam depth

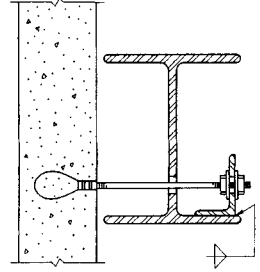
Erection

- use where no access between beam flange and panel

Variations

- use MC, C or TS

TIE-BACK WITH NO ACCESS BETWEEN PANEL & BEAM



Design

- need for blind connection to precast concrete panel
- allow for tolerance
- requires layout drwg. to be provided to G.C.
- face of panel needs no patching

Production

- no special production problems

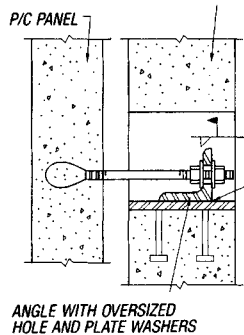
Erection

- requires temporary bracing if angle not welded until after alignment
- simple, welded slotted tie-back connection

Variations

- insert could be slotted

CAST-IN-PLACE OR MASONRY WALL



Design

- tolerates high seismic drift without complications of sliding or flexing of rod
- intermediate length rods often bind rather than slide
- length/diameter ratio of rod may not take adequate compression or allow sufficient flexing
- wave washer flattens under nominal movement; prior to that, rod is pinned both ends, subsequently pinned left end only

Production

- simple
- economical flat bar embedment

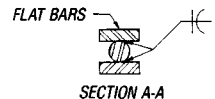
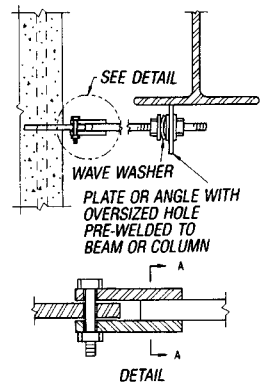
Erection

- fast; carries load immediately yet allows subsequent alignment
- wave washer (spring, etc.) must be installed on side which is not loaded under dead load only but should not be over tightened
- wave washer is standard off the shelf hardware
- ample tolerance

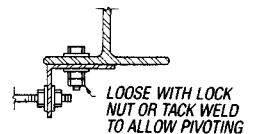
Variations

- for full pivot at beam end, see variation
- coil spring or neoprene washer could be substituted for wave washer
- compression capacity can be increased with loose pipe over rod since it limits rod buckling

ARTICULATED TIE-BACK



VARIATION



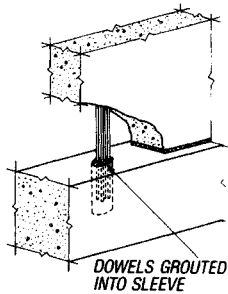
11.5.18 Wall-To-Foundation Connections

Design

- shear resistance is achieved
- capacity can be increased by use of confinement reinforcement around sleeve and bars

Production

- projecting dowels from panel can cause difficulties in storing and transporting panel
- location and alignment of dowels is critical



Erection

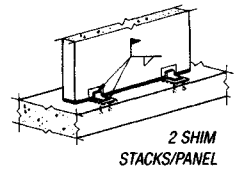
- grouting coordination required
- location and alignment of sleeve is critical
- no connection for panel during erection; necessary to brace
- use grout under panel
- alignment of panel must be made before initial set of grout
- must weather protect sleeve to prevent ice, water or debris from filling cavity

Variations

- sleeve may be placed in panel to receive dowels from foundation
- grout can be pumped into sleeve after alignment or before panel erection
- proprietary sleeve systems
- use insert or coupler and add threaded dowel in the field to reduce production and transportation problems
- single dowel is most commonly used

Design

- if connection is on exterior face of panel, it is susceptible to corrosion unless protected with mastic or grout
- hardware layout drwg. required for G.C.
- can be designed for horizontal shear and uplift; flexure in angle limits uplift capacity



Production

- simple
- embedded plates in wall may need to be jugged level if cast top-in-form to avoid tilting

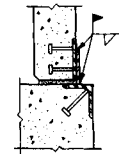
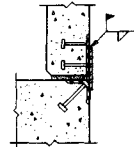
Erection

- quick and easy
- few tolerance problems if embedded plates are wider than angle
- welding may be difficult when connection is below grade
- space under wall usually filled with grout

Variations

- connections may be placed on both sides of wall to develop nominal moment resistance
- angles may be bolted to wall and/or foundation
- plates may be used in place of connection angles

VARIATIONS



Design

- develops moment resistance at base
- can be used to resist uplift forces
- no positive connection until bar is tensioned
- hardware layout drwg. required for G. C.

Production

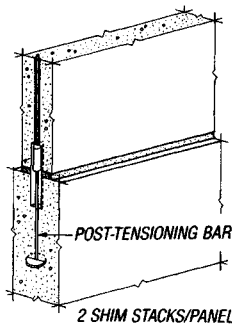
- duct placement tolerance in wall panel is critical
- grout vents may be required

Erection

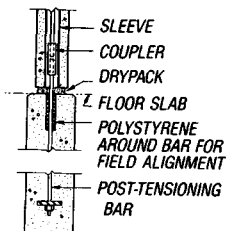
- may require temporary bracing
- bar, duct and hardware placement tolerance in foundation and wall panel is critical
- requires drypack to reach design strength prior to tensioning
- post-tensioning equipment necessary

Variations

- shim under panel
- bars may be coupled at top of foundation
- post-tensioned bar may or may not be grouted



VARIATIONS



11.5.19 Slab-To-Wall Connections

Design

- welding at bottom of slab is not recommended as excess restraint results
- no moment capacity
- must consider eccentricity of loads
- top connection transfers horizontal shear forces or provides nominal torsion restraint for spandrel

Production

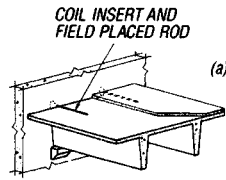
- special forming required for corbel
- corbel may be precast and set in form

Erection

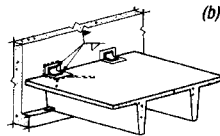
- quick and easy
- allows adequate tolerances
- temporary bracing may be necessary

Variations

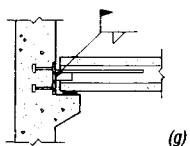
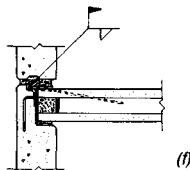
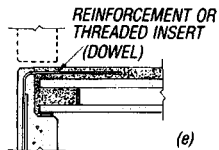
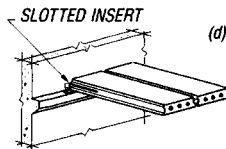
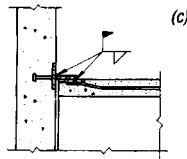
- steel corbel; may use inserts in panel to position angle while welding
- flag shaped plate (g) welded to embedded plate in wall can be used in hollow-core joints
- variation of (d) and (g), dowel may be in topping



VARIATIONS



OR



Design

- connection allows movements caused by temperature changes
- positive horizontal force transfer
- connection (c) allows vertical movement by flexing of plate and welds
- connection (d) allows vertical movement through flexibility of double tee flange

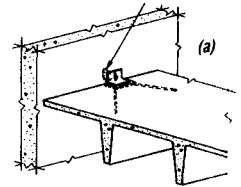
Production

- insert must be plumb and true
- washer must be oversize so it does not bind in the slot
- simple

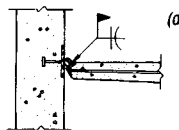
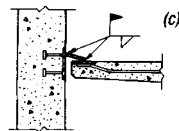
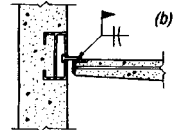
Erection

- quick and easy
- tolerance problems minimized
- do not overtighten bolt in (a)

THREADED INSERT IN WALL PANEL



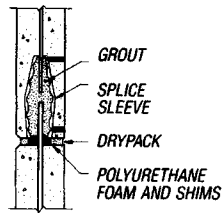
VARIATIONS



11.5.20 Wall-To-Wall Connections

Design

- continuity through the connections
- connection is concealed and protected
- no connection between walls until splice sleeves or ducts are grouted
- sleeve and sleeve grout are proprietary



Production

- hardware placement is critical
- projecting dowels can cause difficulties in storing and transporting panels if dowels project from bottom of panel

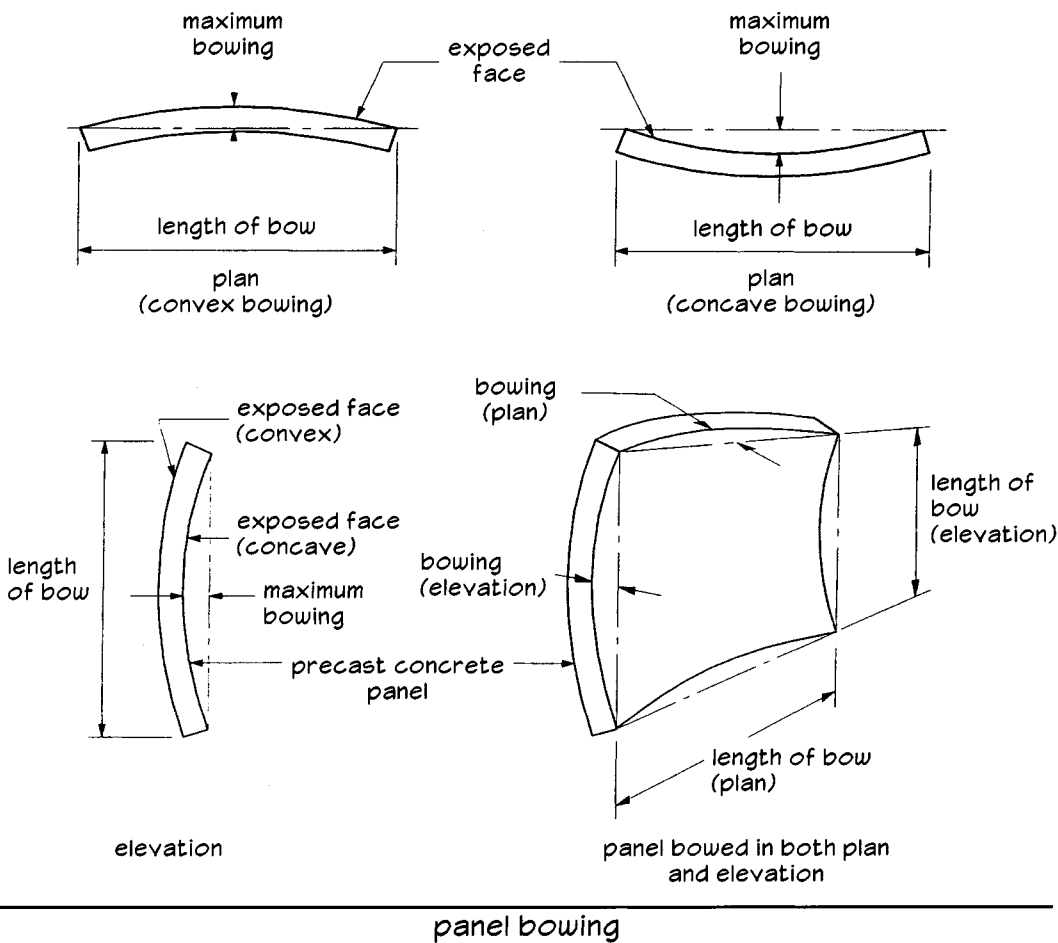
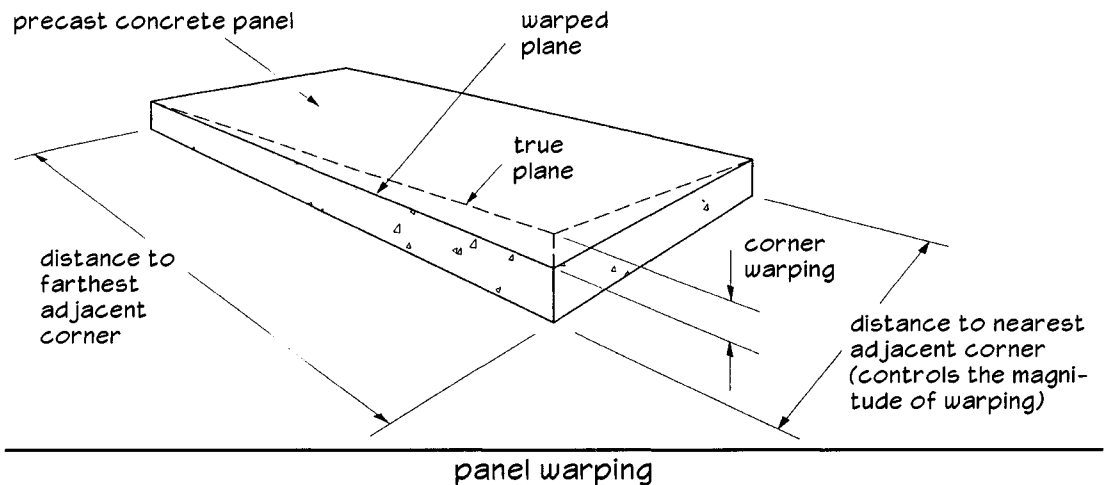
Erection

- may be necessary to heat grout in cold weather
- temporary brace required
- requires a grout crew in addition to setting crew

Variations

- sleeve connector can be placed in either upper or lower panel — upper panel is preferred

11.6.1 Panel Warping and Bowing



(From PCI Design Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)

11.6.2 Precast Panel Clearances, Smoothness and Bowing

PANEL CLEARANCES

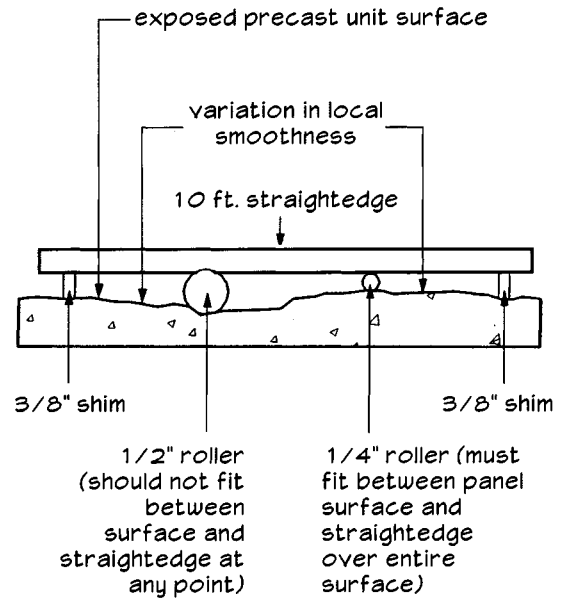
Clearance is the space between adjacent members and provides a buffer area where erection and production tolerance variations can be absorbed. The following items should be addressed when determining the appropriate clearance to provide in the design.

- product tolerance
- type of member
- member size
- member location
- member movement
- member function
- erection tolerance
- steel fireproofing
- thickness of plates, bolt heads, and other projecting elements

Recommended Panel Clearances

Item	Recommended Minimum Clearance (in.)
Precast to precast	1/2 (1 preferred)
Precast to cast-in-place	1 (2 preferred)
Precast to steel	1 (2 preferred)
Precast column covers	1-1/2 (3 preferred for tall buildings)

(From PCI Design Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)



local smoothness variation

(From PCI Design Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)

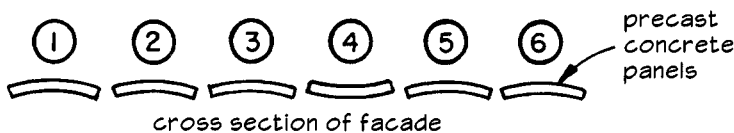
Panel Thickness (in.) to Maintain Bowing and Warping Within Suggested Normal Tolerances^{§†}

Panel Dimension (ft.) → ↓	8	10	12	16	20	24	28	32
4	3	4	4	5	5	6	6	7
6	3	4	4	5	5	6	6	7
8	4	5	5	6	6	7	7	8
10	5	5	6	6	7	7	8	8

[§] Do not use this table for panel thickness selection.

[†] For ribbed panels, the overall thickness of ribs may be used for comparison with this table if the ribs are continuous from one end of the panel to the other.

(From PCI Design Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)



differential bowing of panels

(From Architectural Precast Concrete, 2nd ed., PCI, 1989)

11.6.3 Concrete and Steel Construction Tolerances

Relevant Erection Tolerances for Cast-in-Place Concrete and Steel Structures		
Variation or Tolerance	Cast-in-Place Concrete	Steel
Variations from plumb, or column tolerances	1/4 in. per 10 ft., but not more than 1 in. Valid 100 ft. height. No tolerances suggested above 100 ft.	1 to 1000, no more than 1 in. towards building nor 2 in. away from building line in the first 20 stories; plus 1/16 in. for each additional story up to a maximum of 2 in. towards building or 3 in. away from building line
Tolerances in levels	±1/4 in. in 10 ft. ±3/8 in. up to 20 ft. bay ±3/4 in. in 40 ft. or more	Erection tolerances for levels normally not stated, as levels should be governed by close manufacturing tolerances
Variations from the linear building lines in relation to columns and walls	±1/2 in. in any bay ±1/2 in. in bay 20 ft. maximum ±1 in. in bay 40 ft. maximum	As set by column alignments, closer for elevator columns
Tolerances in beams and columns	Cross section dimensions, -1/4 in. + 1/2 in.	1 to 1000 in alignment. Section tolerances are close.
Tolerances for placing or fastening of other materials such as connection hardware in relation to building lines	± 1/4 in. from specified location	Not established.

(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

Supplementary Tolerances for Cast-in-Place Concrete Structural Frames to Which Precast Concrete is to be Attached	
Item	Recommended Tolerances
Footings, caisson caps, and pile caps—variation of bearing surface from specified elevation	±1/2 in.
Piers, columns and walls—deviation from the specified level or grades	
Any bay or wall length less than 20 ft.	±1/2 in.
Any bay or wall length greater than 20 ft.	±3/4 in.
Deviation from column cross-sectional dimensions or wall thickness	+1/2 in., -1/4 in.
Anchor bolts	
Variation from specified location in plan	±1/4 in.
Variation from specified elevation	±1/2 in.
Anchor bolt projection	+1/2 in., -1/4 in.
Plumbness of anchor bolt	±1/16 in. per ft.
Floor elevations—variation from specified level	±1/4 in. in 10 ft.; ±1/2 in. in 30 ft. or greater length

If reasonable tolerances and adjustments have been designed into the construction details and are adhered to, the erector should be able to:

- minimize joint irregularities such as tapered joints (panel edges not parallel)
- minimize jogs at intersections
- minimize nonuniformity of joint width
- maintain the proper opening dimensions
- properly construct all precast connections
- align the vertical faces of the units to avoid offsets
- prevent the accumulation of tolerances

A more precise installation and general improvement in appearance are thus achieved.

(From ACI 533, Guide for Precast Concrete Wall Panels)

11.6.4 Precast Concrete Tolerances

Typical Tolerances for Precast/Prestressed Concrete Products ^a	
Product Tolerances	Products
Length ^b —	
± ¼ in.	16,17,18
± ½ in.	6,7,8,9,13,15
± ¾ in.	3,5
± 1 in.	1,2,4,11,12,14
Width ^b —	
± ¼ in.	1,2,3,5,6,7,8,9,12,15,17,18
+ ¾ in.	14
+ ¾ in., - ¼ in.	4
± ¾ in.	11,13
Depth—	
+ ¼ in., - ½ in.	10,18
± ¼ in.	1,2,3,5,6,7,8,9,12,14,15
+ ½ in., - ¼ in.	4
± ¾ in.	11
± ½ in.	13
Flange Thickness—	
+ ¼ in., - ½ in.	1,2,8,10,12,15
± ¼ in.	3,4,13
Web Thickness—	
± ½ in.	1,8,10,12,15
± ¼ in.	2,3
+ ¾ in., - ¼ in.	4
± ¾ in.	5
Position of Tendons—	
± ¼ in.	1,2,3,4,5,6,8,9,11,12,14,15,18
± ½ in.	10
Camber, variation from design—	
± ¼ in. per 10 ft,	1,2,12,15
± ¾ in. max.	
± ½ in. per ft,	4
± 1 in. max.	
± ¾ in. max.	3
± ½ in. max.	5,15
Camber, differential—	
¼ in. per 10 ft,	1,2,5
¾ in. max.	
± ¼ in. per 10 ft,	
± ½ in. max.	15
Bearing Plates, position—	
± ½ in.	1,2,3,12
± ¾ in.	4
Bearing Plates, tipping and flushness—	
± ½ in.	1,2,3,4,12,15

Erection Tolerances for Interface Design	
Item	Recommended Tolerances (in.)
Variation in plan location (any column or beam, any location).	± ½
Variation in plan parallel to specified building lines.	¼ ₄₀ per ft, any beam less than 20 ft or adjacent columns less than 20 ft apart ½, adjacent columns 20 ft or more apart
Difference in relative position of adjacent columns from specified relative position (at any deck level)	½
Variation from plumb	¼, any 10 ft of height 1, maximum for the entire height
Variation in elevation of bearing surfaces from specified elevation (any column or beam, any location)	± ½
Variation of top of spandrel from specified elevation (any location)	± ½
Variation in elevation of bearing surfaces from lines parallel to specified grade lines.	¼ ₄₀ per ft, any beam less than 20 ft or adjacent columns less than 20 ft apart ½, maximum any beam 20 ft or more in length or adjacent columns 20 ft or more apart
Variation from specified bearing length on support	± ¾
Variation from specified bearing width on support	± ½
Jog in alignment of matching edges	½, maximum

a. For more details such as graphic descriptions of features to which tolerances apply and tolerances for sleeves, blockouts, inserts, plates, end squareness, surface smoothness, etc., see committee report [1].

b. See Sect. 11.6.8 for dimensional tolerances for architectural wall panels.

Key:

1 = double tee

2 = single tee

3 = building beam (rect. and ledger)

4 = I-beam

5 = box beam

6 = column

7 = hollow-core slab

8 = ribbed wall panel

9 = insulated wall panel

10 = architectural wall panel

11 = pile

12 = joist

13 = step unit

14 = sheet piling

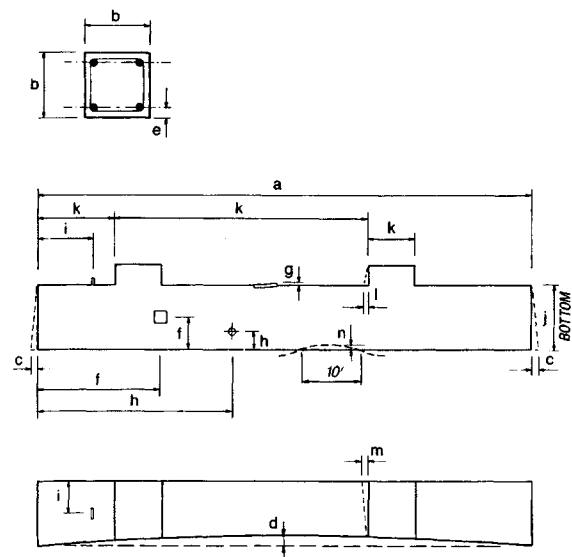
15 = single riser bleacher slabs

16 = prison cell module—single

17 = prison cell module—double

18 = prestressed concrete panels for storage tanks

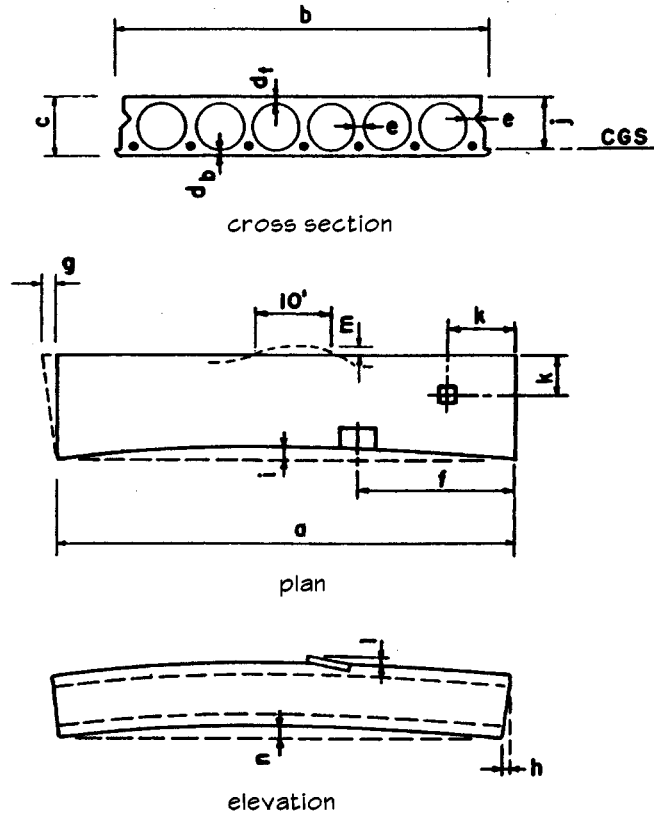
11.6.5 Fabrication Tolerances for Precast Columns



- a = Length $\pm \frac{1}{2}$ in.
 - b = Cross section dimensions $\pm \frac{1}{4}$ in.
 - c = Variation from specified end squareness or skew $\pm \frac{1}{8}$ in. per 12 in., $\pm \frac{3}{8}$ in. max.
 - d = Sweep (variation from straight line parallel to centerline of member) $\pm \frac{1}{8}$ in. per 10 ft, $\pm \frac{1}{2}$ in. max.
 - e = Position of tendons or reinforcing steel .. $\pm \frac{1}{4}$ in.
 - f = Position of plates ± 1 in.
 - g = Tipping and flushness of plates $\pm \frac{1}{4}$ in.
 - h = Position of inserts for structural connections $\pm \frac{1}{2}$ in.
 - i = Positions of handling devices
 - Parallel to length ± 6 in.
 - Transverse to length ± 1 in.
 - j = Baseplates overall dimensions $\pm \frac{1}{4}$ in.
 - k = Haunch size and locations (not cumulative) $\pm \frac{1}{4}$ in.
 - l = Squareness of bearing $\pm \frac{1}{8}$ in.
 - m = Squareness of bearing $\pm \frac{1}{8}$ in. per 12 in., $\frac{3}{8}$ in. max.
 - n = Local smoothness any surface $\frac{1}{4}$ in. in 10 ft
- Does not apply to visually concealed surfaces.

(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

11.6.6 Fabrication Tolerances for Hollow Core Slabs Used as Wall Panels



a = Length	$\pm 1/2$ in.
b = Width	$\pm 1/4$ in.
c = Depth	$\pm 1/4$ in.

d_t = Top flange thickness

Top flange area defined by the actual measured values of average $d_t \times b$ shall not be less than 85 percent of the nominal area calculated by d_t nominal $\times b$ nominal.

d_b = Bottom flange thickness

Bottom flange area defined by the actual measured values of average $d_b \times b$ shall not be less than 85 percent of the nominal area calculated by d_b nominal $\times b$ nominal.

e = Web thickness

The total cumulative web thickness defined by the summation of actual measured values of e shall not be less than 85 percent of the nominal cumulative width calculated using summation of e nominal.

f = Blockout location	± 2 in.
g = Flange angle	$1/8$ in. per 12 in., $1/2$ in. maximum

h = Variation from specified end squareness or skew $\pm 1/2$ in.

i = Sweep (variation from straight line parallel to centerline of member) $\pm 3/8$ in.

j = Center of gravity (CG) of the strand group

The CG of the strand group relative to the top of the plank shall be within $\pm 1/4$ in. of the nominal strand group CG.

Any individual strand should be within $\pm 1/2$ in. of nominal vertical position and $\pm 3/4$ in. of nominal horizontal position and shall have a minimum cover of $3/4$ in.

k = Position of plates ± 2 in.

l = Tipping and flushness of plates $\pm 1/4$ in.

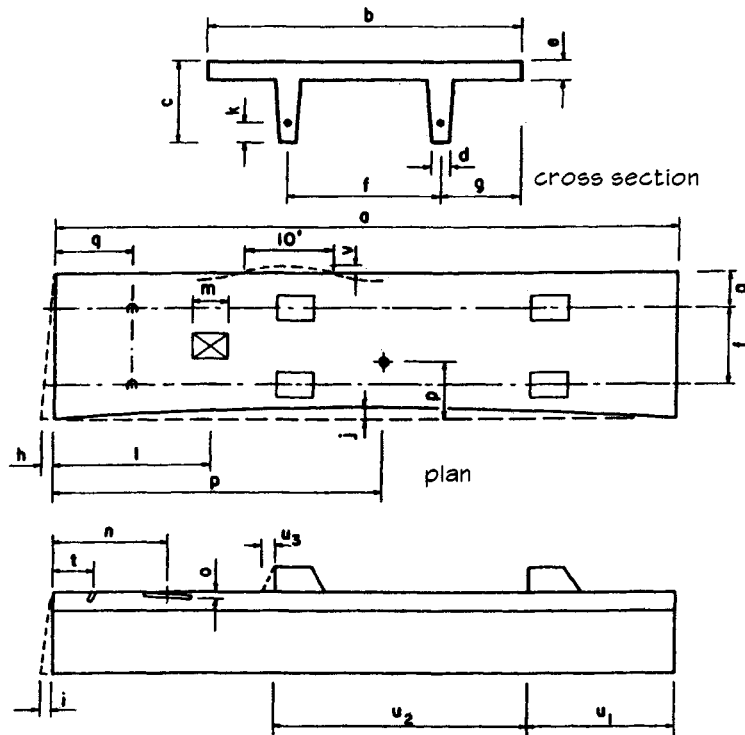
m = Local smoothness $1/4$ in. in 10 ft*

n = Camber applications requiring close control of differential camber between adjacent members of the same design should be discussed in detail with the producer to determine applicable tolerances.

PLANK WEIGHT: Excess concrete material in the plank internal features is within tolerance as long as the measured weight of the individual plank does not exceed 110 percent of the nominal published unit weight used in the load capacity calculations.

* Does not apply to top deck surface left rough to receive a topping or visually concealed surface.

11.6.7 Fabrication Tolerances for Ribbed Precast Panels Used as Wall Panels

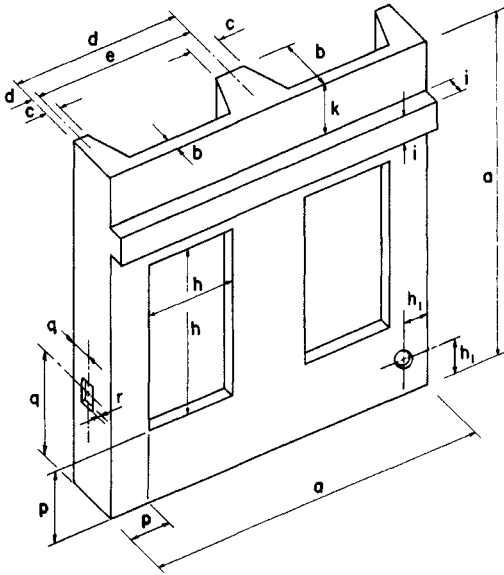


a = Length	± 1/2 in.	p = Position of inserts for structural connections	± 1/2 in.
b = Width	± 1/4 in.	q = Position of handling devices	
c = Depth	± 1/4 in.	Parallel to length	± 6 in.
d = Stem width	± 1/8 in.	Transverse to length	± 1 in.
e = Flange thickness	+ 1/4 in., - 1/8 in.	r = Bowing	L/360 maximum*
f = Distance between stems	± 1/8 in.	s = Differential bowing between adjacent panels of the same design	1/2 in. (13 mm)*
g = Stem to edge of top flange	± 1/8 in.	t = Position of flashing reglets	± 1/4 in.
h = Variation from specified flange squareness or skew	± 1/8 in. per 12 in. of width, ± 1/4 in. maximum	u = Haunches (noncumulative)	
i = Variation from specified end squareness or skew	± 1/8 in. per 12 in.	u ₁ = Bearing elevation from bottom of panel	± 1/4 in.
j = Sweep (variation from straight line parallel to center line of member)		u ₂ = Relative position of bearing elevation in vertical plane	± 1/8 in.
Members up to 40 ft long	± 1/4 in.	u ₃ = Haunch bearing surface squareness perpendicular to applied major load	± 1/8 in. per 18 in., ± 1/4 in. maximum
Members 40 ft or longer	± 3/8 in.	v = Local smoothness any surface	± 1/4 in. in 10 ft*
k = Position of tendons	± 1/4 in.	w = Warping	1/16 in. per ft of distance from nearest adjacent corner
l = Position of blockouts	± 1 in.		
m = Size of blockouts			
Finished opening	± 1/2 in.		
Rough opening	± 1 in.		
n = Position of plates	± 1 in.		
o = Tipping and flushness of plates	± 1/4 in.		

*Does not apply to visually concealed surfaces.

(From ACI 533R-93 Guide for Precast Concrete Wall Panels)

11.6.8 Fabrication Tolerances for Architectural Panels, Spandrels, and Column Covers



a	= Overall length and width (measured at neutral axis of ribbed members)
	10 ft or under $\pm \frac{1}{8}$ in.
	10 to 20 ft $+\frac{1}{8}$ in., $-\frac{3}{16}$ in.
	20 to 40 ft $\pm \frac{1}{4}$ in.
	Each additional 10 ft $\pm \frac{1}{16}$ in. per 10 ft
b	= Total thickness or flange thickness $-\frac{1}{8}$ in., $+\frac{1}{4}$ in.
c	= Rib thickness $\pm \frac{1}{8}$ in.
d	= Rib to edge of flange $\pm \frac{1}{8}$ in.
e	= Distance between ribs $\pm \frac{1}{8}$ in.
f	= Angular variation of plane of side mold $\pm \frac{1}{32}$ in. per 3 in. of depth or $\pm \frac{1}{16}$ in. whichever is greater
g	= Variation from square or designated skew (difference in length of the two diagonal measurements) $\pm \frac{1}{8}$ in. per 6 ft of diagonal or $\pm \frac{1}{2}$ in. whichever is greater*
h	= Length and width of blockouts and openings within one unit $\pm \frac{1}{4}$ in.

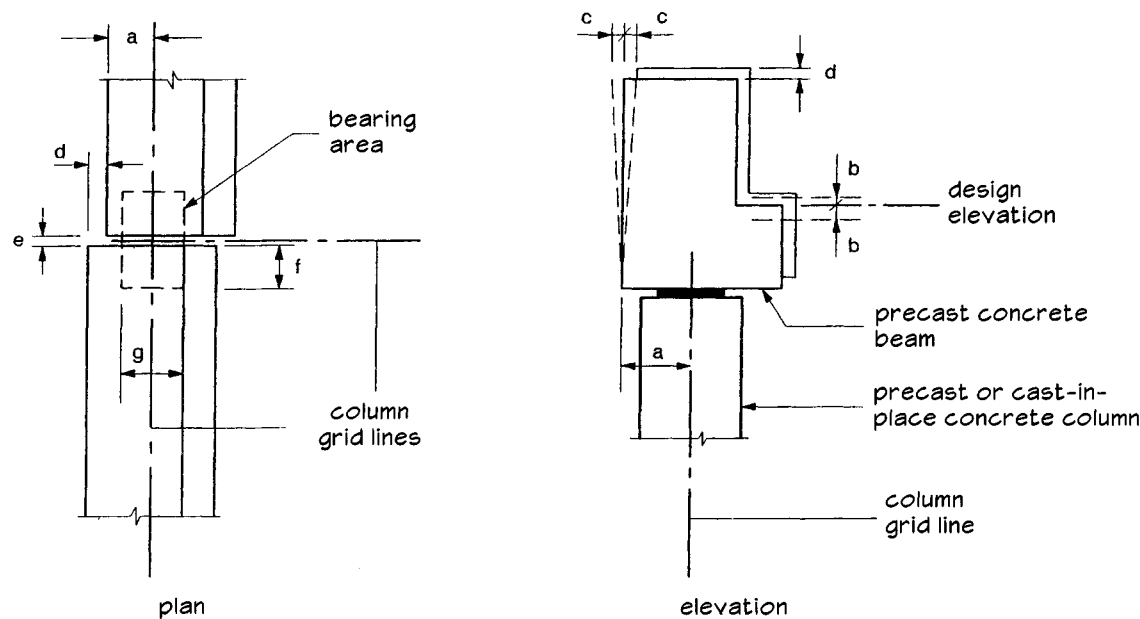
h ₁	= Location and dimensions of blockouts hidden from view and used for HVAC and utility penetrations $\pm \frac{3}{4}$ in.
h ₂	= Some types of window and equipment frames require openings more accurately placed. When this is the case, the minimum practical tolerance should be defined with input from the producer.
i	= Dimensions of haunches $\pm \frac{1}{4}$ in.
j	= Haunch bearing surface deviation from specified plane $\pm \frac{1}{8}$ in.
k	= Difference in relative position of adjacent haunch bearing surfaces from specified relative position $\pm \frac{1}{4}$ in.
l	= Bowing $\pm L/360$ max. 1 in.
m	= Differential bowing between adjacent panels of the same design $\frac{1}{2}$ in.
n	= Local smoothness $\frac{1}{4}$ in. in 10 ft. Does not apply to visually concealed surfaces.
o	= Warping $\frac{1}{16}$ in. per ft. of distance from nearest adjacent corner
p	= Location of window opening within panel $\pm \frac{1}{4}$ in.
q	= Position of plates ± 1 in.
r	= Tipping and flushness of plates $\pm \frac{1}{4}$ in.
Positions tolerances. For cast-in items measured from datum line location as shown on approved erection drawings:	
	Weld plates ± 1 in.
	Inserts $\pm \frac{1}{2}$ in.
	Handling devices ± 3 in.
	Reinforcing steel and welded wire fabric $\pm \frac{1}{4}$ in. where position has structural implications or affects concrete cover, otherwise $\pm \frac{1}{2}$ in.
	Tendons $\pm \frac{1}{8}$ in.
	Flashing reglets $\pm \frac{1}{4}$ in.
	Flashing reglets at edge of panel $\pm \frac{1}{8}$ in.
	Reglets for glazing gaskets $\pm \frac{1}{16}$ in.
	Groove width for glazing gaskets $\pm \frac{1}{16}$ in.
	Electrical outlets, hose bibs, etc. $\pm \frac{1}{2}$ in.
	Haunches $\pm \frac{1}{4}$ in.

* Applies both to panel and to major openings in the panel.

11.6.9 Erection Tolerances for Precast Beams and Spandrels

a	=	Plan location from building grid datum	± 1 in.
a ₁	=	Plan location from centerline of steel*	± 1 in.
b	=	Bearing elevation** from nominal elevation at support	
		Maximum low	½ in.
		Maximum high	¼ in.
c	=	Maximum plumb variation over height of element	
		Per 12 in. height	¼ in.
		Maximum	½ in.
d	=	Maximum jog in alignment of matching edges	
		Architectural exposed edges	¼ in.
		Visually non-critical edges	½ in.
e	=	Joint width	
		Architectural exposed joints	± ¼ in.
		Hidden joints	± ¾ in.
		Exposed structural joint <i>not</i> visually critical	± ½ in.
f	=	Bearing length*** (span direction)	± ¾ in.
g	=	Bearing width***	± ½ in.

* For precast elements erected on a steel frame, this tolerance takes precedence over tolerance dimension "a".
** Or member top elevation where member is part of a frame without bearings.
*** This is a setting tolerance and should not be confused with structural performance requirements set by the architect/engineer. The nominal bearing dimensions and the allowable variations in bearing length and width should be specified by the engineer and shown on the contract drawings.



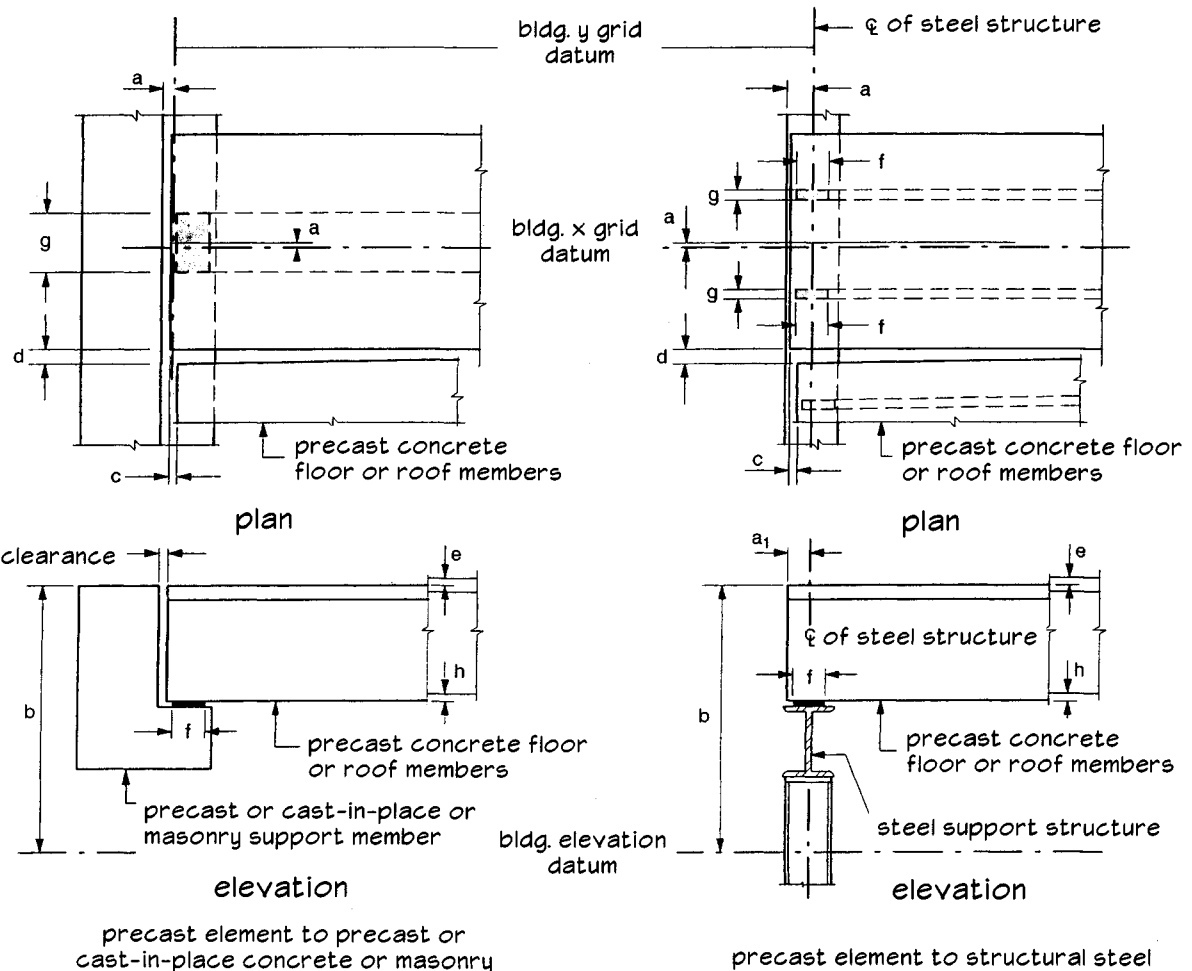
precast element to precast concrete, cast-in-place concrete, masonry, or structural concrete

(From PCI Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)

11.6.10 Erection Tolerances for Precast Floor and Roof Members

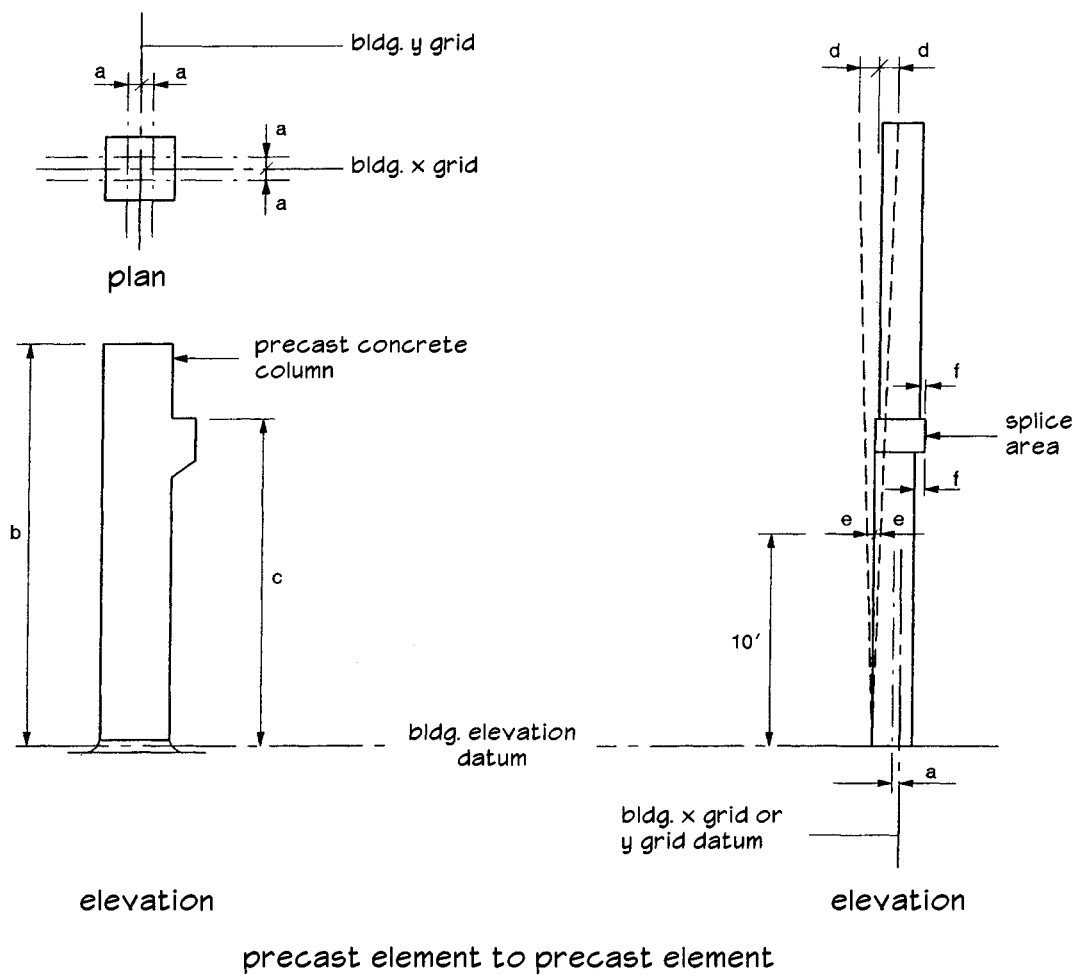
a	=	Plan location from building grid datum	± 1 in.
a ₁	=	Plan location from centerline of steel ⁽¹⁾	± 1 in.
b	=	Top elevation from nominal top elevation at member ends	
		Covered with topping	± ¾ in.
		Untopped floor	± ¼ in.
		Untopped roof	± ¾ in.
c	=	Maximum jog in alignment of matching edges (both topped and untopped construction)	1 in.
d	=	Joint width	
		0 to 40 ft member length	± ½ in.
		41 to 61 ft member length	± ¾ in.
		61 ft plus	± 1 in.
e	=	Differential top elevation as erected	
		Covered with topping	¾ in.
		Untopped floor	¼ in.
		Untopped roof	¾ in.
f	=	Bearing length ⁽²⁾ (span direction)	± ¾ in.
g	=	Bearing width ⁽²⁾	± ½ in.
h	=	Differential bottom elevation of exposed hollow-core slabs ⁽³⁾	¼ in.

- (1) For precast elements erected on a steel frame, this tolerance takes precedence over tolerance dimension "a".
- (2) This is a setting tolerance and should not be confused with structural performance requirements set by the architect/engineer. The nominal bearing dimensions and the allowable variations in bearing length and width should be specified by the engineer and shown on the contract drawings.
- (3) Untopped installation will require a larger tolerance.



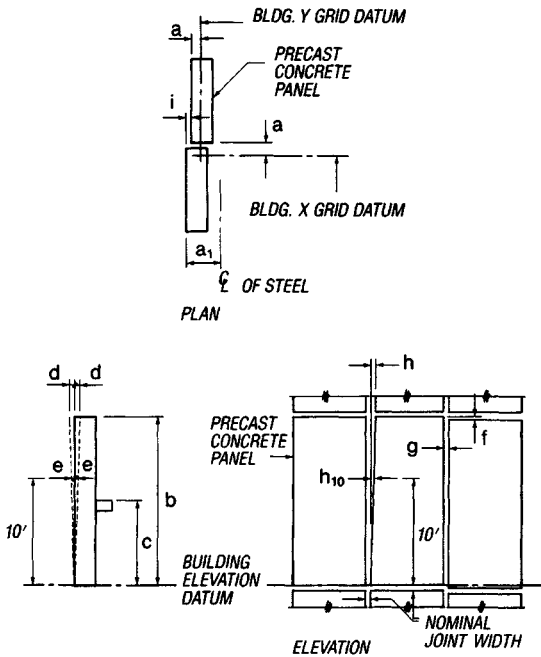
11.6.11
Erection Tolerances for Precast Columns

a	=	Plan location from building grid datum	
		Structural applications	± ½ in.
		Architectural applications	± ¾ in.
b	=	Top elevation from nominal top elevation	
		Maximum low	½ in.
		Maximum high	¼ in.
c	=	Bearing haunch elevation from nominal elevation	
		Maximum low	½ in.
		Maximum high	¼ in.
d	=	Maximum plumb variation over height of element	
		(element in structure of maximum height of 100 ft)	1 in.
e	=	Plumb in any 10 ft of element height	¼ in.
f	=	Maximum jog in alignment of matching edges	
		Architectural exposed edges	¼ in.
		Visually non-critical edges	½ in.



(From PCI Handbook, 5th ed., Precast/Prestressed Concrete Institute, 1999)

11.6.12 Erection Tolerances for Architectural Wall Panels



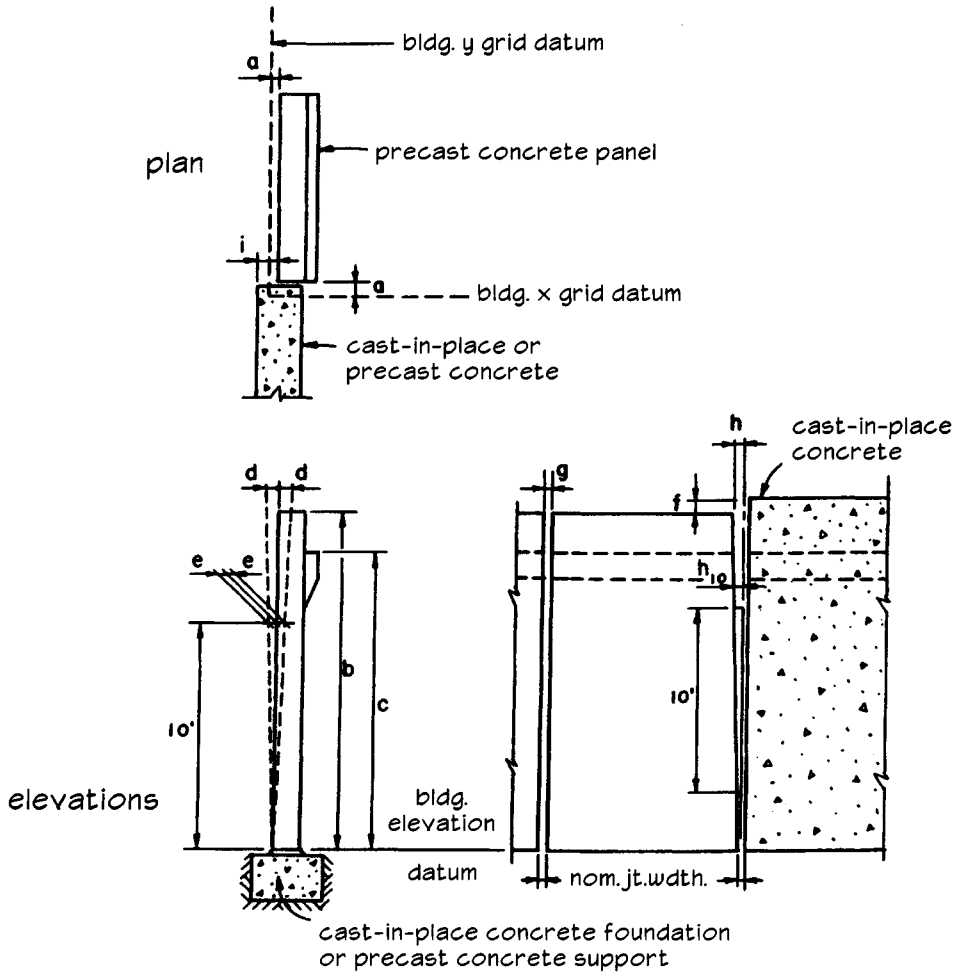
PRECAST ELEMENT TO PRECAST OR CAST-IN-PLACE
CONCRETE, MASONRY, OR STRUCTURAL STEEL

a	=	Plan location from building grid datum*	± ½ in.
a ₁	=	Plan location from centerline of steel**	± ½ in.
b	=	Top elevation from nominal top elevation	
		Exposed individual panel	± ¼ in.
		Nonexposed individual panel	± ½ in.
		Exposed relative to adjacent panel	¼ in.
		Nonexposed relative to adjacent panel	½ in.
c	=	Support elevation from nominal elevation	
		Maximum low	½ in.
		Maximum high	¼ in.
d	=	Maximum plumb variation over height of structure or 100 ft. whichever is less*	1 in.
e	=	Plumb in any 10 ft of element height	¼ in.
f	=	Maximum jog in alignment of matching edges	¼ in.
g	=	Joint width (governs over joint taper)	± ¼ in.
h	=	Joint taper maximum	⅜ in.
h ₁₀	=	Joint taper over 10 ft. length	¼ in.
i	=	Maximum jog in alignment of matching faces	¼ in.
j	=	Differential bowing or camber as erected between adjacent members of the same design	¼ in.

*For precast buildings in excess of 100 ft. tall, tolerances "a" and "d" can increase at the rate of ¼ in. per story to a maximum of 2 in.

**For precast concrete erected on a steel frame building, this tolerance takes precedence over tolerance on dimension "a".

11.6.13 Erection Tolerances for Precast Structural Wall Panels



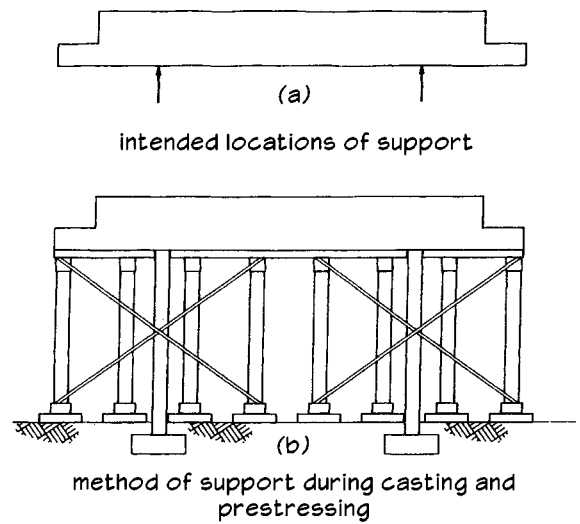
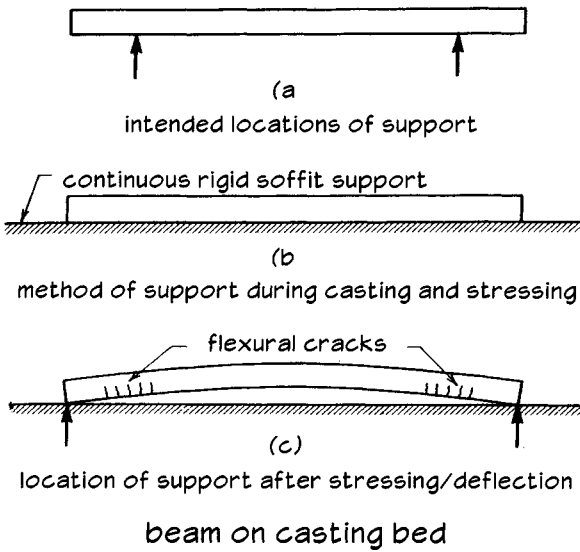
a = Plan location from building grid datum*	±1/2 in.
a ₁ = Plan location from center-line of steel†	±1/2 in.
b = Top elevation from nominal top elevation	
Exposed individual panel	±1/2 in.
Nonexposed individual panel	±3/4 in.
Exposed relative to adjacent panel	1/2 in.
Nonexposed relative to adjacent panel	3/4 in.
c = Bearing elevation from nominal elevation	
Maximum low	1/2 in.
Maximum high	1/4 in.
d = Maximum plumb variation over height of structure or 100 ft, whichever is less*	1 in.
e = Plumb in any 10 ft of element height	1/4 in.
f = Maximum jog in alignment of matching edges	1/2 in.
g = Joint width (governs over joint taper)	±3/8 in.

h = Joint taper over length of panel	1/2 in.
h ₁₀ = Joint taper over 10 ft length	3/8 in.
i = Maximum jog in alignment of matching faces	
Exposed	3/8 in.
Nonexposed	3/4 in.
j = Differential bowing, as erected, between adjacent members of the same design‡	1/2 in.

*For precast buildings in excess of 100 ft tall, tolerances "a" and "d" can increase at the rate of 1/8 in. per story over 100 ft to a maximum of 2 in.

‡For precast elements erected on a steel frame, this tolerance takes precedence over tolerance on dimension "a."

11.6.14 Unintended Mode of Support for Prestressed Concrete

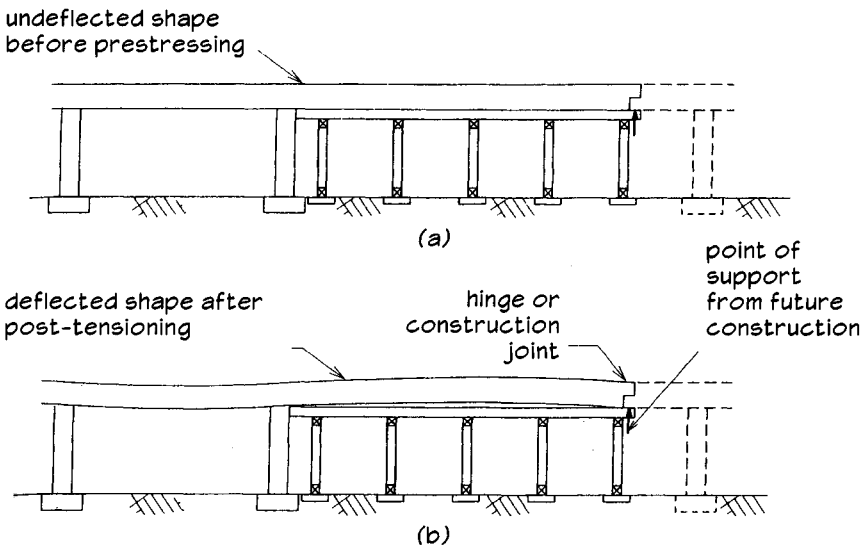


Examples of unintended mode of support of prestressed concrete beams.

(a) Intended locations of supports.

(b) Mode of support during casting and prestressing.

(c) Deflected shape and locations of supports after prestressing.

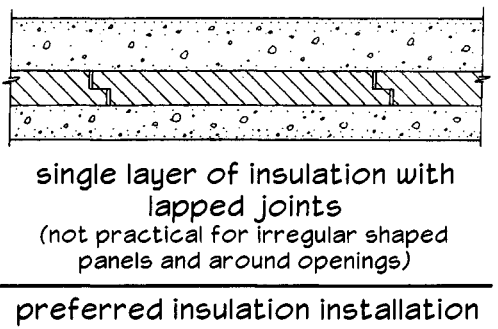
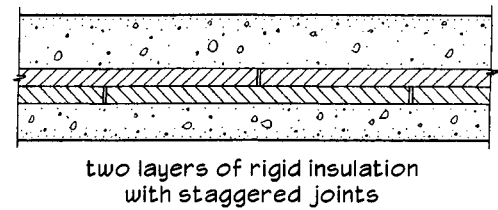
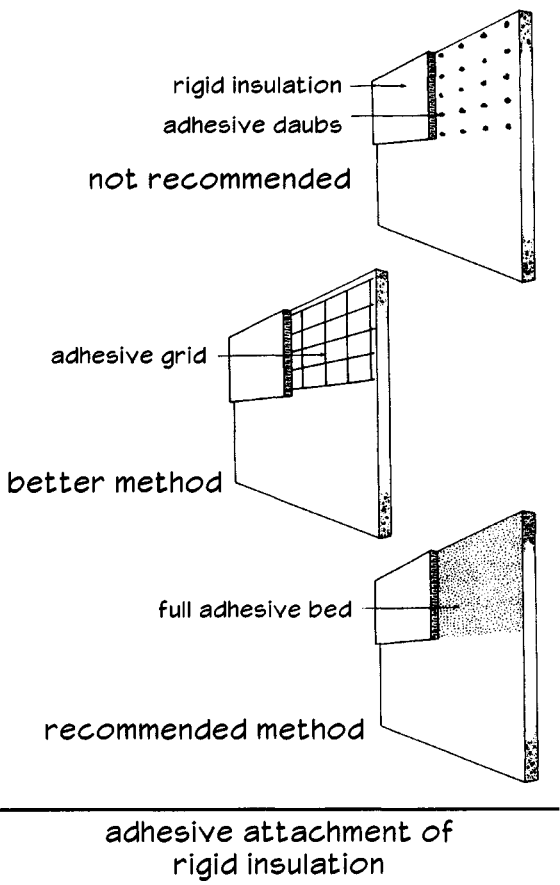
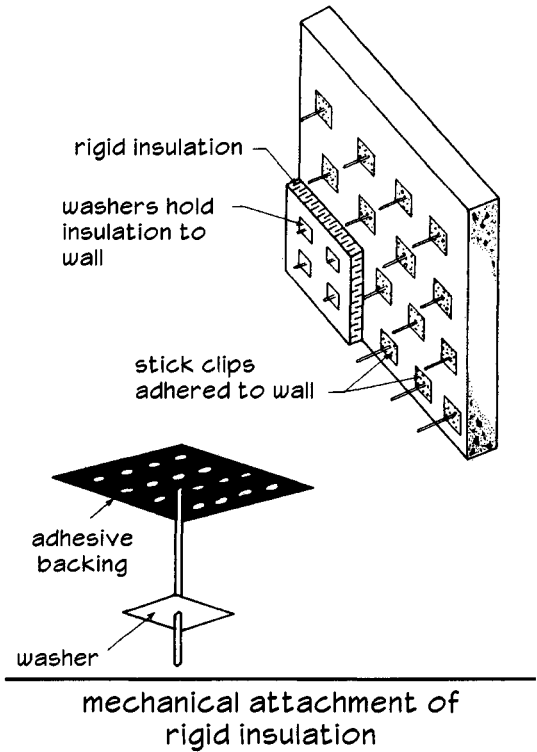


Cast-in-place prestressed concrete bridge with an in-span hinged or construction joint.

(a) Before prestressing with all shores supporting load.

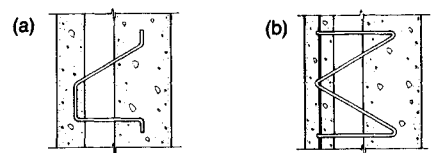
(b) After upward deflection due to prestressing and a large reaction being supported by the falsework bent at the joint.

11.7.1 **Insulation for Precast Wall Panels**

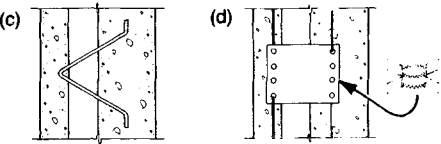


(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

11.7.2 Connectors for Insulated Precast Sandwich Panels

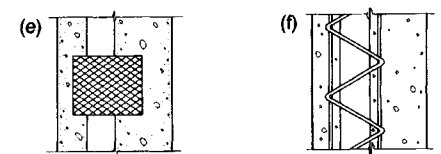


bent reinforcing bars



bent reinforcing bars

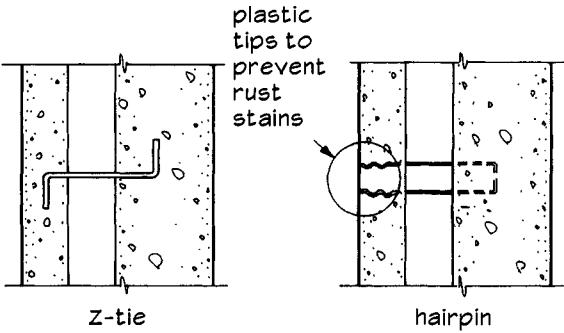
sleeve anchor



expanded metal

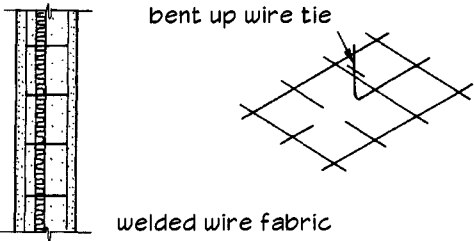
welded wire truss

typical shear connectors



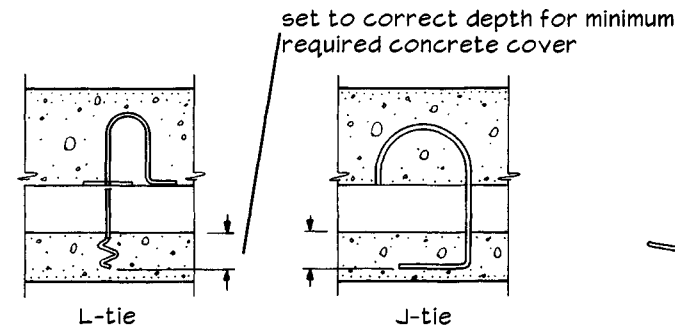
Z-tie

hairpin



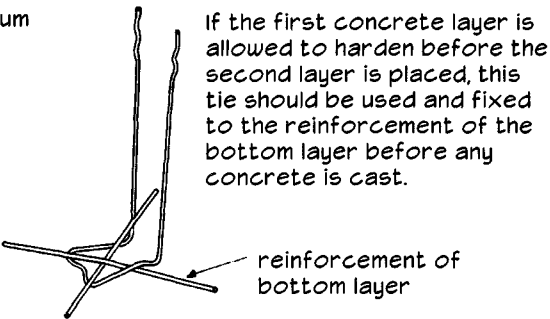
bent up wire tie

welded wire fabric



L-tie

J-tie

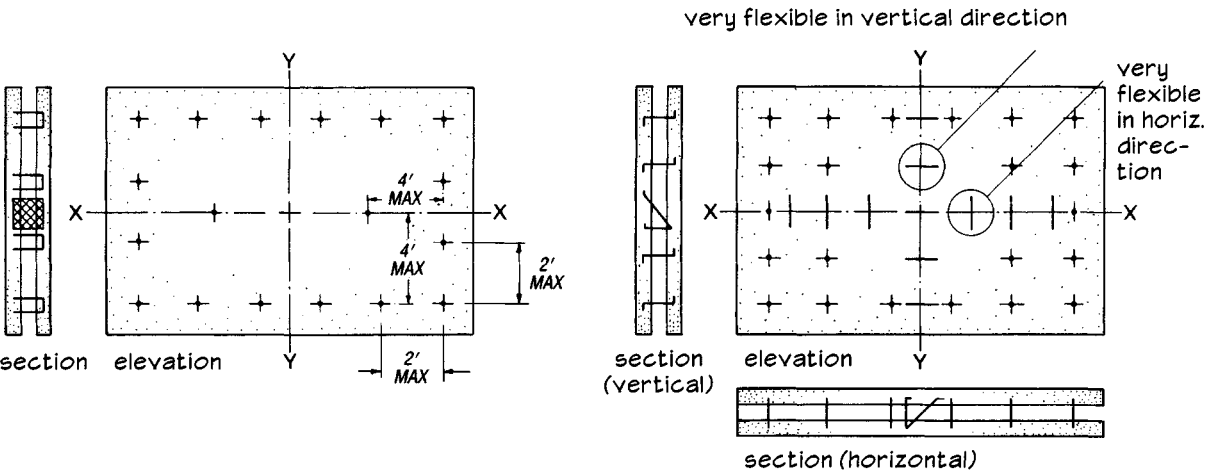


reinforcement of bottom layer

tension/compression ties

(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

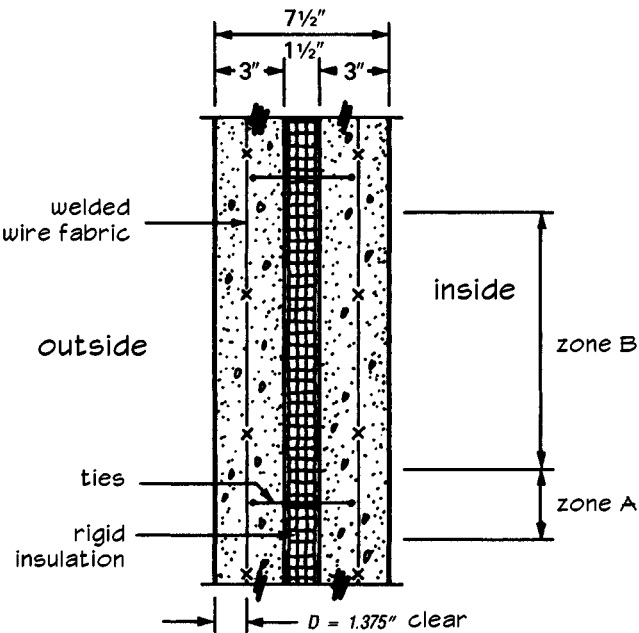
11.7.3 Connector Arrangement and Thermal Bridges



One device transfers of non-structural wythe to structural wythe, as well as any racking shear. Ties spaced in the field of the panel transfer direct wind loads and stripping forces from the non-structural wythe to the structural wythe.

Devices spaced along the x-x axis transfer weight of non-structural wythe to structural wythe. Similar devices along the y-y axis transfer racking shear from non-structural to structural wythe. Ties spaced in the field of the panel transfer direct wind loads and stripping forces from the non-structural wythe to the structural wythe.

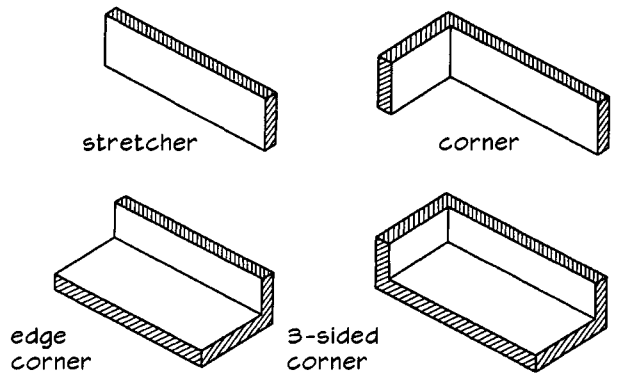
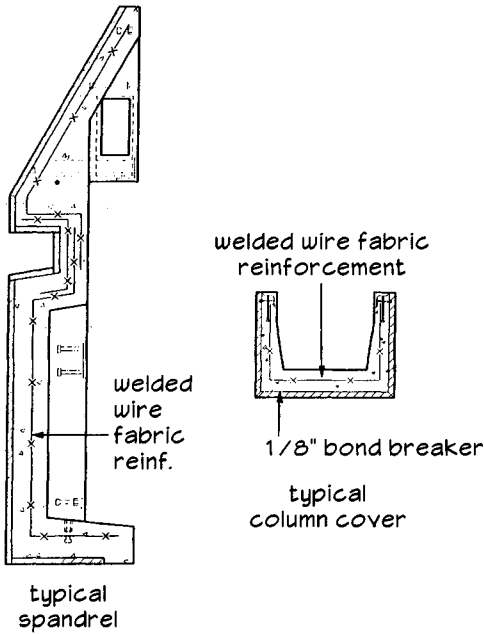
arrangement of connectors between wythes



thermal bridges at metal connectors

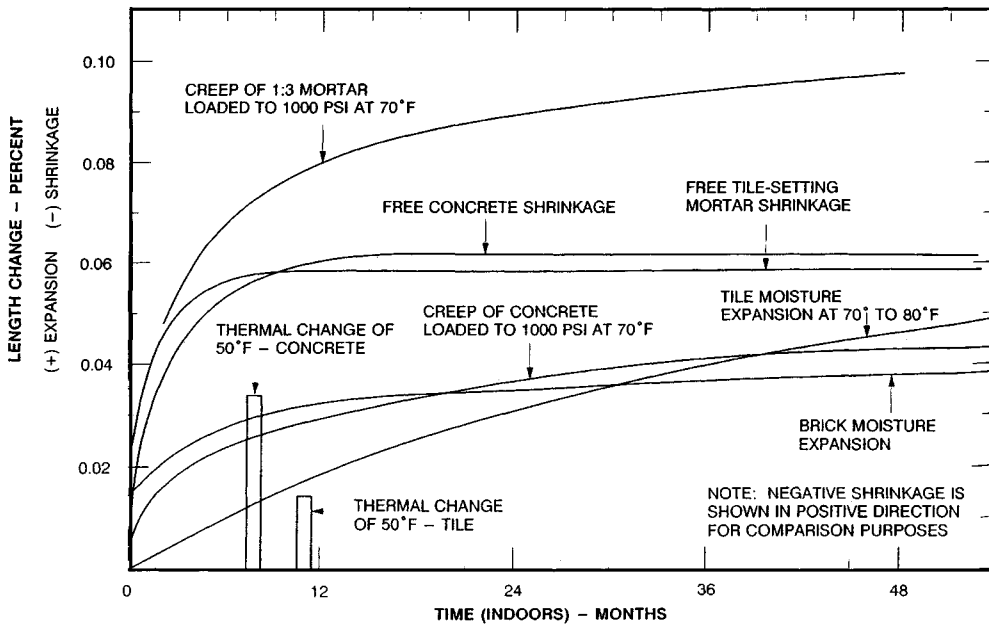
(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

11.8.1 Veneer Faced Composite Precast Panels



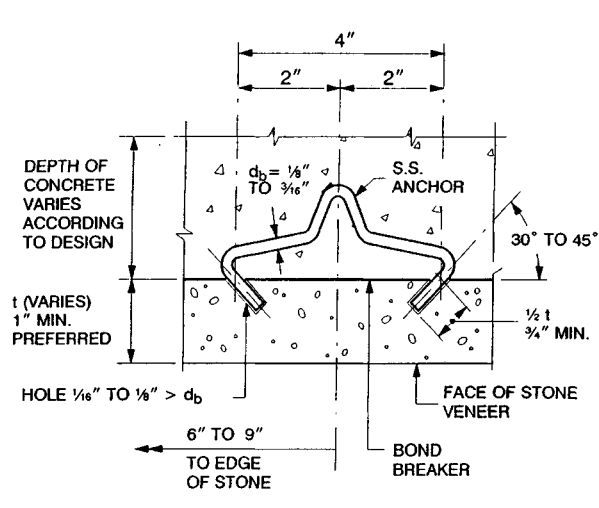
thin brick units or thin stone can be used as a facing on architectural precast concrete panels

applications of veneer faced precast concrete

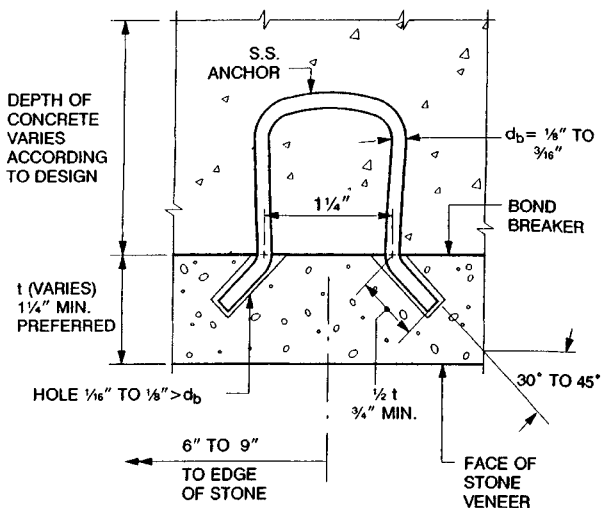


relative temperature, creep and moisture movements of concrete, tile, brick and mortar

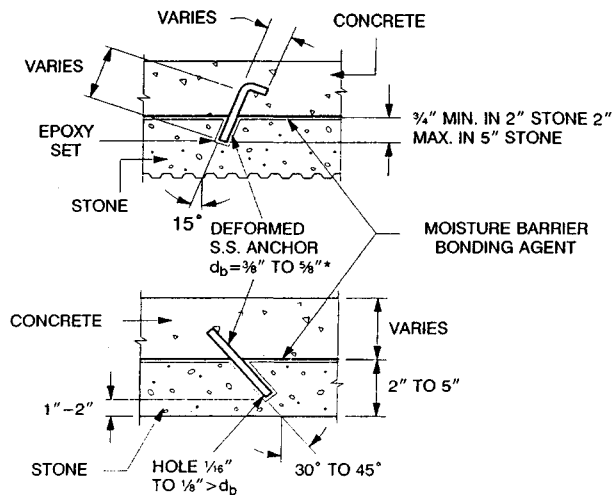
11.8.2 Typical Anchor Details for Attaching Stone Veneer to Precast



typical anchor for marble veneer

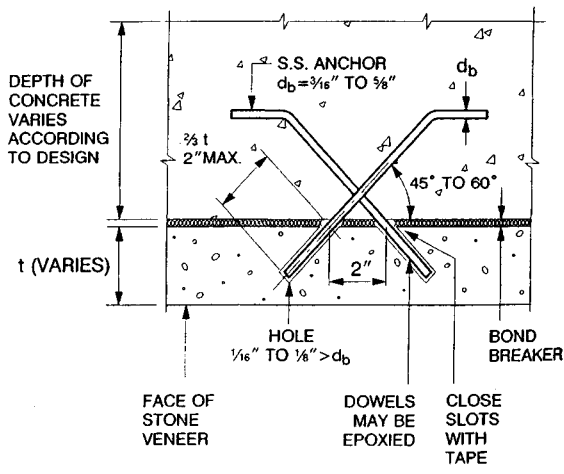


typical anchor for granite veneer



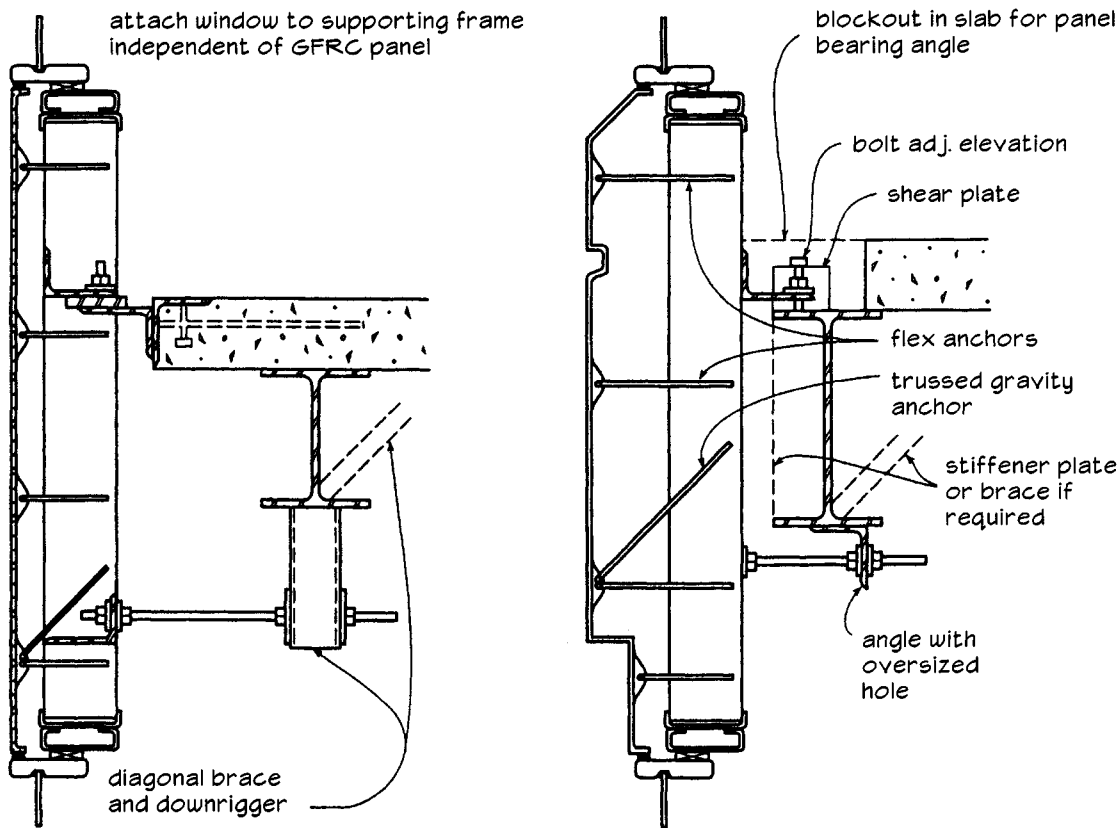
* USE ANCHORS AT OPPOSING ANGLES

typical anchor for limestone veneer



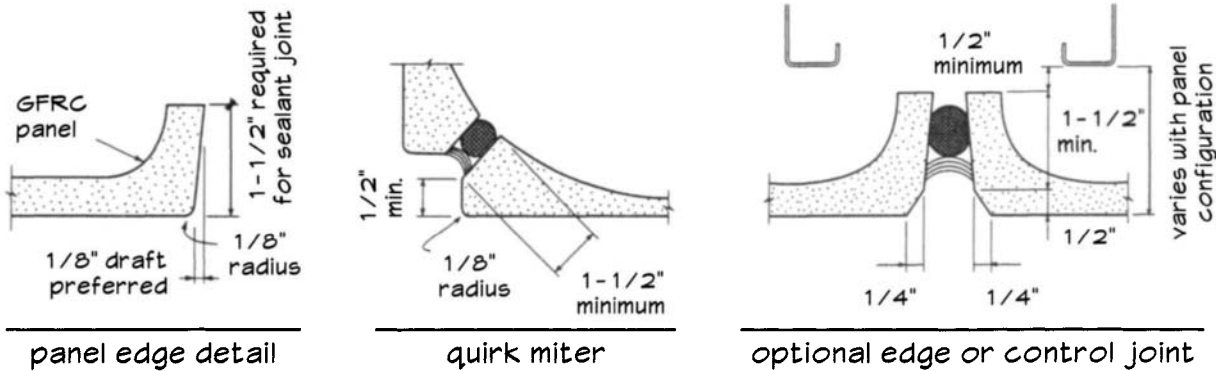
typical cross anchor dowel
for stone veneer

11.8.3 GFRP Panels



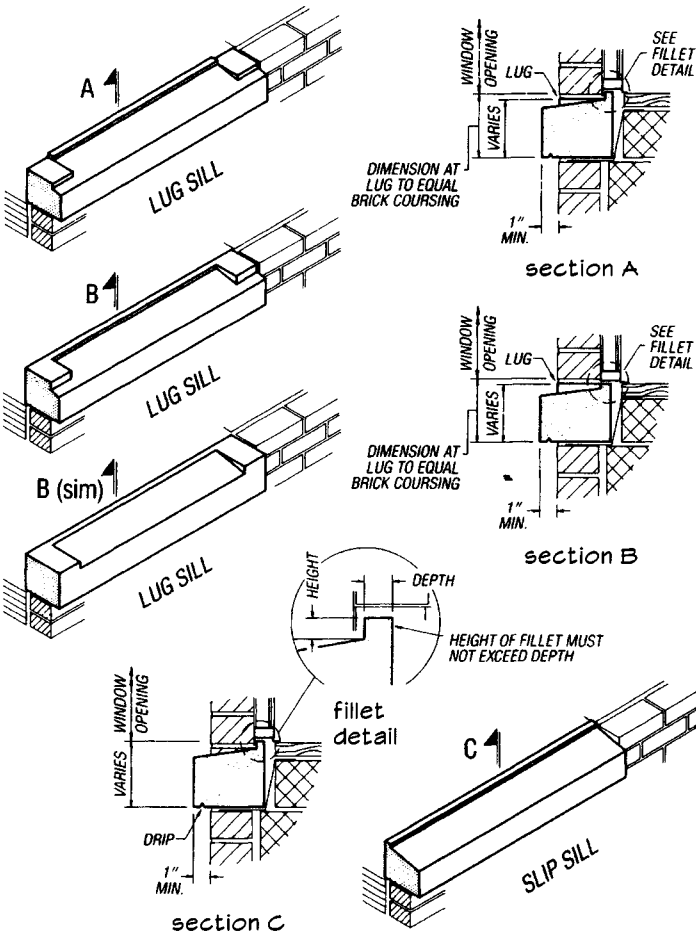
The lower connection is a threaded rod that can flex as necessary as the height of the upper connection is adjusted with shims.

typical connections of GFRP panels to a steel frame

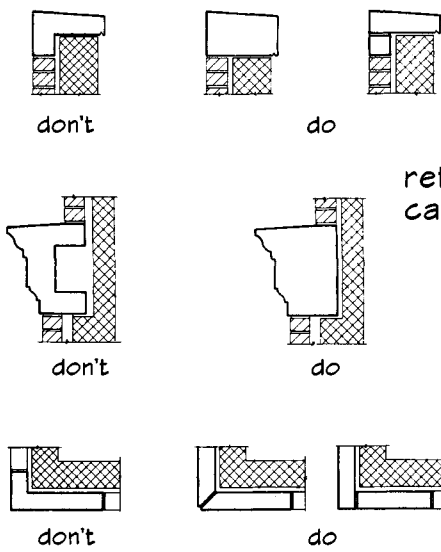


(From Allen, Fundamentals of Building Construction, John Wiley & Sons, 1999)

11.8.4 Cast Stone



typical lug and slip sills



returns in cast stone

Cast stone should have a minimum thickness of 2- 1/2 in. to reduce stripping, handling and packaging costs. A 2- 1/2 in. stone generally costs the same as a 4 in. stone.

Fabrication Tolerances for Cast Stone	
Item	Tolerance
Height and width	+1/16", -1/8"
Length less than 2 ft.	+1/16", -1/8"
Length 2 to 5 ft.	±1/8"
Length 5 to 10 ft.	+1/8", -3/16"

(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

Tilt-Up Concrete

12.1 Loadbearing Tilt-Up Walls

- 12.1.1 Loadbearing Tilt-Up Concrete Walls
- 12.1.2 Load Table for 5-1/2" Walls, 0 or 15 psf
- 12.1.3 Load Table for 5-1/2" Walls, 30 or 45 psf
- 12.1.4 Load Table for 5-1/2" Walls, 60 or 75 psf
- 12.1.5 Load Table for 5-1/2" Walls, 90 or 105 psf
- 12.1.6 Load Table for 6-1/2" Walls, 0 or 15 psf
- 12.1.7 Load Table for 6-1/2" Walls 30 or 45 psf
- 12.1.8 Load Table for 6-1/2" Walls, 60 or 75 psf
- 12.1.9 Load Table for 6-1/2" Walls, 90 or 105 psf
- 12.1.10 Load Table for 7-1/2" Walls, 0 or 15 psf
- 12.1.11 Load Table for 7-1/2" Walls, 30 or 45 psf
- 12.1.12 Load Table for 7-1/2" Walls, 60 or 75 psf
- 12.1.13 Load Table for 7-1/2" Walls 90 or 105 psf
- 12.1.14 Load Table for 7-1/2" Walls, 0 psf, Two Rows of Reinforcement
- 12.1.15 Load Table for 7-1/2" Walls, 30 or 45 psf, Two Rows of Reinforcement
- 12.1.16 Load Table for 7-1/2" Walls, 60 or 75 psf, Two Rows of Reinforcement
- 12.1.17 Load Table for 7-1/2" Walls, 90 or 105 psf, Two Rows of Reinforcement
- 12.1.18 Load Table for 9-1/2" Walls, 0 psf, Two Rows of Reinforcement
- 12.1.19 Load Table for 9-1/2" Walls, 60 or 75 psf, Two Rows of Reinforcement
- 12.1.20 Load Table for 9-1/2" Walls 90 or 105 psf, Two Rows of Reinforcement

12.2 Forming, Rigging and Connecting Tilt-Up Wall Panels

- 12.2.1 Forming and Rigging Tilt-Up Wall Panels
- 12.2.2 Tilt-Up Panel Connection Considerations

12.3 Wall-To-Foundation Connections

- 12.3.1 Trenched Footing/Wall Connection
- 12.3.2 Footing With Exterior Dowels

12.4 Wall-To-Floor Connections

- 12.4.1 Slab-On-Grade/Wall Connection

- 12.4.2 Precast Double Tee/Wall Connection With Ledge
- 12.4.3 Wood Joist/Wall Connection With Joist Hanger on Wood Ledger
- 12.4.4 Heavy Timber Beam/Wall Connection With Steel Shoe

12.5 Wall-To-Roof Connections

- 12.5.1 Precast Double Tee Roof/Precast Beam
- 12.5.2 Precast Double Tee Roof
- 12.5.3 Precast Double Tee Roof Bearing on Wall
- 12.5.4 Precast Hollow-Core Roof Bearing on Wall
- 12.5.5 Steel Girder/Pilaster
- 12.5.6 Steel Girder With Recessed Pocket
- 12.5.7 Steel Girder/Clip Angle
- 12.5.8 Steel Joist With Seat Angle
- 12.5.9 Metal Deck
- 12.5.10 Wood Joist With Wood Ledger
- 12.5.11 Wood Joist With Joist Hanger on Wood Ledger
- 12.5.12 Wood Joist With Joist Hanger on Panel Top
- 12.5.13 Plywood Roof Deck With Wood Ledger on Panel Top

12.6 Wall-To-Wall Connections

- 12.6.1 In-Plane Wall With Steel Embedments
- 12.6.2 In-Plane Wall With Threaded Inserts
- 12.6.3 In-Plane Wall With Slit Pipe
- 12.6.4 Corner Wall With Steel Embedments
- 12.6.5 Corner Wall With Threaded Inserts
- 12.6.6 In-Plane Wall With Continuous Steel Chord
- 12.6.7 In-Plane Diaphragm Chord

12.7 Wall-To-Steel Column Connections

- 12.7.1 Steel Column With Bolted Steel Angles
- 12.7.2 Steel Corner Column With Bolted Steel Angles

12.1.1 Loadbearing Tilt-Up Concrete Walls

Tilt-up construction was introduced in North America around the turn of the twentieth century, but was not widely used until after World War II. Tilt-up became popular in the commercial and industrial sectors for low- and mid-rise structures. Because tilt-up panels are site cast, transportation is eliminated and handling is greatly reduced. Consequently, tilt-up panels offer an efficient, economical alternative to pre-engineered buildings.

The load-capacity tables presented on the following pages are taken from *Tilt-Up Load-Bearing Walls*, 3rd edition (Portland Cement Association, 1994). These tables are based on the following parameters:

- Walls are slender with thicknesses ranging from 5.5 to 9.5 inches.
- Walls are supported on continuous footings.
- Ultimate transverse loads are between 0 and 105 psf.
- Ratios of vertical reinforcement (of yield strength 60 ksi) vary from 0.15% to 0.75%.
- Concrete compressive strength at 28 days is up to 4000 psi.
- Concrete self-weight is 150 pcf.
- Concrete panels are hinged along their loaded edges and free along vertical edges.
- Concrete panels are initially straight and laterally restrained at the top.

The capacity reduction factor, Φ (phi), used in these tables is 1.0. Stresses induced in the wall panels by lifting or tilting have not been considered. Additional information on analysis parameters and estimating load capacities for lightweight concrete and when additional lateral restraint is provided by a floor slab may be obtained by reviewing the PCA publication cited above.

There are few published values specific to *tolerances* and *clearances* in tilt-up construction. For clearances, the larger values are preferred over the smaller values for ease of construction. For connections, inserts to receive bolts must have lower tolerances than welded connections. The following are recommended by the Portland Cement Association:

Clearance:

Between panels	1/2 to 3/4 inch
Between structural support members and panels	1 to 2 inches

Tolerances:

Field-placed anchor bolts	±1/4 inch
Elevation of footings or piers	+1/2 inch, -2 inches
Position of bearing plates	±1/2 inch
Position of embedded plates	±1 inch
Position of inserts	±1/2 inch
Specified clearance space	±3/8 inch

12.1.2 Load Table for 5-1/2" Thick Tilt-Up Walls with Ultimate Transverse Loads 0 or 15 psf

($h = 5\frac{1}{2}"$ (140 mm) and $q_u/\phi = 0$ or 15 psf (0 or 0.7 kN/m²))

<div style="display: flex; justify-content: space-between; align-items: center;"> <div> $w = 150 \text{ pcf (2400 kg/m}^3\text{)}$ $f'_c \leq 4000 \text{ psi (28 MPa)}$ $f_y = 60 \text{ ksi (400 MPa)}$ </div> <div> </div> <div> $h = 5\frac{1}{2}"$ (140 mm) $P_u/\phi = (\text{coeff.}) b_l h f'_c$ </div> </div>											
$\rho = \frac{A_s \times 100}{b_l \times h}$	End eccentricity, e , in. (mm)	$q_u/\phi = 0 \text{ psf (0 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001	$q_u/\phi = 15 \text{ psf (0.7 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001
		20	30	40	50		20	30	40	50	
0.15	1.00 (25)	0.458	0.298	0.196	0.137	**	0.458	0.296	0.166	0.070	**
	2.75 (70)	0.094	0.039	0.023	0.011	**	0.087	0.021	0.004	—	49
	6.25 (160)	0.016	0.012	0.007	0.004	**	0.014	0.010	0.003	—	49
0.25	1.00 (25)	0.458	0.298	0.203	0.137	**	0.458	0.296	0.166	0.080	**
	2.75 (70)	0.110	0.051	0.030	0.017	**	0.102	0.036	0.011	0.003	**
	6.25 (160)	0.026	0.020	0.013	0.007	**	0.025	0.016	0.006	0.002	**
0.50	1.00 (25)	0.458	0.298	0.203	0.137	**	0.458	0.296	0.166	0.095	**
	2.75 (70)	0.128	0.062	0.039	0.024	**	0.123	0.054	0.024	0.011	**
	6.25 (160)	0.043	0.033	0.020	0.013	**	0.041	0.029	0.016	0.009	**
0.75	1.00 (25)	0.458	0.298	0.203	0.137	**	0.458	0.296	0.166	0.110	**
	2.75 (70)	0.146	0.074	0.048	0.030	**	0.141	0.071	0.036	0.019	**
	6.25 (160)	0.059	0.045	0.028	0.019	**	0.057	0.041	0.026	0.016	**

* Observe the direction of ultimate transverse loads (q_u) and note the bending moments due to transverse loads are additive to those caused by the axial loads. A dash indicates that the wall panel cannot sustain any load.

** Walls with slenderness ratios, kl_u/h , greater than 50 are not recommended.

† This column gives the value to the slenderness ratios above which the walls have negligible load-carrying capacity.

Notations and Symbols

The following notations and symbols apply to the load capacity tables in 12.1.2 through 12.1.20

- A_s = amount of vertical reinforcement
 b_l = unit width of panel
 e = end eccentricity
 f'_c = specified compressive strength of concrete
 f_y = specified yield strength of reinforcement
 g = (distance between rows of vertical reinforcement)/thickness
 h = overall thickness of panel
 i = effective length factor for compression members
 l_u = unsupported height of the panel
 P_u = ultimate load at the top of the panel
 q_u = ultimate transverse load
 w = unit weight of concrete
 ρ = ratio of vertical reinforcement expressed as a percentage

$$\frac{A_s \times 100}{b_l \times h}$$

Φ = capacity reduction factor

12.1.3 Load Table for 5-1/2" Thick Tilt-Up Walls with Ultimate Transverse Loads 30 or 45 psf

($h = 5\frac{1}{2}"$ (140 mm) and $q_u l \phi = 30$ or 45 psf (1.4 or 2.2 kN/m²))

$w = 150 \text{ pcf (2400 kg/m}^3\text{)}$
 $f'_c \leq 4000 \text{ psi (28 MPa)}$
 $f_y = 60 \text{ ksi (400 MPa)}$

Diagram illustrating the wall panel under transverse load q_u . The wall has height h and end eccentricity e . The slenderness ratio is $k l_u / h$. The cross-section shows width b_1 and b_2 .

$h = 5\frac{1}{2}"$ (140 mm)

$P_u / \phi = (\text{coeff.}) b_1 h f_c$

$\rho = \frac{A_s \times 100}{b_1 \times h}$	End eccentricity, e , in. (mm)	$q_u l \phi = 30 \text{ psf (1.4 kN/m}^2\text{)}$ Slenderness ratio, $k l_u / h =$				$k l_u / h$ @ coeff.† ≤ 0.001	$q_u l \phi = 45 \text{ psf (2.2 kN/m}^2\text{)}$ Slenderness ratio, $k l_u / h =$				$k l_u / h$ @ coeff.† ≤ 0.001
		20	30	40	50		20	30	40	50	
0.15	1.00 (25)	0.438	0.278	0.030	—	49	0.438	0.110	—	—	39
	2.75 (70)	0.078	0.011	—	—	39	0.067	—	—	—	33
	6.25 (160)	0.013	0.005	—	—	39	0.012	—	—	—	33
0.25	1.00 (25)	0.438	0.278	0.099	0.020	**	0.438	0.218	0.040	—	49
	2.75 (70)	0.096	0.028	0.007	—	49	0.087	0.019	—	—	39
	6.25 (160)	0.024	0.014	0.004	—	49	0.023	0.010	—	—	39
0.50	1.00 (25)	0.438	0.278	0.099	0.035	**	0.438	0.218	0.045	0.010	**
	2.75 (70)	0.118	0.046	0.019	0.007	**	0.111	0.038	0.013	0.005	**
	6.25 (160)	0.040	0.027	0.013	0.006	**	0.038	0.020	0.010	0.004	**
0.75	1.00 (25)	0.438	0.278	0.099	0.050	**	0.438	0.218	0.045	0.020	**
	2.75 (70)	0.139	0.063	0.031	0.014	**	0.134	0.056	0.027	0.010	**
	6.25 (160)	0.055	0.039	0.022	0.012	**	0.063	0.035	0.020	0.009	**

* Observe the direction of ultimate transverse loads (q_u) and note the bending moments due to transverse loads are additive to those caused by the axial loads. A dash indicates that the wall panel cannot sustain any load.

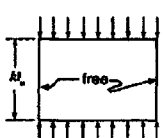
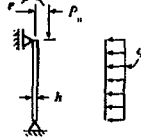
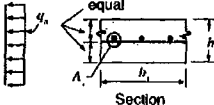
** Walls with slenderness ratios, $k l_u / h$, greater than 50 are not recommended.

† This column gives the value to the slenderness ratios above which the walls have negligible load-carrying capacity.

(From Tilt-Up Load-Bearing Walls, 3rd ed., Portland Cement Association, 1994)

12.1.4 Load Table for 5-1/2" Thick Tilt-Up Walls with Ultimate Transverse Loads 60 or 75 psf

($h = 5\frac{1}{2}"$ (140 mm) and $q_u/\phi = 60$ or 75 psf (2.9 or 3.6 kN/m²))

$w = 150 \text{ pcf (2400 kg/m}^3\text{)}$ $f'_c \leq 4000 \text{ psi (28 MPa)}$ $f_y = 60 \text{ ksi (400 MPa)}$								$P_u/\phi = (\text{coeff.}) b_1 h f_c$		$h = 5\frac{1}{2}" \text{ (140 mm)}$	
$\rho = \frac{A_s \times 100}{b_1 \times h}$	End eccentricity, e , in. (mm)	$q_u/\phi = 60 \text{ psf (2.9 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001	$q_u/\phi = 75 \text{ psf (3.6 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001
		20	30	40	50		20	30	40	50	
0.50	1.00 (25)	0.418	0.180	0.012	—	49	0.418	0.120	0.006	—	47
	2.75 (70)	0.104	0.030	0.010	—	49	0.097	0.022	0.004	—	47
	6.25 (160)	0.036	0.015	0.006	—	49	0.034	0.010	0.002	—	47
0.75	1.00 (25)	0.418	0.180	0.025	0.006	**	0.418	0.120	0.020	0.001	**
	2.75 (70)	0.130	0.054	0.021	0.004	**	0.126	0.050	0.016	0.001	**
	6.25 (160)	0.051	0.033	0.016	0.003	**	0.049	0.031	0.012	—	49

* Observe the direction of ultimate transverse loads (q_u) and note the bending moments due to transverse loads are additive to those caused by the axial loads. A dash indicates that the wall panel cannot sustain any load.

** Walls with slenderness ratios, kl_u/h , greater than 50 are not recommended.

† This column gives the value to the slenderness ratios above which the walls have negligible load-carrying capacity.

(From Tilt-Up Load-Bearing Walls, 3rd ed., Portland Cement Association, 1994)

12.1.6 Load Table for 6-1/2" Thick Tilt-Up Walls with Ultimate Transverse Loads 0 or 15 psf

($h = 6\frac{1}{2}"$ (165 mm) and $q_u k\phi = 0$ or 15 psf (0 or 0.7 kN/m²))

<div style="display: flex; justify-content: space-between; align-items: center;"> <div> $w = 150 \text{ pcf (2400 kg/m}^3\text{)}$ $f_c \leq 4000 \text{ psi (28 MPa)}$ $f_y = 60 \text{ ksi (400 MPa)}$ </div> <div> </div> <div> $h = 6\frac{1}{2}"$ (165 mm) </div> </div> <div style="text-align: right; margin-top: 10px;"> $P_u / \phi = (\text{coeff.}) b_1 h f_c$ </div>											
$\rho = \frac{A_s \times 100}{b_1 \times h}$	End eccentricity, e , in. (mm)	$q_u k\phi = 0 \text{ psf (0 kN/m}^2\text{)}$ Slenderness ratio, $k l_u / h =$				$k l_u / h$ @ coeff.† ≤ 0.001	$q_u k\phi = 15 \text{ psf (0.7 kN/m}^2\text{)}$ Slenderness ratio, $k l_u / h =$				$k l_u / h$ @ coeff.† ≤ 0.001
		20	30	40	50		20	30	40	50	
0.15	1.00 (25)	0.498	0.347	0.227	0.155	**	0.468	0.331	0.191	0.085	**
	3.25 (85)	0.094	0.042	0.018	0.013	**	0.087	0.021	0.005	—	49
	6.75 (170)	0.018	0.014	0.005	0.003	**	0.017	0.009	0.003	—	49
0.25	1.00 (25)	0.498	0.347	0.227	0.155	**	0.468	0.331	0.191	0.090	**
	3.25 (85)	0.110	0.050	0.026	0.018	**	0.105	0.037	0.011	0.003	**
	6.75 (170)	0.029	0.022	0.010	0.006	**	0.025	0.015	0.006	0.002	**
0.50	1.00 (25)	0.498	0.347	0.227	0.155	**	0.483	0.331	0.191	0.100	**
	3.25 (85)	0.128	0.066	0.034	0.022	**	0.124	0.055	0.023	0.011	**
	6.75 (170)	0.049	0.034	0.020	0.012	**	0.045	0.029	0.016	0.009	**
0.75	1.00 (25)	0.498	0.347	0.227	0.155	**	0.498	0.331	0.191	0.110	**
	3.25 (85)	0.146	0.082	0.042	0.026	**	0.142	0.073	0.035	0.019	**
	6.75 (170)	0.069	0.046	0.030	0.018	**	0.065	0.044	0.026	0.016	**

* Observe the direction of ultimate transverse loads (q_u) and note the bending moments due to transverse loads are additive to those caused by the axial loads. A dash indicates that the wall panel cannot sustain any load.

** Walls with slenderness ratios, $k l_u / h$, greater than 50 are not recommended.

† This column gives the value to the slenderness ratios above which the walls have negligible load-carrying capacity.

(From Tilt-Up Load-Bearing Walls, 3rd ed., Portland Cement Association, 1994)

12.1.7 Load Table for 6-1/2" Thick Tilt-Up Walls with Ultimate Transverse Loads 30 or 45 psf

($h = 6\frac{1}{2}"$ (165 mm) and $q_u l \phi = 30$ or 45 psf (1.4 or 2.2 kN/m²))

$w = 150 \text{ pcf (2400 kg/m}^3\text{)}$
 $f'_c \leq 4000 \text{ psi (28 MPa)}$
 $f_y = 60 \text{ ksi (400 MPa)}$

Section

$P_u / \phi = (\text{coeff.}) b_1 h f_c$

$h = 6\frac{1}{2}"$ (165 mm)

$\rho = \frac{A_s \times 100}{b_1 \times h}$	End eccentricity, e , in. (mm)	$q_u l \phi = 30 \text{ psf (1.4 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001	$q_u l \phi = 45 \text{ psf (2.2 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001
		20	30	40	50		20	30	40	50	
0.15	1.00 (25)	0.468	0.316	0.035	—	49	0.438	0.110	—	—	39
	3.25 (85)	0.079	0.011	—	—	39	0.067	—	—	—	29
	6.75 (170)	0.016	0.005	—	—	39	0.014	—	—	—	29
0.25	1.00 (25)	0.468	0.316	0.151	0.030	**	0.438	0.301	0.065	—	49
	3.25 (85)	0.101	0.026	0.006	—	49	0.092	0.016	—	—	39
	6.75 (170)	0.024	0.014	0.004	—	49	0.023	0.009	—	—	39
0.50	1.00 (25)	0.483	0.316	0.151	0.040	**	0.453	0.301	0.070	0.010	**
	3.25 (85)	0.121	0.046	0.016	0.004	**	0.114	0.036	0.010	0.003	**
	6.75 (170)	0.042	0.028	0.013	0.003	**	0.040	0.024	0.009	0.002	**
0.75	1.00 (25)	0.498	0.316	0.151	0.050	**	0.468	0.301	0.070	0.020	**
	3.25 (85)	0.141	0.066	0.026	0.009	**	0.137	0.056	0.021	0.006	**
	6.75 (170)	0.061	0.042	0.023	0.007	**	0.059	0.039	0.020	0.005	**

*

Observe the direction of ultimate transverse loads (q_u) and note the bending moments due to transverse loads are additive to those caused by the axial loads. A dash indicates that the wall panel cannot sustain any load.

**

Walls with slenderness ratios, kl_u/h , greater than 50 are not recommended.

†

This column gives the value to the slenderness ratios above which the walls have negligible load-carrying capacity.

(From Tilt-Up Load-Bearing Walls, 3rd ed., Portland Cement Association, 1994)

12.1.8 Load Table for 6-1/2" Thick Tilt-Up Walls with Ultimate Transverse Loads 60 or 75 psf

($h = 6\frac{1}{2}"$ (165 mm) and $q_u/\phi = 60$ or 75 psf (2.9 or 3.6 kN/m^2))

$w = 150 \text{ pcf (2400 kg/m}^3\text{)}$
 $f_c \leq 4000 \text{ psi (28 MPa)}$
 $f_y = 60 \text{ ksi (400 MPa)}$

$h = 6\frac{1}{2}" \text{ (165 mm)}$

$P_u/\phi = (\text{coeff.}) b_1 h f_c$

$\rho = \frac{A_s \times 100}{b_1 \times h}$	End eccentricity, e , in. (mm)	$q_u/\phi = 60 \text{ psf (2.9 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001	$q_u/\phi = 75 \text{ psf (3.6 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001
		20	30	40	50		20	30	40	50	
0.50	1.00 (25)	0.438	0.270	0.013	—	49	0.428	0.241	0.004	—	47
	3.25 (85)	0.114	0.036	0.006	—	49	0.110	0.035	0.004	—	47
	6.75 (170)	0.040	0.024	0.007	—	49	0.040	0.021	0.003	—	47
0.75	1.00 (25)	0.468	0.273	0.026	0.006	**	0.453	0.247	0.019	—	49
	3.25 (85)	0.129	0.055	0.021	0.005	**	0.126	0.050	0.017	—	49
	6.75 (170)	0.057	0.036	0.017	0.004	**	0.055	0.033	0.013	—	49

* Observe the direction of ultimate transverse loads (q_u) and note the bending moments due to transverse loads are additive to those caused by the axial loads. A dash indicates that the wall panel cannot sustain any load.

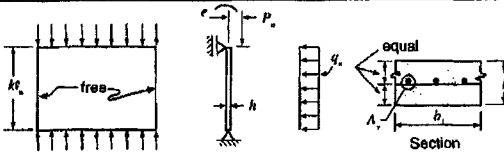
** Walls with slenderness ratios, kl_u/h , greater than 50 are not recommended.

† This column gives the value to the slenderness ratios above which the walls have negligible load-carrying capacity.

(From Tilt-Up Load-Bearing Walls, 3rd ed., Portland Cement Association, 1994)

12.1.10 Load Table for 7-1/2" Thick Tilt-Up Walls with Ultimate Transverse Loads 0 or 15 psf

($h = 7\frac{1}{2}"$ (190 mm) and $q_u l \phi = 0$ or 15 psf (0 or 0.7 kN/m²))

<div style="display: flex; justify-content: space-between; align-items: center;"> <div> $w = 150 \text{ pcf (2400 kg/m}^3\text{)}$ $f'_c \leq 4000 \text{ psi (28 MPa)}$ $f_y = 60 \text{ ksi (400 MPa)}$ </div> <div>  </div> <div> $h = 7\frac{1}{2}"$ (190 mm) $P_u / \phi = (\text{coeff.}) b_1 h f'_c$ </div> </div>											
$\rho = \frac{A_s \times 100}{b_1 \times h}$	End eccentricity, e , in. (mm)	$q_u l \phi = 0 \text{ psf (0 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001	$q_u l \phi = 15 \text{ psf (0.7 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001
		20	30	40	50		20	30	40	50	
0.15	1.00 (25)	0.518	0.371	0.243	0.163	**	0.518	0.349	0.217	0.095	**
	3.75 (95)	0.099	0.046	0.026	0.014	**	0.092	0.021	0.004	—	49
	7.25 (185)	0.024	0.018	0.008	0.003	**	0.021	0.010	0.003	—	49
0.25	1.00 (25)	0.518	0.371	0.243	0.163	**	0.518	0.349	0.217	0.100	**
	3.75 (95)	0.110	0.054	0.030	0.019	**	0.105	0.035	0.013	0.003	**
	7.25 (185)	0.034	0.026	0.014	0.010	**	0.031	0.019	0.008	0.002	**
0.50	1.00 (25)	0.518	0.371	0.243	0.163	**	0.518	0.349	0.217	0.110	**
	3.75 (95)	0.129	0.065	0.038	0.024	**	0.125	0.055	0.023	0.011	**
	7.25 (185)	0.054	0.038	0.022	0.014	**	0.050	0.032	0.018	0.009	**
0.75	1.00 (25)	0.518	0.371	0.243	0.163	**	0.518	0.349	0.217	0.120	**
	3.75 (95)	0.149	0.086	0.046	0.030	**	0.146	0.074	0.033	0.019	**
	7.25 (185)	0.074	0.050	0.030	0.018	**	0.069	0.045	0.028	0.016	**

* Observe the direction of ultimate transverse loads (q_u) and note the bending moments due to transverse loads are additive to those caused by the axial loads. A dash indicates that the wall panel cannot sustain any load.

** Walls with slenderness ratios, kl_u/h , greater than 50 are not recommended.

† This column gives the value to the slenderness ratios above which the walls have negligible load-carrying capacity.

(From Tilt-Up Load-Bearing Walls, 3rd ed., Portland Cement Association, 1994)

12.1.11
Load Table for 7-1/2" Thick Tilt-Up Walls with Ultimate Transverse Loads 30 or 45 psf

(h = 7'1/2" (190 mm) and $q_u/\phi = 30$ or 45 psf (1.4 or 2.2 kN/m^2))

$w = 150 \text{ pcf (2400 kg/m}^3\text{)}$
 $f'_c \leq 4000 \text{ psi (28 MPa)}$
 $f_y = 60 \text{ ksi (400 MPa)}$

$h = 7'1/2" (190 \text{ mm})$

$P_u/\phi = (\text{coeff.}) b_1 h f'_c$

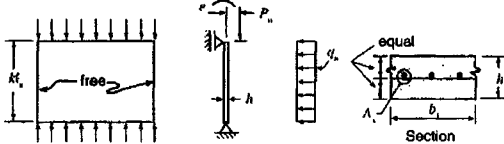
$\rho = \frac{A_s \times 100}{b_1 \times h}$	End eccentricity, e_1 in. (mm)	$q_u/\phi = 30 \text{ psf (1.4 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001	$q_u/\phi = 45 \text{ psf (2.2 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001
		20	30	40	50		20	30	40	50	
0.15	1.00 (25)	0.518	0.341	0.040	—	49	0.478	0.110	—	—	39
	3.75 (95)	0.084	0.011	—	—	38	0.076	—	—	—	29
	7.25 (185)	0.019	0.006	—	—	38	0.017	—	—	—	29
0.25	1.00 (25)	0.518	0.341	0.171	0.040	**	0.478	0.301	0.065	—	49
	3.75 (95)	0.102	0.021	0.005	—	48	0.093	0.016	—	—	39
	7.25 (185)	0.029	0.011	0.003	—	48	0.027	0.009	—	—	39
0.50	1.00 (25)	0.518	0.341	0.171	0.050	**	0.498	0.301	0.070	0.010	**
	3.75 (95)	0.123	0.041	0.016	0.005	**	0.115	0.035	0.011	0.003	**
	7.25 (185)	0.047	0.026	0.013	0.003	**	0.045	0.024	0.010	0.002	**
0.75	1.00 (25)	0.518	0.341	0.171	0.060	**	0.518	0.301	0.070	0.020	**
	3.75 (95)	0.143	0.061	0.026	0.009	**	0.137	0.056	0.021	0.006	**
	7.25 (185)	0.065	0.041	0.023	0.007	**	0.063	0.039	0.020	0.005	**

* Observe the direction of ultimate transverse loads (q_u) and note the bending moments due to transverse loads are additive to those caused by the axial loads. A dash indicates that the wall panel cannot sustain any load.
 ** Walls with slenderness ratios, kl_u/h , greater than 50 are not recommended.
 † This column gives the value to the slenderness ratios above which the walls have negligible load-carrying capacity.

(From Tilt-Up Load-Bearing Walls, 3rd ed., Portland Cement Association, 1994)

12.1.12 Load Table for 7-1/2" Thick Tilt-Up Walls with Ultimate Transverse Loads 60 or 75 psf

($h = 7\frac{1}{2}"$ (190 mm) and $q_u l \phi = 60$ or 75 psf (2.9 or 3.6 kN/m²))

$w = 150 \text{ pcf (2400 kg/m}^3\text{)}$ $f_c \leq 4000 \text{ psi (28 MPa)}$ $f_y = 60 \text{ ksi (400 MPa)}$											
											
$P_u / \phi = (\text{coeff.}) b_1 h f_c$											
$\rho = \frac{A_s \times 100}{b_1 \times h}$	End eccentricity, e , in. (mm)	$q_u l \phi = 60 \text{ psf (2.9 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001	$q_u l \phi = 75 \text{ psf (3.6 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001
		20	30	40	50		20	30	40	50	
0.50	1.00 (25)	0.496	0.285	0.011	—	48	0.492	0.280	0.006	—	46
	3.75 (95)	0.113	0.031	0.008	—	48	0.110	0.030	0.003	—	46
	7.25 (185)	0.043	0.022	0.007	—	48	0.041	0.020	0.002	—	46
0.75	1.00 (25)	0.518	0.302	0.025	0.005	**	0.512	0.285	0.020	—	49
	3.75 (95)	0.129	0.054	0.019	0.004	**	0.125	0.049	0.015	—	49
	7.25 (185)	0.060	0.036	0.015	0.003	**	0.058	0.034	0.012	—	49

* Observe the direction of ultimate transverse loads (q_u) and note the bending moments due to transverse loads are additive to those caused by the axial loads. A dash indicates that the wall panel cannot sustain any load.

** Walls with slenderness ratios, kl_u/h , greater than 50 are not recommended.

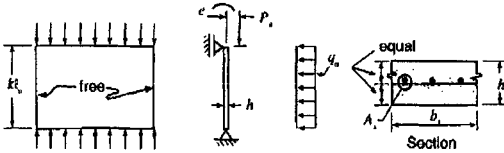
† This column gives the value to the slenderness ratios above which the walls have negligible load-carrying capacity.

(From Tilt-Up Loadbearing Walls, 3rd ed., Portland Cement Association, 1994)

12.1.13 Load Table for 7-1/2" Thick Tilt-Up Walls with Ultimate Transverse Loads 90 or 105 psf

($h = 7\frac{1}{2}"$ (190 mm) and $q_u/\phi = 90$ or 105 psf (4.3 or 5.0 kN/m²))

$w = 150 \text{ pcf (2400 kg/m}^3\text{)}$
 $f'_c \leq 4000 \text{ psi (28 MPa)}$
 $f_y = 60 \text{ ksi (400 MPa)}$



$h = 7\frac{1}{2}"$ (190 mm)

$P_u/\phi = (\text{coeff.}) b_1 h f'_c$

$\rho = \frac{A_s \times 100}{b_1 \times h}$	End eccentricity, $e,$ in. (mm)	$q_u/\phi = 90 \text{ psf (4.3 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001	$q_u/\phi = 105 \text{ psf (5.0 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001
		20	30	40	50		20	30	40	50	
0.50	1.00 (25)	0.487	0.260	—	—	39	0.482	0.210	—	—	39
	3.75 (95)	0.105	0.027	—	—	39	0.100	0.026	—	—	39
	7.25 (185)	0.039	0.018	—	—	39	0.037	0.013	—	—	39
0.75	1.00 (25)	0.507	0.275	0.014	—	49	0.502	0.260	0.008	—	48
	3.75 (95)	0.122	0.046	0.012	—	49	0.118	0.040	0.007	—	48
	7.25 (185)	0.058	0.032	0.009	—	49	0.058	0.028	0.005	—	48

* Observe the direction of ultimate transverse loads (q_u) and note the bending moments due to transverse loads are additive to those caused by the axial loads. A dash indicates that the wall panel cannot sustain any load.

** Walls with slenderness ratios, kl_u/h , greater than 50 are not recommended.

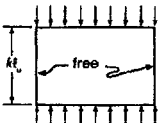
† This column gives the value to the slenderness ratios above which the walls have negligible load-carrying capacity.

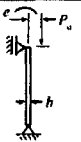
(From Tilt-Up Load-Bearing Walls, 3rd ed., Portland Cement Association, 1994)

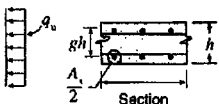
12.1.14 Load Table for 7-1/2" Thick Tilt-Up Walls with Ultimate Transverse Load 0 psf with Two Rows of Reinforcement

($h = 7\frac{1}{2}"$ (190 mm) and $q_u/\phi = 0$ psf (0 kN/m²))

$w_c = 150$ pcf (2400 kg/m³)
 $f'_c \leq 4000$ psi (28 MPa)
 $f_y = 60$ ksi (400 MPa)







$h = 7\frac{1}{2}"$ (190 mm)
 $P_u/\phi = (\text{coeff.}) b_1 h f'_c$
 $g = 0.60$

$\rho = \frac{A_s \times 100}{b_1 \times h}$	End eccentricity, e , in. (mm)	$q_u/\phi = 0$ psf (0 kN/m ²) Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001
		20	30	40	50	
0.50	1.00 (25)	0.556	0.390	0.227	0.141	**
	3.75 (95)	0.177	0.108	0.060	0.035	**
	7.25 (185)	0.055	0.046	0.034	0.024	**
0.75	1.00 (25)	0.573	0.401	0.240	0.141	**
	3.75 (95)	0.214	0.133	0.075	0.040	**
	7.25 (185)	0.076	0.064	0.050	0.035	**

* Observe the direction of ultimate transverse loads (q_u) and note the bending moments due to transverse loads are additive to those caused by the axial loads. A dash indicates that the wall panel cannot sustain any load.

** Walls with slenderness ratios, kl_u/h , greater than 50 are not recommended.

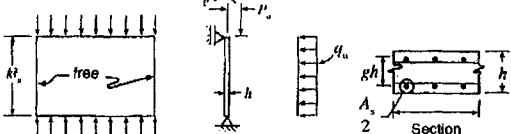
† This column gives the value to the slenderness ratios above which the walls have negligible load-carrying capacity.

(From Tilt-Up Load-Bearing Walls, 3rd ed., Portland Cement Association, 1994)

12.1.15 Load Table for 7-1/2" Thick Tilt-Up Walls with Ultimate Transverse Loads 30 or 45 psf with Two Rows of Reinforcement

($h = 7\frac{1}{2}"$ (190 mm) and $q_u l\phi = 30$ or 45 psf (1.4 or 2.2 kN/m²))

$w_c = 150 \text{ pcf (2400 kg/m}^3\text{)}$
 $f'_c \leq 4000 \text{ psi (28 MPa)}$
 $f_y = 60 \text{ ksi (400 MPa)}$



$h = 7\frac{1}{2}"$ (190 mm)
 $P_u l\phi = (\text{coeff.}) b_1 h f'_c$
 $g = 0.60$

$\rho = \frac{A_s}{b_1 \times h} \times 100$	End eccentricity, e , in. (mm)	$q_u l\phi = 30 \text{ psf (1.4 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001	$q_u l\phi = 45 \text{ psf (2.2 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001
		20	30	40	50		20	30	40	50	
0.50	1.00 (25)	0.548	0.365	0.195	0.045	**	0.544	0.350	0.170	0.012	**
	3.75 (95)	0.172	0.089	0.036	0.012	**	0.170	0.081	0.026	0.001	**
	7.25 (185)	0.053	0.040	0.022	0.009	**	0.051	0.036	0.016	—	49
0.75	1.00 (25)	0.565	0.376	0.204	0.045	**	0.561	0.361	0.180	0.024	**
	3.75 (95)	0.209	0.118	0.058	0.027	**	0.207	0.110	0.048	0.017	**
	7.25 (185)	0.074	0.060	0.038	0.021	**	0.073	0.056	0.031	0.013	**

* Observe the direction of ultimate transverse loads (q_u) and note the bending moments due to transverse loads are additive to those caused by the axial loads. A dash indicates that the wall panel cannot sustain any load.

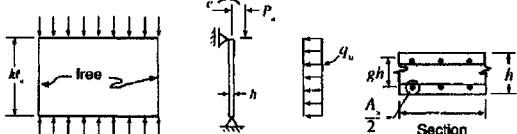
** Walls with slenderness ratios, kl_u/h , greater than 50 are not recommended.

† This column gives the value to the slenderness ratios above which the walls have negligible load-carrying capacity.

(From Tilt-Up Load-Bearing Walls, 3rd ed., Portland Cement Association, 1994)

12.1.16 Load Table for 7-1/2" Thick Tilt-Up Walls with Ultimate Transverse Loads 60 or 75 psf with Two Rows of Reinforcement

($h = 7\frac{1}{2}"$ (190 mm) and $q_u/\phi = 60$ or 75 psf (2.9 or 3.6 kN/m²))

$w = 150 \text{ pcf (2400 kg/m}^3\text{)}$ $f'_c \leq 4000 \text{ psi (28 MPa)}$ $f_y = 60 \text{ ksi (400 MPa)}$											
											
$h = 7\frac{1}{2}"$ (190 mm) $P_u/\phi = (\text{coeff.}) b_1 h f'_c$ $g = 0.60$											
$\rho = \frac{A_s \times 100}{b_1 \times h}$	End eccentricity, e , in. (mm)	$q_u/\phi = 60 \text{ psf (2.9 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001	$q_u/\phi = 75 \text{ psf (3.6 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001
		20	30	40	50		20	30	40	50	
0.50	1.00 (25)	0.540	0.332	0.155	0.001	**	0.536	0.314	0.145	—	49
	3.75 (95)	0.165	0.069	0.013	—	49	0.160	0.060	0.002	—	45
	7.25 (185)	0.050	0.031	0.008	—	49	0.049	0.027	0.001	—	41
0.75	1.00 (25)	0.557	0.343	0.165	0.009	**	0.553	0.325	0.152	0.002	**
	3.75 (95)	0.202	0.102	0.039	0.007	**	0.197	0.093	0.028	—	49
	7.25 (185)	0.072	0.051	0.025	0.005	**	0.071	0.043	0.019	—	49

* Observe the direction of ultimate transverse loads (q_u) and note the bending moments due to transverse loads are additive to those caused by the axial loads. A dash indicates that the wall panel cannot sustain any load.

** Walls with slenderness ratios, kl_u/h , greater than 50 are not recommended.

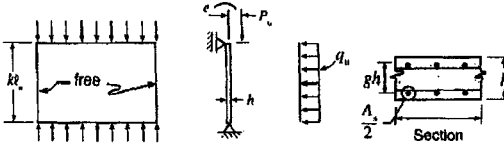
† This column gives the value to the slenderness ratios above which the walls have negligible load-carrying capacity.

(From Tilt-Up Load-Bearing Walls, 3rd ed., Portland Cement Association, 1994)

12.1.17 Load Table for 7-1/2" Thick Tilt-Up Walls with Ultimate Transverse Loads 90 or 105 psf with Two Rows of Reinforcement

($h = 7\frac{1}{2}"$ (190 mm) and $q_u l\phi = 90$ or 105 psf (4.3 or 5.0 kN/m²))

$w' = 150 \text{ pcf (2400 kg/m}^3\text{)}$
 $f'_c \leq 4000 \text{ psi (28 MPa)}$
 $f_y = 60 \text{ ksi (400 MPa)}$



$h = 7\frac{1}{2}"$ (190 mm)

$P_u l\phi = (\text{coeff.}) b_l h f'_c$
 $g = 0.60$

$\rho = \frac{A_s \times 100}{b_l \times h}$	End eccentricity, $e,$ in. (mm)	$q_u l\phi = 90 \text{ psf (4.3 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001	$q_u l\phi = 105 \text{ psf (5.0 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001
		20	30	40	50		20	30	40	50	
0.50	1.00 (25)	0.532	0.294	0.120	—	49	0.528	0.274	0.110	—	49
	3.75 (95)	0.155	0.047	—	—	39	0.150	0.035	—	—	39
	7.25 (185)	0.048	0.021	—	—	39	0.047	0.015	—	—	39
0.75	1.00 (25)	0.549	0.305	0.125	0.001	**	0.545	0.285	0.115	—	49
	3.75 (95)	0.192	0.080	0.018	—	49	0.187	0.075	0.007	—	48
	7.25 (185)	0.070	0.039	0.012	—	49	0.069	0.032	0.005	—	48

* Observe the direction of ultimate transverse loads (q_u) and note the bending moments due to transverse loads are additive to those caused by the axial loads. A dash indicates that the wall panel cannot sustain any load.

** Walls with slenderness ratios, kl_u/h , greater than 50 are not recommended.

† This column gives the value to the slenderness ratios above which the walls have negligible load-carrying capacity.

(From Tilt-Up Load-Bearing Walls, 3rd ed., Portland Cement Association, 1994)

12.1.18 Load Table for 9-1/2" Thick Tilt-Up Walls with Ultimate Transverse Load 0 psf with Two Rows of Reinforcement

($h = 9\frac{1}{2}"$ (240 mm) and $q_u l\phi = 0$ psf (0 kN/m²))

$w = 150 \text{ pcf (2400 kg/m}^3\text{)}$
 $f'_c \leq 4000 \text{ psi (28 MPa)}$
 $f_y = 60 \text{ ksi (400 MPa)}$

Diagram of a wall cross-section showing height h , thickness t , and reinforcement details. The wall is subjected to a horizontal load q_u and a vertical load P_u . The reinforcement consists of vertical bars and horizontal stirrups.

Diagram of a wall cross-section showing height h , thickness t , and reinforcement details. The wall is subjected to a horizontal load q_u and a vertical load P_u . The reinforcement consists of vertical bars and horizontal stirrups.

Diagram of a wall cross-section showing height h , thickness t , and reinforcement details. The wall is subjected to a horizontal load q_u and a vertical load P_u . The reinforcement consists of vertical bars and horizontal stirrups.

$P_u l\phi = (\text{coeff.}) b_1 h f'_c$
 $g = 0.60$

$h = 9\frac{1}{2}"$ (240 mm)

$\rho = \frac{A_s \times 100}{b_1 \times h}$	End eccentricity, e_s in. (mm)	$q_u l\phi = 0 \text{ psf (0 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001
		20	30	40	50	
0.25	1.00 (25)	0.573	0.416	0.265	0.043	**
	4.75 (120)	0.135	0.084	0.047	0.027	**
	8.25 (210)	0.037	0.033	0.023	0.013	**
0.50	1.00 (25)	0.600	0.432	0.285	0.065	**
	4.75 (120)	0.191	0.120	0.069	0.035	**
	8.25 (210)	0.066	0.058	0.042	0.029	**
0.75	1.00 (25)	0.623	0.446	0.305	0.105	**
	4.75 (120)	0.233	0.150	0.088	0.056	**
	8.25 (210)	0.093	0.080	0.060	0.041	**

* Observe the direction of ultimate transverse loads (q_u) and note the bending moments due to transverse loads are additive to those caused by the axial loads. A dash indicates that the wall panel cannot sustain any load.

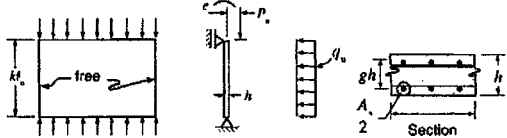
** Walls with slenderness ratios, kl_u/h , greater than 50 are not recommended.

† This column gives the value to the slenderness ratios above which the walls have negligible load-carrying capacity.

(From Tilt-Up Load-Bearing Walls, 3rd ed., Portland Cement Association, 1994)

12.1.20 Load Table for 9-1/2" Thick Tilt-Up Walls with Ultimate Transverse Loads 90 or 105 psf with Two Rows of Reinforcement

($h = 9\frac{1}{2}"$ (240 mm) and $q_u l \phi = 90$ or 105 psf (4.3 or 5.0 kN/m²))

<div style="display: flex; justify-content: space-between; align-items: center;"> <div> $w = 150 \text{ pcf (2400 kg/m}^3\text{)}$ $f'_c \leq 4000 \text{ psi (28 MPa)}$ $f_y = 60 \text{ ksi (400 MPa)}$ </div> <div>  </div> <div> $h = 9\frac{1}{2}"$ (240 mm) </div> </div>											
$\rho = \frac{A_s \times 100}{b_1 \times h}$	End eccentricity, e , in. (mm)	$q_u l \phi = 90 \text{ psf (4.3 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001	$q_u l \phi = 105 \text{ psf (5.0 kN/m}^2\text{)}$ Slenderness ratio, $kl_u/h =$				kl_u/h @ coeff.† ≤ 0.001
		20	30	40	50		20	30	40	50	
0.25	1.00 (25)	0.553	0.325	0.060	—	49	0.550	0.307	0.050	—	49
	4.75 (120)	0.107	0.002	—	—	31	0.100	0.001	—	—	31
	8.25 (210)	0.028	—	—	—	29	0.023	—	—	—	29
0.50	1.00 (25)	0.578	0.345	0.070	—	49	0.573	0.325	0.060	—	49
	4.75 (120)	0.171	0.059	—	—	39	0.166	0.046	—	—	39
	8.25 (210)	0.060	0.029	—	—	39	0.058	0.022	—	—	39
0.75	1.00 (25)	0.600	0.363	0.080	—	49	0.596	0.345	0.070	—	49
	4.75 (120)	0.217	0.101	0.025	—	49	0.212	0.092	0.013	—	49
	8.25 (210)	0.087	0.054	0.017	—	49	0.085	0.050	0.009	—	48

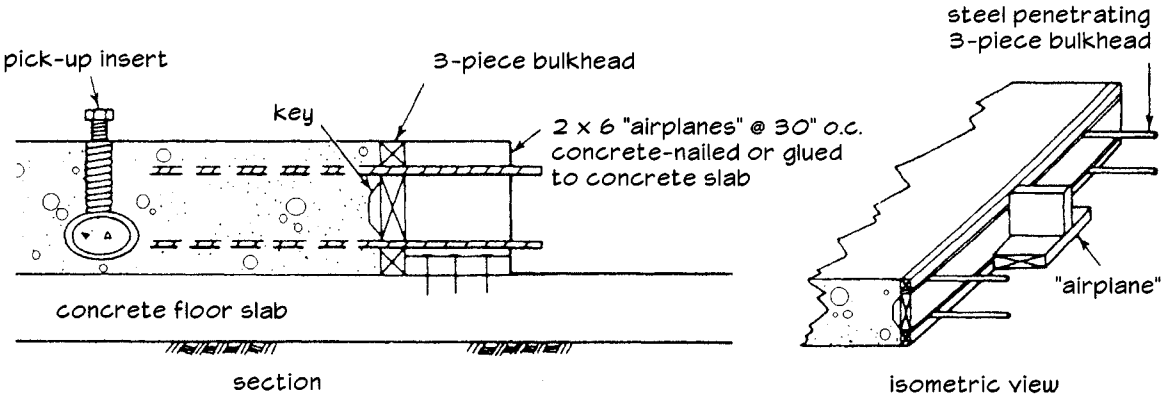
* Observe the direction of ultimate transverse loads (q_u) and note the bending moments due to transverse loads are additive to those caused by the axial loads. A dash indicates that the wall panel cannot sustain any load.

** Walls with slenderness ratios, kl_u/h , greater than 50 are not recommended.

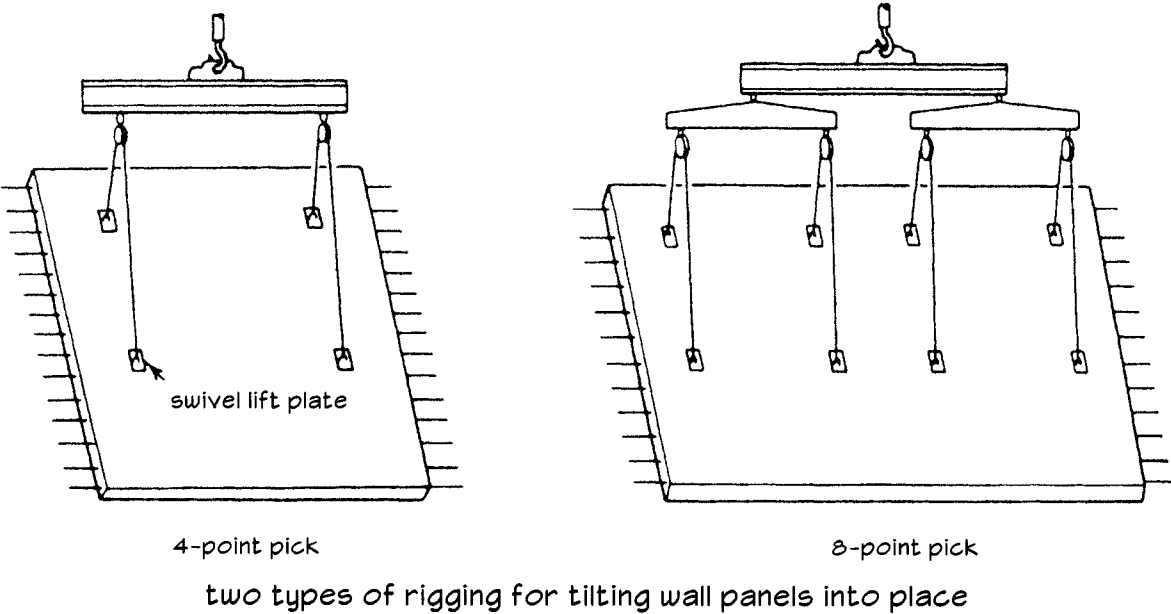
† This column gives the value to the slenderness ratios above which the walls have negligible load-carrying capacity.

(From Tilt-Up Load-Bearing Walls, 3rd ed., Portland Cement Association, 1994)

12.2.1 Forming and Rigging Tilt-Up Wall Panels



standard edge form for tilt-up wall panel
shown for a double-curtain steel arrangement with steel
penetrating a 3-piece bulkhead



(From Dobrowolski, Concrete Construction, 4th ed.)

12.2.2 Tilt-Up Panel Connection Considerations

Design Loads: In addition to vertical live and dead loads, lateral wind loads, soil pressure, and seismic events, consider temporary erection loads and volume changes. Avoid overly strengthened connections since they can introduce unwanted restraints. Connections are often designed to resist only one type of loading.

Ductility: The ability to withstand deformation and load beyond the initial yield is desirable. Ductile connections can still support loads even if unexpected forces occur and large deformations develop.

Restraint to Volume Change: Design connections to accommodate, rather than restrain, panel movements caused by drying shrinkage, temperature changes, moisture content changes, and creep.

Durability: Connections should be capable of maintaining strength and serviceability throughout their service life. Connections exposed to weather require proper protection of components, including coatings on steel, treatments for wood, and air-entrainment for concrete in freeze-thaw climates.

Fire Resistance: Fire protection requirements are dictated by code. When required, provide intumescent mastic (paint-on liquid that, when dry, foams under elevated temperatures), mineral fibers (mixed with bonding agents and sprayed or troweled on), or vermiculite (mixed with cement paste and applied by trowel or spray).

Efficiency: Design connections to optimize construction time. Factors that affect connection efficiency include:

- Design simplicity – reduce the number of components
- Repetition of details – minimize the number of different-size components
- Reinforcement – evaluate feasibility of fabrication by providing scale drawings; smaller bars alleviate congestion and require shorter development lengths
- Embedments – firmly anchor embedments to forms to prevent movement during concreting; provide holes in horizontal components under which concrete must be placed to avoid trapping air under the embedment
- Dimensions – dimension to nearest half-inch to simplify production; provide clearances of 1-1/3 times the maximum aggregate size between reinforcing bars and other components
- Formwork – forms that are not square and vertical will make allowable tolerances insufficient

Erection Considerations: The method by which the connection is implemented affects its efficiency and economy. For example, it is easier to make a connection at ground level than while working on a ladder. Inadequate clearances can impede construction. Failure to adhere to specified tolerances may adversely affect the strength of the connection. Field welding should not be used indiscriminately, since welded connections are relatively rigid and may restrain volume changes, resulting in large forces. Steel may require preheating prior to welding, which can damage the surrounding concrete if care is not taken. During erection, temporary bracing, guywires, or other means of support may be required. Use permanent connection devices for temporary bracing whenever possible. If temporary connections must be used, remove them after final connections are complete.

Load Paths: A connection is part of an integrated system, not an isolated element. Ensure that applied external loads can be distributed through the structural system to the foundation and supports.

Failure Modes: Understand potential failure modes in each connection. Provide sufficient redundancy to eliminate potential for progressive collapse. Connections that subject concrete to tensile forces can result in a brittle failure which is sudden and without warning. If these are unavoidable, increase the connection's safety factor.

Pliant Connections: Rigid connections that restrain volume changes can be subject to unanticipated stresses and may fail. Allow movement to occur by using bearing pads or low-friction materials to support structural members and by using slotted holes for bolts.

The typical details on the following pages were drawn from sources throughout the United States and Canada. Some may not be suitable or economical in a specific locale due to environmental conditions or locally accepted practices. Study each detail carefully before adopting its use.

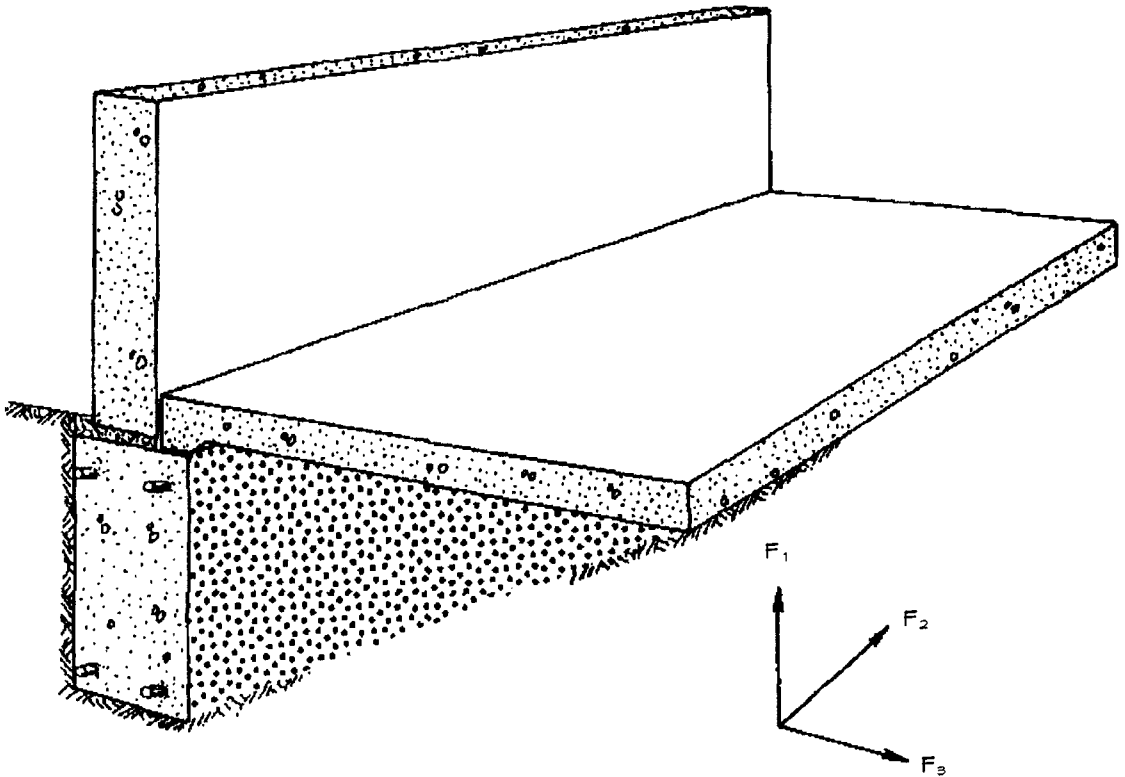
12.3.1 Trenched Footing / Wall Connection

In this connection, the top elevation of the continuous footing is raised to allow direct support of the slab-on-grade. The edge of the slab is used for proper alignment of the wall panel. Lateral support at the base is provided by embedded material in wall and floor.

Advantages: Slab-on-grade facilitates erection of the wall.

Disadvantages: Forming of the slab-on-grade requires tight tolerances.

Restraints: Primary— F_1 and F_3
Secondary— F_2

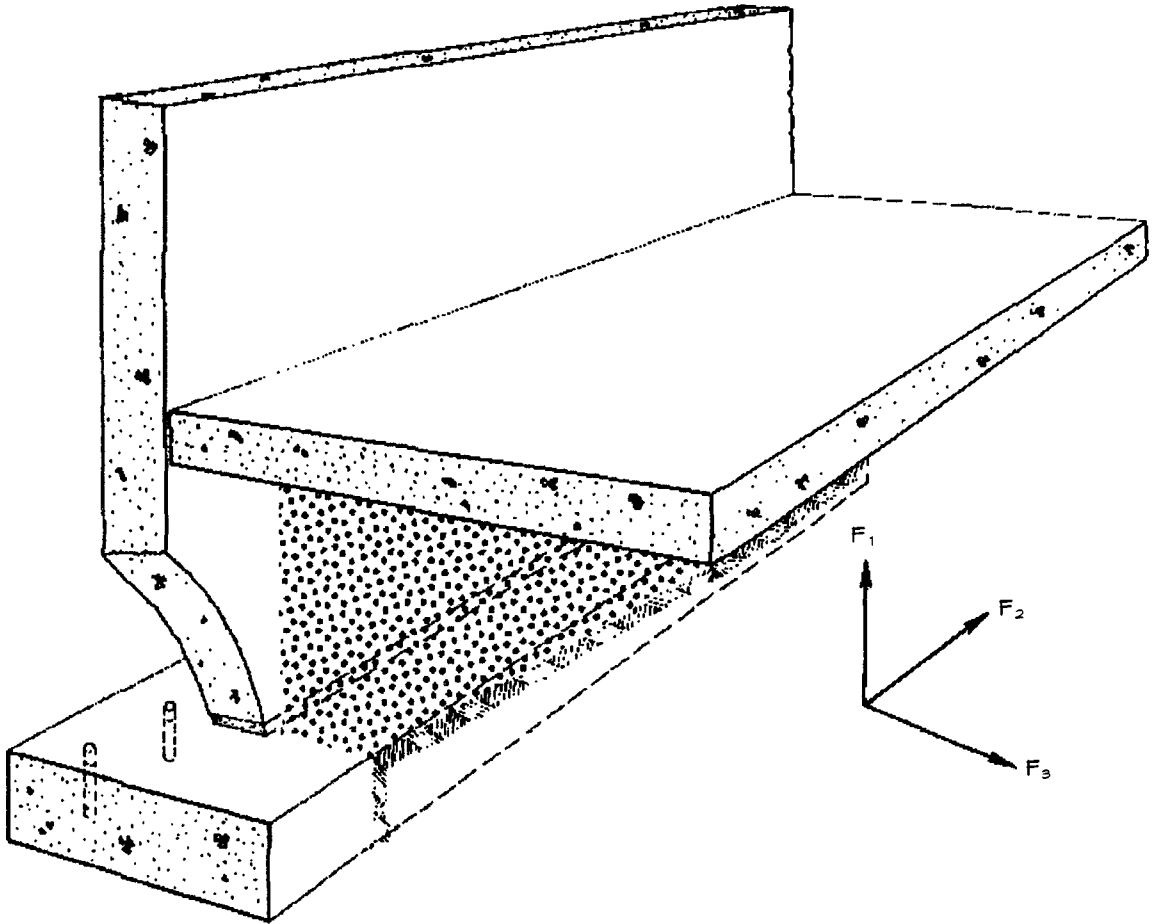


12.3.2 Footing / Wall Connection with Exterior Dowels

In this connection, the wall panel is grouted onto a continuous footing, isolated footings, or drilled pier. Drilled-in dowels are provided on one or both sides of the wall panel. The dowels are used for proper alignment of the wall panel during construction. Leveling shims are placed at each end of the panel. The panel is connected to the slab-on-grade with dowels or embedments (see detail for "Slab-On-Grade / Wall Connection").

Advantages: Use of the dowel facilitates erection of the wall.

Restraints: Primary— F_1 and F_3



(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

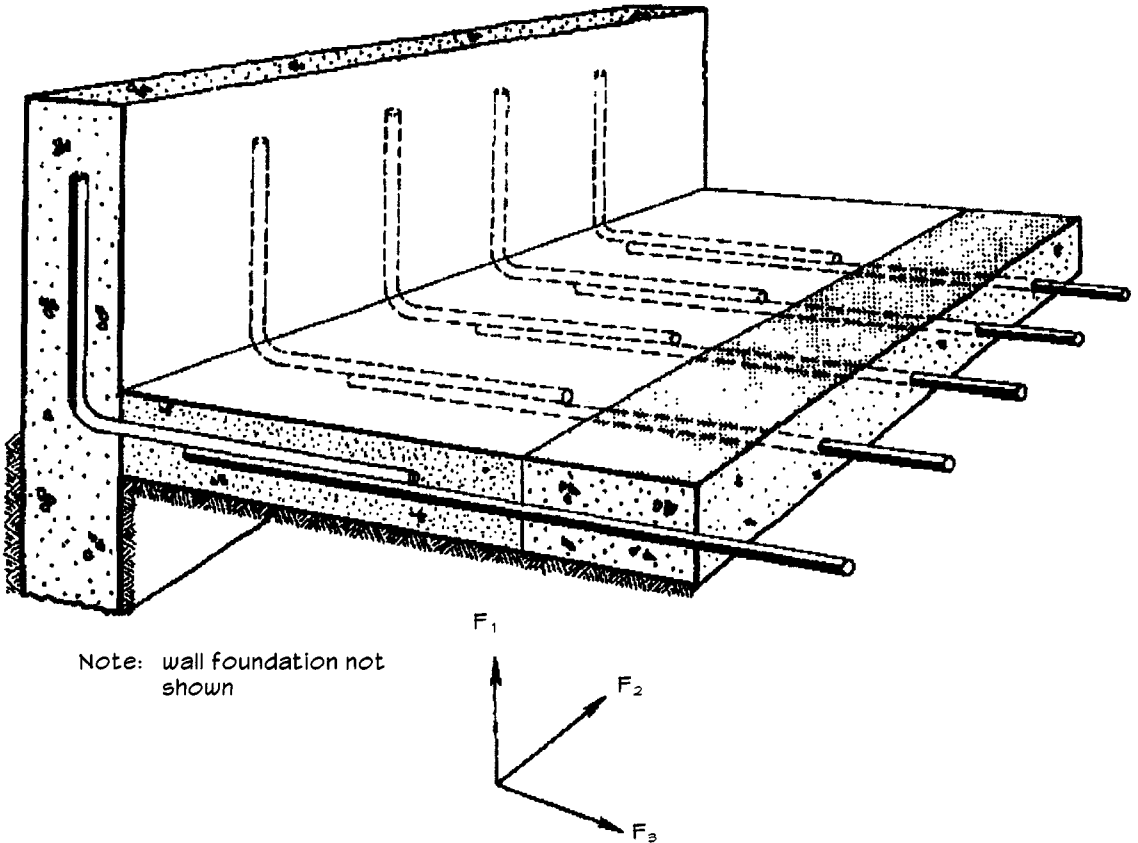
12.4.1 Slab-On-Grade / Wall Connection

In this connection, the floor slab provides lateral support for a wall panel. The slab-on-grade is cast, except for a narrow strip 2 to 4 feet wide adjacent to the wall panel. The wall panel has cast-in-place bent dowels. Threaded inserts can be used in place of bent bars. Dowels or bars are used to form splices with reinforcement in the floor slab. The floor area adjacent to the wall panel is then cast. Control joints in closure strips should match control joints in the slab.

Advantages: Fabrication is simple and connection is self-forming.

Disadvantages: Dowels may be damaged during handling.

Restraints: Primary— F_3
Secondary— F_1 and F_2



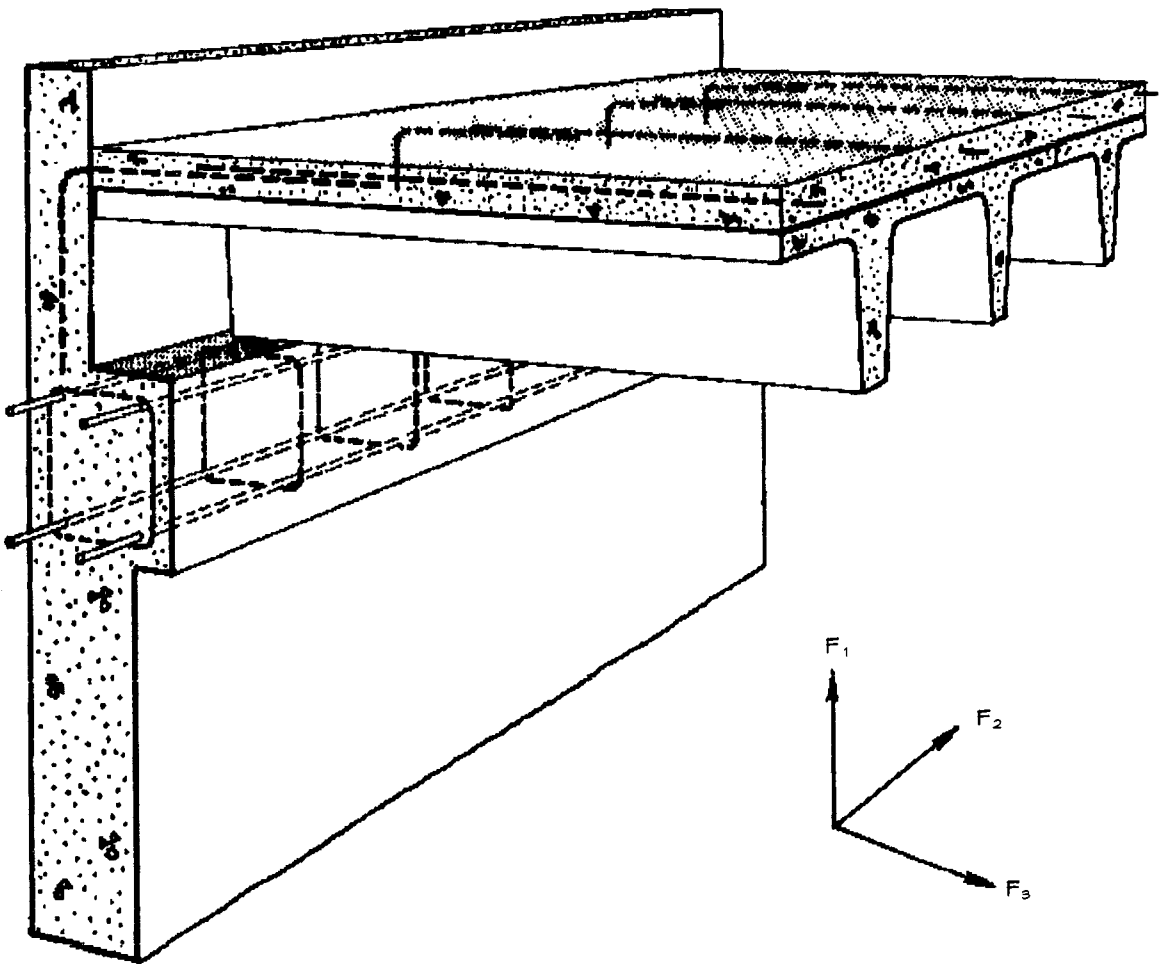
12.4.2 Precast Double Tee / Wall Connection with Ledge

In this connection, a concrete ledge is cast monolithically with a wall panel. The ledge provides vertical support for a double-tee floor system. The double-tee beams rest on bearing pads. The double-tee floor system is topped with a thin layer of reinforced concrete. Deformed dowels in the wall extend into the reinforced concrete topping to provide lateral support for the wall panel. Steel embedments or threaded inserts may be used in place of bent bars.

Advantages: Minimal number of components in connection. Connection is self-forming.

Disadvantages: Casting of ledge complicates fabrication of wall panel. Special steps are required to protect dowels during handling. Placing of the double tee units under the dowels may complicate erection.

Restraints: Primary— F_1 and F_3
Secondary— F_2



(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

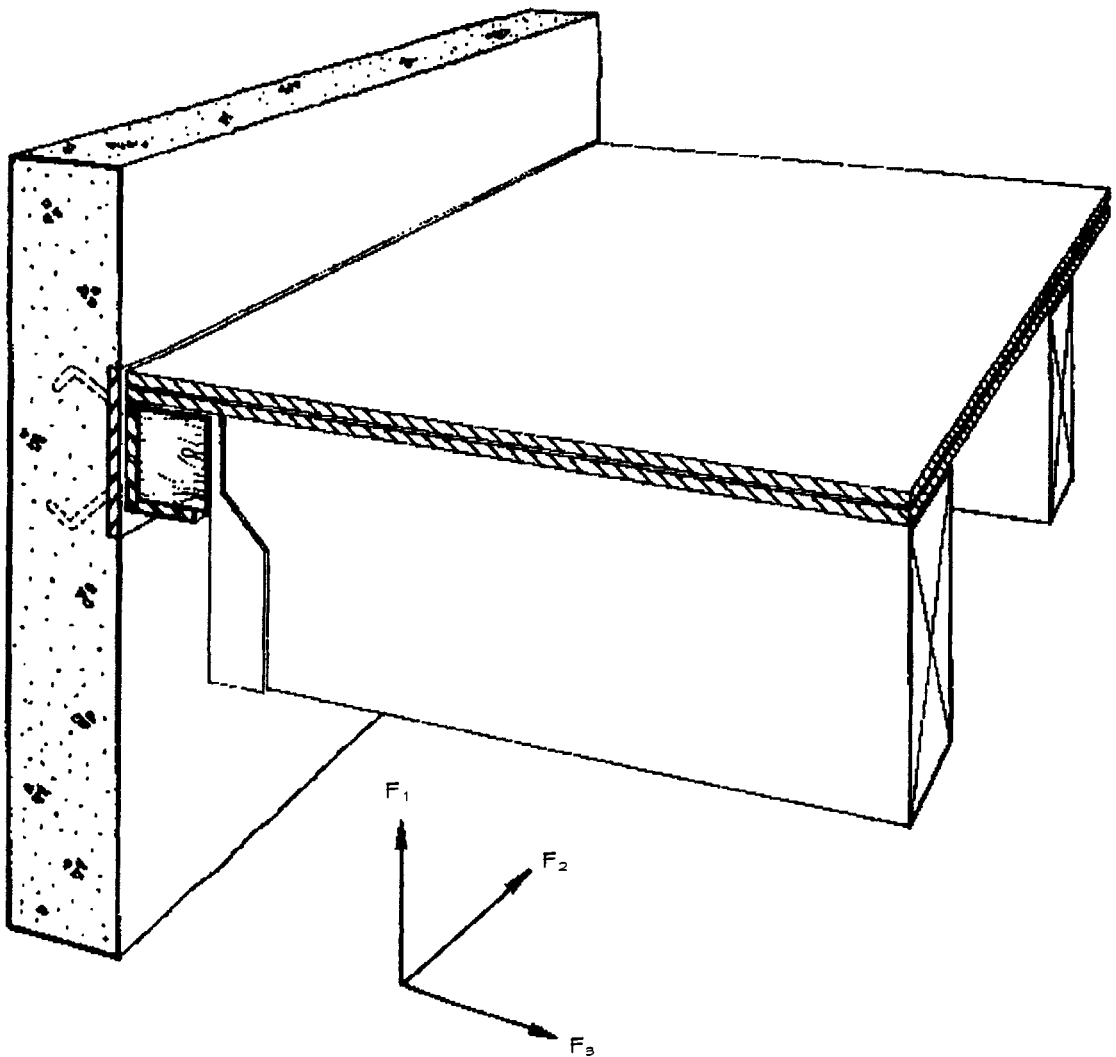
12.4.3 Wood Joist / Wall Connection with Joist Hanger on Wood Ledger

In this connection, a composite ledger provides vertical support for wood joists. The ledger includes a wood nailer bolted to a continuous steel angle using countersunk nuts. The continuous steel angle is welded to steel embedments located at selected intervals. Each joist is connected to the ledger through a steel hanger. Each steel hanger is nailed to the top face of the ledger. The plywood flooring sheets are nailed to the ledger and the wood joist to provide lateral support for the wall panel.

Advantages: Embedment plates allow large construction tolerances.

Disadvantages: Fabrication of the composite ledger requires additional effort. Welding in the up-hand position may be required. Consolidation of concrete near embedment plate may be difficult.

Restraints: Primary— F_1 and F_3
Secondary— F_2



(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

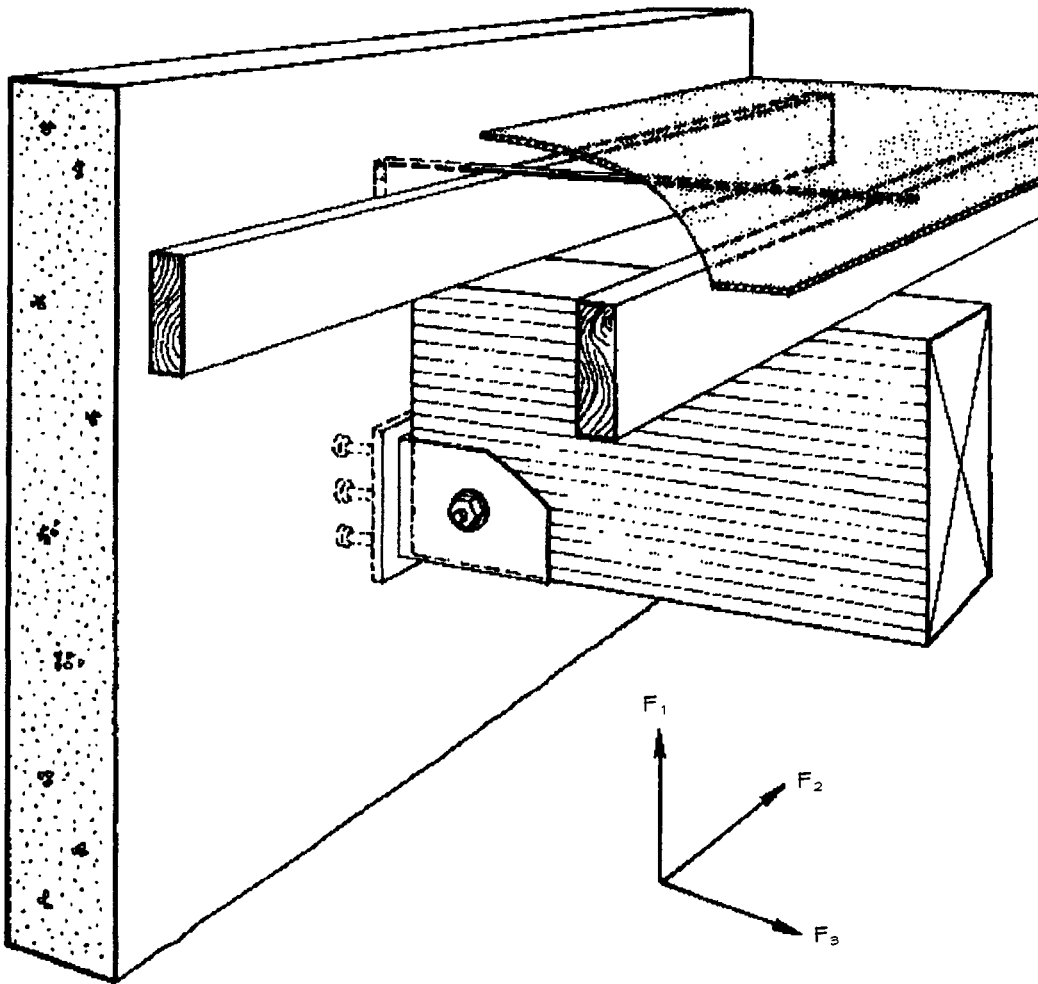
12.4.4 Heavy Timber Beam / Wall Connection with Steel Shoe

In this connection, a steel shoe welded to a steel embedment provides vertical support for the heavy timber beam. The beam and the roof diaphragm provide lateral support for the wall panel. Wood joists are secured to the wall panel through embedded steel straps in Seismic Zones 2, 3 and 4.

Advantages: Fabrication and erection are simple. Steel embedment allows large construction tolerances.

Disadvantages: Bearing-type bolted connection requires tight tolerances. Consolidation of concrete around embedment may be difficult. Exposed steel may require fireproofing.

Restraints: Primary— F_1 and F_3
Secondary— F_2



(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

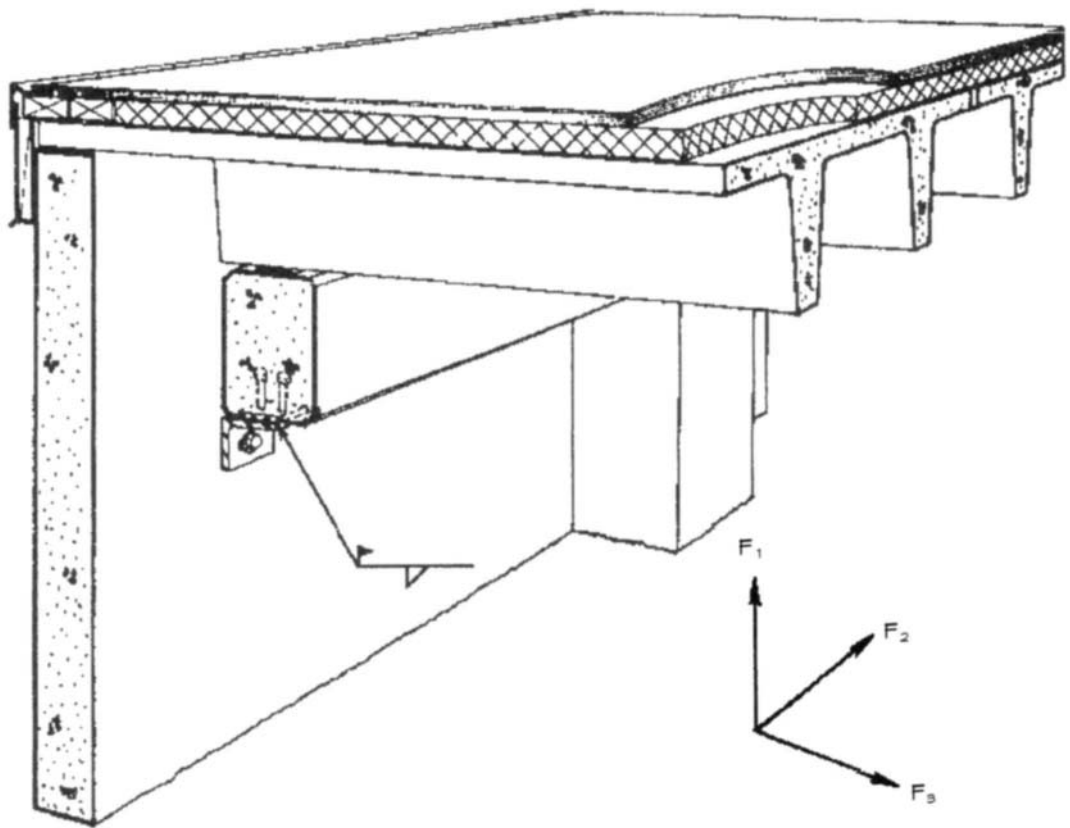
12.5.1 Precast Double Tee Roof / Precast Beam / Wall Connection

In this connection, a precast concrete beam spans between adjacent reinforced concrete columns. The beam provides vertical support for a double-tee roof system. The precast concrete beam also provides lateral support for the wall panel. One end of the double-tee beam rests on a flexible bearing pad that accommodates movement due to volume change while the opposite end-bearing is rigid. The double-tee flange is cantilevered at the end so that the flange extends over the wall panel. Clip angles are used at selected intervals to tie the wall panel to the beam. Each angle is welded to a steel embedment cast into the beam. Each angle is bolted to the wall panel through embedded threaded parts. Oversized holes are used in the angles to accommodate movement due to the volume change and deflection of the beam. An alternate supporting detail for the precast double tee is shown in the detail for "Precast Double Tee / Wall Connection with Ledge".

Advantages: Erection is simple. The connection accommodates movement due to volume change.

Disadvantages: Exposed steel angles may require fireproofing. The welder must work in the up-hand position. Placing of cast-in-place inserts requires tight tolerances.

Restraints: Double Tee / Precast Concrete Beam, Primary— F_1
Precast Beam / Wall, Primary— F_3



(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

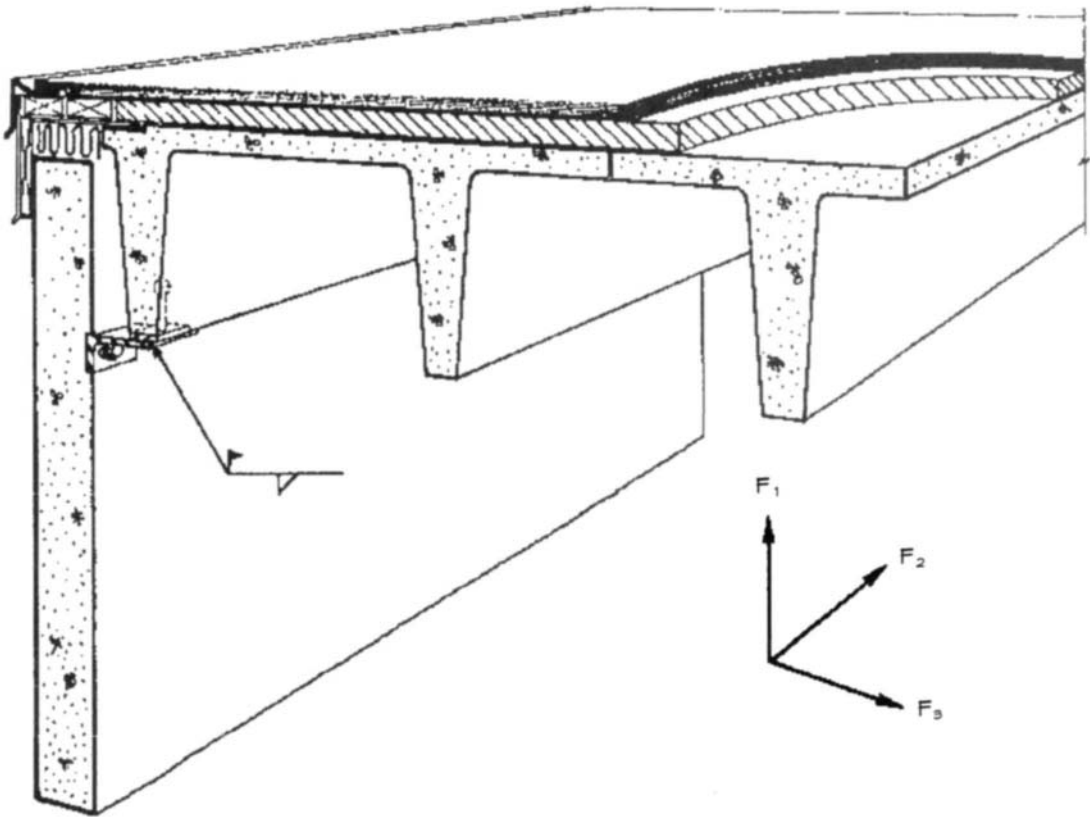
12.5.2 Precast Double Tee Roof / Wall Connection

In this connection, the edge beam of a double-tee roof system provides lateral support for a wall panel. Clip angles are used at selected intervals to tie the wall panel to the edge beam. Each angle is welded to a steel embedment cast into the edge beam. Each angle is bolted to the wall panel through embedded threaded parts. Oversize holes are used in the angles to accommodate movement due to volume change and deflection of the edge beam. Vertical support for the roof should be provided through a separate system, such as the one shown in the detail for "Precast Double Tee Roof / Precast Beam / Wall Connection."

Advantages: Fabrication and erection are simple. The connection accommodates movement due to volume change and deflection of the edge beam.

Disadvantages: Exposed steel angles may require fireproofing. The welder must work in the up-hand position. Placing of cast-in-place inserts requires tight tolerances.

Restraint: Primary— F_3



(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

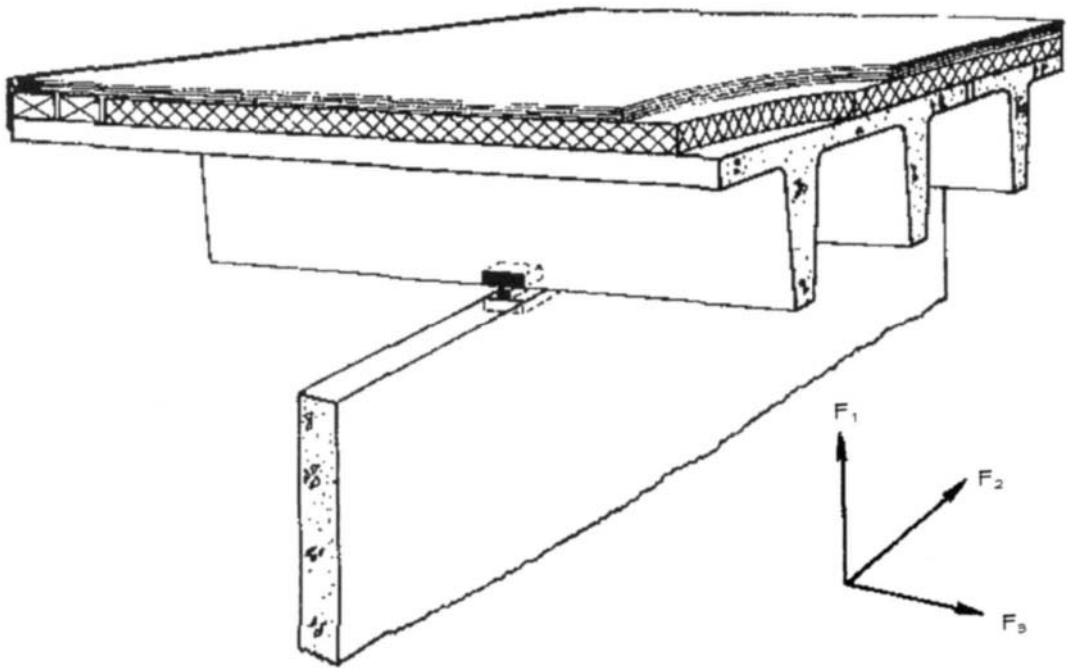
12.5.3 Precast Double Tee Roof / Bearing on Wall Connection

In this connection, the double-tee roof system is supported directly by the tilt-up wall panels. Steel embedments are cast into the underside of the stems of the double tees and into the top edge of the wall panels. A pivot bar is welded between the bearing plates in the tee stems and the wall panel. The double-tee roof provides lateral support at the top of the wall panels.

Advantages: Erection is simple. Minimal number of components. Embedments allow large construction tolerances.

Disadvantages: The connection accommodates only minimal displacement or rotation due to volume changes or deflections in the double tee. Exposed steel may require fireproofing and weather protection. The welder must work in the up-hand position. Special reinforcement may be required in the wall panels at bearing points.

Restraints: Primary— F_1 and F_3



(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

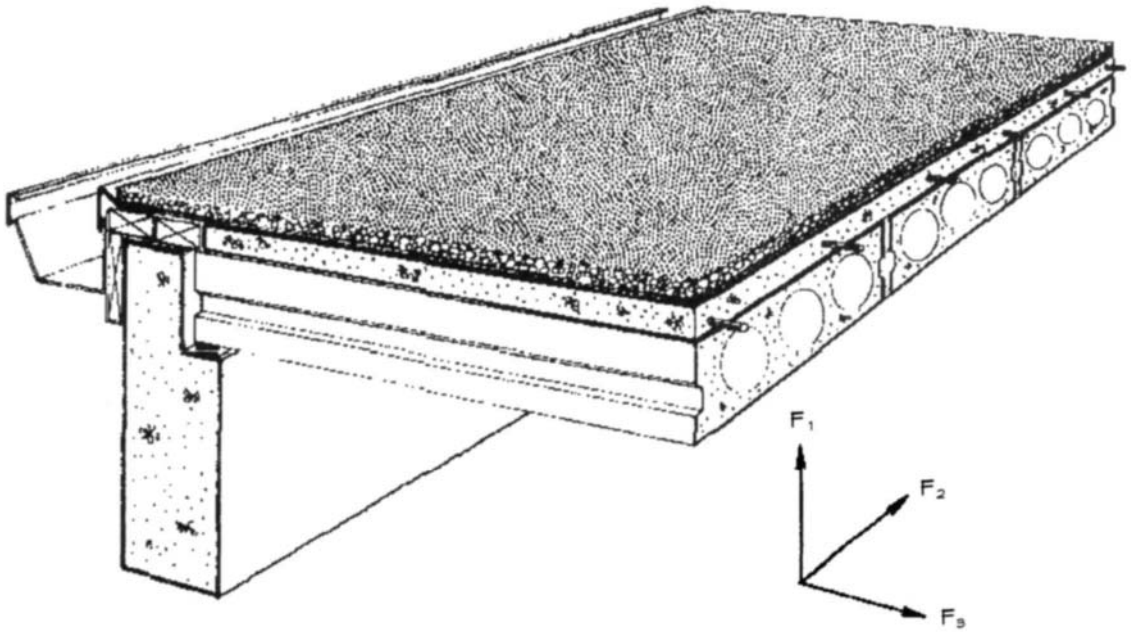
12.5.4 Precast Hollow-Core Roof / Bearing on Wall Connection

In this connection, a recessed ledge in the tilt-up wall provides vertical support for a precast hollow-core roof system. The hollow-core units rest on a flexible bearing pad that accommodates movement due to volume change. Clip angles similar to those shown in the detail for “Precast Double Tee Roof / Precast Beam / Wall Connection” may be needed to provide lateral support to panels.

Advantages: Erection is simple. Connection accommodates movement due to volume change.

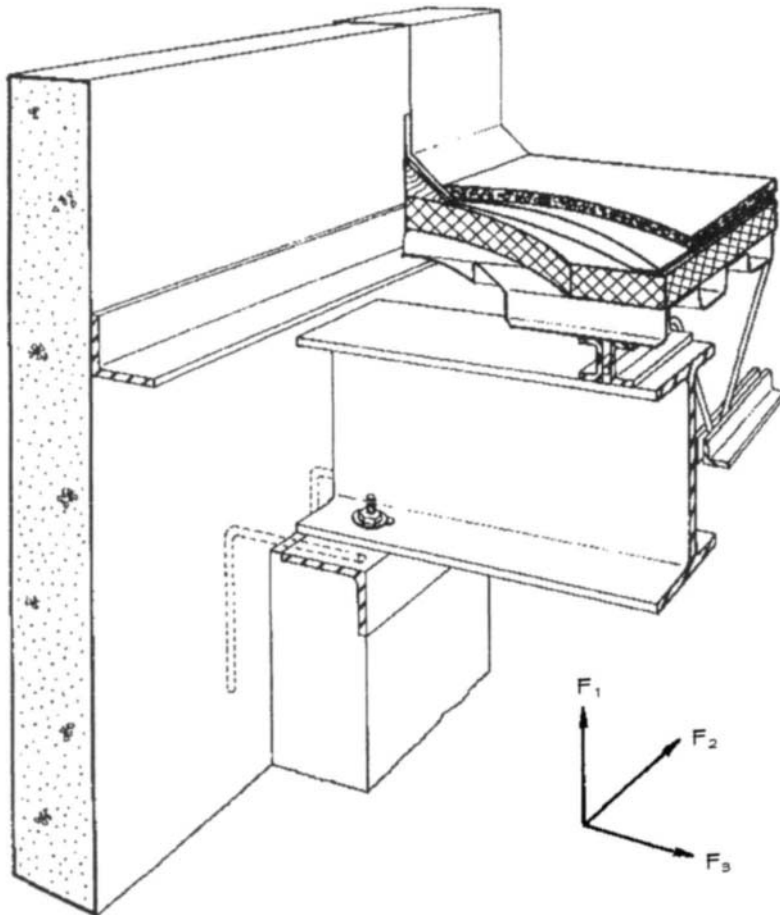
Disadvantages: Special reinforcement and forming may be required at the ledge.

Restraints: Primary— F_1 and F_3



(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

Restrains:	Steel Girder / Pilaster	Primary— F_1
		Secondary— F_3
	Pilaster / Wall	Primary— F_3
		Secondary— F_1 and F_2



(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

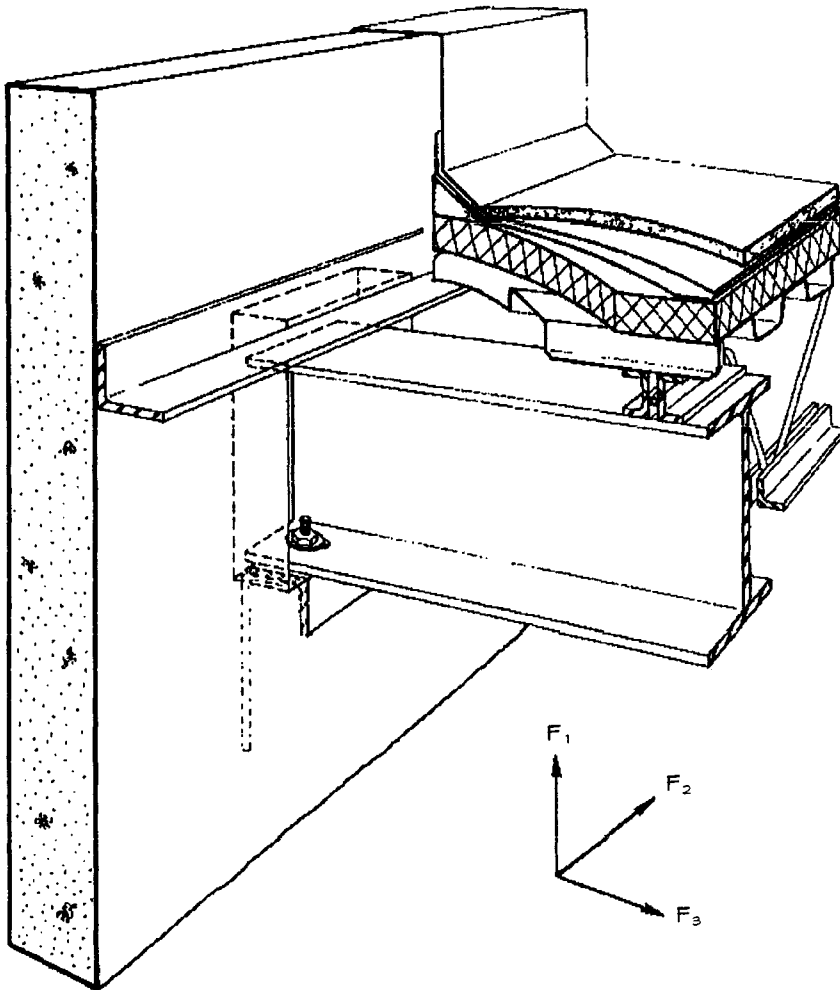
12.5.6 Steel Girder / Wall Connection with Recessed Pocket

In this connection, a recessed pocket in the wall panel provides vertical support for a steel girder. The load is transmitted through bearing on an embedded steel angle. Reinforcing bars are welded to the steel angle for anchorage. The steel girder and the concrete roof diaphragm provide lateral support of the wall panel. The steel girder is bolted to the wall panel through embedded threaded parts. Slotted holes are used in the girder to accommodate construction tolerances. This detail can also be applied to a steel joist / wall connection. For comments on the continuous angle, refer to the detail for "In-Plane Wall / Wall Connection with Continuous Steel Chord."

Advantages: Number of components in connection is minimal.

Disadvantages: Forming of the recessed pocket and embedment of the angle require tight tolerances. Consolidation of concrete near the pocket may be difficult. Exposed steel may require fireproofing. Placing the end of the girder within the recessed pocket may complicate erection procedures.

Restraints: Primary— F_1 and F_3
Secondary— F_2



(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

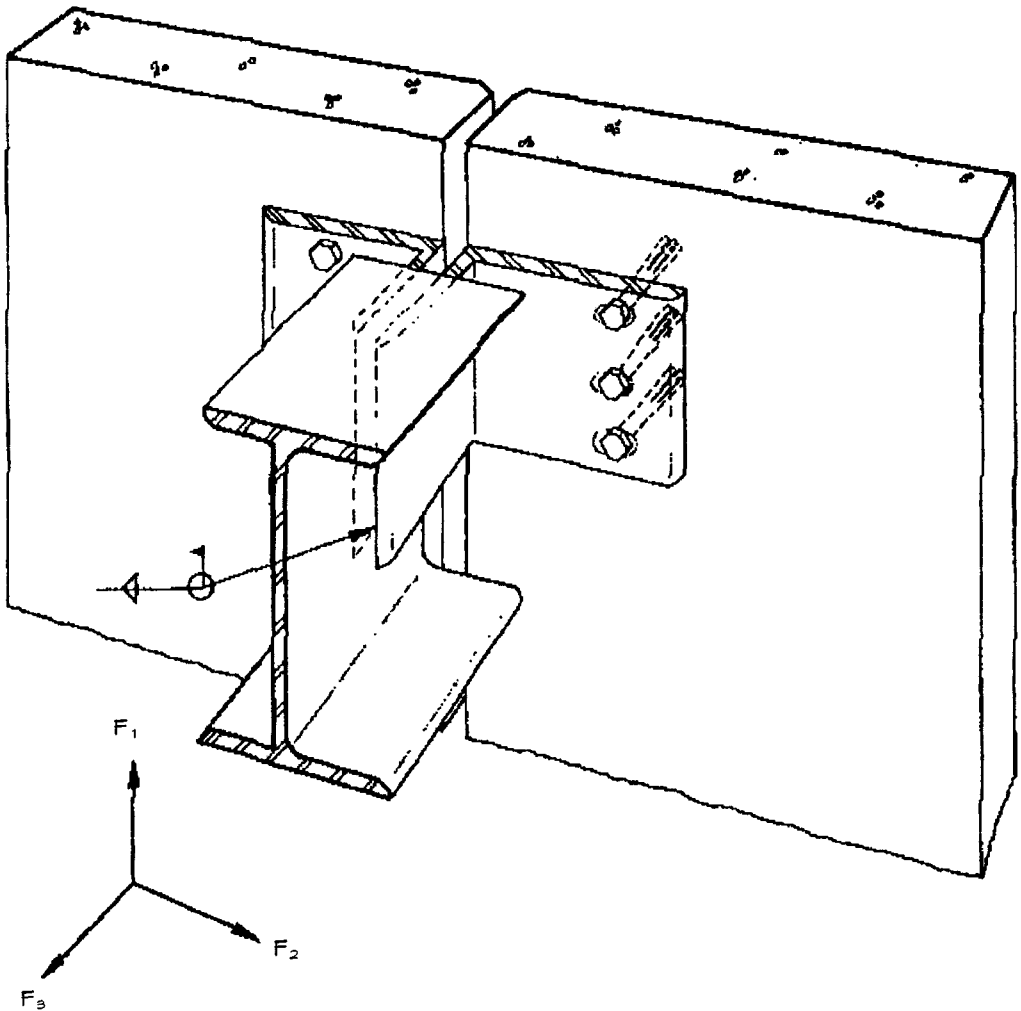
12.5.7 Steel Girder / Clip Angle Wall Connection

In this connection, vertical support for a steel girder is provided by a clip angle attached to the wall panel by threaded inserts. An alternate for attachment is to weld the clip angle to an embedded plate. The clip angle is then welded to the web of the beam. An alternate connection of beam to clip angle is bolting. The clip angle has slotted holes to allow in-plane movement of the panels and accommodate large construction tolerances. It is preferable to locate beam or girder supports away from joints between panels. A minimum of 2 ft. is suggested.

Advantages: Number of components in connection is minimal. Slotted holes (or embedments) allow large construction tolerances.

Disadvantages: Exposed steel may require fireproofing. Welding of beam to clip angle must be done in overhead position.

Restraints: Primary— F_1
Secondary— F_2 and F_3



(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

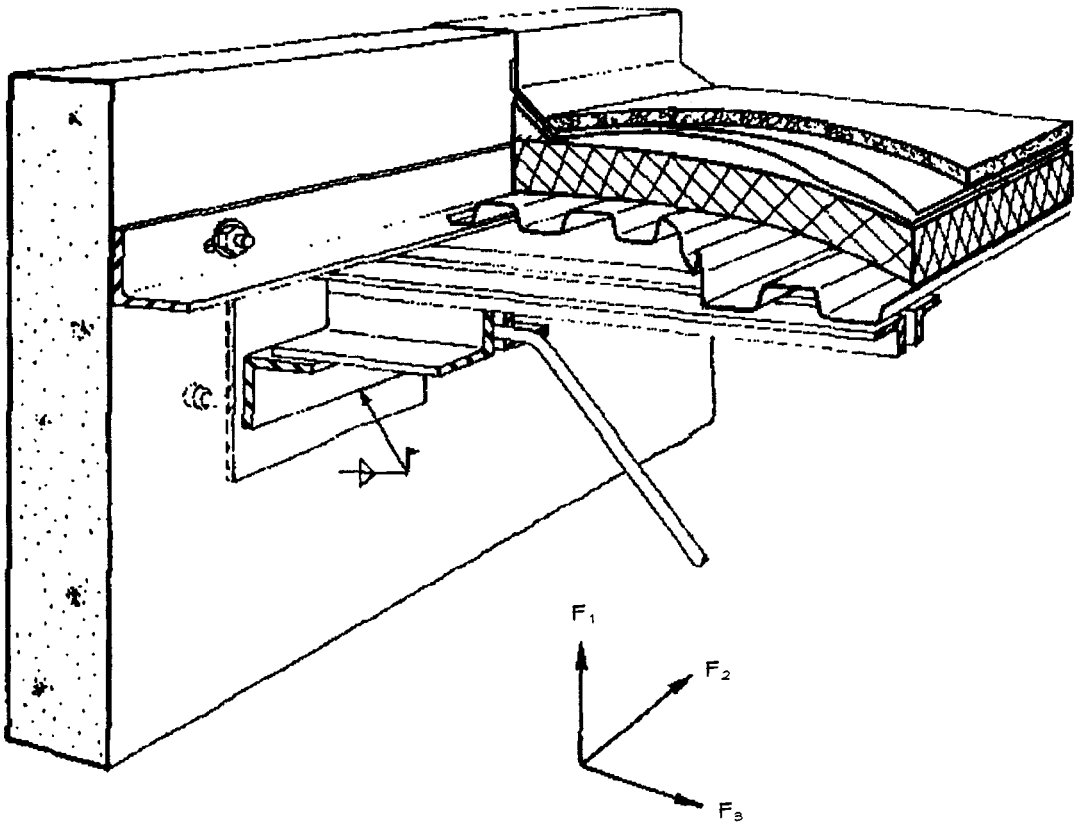
12.5.8 Steel Joist / Wall Connection with Seat Angle

In this connection, a seat angle provides vertical support for a steel joist. The seat angle is welded to a steel embedment after the panel is cast. Alternatively, a built-up steel-plate bracket can replace the seat angle. The steel joist is welded or bolted to the seat angle. The steel joist and roof diaphragm provide lateral support for the wall panel. For comments on the continuous angle, refer to the detail for "In-Plane Wall / Wall Connection with Continuous Steel Chord."

Advantages: Erection is simple. Steel embedment allows large construction tolerances.

Disadvantages: Exposed steel may require fireproofing. Consolidation of concrete near steel embedment may be difficult.

Restraints: Primary— F_1 and F_3
Secondary— F_2



(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

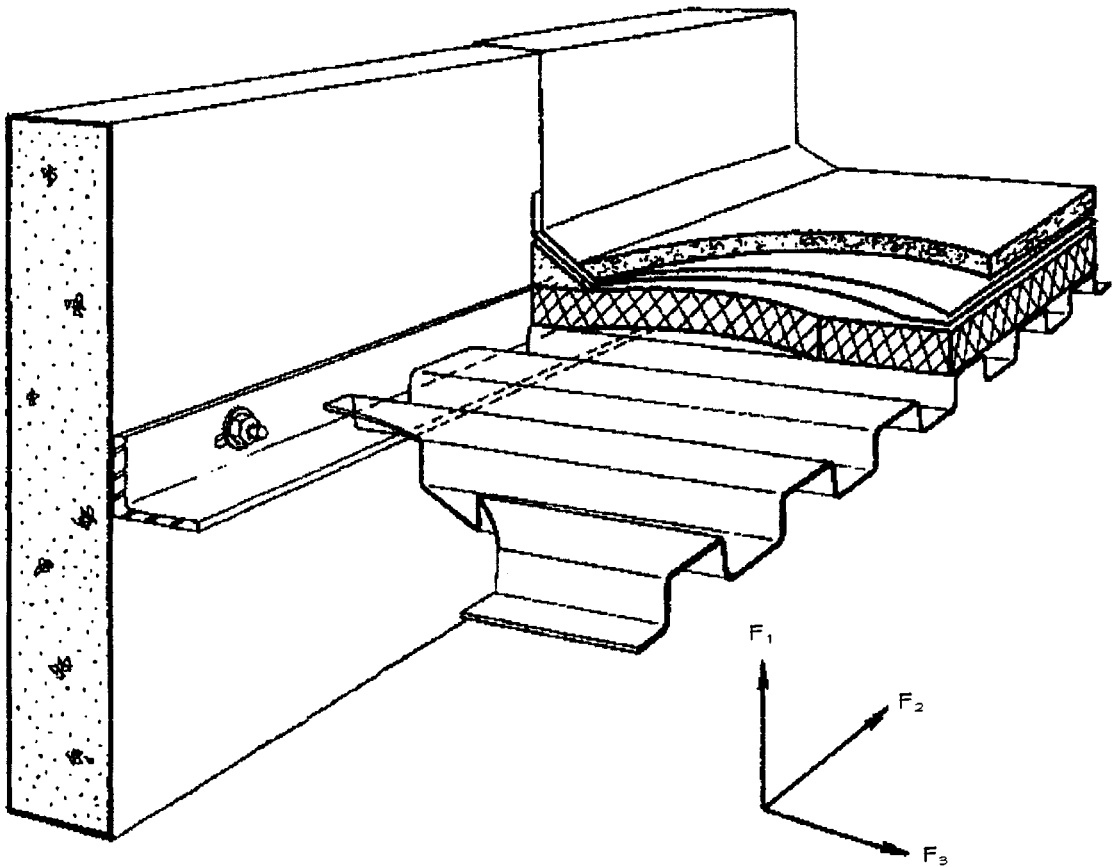
12.5.9 Metal Deck / Wall Connection

In this connection, a continuous steel angle provides vertical support for a corrugated metal roof deck and can be used as the chord for the roof diaphragm. The roof deck is tack or puddle welded to the angle. The angle is bolted to the wall through embedded threaded parts. Alternatively, the steel angle can be welded to steel embedments at selected intervals. The roof diaphragm provides lateral support for the wall panel. For additional comments on continuous angle, refer to the detail for "In-Plane Wall / Wall Connection with Continuous Steel Chord."

Advantage: Fabrication and erection are simple.

Disadvantage: Installation of the continuous angle may require tight tolerances. Exposed steel may require fireproofing.

Restraints: Primary— F_1 and F_3
Secondary— F_2



(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

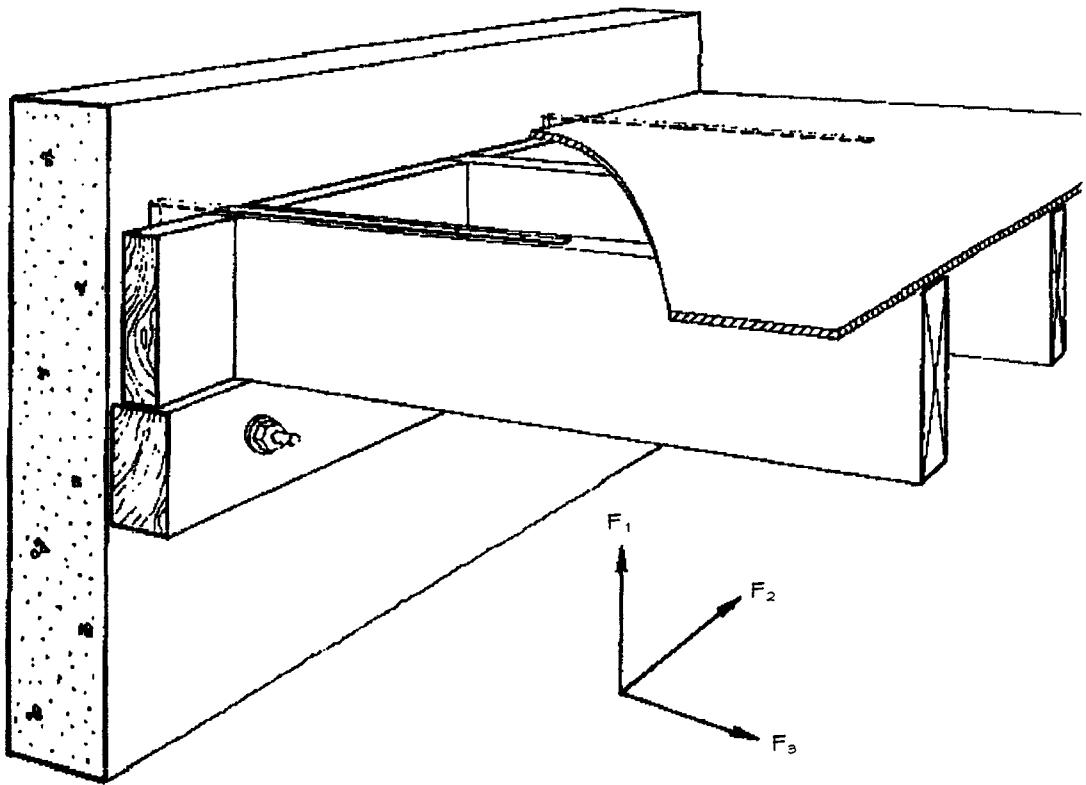
12.5.10 Wood Joist / Wall Connection with Wood Ledger

In this connection, a wood ledger provides vertical support for a wood-joist roof system. The ledger is connected to the wall panel using embedded threaded parts. The embedments can be cast in the concrete by using the predrilled ledger as a template. Embedded steel straps are nailed to wood joists to provide lateral support for the wall panel in Seismic Zones 2, 3 and 4. Bearing between the wall panel and the wood joists provides lateral support when an inward horizontal force is applied.

Advantages: Fabrication and erection are simple.

Disadvantages: Close placement tolerances are required on cast-in-place steel straps.

Restraints: Primary— F_1 and F_3
Secondary— F_2



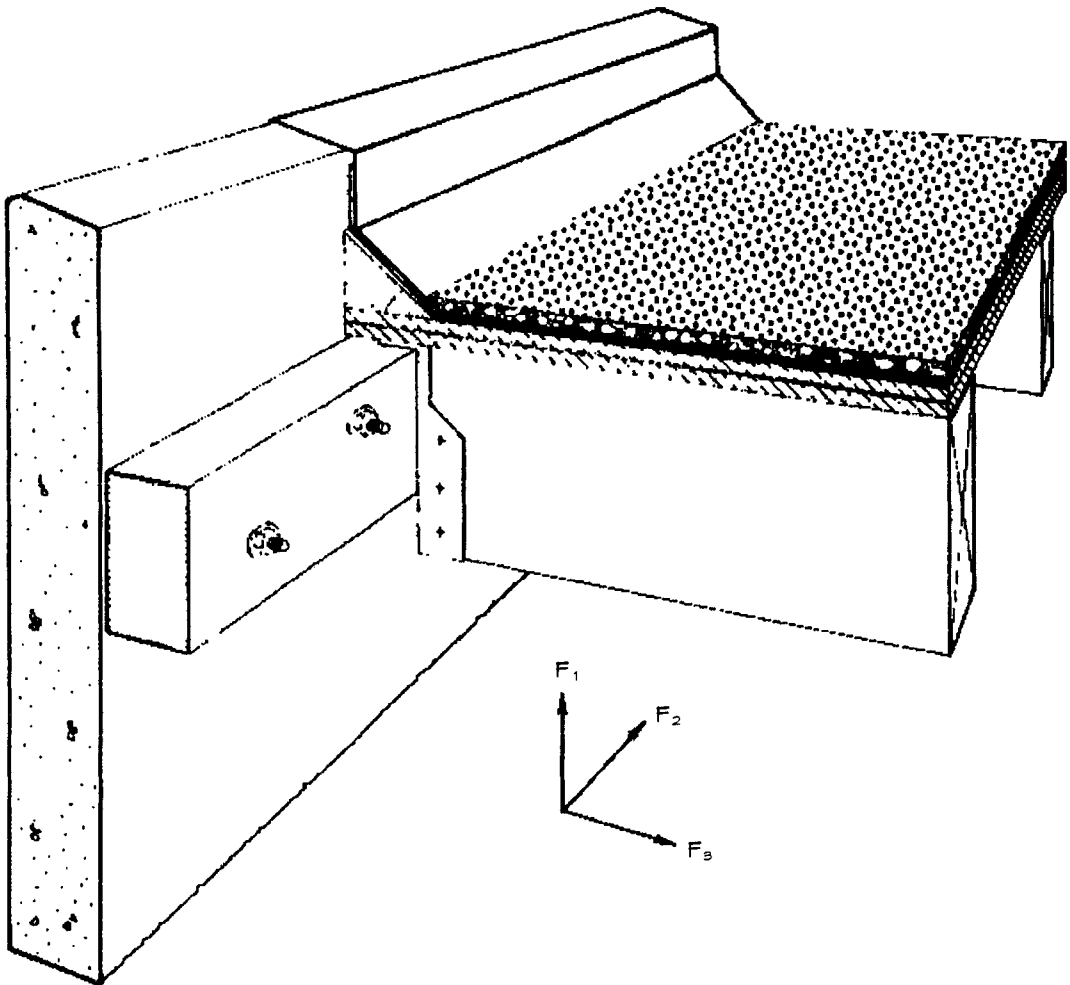
(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

12.5.11 Wood Joist / Wall Connection with Joist Hanger on Wood Ledger

In this connection, a wood ledger provides vertical support for wood joists. Each joist is connected to the ledger through a steel hanger. Each steel hanger is nailed to top face of the ledger. The ledger is connected to the wall panel through embedded threaded parts. The embedments can be cast in the concrete using the pre-drilled ledger as a template. An alternate attachment for the wood ledger connection to the wall panel is shown in the detail for "Wood Joist / Wall Connection with Wood Ledger." The plywood roof sheets are nailed to the ledger and the wood joists to provide lateral support for the wall panel. Embedded steel-strap ties are required in Seismic Zone 2, 3 and 4 as shown in the detail for "Wood Joist / Wall Connection with Wood Ledger."

Advantages: Fabrication and erection are simple.

Restraints: Primary— F_1 and F_3
Secondary— F_2



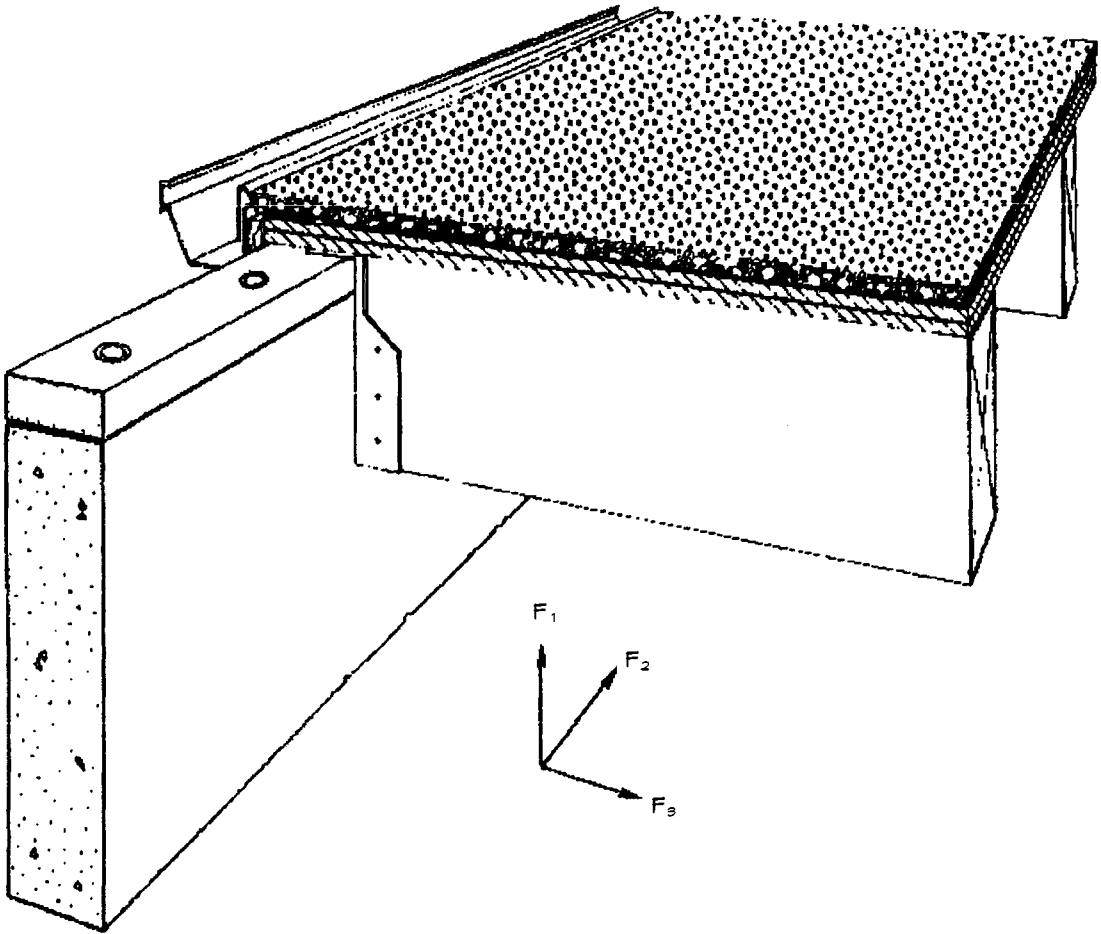
(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

12.5.12 Wood Joist / Wall Connection with Joist Hanger on Panel Top

In this connection, the top of a wall panel provides vertical support for the wood joists. Each joist is connected to top of wall panel through a steel hanger. Each hanger is nailed to a wood nailer. The wood nailer is bolted to the top of the wall panel using embedded threaded parts with countersunk heads. The wood nailer can be utilized as part of the formwork for casting the wall panel or as a template for the embedments. The plywood roof sheets are nailed to the wood nailer and the wood joists to provide lateral support for the wall panel.

Advantages: Fabrication and erection are simple.

Restraints: Primary— F_1 and F_3
Secondary— F_2



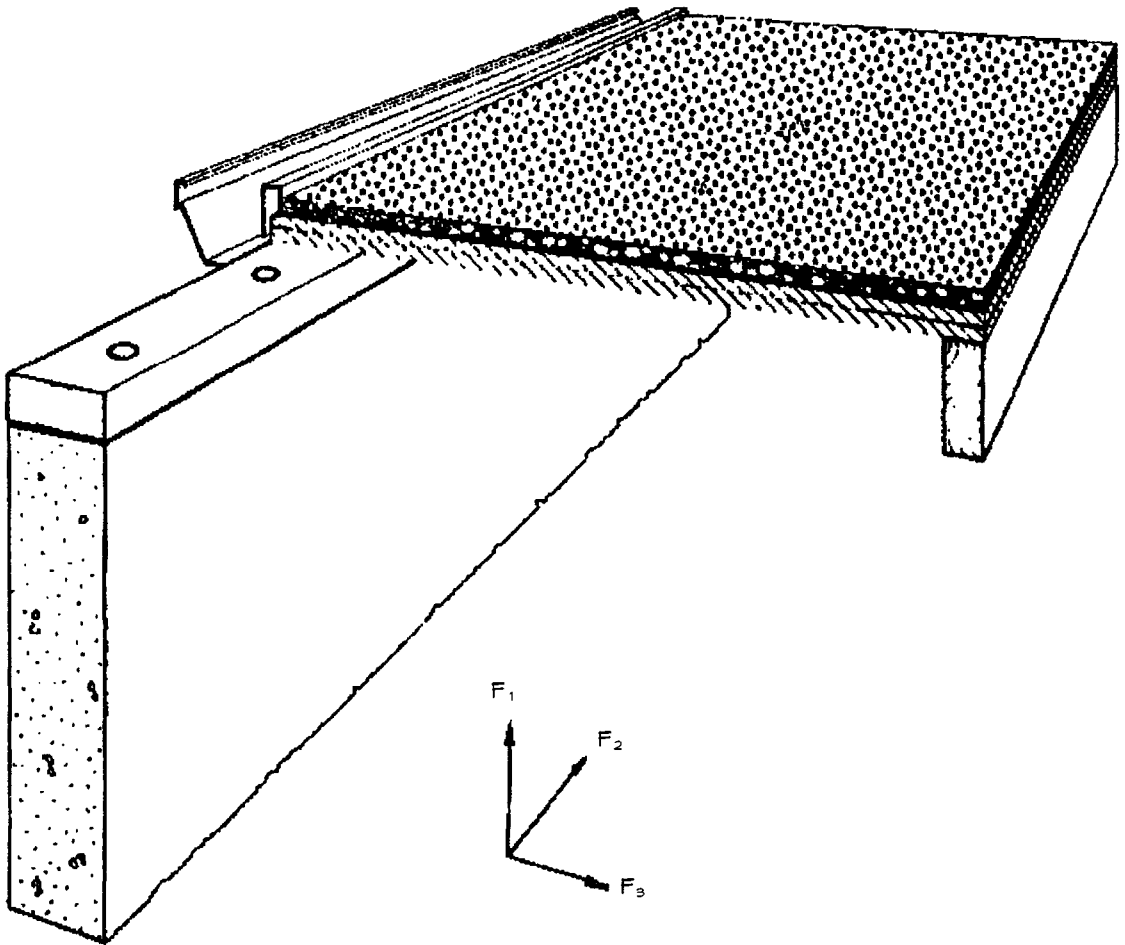
(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

12.5.13 Plywood Roof Deck / Wall Connection with Wood Ledger on Panel Top

In this connection, the top of a wall panel provides vertical support for a narrow strip of the roof adjacent to the wall panel. The wood joists span parallel to the wall panel. The plywood sheets are nailed to a wood nailer. The wood nailer is bolted to the top face of the wall panel using embedded threaded parts with counter-sunk heads. The wood nailer can be efficiently utilized as part of the formwork for casting the wall panel. The plywood sheets provide lateral support for the wall panel.

Advantages: Fabrication and erection are simple.

Restraints: Primary— F_1 and F_3
Secondary— F_2



(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

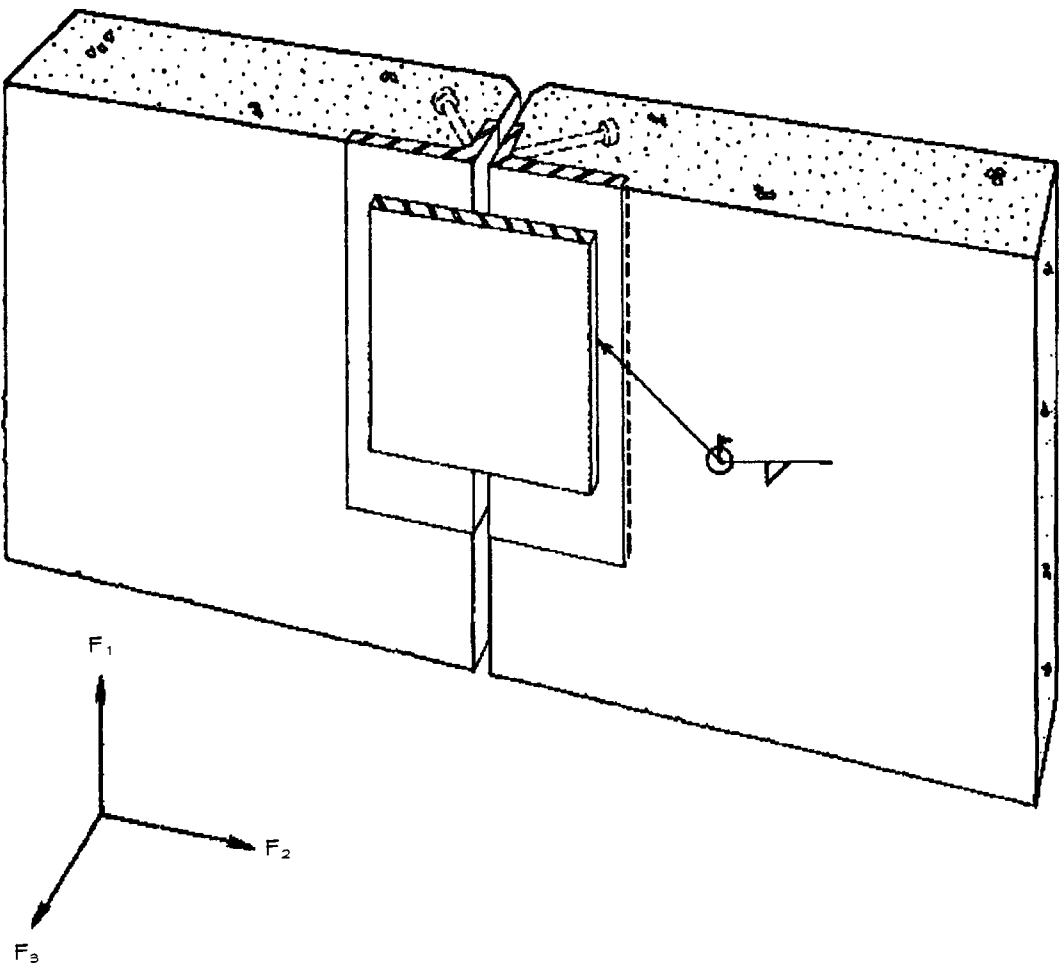
12.6.1 In-Plane Wall / Wall Connection with Steel Embedments

In this connection, steel angles are embedded at the interior face of the wall panels. A steel plate is welded to both embedments to form the connection. It is recommended that no more than two or three panels be connected without a free joint. This detail can also be used with a recessed pocket and then plastered for aesthetics.

Advantages: Number of components in connection is minimal. Fabrication and erection are simple. Steel embedments allow large construction tolerances.

Disadvantages: Exposed steel may require fireproofing. Consolidation of concrete near steel embedments may be difficult. Very rigid connection can cause local distress due to volume changes.

Restraint: Primary— F_1 and F_2
Secondary— F_3



(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

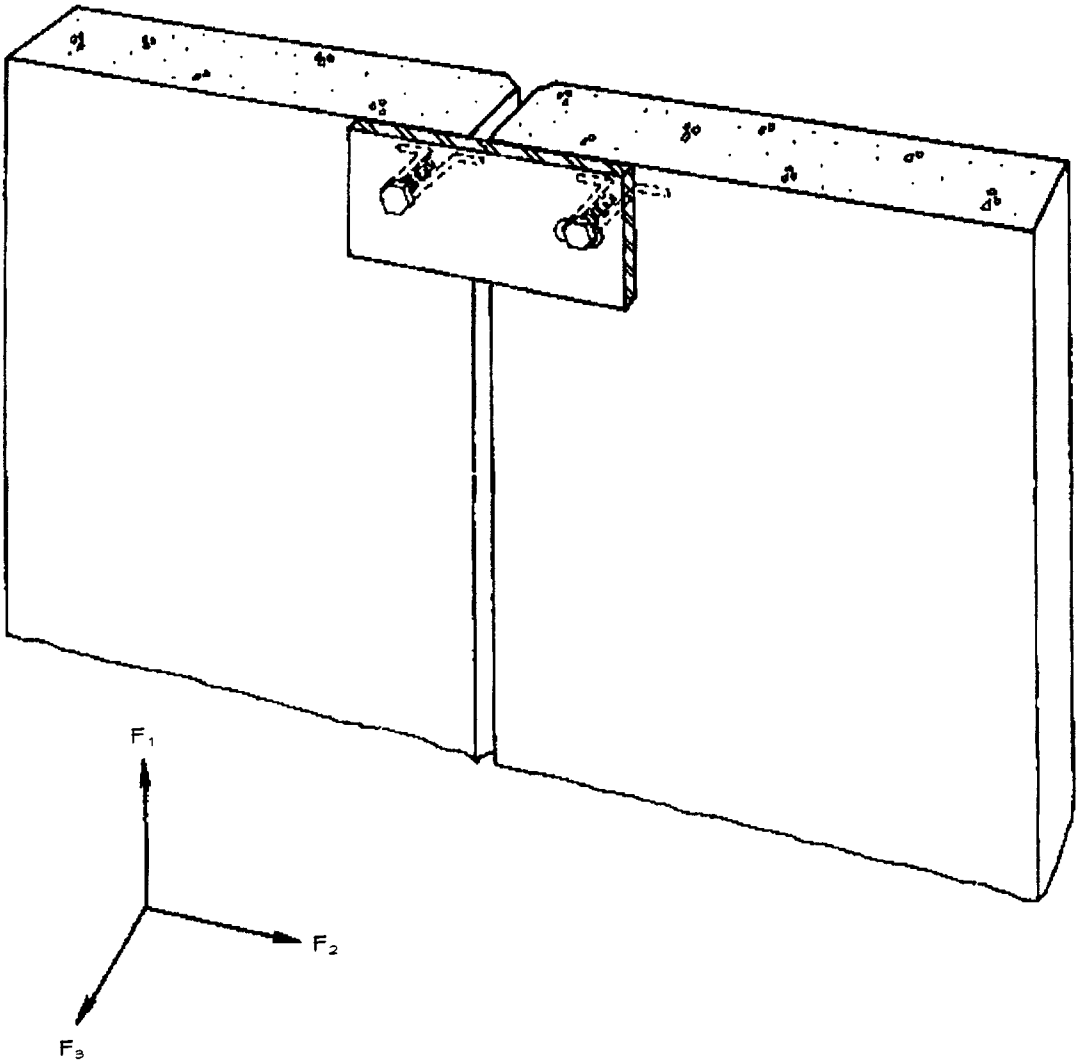
12.6.2 In-Plane Wall / Wall Connections with Threaded Inserts

In this connection, threaded inserts are embedded at the interior face of the wall panels. A steel plate is bolted to both panels. One of the bolt holes in the connection plate is slotted to allow movement due to volume change and to make alignment easier.

Advantages: Fabrication and erection are simple. Slotted holes allow movement due to volume change.

Disadvantages: Exposed steel may require fireproofing. Consolidation of concrete near steel embedments may be difficult.

Restraints: Primary— F_3



(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

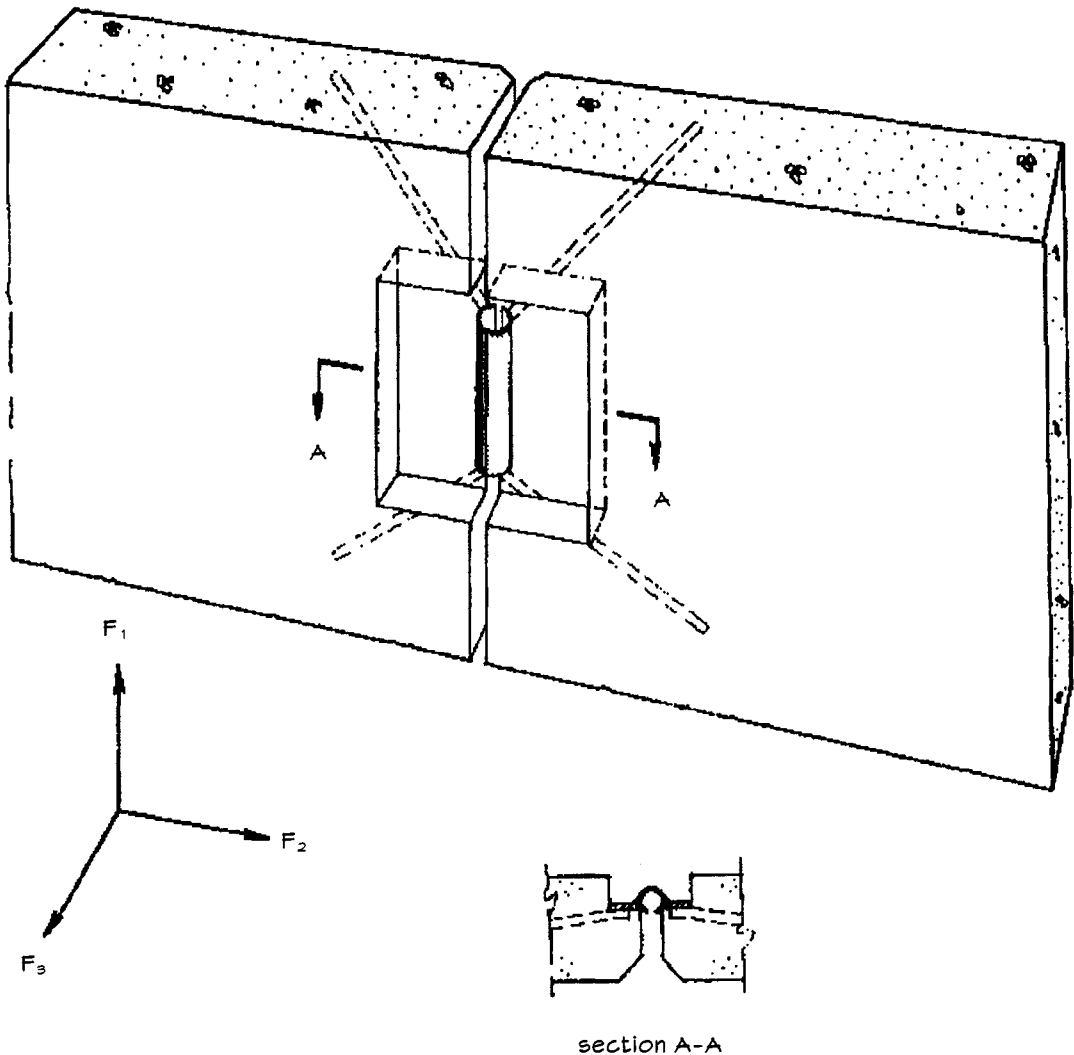
12.6.3 In-Plane Wall / Wall Connection with Slit Pipe

In this connection, two adjacent wall panels are connected through slit pipes. Each pipe includes one longitudinal slit. At either side of the slit, the pipe is welded to embedments to form a connection. Generally, the pipe is placed into a recessed pocket. After erection, a bond-breaking agent is applied on the pipe and the recessed pocket is grouted for aesthetics.

Advantages: Connection accommodates some horizontal differential movement between wall panels. Connection can be "hidden."

Disadvantages: Consolidation of concrete near steel embedments may be difficult. Pocket complicates fabrication of wall panel. Welding of pipe may be difficult.

Restraints: Primary— F_1 and F_3



(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

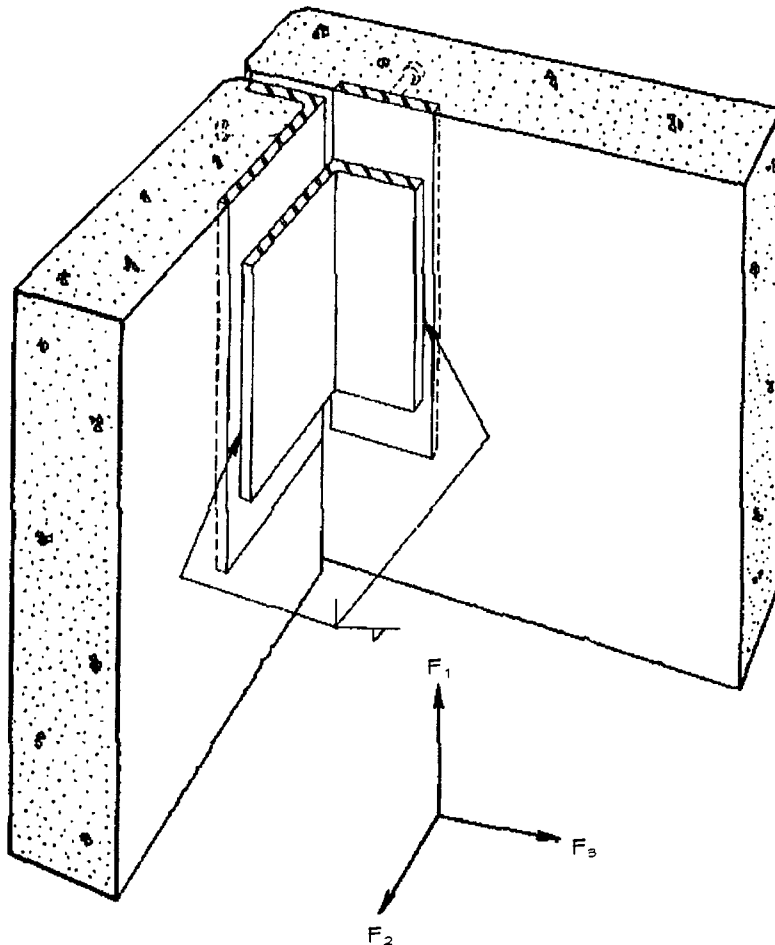
12.6.4 Corner Wall / Wall Connection with Steel Embedments

In this connection, wall panels are connected through clip angles. Each clip angle is welded to steel embedments cast into the wall panels. Alternatively, the clip angles can be bolted to the wall panels through embedded threaded parts. The rigid, welded corner connection is less critical for distress due to volume change than “In-Plane Wall / Wall Connection with Steel Embedments.”

Advantages: Number of components in connection is minimal. Fabrication and erection are simple. Steel embedments allow large construction tolerances.

Disadvantages: Exposed steel may require fireproofing. Consolidation of concrete near embedment may be difficult. Connection may require welding in the up-hand position.

Restraints: Primary— F_1 , F_2 and F_3



(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

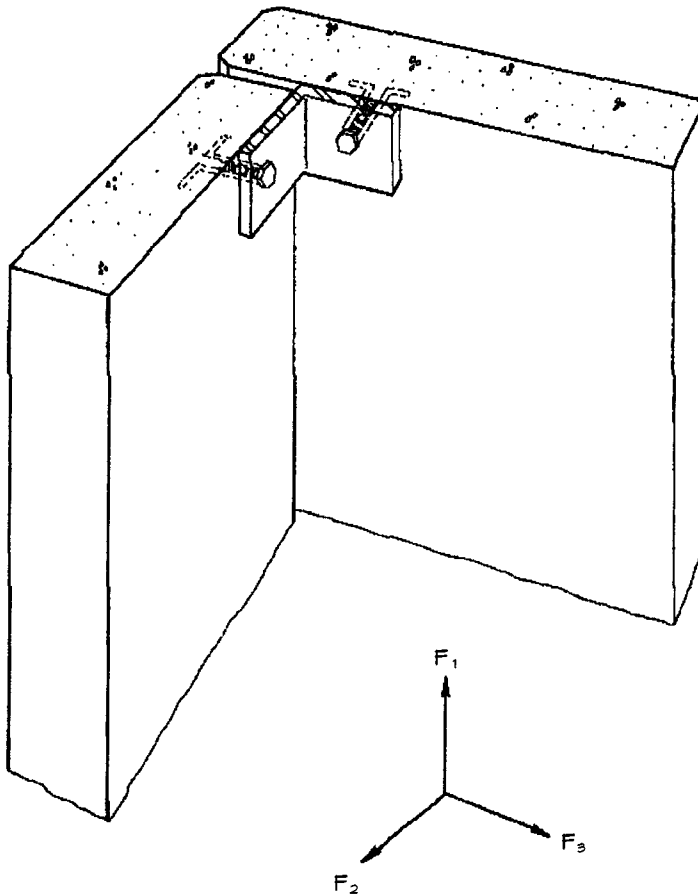
12.6.5 Corner Wall / Wall Connection with Threaded Inserts—Type I

In this connection, wall panels are connected through clip angles. The clip angles are bolted to the panels with threaded inserts cast into the panels.

Advantages: Number of components in connection is minimal. Fabrication and erection are simple.

Disadvantages: Exposed steel may require fireproofing. Close construction tolerances required.

Restraints: Primary— F_2 and F_3



(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

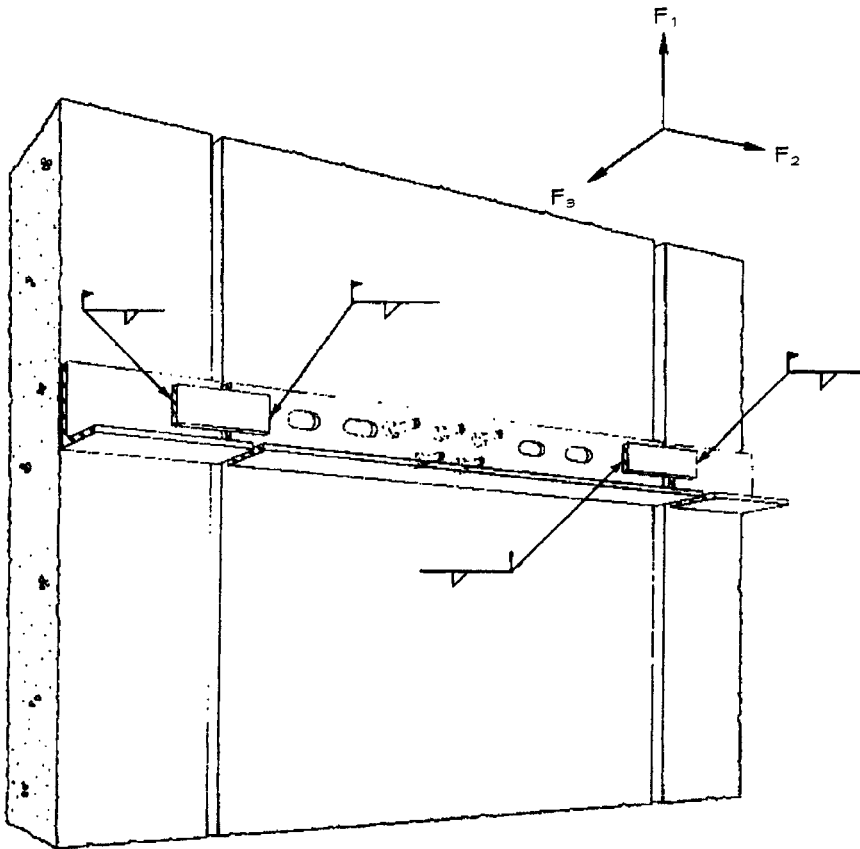
12.6.6 In-Plane Wall / Wall Connection with Continuous Steel Chord

In this connection, a continuous angle is embedded in the surface with headed studs anchoring the steel section over one quarter of the panel length centered on the centerline of the panel. In the remaining three quarters of the panel width, the chord is bolted to the panel through slotted holes. At each joint, a steel plate is welded to the angles attached to the adjacent panels to form the connection. The continuous steel section may provide vertical support for a portion of a roof or floor system and also act as chord for the roof diaphragm.

Advantages: Fabrication and erection are simple. Steel embedments allow large construction tolerances.

Disadvantages: Exposed steel may require fireproofing. Connection may require welding in up-hand position. Consolidation of concrete near embedment may be difficult.

Restraint: Primary— F_1 and F_2
Secondary— F_3



(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

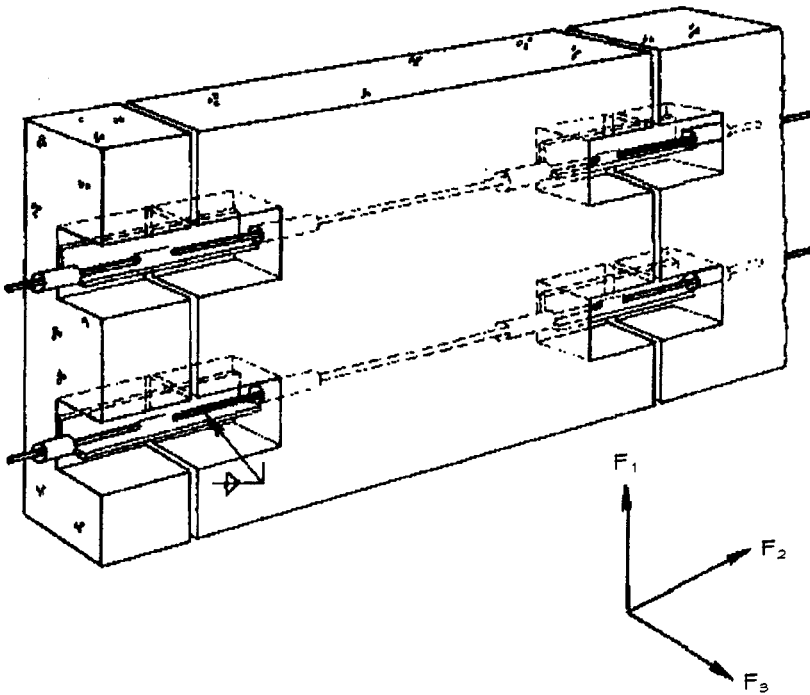
12.6.7 In-Plane Diaphragm Chord Wall / Wall Connection

In this connection, wall panels are connected continuously by means of continuous reinforcement. Reinforcement is mechanically anchored to the center one-third of the panel. The outer one-third of the top chord of reinforcement is unbonded by encasement in cardboard or plastic sleeves. A recessed pocket is provided to allow weldment of an angle to reinforcement in adjacent wall panels, thus forming the continuous chord. This detail is commonly used with wood roof systems.

Advantages: Erection is simple. Accommodates movement due to volume change.

Disadvantages: Additional material and labor costs in forming recessed pocket and forming unbonded length of reinforcement. Welding in up-hand position.

Restraints: Primary— F_2



(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

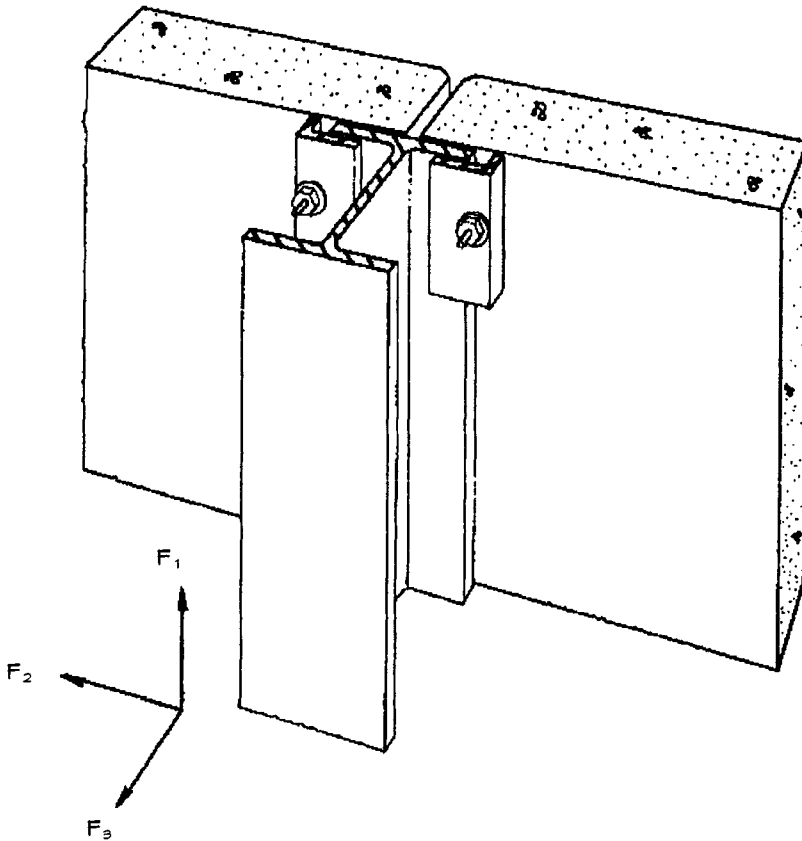
12.7.1 Steel Column / Wall Connection with Bolted Steel Angles

In this connection, each wall panel is connected to a steel column through bolted steel angles. Each steel angle bears against the interior face of a column flange and is bolted to the wall panel through embedded threaded parts.

Advantages: Fabrication and erection are simple. Connection accommodates movement due to volume change. Large tolerances can be specified.

Disadvantages: Special steps may be required to protect exposed threaded parts during handling. Exposed steel may require fireproofing.

Restraints: Primary— F_3



(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

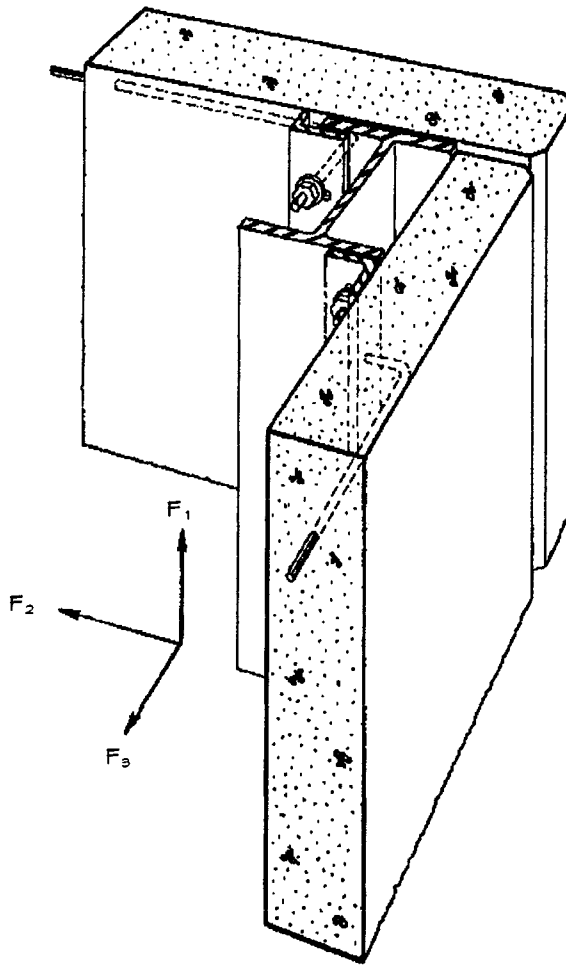
12.7.2 Wall / Steel Column / Wall Connection with Bolted Steel Angles

In this connection, the detail for “Steel Column / Wall Connection” is applied to corner wall panels adjacent to a steel column.

Advantages: Fabrication and erection are simple. Connection accommodates movement due to volume change. Large tolerances can be specified.

Disadvantages: Special steps may be required to protect exposed threaded parts during handling. Exposed steel may require fireproofing.

Restraints: Primary— F_2 and F_3

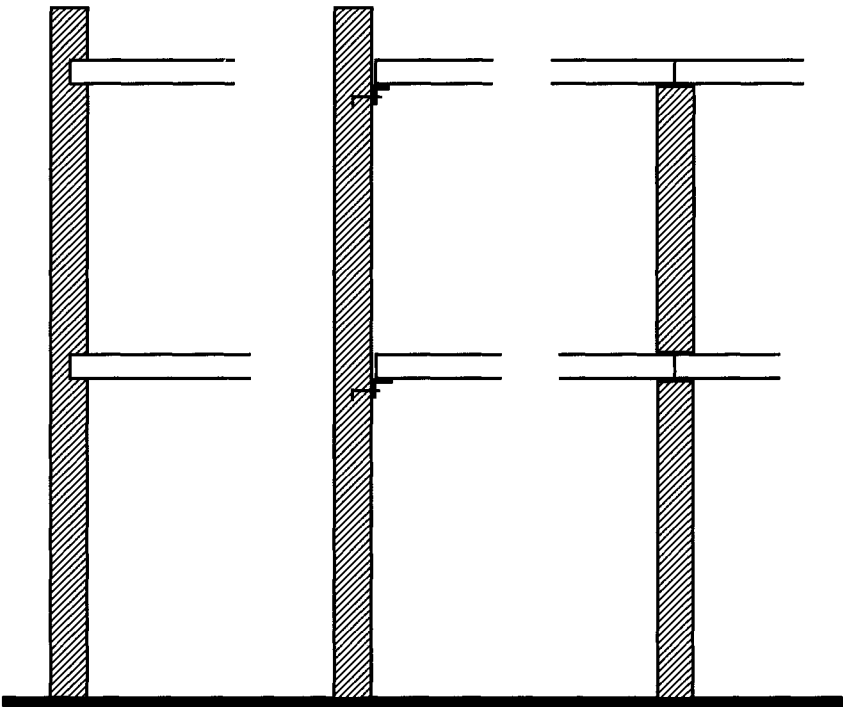


(From Connections for Tilt-Up Wall Construction, Portland Cement Association, 1987)

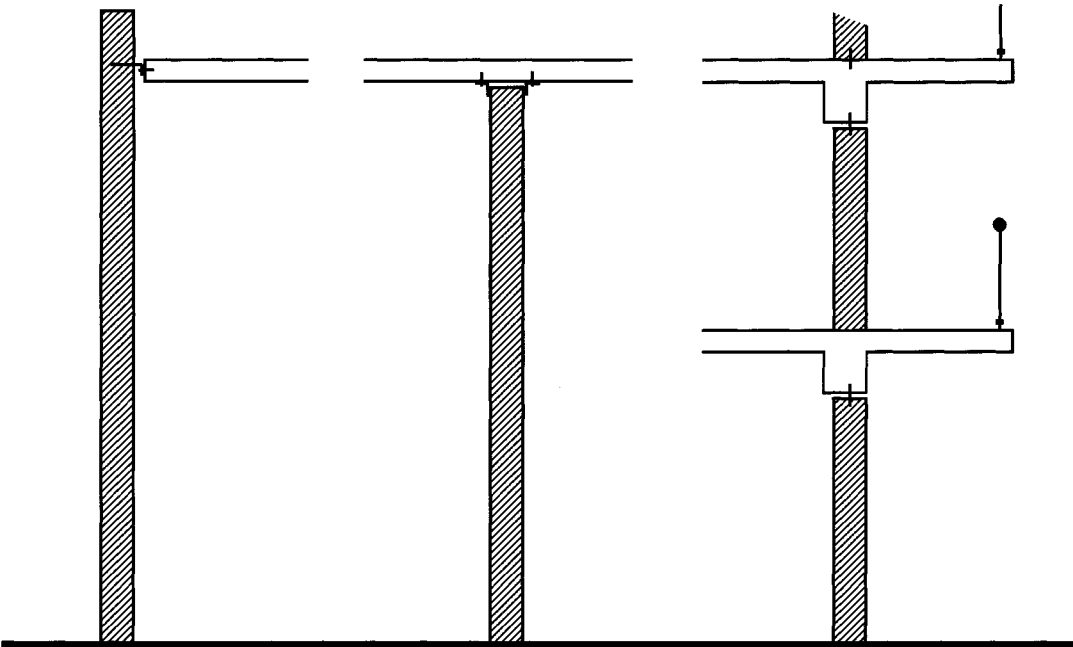
Single-Wythe Masonry Walls

- 13.1 Concrete Block**
 - 13.1.1 Single-Wythe CMU Wall Types
 - 13.1.2 Lateral Support Requirements
 - 13.1.3 Mortar Bedding of Hollow Masonry Units
 - 13.1.4 Masonry Shear Wall Types
 - 13.1.5 Empirical Masonry Shear Wall Requirements
 - 13.1.6 Steel Reinforcing at Intersecting Single-Wythe Masonry Walls
 - 13.1.7 Lateral Support Connections at Intersecting Single-Wythe Masonry Walls
 - 13.1.8 Connecting to Concrete Floors and Roofs
 - 13.1.9 Connecting to Steel Floor and Roof Framing
 - 13.1.10 Connecting to Wood Framing
 - 13.1.11 Single-Wythe Curtain Walls
 - 13.1.12 Single-Wythe Wall Pilasters
 - 13.1.13 Single-Wythe Wall Flashing Details
 - 13.1.14 Single-Wythe Wall Columns
 - 13.1.15 Lateral Support for Non-Loadbearing Partitions
 - 13.1.16 Prescriptive Masonry Reinforcing Requirements
 - 13.1.17 Masonry Reinforcement in Seismic Design Category C
 - 13.1.18 Masonry Reinforcement in Seismic Design Categories D, E and F
 - 13.1.19 Reinforcing Bar Size Limitations for Hollow Unit Masonry Construction
 - 13.1.20 Maximum Area of vertical Steel for Hollow Unit Masonry Construction
- 13.2 Glass Block Masonry**
 - 13.2.1 Glass Block Panel Code Requirements
 - 13.2.2 Typical Glass Block Panel Details
 - 13.2.3 Glass Block Panel Stiffeners and Supports
 - 13.2.4 Glass Block Shower Enclosures
 - 13.2.5 Glass Block Corner Details
 - 13.2.6 Curved Glass Block Walls

13.1.1 Single-Wythe CMU Wall Types



interior and exterior loadbearing walls



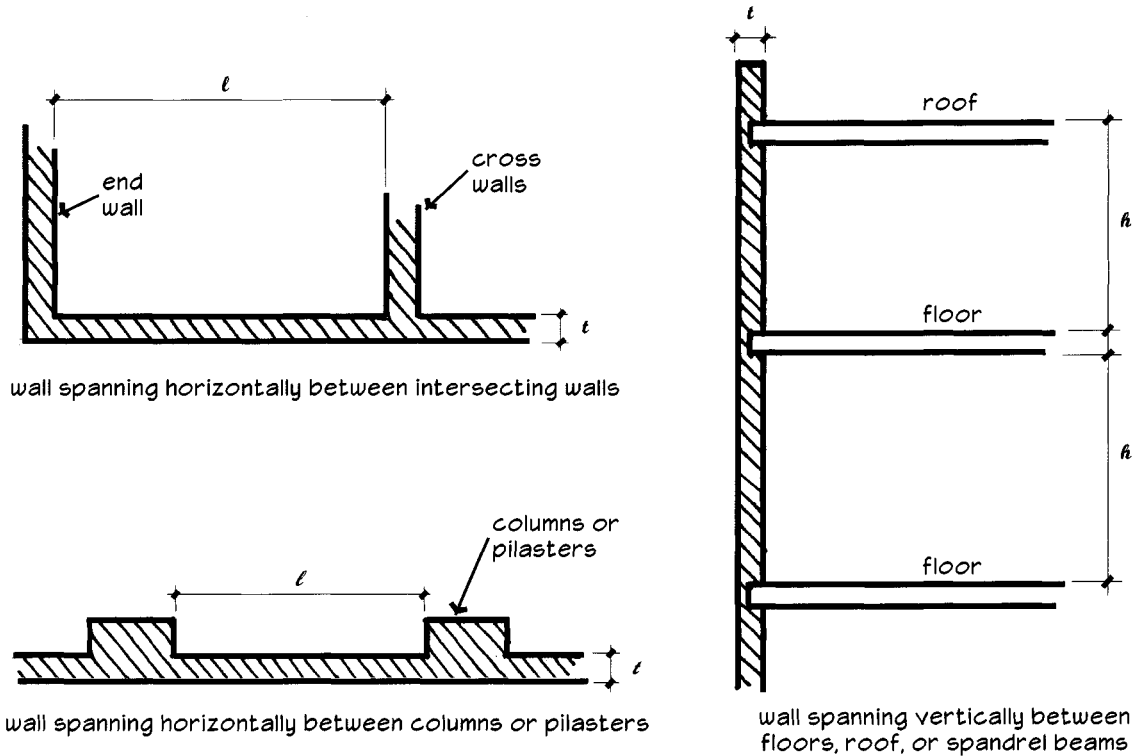
non-loadbearing
exterior curtain walls

non-loadbearing
interior partitions

exterior non-loadbearing
infill walls

13.1.2 Lateral Support Requirements

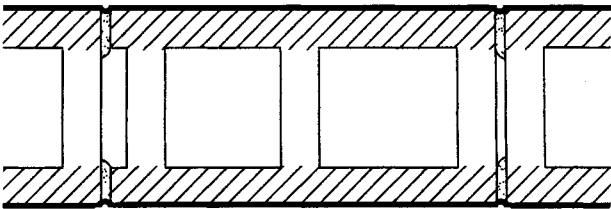
Masonry walls may span vertically between floors and roof or between spandrel beams, or span horizontally between intersecting walls, columns or pilasters. Building codes specify span-to-thickness ratios as ℓ/t or h/t which determines the minimum required wall thickness for a given span. Determine wall thickness and then design the lateral support system and connections by either empirical or engineered design methods to transfer loads to the force-resisting elements.



Empirical Span-to-Thickness Ratios for Lateral Support of Masonry Walls		
Wall or Element	Maximum Unsupported Height or Length to Nominal Thickness (ℓ/t or h/t)	
Bearing walls		
solid or grouted solid	20	
all other walls	18	
Non-bearing walls		
exterior	18	
interior	36	
Cantilever walls (except parapets)		
solid or solidly grouted	6 (CABO only)	
hollow	4 (CABO only)	
Unreinforced parapets		
solid or solidly grouted	CABO	MSJC and IBC
hollow	4	3
	3	3

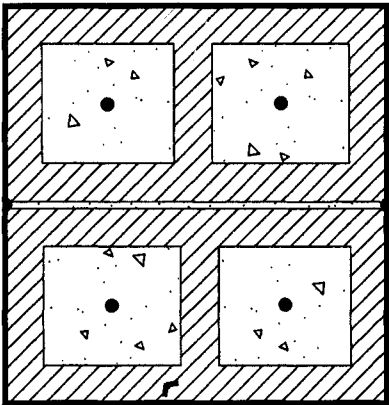
(Based on requirements of CABO One and Two Family Dwelling Code, MSJC Building Code Requirements for Masonry Structures ACI 530/ASCE 5/TMS 402, and International Building Code 2000)

13.1.3 Mortar Bedding of Hollow Masonry Units



face shell bedding

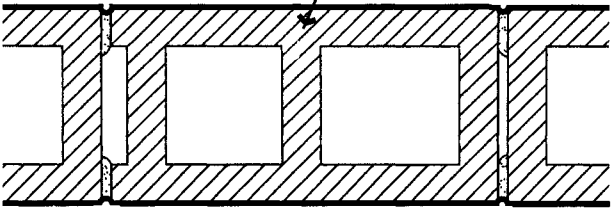
bed joints at face shells must be fully mortared, depth of head joints must be equal to thickness of face shell (in fully grouted walls, grout can flow laterally across webs for interlocking)



piers, columns and pilasters

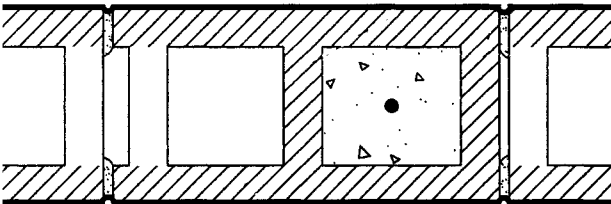
bed joints at face shells and webs must be fully mortared

hatched area indicates mortar



full mortar bedding

bed joints at face shells and webs must be fully mortared only for the first course on foundations and when specified



grouted cores

bed joints at face shells and webs at grouted cores must be fully mortared

13.1.4 Masonry Shear Wall Types

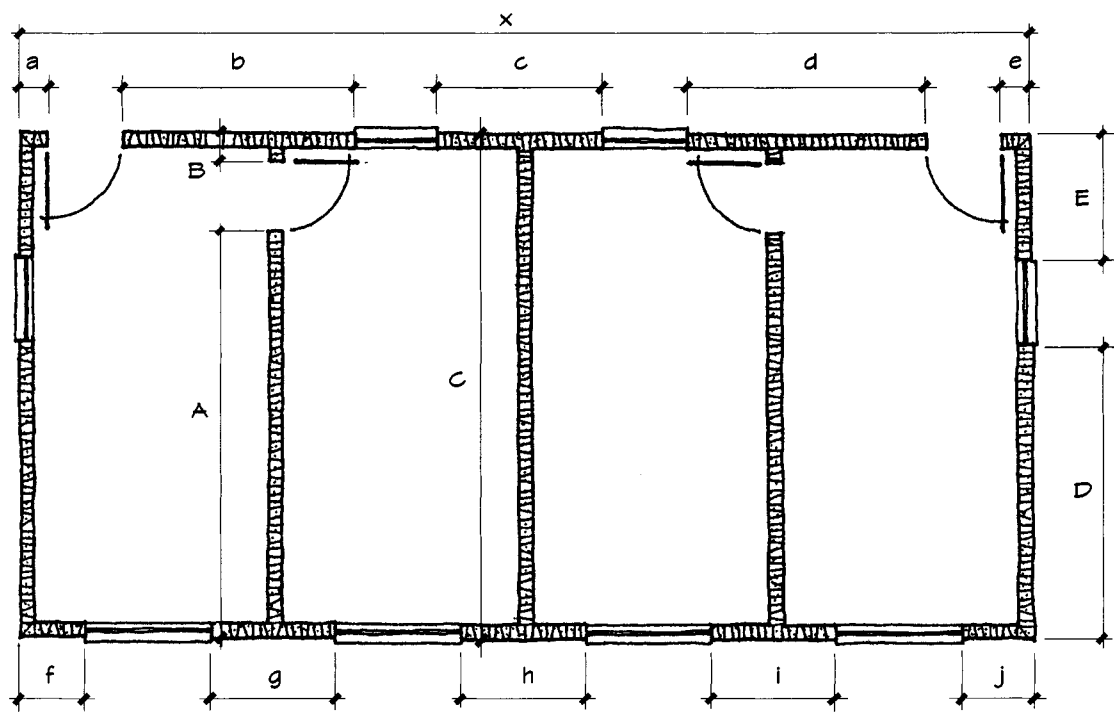
Type of Shear Wall	Design Method	Minimum Required Reinforcement	Permitted in Seismic Design Category
Empirical	Empirical Design	None	A
Ordinary Plain (unreinforced)	Allowable Stress Design, Strength Design, or Prestressed Masonry	None	A, B
Detailed Plain (unreinforced)	Allowable Stress Design or Strength Design	<p><i>Vertical</i> reinforcement of minimum one No. 4 or two No. 3 deformed steel bars area at corners, within 16" of each side of openings, within 8" of each side of movement joints, within 8" of the ends of walls, and at a maximum spacing of 10 ft.</p> <p><i>Horizontal</i> reinforcement of either 2-wire, 9 gauge prefabricated joint reinforcement or minimum one No. 4 or two No. 3 deformed steel bond beam bars continuously at structurally connected roof and floor levels, within 16" of the top of walls, at the bottom and top of wall openings extending at least 24" or 40 bar diameters past the opening*, as well as 2-wire, 9 gauge prefabricated joint reinforcement spaced not more than 16" on center or minimum one No. 4 or two No. 3 deformed steel bond beam bars spaced 10 ft. on center.</p>	A, B
Ordinary Reinforced	Allowable Stress Design or Strength Design	<p><i>Vertical</i> reinforcement of minimum one No. 4 or two No. 3 deformed steel bars at corners, within 16" of each side of openings, within 8" of each side of movement joints, within 8" of the ends of walls, and at a maximum spacing of 10 ft.</p> <p><i>Horizontal</i> reinforcement of either 2-wire, 9 gauge prefabricated joint reinforcement or minimum one No. 4 or two No. 3 deformed steel bond beam bars continuously at structurally connected roof and floor levels, within 16" of the top of walls, at the bottom and top of wall openings extending at least 24" or 40 bar diameters past the opening*, as well as 2-wire 9 gauge prefabricated joint reinforcement spaced not more than 16" on center or minimum one No. 4 or two No. 3 deformed steel bond beam bars spaced 10 ft. on center.</p>	A, B, C
Intermediate Reinforced	Allowable Stress Design or Strength Design	<p><i>Vertical</i> reinforcement of minimum one No. 4 or two No. 3 deformed steel bars at corners, within 16" of each side of openings, within 8" of each side of movement joints, within 8" of the ends of walls, and at a maximum spacing of 4 ft.</p> <p><i>Horizontal</i> reinforcement of either 2-wire, 9 gauge prefabricated joint reinforcement or minimum one No. 4 or two No. 3 deformed steel bond beam bars continuously at structurally connected roof and floor levels, within 16" of the top of walls, at the bottom and top of wall openings extending at least 24" or 40 bar diameters past the opening*, as well as 2-wire 9 gauge prefabricated joint reinforcement spaced not more than 16" on center or minimum one No. 4 or two No. 3 deformed steel bond beam bars spaced 10 ft. on center.</p>	A, B, C
Special Reinforced	Allowable Stress Design or Strength Design	Combined vertical and horizontal reinforcement at least 0.002 times gross cross-sectional area of wall, with a minimum of 0.0007 times gross cross-sectional area of wall in each direction, uniformly distributed and spaced at the smaller of 1/3 the length of the shear wall, 1/3 the height of the shear wall, or 4 ft. on center for masonry laid in other than stack bond. Shear reinforcement must be anchored around vertical reinforcing bars with a standard hook.	A, B, C, D, E, F

* Reinforcement adjacent to openings need not be provided for openings smaller than 16 in. in either the horizontal or vertical direction, unless the spacing of distributed reinforcement is interrupted by such reinforcement.

(Based on requirements of the MSJC Building Code Requirements for Masonry Structures, ACI 530/ASCE 5/TMS 402-02)

13.1.5 Empirical Masonry Shear Wall Requirements

Where structures depend on masonry walls for lateral support, provide shear walls parallel to the direction of the lateral forces to be resisted. In each direction in which they are required for lateral stability, shear walls must be positioned in two separate planes. The minimum cumulative length of shear walls provided must be 0.4 times the long dimension of the building. Cumulative length of shear walls does not include openings. The maximum ratio of shear wall spacing divided by shear wall segment length may not exceed the ratios listed in the table below. Shear walls must be a minimum of 8 in. thick.

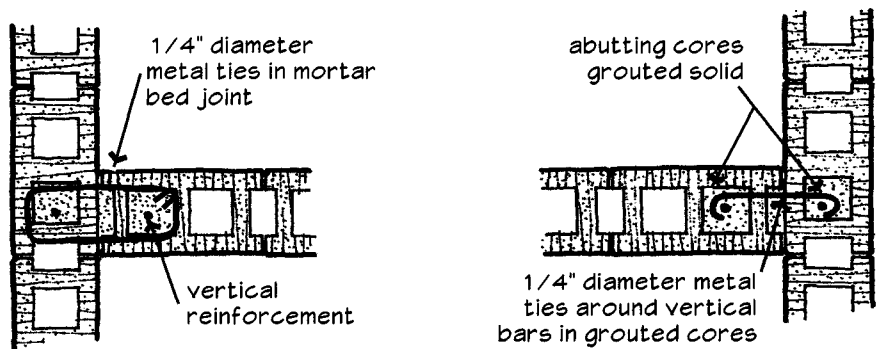


walls in long dimension of building: $a + b + c + d + e + f + g + h + i + j \geq 0.4 \times$
walls in short dimension of building: $A + B + C + A + B + D + E + D + E \geq 0.4 \times$

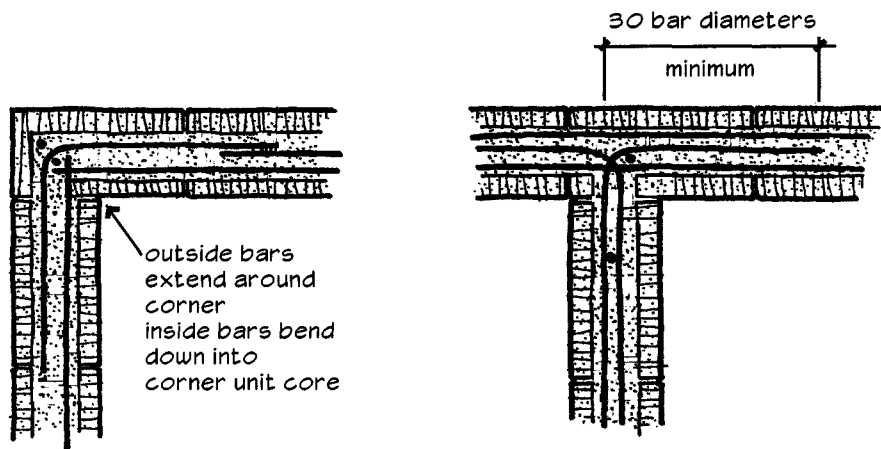
Floor or Roof Construction	Maximum Ratio of Shear Wall Spacing to Shear Wall Length
Cast-in-place concrete	5:1
Precast concrete	4:1
Metal deck with concrete fill	3:1
Metal deck with no fill	2:1
Wood diaphragm	2:1

(Based on requirements of the Masonry Standards Joint Committee (MSJC) Building Code Requirements for Masonry Structures, ACI 530/ASCE 5/TMS 402, and International Building Code 2000)

13.1.6 Steel Reinforcing at Intersecting Single-Wythe Masonry Walls

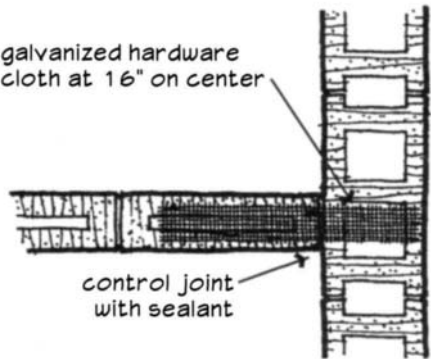
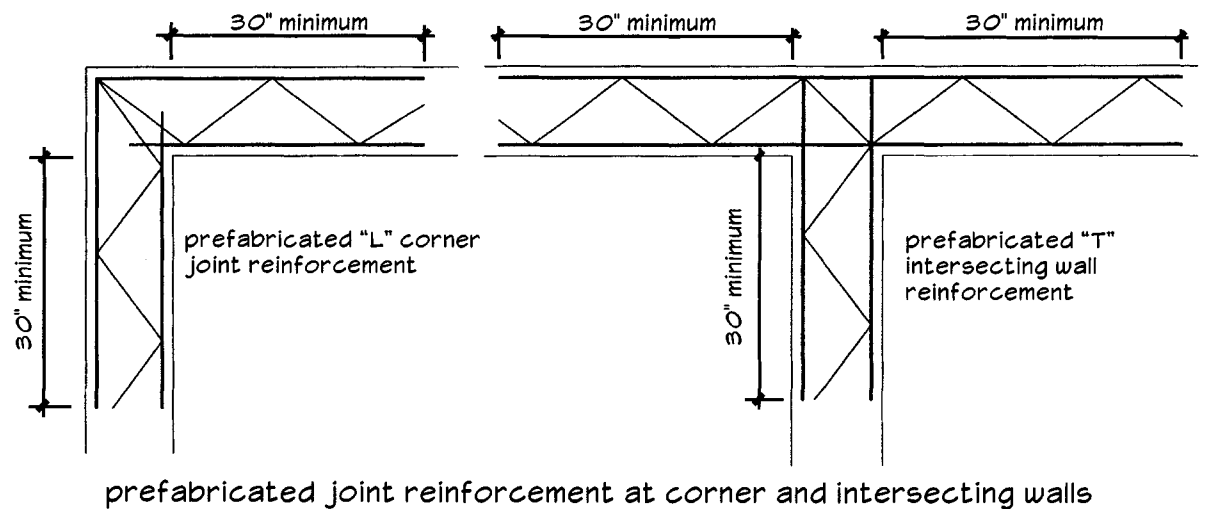


shear connections at cores with vertical reinforcing

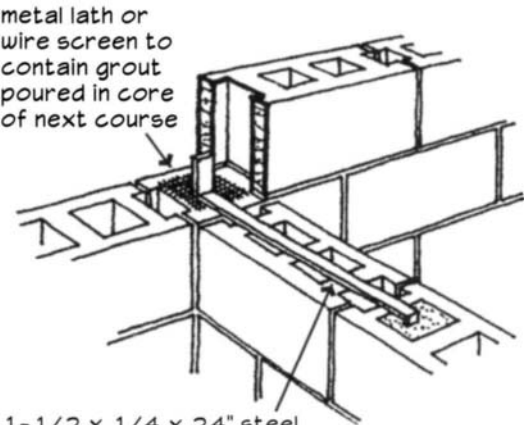


shear connections at continuous bond beams

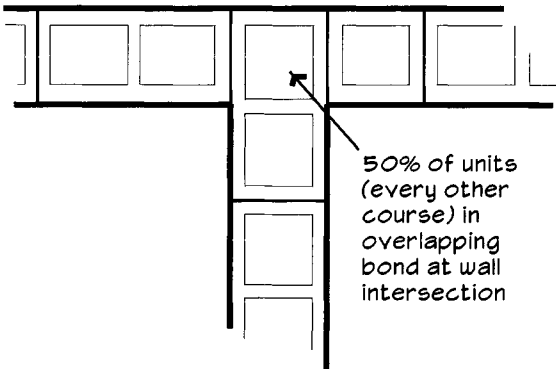
13.1.7 Lateral Support Connections at Intersecting Single-Wythe Masonry Walls



flexible connection with hardware cloth

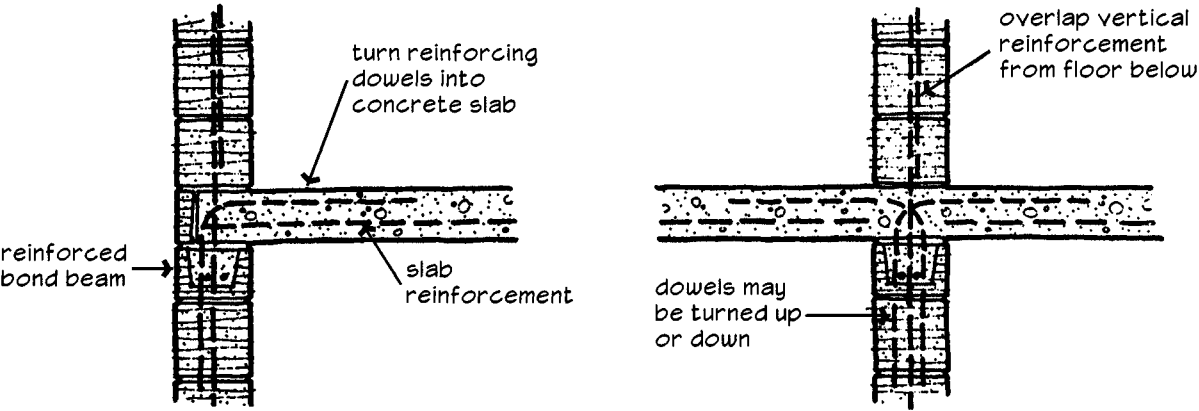


rigid connection with steel strap anchors

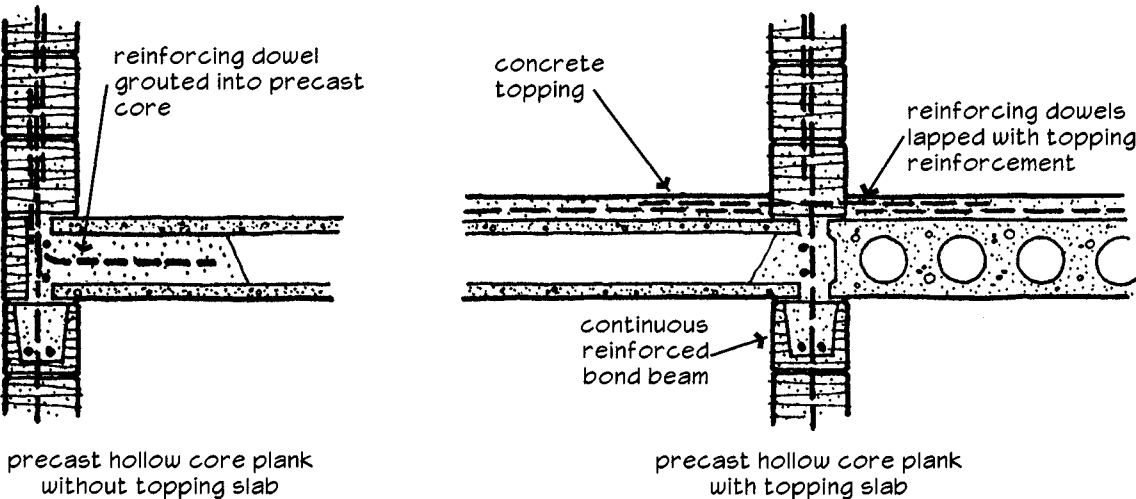


masonry unit bonding

13.1.8 Connecting to Concrete Floors and Roofs



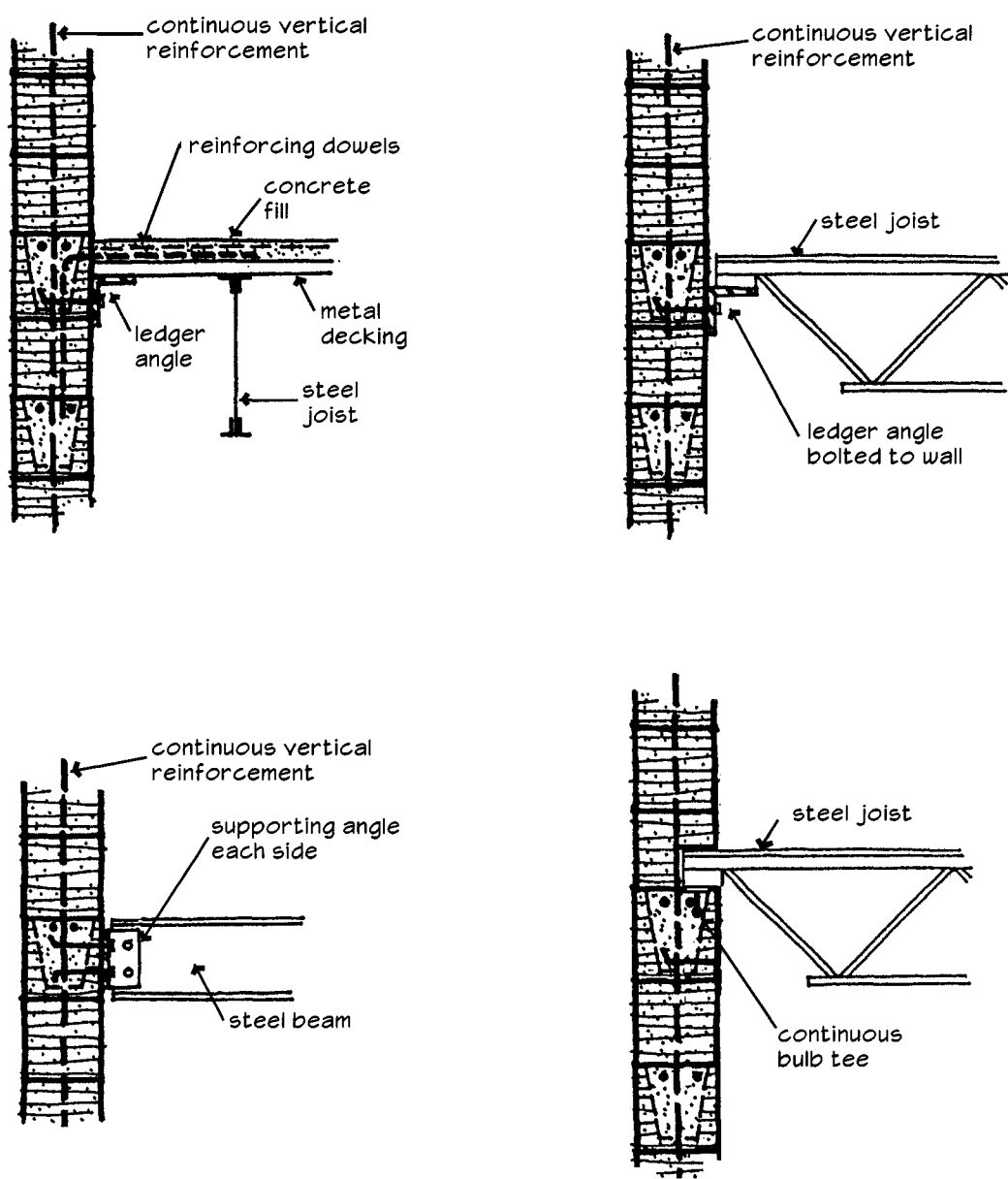
examples of CMU wall connection to cast-in-place concrete



examples of CMU wall connection to precast concrete

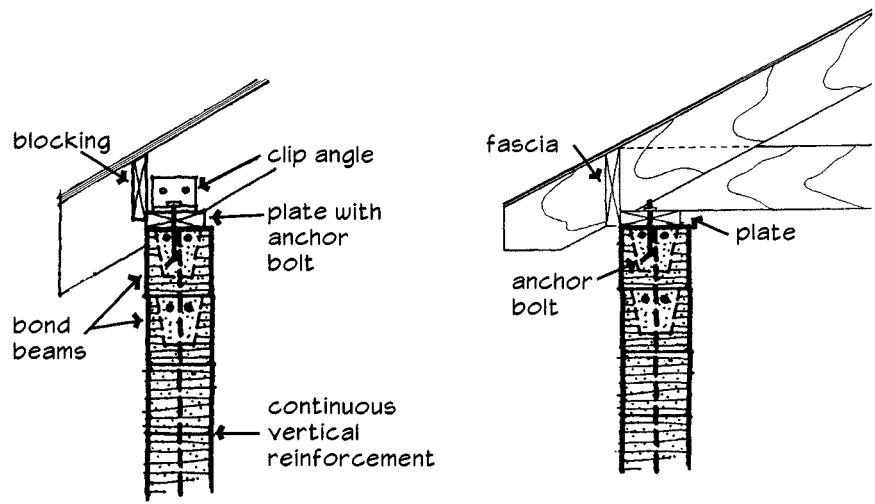
(From Schneider and Dickey, Reinforced Masonry Design, 2nd ed., Prentice-Hall, 1987)

13.1.9 Connecting to Steel Floor and Roof Framing

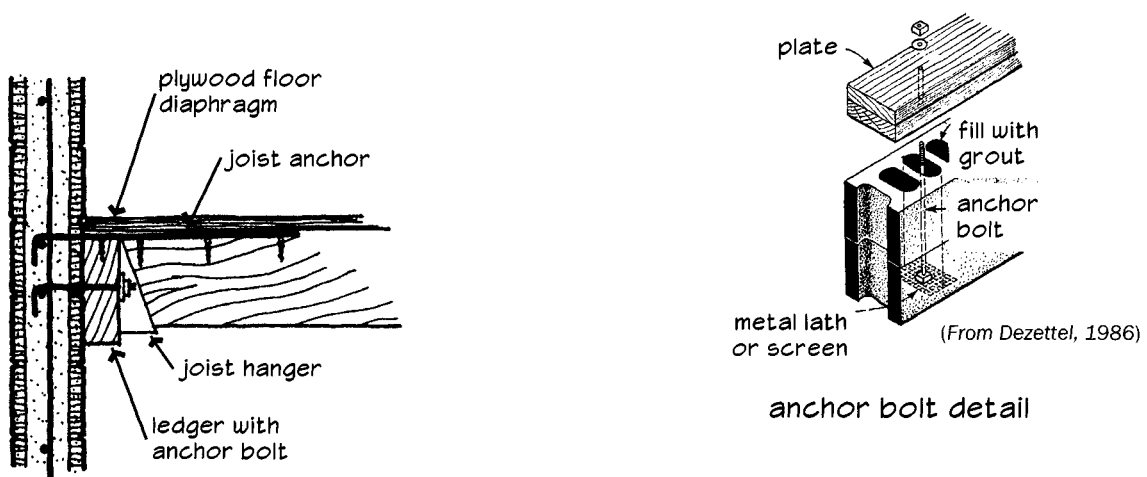


examples of CMU wall connection to steel beams and joists

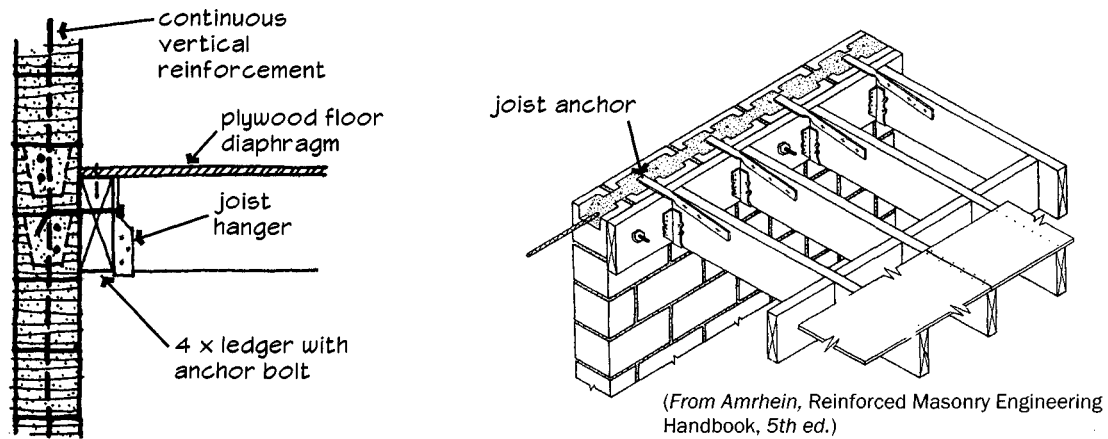
13.1.10 Connecting to Wood Framing



examples of CMU wall connection to wood roof framing

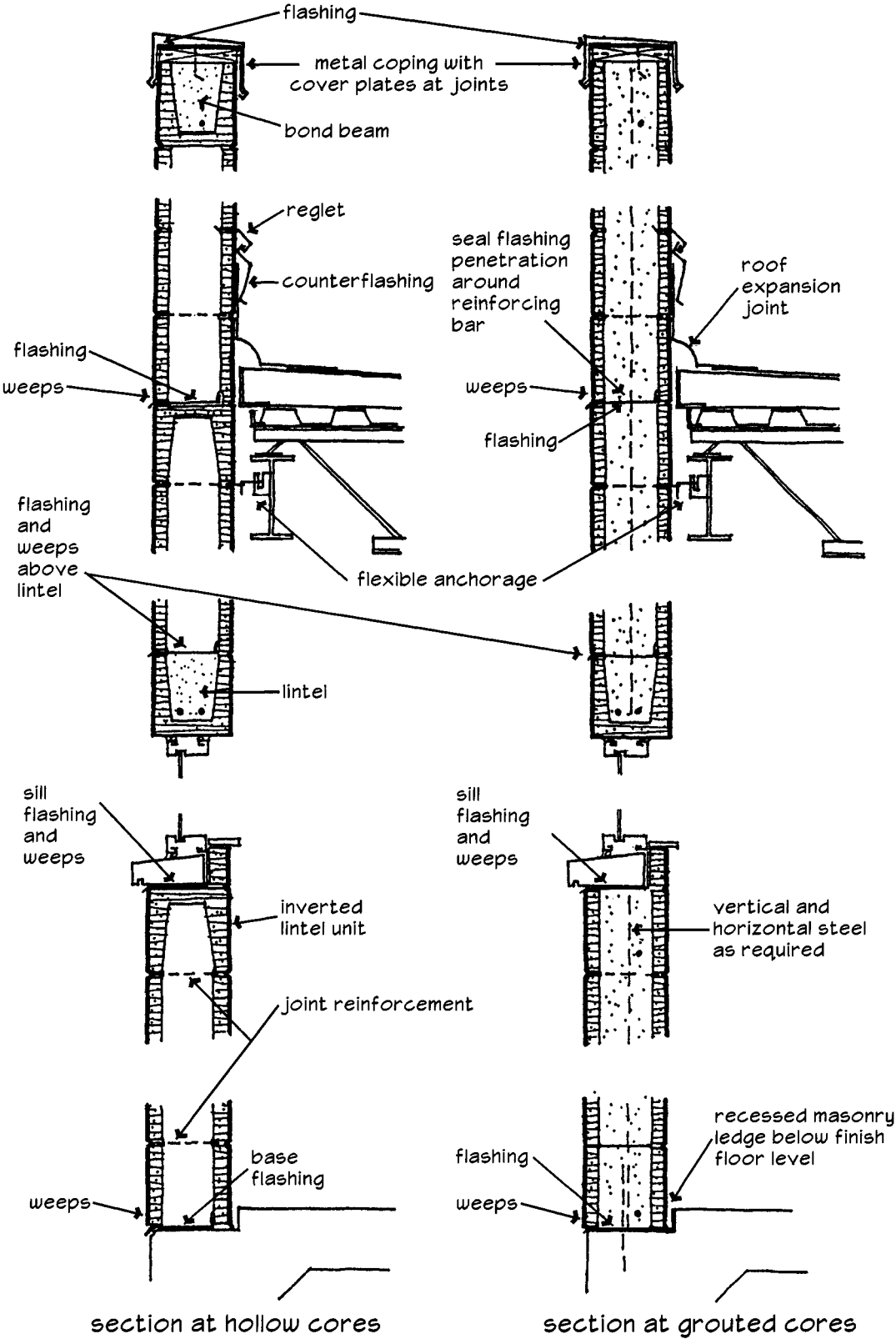


anchor bolt detail

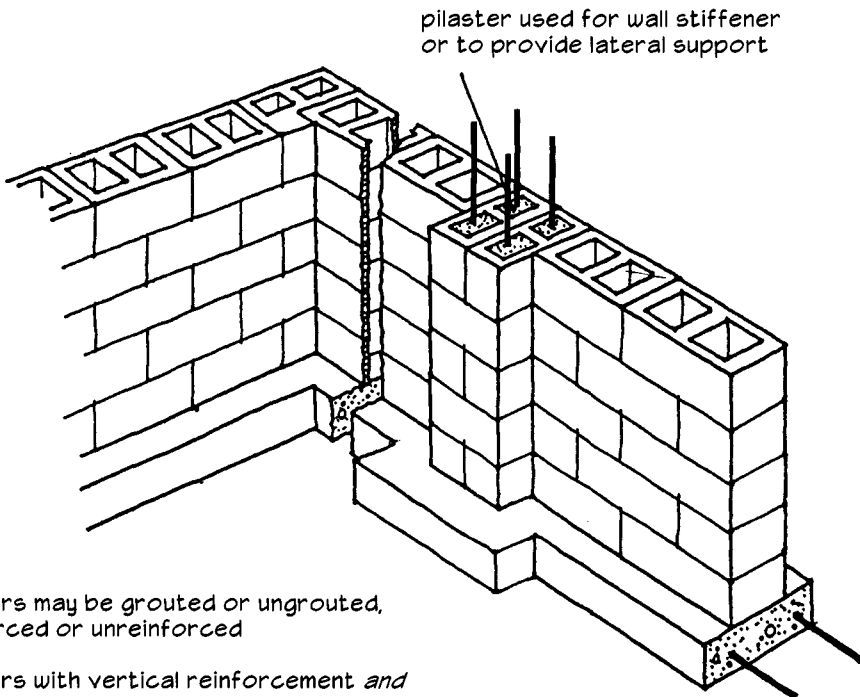
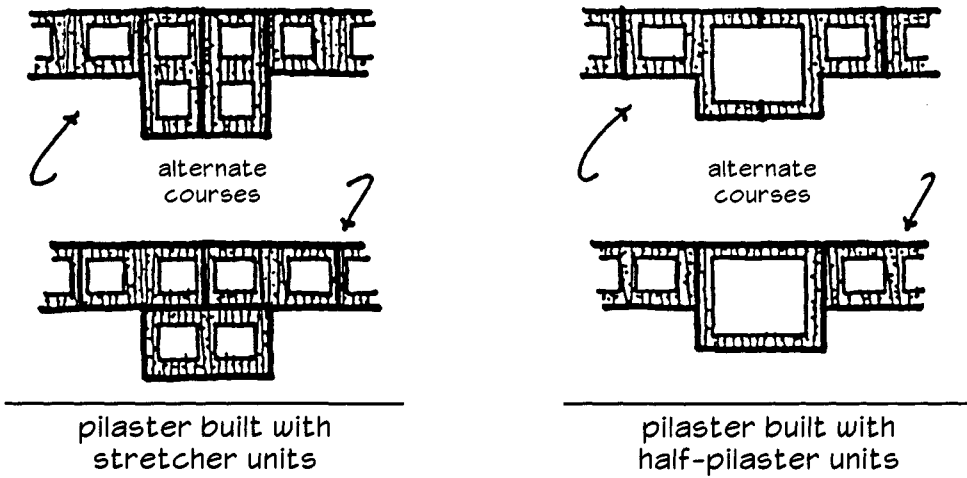


examples of CMU wall connection to wood floor framing

13.1.11 Single-Wythe Curtain Walls



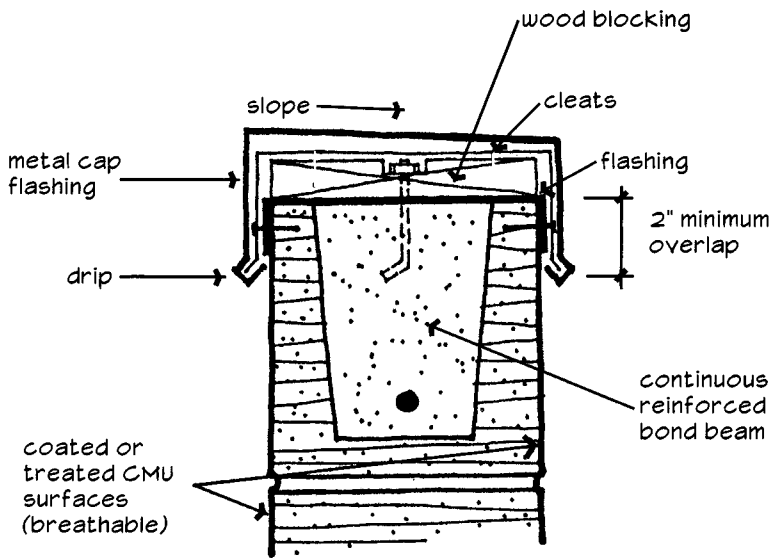
13.1.12 Single-Wythe Wall Pilasters



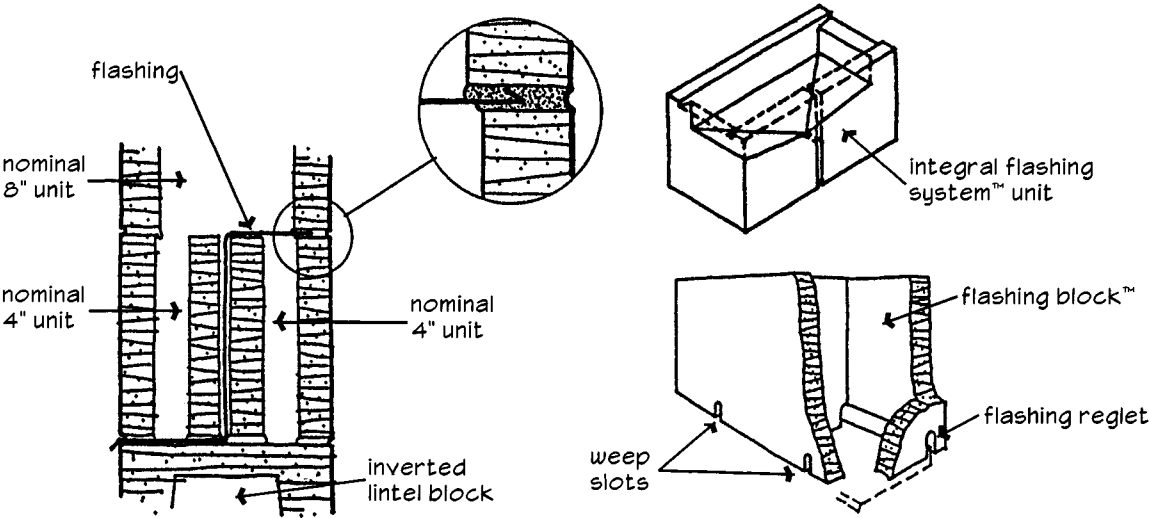
pilasters may be grouted or ungrouted, reinforced or unreinforced

pilasters with vertical reinforcement and lateral restraining ties are considered structural columns (see next page)

13.1.13 Single-Wythe Wall Flashing Details

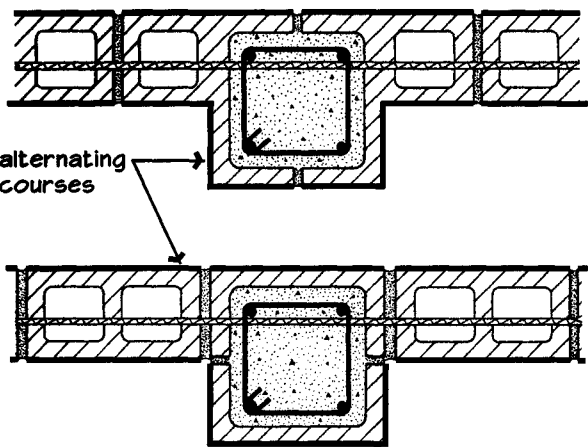


metal cap flashing for single-wythe parapet

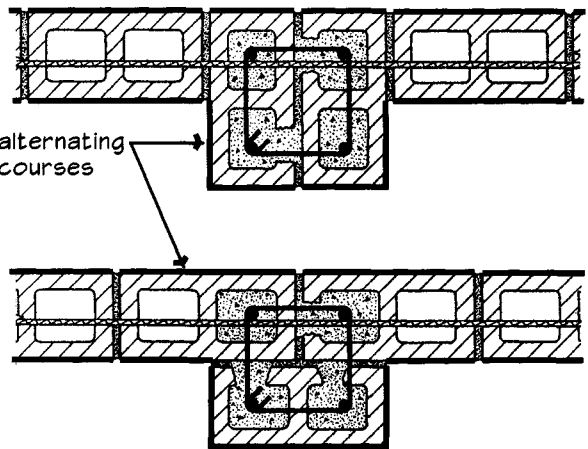


methods of flashing single-wythe walls

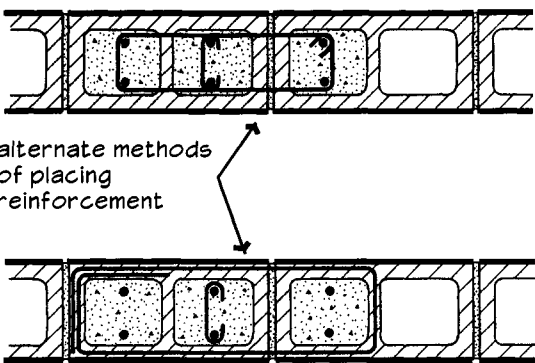
13.1.14 Single-Wythe Wall Columns



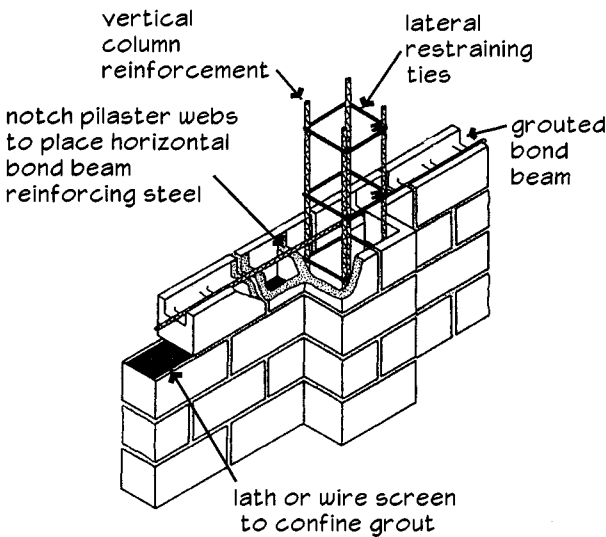
reinforced columns built with pilaster units



reinforced columns built with standard stretcher units

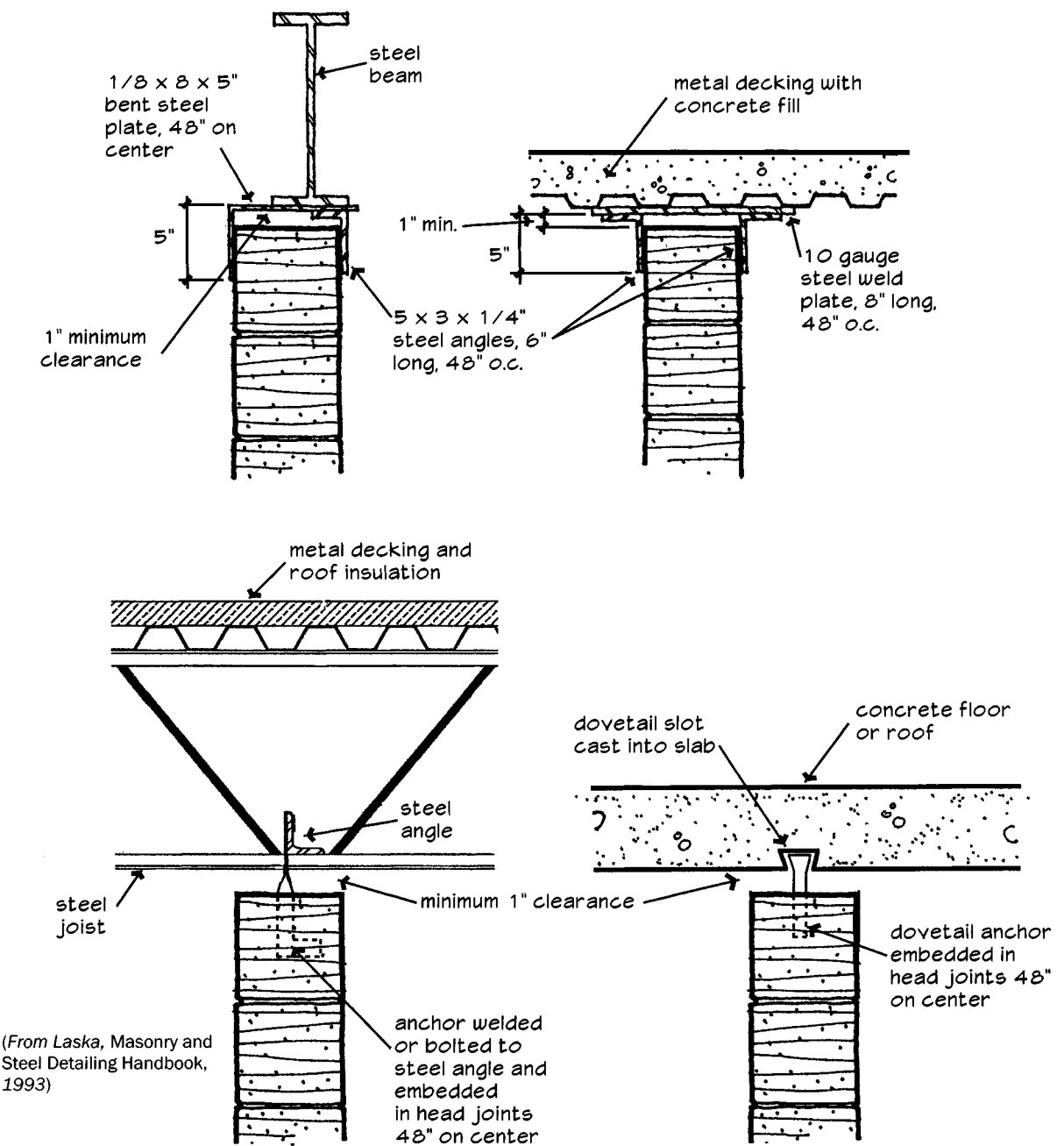


flush wall columns



(From Amrhein, Reinforced Masonry Engineering Handbook, 5th ed.)

13.1.15 Lateral Support for Non-Loadbearing Partitions



13.1.16 Prescriptive Masonry Reinforcing Requirements

Seismic Design Category A or B

- No minimum reinforcing requirements. Walls must be anchored to walls, floors or roofs providing lateral support. For Seismic Category B, shear walls may not be empirically designed and must meet minimum requirements for “ordinary plain” shear walls.

Seismic Design Category C

- Comply with requirements for Categories A and B plus the following requirements.
- Masonry elements which are *not* part of the lateral-force-resisting system must be reinforced in *either* the vertical or horizontal direction, depending on location of the lateral supporting elements.
 - Horizontal joint reinforcement with two longitudinal 9 gauge (W1.7) wires spaced 16" on center maximum, or two #3 or one #4 bar spaced 48" on center maximum. Must include horizontal reinforcement within 16" of the top and bottom of wall.
 - Vertical reinforcement of two #3 or one #4 bar 48" on center maximum and within 16" of ends of walls.
 - In addition to minimum reinforcing requirements, two #3 or one #4 bar on all sides of and adjacent to every opening larger than 16" in either direction, and extending 40 bar diameters or 24" minimum beyond the corners of the opening.
- For masonry elements which *are* part of the lateral-force-resisting system, shear walls must be reinforced in *both* the vertical and horizontal direction to comply with the minimum requirements for “ordinary reinforced” shear walls as follows:
 - Horizontal joint reinforcement with two longitudinal 9 gauge (W1.7) wires, spaced 16" on center, or two #3 or one #4 bar spaced not more than 10 ft. on center. Must include horizontal reinforcement at top and bottom of wall openings and extending 40 bar diameters or 24" minimum beyond the corners of the opening, within 16" of the tops of walls, and continuously at structurally connected roofs and floors.
 - Vertical reinforcement of two #3 or one #4 bar at corners, within 16" of each side of openings, within 8" of each side of movement joints, within 8" of ends of walls, and at 10 ft. on center maximum.

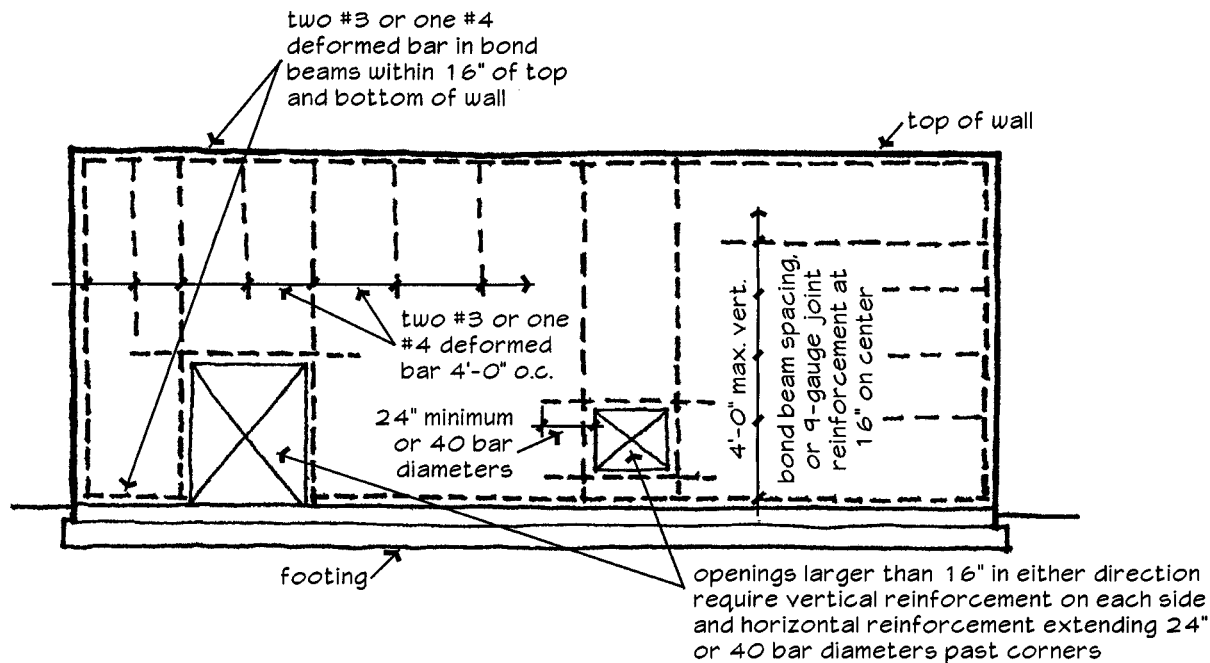
Seismic Design Category D

- Comply with requirements for Category C plus the following requirements.
- Masonry elements which *are* part of the lateral-force-resisting system must be reinforced in *both* the vertical and horizontal direction. The sum of the cross-sectional area of horizontal and vertical reinforcement must be at least 0.002 times the gross cross-sectional area of the wall, with 0.0007 minimum in each direction. Reinforcement must be evenly distributed. Maximum spacing of reinforcement is 48" for other than stack bond masonry. For stack bond masonry, units must be solid, solidly grouted hollow open-end units, or solidly grouted hollow units with full head joints, and reinforcement spaced a maximum of 24" on center.
- Shear walls must comply with the minimum requirements for “special reinforced” shear walls. Reinforcement spacing must be the smaller of one-third the height or length of the shear wall or 48" on center. Minimum cross-sectional area of vertical reinforcement must be one-third of the required shear wall reinforcement. Shear reinforcement must be anchored around vertical reinforcing bars with standard hook. Hooks for lateral tie anchorage shall be either 135° or 180° standard hooks. Columns must have lateral ties at 8" on center, minimum 3/8" diameter embedded in grout.

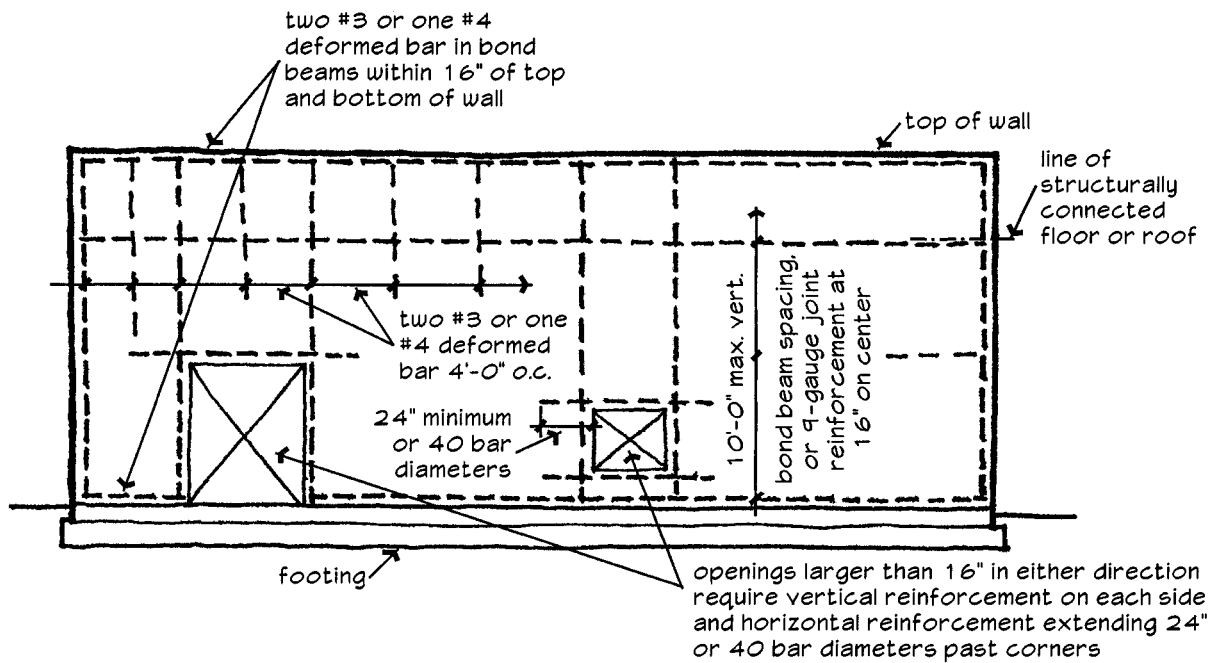
Seismic Design Category E or F

- Comply with requirements for Category D plus the following requirements.
- For stack bond walls which are *not* part of the lateral-force-resisting system, solid units or solidly grouted hollow open-end units, horizontal reinforcement with a cross-sectional area at least 0.0015 times the gross cross-sectional area of the masonry, maximum spacing 24" on center.
- For stack bond walls which *are* part of the lateral-force-resisting system, solid units or solidly grouted open-end units, horizontal reinforcement with a cross-sectional area at least 0.0025 times the gross cross-sectional area of the masonry, maximum spacing 16" on center.

13.1.17 Masonry Reinforcement in Seismic Design Category C



masonry elements which are *not* part of the lateral-force-resisting system
reinforcement required in *either* the vertical or horizontal direction



masonry elements which *are* part of the lateral-force-resisting system
reinforcement required in *both* the vertical or horizontal direction

(Based on requirements of the MSJC Building Code Requirements for Masonry Structures, ACI 530/ASCE 5/TMS 402-02)

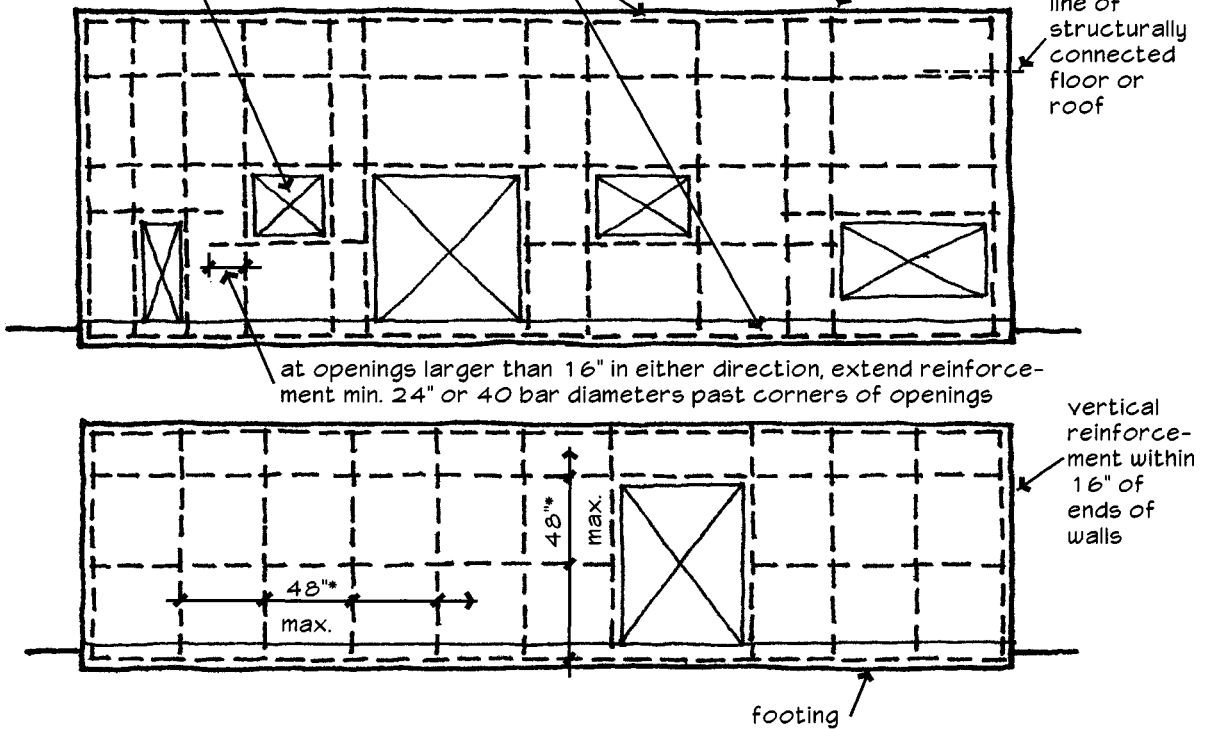
13.1.18 Masonry Reinforcement in Seismic Design Categories D, E and F

provide vertical reinforcement on either side of openings larger than 16" in either direction

horizontal reinforcement within 16" of top and bottom of wall

top of wall

line of structurally connected floor or roof



- * Masonry elements that are part of the lateral-force-resisting system must have reinforcement in *both* the vertical and horizontal direction. The sum of the cross-sectional area of horizontal and vertical reinforcement must be 0.002 times the gross cross-sectional area of the wall, with 0.0007 minimum in each direction. Reinforcement must be evenly distributed and have a maximum spacing of the smaller of $1/3$ the wall height, $1/3$ the wall length, or 4'-0" on center. *Requirements for stack bond masonry are more restrictive.*

13.1.19 Reinforcing Bar Size Limitations for Hollow Unit Masonry Construction

Reinforcing bars in masonry construction must be fully embedded in grout for effective structural function. Because the cavity or collar joint between masonry wythes and the cores or cells of CMU and hollow brick are small, the MSJC and International Building Codes impose bar size limitations to assure adequate grout flow and embedment of the reinforcing steel. These limitations may be based on the nominal wall thickness or the clear dimension of the cell or collar joint, and are summarized as follows:

- Maximum bar size
 No. 11 (MSJC and IBC)
- Maximum bar size based on nominal wall thickness
 1/8 nominal wall thickness (IBC)
- Maximum bar size based on clear dimension of unit cell
 1/2 clear cell or collar joint thickness (MSJC)
 1/4 clear cell or collar joint thickness (IBC)

The following tables list code limitations imposed by the MSJC *Building Code Requirements for Masonry Structures* (ACI 530/ASCE 5/TMS 402-99) and the *International Building Code 2000*.

Note: Compare limitations based on 1/4 or 1/2 of clear grout space dimension or on 1/8 of wall thickness (tables on this page) with limitations based on percent of grout space area (tables on next page) to determine which governs.

Maximum Reinforcing Bar Size Based on 1/8 Wall Thickness, t					
Nominal Wall Thickness, t (in.) →	4 [§]	6	8	10	12
Max. Bar Diameter (in.)	0.5 in.	0.75 in.	1.0 in.	1.25 in.	1.5 in.
Bar Size Designation	No. 4	No. 6	No. 8	No. 9	No. 11

§ While 4-in. nominal hollow clay masonry units are available, most 4-in. nominal hollow concrete masonry is nearly solid and cannot be reinforced and grouted.

Bar Diameter Limitations Based on Clear Cell or Collar Joint Thickness			
Nominal Unit Thickness (in.)	Probable Maximum Clear Cell or Collar Joint Dimension (in.) [§]	Maximum Bar Diameter Based on 1/2 Clear Cell or Collar Joint	Maximum Bar Diameter Based on 1/4 Clear Cell or Collar Joint
Hollow Clay Masonry			
4 [†]	1.0	0.5	0.25
5	1.5	0.75	0.38
6	2.5	1.25	0.63
8	4	3.0	1.0
10	5.75	2.88	1.44
12	7.5	3.75	1.88
Hollow Concrete Masonry			
4	1.125	0.56	0.28
6	2.625	1.31	0.66
8	4.125	2.06	1.03
10	5.875	2.94	1.47
12	7.625	3.81	1.91

§ Based on minimum face shell thickness from ASTM C652 for hollow clay units and ASTM C90 for concrete units, and assuming maximum allowable mortar protrusions of 1/2" both sides, reducing clear dimension by 1" total.

† While 4-in. nominal hollow clay masonry units are available, most 4-in. nominal hollow concrete masonry is nearly solid and cannot be reinforced and grouted.

13.1.20 Maximum Area of Vertical Steel for Hollow Unit Masonry Construction

The maximum area of vertical steel permitted in hollow unit cores or cells is based on the area of the grout space. The limitations imposed by the *MSJC Building Code Requirements for Masonry Structures* and the *International Building Code 2000* are slightly different for working stress and strength design.

- 6% of grout space area (MSJC and IBC working stress design)
- 4% of grout space area, except where splices occur (IBC strength design)

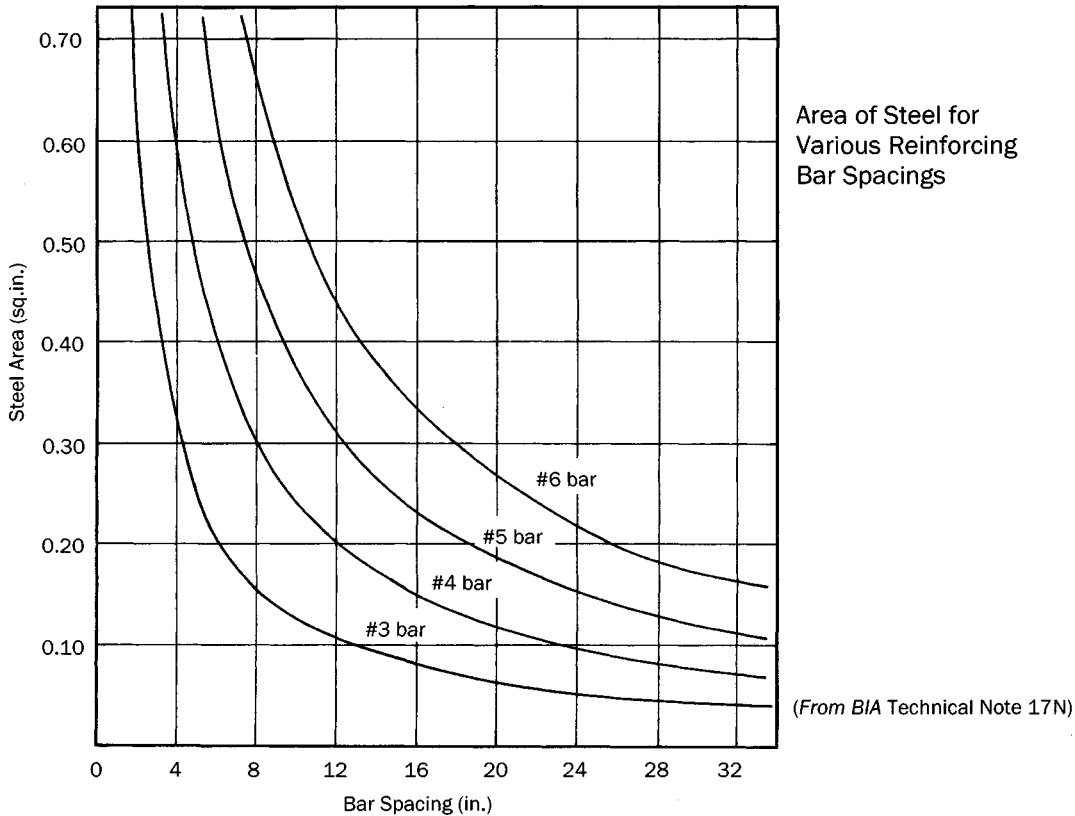
The following table lists maximum area limitations based on the approximate area of hollow cells in concrete masonry units of various nominal thicknesses. The area of cells in hollow clay units may be slightly larger or smaller depending on face shell thickness, web thickness, core shape, etc.

Note: Compare limitations based on percent of grout space area (table on this page) with limitations based on 1/4 or 1/2 of clear grout space dimension or on 1/8 wall thickness (see tables on previous page) to determine which governs.

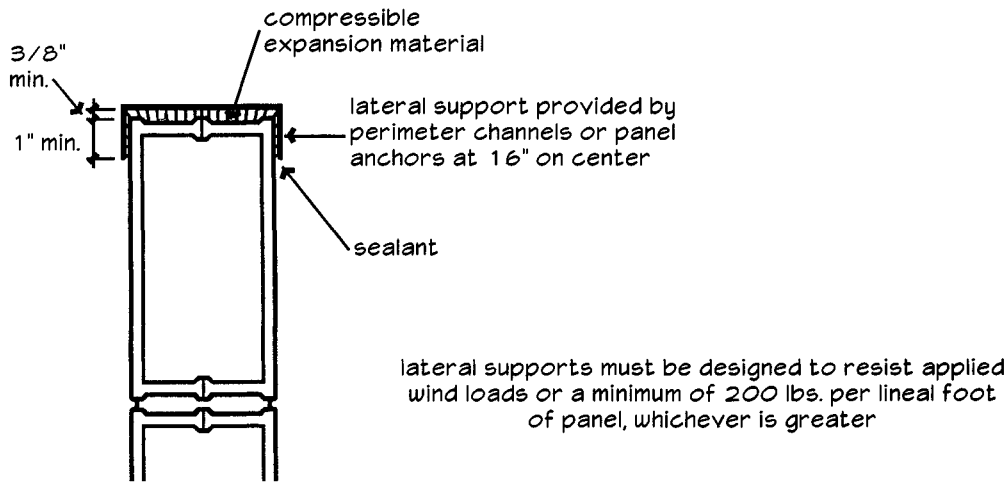
Maximum Area of Reinforcing Steel Based on Percentage of Grout Space Area			
Nominal CMU Wall Thickness, t (in.)	Approximate Area of CMU Cell (sq.in.) [§]	Maximum Area of Vertical Reinforcement Based on MSJC 6% Limit	Maximum Area of Vertical Reinforcement Based on IBC 4% Limit
4†	12.5	0.75	0.50
6	21	1.26	0.84
8	30	1.80	1.20
10	42	2.52	1.68
12	54	3.24	2.16

§ Cell area will vary based on actual face shell thickness, web thickness, core shape, etc. Check with local manufacturers to verify actual cell area.

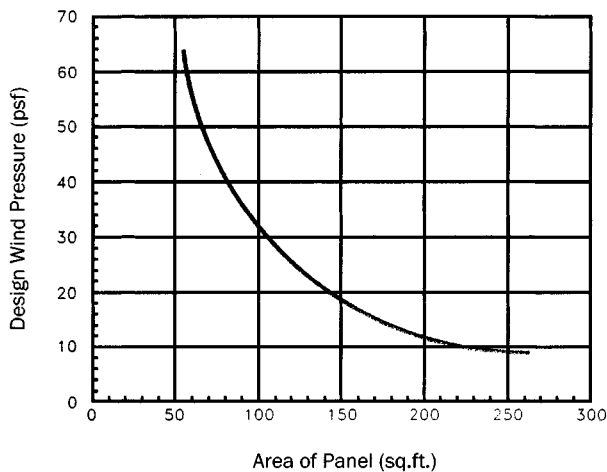
† Many nominal 4-in. CMU are nearly solid and cannot be reinforced and grouted.



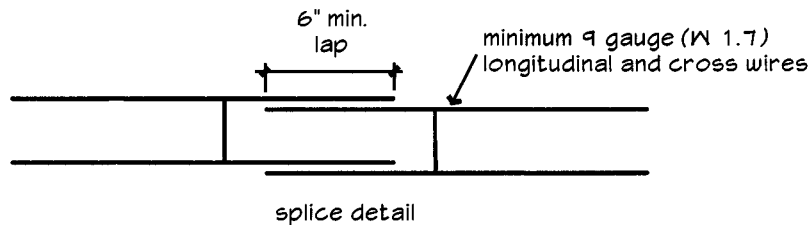
13.2.1 Glass Block Panel Code Requirements



(From Patterson, Illustrated 2000 Building Code Handbook)



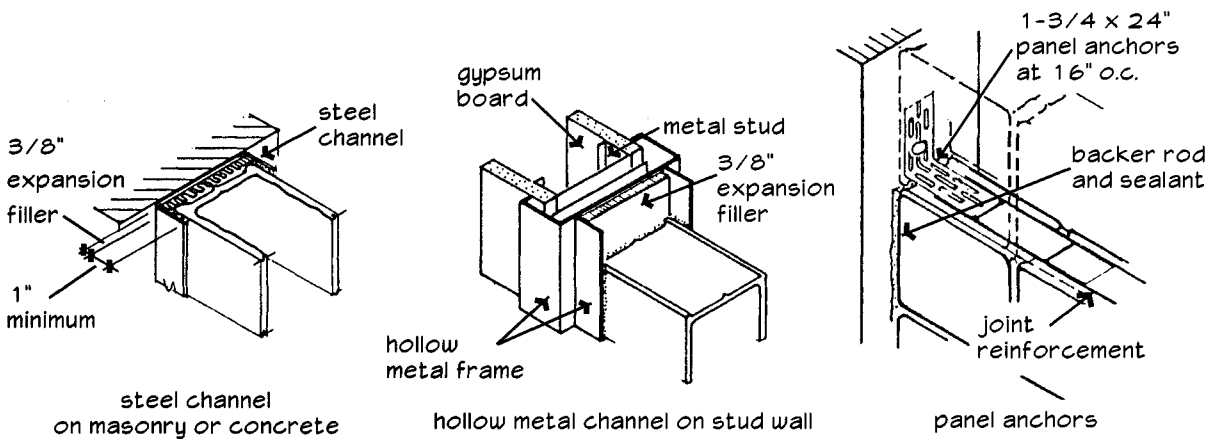
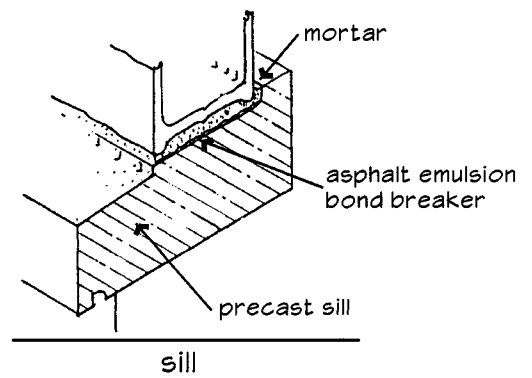
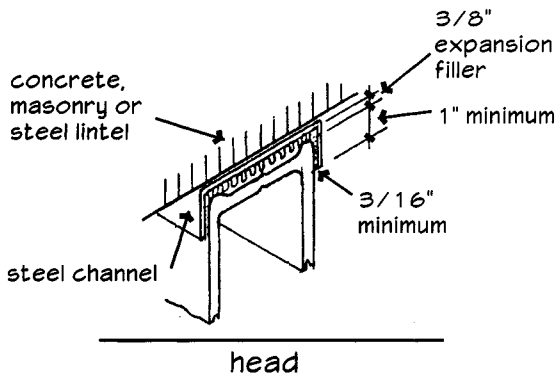
(From MSJC Building Code Requirements for Masonry Structures, ACI 530/ASCE 5/ TMS 402)



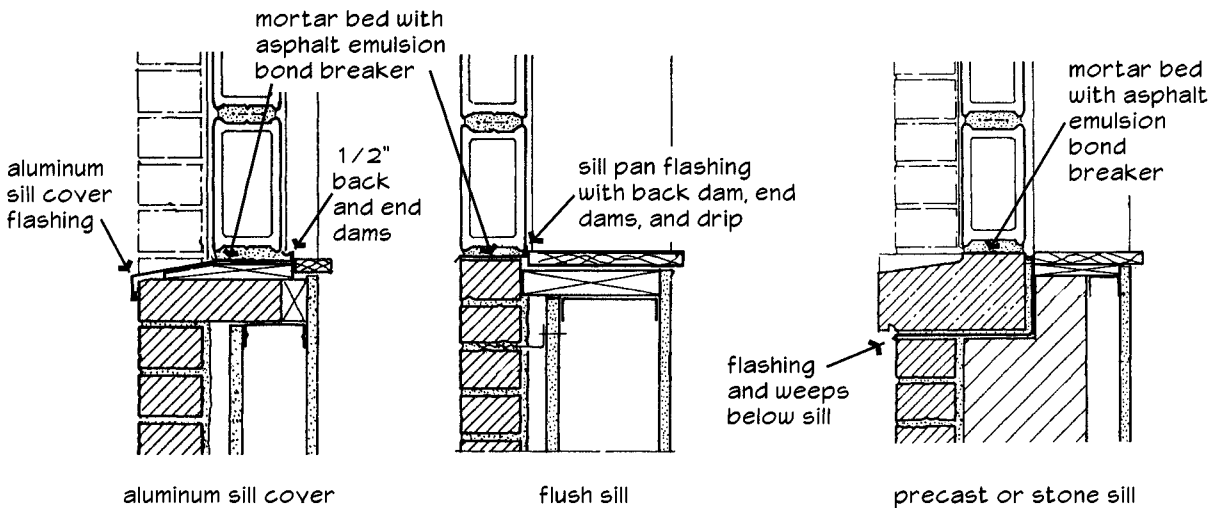
joint reinforcement is required in bed joints at 16" on center, and in the first bed joint above and below openings

(From Patterson, Illustrated 2000 Building Code Handbook)

13.2.2 Typical Glass Block Panel Details

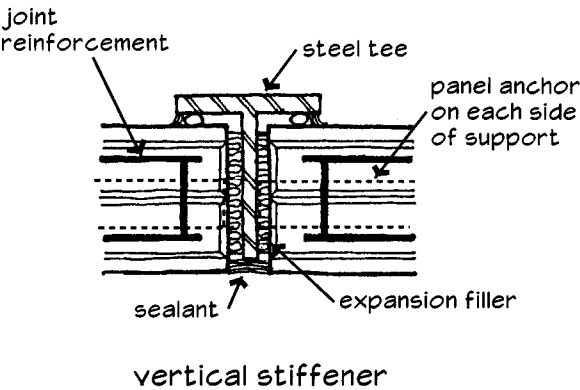
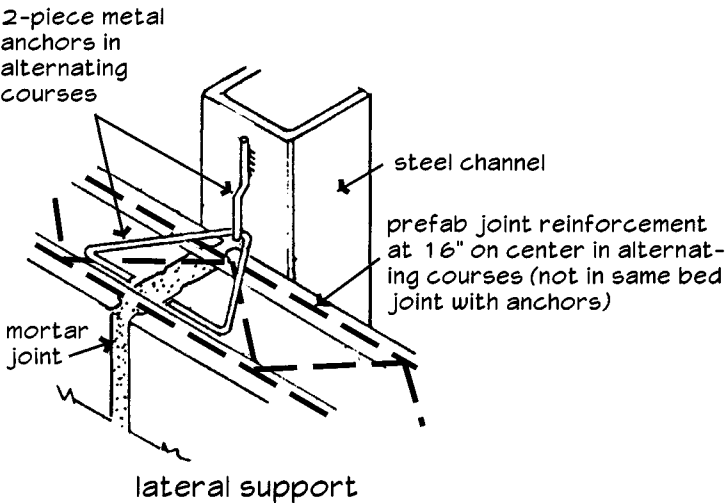
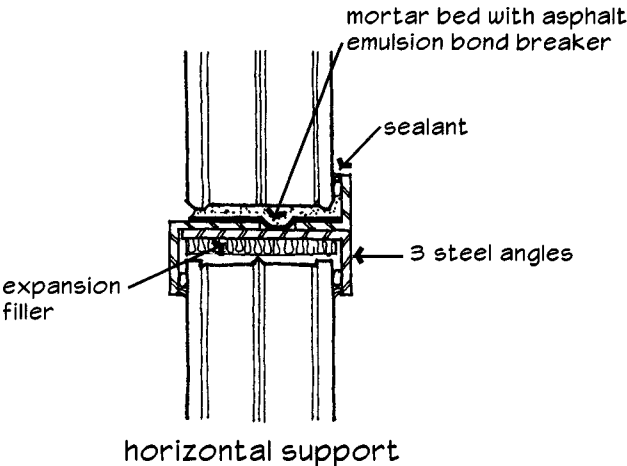


alternate jamb details

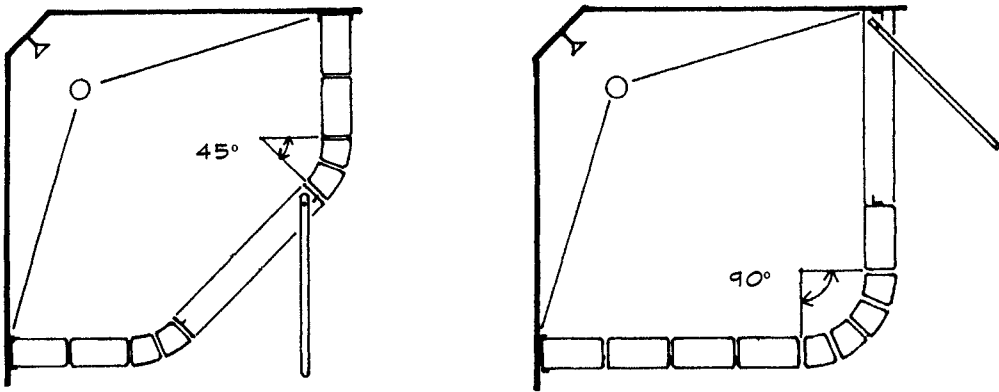


alternate sill details

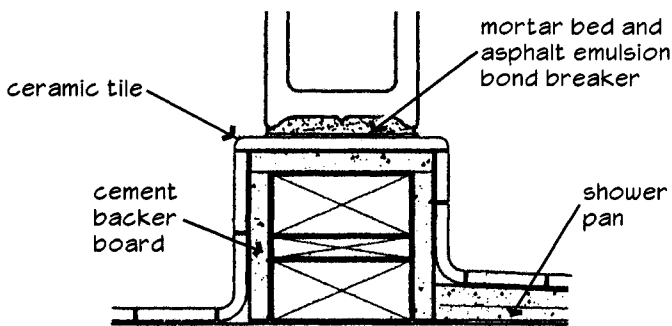
13.2.3 Glass Block Panel Stiffeners and Supports



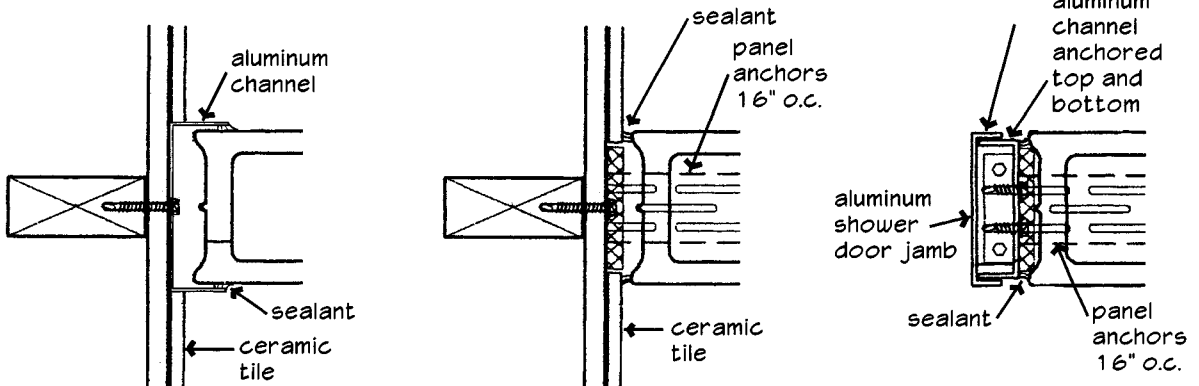
13.2.4 Glass Block Shower Enclosures



alternate shower plans using proprietary radial block shapes



sill detail

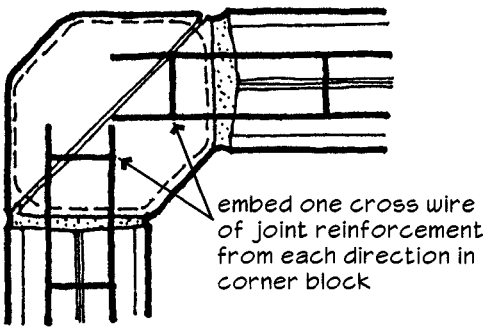


alternate details at wall anchorage (ceiling similar)

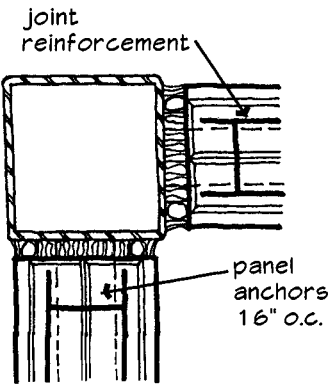
door jamb

(From Glashaus, Inc.)

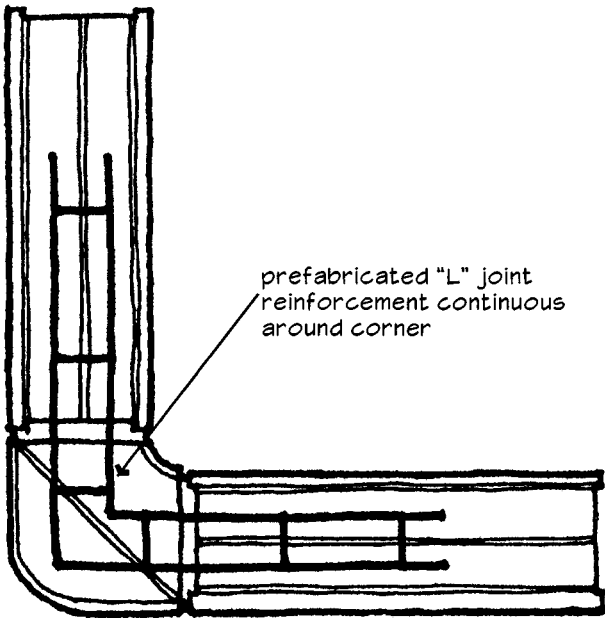
13.2.5 Glass Block Corner Details



proprietary hexagonal corner block

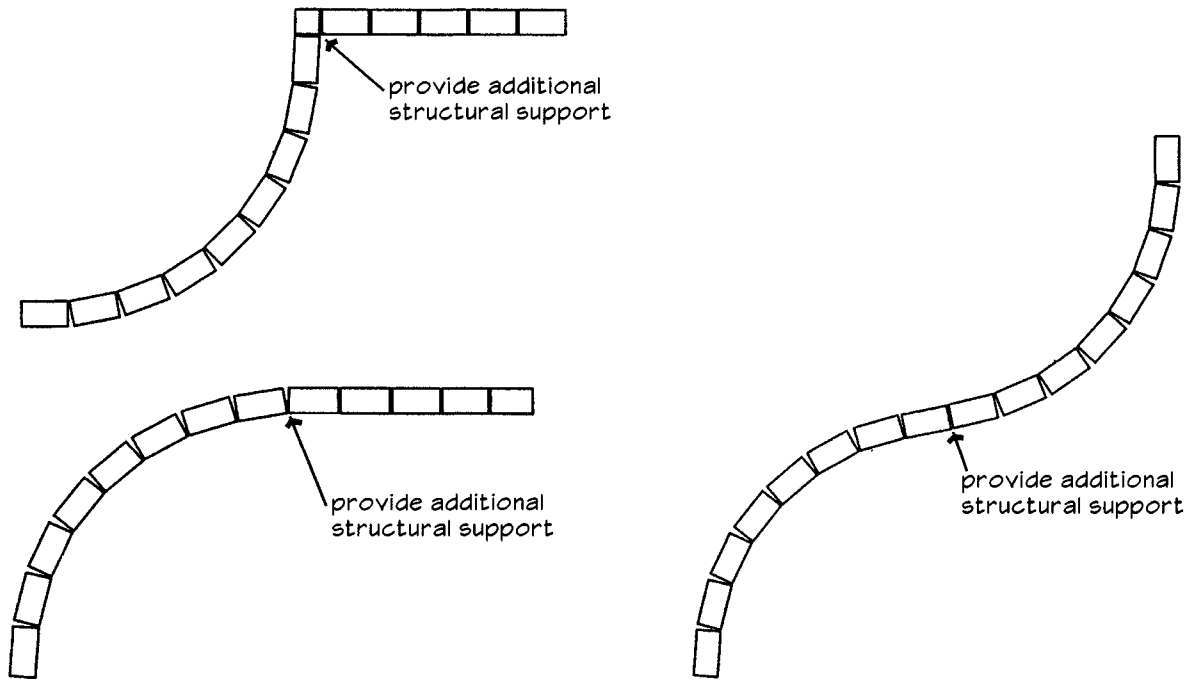


steel tube corner



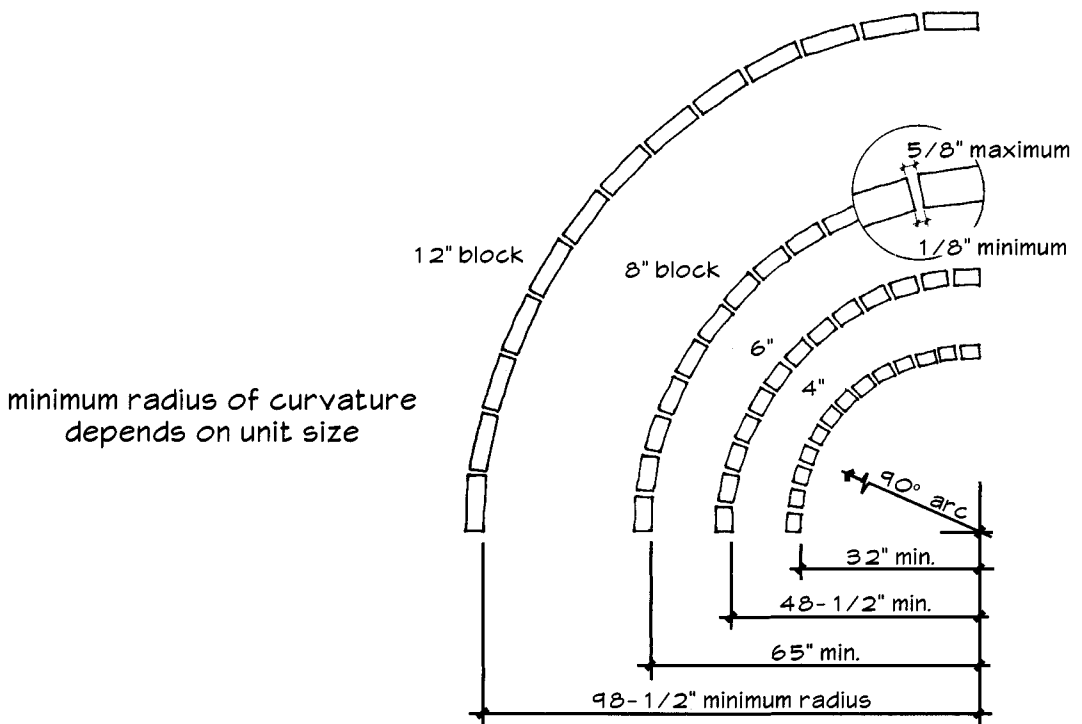
proprietary bullnose corner block

13.2.6 Curved Glass Block Walls



additional structural supports required at connection between curved and straight panels, and at inflection points of serpentine curves

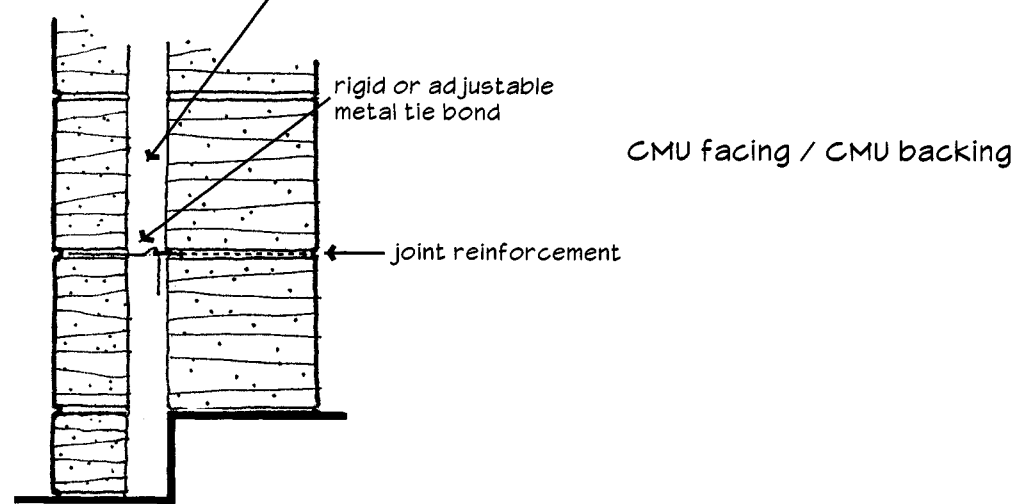
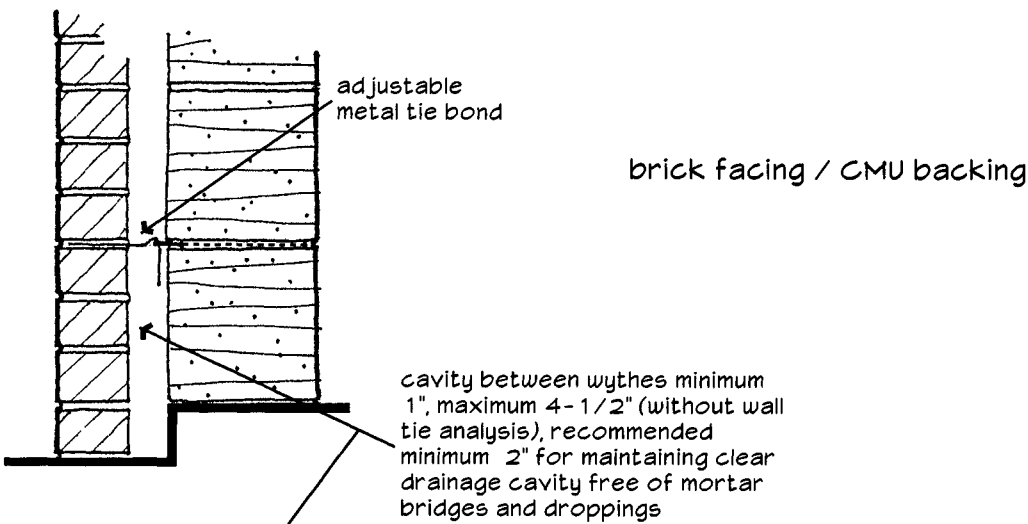
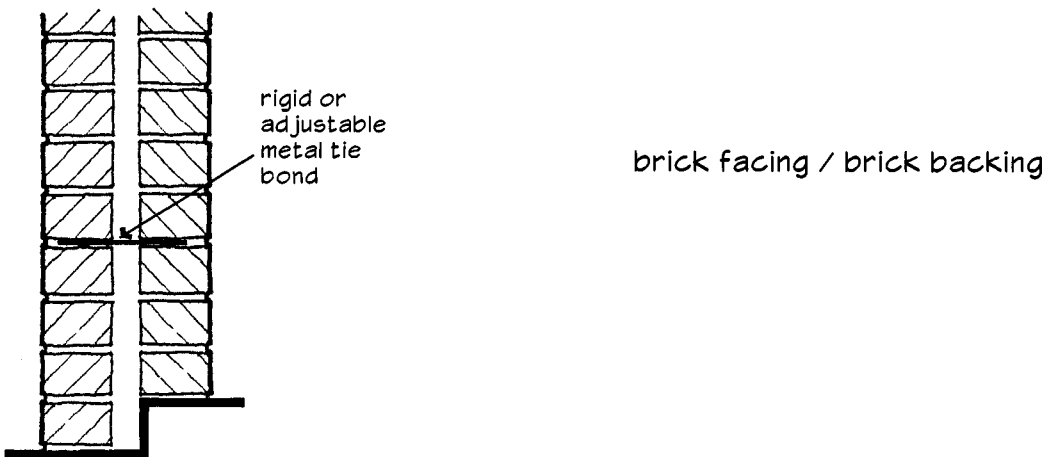
(From Patterson, Illustrated 2000 Building Code Handbook)



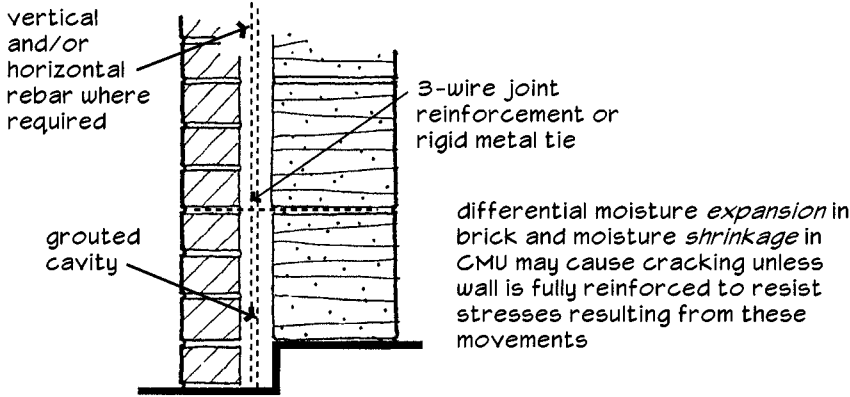
Multi-Wythe Masonry Walls

14.1	Multi-Wythe Wall Types	14.3.8	Cast Stone Parapet Copings
14.1.1	Masonry Cavity Walls	14.3.9	Metal Parapet Copings
14.1.2	Composite Masonry Walls	14.3.10	Reglet and Counterflashing at Roof
14.2	Empirical Design Requirements	14.3.11	Differential Movement at Shelf Angles
14.2.1	Load Distribution in Multi-Wythe Masonry Walls	14.3.12	Masonry Shelf Angle at Concrete Beam
14.2.2	Lateral Support Requirements	14.3.13	Masonry Shelf Angle at Steel Beam/Column Corner
14.2.3	Multi-Wythe Masonry Wall Ties	14.3.14	Suspended Brick Soffit at Steel Beam
14.2.4	Tie Spacing in Multi-Wythe Masonry Walls		
14.2.5	Header Spacing in Multi-Wythe Masonry Walls		
14.2.6	Masonry Shear Wall Types		
14.2.7	Empirical Masonry Shear Wall Requirements		
14.2.8	Prescriptive Masonry Reinforcing Requirements		
14.2.9	Masonry Reinforcement in Seismic Design Category C		
14.2.10	Masonry Reinforcement in Seismic Design Categories D, E and F		
14.2.11	Reinforcing Bar Size Limitations for Hollow Unit Masonry Construction		
14.2.12	Area of Reinforcing Steel for Masonry Construction		
14.2.13	Empirical Requirements for Corbelled Masonry		
14.2.14	Empirical Requirements for Masonry Parapets		
14.2.15	Wind Speed and Pressure Equivalents		
14.3	Multi-Wythe Masonry Wall Details		
14.3.1	Connecting to Precast Concrete		
14.3.2	Connecting to Steel Joists and Beams		
14.3.3	Connecting to Wood Frame Floors and Roofs		
14.3.4	Reinforced Masonry Beams		
14.3.5	Multi-Wythe Masonry Wall Pilasters		
14.3.6	Basic Cavity Wall Detailing		
14.3.7	Cavity Wall Flashing at Steel Columns		

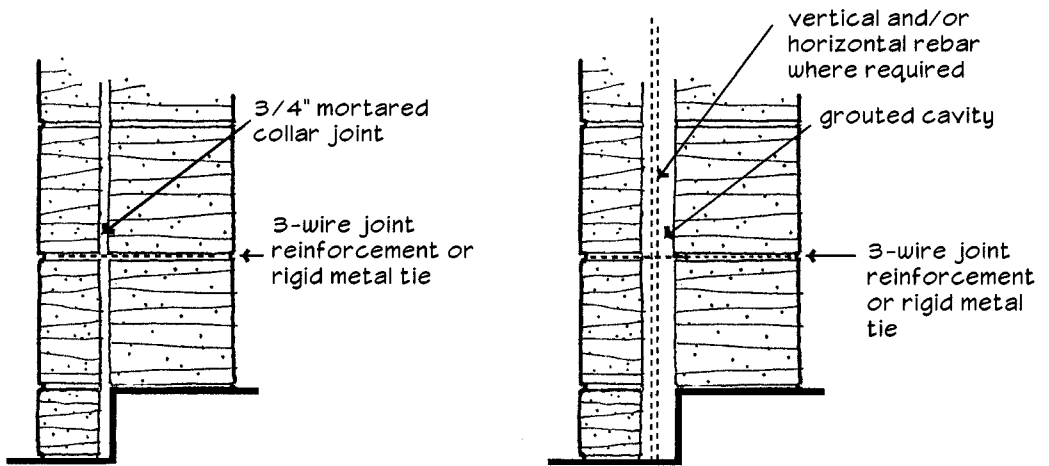
14.1.1 Masonry Cavity Walls



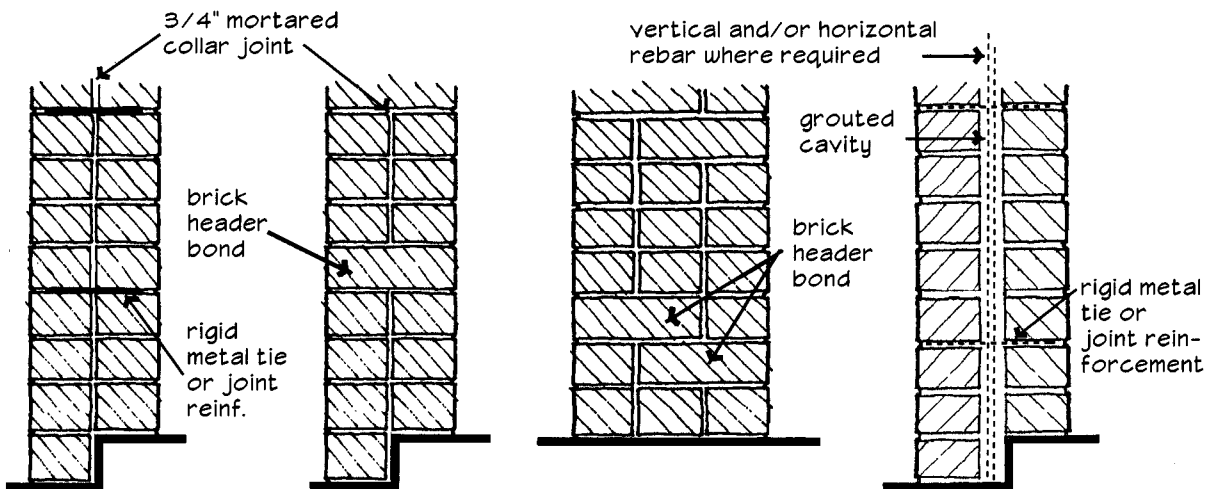
14.1.2 Composite Masonry Walls



brick facing / CMU backing



CMU facing / CMU backing

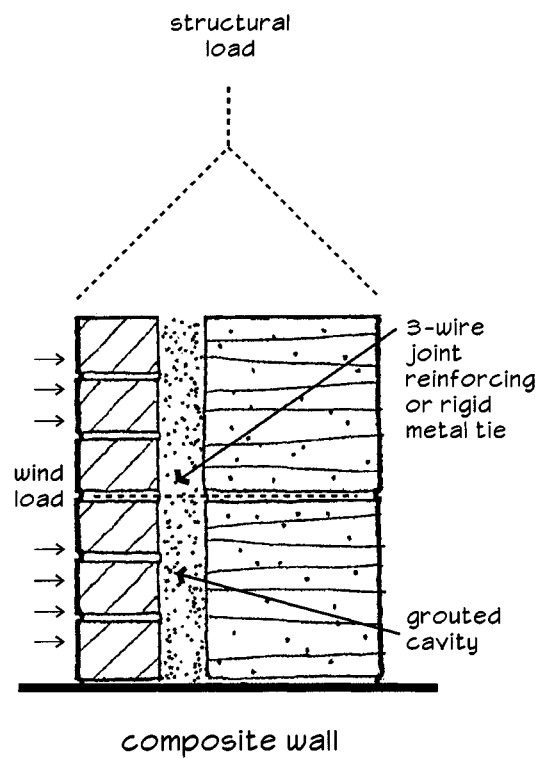
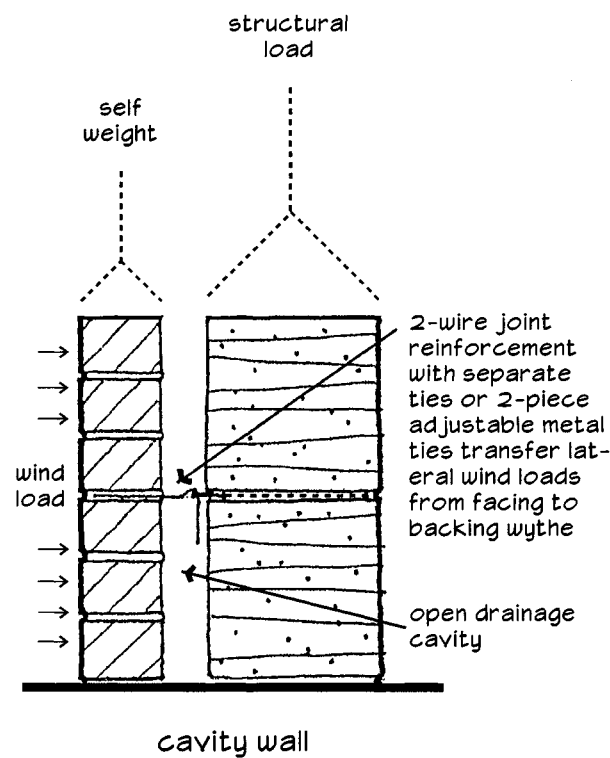


brick facing / brick backing

14.2.1 Load Distribution in Multi-Wythe Masonry Walls

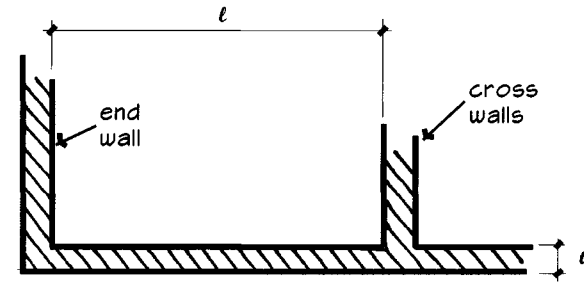
backing and facing wythes act independently in resisting applied vertical and lateral loads

backing and facing wythes act together in resisting applied vertical and lateral loads

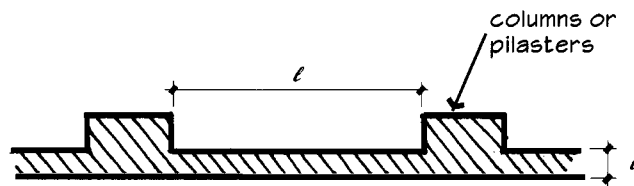


14.2.2 Lateral Support Requirements

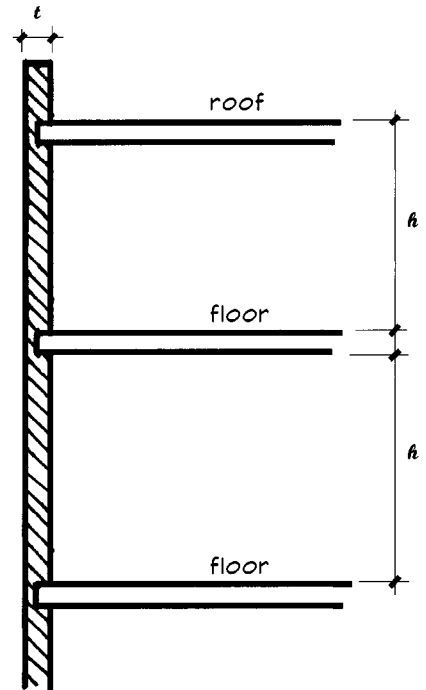
Masonry walls may span vertically between floors and roof or between spandrel beams, or span horizontally between intersecting walls, columns or pilasters. Building codes specify span-to-thickness ratios as ℓ/t or h/t which determines the minimum required wall thickness for a given span. Determine wall thickness and then design the lateral support system and connections by either empirical or engineered design methods to transfer loads to the force-resisting elements.



wall spanning horizontally between intersecting walls



wall spanning horizontally between columns or pilasters



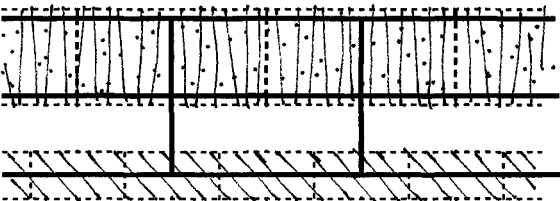
wall spanning vertically between floors, roof, or spandrel beams

Empirical Span-to-Thickness Ratios for Lateral Support of Masonry Walls

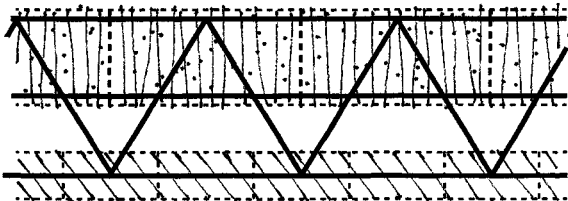
Wall or Element	Maximum Unsupported Height or Length to Nominal Thickness (ℓ/t or h/t)
Bearing walls	
solid or grouted solid	20
all other walls	18
Non-bearing walls	
exterior	18
interior	36
Cantilever walls	
solid or solidly grouted	6
hollow	4
Unreinforced parapets ($\ell = 8$ in. min.)	3

(Based on requirements of MSJC Building Code Requirements for Masonry Structures, ACI 530/ASCE 6/TMS 402)

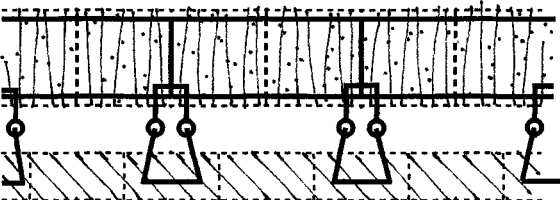
14.2.3 Multi-Wythe Masonry Wall Ties



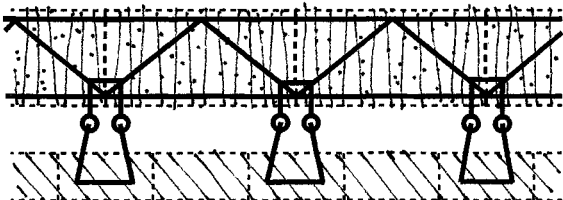
3-wire ladder reinforcement



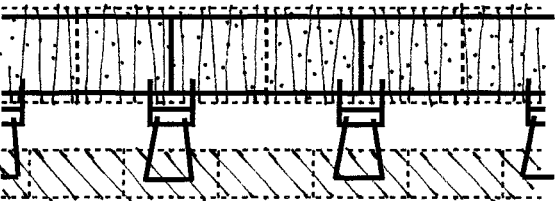
3-wire truss reinforcement



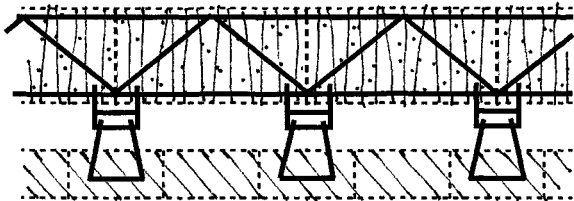
ladder reinforcement with eye and pintle ties



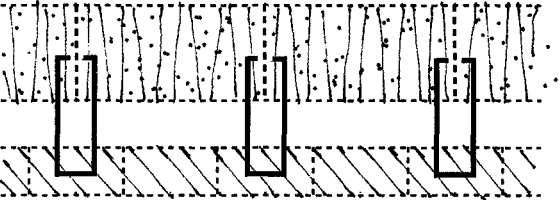
truss reinforcement with eye and pintle ties



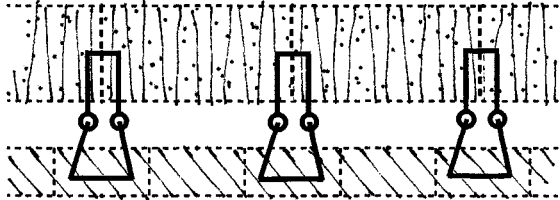
ladder reinforcement with tab ties



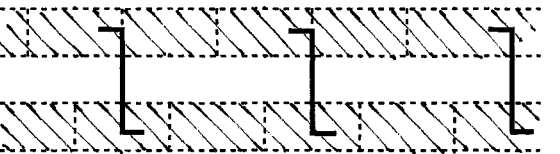
truss reinforcement with tab ties



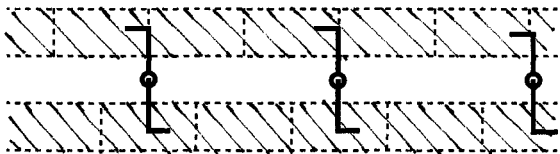
rigid rectangular ties



adjustable triangular ties

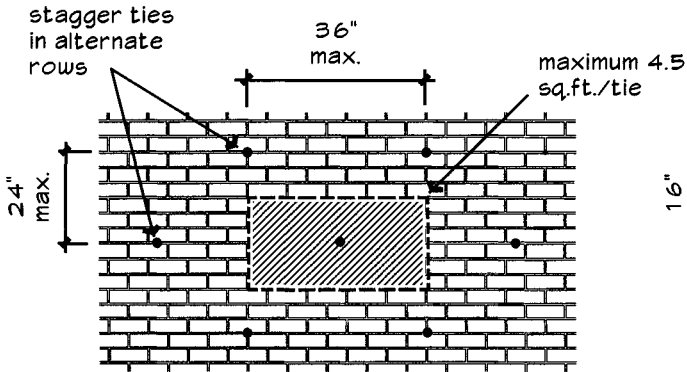


rigid "Z" ties
(for use with solid units only)

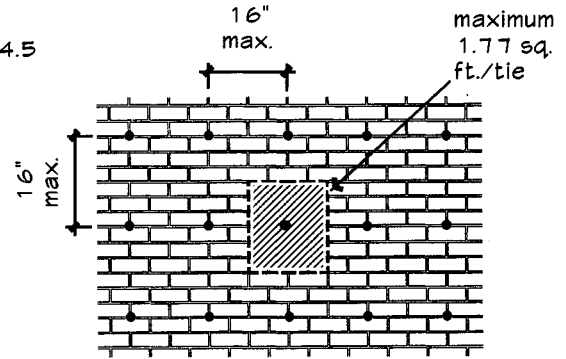


adjustable "Z" ties
(for use with solid units only)

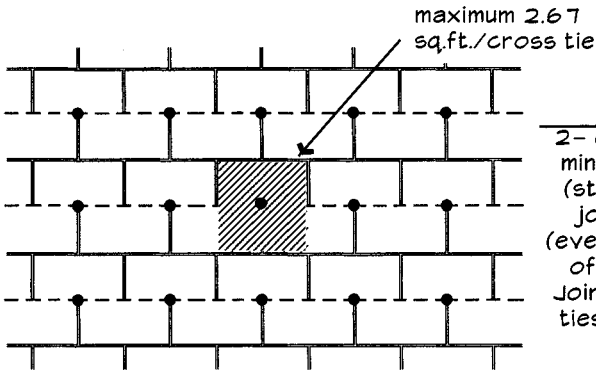
14.2.4 Tie Spacing in Multi-Wythe Masonry Walls



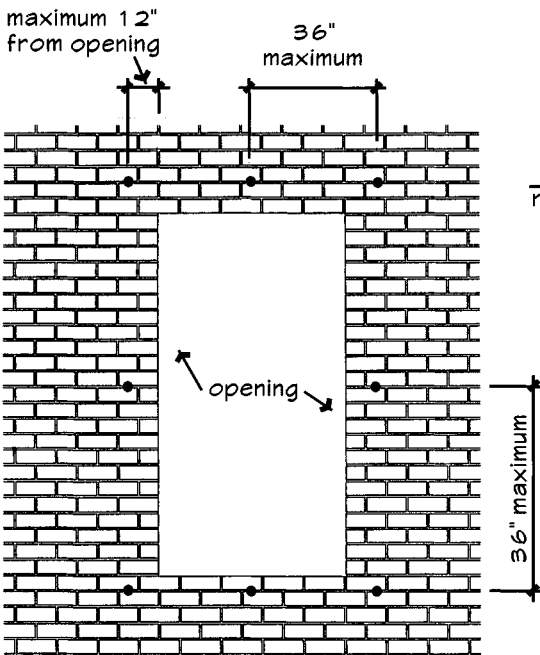
rigid ties
minimum 3/16" (w2.8) wire diameter,
maximum spacing 24" on center vertical
x 36" on center horizontal, maximum
4.5 sq.ft./tie



adjustable ties
minimum 3/16" (w2.8) wire diameter,
maximum spacing 16" on center
vertical and horizontal, maximum
1.77 sq.ft./tie

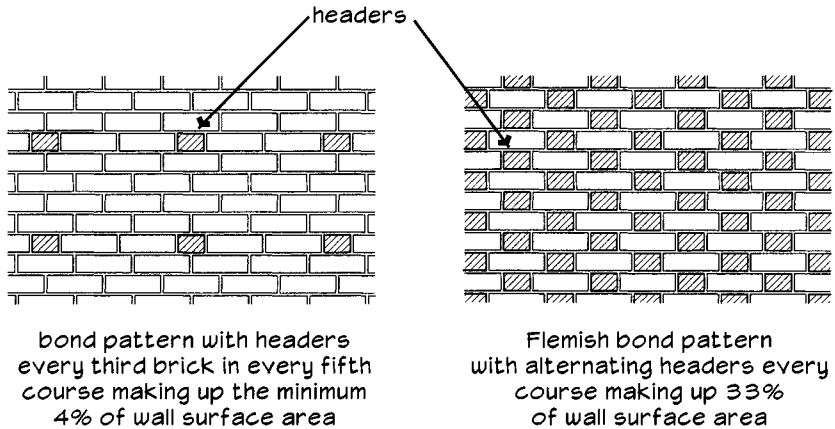
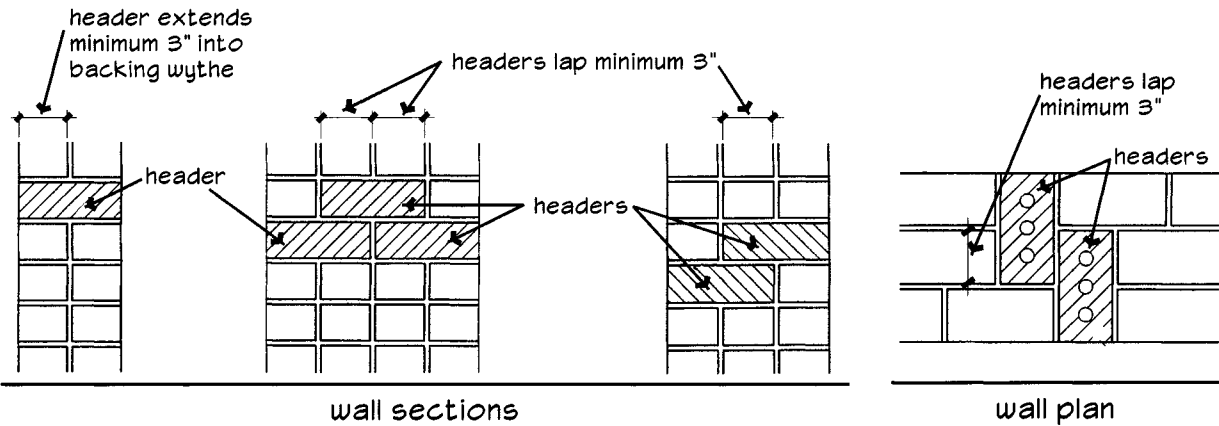


prefabricated joint reinforcement ties
2- or 3-wire ladder or truss type joint reinforcement,
minimum 9 gauge (W1.7) cross wires at 16" on center
(standard on prefabricated joint reinforcement) and
joint reinforcement spaced 24" on center maximum
(every third course of 8" high units or every 2nd course
of 12" high units), maximum 2.67 sq.ft. per cross tie.
Joint reinforcement with eye and pintle or loop and tab
ties subject to same requirements as adjustable ties.

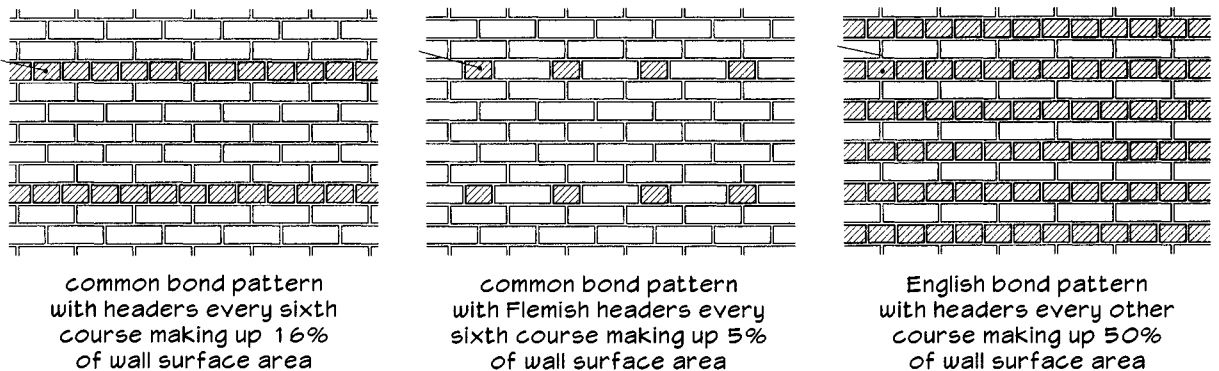


additional ties
required around openings at maximum 36" on
center and within 12" of opening

14.2.5 Header Spacing in Multi-Wythe Masonry Walls



- 24" maximum vertical or horizontal distance between headers
- headers must make up a minimum of 4% of wall surface area



header bond patterns

(Adapted from Patterson, Illustrated 2000 Building Code Handbook, McGraw-Hill, 2001)

14.2.6 Masonry Shear Wall Types

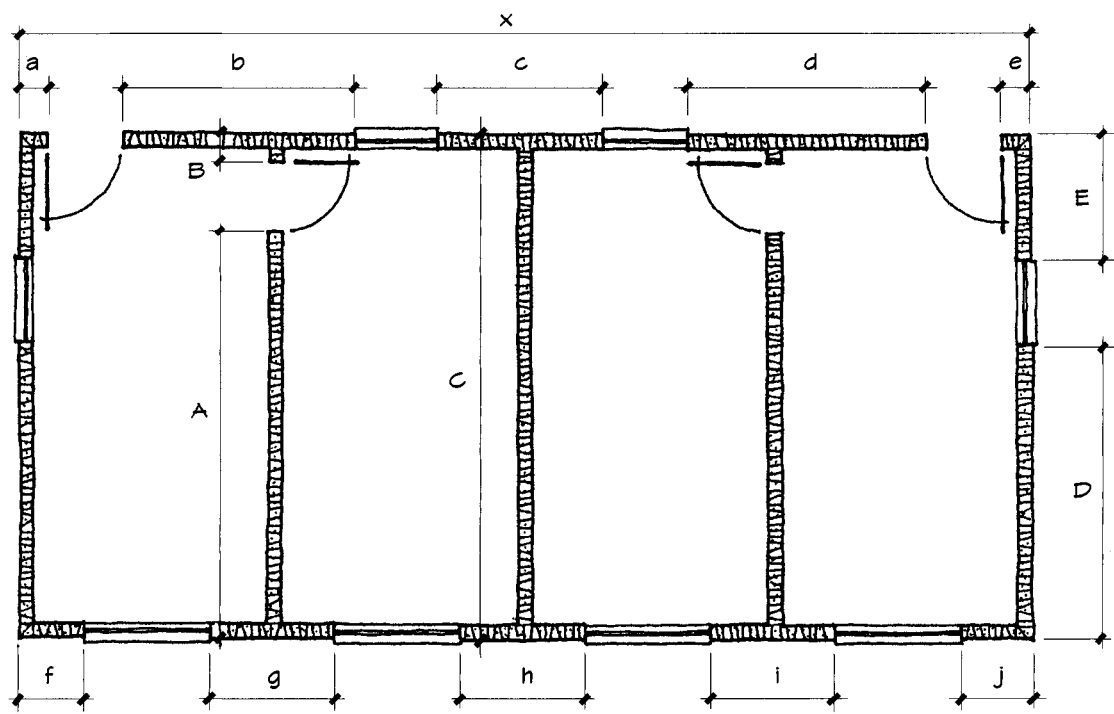
Type of Shear Wall	Design Method	Minimum Required Reinforcement	Permitted in Seismic Design Category
Empirical	Empirical Design	None	A
Ordinary Plain (unreinforced)	Allowable Stress Design, Strength Design, or Prestressed Masonry	None	A, B
Detailed Plain (unreinforced)	Allowable Stress Design or Strength Design	<p><i>Vertical</i> reinforcement of minimum one No. 4 or two No. 3 deformed steel bars area at corners, within 16" of each side of openings, within 8" of each side of movement joints, within 8" of the ends of walls, and at a maximum spacing of 10 ft.</p> <p><i>Horizontal</i> reinforcement of either 2-wire, 9 gauge prefabricated joint reinforcement or minimum one No. 4 or two No. 3 deformed steel bond beam bars continuously at structurally connected roof and floor levels, within 16" of the top of walls, at the bottom and top of wall openings extending at least 24" or 40 bar diameters past the opening*, as well as 2-wire, 9 gauge prefabricated joint reinforcement spaced not more than 16" on center or minimum one No. 4 or two No. 3 deformed steel bond beam bars spaced 10 ft. on center.</p>	A, B
Ordinary Reinforced	Allowable Stress Design or Strength Design	<p><i>Vertical</i> reinforcement of minimum one No. 4 or two No. 3 deformed steel bars at corners, within 16" of each side of openings, within 8" of each side of movement joints, within 8" of the ends of walls, and at a maximum spacing of 10 ft.</p> <p><i>Horizontal</i> reinforcement of either 2-wire, 9 gauge prefabricated joint reinforcement or minimum one No. 4 or two No. 3 deformed steel bond beam bars continuously at structurally connected roof and floor levels, within 16" of the top of walls, at the bottom and top of wall openings extending at least 24" or 40 bar diameters past the opening*, as well as 2-wire 9 gauge prefabricated joint reinforcement spaced not more than 16" on center or minimum one No. 4 or two No. 3 deformed steel bond beam bars spaced 10 ft. on center.</p>	A, B, C
Intermediate Reinforced	Allowable Stress Design or Strength Design	<p><i>Vertical</i> reinforcement of minimum one No. 4 or two No. 3 deformed steel bars at corners, within 16" of each side of openings, within 8" of each side of movement joints, within 8" of the ends of walls, and at a maximum spacing of 4 ft.</p> <p><i>Horizontal</i> reinforcement of either 2-wire, 9 gauge prefabricated joint reinforcement or minimum one No. 4 or two No. 3 deformed steel bond beam bars continuously at structurally connected roof and floor levels, within 16" of the top of walls, at the bottom and top of wall openings extending at least 24" or 40 bar diameters past the opening*, as well as 2-wire 9 gauge prefabricated joint reinforcement spaced not more than 16" on center or minimum one No. 4 or two No. 3 deformed steel bond beam bars spaced 10 ft. on center.</p>	A, B, C
Special Reinforced	Allowable Stress Design or Strength Design	Combined vertical and horizontal reinforcement at least 0.002 times gross cross-sectional area of wall, with a minimum of 0.0007 times gross cross-sectional area of wall in each direction, uniformly distributed and spaced at the smaller of 1/3 the length of the shear wall, 1/3 the height of the shear wall, or 4 ft. on center for masonry laid in other than stack bond. Shear reinforcement must be anchored around vertical reinforcing bars with a standard hook.	A, B, C, D, E, F

* Reinforcement adjacent to openings need not be provided for openings smaller than 16 in. in either the horizontal or vertical direction, unless the spacing of distributed reinforcement is interrupted by such reinforcement.

(Based on requirements of the MSJC Building Code Requirements for Masonry Structures, ACI 530/ASCE 5/TMS 402-02)

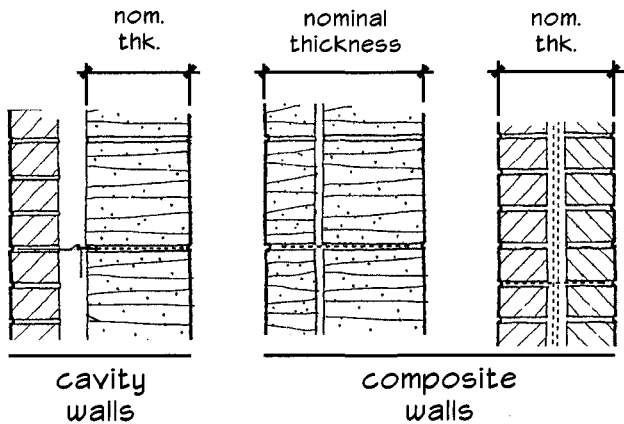
14.2.7 Empirical Masonry Shear Wall Requirements

Where structures depend on masonry walls for lateral support, provide shear walls parallel to the direction of the lateral forces to be resisted. In each direction in which they are required for lateral stability, shear walls must be positioned in two separate planes. The minimum cumulative length of shear walls provided must be 0.4 times the long dimension of the building. Cumulative length of shear walls does not include openings. The maximum ratio of shear wall spacing divided by shear wall segment length may not exceed the ratios listed in the table below. Shear walls must be a minimum of 8 in. thick. In composite walls, the thickness is measured as the nominal thickness of the two wythes plus the mortared collar joint or grouted cavity. In cavity walls, thickness is measured as the nominal dimension of the shear-resisting wythe only.



walls in long dimension of building: $a + b + c + d + e + f + g + h + i + j \geq 0.4 X$
walls in short dimension of building: $A + B + C + A + B + D + E + D + E \geq 0.4 X$

Floor or Roof Construction	Maximum Ratio of Shear Wall Spacing to Shear Wall Length
Cast-in-place concrete	5:1
Precast concrete	4:1
Metal deck with concrete fill	3:1
Metal deck with no fill	2:1
Wood diaphragm	2:1



(Based on requirements of the Masonry Standards Joint Committee (MSJC) Building Code Requirements for Masonry Structures, ACI 530/ASCE 5/TMS 402, and International Building Code 2000)

14.2.8 Prescriptive Masonry Reinforcing Requirements

Seismic Design Category A or B

- No minimum reinforcing requirements. Walls must be anchored to walls, floors or roofs providing lateral support. For Seismic Category B, shear walls may not be empirically designed and must meet minimum requirements for “ordinary plain” shear walls.

Seismic Design Category C

- Comply with requirements for Categories A and B plus the following requirements.
- Masonry elements which are *not* part of the lateral-force-resisting system must be reinforced in *either* the vertical or horizontal direction, depending on location of the lateral supporting elements.
 - Horizontal joint reinforcement with two longitudinal 9 gauge (W1.7) wires spaced 16" on center maximum, or two #3 or one #4 bar spaced 48" on center maximum. Must include horizontal reinforcement within 16" of the top and bottom of wall.
 - Vertical reinforcement of two #3 or one #4 bar 48" on center maximum and within 16" of ends of walls.
 - In addition to minimum reinforcing requirements, two #3 or one #4 bar on all sides of and adjacent to every opening larger than 16" in either direction, and extending 40 bar diameters or 24" minimum beyond the corners of the opening.
- For masonry elements which *are* part of the lateral-force-resisting system, shear walls must be reinforced in *both* the vertical and horizontal direction to comply with the minimum requirements for “ordinary reinforced” shear walls as follows:
 - Horizontal joint reinforcement with two longitudinal 9 gauge (W1.7) wires, spaced 16" on center, or two #3 or one #4 bar spaced not more than 10 ft. on center. Must include horizontal reinforcement at top and bottom of wall openings and extending 40 bar diameters or 24" minimum beyond the corners of the opening, within 16" of the tops of walls, and continuously at structurally connected roofs and floors.
 - Vertical reinforcement of two #3 or one #4 bar at corners, within 16" of each side of openings, within 8" of each side of movement joints, within 8" of ends of walls, and at 10 ft. on center maximum.

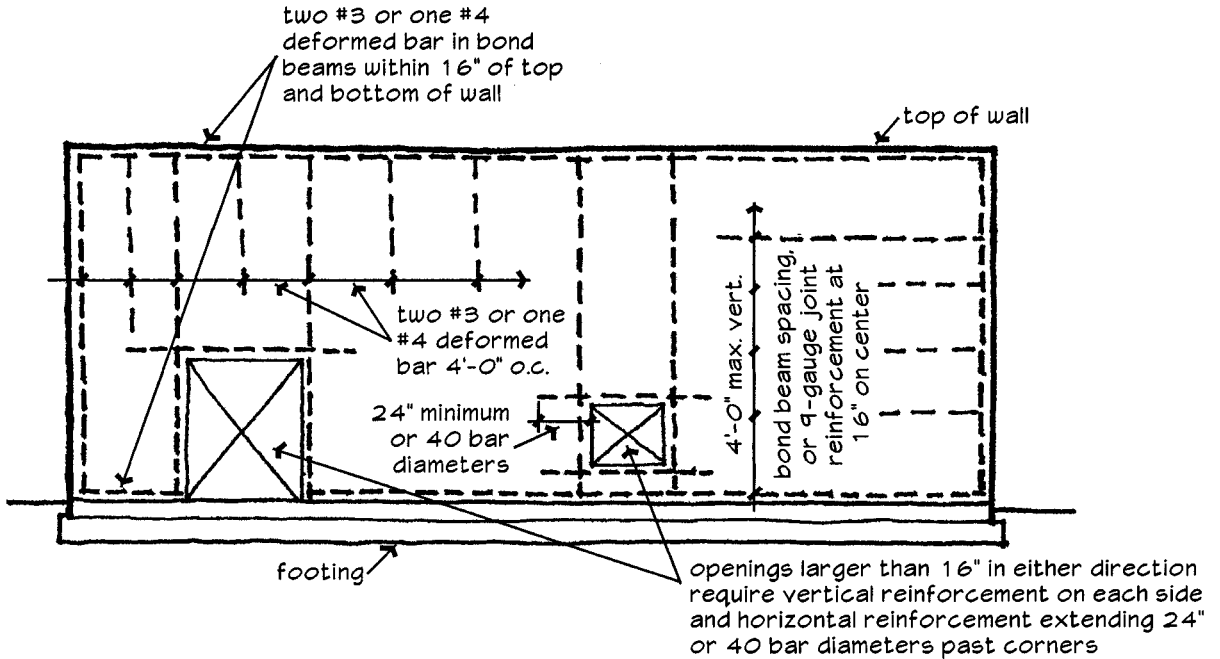
Seismic Design Category D

- Comply with requirements for Category C plus the following requirements.
- Masonry elements which *are* part of the lateral-force-resisting system must be reinforced in *both* the vertical and horizontal direction. The sum of the cross-sectional area of horizontal and vertical reinforcement must be at least 0.002 times the gross cross-sectional area of the wall, with 0.0007 minimum in each direction. Reinforcement must be evenly distributed. Maximum spacing of reinforcement is 48" for other than stack bond masonry. For stack bond masonry, units must be solid, solidly grouted hollow open-end units, or solidly grouted hollow units with full head joints, and reinforcement spaced a maximum of 24" on center.
- Shear walls must comply with the minimum requirements for “special reinforced” shear walls. Reinforcement spacing must be the smaller of one-third the height or length of the shear wall or 48" on center. Minimum cross-sectional area of vertical reinforcement must be one-third of the required shear wall reinforcement. Shear reinforcement must be anchored around vertical reinforcing bars with standard hook. Hooks for lateral tie anchorage shall be either 135° or 180° standard hooks. Columns must have lateral ties at 8" on center, minimum 3/8" diameter embedded in grout.

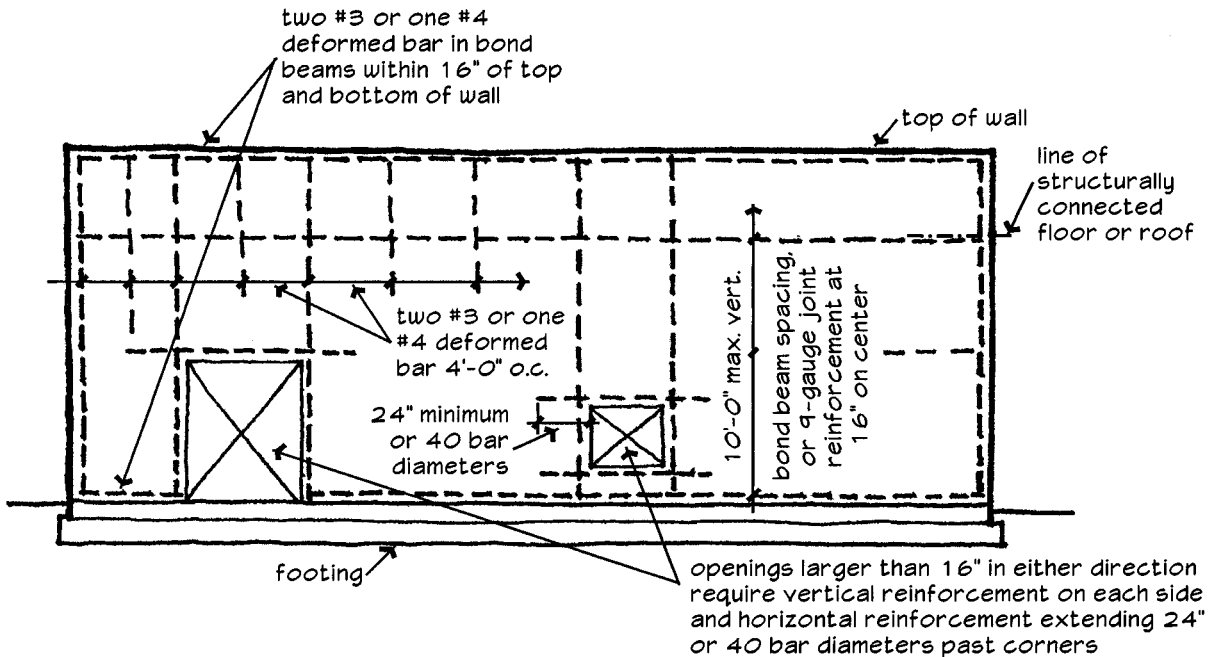
Seismic Design Category E or F

- Comply with requirements for Category D plus the following requirements.
- For stack bond walls which are *not* part of the lateral-force-resisting system, solid units or solidly grouted hollow open-end units, horizontal reinforcement with a cross-sectional area at least 0.0015 times the gross cross-sectional area of the masonry, maximum spacing 24" on center.
- For stack bond walls which *are* part of the lateral-force-resisting system, solid units or solidly grouted open-end units, horizontal reinforcement with a cross-sectional area at least 0.0025 times the gross cross-sectional area of the masonry, maximum spacing 16" on center.

14.2.9 Masonry Reinforcement in Seismic Design Category C



masonry elements which are *not* part of the lateral-force-resisting system
reinforcement required in *either* the vertical or horizontal direction



masonry elements which *are* part of the lateral-force-resisting system
reinforcement required in *both* the vertical or horizontal direction

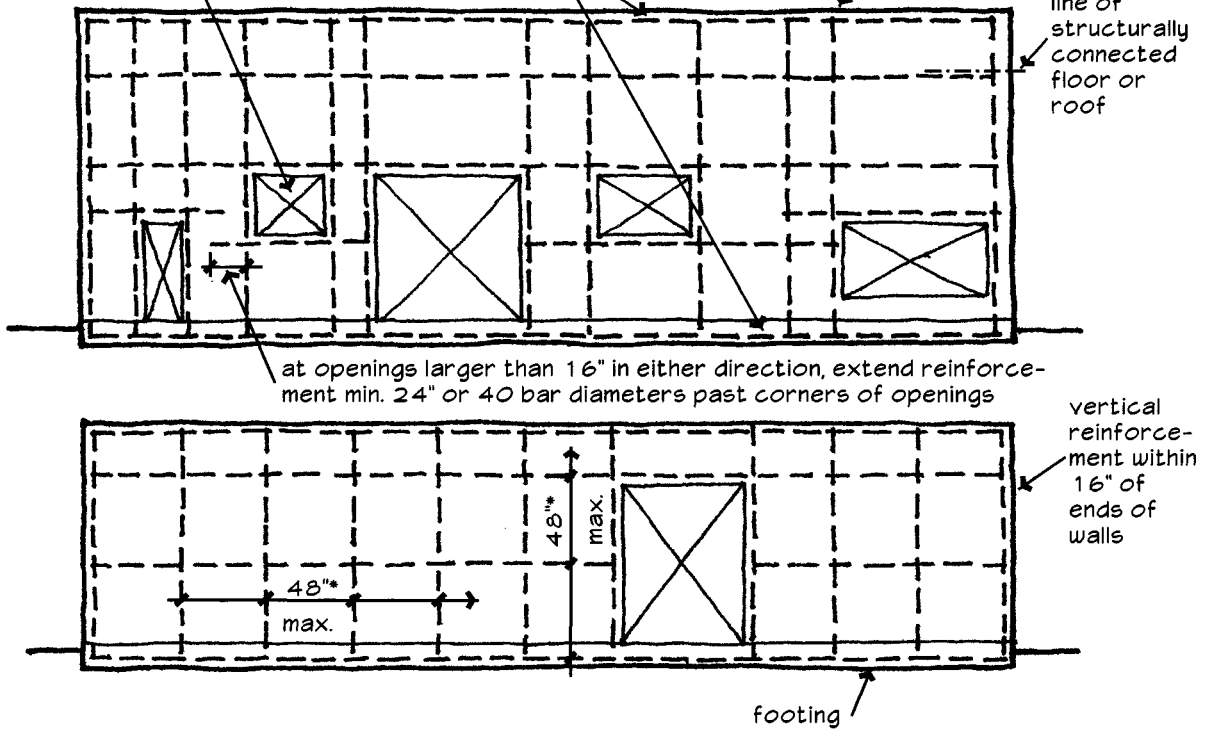
14.2.10 Masonry Reinforcement in Seismic Design Categories D, E and F

provide vertical reinforcement on either side of openings larger than 16" in either direction

horizontal reinforcement within 16" of top and bottom of wall

top of wall

line of structurally connected floor or roof



- * Masonry elements that are part of the lateral-force-resisting system must have reinforcement in *both* the vertical and horizontal direction. The sum of the cross-sectional area of horizontal and vertical reinforcement must be 0.002 times the gross cross-sectional area of the wall, with 0.0007 minimum in each direction. Reinforcement must be evenly distributed and have a maximum spacing of the smaller of $1/3$ the wall height, $1/3$ the wall length, or 4'-0" on center. *Requirements for stack bond masonry are more restrictive.*

14.2.11 Reinforcing Bar Size Limitations for Hollow Unit Masonry Construction

Reinforcing bars in masonry construction must be fully embedded in grout for effective structural function. Because the cavity or collar joint between masonry wythes and the cores or cells of CMU and hollow brick are small, the MSJC and International Building Codes impose bar size limitations to assure adequate grout flow and embedment of the reinforcing steel. These limitations may be based on the nominal wall thickness or the clear dimension of the cell or collar joint, and are summarized as follows:

- Maximum bar size
 No. 11 (MSJC and IBC)
- Maximum bar size based on nominal wall thickness
 1/8 nominal wall thickness (IBC)
- Maximum bar size based on clear dimension of unit cell
 1/2 clear cell or collar joint thickness (MSJC)
 1/4 clear cell or collar joint thickness (IBC)

The following tables list code limitations imposed by the MSJC *Building Code Requirements for Masonry Structures* (ACI 530/ASCE 5/TMS 402-99) and the *International Building Code 2000*.

Note: Compare limitations based on 1/4 or 1/2 of clear grout space dimension or on 1/8 of wall thickness (tables on this page) with limitations based on percent of grout space area (tables on next page) to determine which governs.

Maximum Reinforcing Bar Size Based on 1/8 Wall Thickness, t					
Nominal Wall Thickness, t (in.) →	4 [§]	6	8	10	12
Max. Bar Diameter (in.)	0.5 in.	0.75 in.	1.0 in.	1.25 in.	1.5 in.
Bar Size Designation	No. 4	No. 6	No. 8	No. 9	No. 11

§ While 4-in. nominal hollow clay masonry units are available, most 4-in. nominal hollow concrete masonry is nearly solid and cannot be reinforced and grouted.

Bar Diameter Limitations Based on Clear Cell or Collar Joint Thickness			
Nominal Unit Thickness (in.)	Probable Maximum Clear Cell or Collar Joint Dimension (in.) [§]	Maximum Bar Diameter Based on 1/2 Clear Cell or Collar Joint	Maximum Bar Diameter Based on 1/4 Clear Cell or Collar Joint
Hollow Clay Masonry			
4 [†]	1.0	0.5	0.25
5	1.5	0.75	0.38
6	2.5	1.25	0.63
8	4	3.0	1.0
10	5.75	2.88	1.44
12	7.5	3.75	1.88
Hollow Concrete Masonry			
4	1.125	0.56	0.28
6	2.625	1.31	0.66
8	4.125	2.06	1.03
10	5.875	2.94	1.47
12	7.625	3.81	1.91

§ Based on minimum face shell thickness from ASTM C652 for hollow clay units and ASTM C90 for concrete units, and assuming maximum allowable mortar protrusions of 1/2" both sides, reducing clear dimension by 1" total.

† While 4-in. nominal hollow clay masonry units are available, most 4-in. nominal hollow concrete masonry is nearly solid and cannot be reinforced and grouted.

14.2.12 Maximum Area of Vertical Steel for Hollow Unit Masonry Construction

The maximum area of vertical steel permitted in hollow unit cores or cells is based on the area of the grout space. The limitations imposed by the MSJC *Building Code Requirements for Masonry Structures* and the *International Building Code 2000* are slightly different for working stress and strength design.

- 6% of grout space area (MSJC and IBC working stress design)
- 4% of grout space area, except where splices occur (IBC strength design)

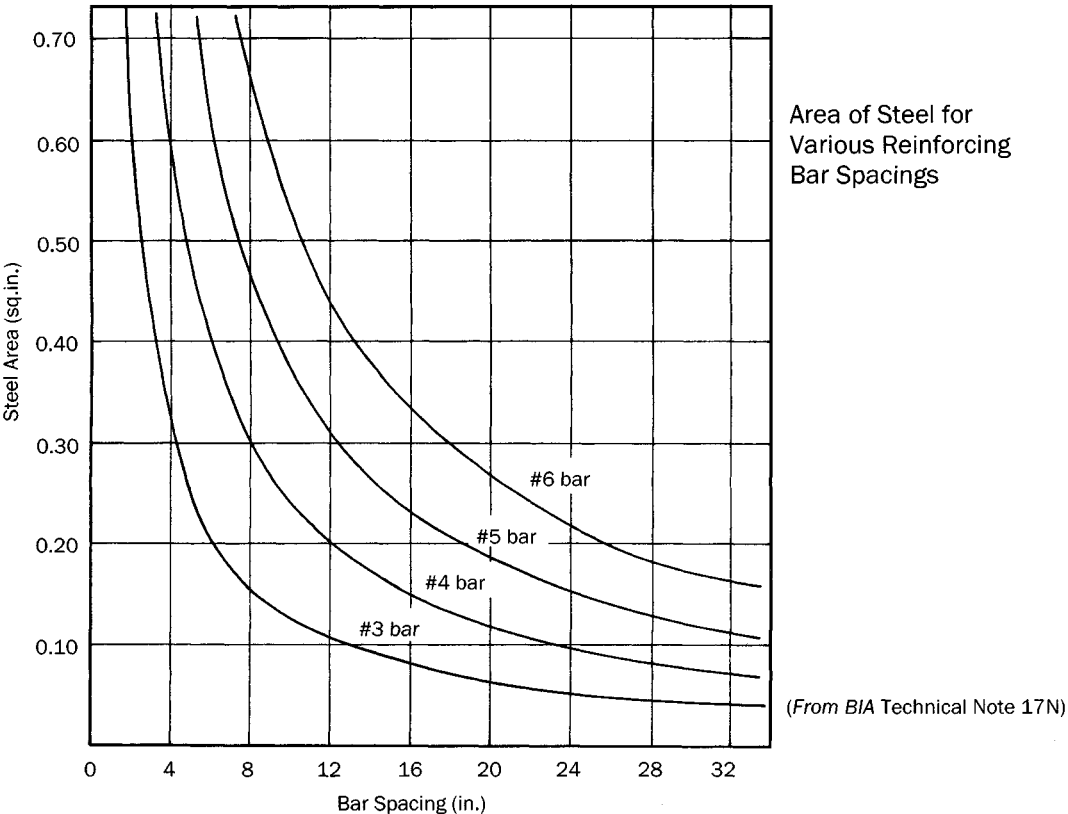
The following table lists maximum area limitations based on the approximate area of hollow cells in concrete masonry units of various nominal thicknesses. The area of cells in hollow clay units may be slightly larger or smaller depending on face shell thickness, web thickness, core shape, etc.

Note: Compare limitations based on percent of grout space area (table on this page) with limitations based on 1/4 or 1/2 of clear grout space dimension or on 1/8 wall thickness (tables on previous page) to determine which governs.

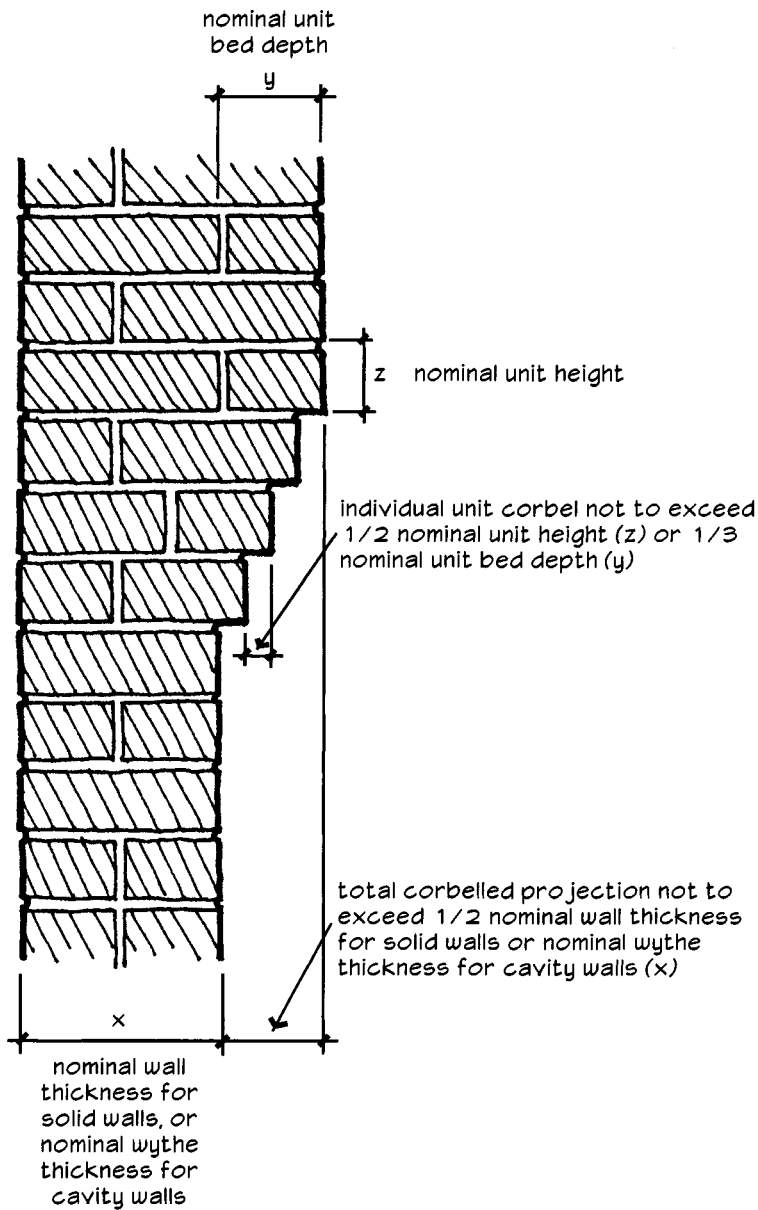
Maximum Area of Reinforcing Steel Based on Percentage of Grout Space Area			
Nominal CMU Wall Thickness, t (in.)	Approximate Area of CMU Cell (sq.in.) [§]	Maximum Area of Vertical Reinforcement Based on MSJC 6% Limit	Maximum Area of Vertical Reinforcement Based on IBC 4% Limit
4†	12.5	0.75	0.50
6	21	1.26	0.84
8	30	1.80	1.20
10	42	2.52	1.68
12	54	3.24	2.16

§ Cell area will vary based on actual face shell thickness, web thickness, core shape, etc. Check with local manufacturers to verify actual cell area.

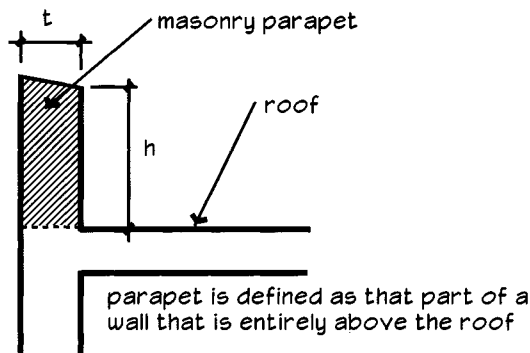
† Many nominal 4-in. CMU are nearly solid and cannot be reinforced and grouted.



14.2.13 Empirical Requirements for Corbelled Masonry



14.2.14 Empirical Requirements for Masonry Parapets



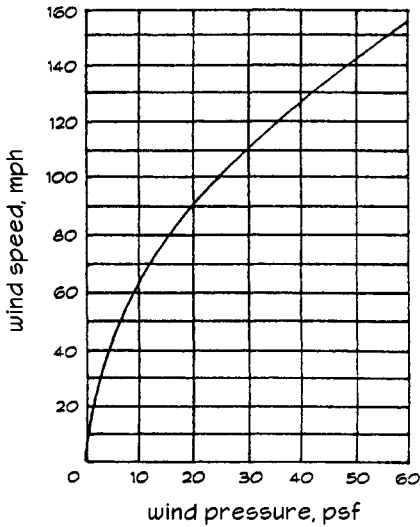
Masonry Parapet Wall Requirements		
Requirement	CABO*	MSJC*
Minimum thickness (t)		
solid masonry units	8	8
hollow masonry units	8	8
Maximum h/t ratio for unreinforced masonry parapets		
solid masonry units	4	3
hollow masonry units	3	3
Maximum height of unreinforced masonry parapets		
solid masonry units	4t	3t
hollow masonry units	3t	3t
Maximum wind loads for unreinforced parapets	30 psf	110 mph basic wind speed
Steel reinforcement required	Seismic Zones 3 and 4	Seismic Design Categories D, E and F

* Based on requirements of the CABO One and Two Family Dwelling Code, and Masonry Standards Joint Committee Building Code Requirements for Masonry Structures, ACI 530/ASCE 5/TMS 402-02)

14.2.15
Wind Speed and Pressure Equivalents

Equivalent Basic Wind Speeds (mph)													
3-second gust wind speed	85	90	100	105	110	120	125	130	140	145	150	160	170
Fastest mile wind speed	70	75	80	85	90	100	105	110	120	125	130	140	150

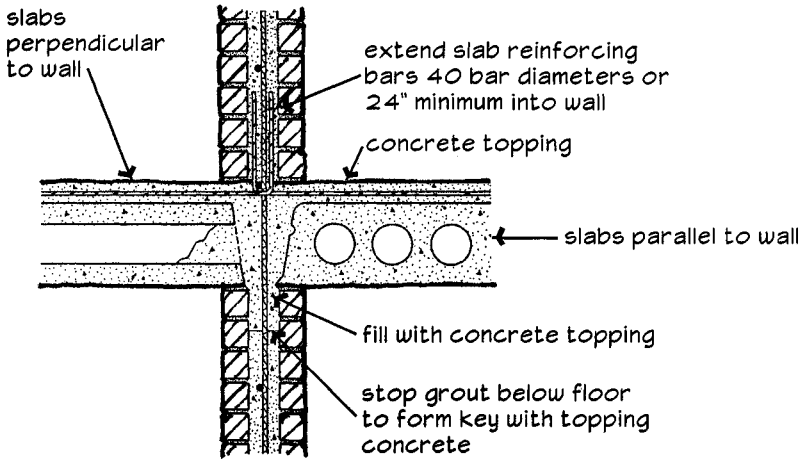
(From International Building Code 2000, based on ASCE 7-98 wind speed maps)



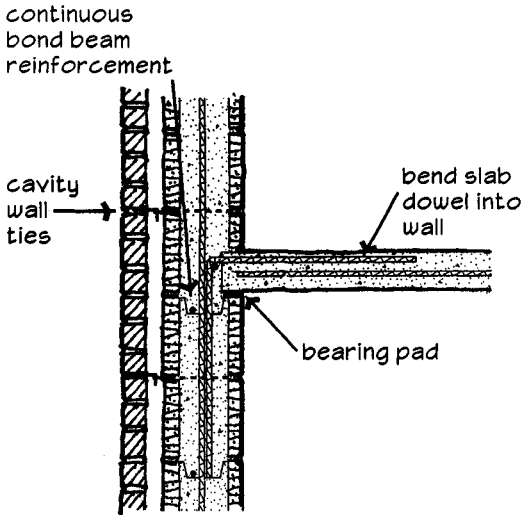
wind speed & pressure graph

Beaufort Wind Scale	
Description	Wind Speed (mph)
Calm	<1
Light air	1 to 3
Light breeze	5 to 7
Gentle breeze	8 to 12
Moderate breeze	13 to 18
Fresh breeze	20 to 24
Strong breeze	25 to 31
Moderate gale	32 to 38
Fresh gale	39 to 46
Strong gale	47 to 54
Whole gale	55 to 63
Storm	64 to 72
Hurricane	>74

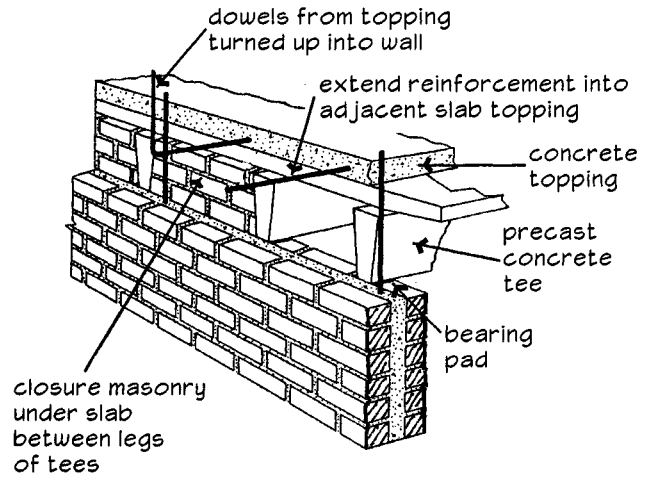
14.3.1 Connecting to Precast Concrete



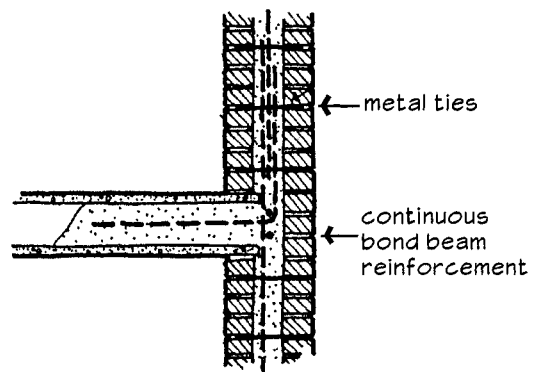
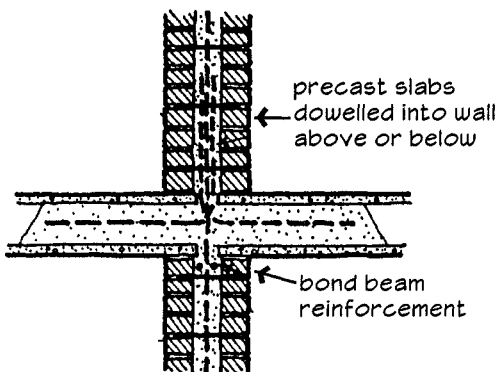
precast hollow plank floor with topping slab



precast concrete slab



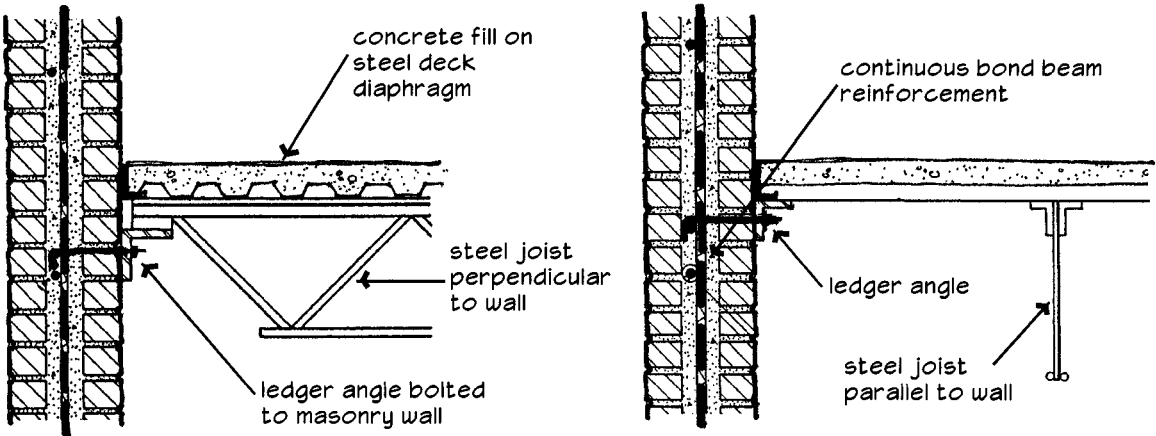
precast double tee



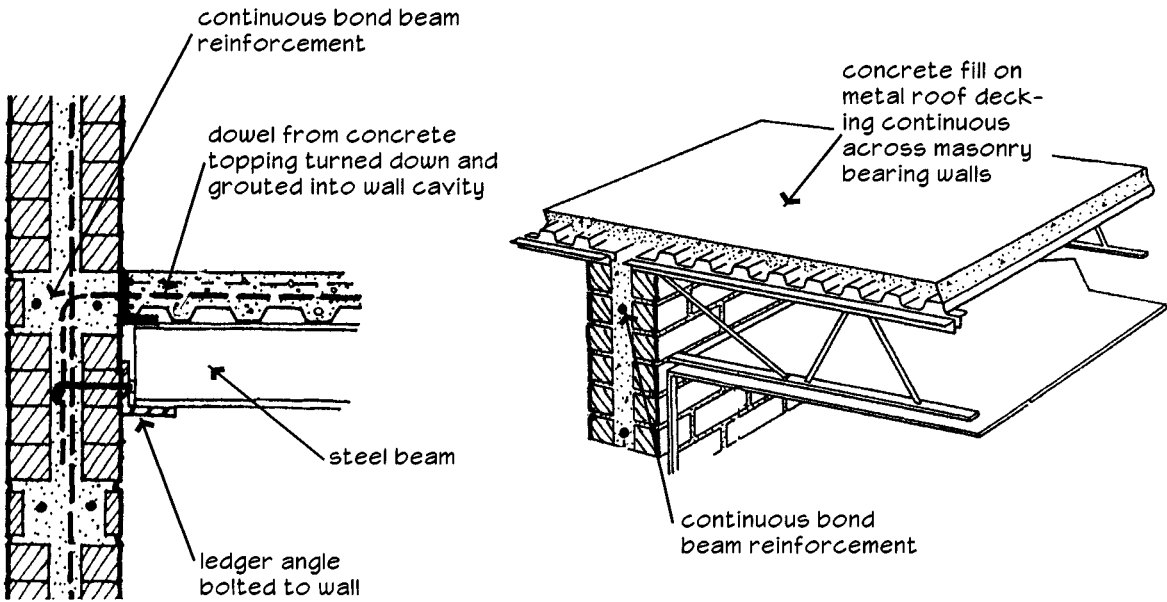
precast hollow plank floors without topping slab

(Adapted from Amrhein, Reinforced Masonry Engineering Handbook, 5th ed.)

14.3.2 Connecting to Steel Joists and Beams



steel joist supported on ledger angle

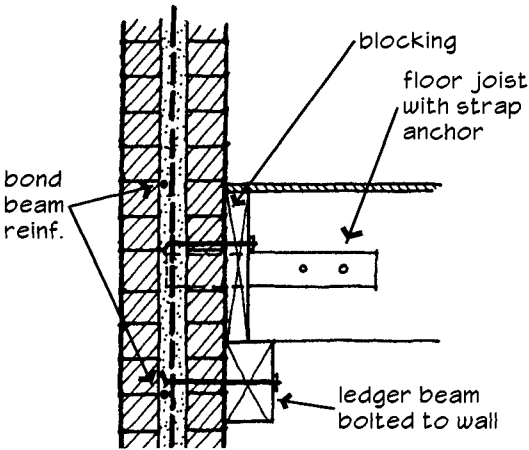
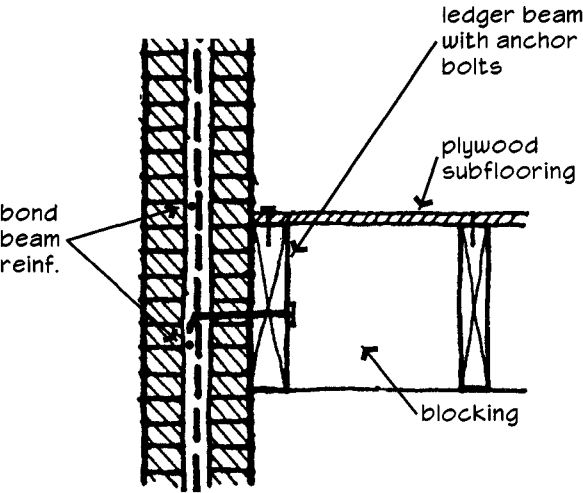
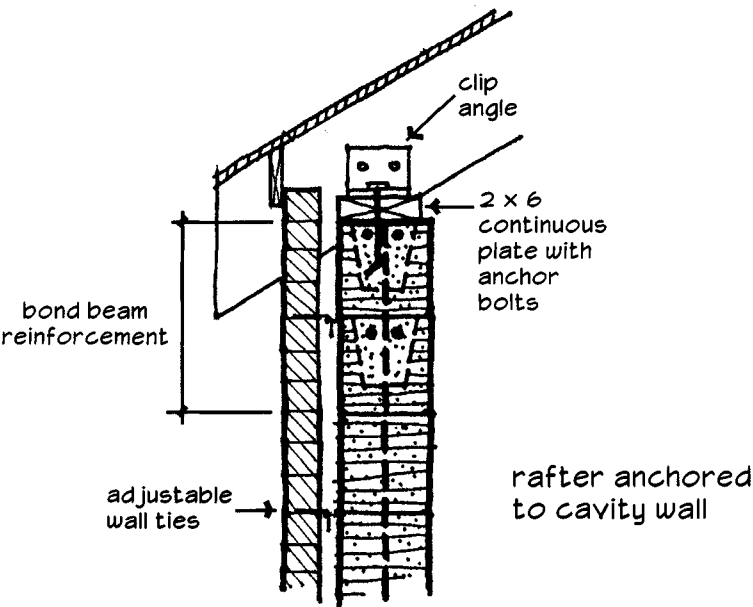


steel beam supported on ledger angle

steel joists supported on bearing pads placed directly on wall

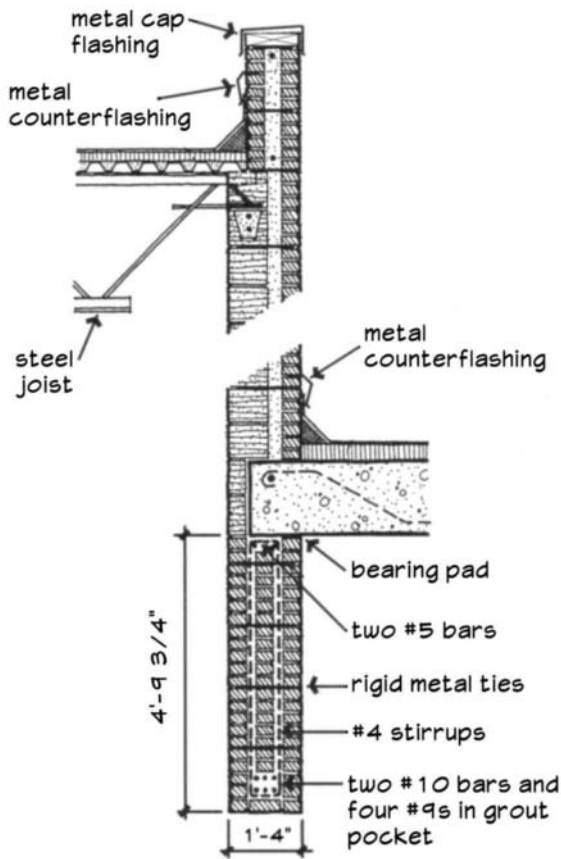
(Adapted from Amrhein, Reinforced Masonry Engineering Handbook, 5th ed.)

14.3.3 Connecting to Wood Frame Floors and Roofs

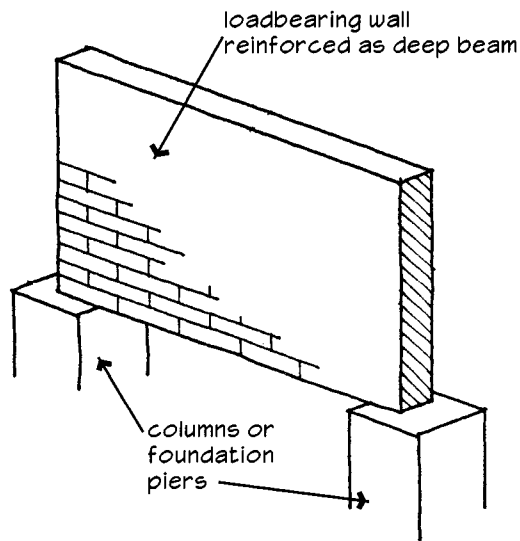
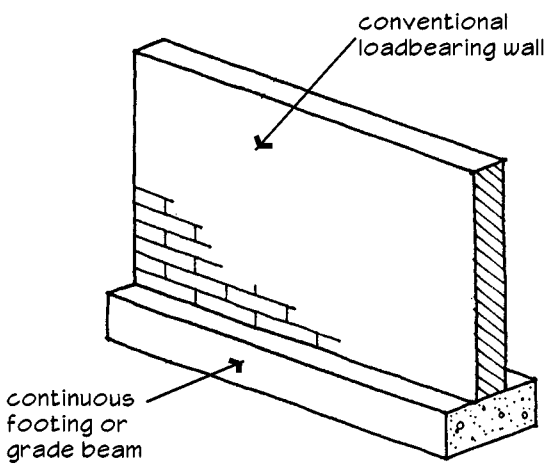


two methods of anchoring floor joists

14.3.4 Reinforced Masonry Beams



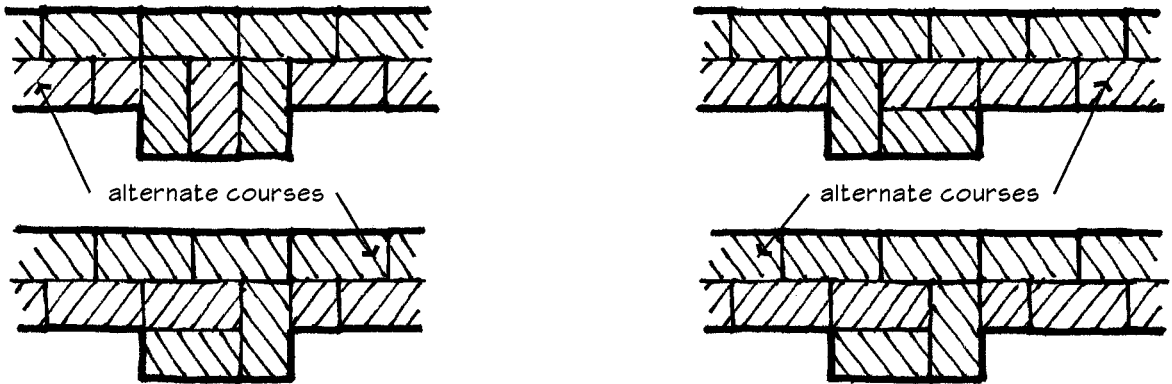
example of reinforced masonry beam



deep wall beams

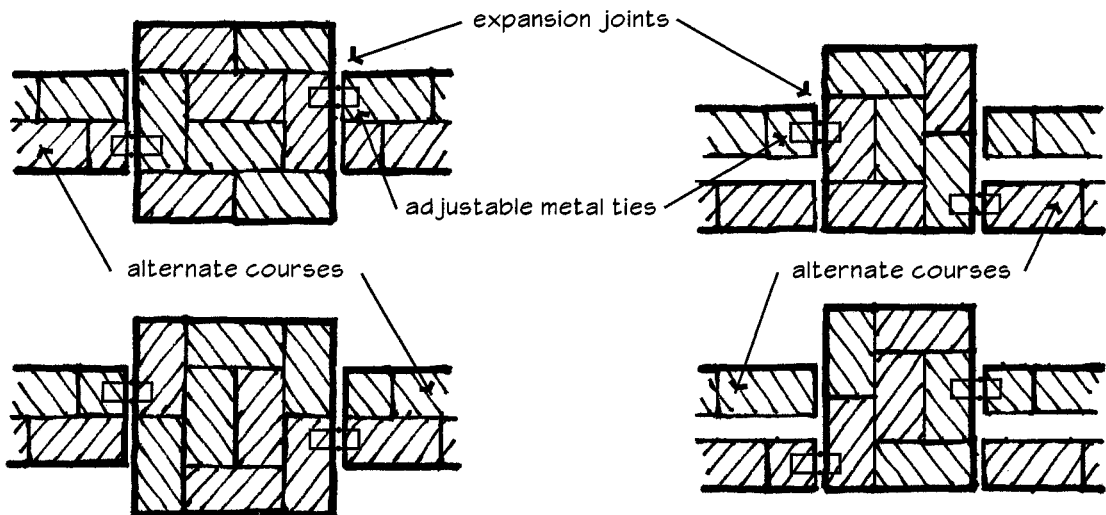
(Adapted from Schneider and Dickey, Reinforced Masonry Design, 2nd ed., Prentice-Hall, 1987)

14.3.5 Multi-Wythe Masonry Wall Columns and Pilasters



masonry unit bonded pilasters

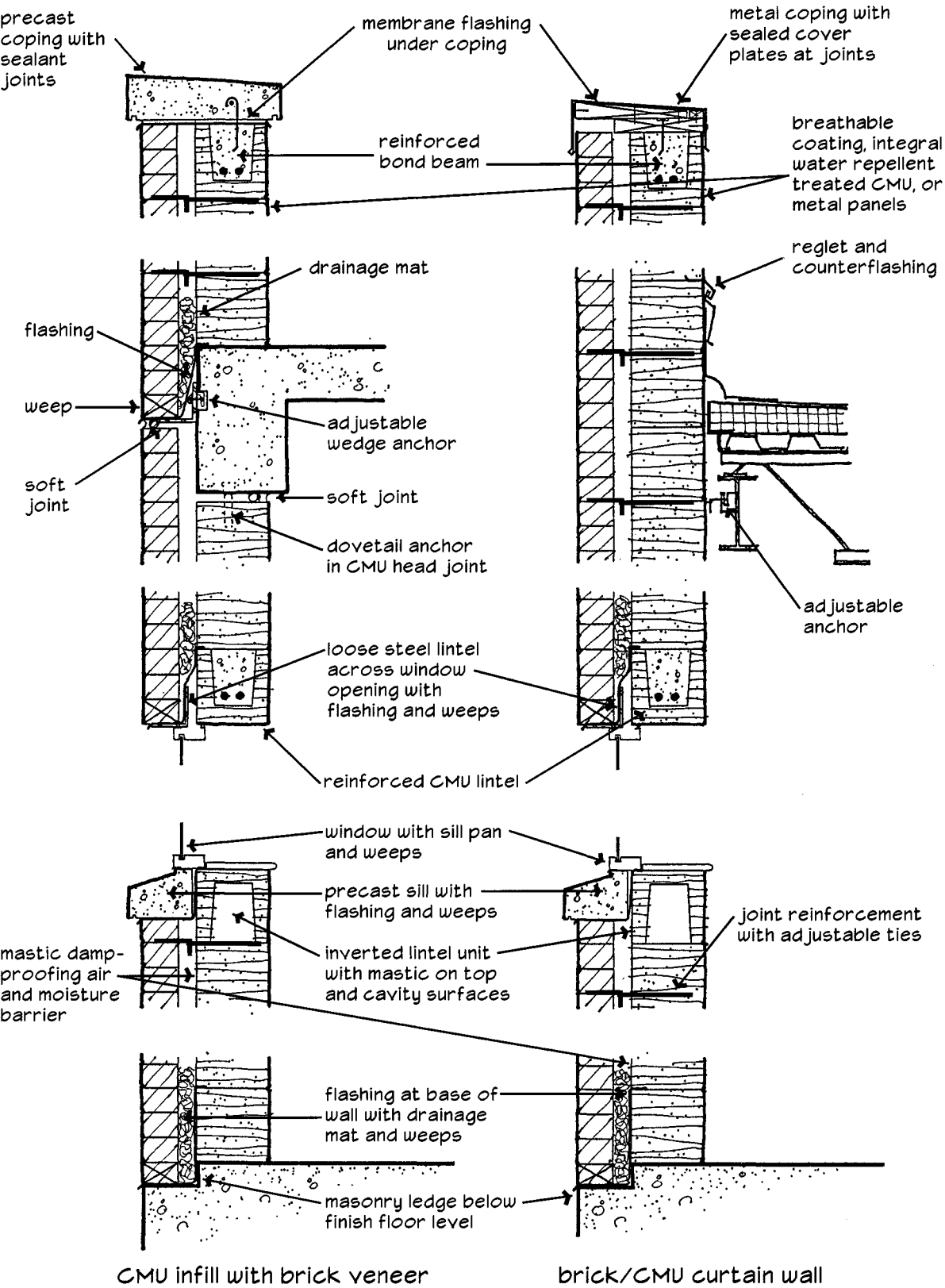
Pilasters connected to walls by masonry unit bonding or with rigid metal ties do not accommodate clay masonry expansion. Movement must be accommodated at other locations to prevent cracking.



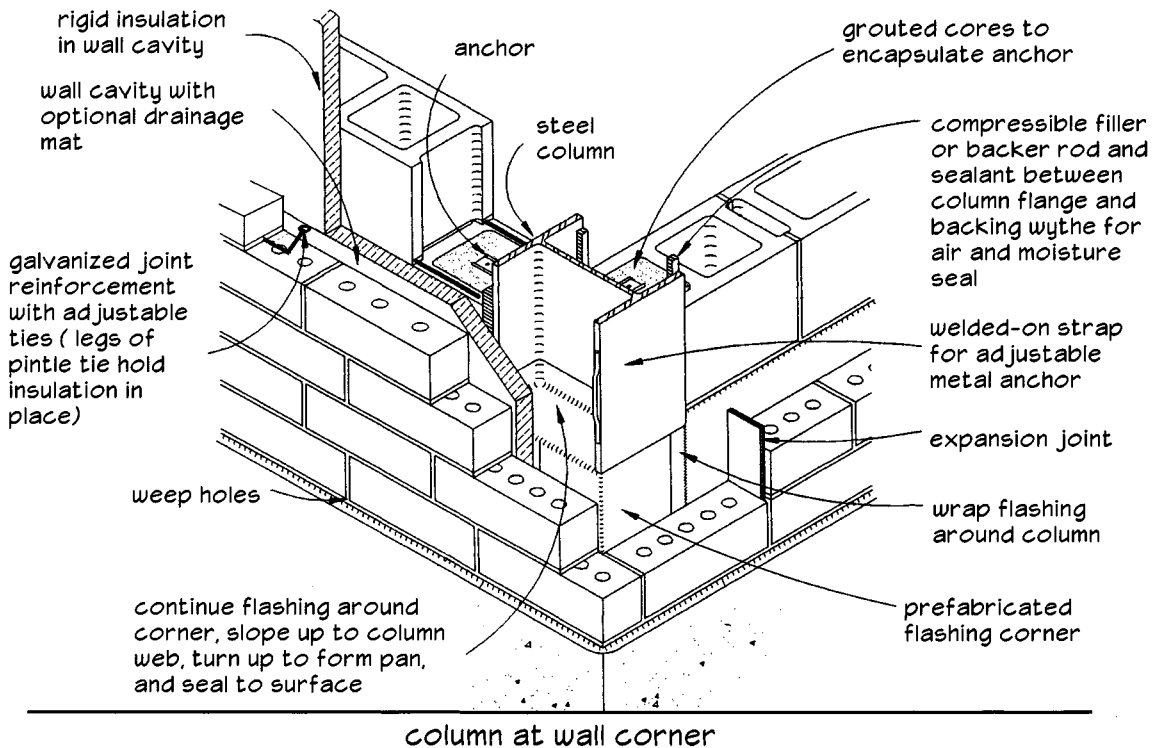
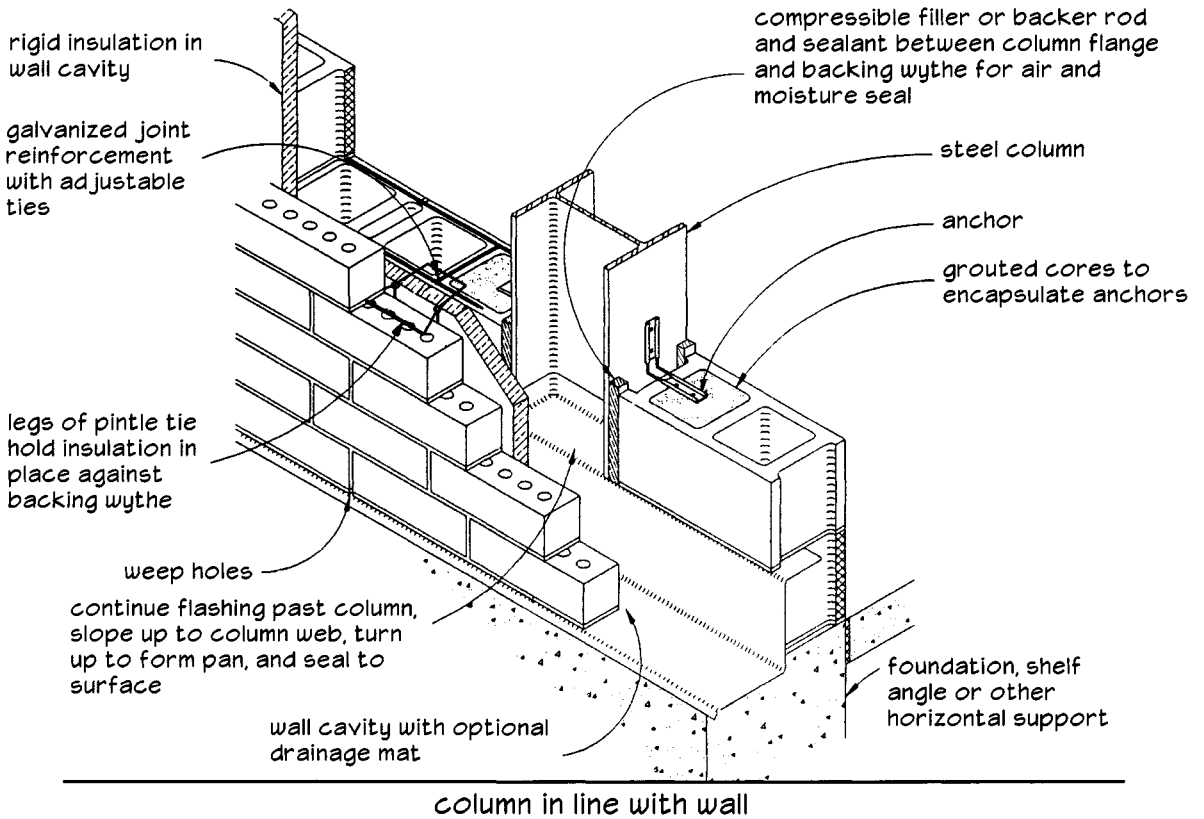
metal-tie bonded columns

Adjustable ties and expansion joints are required to accommodate clay masonry expansion. Supporting elements function as columns rather than pilasters.

14.3.6 Basic Cavity Wall Detailing

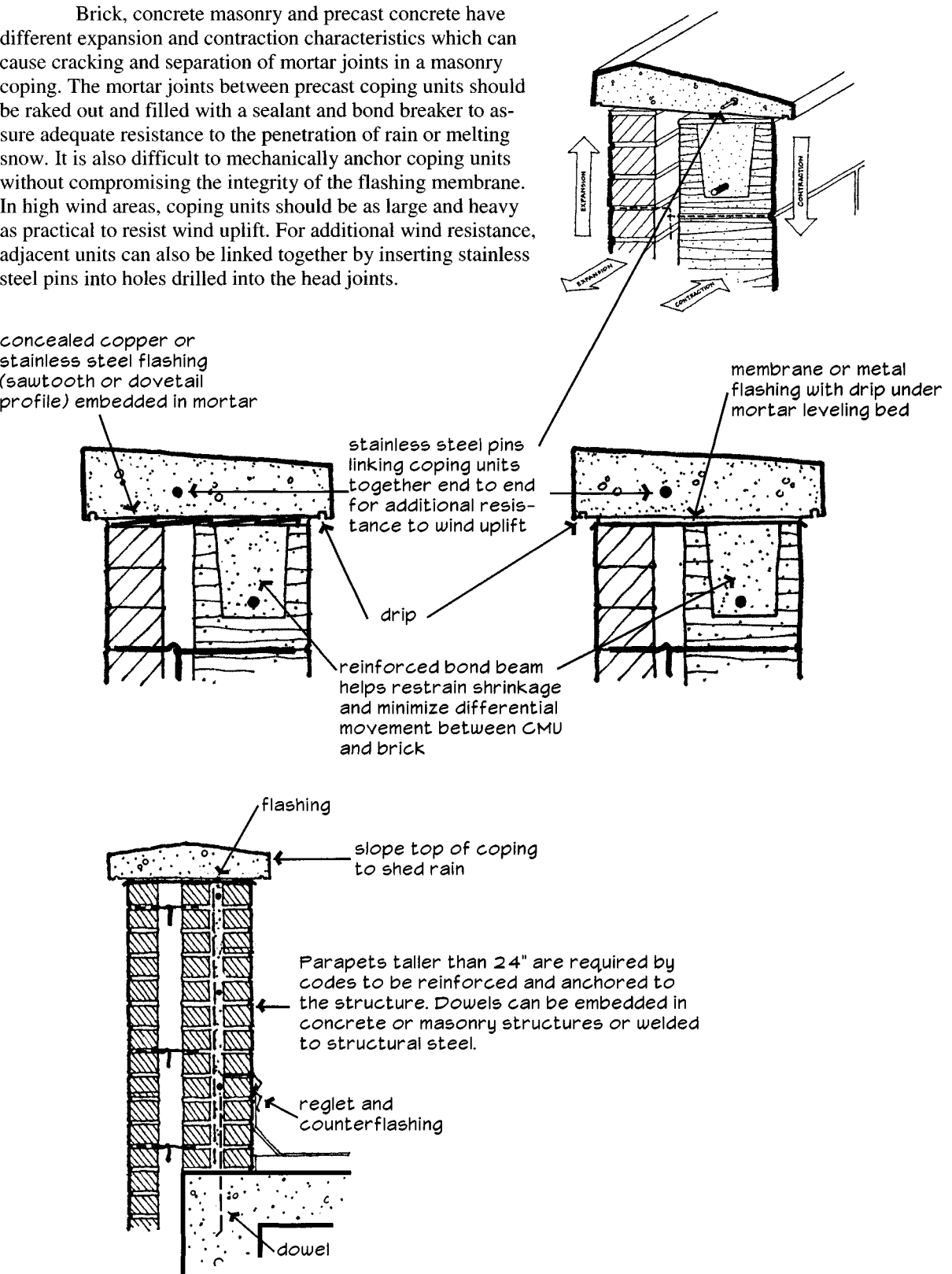


14.3.7 Cavity Wall Flashing at Steel Columns

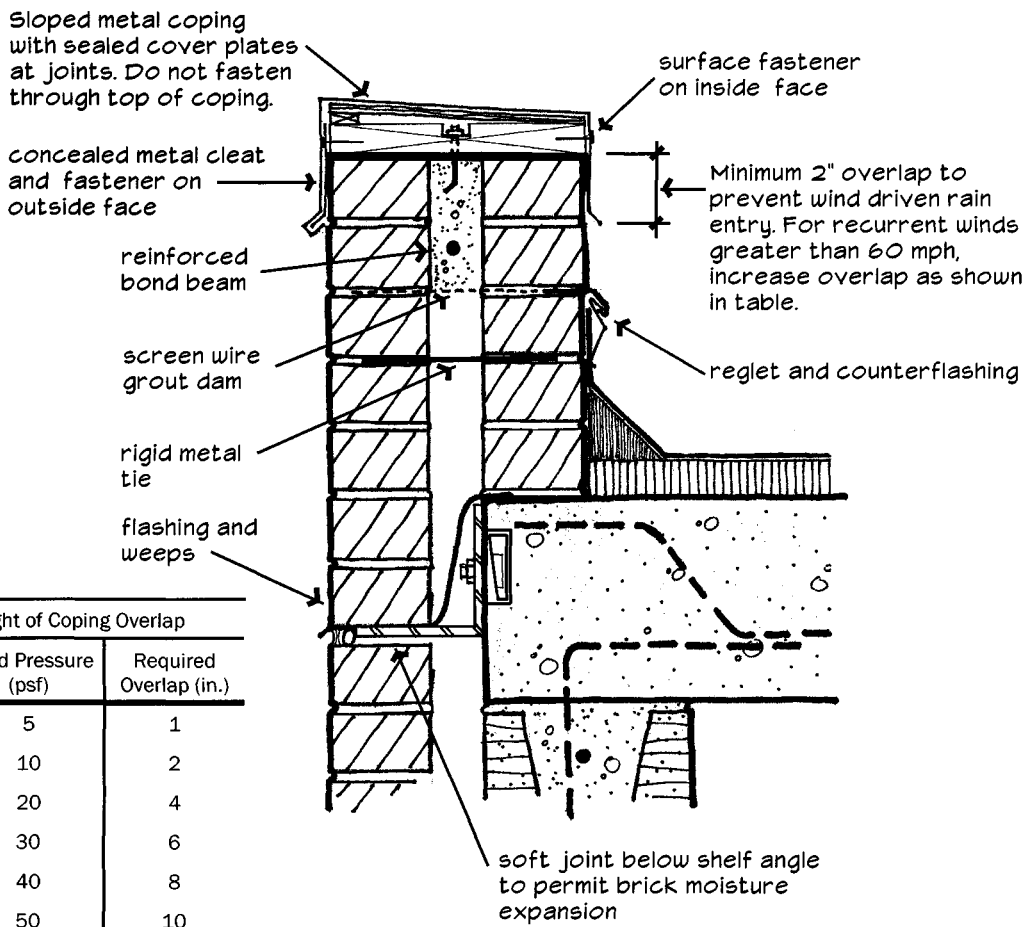
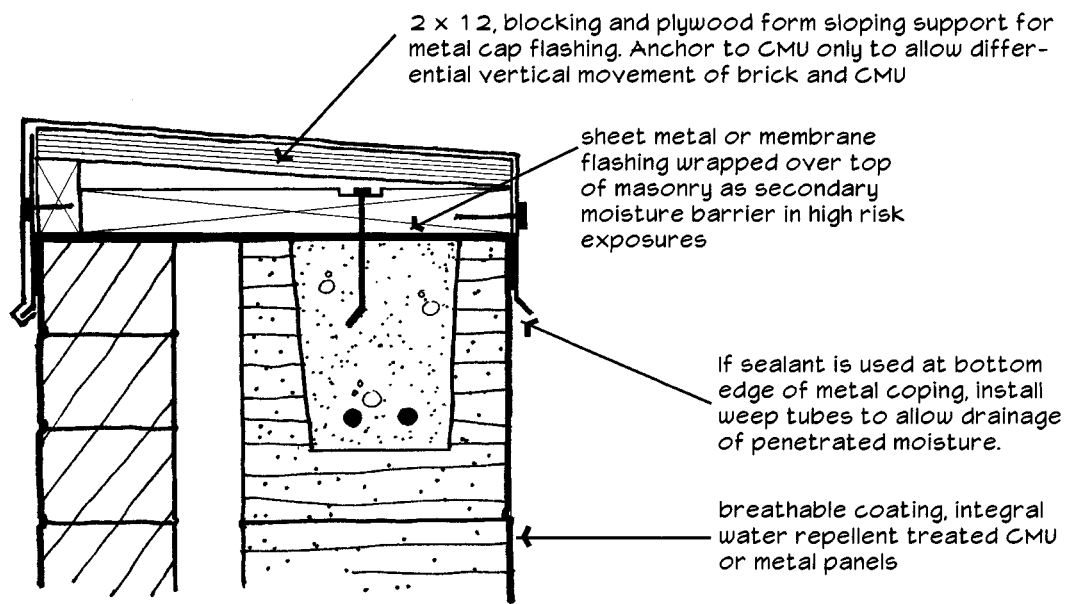


14.3.8 Cast Stone Parapet Copings

Brick, concrete masonry and precast concrete have different expansion and contraction characteristics which can cause cracking and separation of mortar joints in a masonry coping. The mortar joints between precast coping units should be raked out and filled with a sealant and bond breaker to assure adequate resistance to the penetration of rain or melting snow. It is also difficult to mechanically anchor coping units without compromising the integrity of the flashing membrane. In high wind areas, coping units should be as large and heavy as practical to resist wind uplift. For additional wind resistance, adjacent units can also be linked together by inserting stainless steel pins into holes drilled into the head joints.



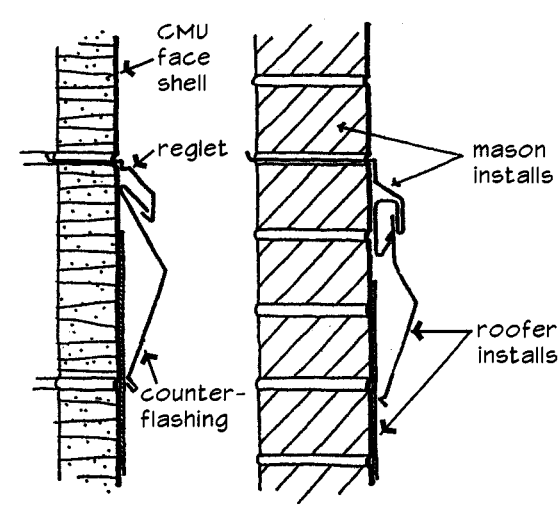
14.3.9 Metal Parapet Copings



Required Height of Coping Overlap		
Wind Speed (mph)	Wind Pressure (psf)	Required Overlap (in.)
45	5	1
60	10	2
90	20	4
110	30	6
125	40	8
140	50	10

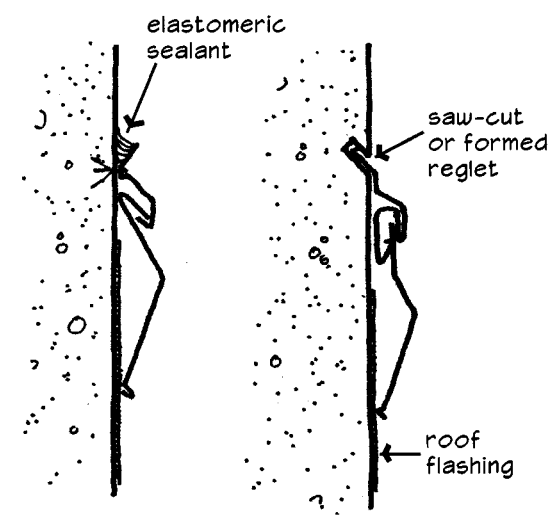
(From AAMA Aluminum Curtain Wall Design Guide Manual)

14.3.10 Reglet and Counterflashing at Roof



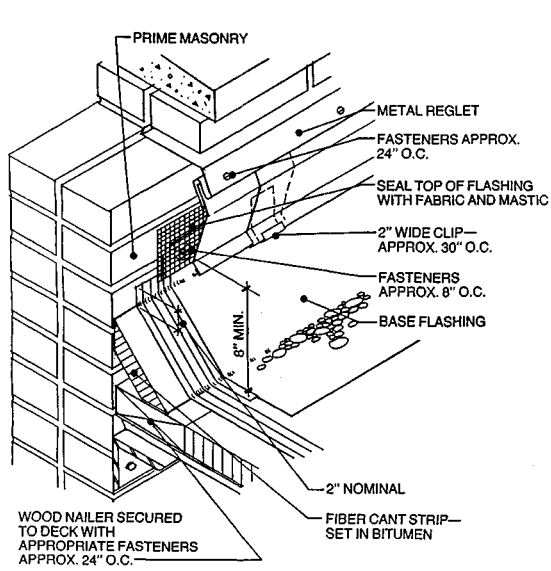
short horizontal leg extends through CMU face shell long horizontal leg extends through brick wythe

masonry reglets

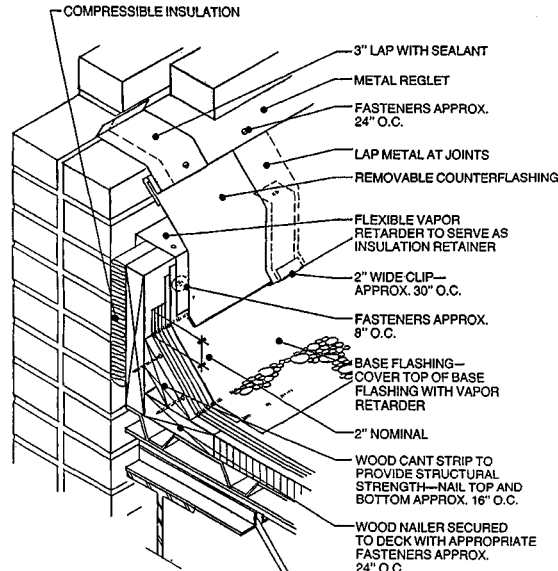


surface-mounted reglets for use only on solid concrete surface saw-cut or formed reglet in precast or cast-in-place concrete surface

concrete reglets



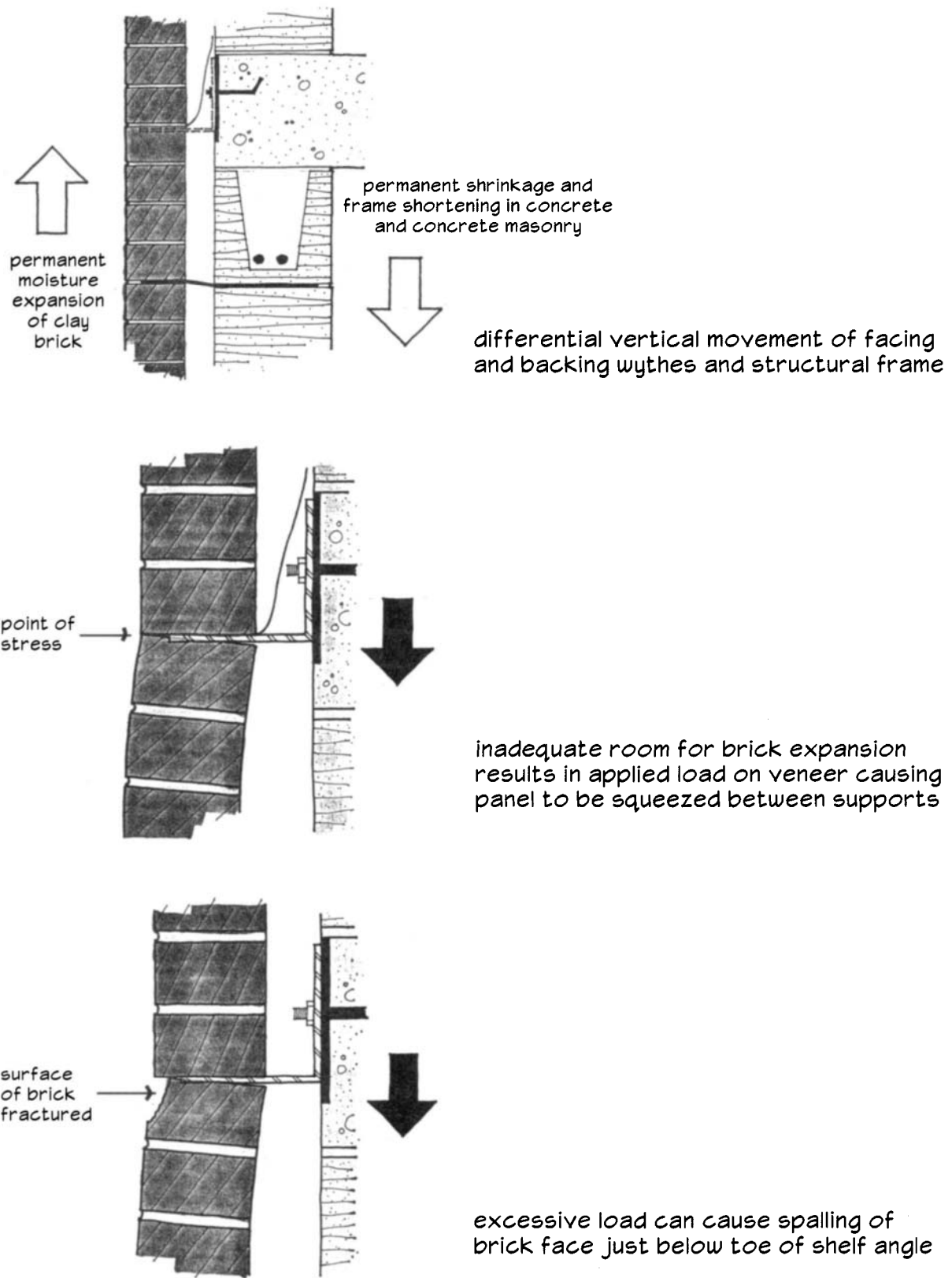
no allowance for differential movement
roof deck supported by wall



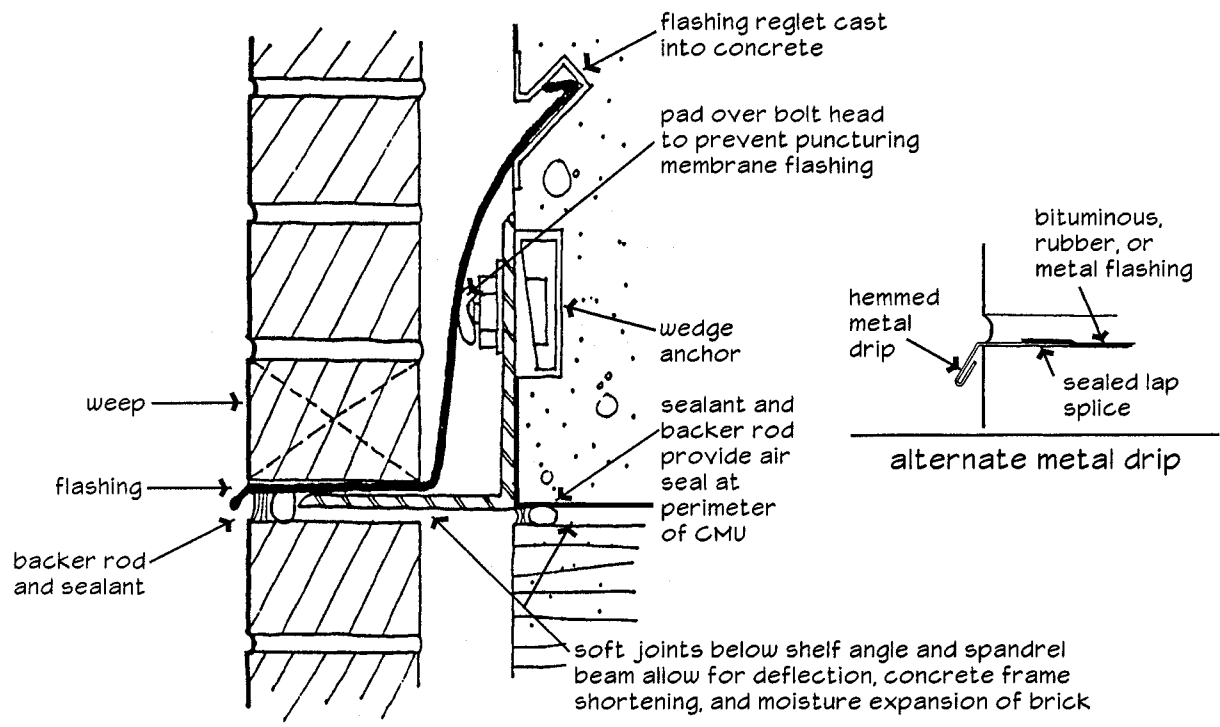
preferred detail
allows for differential movement
roof deck not supported by wall

NRCA recommended details for reglet and counterflashing at roof
(From NRCA Roofing and Waterproofing Handbook, National Roofing Contractors Association)

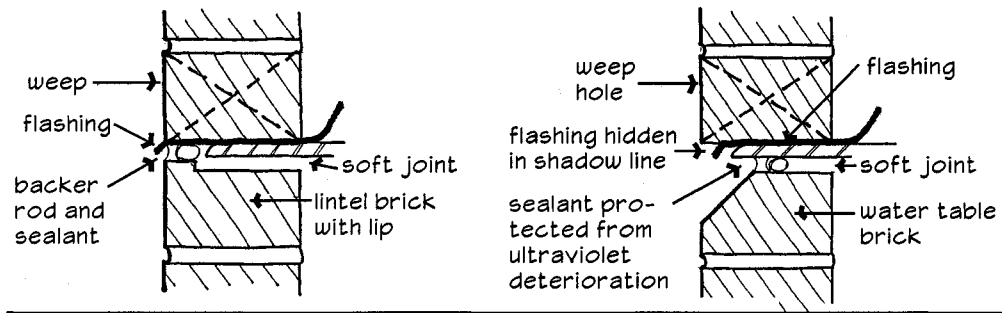
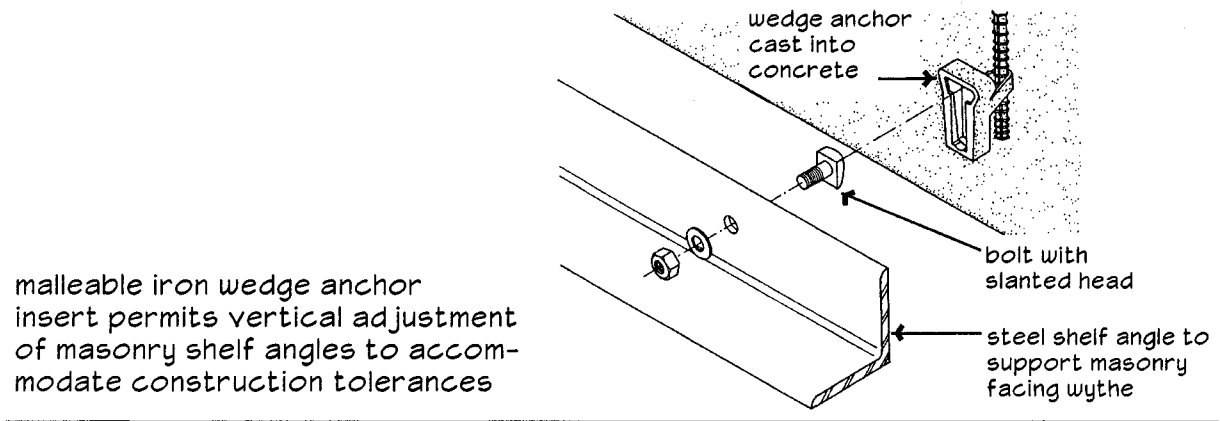
14.3.11 Differential Movement at Shelf Angles



14.3.12 Masonry Shelf Angle at Concrete Beam

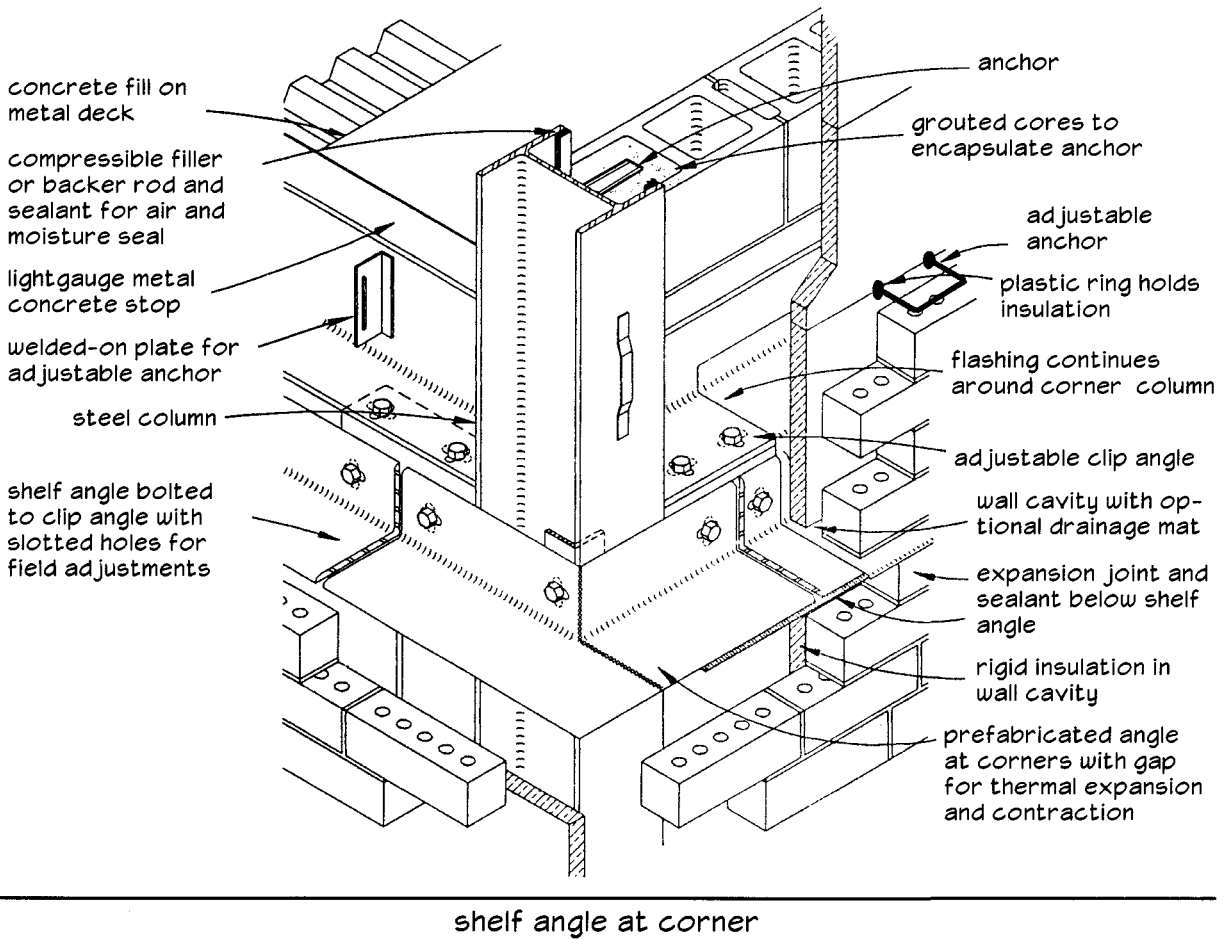


traditional shelf angle detail

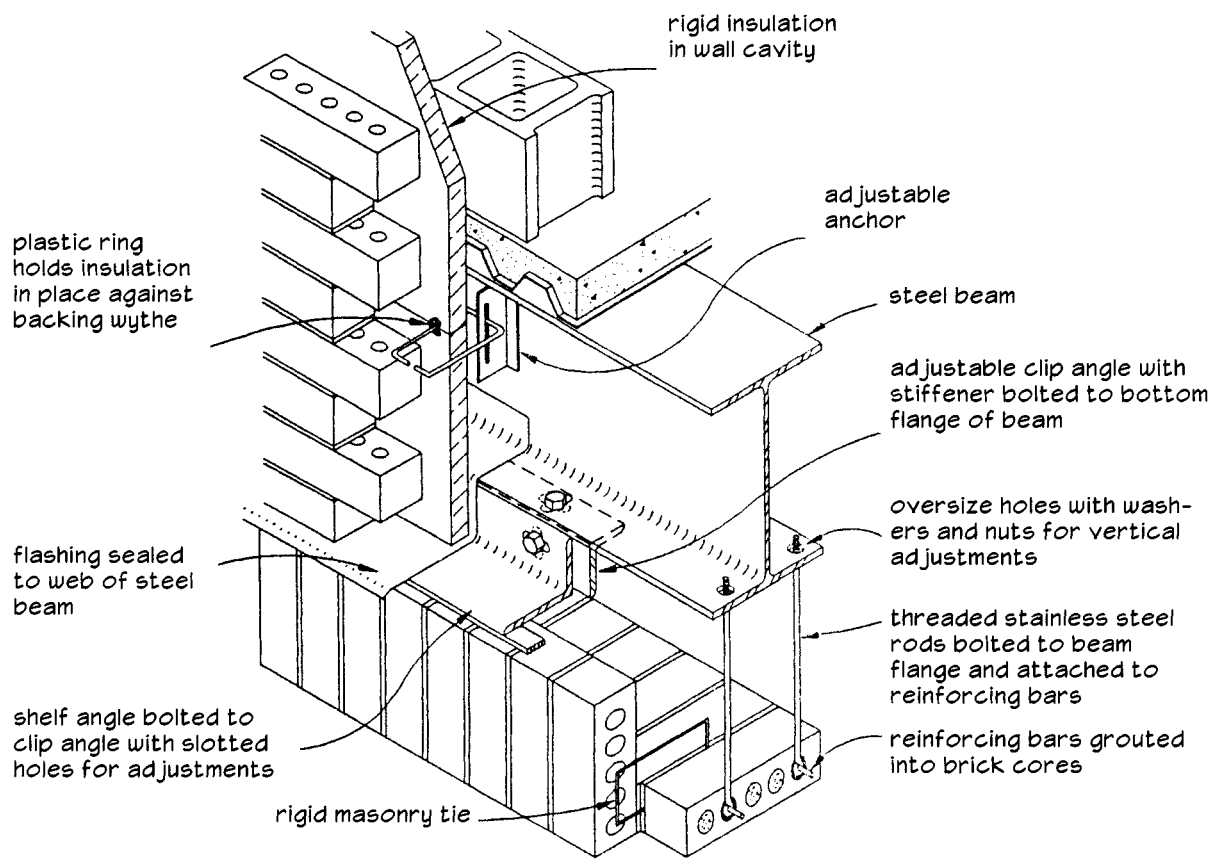


alternate shelf angle details

14.3.13 Masonry Shelf Angle at Steel Beam/Column Corner



14.3.14 Suspended Brick Soffit at Steel Beam



suspended brick soffit

(From Laska, Masonry and Steel Detailing Handbook, 1993)

Veneer Masonry

15.1 Masonry Veneer and Code Requirements

- 15.1.1 Wood and Metal Stud Veneer Backing
- 15.1.2 CABO Code Requirements for Masonry Veneer
- 15.1.3 CABO Veneer Support Requirements
- 15.1.4 MSJC Code Requirements for Masonry Veneer
- 15.1.5 Veneer Anchorage Requirements and Recommendations
- 15.1.6 MSJC Seismic Requirements for Masonry Veneer

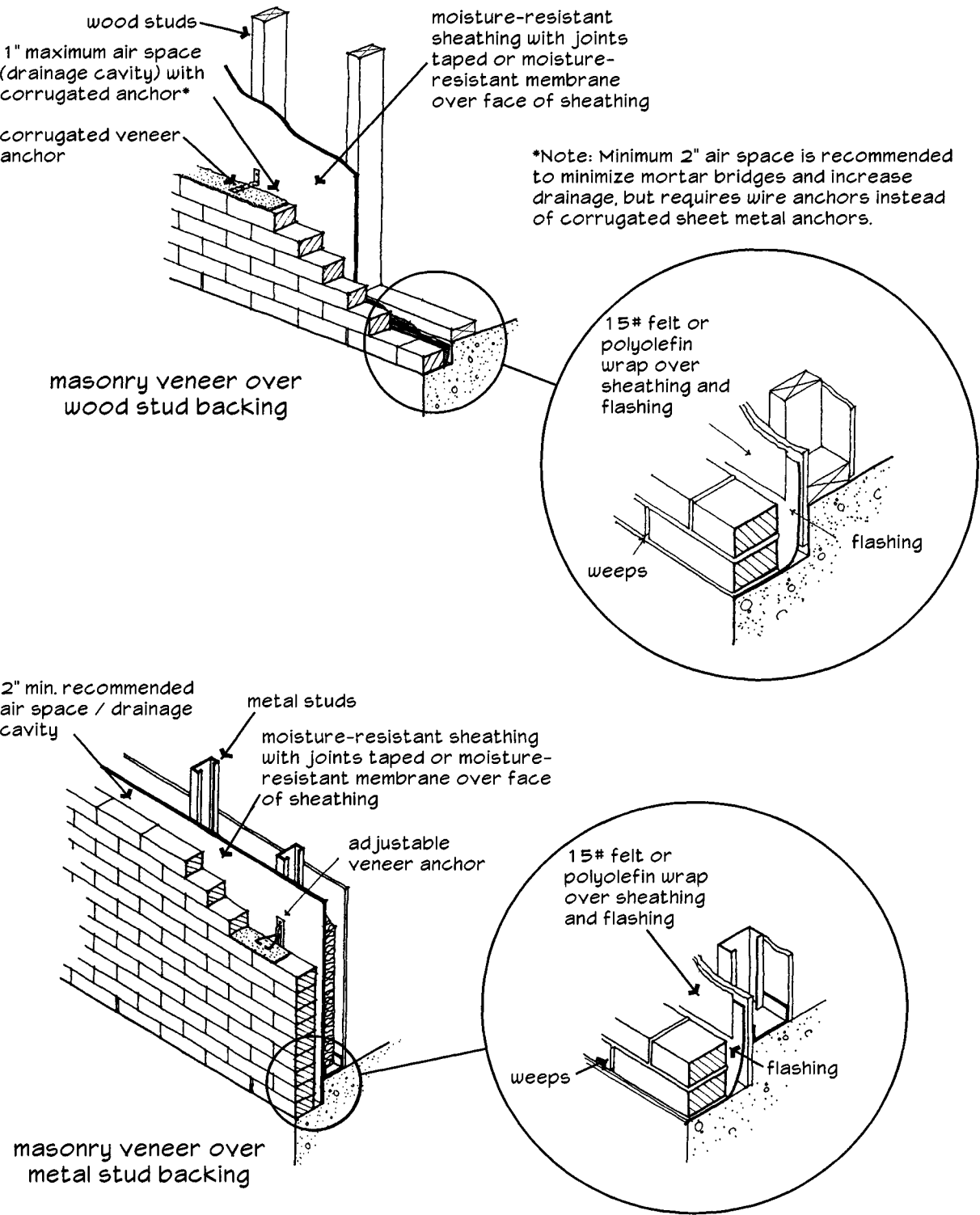
15.2 Residential Construction Details

- 15.2.1 Basic Residential Veneer Detailing
- 15.2.2 Alternate Base Flashing Details
- 15.2.3 Alternate Base Flashing and Foundation Details
- 15.2.4 Residential Wood Window Head, Jamb and Sill Details
- 15.2.5 Residential Window Flashing
- 15.2.6 Window Flashing at Arched Opening
- 15.2.7 Window With Sill Pan Flashing
- 15.2.8 Masonry Chimney Flashing

15.3 Commercial Construction Details

- 15.3.1 Basic Commercial Veneer Detailing
- 15.3.2 Masonry Shelf Angle Details
- 15.3.3 Adjustable Shelf Angle Connections
- 15.3.4 Masonry Spandrels
- 15.3.5 Commercial Window Sill Detail
- 15.3.6 Masonry Sill Details
- 15.3.7 Sill Pan Details

15.1.1 Wood and Metal Stud Veneer Backing



(From Beall, Masonry Design and Detailing, 4th ed., McGraw-Hill, 1997)

15.1.2 CABO Code Requirements for Masonry Veneer

CABO Requirements for Anchored Masonry Veneer

Item	Minimum Requirements
Support	must be supported on non-combustible construction (i.e., concrete, masonry or steel) <i>except</i> may be supported on wood construction if veneer weighs 40 psf or less and deflection of supporting construction is limited to 1/600, and expansion joint is installed between veneer supported on wood and veneer supported on foundation (see detail on next page)
Support over openings	unless the veneer is self-supporting (e.g., masonry arches), veneer above openings must be supported on non-combustible steel, concrete, or masonry lintels with minimum 4 in. bearing on each side and maximum span as shown in table on next page
Maximum stud spacing	24 in. on center
Maximum height above non-combustible foundation	30 ft., with an additional 8 ft. permitted for gable ends
Anchors	corrosion-resistant wire ties not less than W 1.7 (9 gauge) with minimum 2 in. hook, or corrugated sheet metal not less than 22 gauge x 7/8 in., and embedded in mortar or grout and extended into veneer wythe at least 1-1/2 in. with at least 5/8 in. mortar or grout cover to the exterior face <i>except</i> in Seismic Zones 3 and 4, anchors must be mechanically attached to single-wire, W1.7 (9 gauge) horizontal joint reinforcement spaced a maximum of 18 in. on center vertically and running continuously in the veneer bed joint with lap splices permitted between the veneer anchor spacing
Anchor spacing	32 in. maximum horizontal spacing maximum 2-2/3 sq.ft. of wall area per anchor <i>except</i> in Seismic Zone 3 or 4 and where basic wind pressure exceeds 30 psf, each anchor shall support a maximum of 2 sq.ft. of wall area
Air space	minimum 1 in., maximum 4-1.2 in.
Sheathing	moisture-resistant membrane or asphalt-saturated felt over non-water-repellent sheathing, or approved water-repellent sheathing (with joints taped and with 1 in. clear air space between veneer and sheathing)
Flashing	approved corrosion-resistant flashing <ul style="list-style-type: none"> ▪ beneath first course of masonry above finished ground level, and at other points of support including structural floors, shelf angles and lintels ▪ at top and sides of all exterior door and window openings, except that self-flashing windows with a minimum 1-1/8 in. lap over sheathing material around perimeter of openings including corners do not require additional flashings ▪ at intersection of chimneys or other masonry construction with frame or stucco walls, with projecting lips on both sides under masonry copings ▪ under and at the ends of masonry, wood or metal copings and sills ▪ continuously above all projecting wood trim ▪ where exterior porches, decks or stairs attach to a wall or floor assembly of wood-frame construction ▪ at wall and roof intersections
Weepholes	minimum 3/16 in. diameter, maximum spacing 33 in., located immediately above flashing

(Based on CABO One and Two Family Dwelling Code)

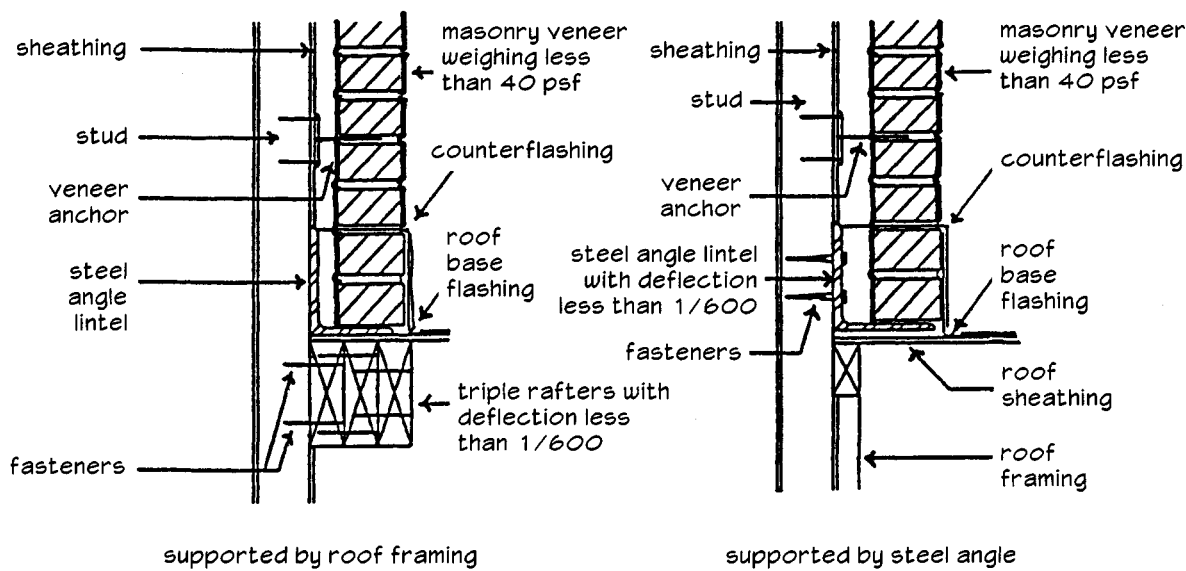
15.1.3 CABO Veneer Support Requirements

Allowable Spans for Steel, Concrete and Masonry Lintels Supporting Masonry Veneer				
Size of Steel Angle Lintel [§] , Vertical X Horizontal X Thickness (in.)	Number of 1/2" or Equivalent Reinforcing Bars in Masonry or Concrete Lintels [†]	Less Than One Story of Masonry Above Lintel	Lintel Supporting One Story of Masonry Above Opening	Lintel Supporting Two Stories of Masonry Above Opening
3 x 3 x 1/4	1	6'-0"	3'-6"	3'-0"
4 x 3 x 1/4	1	8'-0"	5'-0"	3'-0"
6 x 3-1/2 x 1/4	2	14'-0"	8'-0"	3'-6"
two 6 x 3-1/2 x 1/4	4	20'-0"	11'-0"	5'-0"

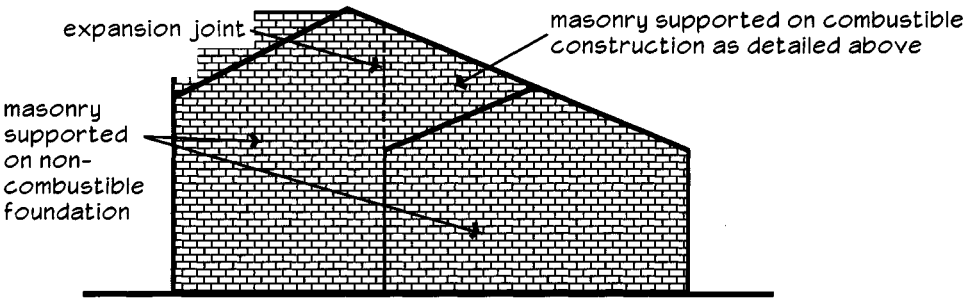
§ Steel lintels indicated are adequate typical examples. Other steel lintels meeting structural design requirements may be used.

† Depth of reinforced lintels shall not be less than 8 inches, and all cells or cores of hollow masonry lintels shall be grouted solid. Reinforcing bars shall extend not less than 8 inches into the support.

(From CABO One and Two Family Dwelling Code)



masonry supported on combustible construction



(Based on CABO One and Two Family Dwelling Code)

15.1.4 MSJC Code Requirements for Masonry Veneer

MSJC Prescriptive Requirements for Anchored Masonry Veneer

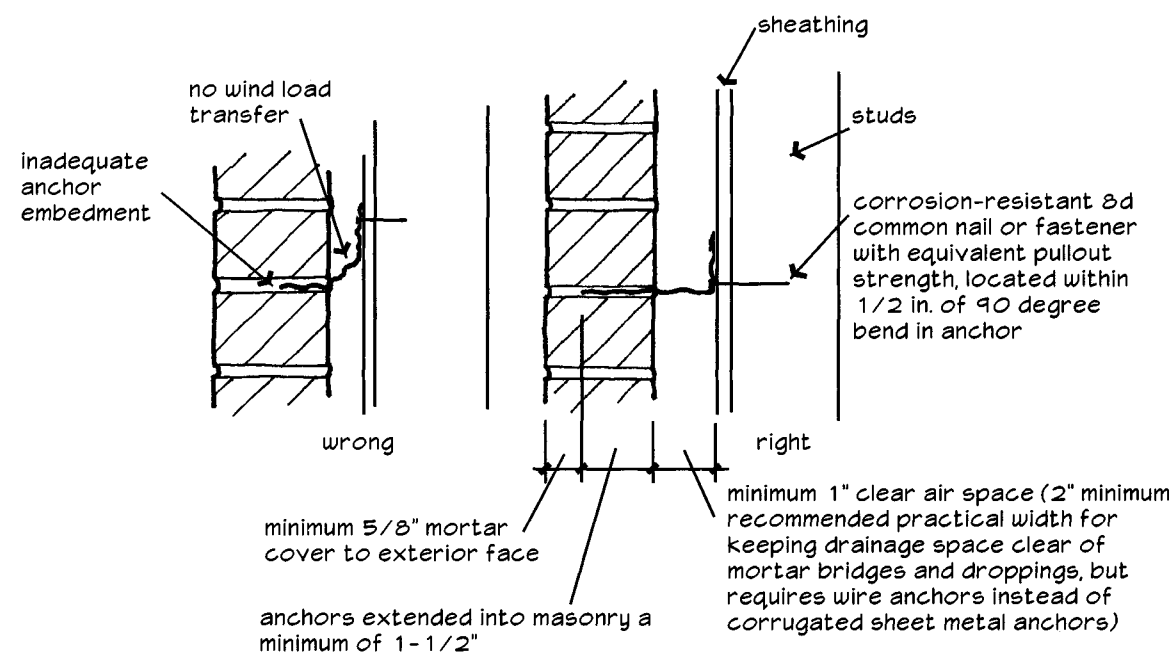
Item	Minimum Requirements
Applicability	prescriptive requirements may not be used where basic wind speed exceeds 110 mph
Support	<p>must be supported on non-combustible foundations (i.e., concrete or masonry) <i>except</i></p> <ul style="list-style-type: none"> may be supported on preservative-treated wood foundations to a maximum height of 18 ft. above the support may be supported on wood construction if veneer weighs 40 psf or less with a height of 12 ft. or less, deflection of supporting member from dead and live loads is limited to 1/600, masonry is not in direct contact with wood, and expansion joint is installed between veneer supported on wood and veneer supported on foundation (see detail on previous page) when veneer is supported by floor construction deflection is limited to 1/600
Support over openings	unless the veneer is self-supporting (e.g., masonry arches), veneer above openings must be supported on non-combustible steel, concrete, or masonry lintels with minimum 4 in. bearing on each side and deflection limited to 1/600
Maximum height above non-combustible foundation	30 ft., with an additional 8 ft. permitted for gable ends, <i>except</i> if veneer with cold-formed steel stud backing exceeds this height, it shall be supported by non-combustible construction for each story above the height limit (unless designed by engineering methods)
Anchors	<ul style="list-style-type: none"> corrosion resistant wire anchors not less than W 1.7 (9 gauge) with minimum 2 in. hook, or corrugated sheet metal not less than 7/8 in. wide with base metal thickness of 0.03 in. (22 gauge) and corrugations with a wavelength of 0.3 to 0.5 in. and an amplitude of 0.06 to 0.10, or adjustable anchors as above, or with pintles not less than W2.8 (3/16 in. diameter) with an offset not exceeding 1-1/4 in. and maximum clearance between connecting parts of 1/16 in., or joint reinforcement embedded in mortar joint (solid masonry units) or in mortar or grout (hollow masonry units) and extended into veneer wythe at least 1-1/2 in. with at least 5/8 in. mortar or grout cover to the exterior face maximum 1 in. between veneer and sheathing with corrugated anchors minimum 1 in. and maximum 4-1/2 in. between veneer and wood stud or framing with other anchors minimum bed joint thickness 2 x thickness of embedded anchor
Anchor spacing	<ul style="list-style-type: none"> maximum 32 in. on center horizontal x 18 in. on center vertical adjustable two-piece anchors of W1.7 or 22 gauge corrugated sheet metal maximum 2.67 sq.ft. of wall area per anchor all other anchors maximum of 3.5 sq.ft. of wall area per anchor additional anchors around all openings larger than 16 in. in either dimension, spaced 3 ft. on center around opening, and within 12 in. of opening
Air space	minimum 1 in. clear air space
Sheathing	moisture-resistant membrane over non-moisture-resistant sheathing, or moisture-resistant sheathing (with joints taped)
Flashing	designed and detailed to resist water penetration into the building interior, with backing system designed and detailed to resist water penetration
Weepholes	minimum 3/16 in. diameter, maximum spacing 33 in., located immediately above flashing
Differential movement	design and detail veneer to accommodate differential movement
Stack bond	provide joint reinforcement of at least one W1.7 wire spaced a maximum of 18 in. on center vertically

(Based on MSJC Building Code Requirements for Masonry Structures, ACI 530/ASCE 5/TMS 402-02)

15.1.5 Veneer Anchorage Requirements and Recommendations

Veneer Anchor Spacing		
Building Code	Maximum Spacing, Horizontal x Vertical (in. x in.)	Maximum Wall Area Per Anchor (sq.ft.)
CABO One and Two Family Dwelling Code		
Seismic Zones 1 and 2	24 x 16	2.67
Seismic Zones 3 and 4	16 x 16	2
wind loads > 30 psf	16 x 16	2
MSJC Masonry Code	32 x 18	adjustable two-piece anchors of W1.7 (9 gauge) wire and 22 gauge corrugated sheet metal anchors, 2.67 all others, 3.5
International Building Code	See MSJC Code	See MSJC Code

Recommended Corrosion Protection for Veneer Anchors and Joint Reinforcement	
Application	Corrosion Protection
Interior	mill galvanized ASTM A653, Class G60
Exterior walls and interior walls exposed to mean relative hu midity of 75% or more	hot-dip galvanized ASTM A153

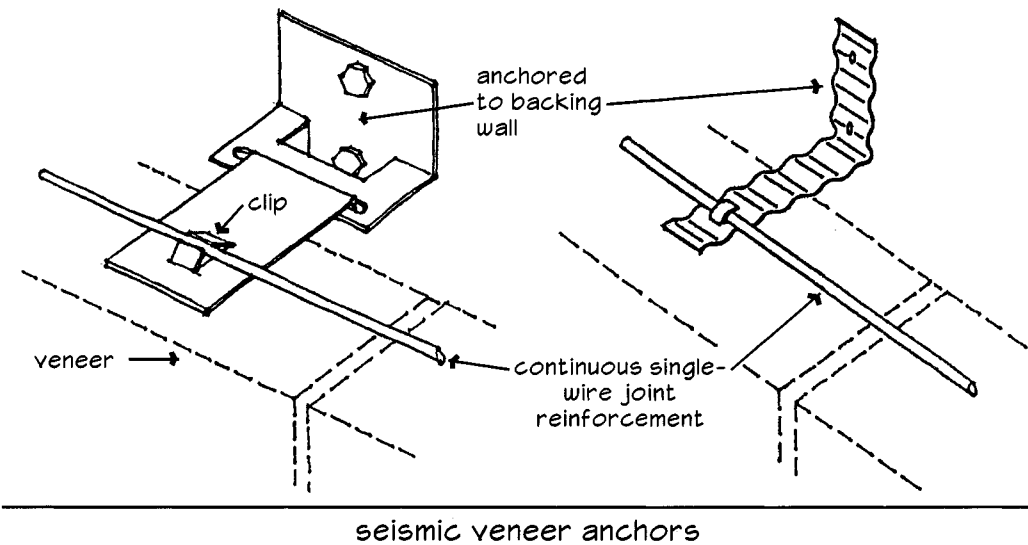


requirements for corrugated anchors

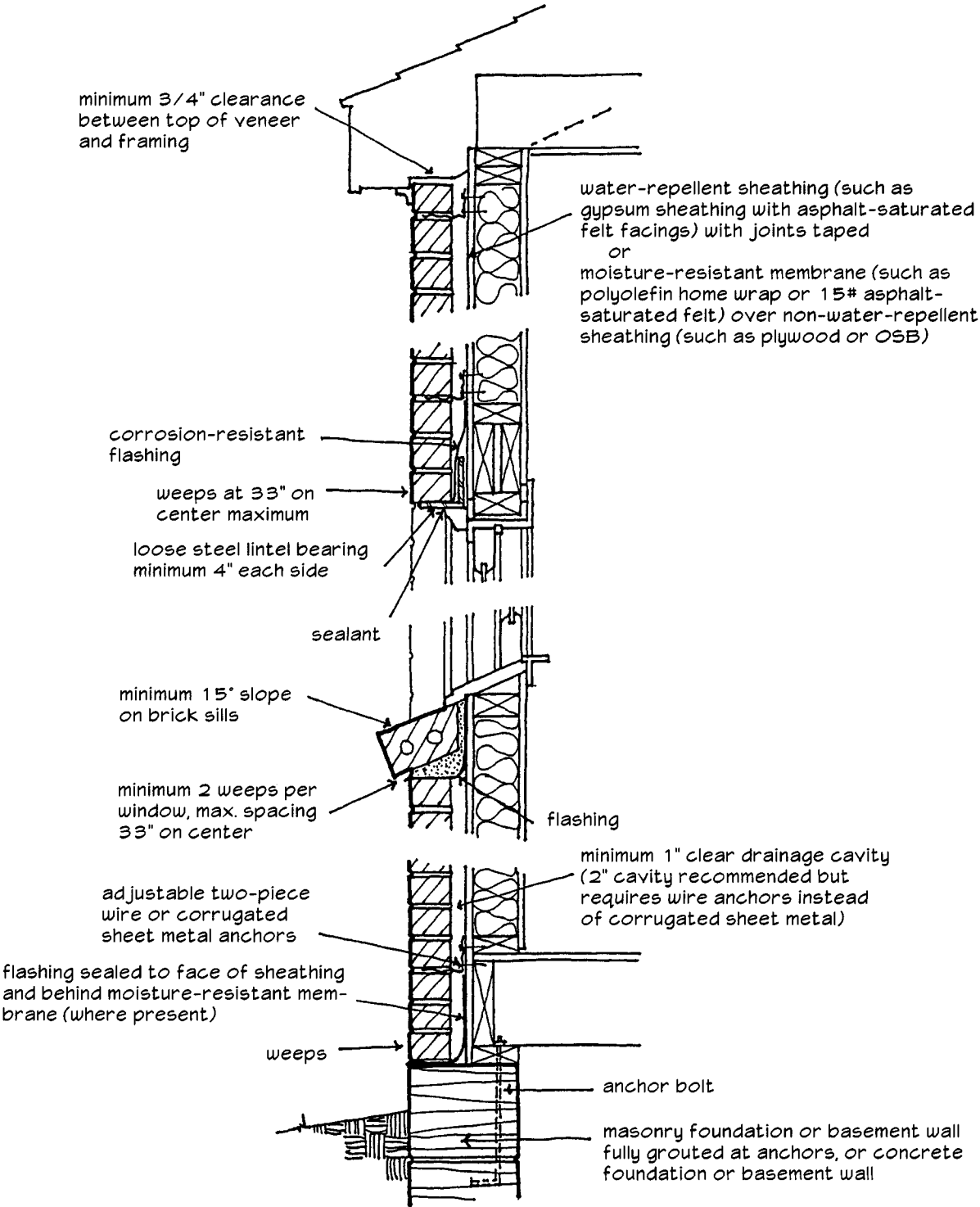
15.1.6 MSJC Seismic Requirements for Masonry Veneer

MSJC Prescriptive Seismic Requirements for Anchored Masonry Veneer	
Seismic Risk	Minimum Requirements
Seismic Design Categories A and B	Basic code requirements, no special provisions
Seismic Design Category C	Basic code requirements plus the following special provisions <ul style="list-style-type: none">Isolate sides and top of anchored veneer from structure so that vertical and lateral seismic forces resisted by the structure are not imparted to the veneer.
Seismic Design Category D	Basic code requirements plus the following special provisions <ul style="list-style-type: none">Isolate sides and top of anchored veneer from structure so that vertical and lateral seismic forces resisted by the structure are not imparted to the veneer.Support the weight of anchored veneer for each story independent of the other stories.Reduce the maximum wall area supported by each anchor to 75% of that normally required (maximum horizontal and vertical spacings are unchanged).Provide continuous, single-wire joint reinforcement of minimum W1.7 wire at a maximum spacing of 18 in. on center vertically.
Seismic Design Categories E and F	Basic code requirements plus the following special provisions <ul style="list-style-type: none">Isolate sides and top of anchored veneer from structure so that vertical and lateral seismic forces resisted by the structure are not imparted to the veneer.Support the weight of anchored veneer for each story independent of the other stories.Reduce the maximum wall area supported by each anchor to 75% of that normally required (maximum horizontal and vertical spacings are unchanged).Provide continuous, single-wire joint reinforcement of minimum W1.7 wire at a maximum spacing of 18 in. on center vertically.Provide vertical expansion joints at all returns and corners.Mechanically attach anchors with clips or hooks to joint reinforcement required above.

(Based on MSJC Building Code Requirements for Masonry Structures, ACI 530/ASCE 5/TMS 402)

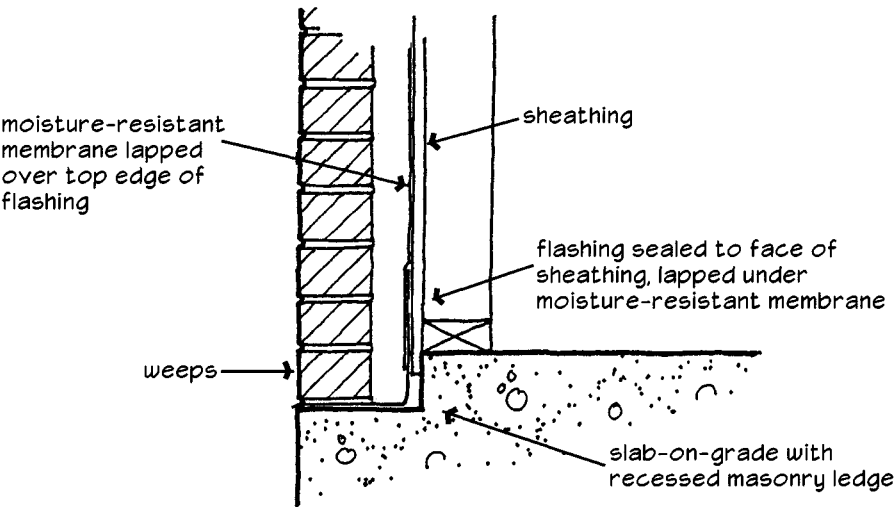


15.2.1 Basic Residential Veneer Detailing

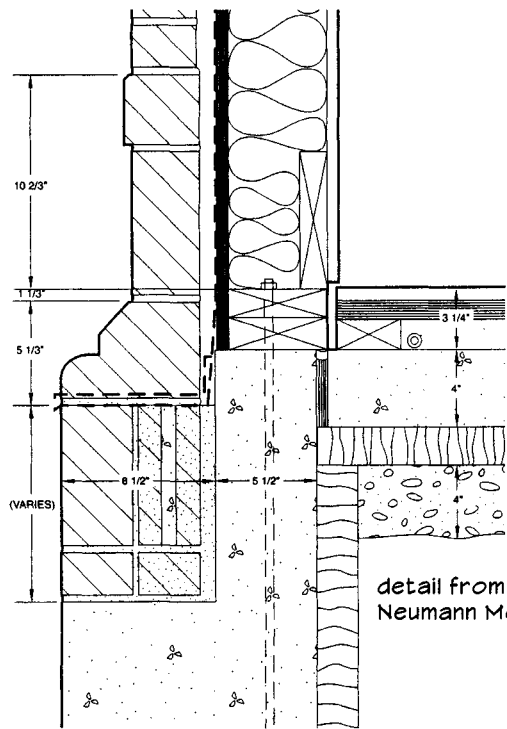


(From Beall, Masonry and Concrete for Residential Construction, McGraw-Hill, 2001)

15.2.2 Alternate Base Flashing Details



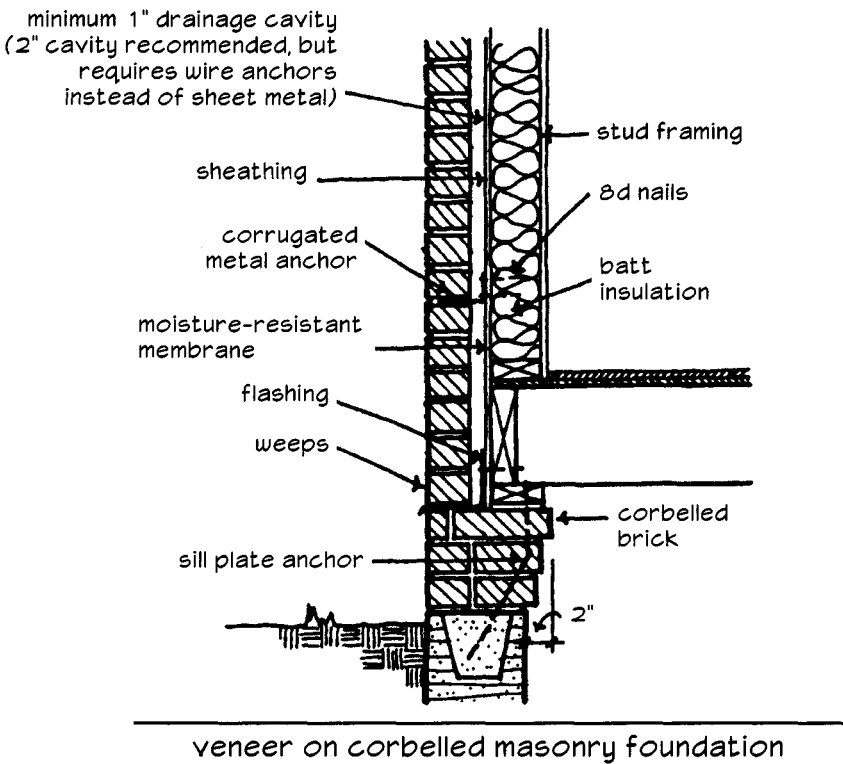
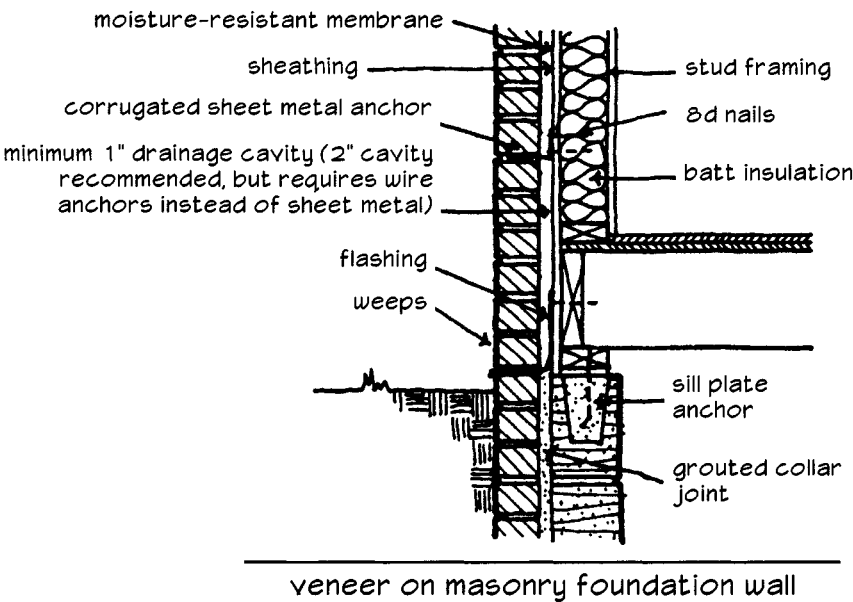
flashing at slab-on-grade



detail from private residence
Neumann Monson Wictor Architects

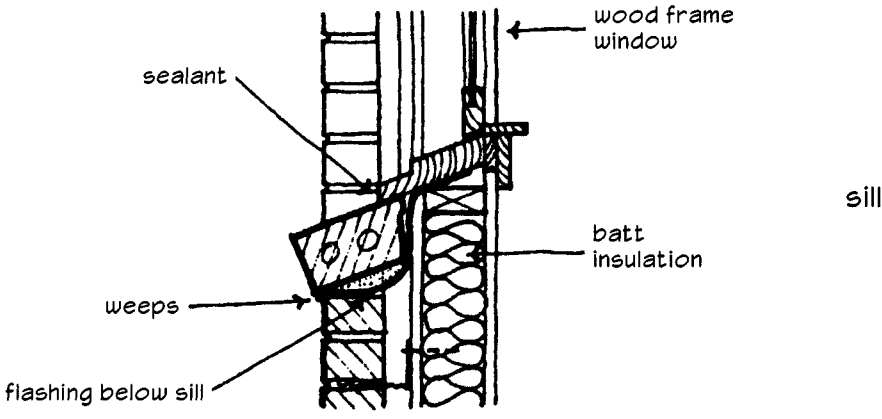
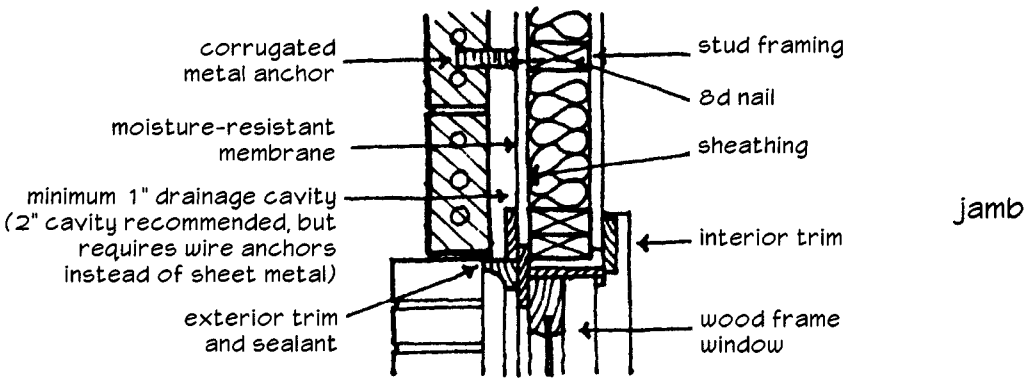
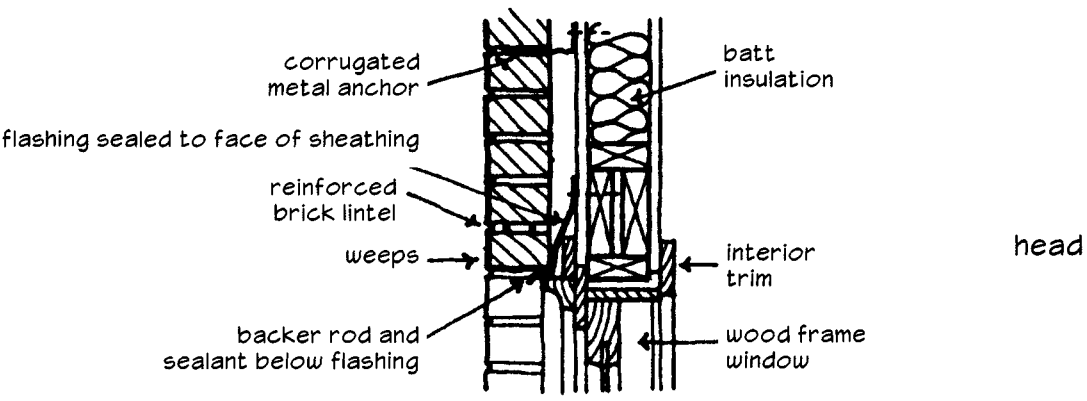
water table at concrete stem wall

15.2.3 Alternate Base Flashing and Foundation Details



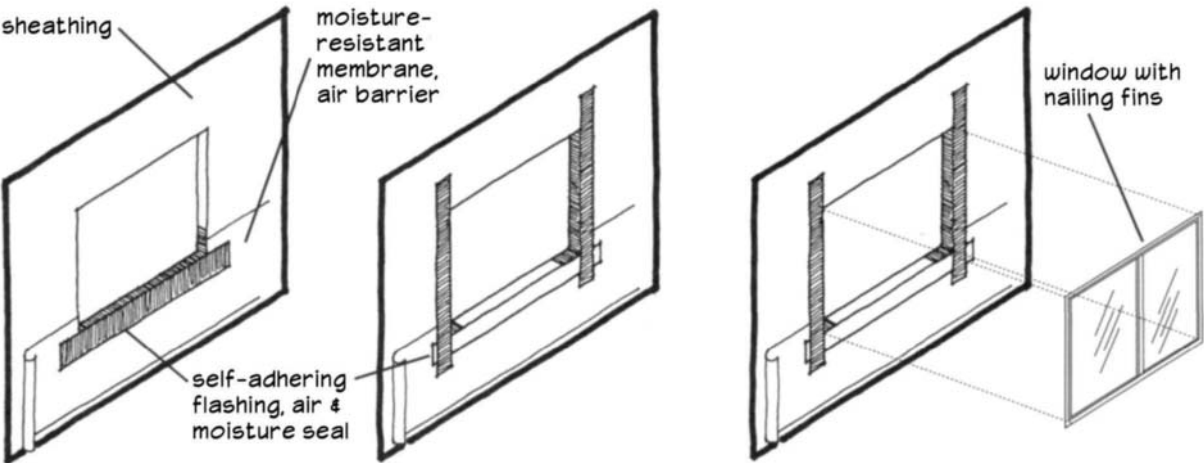
(From BIA Technical Note 28)

15.2.4 Residential Wood Window Head, Jamb and Sill Details

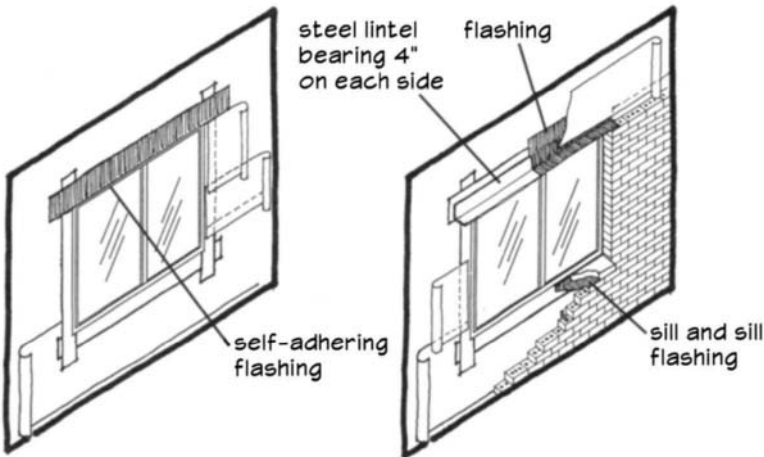


(From BIA Technical Note 28)

15.2.5 Residential Window Flashing



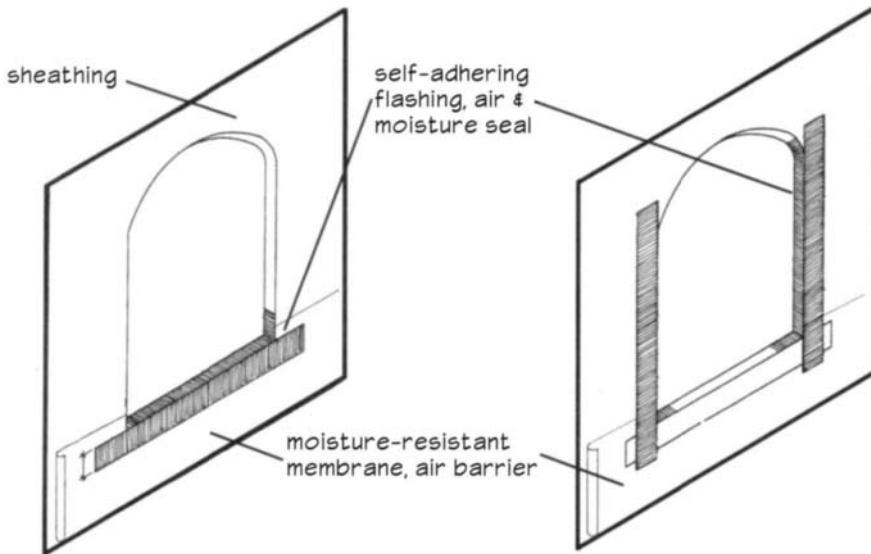
1. install moisture-resistant membrane around bottom of opening, then sill flashing lapped over
2. install jamb flashing lapped over sill flashing
3. install window and attach through nailing fins



4. install head flashing lapped over top nailing fin, and continue lapping moisture-resistant membrane
5. install masonry, sill and sill flashing, lintel and lintel flashing, and continue lapping moisture-resistant membrane

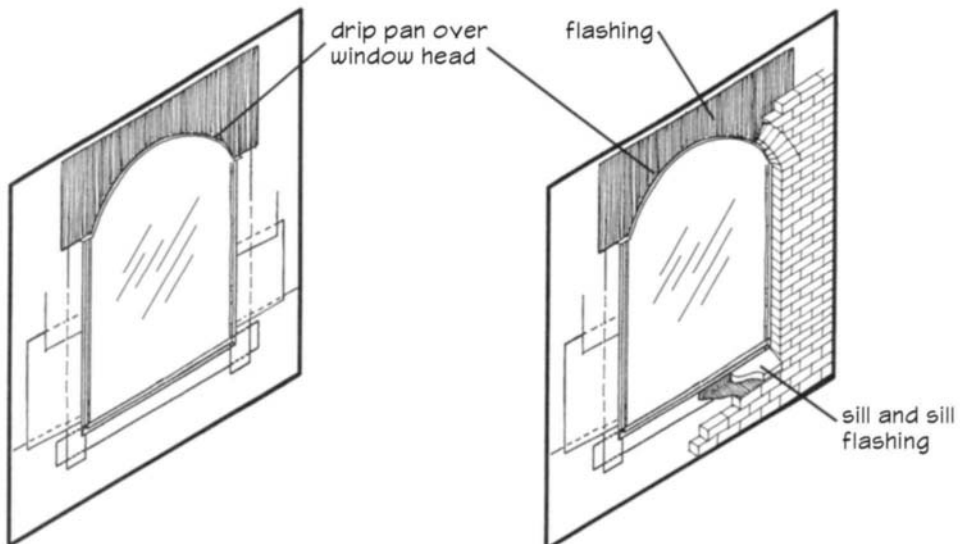
installing window with nailing fins

15.2.6 Window Flashing at Arched Opening



1. install moisture-resistant membrane around bottom of opening, then sill flashing lapped over

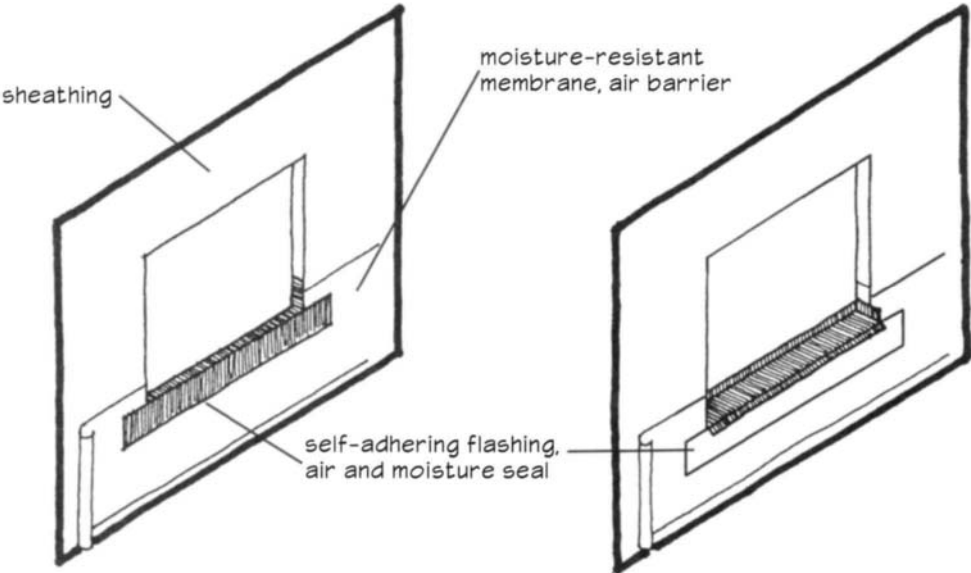
2. install jamb flashing lapped over sill flashing



3. install window and attach through nailing fins, install curved drip pan at head, with flashing lapped over pan, continue lapping moisture-resistant membrane

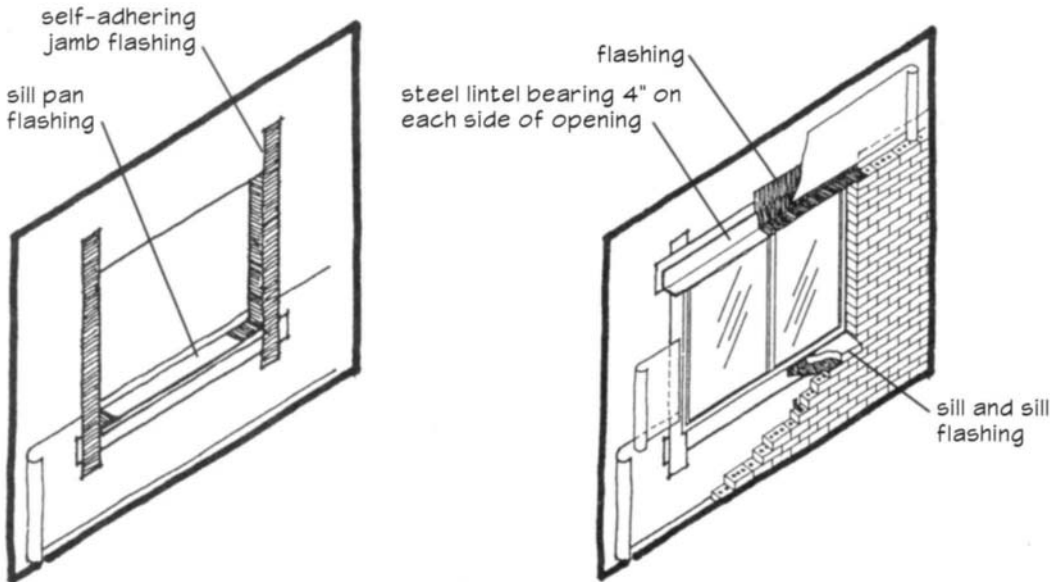
4. install masonry, sill and sill flashing, and construct arch using temporary centering

15.2.7 Window With Sill Pan Flashing



1. install moisture-resistant membrane around bottom of opening, then sill flashing lapped over

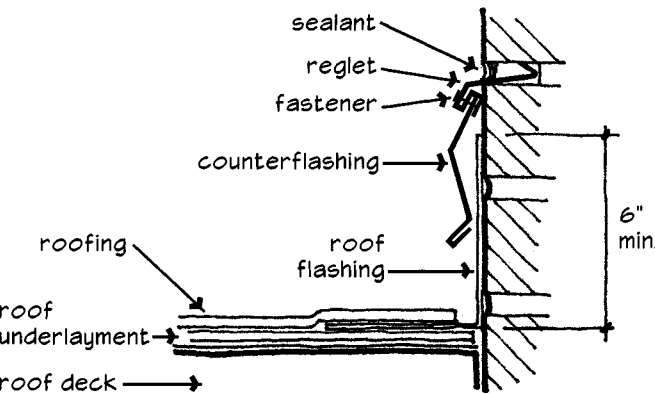
2. install metal sill pan flashing over self-adhered membrane sill flashing



3. install jamb flashing, lapping over metal sill pan flashing

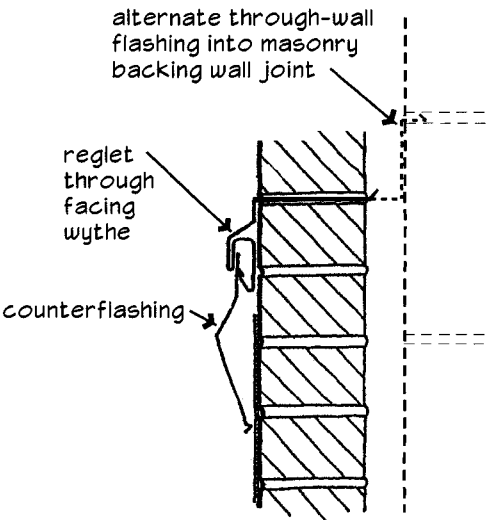
4. install window and window head flashing, continue lapping moisture-resistant membrane, install masonry, sill and sill flashing, lintel and lintel flashing

15.2.8 Masonry Chimney Flashing

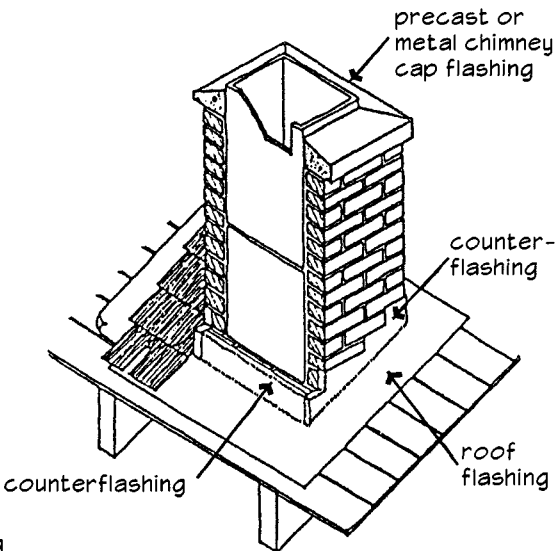
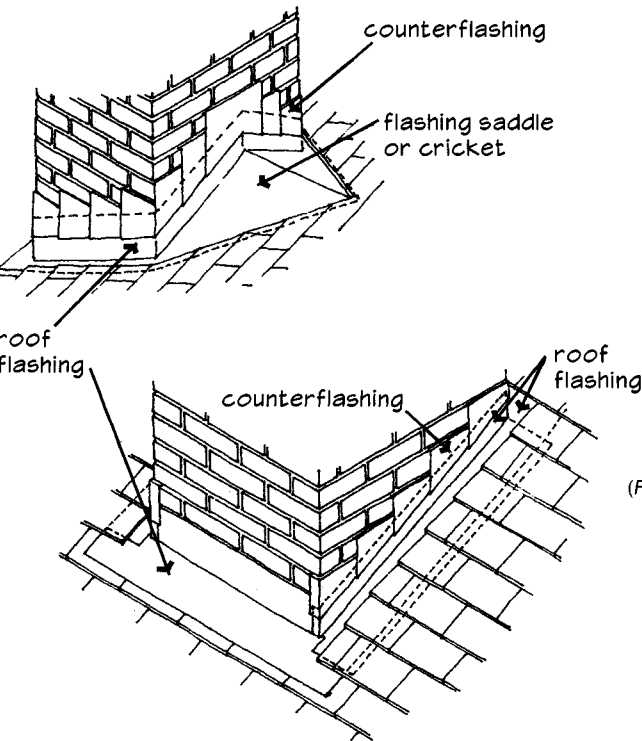


saw-cut counterflashing

(From NRCA Roofing and Waterproofing Manual)

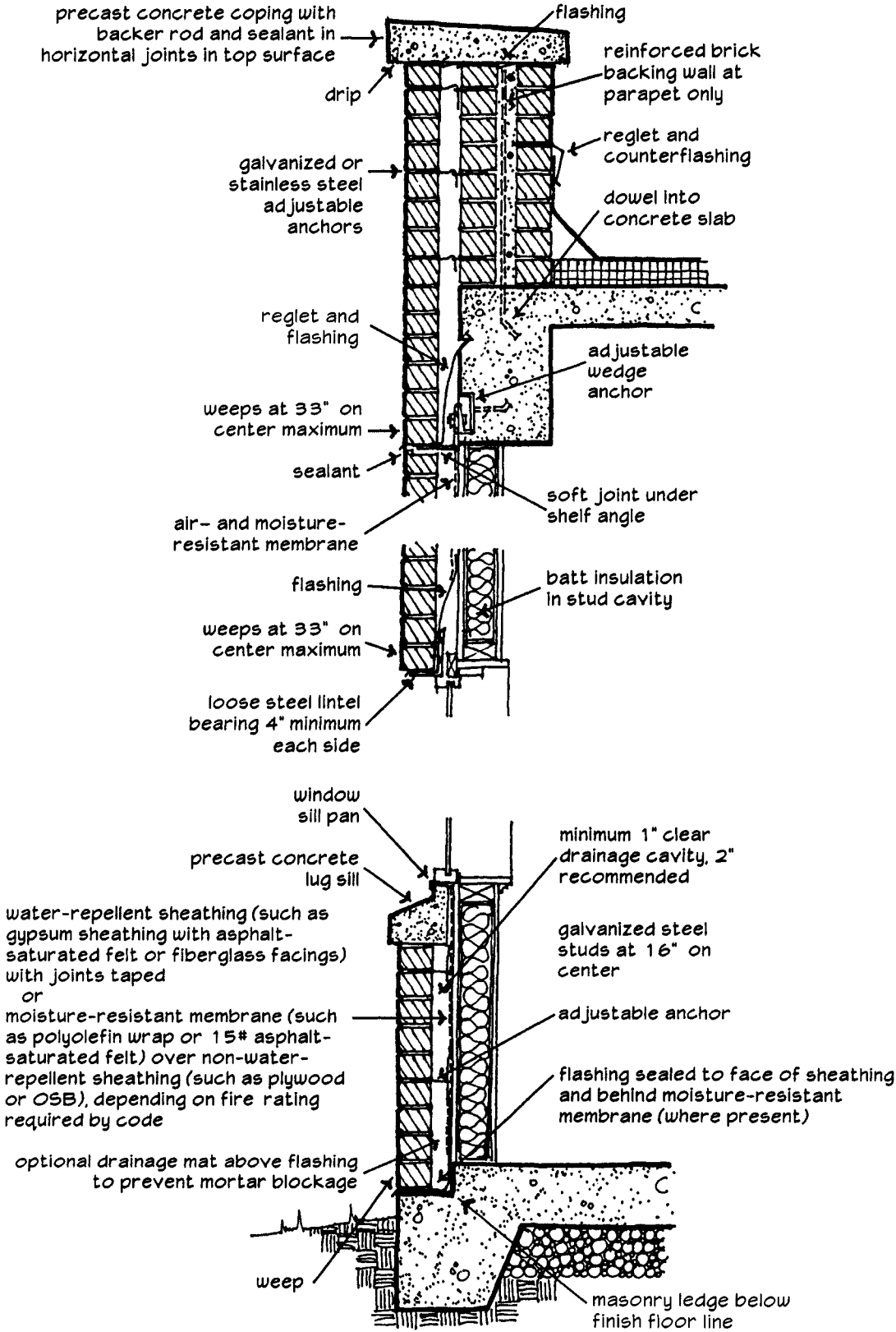


through-wall counterflashing

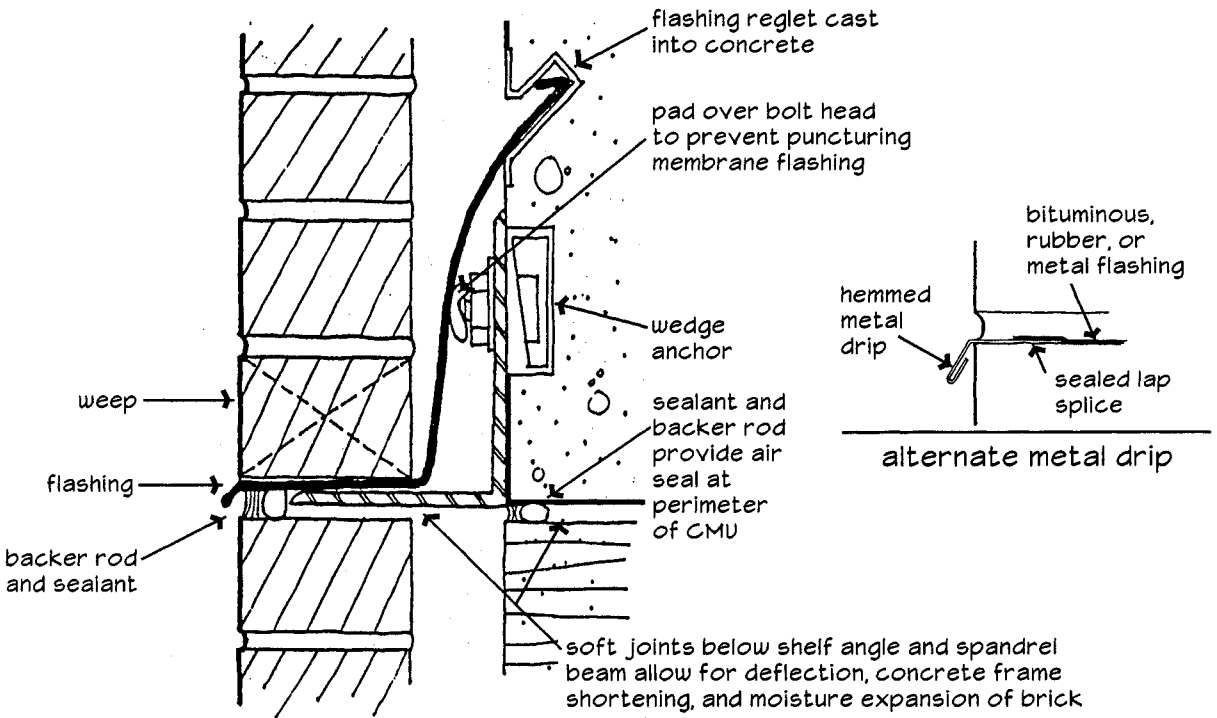


(From BIA Tech Note 7A)

15.3.1 **Basic Commercial Veneer Detailing**

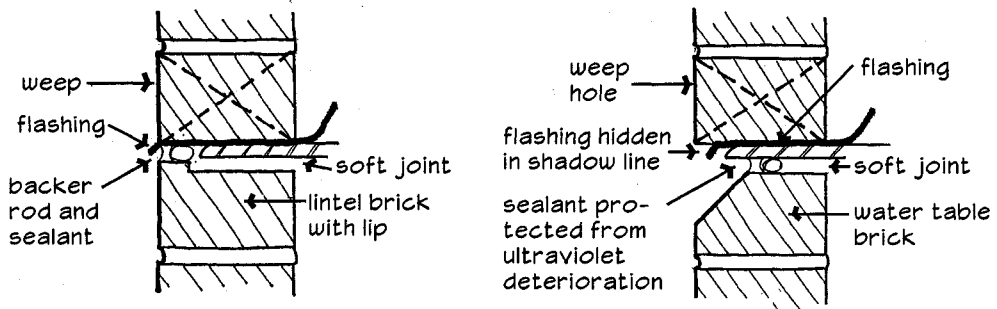
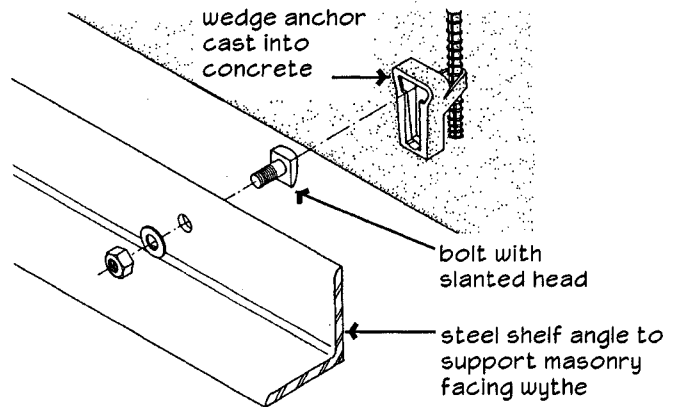


15.3.2 Masonry Shelf Angle Details



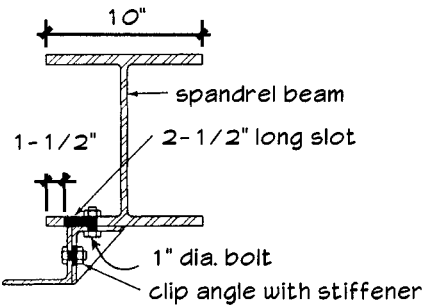
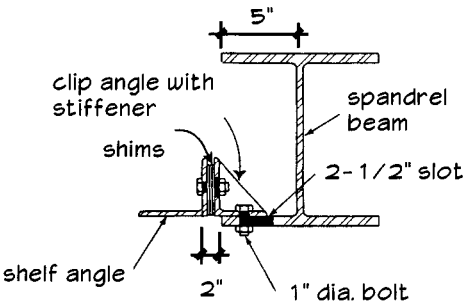
traditional shelf angle detail

malleable iron wedge anchor insert permits vertical adjustment of masonry shelf angles to accommodate construction tolerances

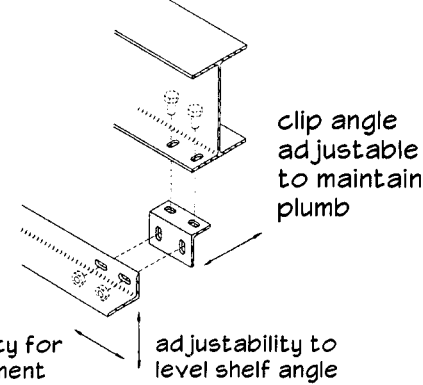
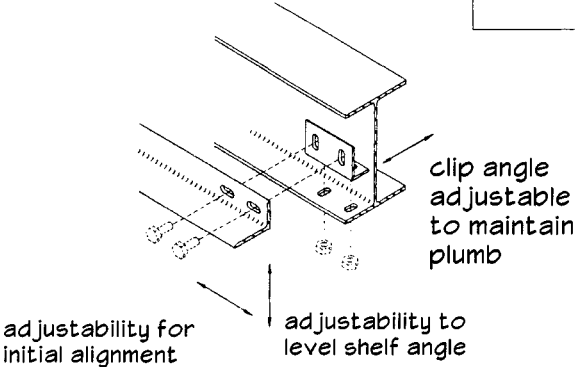


alternate shelf angle details

15.3.3 Adjustable Shelf Angle Connections



Note: Beams must be designed for holes in tension flange and for torsion.

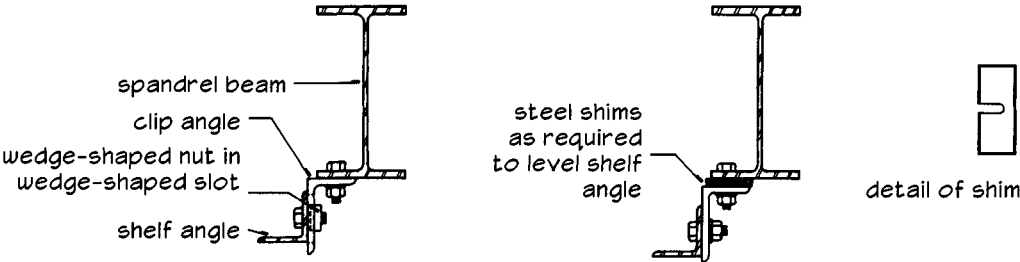


outward adjustability of 2"

inward adjustability of 1-1/2"

Allowable Slotted Hole Dimensions				
Bolt Diameter (in.)	Standard Hole Diameter (in.)	Oversize Hole Diameter (in.)	Short-Slot, Width x Length (in.)	Long-Slot, Width x Length (in.)
1/2	9/16	5/8	9/16 x 11/16	9/16 x 1-1/4
5/8	11/16	13/16	11/16 x 7/8	11/16 x 1-9/16
3/4	13/16	15/16	13/16 x 1	13/16 x 1-7/8
7/8	15/16	1-1/16	15/16 x 1-1/8	15/16 x 2-3/16
1	1-1/16	1-1/4	1-1/16 x 1-5/16	1-1/16 x 2-1/2
≥1-1/8	d + 1/16	d + 5/16	(d + 1/16) x (d + 3/8)	(d + 1/16) x (2.5 d)

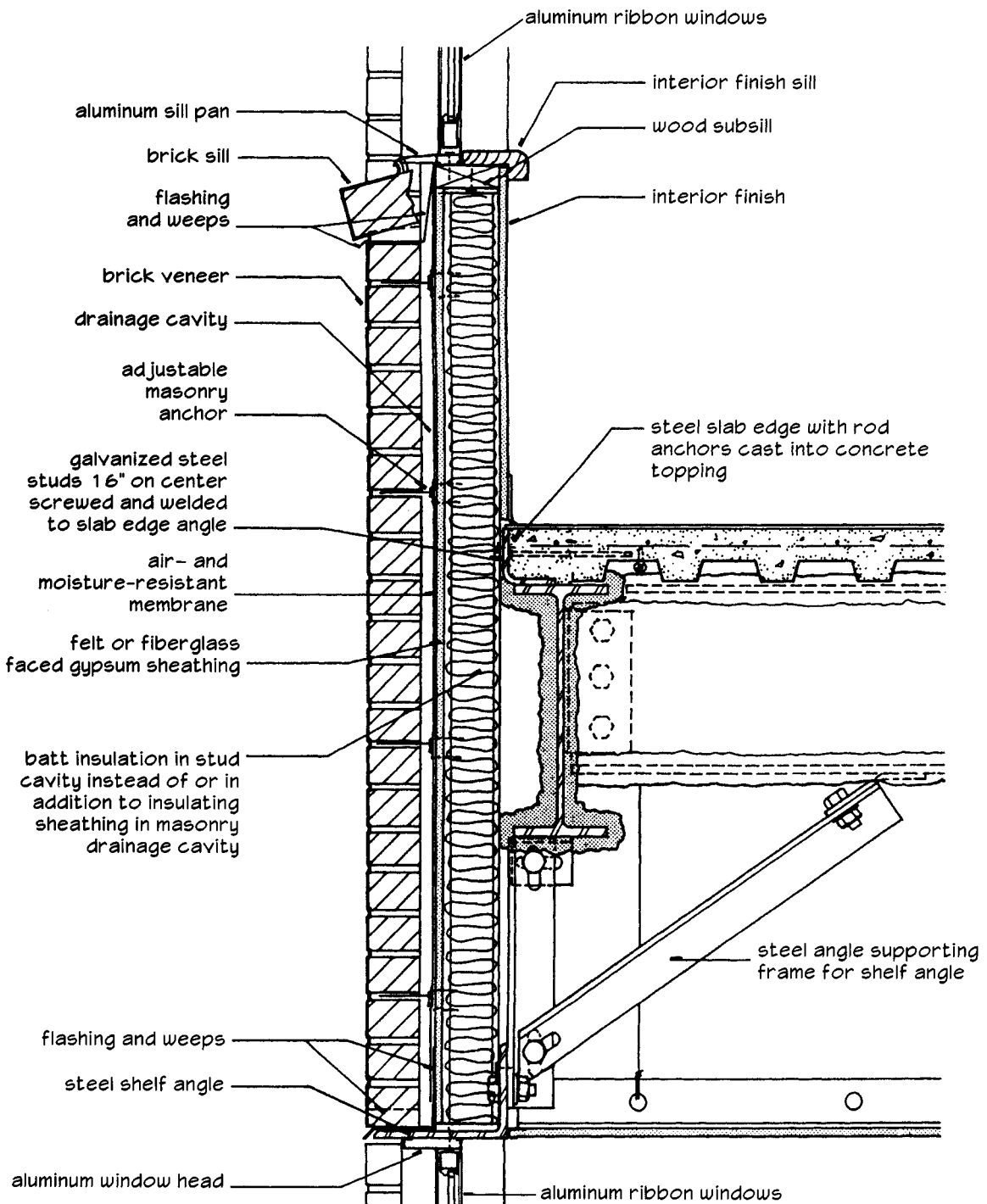
(From Laska, Masonry and Steel Detailing Handbook, 1993)



alternate method of attaching shelf angles

(From Allen, Fundamentals of Building Construction, 1999)

15.3.4 Masonry Spandrels

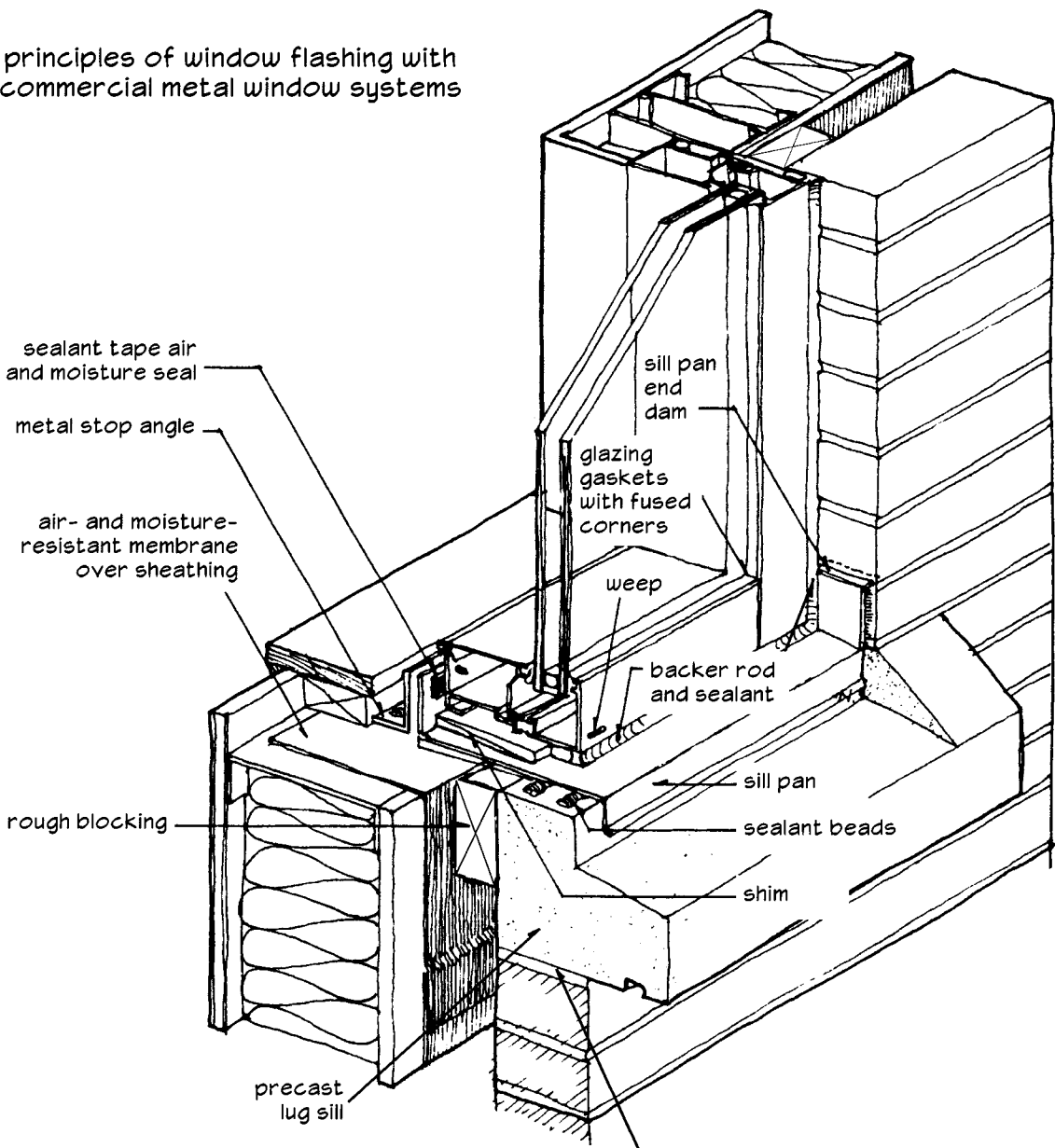


masonry spandrel with continuous ribbon windows above and below

(Adapted from Allen, Fundamentals of Building Construction, 1999)

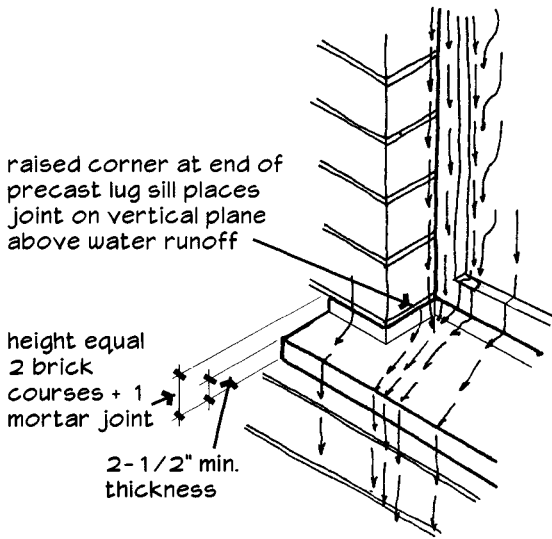
15.3.5 Commercial Window Sill Detail

principles of window flashing with commercial metal window systems



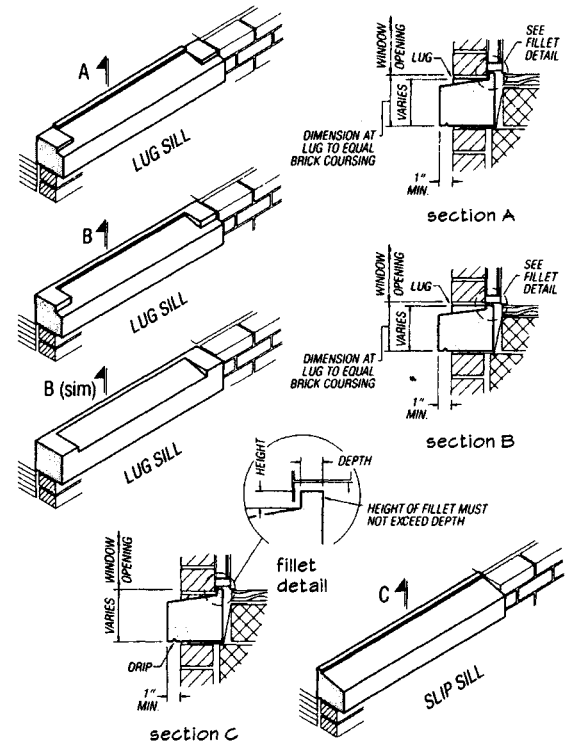
With metal window sill pan lapped over top of large pre-cast or cast stone sill, flashing under masonry sill is usually not necessary. With brick rowlok or CMU or porous stone sill, water can penetrate through mortar joints or through porous units, so through-wall flashing and weeps should be installed under the masonry sill.

15.3.6 Masonry Sill Details



lug sill

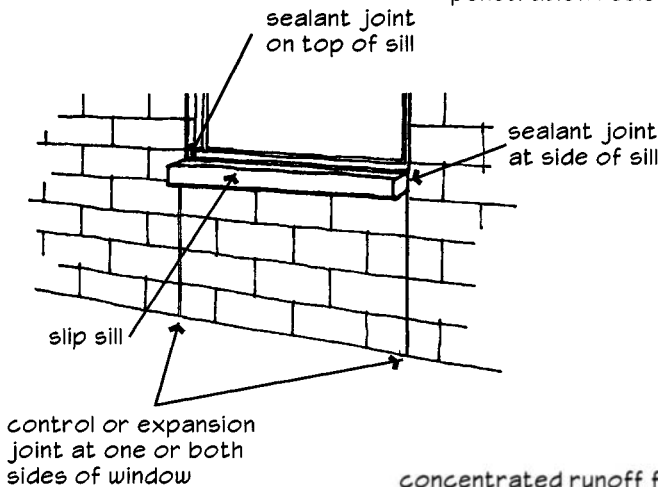
(Adapted from Marsh, Air and Rain Penetration of Buildings)



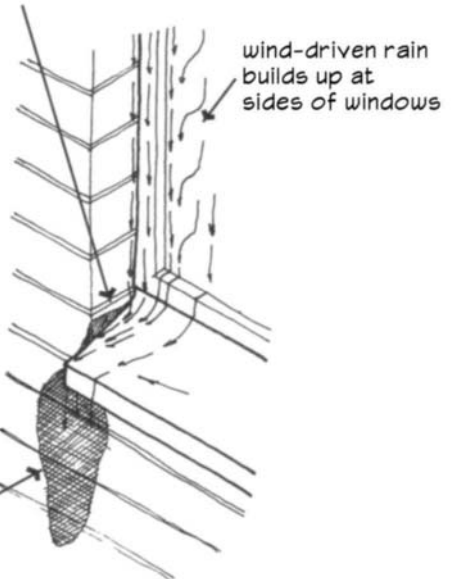
precast concrete sills

(From Architectural Precast Concrete, 2nd ed., Precast/Prestressed Concrete Institute, 1989)

shrinkage cracks in mortar joints on top of sill can result in leaks—backer rod and sealant provide best moisture penetration resistance



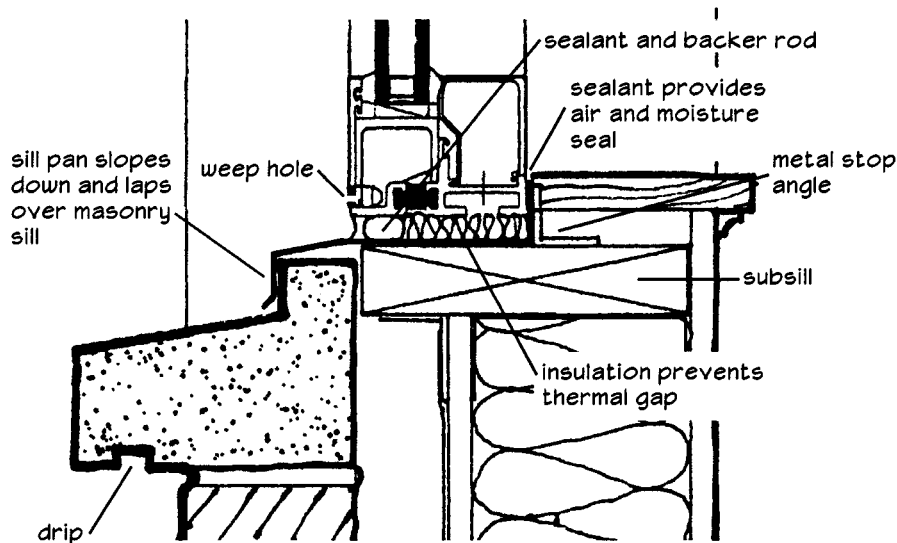
concentrated runoff from slip sill can create stains below corners of sills



slip sills are required with expansion or control joints at sides of windows

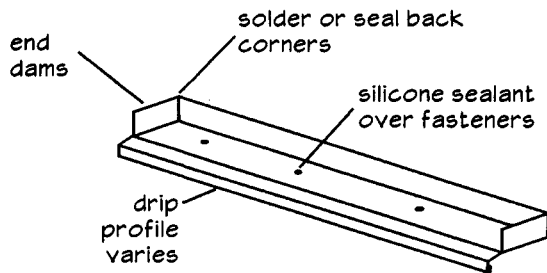
(Adapted from Marsh, Air and Rain Penetration of Buildings)

15.3.7 Sill Pan Details

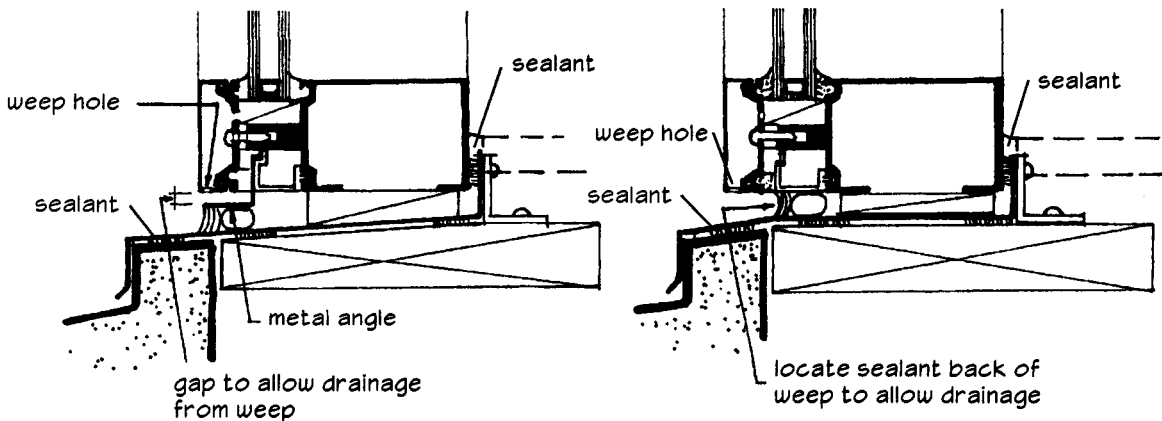


metal window sill pan at cast stone sill

(From Allen, Architectural Detailing, 1993)



metal sill pan collects water which enters window unit through glazing gaskets



location of sealant should not block weeps

(Adapted from Nashed, Time-Saver Details for Exterior Wall Design, McGraw-Hill, 1996)

Masonry Arches and Lintels

16.1 Masonry Arches

- 16.1.1 Load Distribution in Masonry Arches
- 16.1.2 Arch Terminology
- 16.1.3 Arch Shapes
- 16.1.4 Graphic Arch Analysis
- 16.1.5 Horizontal Thrust Resistance in Masonry Arches

16.2 Lintels

- 16.2.1 Lintel Loading, Deflection and Arching Action
- 16.2.2 Area of Lintel Load With Arching Action
- 16.2.3 Area of Lintel Load Without Arching Action
- 16.2.4 Determination of Lintel Load
- 16.2.5 Allowable Spans for Lintels in Masonry Veneer
- 16.2.6 Reinforced CMU Lintels
- 16.2.7 Reinforced CMU Lintels and Bond Beam
- 16.2.8 Reinforced Brick Lintels
- 16.2.9 Steel Lintels

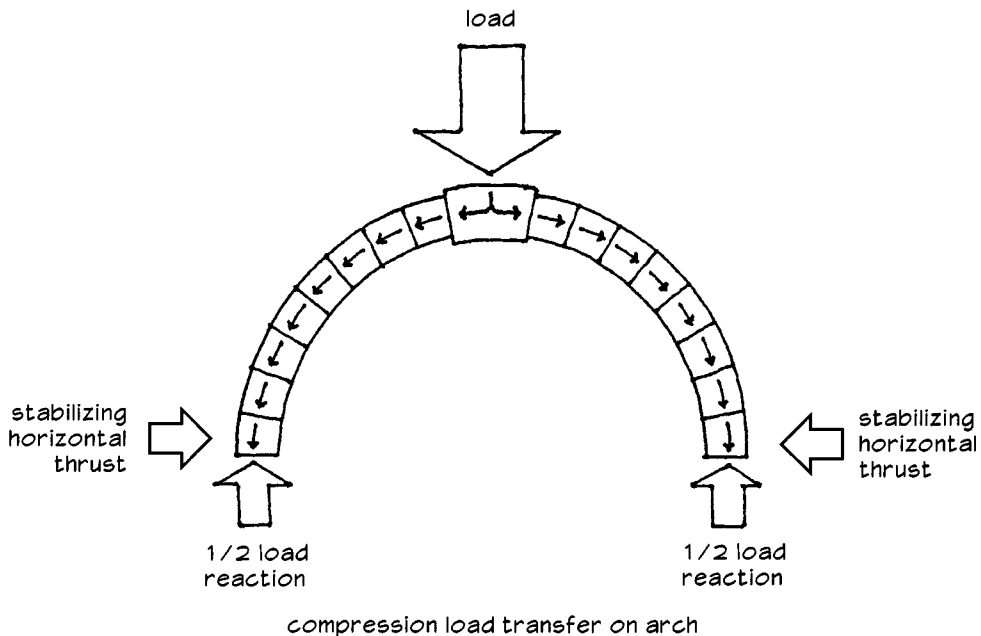
16.1.1 Load Distribution in Masonry Arches

Masonry arches may be flat or curved, and under uniform loading conditions, the induced stress is principally compression rather than tension because of the shape or orientation of the individual units. Arches may be constructed in various forms such as segmental, elliptical, Tudor, Gothic, semicircular, parabolic, and flat or jack arches. Arches are divided structurally into two categories. Minor arches are those whose spans do not exceed 6 ft with a maximum rise/span ratio of 0.15, with equivalent uniform loads on the order of 1000 lb/ft. These are most often used in building walls over door and window openings. Major arches are those whose spans or loadings exceed the maximum for minor arches. In a fixed masonry arch, three conditions must be maintained to ensure the integrity of the arch action:

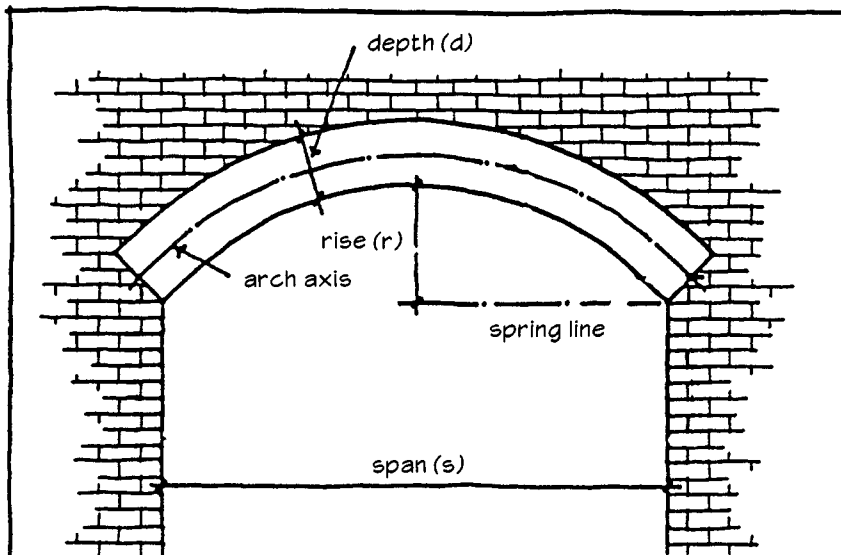
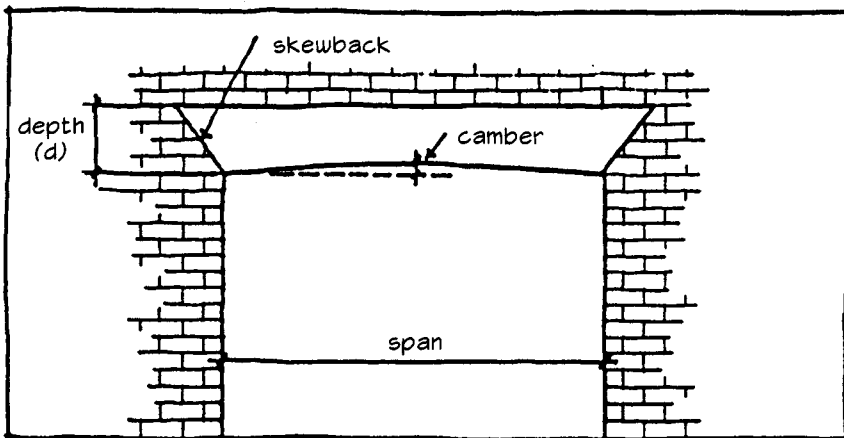
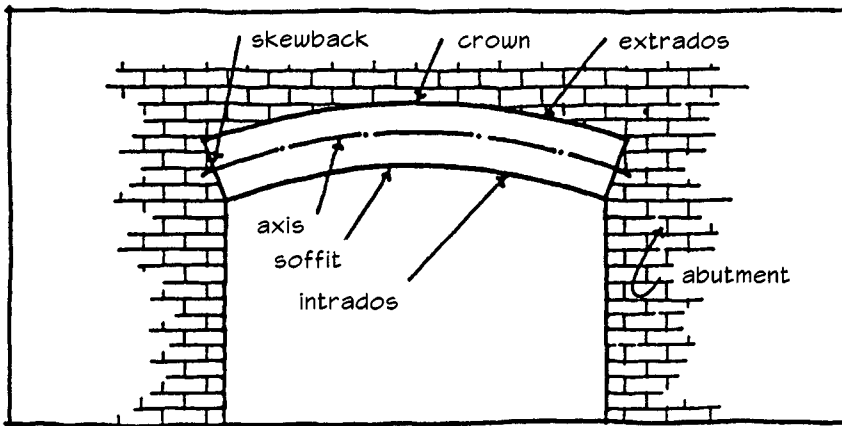
- length of span must remain constant
- elevation of the ends must remain unchanged
- inclination of the skewback must be fixed.

If any of these conditions are altered by sliding, settlement, or rotation of the abutments, critical stresses can develop and may result in structural failure. Adequate foundations and high-quality mortar and workmanship are essential to proper arch construction. The compressive and bond strength of the mortar must be high, and only Types M, S, or N are recommended. It is also particularly important that mortar joints be completely filled to assure maximum bond and even distribution of stresses.

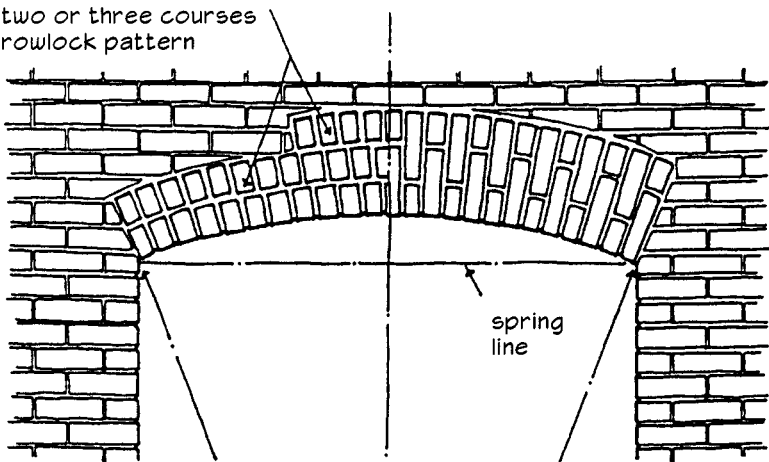
Arches are designed by assuming a shape and cross section based on architectural considerations or empirical methods, and then analyzing the shape to determine its adequacy to carry the superimposed loads. Minor arch loading may consist of live and dead loads from floors, roofs, walls, and other structural members. These may be applied as concentrated loads or as uniform loads fully or partially distributed. The dead load on an arch is the weight of the wall area contained within a triangle immediately above the opening. The sides of the triangle are at 45° angles to the base, and its height is therefore one-half of the span. Such triangular loading is equivalent to a uniformly distributed load of 2.0 times the triangular load. Superimposed uniform loads above this triangle are carried beyond the span of the opening by arching action of the masonry wall itself when running bond patterns are used. Uniform live and dead loads below the apex of the triangle are applied directly on the arch for design purposes. Minor concentrated loads bearing directly or nearly directly on the arch may safely be assumed as equivalent to a uniformly distributed load twice the magnitude of the concentrated load. Heavy concentrated loads should not be allowed to bear directly on minor arches (especially jack arches).



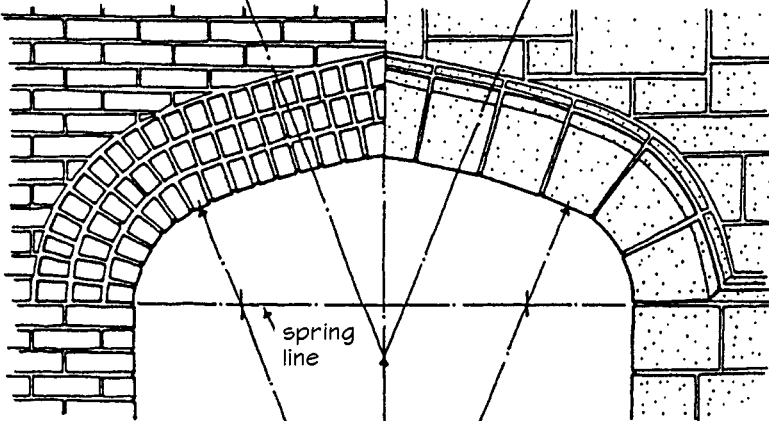
16.1.2 Arch Terminology



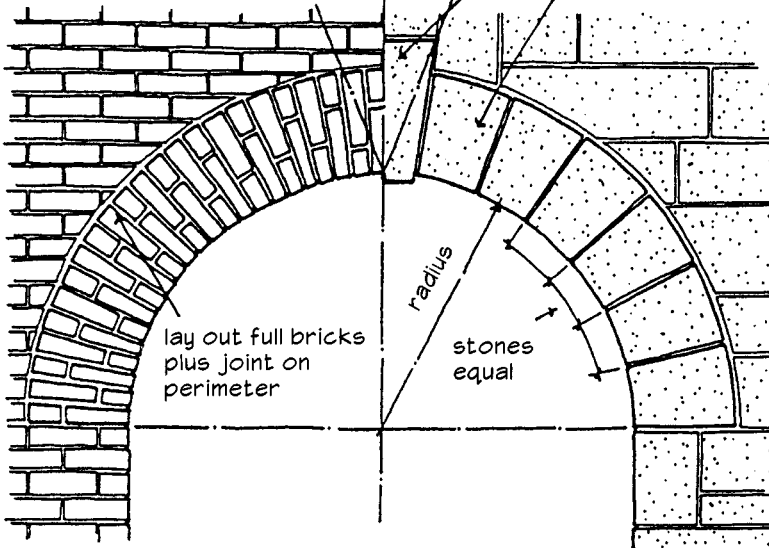
16.1.3 Arch Shapes



segmental arch



Tudor arch

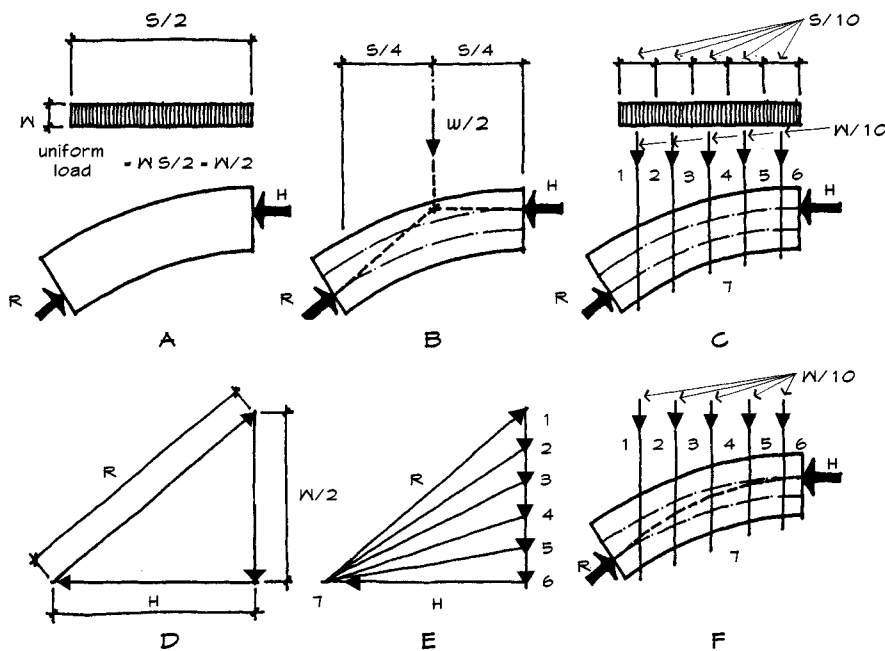


semicircular
or Roman arch

16.1.4 Graphic Arch Analysis

One theory of arch analysis is the line-of-thrust method, which is most applicable to symmetrical arches loaded uniformly over the span or subject to symmetrically placed concentrated loads. The line of thrust resistance must fall within the middle third of the arch section so that no tension develops. The simplest line-of-thrust method is based on the hypothesis of "least crown thrust," which can be applied by static methods if the external forces acting on the arch are known and the point of application and direction of crown thrust are assumed. For symmetrical arches symmetrically loaded, the direction of the crown thrust is assumed as horizontal and its point of application as the upper extremity of the middle third of the section. With these assumptions, the forces acting on each section of an arch may be determined graphically. The first step is to determine the joint of rupture which, for minor segmental arches, is assumed to be the skewback.

Based on the joint of rupture at the skewback and the hypothesis of least crown thrust, the magnitude and direction of the reaction at the skewback may be determined graphically (see below). In this example, only half of the arch is considered since it is symmetrical and uniformly loaded over the entire span. A shows the external forces acting on the arch section. For equilibrium, the lines of action of these three forces ($W/2$, H , and R) must intersect at one point as shown in B. Since the crown thrust (H) is assumed to act horizontally, this determines the direction of the resisting force (R). The magnitude of the resistance may be determined by constructing a force diagram as indicated in Fig. D. The arch is divided into sections or voussoirs and the uniform load transformed into equivalent concentrated loads acting on each section (C). Starting at any convenient point (in this example between the reaction and the first load segment past the skewback) numbers are placed between each pair of forces, so that each force can subsequently be identified by a number (i.e., 1-2, 5-6, 7-1, and so on). The side of the force diagram which represents $W/2$ (D) is divided into the same number of equivalent loads, and the same numbers previously used for identification are placed as shown in E to identify the forces in the new force diagram. Thus, the line 7-1 is the skewback reaction, 6-7 the horizontal thrust, and so on. From the intersection of H and R (7-1 and 6-7) a line is drawn to each intermediate point on the leg representing $W/2$. The equilibrium polygon may now be drawn. First extend the line of reaction until it intersects the line of action of 1-2 (F). Through this point, draw a line parallel to the line 7-2 until it intersects the line of action of 2-3. Through this point, draw a line parallel to the line 7-3, and so on, and complete the polygon in this manner. If the polygon lies completely within the middle third of the arch section, the arch is stable. For a uniformly distributed load, the equilibrium polygon, which coincides with the line of resistance, will normally fall within this section, but for other loading conditions it may not.



(From Brick Industry Association Technical Note 31)

16.1.5 Horizontal Thrust Resistance in Masonry Arches

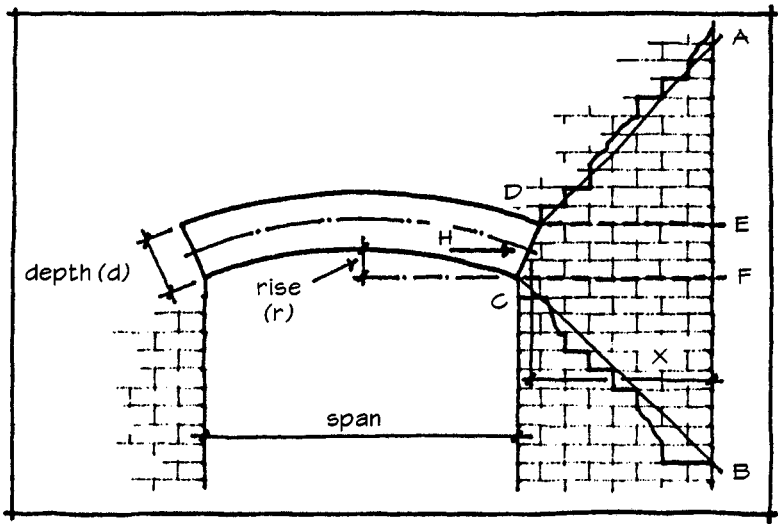
The horizontal thrust resistance developed by an arch is provided by the adjacent mass of the masonry wall. Where the area of the adjacent wall is substantial, thrust is not generally a problem. However, at corners and openings where the resisting mass is limited, it may be necessary to check the resistance of the wall to this horizontal force. The diagram below shows how the resistance is calculated. It is assumed that the arch thrust attempts to move a volume of masonry enclosed by the boundary lines ABCD. For calculating purposes, the area CDEF is equivalent in resistance. The thrust is thus acting against two planes of resistance, CF and DE. Resistance is determined by the formula

$$H_l = v_m n x t$$

- where H_l = resisting thrust, lb.
 v_m = allowable shearing stress in the masonry wall, psi
 n = number of resisting shear planes
 x = distance from the center of the skewback to the end of the wall, in.
 t = wall thickness, in.

By using this principle, the minimum distance from a corner or opening at which an arch may be located is easily determined. To do so, write the formula to solve for x , substituting actual arch thrust for resisting thrust:

$$x = H/v_m n t$$

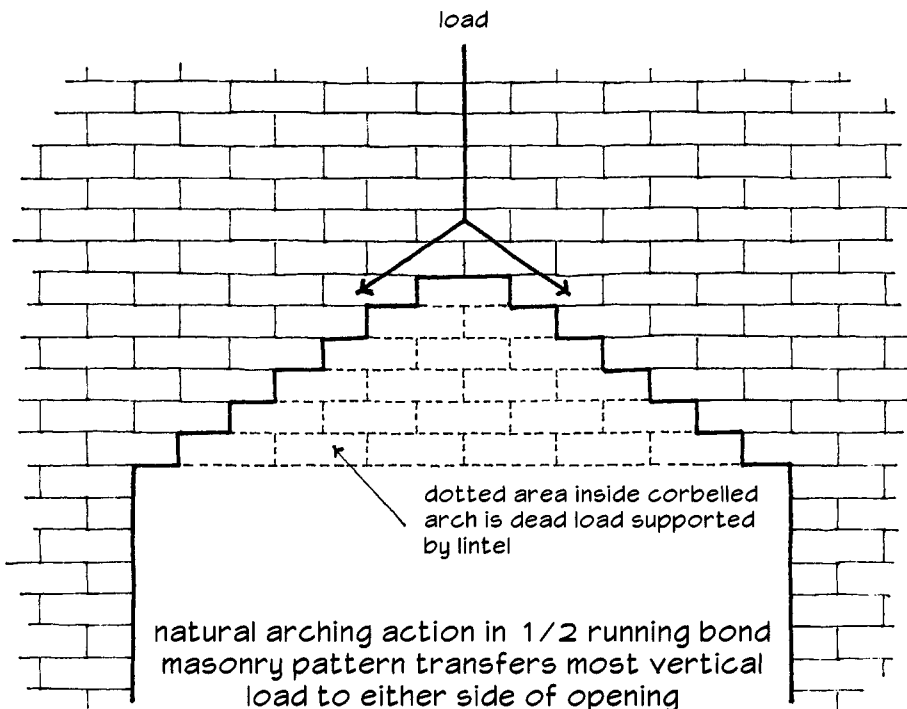
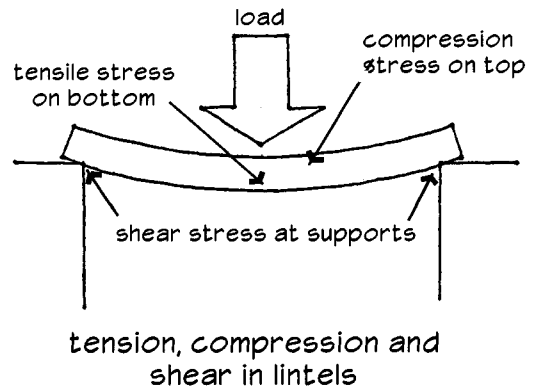
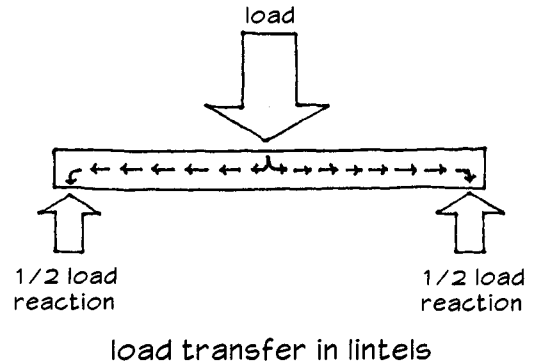


(From Brick Industry Association, Technical Note 31A)

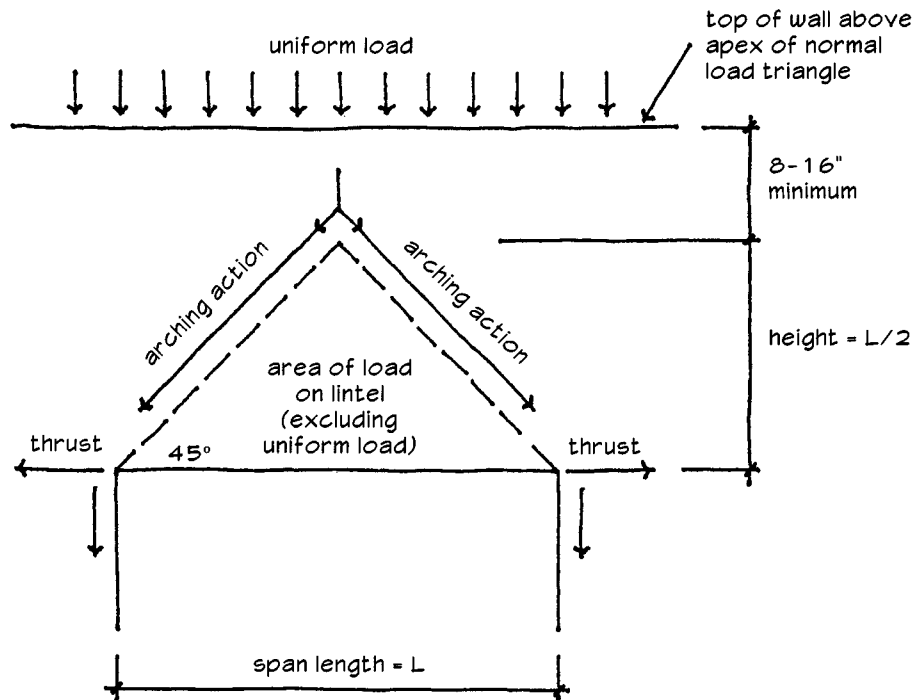
16.2.1 Lintel Loading, Deflection and Arching Action

Lintels must resist compressive, bending and shear stresses. Many of the cracks that appear over door and window openings result from excessive deflection of improperly or inadequately designed lintels.

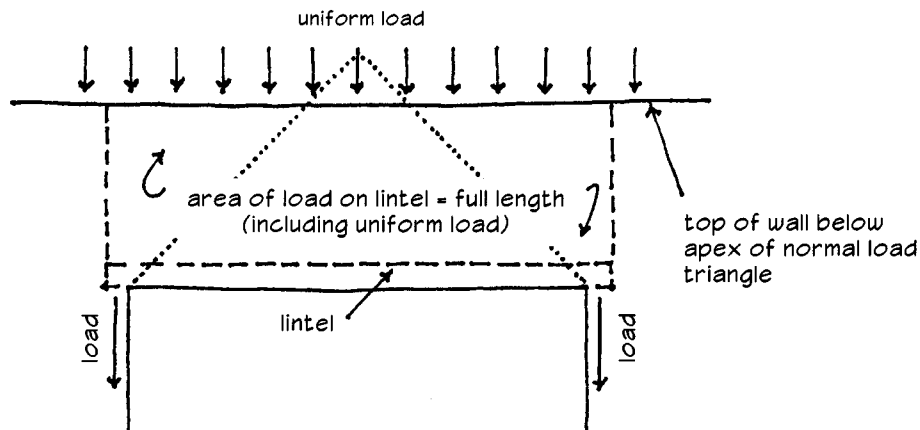
When masonry is laid in a running bond pattern, it creates a natural corbelled arch which transfers much of the vertical load to either side of the opening. The area inside a triangle with sides at 45 degree angles to the lintel represents the masonry which must be supported by the lintel. Outside this area, the weight of the masonry is assumed to be carried to the supporting abutments by natural arching. For this assumption to be true, however, the arching action must be stabilized by a minimum of 8 to 16 inches of masonry above the top of the triangle. There must also be sufficient masonry mass on both sides of the opening to resist the horizontal thrust, and there cannot be a movement joint at either side of the opening. If arching action cannot be assumed to occur because of inadequate height above the load triangle, inadequate thrust resistance, movement joints locations, or because the masonry is not laid in running bond, the lintel must be sized to carry the full weight of the masonry above its entire length. When arching action is assumed, the lintel requires temporary support until the mortar has cured sufficiently to allow the masonry to assume its share of the load.



16.2.2 Area of Lintel Load With Arching Action



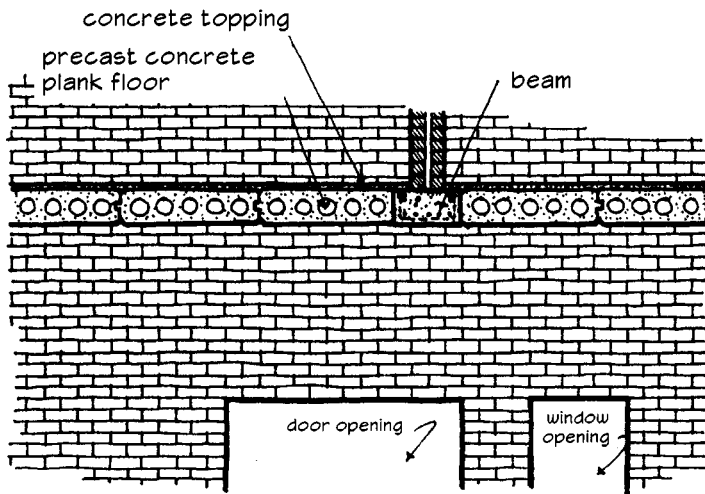
16.2.3 Area of Lintel Load Without Arching Action



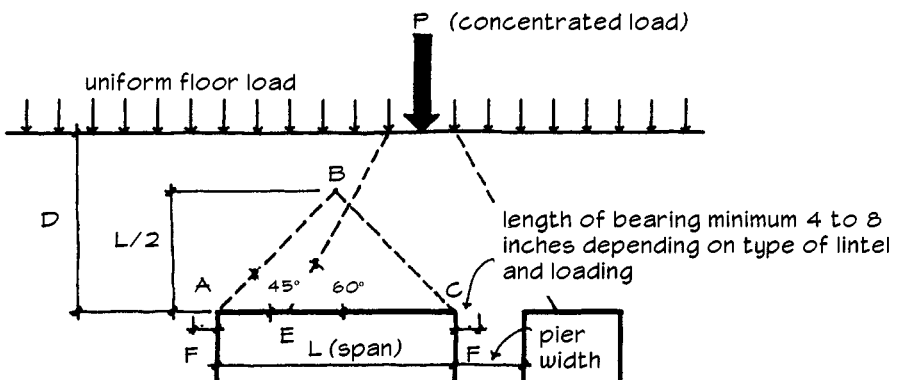
16.2.4 Determination of Lintel Load

Regardless of the material used to form or fabricate a lintel, one of the most important aspects of design is the determination of applied loads. The diagram below shows an elevation of an opening with a concrete plank floor and concrete beam bearing on the wall, and a graphic illustration of the distribution of these loads. The triangular area (ABC) immediately above the opening has sides at 45 degree angles to the base and represents the area of wall weight actually carried by the lintel. "Arching action" of the masonry will carry other loads outside the triangle provided that the height of the wall above the apex is sufficient to resist arching thrusts. Arching action may be assumed only when the masonry is laid in running bond, or when sufficient bond beams distribute the loads in stack bond. For most lintels of ordinary thickness, load, and span, a depth of 8 to 16 in. above the apex is generally sufficient.

In addition to the wall load contained within the triangular area, the lintel will also carry uniform floor loads occurring above the opening and below the apex of the triangle. In this example, the distance D is greater than $L/2$, so the floor load may be ignored. If arching action does occur, loads outside the triangle may be neglected. Consideration must also be given to concentrated loads from beams, girders, or trusses which frame into the wall above the opening. These loads are distributed over a length of wall equal to the base of a trapezoid whose summit is at the point of load application and whose sides make an angle of 60° with the horizontal. In this example, the portion of concentrated load carried by the lintel is distributed over the length EC and is considered as a uniform load partially distributed. The sum of all loads is used to calculate the required lintel size. Lintels should have a minimum 4 to 8 in. bearing length depending on lintel type and loading.



wall elevation



load diagram

(From Brick Industry Association Technical Note 31B)

16.2.5 Allowable Spans for Lintels in Masonry Veneer

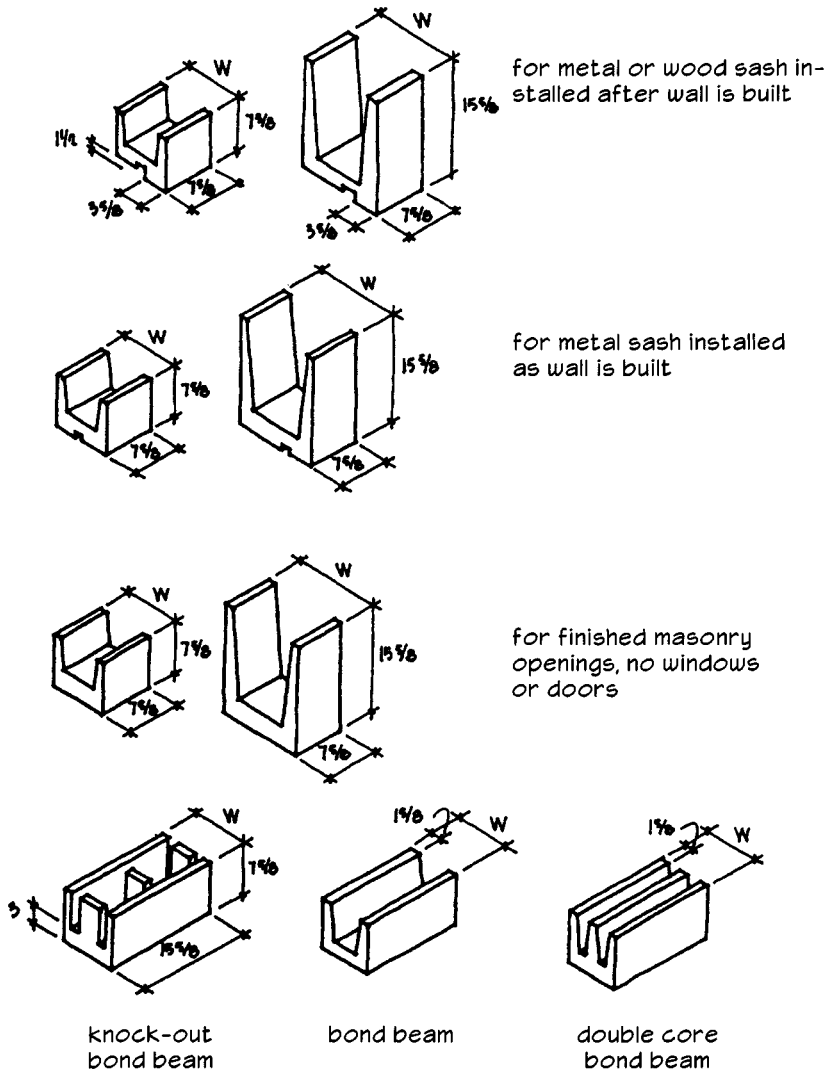
Allowable Spans for Steel, Concrete and Masonry Lintels Supporting Masonry Veneer				
Size of Steel Angle Lintels, Vertical X Horizontal X Thickness (in.)	Number of 1/2" or Equivalent Reinforcing Bars in Masonry or Concrete Lintels†	Less Than One Story of Masonry Above Lintel	Lintel Supporting One Story of Masonry Above Opening	Lintel Supporting Two Stories of Masonry Above Opening
3 x 3 x 1/4	1	6'-0"	3'-6"	3'-0"
4 x 3 x 1/4	1	8'-0"	5'-0"	3'-0"
6 x 3-1/2 x 1/4	2	14'-0"	8'-0"	3'-6"
two 6 x 3-1/2 x 1/4	4	20'-0"	11'-0"	5'-0"

§ Steel lintels indicated are adequate typical examples. Other steel lintels meeting structural design requirements may be used.

† Depth of reinforced lintels shall not be less than 8 inches, and all cells or cores of hollow masonry lintels shall be grouted solid. Reinforcing bars shall extend not less than 8 inches into the support.

(From CABO One and Two Family Dwelling Code)

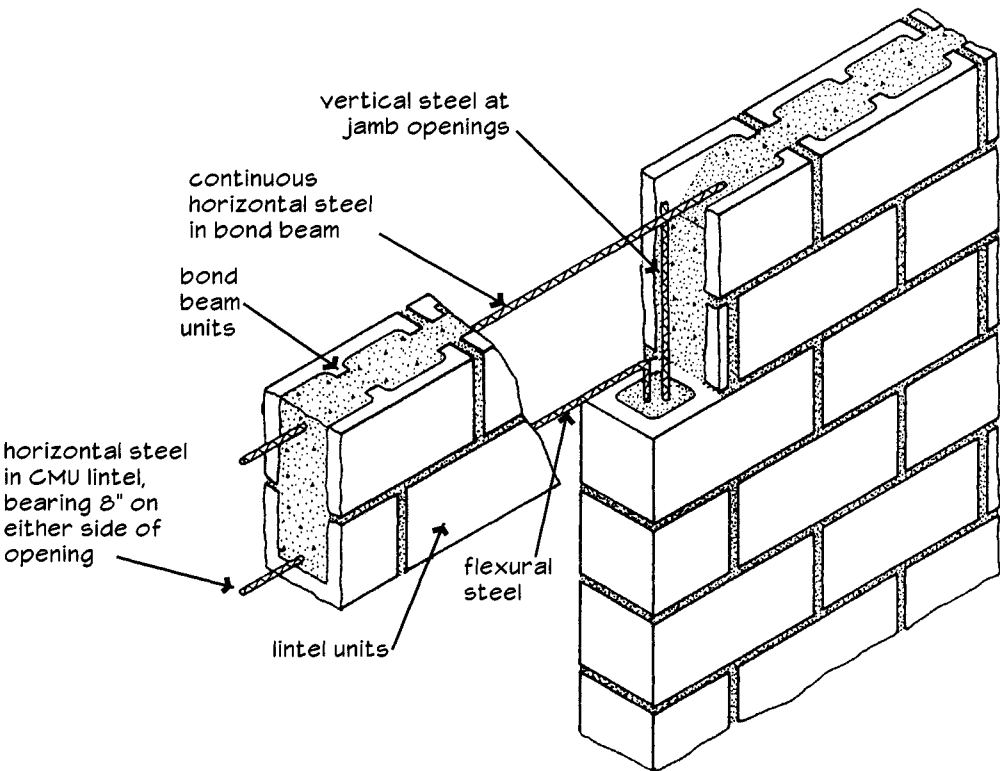
16.2.6 Reinforced CMU Lintels



Required Reinforcement for Simply Supported CMU Lintels									
Type of Loading	Nominal Size of Lintel Section (in.)	Clear Span							
		3'-4"	4'-0"	4'-8"	5'-4"	6'-0"	6'-8"	7'-4"	8'-0"
Wall loads (200-300 lb/lin.ft)	6 x 8	1 #3	1 #4	1 #4	2 #4	2 #5	—	—	—
	6 x 16	—	—	—	—	1 #4	1 #4	1 #4	1 #4
Floor and roof loads (700-1000 lb/lin.ft)	6 x 16	1 #4	1 #4	2 #3	1 #5	2 #4	2 #4	2 #5	2 #5
Wall loads (200-300 lb/lin.ft)	8 x 8	1 #3	2 #3	2 #3	2 #4	2 #4	2 #5	2 #6	—
	8 x 16	—	—	—	—	—	—	2 #5	2 #5
Floor and roof loads (700-1000 lb/lin.ft)	8 x 8	2 #4	—	—	—	—	—	—	—
	8 x 16	2 #3	2 #3	2 #3	2 #4	2 #4	2 #4	2 #5	2 #5

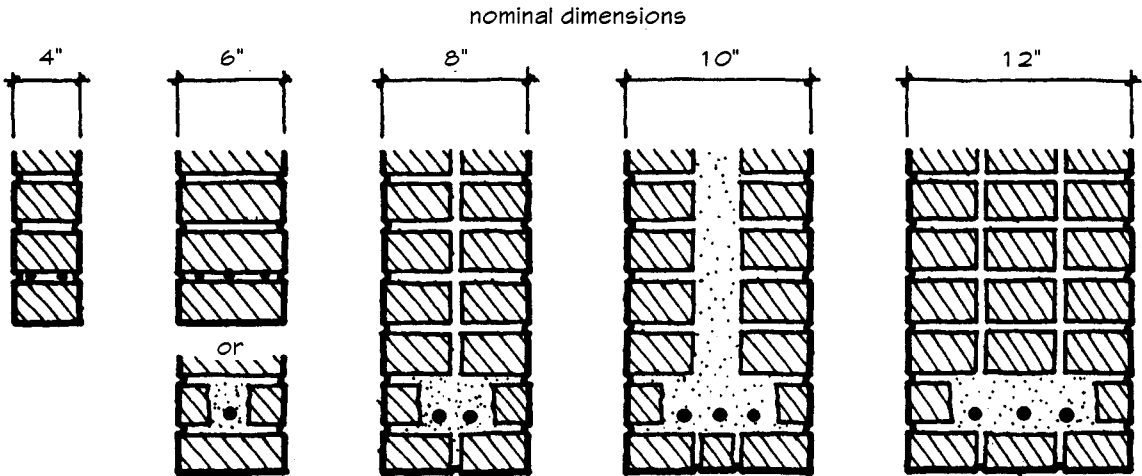
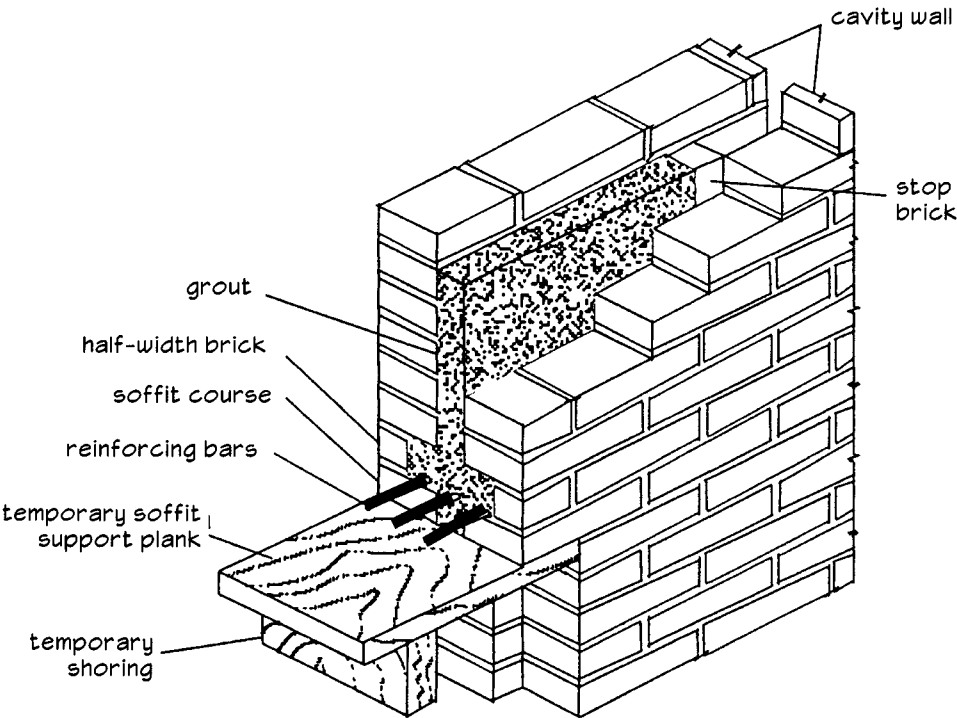
(From National Concrete Masonry Association, TEK Bulletin 25)

16.2.7 Reinforced CMU Lintel and Bond Beam

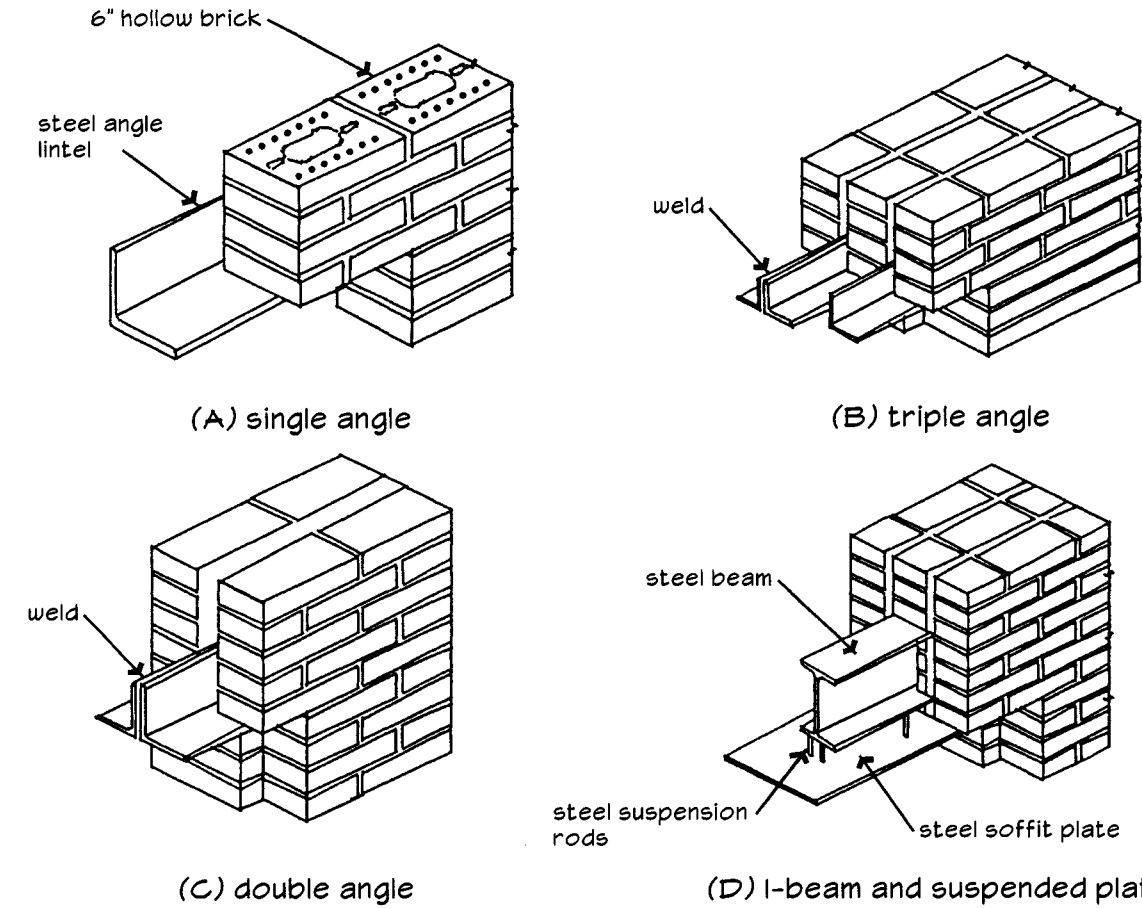


(From Amrhein, Reinforced Masonry Engineering Handbook, 5th ed., Masonry Institute of America)

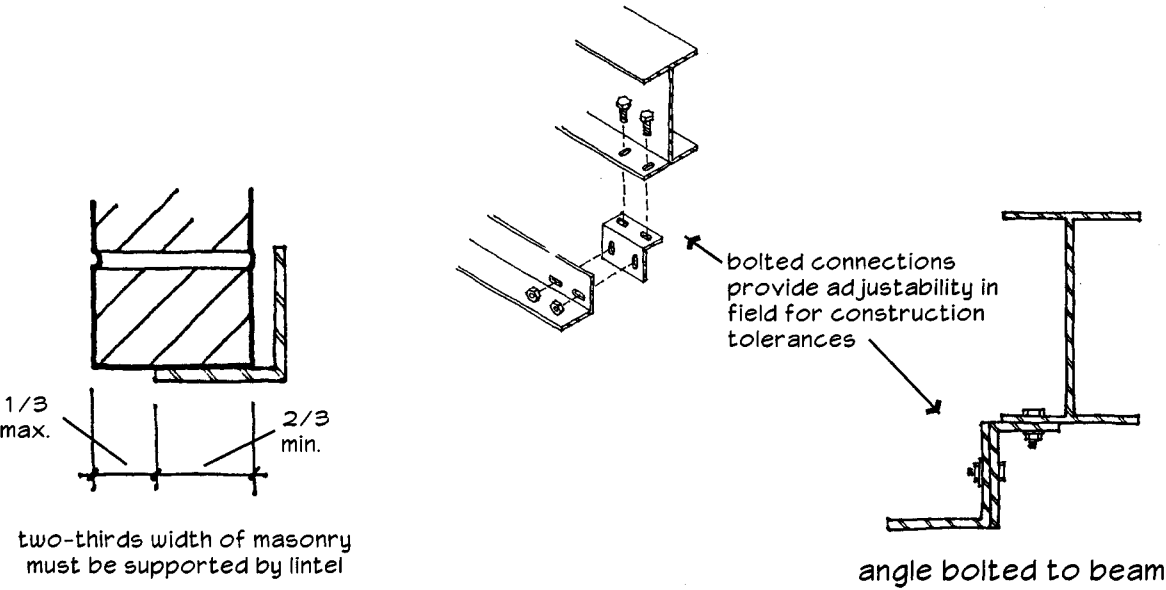
16.2.8 Reinforced Brick Lintels



16.2.9 Steel Lintels



(From Masonry Designers Guide, 3rd ed., The Masonry Society)



17

Masonry Fireplaces

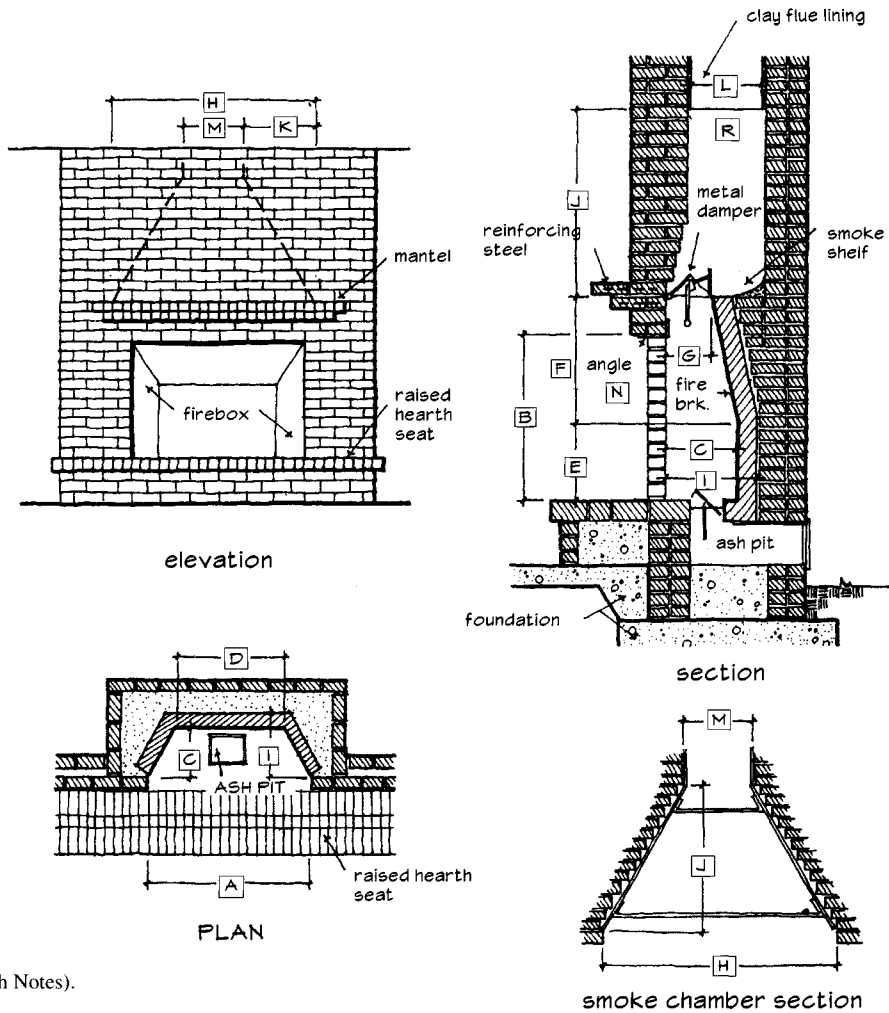
17.1 Fireplaces

- 17.1.1 BIA Fireplace Details and Dimensions
- 17.1.2 IBC 2000 Masonry Fireplace and Chimney Details
- 17.1.3 IBC 2000 Masonry Fireplace and Chimney Requirements

17.2 Fireplace Flues

- 17.2.1 IBC 2000 Flue Size Requirements for Masonry Chimneys
- 17.2.2 Net Cross-Sectional Area of Chimney Flues

17.1.1 BIA Fireplace Details and Dimensions



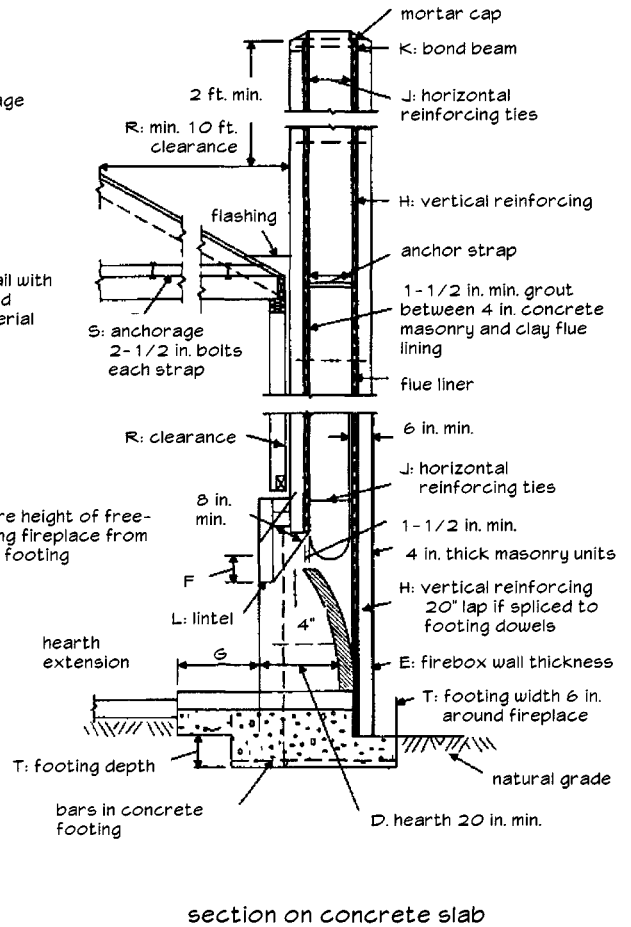
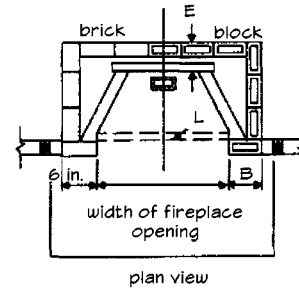
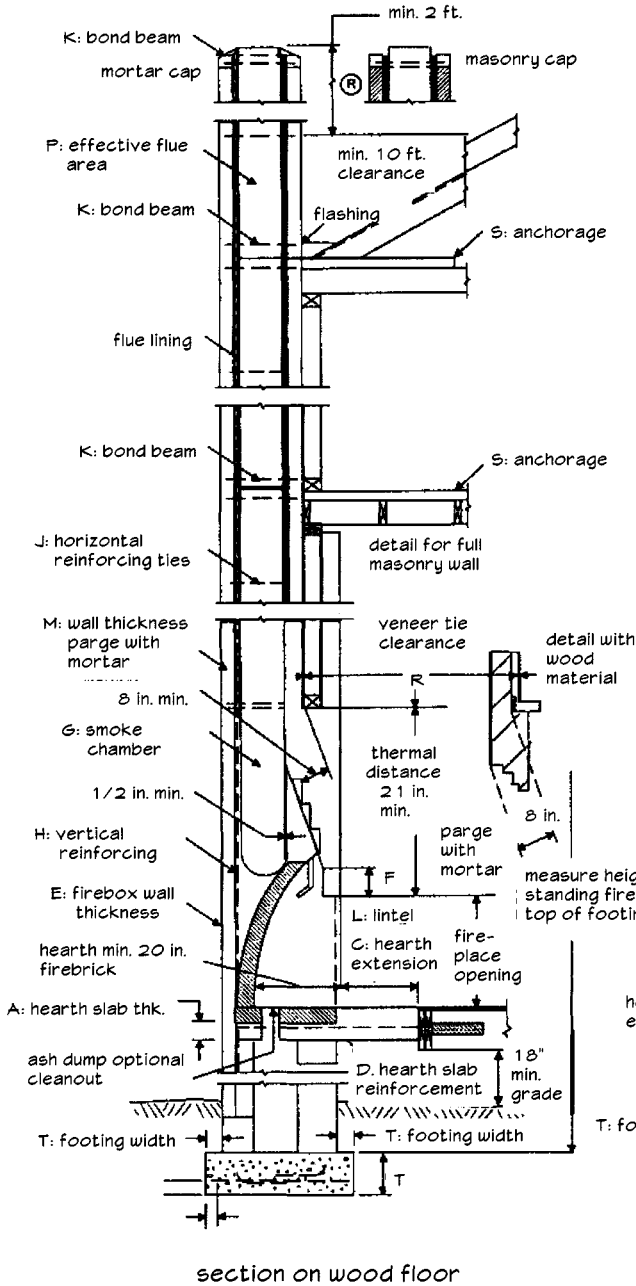
(From: BIA Tech Notes).

Finished Fireplace Opening (in.)							Rough Brick Work and Flue Sizes (in.)							Steel Angles [§]
A	B	C	D	E	F	G	H	I	J	K	L	M	R†	N
24	24	16	11	14	18	8-3/4	32	20	19	10	8	12	8	A-36
26	24	16	13	14	18	8-3/4	34	20	21	11	8	12	8	A-36
28	24	16	15	14	18	8-3/4	36	20	21	12	8	12	10	A-36
30	29	16	17	14	23	8-3/4	38	20	24	13	12	12	10	A-36
32	29	16	19	14	23	8-3/4	40	20	24	14	12	12	10	A-42
36	29	16	23	14	23	8-3/4	44	20	27	16	12	12	12	A-42
40	29	16	27	14	23	8-3/4	48	20	29	16	12	16	12	A-48
42	32	16	29	14	26	8-3/4	50	20	32	17	16	16	12	A-48
48	32	18	33	14	26	8-3/4	56	20	37	20	16	16	15	B-54
54	37	20	37	16	29	13	68	24	45	26	16	16	15	B-60
60	37	22	42	16	29	13	72	27	45	26	16	20	15	B-66
60	40	22	42	16	31	13	72	27	45	26	16	20	18	B-66
72	40	22	54	16	31	13	84	27	56	32	20	20	18	C-84
84	40	24	64	20	28	13	96	29	61	36	20	24	20	C-96
96	40	24	76	20	28	13	108	29	75	42	20	24	22	C-108

§ Angle Sizes: A = 3 x 3 x 3/16, B = 3-1/2 x 3 x 1/4, C = 5 x 3-1/2 x 5/16.

† Round flues.

17.1.2 IBC 2000 Masonry Fireplace and Chimney Details



(From International Building Code 2000).

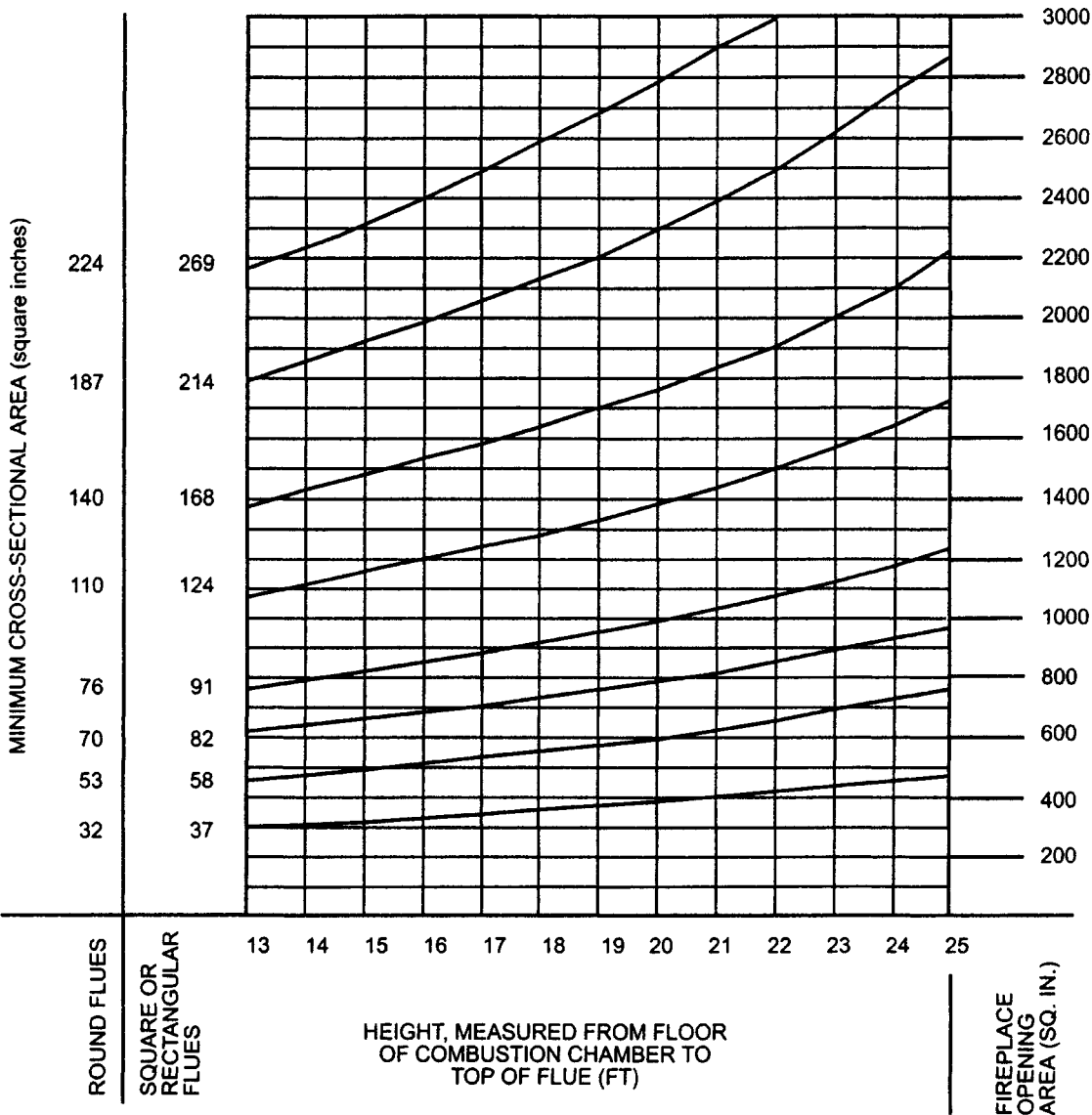
17.1.3 IBC 2000 Masonry Fireplace and Chimney Requirements

Item	Letter Designation§	Requirements
Hearth and hearth extension thickness	A	4 in. minimum thickness for hearth, 2 in. minimum thickness for hearth extension
Hearth extension (each side of opening)	B	8 in. for fireplace opening less than 6 sq.ft; 12 in. for fireplace opening equal to or greater than 6 sq.ft.
Hearth extension (front of opening)	C	16 in. for fireplace opening less than 6 sq.ft; 20 in. for fireplace opening equal to or greater than 6 sq.ft.
Firebox dimensions	D	20 in. minimum firebox depth; 12 in. minimum firebox depth for Rumford fireplaces
Hearth and hearth extension reinforcing	D	Reinforced to carry its own weight and all imposed loads
Thickness of firebox wall	E	10 in. solid masonry or 8 in. where firebrick lining is used
Distance from top of opening to throat	F	8 in. minimum
Smoke chamber wall thickness dimensions	G	6 in. lined; 8 in. unlined; not taller than opening width; walls not inclined more than 45 degrees from vertical for prefabricated smoke chamber lining or 30 degrees from vertical for corbeled masonry
Chimney vertical reinforcing	H	Four No. 4 full-length bars for chimney up to 40 in. wide; add two No. 4 bars for each additional 40 in. or fraction of width, or for each additional flue
Chimney horizontal reinforcing	J	1/4 in. ties at each 18 in. and two ties at each bend in vertical steel
Bond beam	K	As determined by design.
Fireplace lintel	L	Noncombustible material with 4 in. bearing length at each side of opening
Chimney walls with flue lining	M	4 in. thick solid masonry with 5/8 in. fireclay liner or equivalent; 1/2 in. grout or air space between fireclay liner and wall
Effective flue area (based on area of fireplace opening and chimney)	P	See graph on next page
Clearances from chimney from fireplace combustible trim or materials above roof	R	2 in. interior, 1 in. exterior 2 in. back or sides 6 in. from opening 3 ft. above roof penetration, 2 ft. above any part of structure within 10 ft.
Anchorage strap number embedment into chimney fasten to bolts	S	3/16 in. x 1 in. two 12 in. hooked around outer bar with 6 in. extension four joists two 1/2 in. diameter
Footing thickness width	T	12 in. minimum 6 in. each side of fireplace wall

§ See drawing on previous page.

(From International Building Code 2000).

17.2.1 IBC 2000 Flue Size Requirements for Masonry Chimneys



(From International Building Code 2000).

17.2.2 Net Cross-Sectional Area of Chimney Flues

Net Cross-Sectional Area of Square and Rectangular Flues	
ASTM C315 Flue Size Inside Diameter (in.)	Cross-Sectional Area (sq.in.)
4-1/2 x 13	34
7-1/2 x 7-1/2	37
8-1/2 x 8-1/2	47
7-1/2 x 11-1/2	58
8-1/2 x 13	74
7-1/2 x 15-1/2	82
11-1/2 x 11-1/2	91
8-1/2 x 17-1/2	101
13 x 13	122
11-1/2 x 15-1/2	124
13 x 17-1/2	165
15-1/2 x 15-1/2	168
15-1/2 x 19-1/2	214
17-1/2 x 17-1/2	226
19-1/2 x 19-1/2	269
20 x 20	286

Net Cross-Sectional Area of Round Flues	
ASTM C315 Flue Size Inside Diameter (in.)	Cross-Sectional Area (sq.in.)
6	28
7	38
8	50
10	78
10-3/4	90
12	113
15	176
18	254

Glossary

A

AAC See **concrete, autoclaved aerated** ¹

absorption (1) As applied to building materials and insulations, the accumulation of water in a material or in its cells or fibers, accompanied by a physical or chemical change such as softening of the fibers, dissolving of a binding agent, or the swelling of wood. (also see **adsorption**). (2) The amount of water that a masonry unit absorbs when immersed in water under specified conditions for a specified length of time.

absorption rate In masonry, the weight of water absorbed when a brick is partially immersed for 1 minute, usually expressed in either grams or ounces per minute. Also called suction or **initial rate of absorption**.

abutment (1) That part of a pier or wall from which an arch springs, specifically the support at either end of an arch, beam, or bridge. (2) A **skewback** and the masonry that supports it.

accelerator An admixture which speeds the rate of hydration of cement, shortens the normal time of setting, or increases the rate of hardening, strength development, or both, of concrete, mortar or grout.

ACI American Concrete Institute.

actual dimensions Exact size of masonry units, usually width of mortar joint less than nominal dimensions.

adhered Attached by adhesion rather than mechanical anchorage, as in adhered veneer.

admixture A material other than water, aggregate or cement used as an ingredient in concrete, mortar, grout or plaster, and added to the mix either immediately before or during the mixing.

adsorption As applied to building materials and insulations, the accumulation of water in or on the

surface of a material or on its fibers or cell walls, without any chemical or physical change.

aggregate Granular mineral material such as natural sand, manufactured sand, gravel, crushed stone, and air cooled blast furnace slag used with cement to make concrete, mortar, grout or plaster.

aggregate, lightweight Aggregate with a dry, loose weight of 70 pounds per cubic foot or less.

air barrier A system or network of materials that prevents air movement through a building enclosure. See also **vapor retarder**.

air content The volume of air voids in cement paste, concrete or mortar.

air entraining The capability of a material or process to develop a system of minute bubbles of air in cement paste, mortar or grout during mixing.

air-entraining agent An admixture for concrete or mortar which causes the formation of air bubbles in the mix to improve workability and frost resistance.

air entrainment The introduction of air in the form of minute bubbles into concrete or mortar during the mixing in order to improve the flow and workability of fresh mixes and the durability of the hardened material against damage from repeated freezing and thawing when saturated.

air void An entrapped or entrained air pocket in concrete or mortar. Entrapped voids are usually larger than 1 millimeter in diameter and removed by vibration, power screeding or rodding.

ambient temperature Temperature of the surrounding air.

anchor See **connector, anchor**.

anchor bolt A headed or threaded metal bolt or stud either cast in place, grouted in place or cemented into a drilled hole and used to attach steel or wood members to concrete or masonry.

anchorage device In post-tensioning, the hardware used for transferring a post-tensioning force from the tendon to the concrete or masonry.

¹ Boldface type within entries denotes terms for which there are main glossary entries.

angle closer A special-shaped brick used to close the bond at the corner of a wall.

anhydrous Being without water, especially water of hydration.

anode The positive terminal of an electrolytic cell.

arch A vertically curved compressive structural member spanning openings or recesses; may also be built flat using special masonry shapes or specially placed units.

abutment The skewback of an arch and the masonry that supports it.

arch axis The median line of the arch ring.

back arch A concealed arch carrying the back of a wall where the exterior facing is carried by a lintel.

camber The relatively small rise of a jack arch.

constant-cross-section arch An arch whose depth and thickness remain constant throughout the span.

crown The apex of the arch ring. In symmetrical arches, the crown is at midspan.

depth The depth (d) of any arch is the dimension that is perpendicular to the tangent of the axis. The depth of a jack arch is taken to be its greatest vertical dimension.

extrados The exterior curve that bounds the upper extremities of the arch.

fixed arch An arch whose skewback is fixed in position and inclination. Plain masonry arches are, by nature of their construction, fixed arches.

gothic or pointed arch An arch, with relatively high rise, whose sides consist of arcs or circles, the centers of which are at the level of the spring line. The Gothic arch is often referred to as a drop, equilateral, or laced arch, depending on whether the spacings of the center are respectively less than, equal to, or more than the clear span.

intrados The interior curve that bounds the lower extremities of the arch (see *soffit*). The distinction between soffit and intrados is that the intrados is linear, whereas the soffit is a surface.

jack arch An arch having horizontal or nearly horizontal upper and lower surfaces. Also called flat or straight arch.

major arch An arch with span greater than 6 ft and having equivalent uniform loads greater than 1000 lb/ft. Typically, a Tudor arch, semicircular arch, Gothic arch, or parabolic arch. Rise-to-span ratio greater

than 0.15.

minor arch An arch with maximum span of 6 ft and loads not exceeding 1000 lb/ft. Typically, a jack arch, segmental arch, or multi-centered arch. Rise-to-span ratio less than or equal to 0.15.

multi-centered arch An arch whose curve consists of several arcs of circles which are normally tangent at their intersections.

relieving arch One built over a lintel, flat arch, or smaller arch to divert loads, thus relieving the lower member from excessive loading. Also known as a discharging or safety arch.

rise The rise (r) of a minor arch is the maximum height of arch soffit above the level of its spring line. The rise (f) of a major parabolic arch is the maximum height of arch axis above its spring line.

Roman arch A semicircular arch. If built of stone, all units are wedge-shaped.

segmental arch An arch whose curve is circular but less than a semicircle.

semicircular arch An arch whose curve is a semicircle.

skewback The inclined surface on which the arch joins the supporting wall. For jack arches the skewback is indicated by a horizontal dimension (K).

soffit The undersurface of the arch.

span The horizontal distance between abutments. For minor arch calculations the clear span (S) of the opening is used. For a major parabolic arch the span (L) is the distance between the ends of the arch axis at the skewback.

spring line For minor arches the line where the skewback cuts the soffit. For major parabolic arches, the term commonly refers to the intersection of the arch axis with the skewback.

trimmer arch Arch (usually a low-rise brick arch) used to support a fireplace hearth.

Tudor arch A pointed four-centered arch of medium rise-to-span ratio.

voussoir One of the wedge-shaped masonry units which forms an arch ring.

arch stone voussoir stone.

arching action The distribution of loads in masonry over an opening. The load is usually assumed to occur in a triangular pattern above the opening extending from a maximum at the center of the span to zero at the supports.

ASCE American Society of Civil Engineers.

ashlar Squared stones or a pattern of stonework using squared stones.

ASTM American Society for Testing and Materials.

autoclave A type of curing system in the production of concrete masonry units which utilizes super heated steam under pressure to promote strength of units.

autoclaved aerated concrete See **concrete, autoclaved aerated**.

B

backer rod See **sealant backing**.

backing Surface or assembly to which veneer is attached.

backup That part of a masonry wall behind the exterior facing.

band course A continuous, horizontal band of masonry marking a division in the wall elevation. Sometimes called belt course, string course, or sill course.

basketweave A checkerboard pattern of bricks or pavers, flat or on edge. Bricks or modular groups of bricks laid at right angles to those adjacent.

bat A broken brick or piece of brick with one undamaged end. Also called a brickbat. Usually about one-half brick.

batch Quantity of concrete or mortar mixed at one time.

batching Weighing or volumetrically measuring and introducing into the mixer the ingredients for a batch of concrete, mortar or plaster.

batter Masonry that is recessed or sloping back in successive courses; the opposite of a corbel; to rack back.

bearing plate A plate placed under a truss, beam, or girder to distribute the load.

bed (1) In masonry and bricklaying, the side of a masonry unit on which it lies in the course of the wall; the underside when placed horizontally. (2) The layer of mortar on which the masonry unit is set.

bed joint See **joint, bed**.

bedding course The first layer of mortar at the bottom of a masonry wall.

belt course A narrow horizontal course of masonry, sometimes slightly projected, such as window sills which are made continuous. Sometimes called **string course** or sill course.

BIA Brick Industry Association (formerly Brick Institute of America).

bleeding The flow of mixing water within or its emergence on the surface of newly placed concrete or mortar, caused by the settlement of the solid materials within the mass.

blind header A concealed header in the interior of a wall, not showing on the faces of the wall.

block, concrete See **concrete masonry unit**.

bond

adhesion bond The adhesion between masonry units and mortar or grout.

masonry bond Connection of masonry wythes with overlapping header units.

metal tie bond Connection of masonry wythes with metal ties or joint reinforcement.

mortar bond or grout bond Adhesion between mortar or grout and masonry units, reinforcement, or connectors.

pattern bond Patterns formed by the exposed faces of the masonry units, for example, running bond or Flemish bond.

American bond Bond pattern in which every sixth course is a header course and the intervening courses are stretcher courses.

basketweave bond Modular groups of units laid at right angles to those adjacent to form a pattern.

blind bond Bond pattern to tie the front course to the wall where it is not desirable that any headers should be seen in the face work.

common bond Bond pattern in which five to seven stretcher courses are laid between headers.

cross bond Bond pattern in which the joints of the stretcher in the second course come in the middle of the stretcher in the first course

composed of headers and stretchers intervening.

Dutch cross bond A bond having the courses made up alternately of headers and stretchers. Same as an English cross bond.

English bond Bond pattern with alternating courses of headers and stretchers. The headers and stretchers are situated plumb over each other. The headers are divided evenly over the vertical joints between the stretchers.

English cross bond A variation of English bond, but with the stretchers in alternate courses centered on the stretchers above and below. Also called Dutch bond.

Flemish bond Bond pattern in which each course consists of alternate stretchers and headers, with the headers in alternate courses centered over the stretchers in intervening courses.

Flemish garden bond Units laid so that each course has a header to every three to five stretchers.

header bond Bond pattern showing only headers on the face, each header divided evenly on the header under it.

herringbone bond The arrangement of units in a course in a zigzag fashion with the end of one unit laid at right angles against the side of a second unit.

random bond Masonry constructed without a regular pattern.

running bond The placement of masonry units such that head joints in successive courses are horizontally offset at least one quarter the unit length.

stack bond (1) The placement of units such that the head joints in successive courses are vertically aligned. (2) Units laid so no overlap occurs; head joints form a continuous vertical line. Also called plumb joint bond, straight stack, jack bond, jack on jack, and checkerboard bond.

reinforcing bond The adhesion between steel reinforcement and mortar or grout.

bond beam A course or courses of a masonry wall grouted and usually reinforced in the horizontal direction serving as an integral beam in the wall. May serve as a horizontal tie, bearing course for structural members, or as a flexural member itself.

bond beam unit A hollow masonry unit with depressed sections forming a continuous channel in which reinforcing steel can be placed for embedment in grout.

bond-breaker Material to prevent adhesion at designated interface (ASTM C717).

bond course The course consisting of units that overlap more than one wythe of masonry.

bond strength The resistance of mortar or grout to separation from masonry units or reinforcement with which it is in contact.

bonded tendon Prestressing tendon that is bonded to concrete or masonry either directly or through grouting.

bonder A bonding unit. Also called a **header**.

brick A manufactured masonry unit made from fired clay or shale, concrete, or sand-lime materials, which is usually formed in the shape of a rectangular prism, and typically placed with one hand.

acid-resistant brick Brick suitable for use in contact with chemicals, usually in conjunction with acid-resistant mortars.

adobe brick An unfired, air-dried, roughly molded brick of earth or clay. When made with an emulsifier or fibers, called stabilized adobe.

angle brick Any masonry unit shaped to an oblique angle to fit a salient corner.

arch brick Wedge-shaped masonry unit (usually a manufactured clay unit) for special use in an arch. Arch brick provide uniformity of mortar joint thicknesses as the arch is turned. Also refers to the hard burned brick units found in the arch section of a scove kiln.

building brick Brick for building purposes not especially produced for texture or color (formerly called common brick).

bullnose brick A brick having one or more rounded corners.

calcium silicate brick Brick made from sand and lime, with or without the inclusion of other materials.

clay brick A solid or hollow masonry unit

of clay or shale, usually formed into a rectangular prism while plastic and burned or fired in a kiln.

clinker brick A very hard-burned brick whose shape is distorted due to nearly complete vitrification.

common brick See **building brick**.

concrete brick Brick made from portland cement, water and suitable aggregates, with or without the inclusion of other materials.

cored brick A brick in which the holes consist of less than 25% of the section.

dry press brick Brick formed in molds under high pressures from relatively dry clay (5 to 7% moisture content).

economy brick A brick whose nominal dimensions are 4" x 4" x 8".

facing brick Brick made especially for facing purposes.

fire brick (1) Any type of refractory brick, specifically fireclay brick. (2) Brick made of refractory ceramic material that will resist high temperatures.

firebox brick Brick manufactured from clay, fire clay, shale, or similar naturally occurring earthy substances and subjected to heat treatment at elevated temperatures.

floor brick Smooth, dense brick, highly resistant to abrasion, used as finished floor surfaces.

gauged brick (1) Brick that has been ground or otherwise produced according to accurate dimensions. (2) A tapered arch brick.

glazed brick A brick prepared by fusing on the surface a ceramic glazing material; brick having a glassy surface.

hollow brick Brick whose net cross-sectional area (solid area) in any plane parallel to the surface containing the cores, cells or deep frogs, is less than 75% of its gross cross sectional area measured in the same plane.

jumbo brick A generic term indicating a brick larger in size than the standard. Some producers use this term to describe oversize brick of specific dimensions manufactured by them.

Norman brick A brick whose nominal dimensions are 4" x 2-2/3" x 12".

paving brick, heavy vehicular- Brick intended for use in areas with a high volume of heavy vehicular traffic.

paving brick, light traffic Brick intended for use as paving material to support pedestrian and light vehicular traffic.

Roman brick A brick whose nominal dimensions are 4" x 2" x 12".

salmon brick Generic term for underburned brick that is more porous and lighter colored than hard-burned brick. Usually pinkish-orange in color.

sand-lime brick See **calcium silicate brick**.

sand-struck brick See **soft-mud brick**.

SCR brick Brick whose nominal dimensions are 6" x 2-2/3" x 12".

sewer brick Low-absorption, abrasion-resistant brick intended for use in drainage structures.

soft-mud brick Brick produced by molding (often by a hand process) relatively wet clay (20 to 30% moisture).

stiff-mud brick Brick produced by extruding a stiff but plastic clay (12 to 15% moisture) through a die.

wire-cut brick Brick formed by forcing plastic clay through a rectangular opening designed to shape the clay into bars. Before burning, wires pressed through the plastic mass cut the bars into brick units.

brick facing See **veneer**.

brick grade Designation for durability of the unit expressed as SW for severe weathering, MW for moderate weathering, or NW for negligible weathering.

brick ledge A ledge on a footing or wall which supports a course of masonry.

brick trowel A trowel having a flat, triangular steel blade in an offset handle used to pick up and spread mortar. The narrow end of the blade is called the point, the wide end, the heel.

brick type Designation for clay brick that indicates qualities of appearance including tolerance, chippage, and distortion. Expressed as FBS, FBX, and FBA for solid brick, HBS, HBX, HBA, and HBB for hollow brick, and PS, PX and PA for paving brick.

bug holes Small holes in concrete caused by entrapped air voids at the surface of formed concrete during placement and compaction.

building envelope The outer elements of a building, both above and below ground, that divide the external from the internal environments (ASTM E631).

bulking Increase in volume of a quantity of sand in a moist condition compared to the volume of the

same quantity of sand in a dry state.

bull float A tool with a large, flat, rectangular piece of aluminum, wood, or magnesium and a long handle, used to smooth concrete slabs.

bullnose unit A brick or concrete masonry unit having one or more rounded exterior corners.

bush hammer Hammer with a serrated face used to roughen a concrete surface.

butt joint See **joint, butt**.

buttering Placing mortar on a masonry unit with a trowel.

buttness A projecting structure built against a wall or building to give it greater strength and stability.

C

C/B ratio The ratio of the weight of water absorbed by a masonry unit during immersion in cold water for 24 hours to weight absorbed during immersion in boiling water for 5 hours. An indication of the probable resistance of brick to freezing and thawing. Also called **saturation coefficient**. (See ASTM C67.)

capillarity A wick-like action whereby a liquid will migrate through a porous material because of surface tension.

capillary migration (of water) Movement of water induced by the force of molecular attraction (surface tension) between the water and the material it contacts (ASTM E631). See also **rising damp**.

carbonation A process of chemical weathering whereby minerals that contain sodium oxide, calcium oxide, potassium oxide, or other basic oxides are changed to carbonates by the action of carbonic acid derived from atmospheric carbon dioxide and water (ASTM E631),

cast stone See **stone, cast**.

cast-in-place Concrete that is deposited in the place where it will harden as part of a structure; opposite of precast.

cavity An unfilled space.

cell See **core**.

cellular concrete See **concrete, autoclaved aerated**.

cement (1) A burned mixture of clay and limestone pulverized and mixed with water and aggregate for making mortar, grout, or concrete. (2) A general term for an adhesive or binding material.

masonry cement A proprietary hydraulic cement for use in mortars for masonry construction, containing one or more of the following materials: portland cement, portland blast-furnace slab cement, portland-pozzolan cement, natural cement, slag cement, or hydraulic lime; and in addition usually containing one or more materials such as hydrated lime, limestone, chalk, calcareous shell, talc, slag, or clay, as prepared for this purpose.

mortar cement A hydraulic cement, primarily used in masonry construction, consisting of a mixture of portland blended hydraulic cement and plasticizing materials (such as limestone or hydrated or hydraulic lime), together with other materials introduced to enhance one or more properties such as setting time, workability, water retention, and durability. (Similar to masonry cement except that mortar cement must have lower air content and meet flexural bond strength requirements of ASTM C1329.)

portland cement A hydraulic cement produced by pulverizing portland cement clinker, and usually containing calcium sulfate.

cement paste A constituent of concrete and mortar consisting of cement and water.

cementitious material When proportioning masonry mortars, the following are considered cementitious material: portland cement, blended hydraulic cement, masonry cement, quicklime and hydrated lime.

cementitious material, hydraulic An inorganic material or a mixture of inorganic materials, which sets and develops strength by chemical reaction with water by formation of hydrates and is capable of doing so under water.

centering Temporary formwork for the support of masonry arches, hearth extensions, or lintels during construction. Also called center(s).

ceramic Broad term for products made from heat-

resistant, non-metallic, inorganic materials such as clay, bauxite, alumina, silicon carbide, etc. which have been fired to incipient fusion.

ceramic veneer A type of architectural terra cotta, characterized by large face dimensions and thin sections ranging from 1-1/8 to 2-1/4 in. in thickness.

chimney lining Fire clay or terra cotta material or refractory cement made to be built inside a chimney throat. That part of a chimney directly above the fireplace where the walls are brought close together.

cinder An aggregate, sometimes used in the manufacture of concrete masonry units, made from the combustion of coal or volcanic lava.

cinder block See **concrete block**.

clay An earthy or stony mineral aggregate consisting of hydrous silicates of alumina, plastic when sufficiently pulverized and wetted, rigid when dry, and vitreous when fired to a sufficiently high temperature.

clay mortar See **mortar, clay**.

cleanout An opening at the bottom of a grout space of sufficient size and spacing to allow the removal of debris.

closer (1) The last masonry unit laid in a course. It may be whole or a portion of a unit. (2) A stone course running from one window sill to another (a variety of string course).

closure Supplementary or short length units used at corners or jambs to maintain bond patterns.

CMU Concrete masonry unit.

coating A liquid, liquefiable, or mastic composition that, after application in a thin layer, is converted to a solid protective, decorative, or functional adherent film (ASTM E631).

cold joint See **joint, cold**.

cold weather construction Procedures used in constructing concrete or masonry when ambient air temperature or the temperature of the masonry units is below 40°F.

collar joint See **joint, collar**

color pigment Inorganic matter used in concrete

and mortar to vary the color.

combustible Capable of undergoing combustion.

common bond See **bond, pattern, common**.

compaction The process of reducing the volume of freshly placed concrete or grout by vibration, tamping, or rodding to eliminate voids.

component An individually distinguishable product that forms part of a more complex product (i.e., sub-system of a system).

composite action Transfer of stress between components of a member designed so that in resisting loads, the combined components act together as a single member.

compound An intimate mixture of all the ingredients necessary for a finished material or product (ASTM C717).

concrete A homogeneous mixture of portland cement, sand, gravel and water which may contain admixtures or coloring pigments.

autoclaved aerated concrete Lightweight concrete product consisting of portland cement, cement-silica, cement-pozzolan, or lime-silica pastes, or pastes containing blends of these ingredients and having a homogeneous void or cell structure, attained with gas forming chemicals or foaming agents. For cellular concretes containing binder ingredients other than, or in addition to portland cement, autoclave curing is usually employed.

green concrete Concrete which has been placed and has set but is not completely hardened.

high strength concrete Concrete with ultimate compressive strength greater than 6000 psi.

normal weight concrete Concrete having a unit weight of approximately 150 pcf, and made with normal weight aggregates.

lightweight insulating concrete A lightweight concrete made with lightweight coarse aggregate and having relatively low insulating characteristics (ASTM C981).

lightweight structural concrete Concrete having a 28-day compressive strength in excess of 2000 psi and an air-dry unit weight less than 115 pcf.

plain concrete Structural concrete with no reinforcement or with less reinforcement

than the minimum amount specified for reinforced concrete.

concrete block See **concrete masonry unit**.

concrete brick See **concrete masonry unit**

concrete lift (1) An increment of concrete height within the total pour. A pour may consist of one or more lifts. (2) The height to which concrete is placed in a form without intermission.

concrete masonry unit A manufactured masonry unit made from portland cement, mineral aggregates and water, with or without the inclusion of other materials.

concrete block A hollow concrete masonry unit made from portland cement and suitable aggregates such as sand, crushed stone, cinders, burned clay or shale, pumice, scoria, and air-cooled or expanded blast furnace slag, with or without the inclusion of other materials.

"A" block -- A cored masonry unit with one end closed by a cross web and the opposite end open or lacking an end cross web, typically forming two cells when laid in running bond. Also called open end block.

bond beam block A hollow unit with web portions depressed 1-1/4 in. or more to form a continuous channel or channels for reinforcing steel and grout. Lintel blocks are often used to form bond beams.

cap block A solid flat slab, usually 2-1/4 inches thick, used as a capping unit for parapet and garden walls. Also used for stepping stones, patios, veneering, etc.

channel block A hollow unit with web portions depressed less than 1-1/4 inches to form a continuous channel for reinforcing steel and grout.

concrete block A hollow or solid unit consisting of portland cement and suitable aggregates combined with water. Other materials such as lime, fly ash, air-entraining agent, or other admixtures may be permitted.

ground faced block A concrete masonry unit in which the exposed surface is ground to a smooth

finish.

H-block A hollow unit with both ends open, and sometimes a continuous bond beam recess at the intersecting web.

jamb block A block specially formed for the jamb of windows or doors, generally with a vertical slot to receive window frames, etc.

lintel block A masonry unit consisting of one core with one side open. Usually placed with the open side up like a trough to form a continuous beam, as across a window or door opening.

offset block A concrete masonry unit that is not rectangular. Usually used as a corner block to maintain the masonry pattern on the exposed face of a single-wythe wall whose thickness is less than half the length of the unit.

paving block A solid, flat unit used for road and walkway paving.

return corner block Concrete masonry unit that has one flat end for corner construction.

screen block Open-faced masonry units used for decorative purposes or to partially screen areas from the sun or outside viewers.

sculptured block Block with decorative formed or molded surfaces.

shadow block Block with a face formed in planes to develop surface shadow patterns.

sill block A solid concrete masonry unit used for the sills of a wall.

slump block Concrete masonry units produced so that they slump or sag in irregular fashion before they harden.

split-faced block A concrete masonry unit with one or more faces purposely fractured to expose the rough aggregate texture to provide architectural effects in masonry wall construction.

concrete brick A solid concrete masonry unit made from portland cement and suitable aggregates.

concrete masonry unit, architectural Architectural concrete masonry units having textured or sculptured surfaces. Methods

used to obtain different surface textures include splitting, grinding, forming vertical striations, and causing the units to "slump." Sculptured faces are obtained by forming projecting ribs or flutes, either rounded or angular, as well as vertical and horizontal scoring, recesses, and curved faces.

concrete masonry unit, lightweight A unit whose oven-dry density is less than 105 lb./cu.ft.

concrete masonry unit, medium weight A unit whose oven-dry density is at least 105 lb./cu.ft. and less than 125 lb./cu.ft.

concrete masonry unit, moisture-controlled A concrete masonry unit whose moisture content conforms to the requirements for Type I classification of ASTM Specification C55, C90 or C129.

concrete masonry unit, normal weight A unit whose oven-dry density is at least 125 lb./cu.ft. or more.

concrete masonry unit, prefaced Concrete or calcium silicate masonry units with the exposed-to-view-in-place surfaces covered at the point of manufacture with resin, resin and inert filler, or cement and inert filler, to produce a smooth resinous tile facing.

concrete pour The total height of concrete to be placed before stopping work. A concrete pour may consist of one or more concrete lifts.

condensation The process of changing water vapor in the air to liquid water by taking away heat; the opposite of evaporation (which requires the addition of heat).

connector Mechanical devices, including masonry anchors, wall ties, and fasteners, for securing two or more pieces, parts, or members together.

connector, anchor Metal rod, wire or strap that secures masonry to its structural support.

connector, fastener Device used to attach non-masonry materials to masonry.

connector, wall tie Metal connector which connects wythes of masonry walls together.

consistency The relative stiffness or flow of freshly mixed concrete, mortar or grout.

construction joint See **joint, construction**.

contaminants Foreign material such as dust, dirt, oils or rust on the joint surfaces.

continuous hot dipping Automated hot-dip process for coating steel coil in which the steel is cleaned, degreased, pickled, coated, cooled and rewound in a non-stop operation. Zinc, aluminum, and aluminum-zinc alloy coatings are all applied by this method.

control joint See **joint, control**.

coping Masonry units laid on top of a finished wall. (1) A covering on top of a wall exposed to the weather, usually sloped to carry off water (ASTM D1079). (2) The materials or masonry units used to form a cap or a finish on top of a wall, pier, chimney, or pilaster to protect the masonry below from water penetration. Commonly extended beyond the wall face and cut with a drip.

coping unit A solid masonry unit for use as the top and finished course in wall construction.

corbel (1) The projection of successive courses of masonry out from the face of the wall to increase the wall thickness or to form a shelf or ledge. (2) A shelf or ledge formed by successive courses of masonry projecting out from the face of a wall, pier, or column.

corbeled vault A masonry roof constructed from opposite walls or from a circular base, by shifting courses slightly and regularly inward until they meet. The resulting stepped surface may be smoothed or curved, but no true arch action is involved.

core (1) The molded open space in a concrete masonry unit. (2) A hollow space within a concrete masonry unit formed by the face shells and webs. (3) The holes in clay units. Also called cells.

corner pole See **story pole**.

corrosion The chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties.

corrosion resistant Material that is inherently resistant to, or treated or coated to retard harmful oxidation or other corrosive action.

counterflashing Formed metal or elastomeric sheeting secured on or into a wall, curb, pipe, roof-top unit, or other surface, to cover and protect the upper edge of a base flashing and its associated fasteners (ASTM D1079).

course One of the continuous horizontal layers of

units in masonry.

crack A flaw (building defect) consisting of complete or incomplete separation within a single element or between contiguous elements of constructions. *Note:* Occasionally the basic design, or the material characteristics, of a building element will be such that minor cracking may occur. Such cracks are not flaws or defects (ASTM E631).

crack control Methods used to control the extent, size and location of cracking in masonry including reinforcing, movement joints, and dimensional stability of masonry materials.

crazing (1) The cracking that occurs in fired glazes or other ceramic coatings due to tensile stresses. (2) Development of shallow cracks at closely spaced but irregular intervals in concrete, plaster or mortar surfaces. Also known as checking.

creep (1) The dimensional change with time of a material under load, following the initial instantaneous elastic or rapid deformation (ASTM C981). (2) The time dependent part of a strain resulting from stress (ASTM C717).

cross-sectional area, gross (1) The area delineated by the out-to-out dimensions of masonry in the plane under consideration. (2) The total cross-sectional area of a specified section.

cross-sectional area, net (1) The area of masonry units, grout and mortar crossed by the plane under consideration based on out-to-out dimensions. (2) The gross cross-sectional area minus the area of ungrouted cores, notches, cells and unbedded areas. Net area is the actual surface area of a cross section of masonry.

crushed stone The product resulting from the artificial crushing of rocks, boulders, or large cobblestones, substantially all faces of which have resulted from the crushing operation (ASTM D1079).

cure, *n* The process by which a compound attains its intended properties through evaporation, chemical reaction, heat, radiation, or combinations thereof (ASTM C717).

cure, *v* To attain the intended performance properties of a compound by means of evaporation, chemical reaction, heat, radiation, or combinations thereof (ASTM C717).

cured Pertaining to the state of a compound that has

attained its intended performance properties by means of evaporation, chemical reaction, heat, radiation, or combinations thereof (ASTM C717).

curing (1) Chemical process of developing ultimate properties of a finish or other material over a specified period of time (ASTM E631). (2) The maintenance of proper conditions of moisture and temperature during initial set to develop required strength and reduce shrinkage in concrete products and mortar. See also **drying**.

curing compound A membrane-forming liquid applied as a coating to the surface of newly placed concrete to retard the loss of water.

curing method Method by which caulk or sealant cures, i.e., solvent evaporation, chemical reaction, heat, or combinations thereof.

curing time Time in which a compound attains its intended properties; time required to produce vulcanization at a given temperature.

curling The distortion or warping of an essentially flat surface into a slightly curved shape. In concrete slabs, curling is the phenomenon caused primarily by differences in moisture between the top and bottom of the slab.

D

dampcheck An impervious horizontal layer to prevent vertical penetration of water in a wall consisting of either a course of solid masonry, metal, or a thin layer of asphaltic or bituminous material. Generally near grade to prevent upward migration of moisture by capillary action. Also called damp course.

damping Reduction of amplitude of vibrations due to energy loss (as in damping of vibrations from seismic shock).

dampproofing Treatment of a surface or structure to resist the passage of water in the absence of hydrostatic pressure (ASTM D1079).

darby A hand-manipulated straightedge, usually 3 to 8 ft. long, used in the early stage leveling of concrete or plaster surfaces.

deformed reinforcement Reinforcing bar with ridges which serve to interlock with surrounding concrete, mortar or grout.

degradation Deterioration, usually in the sense of a physical or chemical process rather than a mechanical one.

delta T (ΔT) A difference in temperature (T).

density The ratio of the mass of an object to its volume.

design temperature A designated temperature close to the most severe winter or summer temperature extreme of an area, used in estimating heating and cooling demand.

desorption The separation of an adsorbate as such from a sorbent. Opposite of adsorption, absorption, or both.

dew point (1) The temperature corresponding to 100% relative humidity for an air-vapor mixture at constant pressure. (2) The temperature at which condensation of water vapor begins in a given space for a given humidity as the temperature of the vapor is reduced.

differential movement Movement of two elements relative to one another that differs in rate or direction.

dimension stone See **stone, dimension**.

dimensions of masonry units

actual The measured dimensions of a masonry unit.

height (1) The vertical dimension of the unit in the face of a wall. (2) Vertical dimension of masonry units or masonry, measured parallel to the intended face of the unit or units.

length (1) The horizontal dimension of the unit in the face of the wall. (2) Horizontal dimension of masonry units or masonry, measured parallel to the intended face of the unit or units.

nominal (1) A dimension greater than the specified (standard) dimension by the thickness of one joint, but not more than 13 mm or 1/2 in. (2) A dimension that may be greater than the specified masonry dimension by the thickness of a mortar joint.

thickness (1) That dimension designed to lie at right angles to the face of the wall, floor, or other assembly. (2) *thickness (width)* Horizontal dimension of masonry units or masonry measured perpendicular to the intended face of the masonry unit or units.

dog's tooth A brick laid with its corners projecting from the wall face.

dolomitic lime A trade term for high-magnesium lime. Also a misnomer as the product does not contain dolomite.

dovetail anchor A splayed tenon that is shaped like a dove's tail, that is broader at its base, and that fits into the recess of a corresponding mortise.

dowel Steel pin or bar extending into adjoining portions of concrete or masonry to prevent shifting of the two elements relative to one another.

drainage hole An opening in a construction provided for the escape of unwanted liquid, as in a retaining wall (ASTM E631). See also **weep hole**.

drip Groove or slot cut beneath and slightly behind the forward edge of a projecting stone member, such as a sill, lintel, or coping, to cause rainwater to drip off and prevent it from penetrating the wall.

dry stack masonry Masonry work laid without mortar.

drying Process of developing, solely by evaporation of volatile ingredients, ultimate properties of a finish or other material over a specified period of time (ASTM E631). See also **curing**.

ductility The ability of a material to be plastically deformed by elongation without fracture.

durability The capacity of a material, product, component, assembly, or construction to remain serviceable as intended with prudent maintenance during the designed service life under anticipated internal and external environments (ASTM E241).

durability (freeze-thaw) The ability of masonry units to maintain integrity under the forces caused by the cyclic action of freezing and thawing in the presence of moisture.

durometer Instrument used to measure hardness on the Shore A or Shore D scale; may also refer to the relative hardness rather than the instrument itself.

dusting Development of powdered material on the surface of hardened concrete.

E

eccentricity (1) The distance between a vertical load reaction and a centroidal axis of masonry. (2) The normal distance between the centroidal axis of a member and the parallel resultant load.

effective height (1) Clear height of a braced member between lateral supports and used for calculating the slenderness ratio of a member. (2) The height of a member that is assumed when calculating the slenderness ratio.

effective thickness (1) Assumed thickness of a member when calculating the slenderness ratio.

effective width That part of the width of a member taken into account when designing T- or L-beams.

efflorescence, water insoluble A crystalline deposit, usually white, of water-soluble compounds which, on reaching the masonry surface, become water insoluble primarily through carbonation (also sometimes called lime run or calcium carbonate stain). Normally requires acid washing for removal.

efflorescence, water soluble A crystalline deposit, usually white, of water soluble-compounds on the surface of masonry. Normally can be removed with water washing.

elasticity The ability of a material to return to its original shape after deformation such as stretching, compression or torsion.

electrolyte A substance that is capable of forming a conducting liquid medium.

embedment (1) The process of pressing a felt, aggregate, fabric, mat, or panel uniformly and completely into hot bitumen or adhesive to ensure intimate contact at all points. (2) The process of pressing granules into coating in the manufacture of factory-prepared roofing, such as shingles (ASTM D1079).

empirical design Design based on application of physical limitations learned from experience or observations gained through experience, without structural analysis.

end-construction tile Structural clay tile units designed to be laid with the axis of the cells vertical.

engineered masonry Masonry which has been

analyzed for vertical and lateral load resistance and members have been proportioned to resist design loads in accordance with working stress design or strength design principles.

equilibrium moisture content (1) The moisture content of a material stabilized at a given temperature and relative humidity, expressed as a percent of moisture by weight. (2) The typical moisture content of a material in any given geographical area (ASTM D1079).

equivalent thickness (1) Solid thickness to which a hollow unit would be reduced if the material in the unit were recast with the same face dimensions but without voids. (2) The percent solid volume times the actual width divided by 100. (3) E_T = net volume divided by (specified unit length x specified unit height). (4) The average thickness of solid material in the unit.

exfoliation Peeling, swelling or scaling of stone or mineral surfaces in thin layers caused by chemicals, physical weathering, or heat.

expansion joint See **joint, expansion**.

extrados The exterior curve in an arch or vault.

F

face (1) The exposed surface of a wall or masonry unit. (2) The surface of a wall or masonry unit. (3) The surface of a unit designed to be exposed in the finished masonry.

face-bedded Stone set with the stratification vertical.

face shell The side wall of a hollow concrete masonry or clay masonry unit.

face shell bedding Mortar is applied only to the horizontal surface of the face shells of hollow masonry units and in the head joints to a depth equal to the thickness of the face shell.

facing tile Structural clay tile for exterior and interior masonry with exposed faces. (Covered by ASTM C212 and ASTM C126.)

falsework Temporary structures such as shoring or formwork for beams, lintels, arches, slabs built to support work in progress.

fastener See **connector, fastener**.

field The expanse of wall between openings, corners, etc., principally composed of stretcher units.

fillet joint See **joint, fillet**.

film forming Treatment that fills pores, forming a continuous film on the surface.

fin A narrow projection on a concrete surface caused by mortar flowing between the cracks in forms.

finish (1) The final treatment or coating of a surface. (2) The fine or decorative work required to make a building or its parts complete (ASTM E631).

finishing The leveling, smoothing, compacting, and treatment of the surface of concrete or plaster to obtain the final desired finish.

fire box The interior of a fireplace furnace, serving as combustion space.

fire clay Sedimentary clay of low flux content.

fire resistance Property of a material or assemblage to withstand fire or give protection from it.

flagging (1) Collective term for flagstones. (2) A surface paved with flagstones. (3) The process of setting flagstones.

flashing (1) Impermeable sheet or membrane placed in masonry to provide water drainage or prevent water penetration. (2) A technique during brick firing to produce a range of colors by controlling the atmospheric conditions in the kiln.

Flemish bond See **bond, pattern, Flemish**.

flexible Indicates pliability as a permanent condition.

float A rectangular hand tool, usually of wood, aluminum or magnesium, used to impart a relatively even but still open texture to a concrete surface.

floated finish A concrete finish provided by consolidating and leveling the concrete with only a power driven or hand float, or both. *Note:* A floated finish is more coarse than a troweled finish (ASTM C1127).

flow A laboratory-measured property of mortar that

indicates the percent increase in diameter of the base of the truncated cone of mortar when it is placed on a flow table and mechanically raised and dropped specified times under specified conditions.

flow after suction Flow of mortar measured after subjecting it to a vacuum to simulate suction of dry masonry units.

flow-through principle An expression used to describe the performance of a construction such as a wall, in which water vapor that enters one side meets little impedance so that it may flow completely through the construction and out of the opposite side. No seriously deteriorating accumulation of moisture is expected if there are no conditions that cause condensation within the construction (ASTM E241).

flue lining (1) A manufactured tubular non-load-bearing fired clay unit, normally used for conveying hot gases in chimneys. (2) A smooth, hollow clay or concrete tile unit used for the inner lining of masonry chimneys.

fly ash The finely divided residue resulting from the combustion of ground or powdered coal.

fog curing The application of a fine mist of water used during the curing of concrete, masonry or stucco.

form oil Oil applied to the inside surfaces of concrete forms to promote the release of the form from the concrete.

form or formwork A temporary structure or mold used to contain fresh concrete while it hardens and cures.

freeze-thaw Freezing and thawing of moisture in materials and the resultant effects on these materials and on structures of which they are a part or with which they are in contact.

freeze-thaw cycle The freezing and subsequent thawing of a material.

frog An indentation in one bed surface of a brick manufactured by molding or pressing.

furring A method of finishing the interior face of a masonry wall to provide space for insulation, to prevent moisture transmittance, or to provide a smooth or plane surface for finishing.

furring tile Tile for lining the inside of walls and

carrying no superimposed loads.

furring units Thin masonry units used as furring.

furrowing The practice of striking a shallow V-shaped trough in a bed of mortar.

G

galvanizing Applying a coating of zinc to steel by either hot-dipping or electrodeposition.

gauge A number designating a specific thickness of metal sheet, or diameter of wire, cable or fastener shank tabulated in a standardized series, each of which represents a decimal fraction of an inch (or millimeter) (ASTM E631).

glass block Hollow or solid glass masonry unit.

glaze A hard, glassy, fused ceramic coating which may have a matte or glossy finish.

salt glaze A lustrous glazed finish from the thermochemical reaction of the silicates of the clay body with vapors of salt or chemicals.

clear ceramic glaze A ceramic glaze translucent or slightly tinted with a gloss finish.

color ceramic glaze An opaque glaze of satin or gloss finish obtained by spraying the clay body with a compound of metallic oxides, chemicals, and clays.

gradation The particle size distribution of aggregate as determined by separation with standard sieves. Gradation of aggregate is expressed in terms of the individual percentages passing standard screens. Sieve analysis, screen analysis, and mechanical analysis are terms used synonymously in referring to gradation of aggregate.

grade ASTM C216 classification for clay face brick, e.g., moderate weathering (Grade MW), or severe weathering (Grade SW).

granite A visibly granular, igneous rock generally ranging in color from pink to light or dark gray and consisting mostly of quartz and feldspars, accompanied by one or more dark minerals. The texture is typically homogeneous but may be gneissic or porphyritic. Some dark granular igneous rocks, though not geologically granite, are included.

gravel Coarse, granular aggregate, with pieces

larger than sand grains, resulting from the natural erosion of rock (ASTM D1079).

green concrete See **concrete, green**.

"green" masonry A molded clay masonry unit before it has been fired in a kiln; an uncured concrete masonry unit.

green mortar See **mortar, green**.

grid pavers Open type masonry units which allow grass to grow through openings and are used for soil stabilization.

grout, concrete Concrete containing no coarse aggregates; a thin mortar (ASTM C981).

grout lift (1) An increment of grout height within the total pour. A pour may consist of one or more lifts. (2) The height to which grout is placed in a cell, collar joint, or cavity without intermission.

grout, masonry A mixture of cementitious materials, aggregates and water, with or without admixtures, used to fill voids in masonry; initially mixed to a consistency suitable for pouring or pumping without segregation of constituents.

grout pour The total height of a masonry wall to be grouted prior to erection of additional masonry. A grout pour will consist of one or more grout lifts.

grout pumping Method of installing masonry grout.

grouted hollow-unit masonry Form of grouted masonry construction in which certain designated cells of hollow units are continuously filled with grout.

grouted masonry Masonry construction composed of hollow units where designated hollow cells are filled with grout, or multi-wythe construction in which space between wythes is filled with grout.

grouting, high lift The technique of grouting where the masonry is constructed in excess of 5 ft. high prior to grouting.

grouting, low lift The technique of grouting as the wall is constructed, usually to scaffold or bond beam height, but not greater than 4 ft.

H

hard-burned Nearly vitrified clay products which have been fired at high temperatures.

hardener A chemical applied to a concrete floor to reduce wear and dusting.

hardness Resistance of a material to indentation as measured under specified conditions (ASTM C717).

harsh mix A mixture which lacks desired workability and consistency due to a deficiency of cement paste, aggregate fines, or water.

hawk A tool to hold and carry plaster or mortar; generally a flat piece of metal approximately 10 to 14 inches square, with a wooden handle fixed to the center of the underside.

head joint See **joint, mortar, head**.

header A masonry unit that overlaps two or more adjacent wythes of masonry to bond or tie them together. Also called a **bonder**.

header, blind A concealed brick header in the interior of a wall, not showing on the faces.

header, clipped A bat that does not extend into the backup, placed to look like a header for purposes of establishing a pattern. Also called a false header.

header course A continuous bonding course of header brick. Also called a heading course.

hearth (1) The masonry floor of a fireplace together with an adjacent area of fireproof material that may be a continuation of the flooring in the embrasure or some more decorative surfacing, as tile or marble. (2) An area permanently floored with fireproof material beneath and surrounding a stove.

heat capacity The property of a material defined as the quantity of heat needed to raise one cubic foot of the material 1°F. Numerically, the density multiplied by the specific heat.

heat sink A substance that is capable of accepting and storing heat, and therefore can also act as a heat source.

height-thickness (h/t) ratio The height of a masonry wall divided by its nominal thickness. The thickness of cavity walls is taken as the overall

thickness minus the width of the cavity.

high early-strength concrete Concrete which, through the use of high early-strength cement or admixtures, is capable of attaining specified strength at an earlier age than normal concrete.

hot weather construction Procedures used in constructing masonry when ambient air temperature exceeds 100°F or 90°F with a wind velocity greater than 8 mph.

hot-dip In steel mill practice, a process whereby ferrous alloy base metals are dipped into molten metal (usually zinc, aluminum, tin or terne) for the purpose of fixing a rust-resistant coating.

hydrolysis Decomposition or alteration of a chemical substance by water.

hydrophilic Having an affinity for, attracting, adsorbing or absorbing water.

hydrophobic Lacking affinity for, repelling, or failing to adsorb or absorb water.

hydrostatic pressure A state of stress in which all the principal stresses are equal (and there is no shear stress), as in a liquid at rest; the product of the unit weight of the liquid and the difference in elevation between the given point and the free liquid elevation (ASTM C717).

hygroscopic (1) Attracting, absorbing, and retaining atmospheric moisture (ASTM D1079). (2) Pertaining to water absorbed by hydrophilic porous materials.

hysteresis (1) Failure of a property that has been changed by an external agent to return to its original value when that external agent has been removed. (2) The irreversible expansion of marble building stone with cycles of heating and cooling.

I

IMI International Masonry Institute.

impermeable Having a permeance of zero.

initial rate of absorption (IRA) A measure of the capillary suction of water into a dry masonry unit from a bed face during a specified length of time over a specified area.

initial set The beginning change from a plastic to a

hardened state.

insulating concrete See **concrete, lightweight insulating**.

interlocking block pavers Solid masonry units capable of transferring loads and stresses laterally by arching or bridging action between units when subjected to vehicular traffic.

intrados Curve that bounds the lower side of an arch.

isolation joint See **joint, isolation**.

J

joint filler A compressible material used in a partially or totally filled expansion, control, or isolation joint by its permanent placement in or between building materials such as concrete or masonry during construction; sometimes used as a sealant backing in a partially filled joint (ASTM C717).

joint sealing system A combination of joint cleaners, primers, fillers, backer rods, bond breakers, caulking compounds, sealants, gaskets, or tapes used to close joints between building components, sections, panels, or dissimilar materials.

joint The space or opening between two or more adjoining surfaces (ASTM C717).

butt joint (1) A joint having the edge or end of one member matching the edge, end or face of another member without overlap (ASTM E6310). (2) A joint having the edge or face of one member spaced from and sealed to the edge or end of another member without overlap (ASTM C717).

cold joint (1) Boundary between later-applied and previously-applied coatings, plaster, mortar, or concrete. *Note:* At the boundary there can be less than the desired union of materials (ASTM E631). (2) A plane of weakness in concrete caused by an interruption or delay in the placing operation, which permits the first batch to start setting before the next batch is placed, resulting in little or no bond between the two batches (ASTM C717).

construction joint (1) In the construction of members intended to be continuous, a predetermined, intentionally created discontinuity between or within

constructions and having the ends of the discontinuous members fastened to each other to provide structural continuity (ASTM E631). (2) A formed or assembled joint at a predetermined location where two successive placements ("lifts") of concrete meet. *Note:* Frequently a keyway or reinforcement is placed across the joint. With proper design, this joint may also function as a control or an isolation joint (ASTM C717).

contraction joint Formed, sawed, or tooled groove in a concrete structure to create a weakened plane and regulate the location of cracking resulting from the dimensional change of different parts of the structure (ACI 318). (This term is often used interchangeably with the term control joint.)

control joint (1) In concrete, concrete masonry, stucco, or coating systems; a formed, sawed, or assembled joint acting to regulate the location of cracking, separation, and distress resulting from dimensional or positional change (ASTM E631). (2) A formed, sawed, tooled, or assembled joint acting to regulate the location and degree of cracking and separation resulting from the dimensional change of different elements of a structure. *Note:* This joint is usually installed in concrete and concrete masonry construction to induce controlled cracking at preselected locations, or where a concentration of stresses is expected (ASTM C717).

expansion joint (1) A discontinuity between two constructed elements or components, allowing for differential movement (such as expansion) between them without damage (ASTM E631). (2) A formed or assembled joint at a predetermined location, which prevents the transfer of forces across the joint as a result of movement or dimensional change of different elements of a structure or building (ASTM C717).

fillet joint A triangular sealant bead at the internal corner of two intersecting planes; a rounded bead of sealant over the edges of two adjacent or overlapping surfaces.

isolation joint A formed or assembled joint specifically intended to separate and prevent the bonding of one element of a structure to another and having little or no transference of movement or vibration across the joint (ASTM C717).

isolation joint A formed or assembled joint

specifically intended to separate and prevent the bonding of one element of a structure to another and having little or no transference of movement or vibration across the joint (ASTM C717).

mortar joint In mortared masonry construction, the joints between units that are filled with mortar.

bed joint (1) Horizontal layer of mortar on which a masonry unit is laid.

collar joint Vertical, longitudinal joint between wythes of masonry or between masonry wythe and backing.

head joint (1) Vertical transverse mortar joint placed between masonry units within the wythe at the time the masonry units are laid.

shoved joint Vertical joint filled by shoving a unit against the next unit when it is being laid in a bed of mortar.

slushed joint Head or collar joint constructed by "throwing" mortar in with the edge of a trowel.

struck joint A joint from which excess mortar has been removed by a stroke of the trowel, leaving an approximately flush joint.

tooled joint -- a mortar joint between two masonry units manually shaped or compressed with a jointing tool such as a concave or vee-notched jointer.

concave joint A recessed masonry joint formed in mortar by the use of a curved steel jointing tool. Highly resistant to rain penetration.

raked joint A type of joint used in brick masonry which has the mortar raked out to a specified depth while the mortar is still green.

struck joint A mortar joint that is recessed further at the bottom than at the top.

movement joint In building construction, a joint designed to accommodate movement of adjacent elements (includes both control and expansion joints).

perimeter joint A joint formed by the outer

edge of one panel or material and the leading edge of another.

reinforced joint A concrete joint bridged by reinforcing steel embedded in both joining parts (ASTM C717).

joint reinforcement Steel bar, wire, or prefabricated reinforcement (ladder or truss type) which is placed in mortar bed joints.

jointing The finishing of joints between courses of masonry units before the mortar has hardened.

K

keystone Wedge-shaped stone at the center or summit of an arch or vault, binding the structure actually or symbolically.

kiln A furnace, oven, or heated enclosure used for burning or firing brick or other clay material.

kiln run Bricks from the kiln that have not yet been sorted or graded for size or color variations.

king closer A brick cut diagonally to have one 2-in. end and one full-width end.

L

laitance A weak layer of cement and aggregate fines on a concrete surface that is usually caused by an overwet mixture, overworking the mixture, improper or excessive finishing, or combinations thereof (ASTM C717).

lap (1) The distance one masonry unit extends over another. (2) The distance one piece of flashing or reinforcement extends over another.

lateral support Bracing of walls either vertically or horizontally by columns, pilasters, cross walls, beams, floors, roofs, etc.

lead The section of a wall built up and racked back on successive courses. A line is attached to leads as a guide for constructing a wall between them.

leakage See **water leakage**.

lightweight aggregate Aggregate of low density, such as expanded or sintered clay, shale, slate, diatomaceous shale, perlite, vermiculite, or slag, natural pumice, scoria, volcanic cinders, tuff, and diatomite, sintered fly ash or industrial cinders.

lime A general term for the various chemical and physical forms of quicklime, hydrated lime, and hydraulic hydrated lime.

Hydrated lime Quicklime to which sufficient water has been added to convert the oxides to hydroxides.

lime mortar A lime putty mixed with an aggregate, suitable for masonry purposes.

lime putty The product obtained by slaking quicklime with water according to the directions of the manufacturer or by mixing hydrated lime and water to a desired consistency.

quicklime A hot, unslaked lime. A calcined material, a major part of which is calcium oxide (or calcium oxide in natural association with lesser amounts of magnesium oxide) capable of slaking with water.

slaked lime Formed when quicklime is treated with water; same as hydrated lime.

limestone (1) A rock of sedimentary origin composed principally of calcium carbonate (the mineral calcite), or the double carbonate of calcium and magnesium (the mineral dolomite), or some combination of these two minerals. (2) An initially sedimentary rock consisting chiefly of calcium carbonate or of the carbonates of calcium and magnesium. Limestone may be magnesian, oolitic, dolomitic, or of high calcium.

dolomitic limestone Limestone containing from 35 to 46% magnesium carbonate (MgCO_3).

high-calcium limestone Limestone containing from 0 to 5% MgCO_3 .

magnesium limestone Limestone containing from 5 to 35% MgCO_3 .

oolitic limestone A limestone composed largely of the spherical or subspherical particles called oolites or ooliths.

line pin A metal pin used to attach line used for alignment of masonry units.

line The string stretched taut from lead to lead as a guide for laying the top edge of a masonry course.

lintel A beam placed or constructed over an opening in a wall to carry the superimposed load and the masonry above the opening.

loads, allowable The permitted and projected safe load capacity through testing or calculated for a given structural element or combination of elements,

including an acceptable safety factor for given material.

M

marble Carbonate rock that has acquired a distinctive crystalline texture by recrystallization, most commonly by heat and pressure during metamorphism, and is composed principally of the carbonate minerals calcite and dolomite, singly or in combination.

mason A worker skilled in laying brick, tile, stone, or block.

mason's hammer A hammer with a heavy steel head, one face of which is shaped like a chisel for trimming brick or stone.

mason's level Similar to a carpenter's level, but longer.

masonry (1) Construction, usually set in mortar, of natural building stone or manufactured units such as brick, concrete block, adobe, glass block, tile, manufactured stone, or gypsum block. (2) An assemblage of structural clay masonry units, concrete masonry units, stone, etc., or combination thereof, bonded with mortar or grout. (3) Construction of brick, block or stone that is set in mortar, dry-stacked, or mechanically anchored.

masonry cement See **cement, masonry**.

masonry cement mortar See **mortar, masonry cement**.

masonry unit (1) Manufactured material, such as brick, concrete block, structural tile, or cast stone, suitable for the construction of masonry. (2) Natural or manufactured building unit of clay, concrete, stone, glass, or calcium silicate.

masonry unit, clay Hollow or solid masonry unit of clay or shale, including clay brick, structural clay tile, and adobe brick.

masonry unit, concrete A manufactured masonry unit made from portland cement, mineral aggregates and water, with or without the inclusion of other materials.

masonry unit, hollow A unit whose net cross sectional area in any plane parallel to the bearing surface is less than 75% of its gross cross-sectional area measured in the same plane.

masonry unit, modular One whose nominal

dimensions are based on the 4-in. module.
masonry unit, solid A unit whose net cross-sectional area in any plane parallel to the bearing surface is 75% or more of its gross cross-sectional area measured in the same plane.

mass concrete Any volume of concrete with dimensions large enough to require that measures be taken to cope with generation of heat from hydration of the cement and attendant volume change to minimize cracking

mechanical bond Tying masonry units together with metal ties, reinforcing steel, or keys.

mix design The proportions of ingredients to produce mortar, grout or concrete.

mixer A machine employed for blending the constituents of concrete, grout, mortar or other mixtures.

mockup A section of a structure or assembly, built full size or to scale, for the purpose of studying construction details, testing performance, judging appearance, or any combination thereof (ASTM E631).

modular coordination Dimensional coordination of masonry and other construction components through the use of standard incremental units.

modulus of elasticity Stress/strain ratio; the ratio of the force (stress) needed to elongate (strain) a material to a certain point.

moisture content The amount of water contained, expressed as a percentage of the total absorption.

mortar A mixture of cementitious materials, fine aggregate and water, with or without admixtures, used to construct masonry.

clay mortar Finely ground clay used as a plasticizer for masonry mortars.

fat mortar A mortar mixture containing a high ratio of cementitious material to aggregate.

fire clay mortar, ground A refractory mortar consisting of finely ground raw fire clay.

fresh mortar The wet mix of ingredients before they begin to cure.

green mortar Mortar that has begun to set but is not fully cured.

hardened mortar Mortar that has fully

cured.

harsh mortar A mortar that is difficult to spread; not workable.

lean mortar Mortar deficient in cementitious components, and usually harsh and difficult to spread.

masonry cement mortar Mortar produced using ASTM C91 masonry cement.

mortar cement mortar Mortar produced using ASTM C1329 mortar cement.

portland cement and lime mortar Mortar produced using ASTM C150 portland cement and ASTM C207 lime.

ready-mixed mortar Mortar consisting of cementitious materials, aggregate, water and set-control admixtures which are measured and mixed at a central location, using weight- or volume-control equipment. This mortar as delivered to a construction site shall be usable for a period in excess of 2-1/2 hrs.

surface bonding mortar A product containing hydraulic cement, glass fiber reinforcement with or without inorganic fillers, or organic modifiers in a prepackaged form requiring only the addition of water prior to application.

mortar bedding Construction of masonry assemblages with mortar.

mortar board A board, approximately three feet square in area to hold mortar ready for the use by a mason.

mortar bond The adhesion of mortar to masonry units.

mortar joint See **joint, mortar**.

mortar mix A proprietary, mill-mixed, cementitious material to which only water must be added for use in masonry mortar.

movement joint See **joint, movement**.

multi-wythe wall A wall composed of two or more wythes or rows of masonry.

N

NCMA National Concrete Masonry Association.

neat cement A cement undiluted by sand aggregate or admixtures.

neoprene A synthetic rubber (polychloroprene) used in liquid- or sheet-applied elastomeric roofing and waterproofing membranes or flashing (ASTM D1079).

net cross-sectional area See **cross-sectional area, net**.

non-combustible (1) Not combustible. (2) Any material that will neither ignite nor actively support combustion in air at a temperature of 1200°F when exposed to fire.

O

overhand work Masonry laid from the interior side of a wall rather than the exterior side of a wall.

oxidation Formation of an oxide; deterioration of rubbery materials due to the action of oxygen or ozone.

P

parging The application of a coat of cement mortar onto a masonry wall surface.

paver A paving stone, brick, or concrete masonry unit.

paving brick See **brick, paving**.

paving stone Stone used in exterior pedestrian wearing surfaces as in patios, walkways, driveways, and the like.

paving, unit Vehicular or pedestrian traffic surfacing of unit masonry pavers.

PCA Portland Cement Association.

penetrant Treatment that lines pores without forming a film on the surface.

perlite An aggregate used in lightweight insulating concrete and in preformed perlite insulating board; formed by heating and expanding siliceous volcanic glass (ASTM D1079).

perm (1) Time rate of water vapor migration through a material or a construction of 1 grain per hour per square foot, per inch of mercury pressure difference (ASTM E241). (2) Empirical unit of water-vapor permeance (mass flow rate), equal to 1

grain (avoirdupois) of water vapor per hour flowing through 1 square foot of a material or construction induced by a vapor-pressure difference of 1 inch of mercury between the two surfaces. *Note:* This mass flow rate can be stated in other desired or convenient units. A maximum value of 1 perm is the moisture vapor migration rate below which there is low probability of induced moisture problems in conventional buildings in climates not exceeding 5000 heating degree days (65°F base), and not so hot and humid that continual air conditioning would be required (ASTM E631).

permanent set The amount by which an elastic material fails to return to its original form after a deformation.

permeability, vapor See **vapor permeability**.

permeance, vapor See **vapor permeance**.

pick and dip A method of laying brick whereby the bricklayer simultaneously picks up a brick with one hand and, with the other hand, enough mortar on a trowel to lay the brick. Sometimes called the Eastern, New England, or English method.

pier An isolated column of masonry, or a bearing wall not bonded at the sides to associated masonry.

pilaster A portion of a wall serving as an integral vertical column, and usually projecting from one or both wall faces. Sometimes called a pier.

pilaster block Concrete masonry units designed for use in construction of plain or reinforced concrete masonry pilasters and columns.

plasticizer A substance incorporated into a material to increase its workability, flexibility or extensibility.

point (1) A wedge-shaped or pyramidal chisel. (2) To engage in the act of "pointing" mortar joints.

pointing Troweling mortar into a joint after the masonry units are laid.

repointing Filling in cut-out or defective mortar joints in masonry with fresh mortar.
tuckpointing Decorative method of pointing masonry with a surface mortar that is different from the bedding mortar.

porosity Ratio of pore space to the total volume of a material, expressed as a percent.

portland cement See **cement, portland**.

post-tensioning A method of prestressing concrete or masonry in which tendons are tensioned after the concrete has hardened or masonry is placed

precast concrete Structural concrete element cast elsewhere than its final position in the structure.

prefabricated masonry Masonry fabricated at a location other than its final location in the structure. Also known as preassembled, panelized, and sectionalized masonry.

prefabrication To fabricate the parts at a factory or on-site so that construction consists mainly of assembling and utilizing standard parts in a building structure.

prestressed concrete or masonry Concrete or masonry in which internal stresses have been introduced to counteract stresses resulting from applied loads.

pretensioning Method of prestressing in which prestressing tendon is tensioned before the transfer of stress into the masonry or concrete.

primer (1) A compatible coating designed to enhance adhesion (ASTM C717). (2) A thin liquid bitumen applied to a surface to improve the adhesion of heavier applications of bitumen and to absorb dust (ASTM D1079).

prism An assemblage of masonry units and mortar with or without grout used as a test specimen for determining properties of the masonry.

prism strength Maximum compressive strength (force) resisted per unit of net cross-sectional area of masonry, determined by testing masonry prisms.

prism testing Testing an assemblage of masonry units, mortar or grout to determine the compressive strength of masonry.

productivity (1) Rate of production of masonry materials or assemblies. (2) Number of masonry units that a mason can install in a building structure during a given period of time.

pumice Material of volcanic origin being of cellular structure and highly porous which is used as an aggregate for lightweight concrete or concrete masonry units.

Q

quarry An open excavation at the earth's surface for the purpose of extracting usable stone.

quarry run Unselected materials of building stone within the ranges of color and texture available from the source quarry.

quarry sap Colloquial term for the natural moisture in stone as it comes from the quarry ledge. Varies in amount with the porosity of the structure.

queen closer A cut brick having a nominal 2-in. horizontal face dimension.

quoins Projecting courses of brick or stone at the corners and angles of buildings as ornamental features.

R

R-value See **thermal resistance**.

racking Stepping back successive courses of masonry.

racking test Laboratory test for shear strength of masonry wall panels measured as diagonal tension.

rain penetration See **water penetration**.

re-temper To add more water to a hydraulic-setting compound after the initial mixing, but before partial set has occurred (ASTM E631).

rebar Shorthand term for steel reinforcing bar.

reglet (1) A continuous groove, slot or recess within a building component surface which receives other components such as flashing, gaskets or anchors; a continuous prefabricated metal or plastic device containing a groove, slot or recess which can be cast into (as a form) or mounted onto a building component surface (ASTM C717). (2) A groove in a wall or other surface adjoining a roof surface for the attachment of counterflashing (ASTM D1079).

reinforced masonry Masonry units and reinforcing steel bonded with mortar and/or grout in such a manner that the components act together in resisting forces.

repointing See **pointing**.

reshores Shores placed snugly under a structural member after the original forms and shores have been removed from a larger area, thus requiring the new structural member to deflect and support its own weight and existing construction loads applied prior to the installation of the reshores.

retempering Moistening and remixing of concrete, mortar or stucco to a proper consistency for use.

rigid Not flexible.

rising damp Upward moving moisture in a wall or other structure standing in water or in wet soil (ASTM E631). See also **capillary migration**.

rowlock A brick laid on its face edge with the end surface visible in the wall face. Frequently spelled rolok.

rubble See **stone masonry, rubble**.

running bond See **bond, pattern, running**.

rustic (1) Masonry, generally of local stone, that is roughly hand dressed, and intentionally laid with high relief in relatively modest structures of rural character. (2) A grade of building limestone characterized by coarse texture.

rustic joint A deeply sunk mortar joint that has been emphasized by having the edges of the adjacent stones chamfered or recessed below the surface of the face. Also called rusticated joint.

rusticated Cut stone with strongly emphasized recessed joints and smooth or roughly textured block faces. The border of each block may be rebated, chamfered, or beveled on all four sides, at top and bottom only, or on two adjacent sides. The face of the block may be flat, pitched, or diamond point, and if smooth, may be hand or machine tooled.

S

sand-rubbed finish Type of stone surface obtained by rubbing with a sand-and-water mixture under a block. Commonly applied with a rotary or belt sander.

saturation coefficient The ratio of the weight of water absorbed by a masonry unit when immersed 24 hours in cold water to the weight of water absorbed after an additional immersion for five hours in boiling water. An indication of the probable

resistance of brick to freezing and thawing. Also called **C/B ratio**.

scaling See **spalling**.

screed Straightedge used to strike the surface of concrete or stucco or to level the surface of sand.

screen tile Clay tile manufactured for masonry screen wall construction.

seal A barrier against the passage of liquids, solids, or gases (ASTM C717).

sealant A material that has the adhesive and cohesive properties to form a seal (ASTM C717).

sealant backing A compressible material placed in a joint before application of a sealant. *Note:* The purpose of sealant backing is to assist in providing the proper sealant configuration, to limit the depth of the sealant, and in some cases, to act as a bond breaker (ASTM C717).

sealer Liquid coating applied to surfaces to fill pores, voids or hairline cracks.

service life Life expectancy in service.

serviceability The capacity of a material, product, component, assembly, or a construction to perform the function(s) for which it was designed and constructed (ASTM E241).

set A change in consistency from a plastic to a hardened state.

setting Process by which, after application, a liquid (wet-state) material changes to a serviceable condition by **curing** or **drying**. *Note:* Generally, curing implies a chemical reaction, while drying implies evaporation of volatile constituents (ASTM E631).

setting time Term used loosely to describe that period when a material has either dried sufficiently through solvent release, or cured sufficiently through chemical reaction, to reach a specified condition.

shale (1) A thinly stratified, consolidated, sedimentary clay with well-marked cleavage parallel to the bedding. (2) A laminated sedimentary rock composed of clay minerals.

shelf angle Metal angle attached to a structural member used to support masonry.

shop drawing A drawing prepared by the fabricator based on a working drawing and used in a shop or on a site for assembly (ASTM E631).

shores vertical or inclined support members designed to carry the weight of the formwork, concrete, and construction loads above.

shrinkage A decrease in length, area or volume (ASTM C717).

side-construction tile Structural clay tile intended for placement with the axis of the cells horizontal.

silane Generally refers to alkyltrialkoxysilanes. A monomeric organosilicon compound with one unhydrolyzable silicon-carbon bond, which forms a chemical bond with siliceous minerals providing water-repellent protection to the substrate. Silanes are penetrants.

siliconate Organic modified alkali silicates. Siliconates are generally applied in aqueous solution to harden and/or protect masonry substrates. Siliconates are penetrants.

silicone resin Any of the organopolysiloxanes applied to materials for water repellency. Silicone water repellents are generally highly polymerized resins applied in any of several organic solvents. Application is accompanied by chemical bonding to the substrate if silicate minerals are present. The size and shape of the polymer of which the resin is composed determines whether the silicone treatment is classified as a film former or a penetrant.

siloxane Generally refers to alkylalkoxysiloxanes that are oligomeric (i.e., siloxane or low molecular weight with the polymer consisting of two, three or four monomers). As with other silicones, application is accompanied by chemical bonding to the substrate if silicate minerals are present. Oligomeric siloxanes are properly classified as penetrants.

single-wythe wall A wall containing only one masonry unit in wall thickness.

skewback The incline surface on which an arch joins the supporting wall.

slate Microcrystalline metamorphic rock most commonly derived from shale and composed mostly of micas, chlorite, and quartz. The micaceous minerals have a subparallel orientation and thus impart strong cleavage to the rock which allows the

latter to be split into thin but tough sheets.

slenderness ratio (1) The effective unsupported length of a uniform column divided by the least radius of gyration of the cross-sectional area. (2) The ratio of the effective height of a wall or column to its effective thickness; used as a means of assessing the stability of a masonry wall or column.

slushed joints See **joint, mortar, slushed**.

smoke chamber The space in a fireplace immediately above the throat where the smoke gathers before passing into the flue; narrowed by corbelling to the size of the flue lining above.

soap A masonry unit of normal face dimension, having a nominal 2-in. thickness.

soffit The underside of a beam, lintel, or arch.

solar screen A perforated wall used as a sunshade.

soldier A stretcher set on end with face showing on the wall surface.

spall, *n* A fragment or chip as from concrete, brick, stone, or other similar materials (ASTM C717).

spall, *v* To break off fragments or chips, as from concrete, brick, stone or other similar materials by water freezing within the material, corrosion expansion of embedded metal, movement pressures, or other physical or chemical processes (ASTM C717).

spalling (1) The development of spalls (ASTM C717). (2) Crumbling or chipping of a masonry or concrete surface due to freezing of absorbed water, corrosion of embedded steel, cement-aggregate reaction, restraint against movement, or other causes (ASTM C981).

specification A precise statement of a set of requirements to be satisfied by a material, product, system or service. *Note:* It is desirable that the requirements, together with their limits, should be expressed numerically in appropriate units (ASTM E631).

specified compressive strength of masonry f'_m Minimum compressive strength expressed as force per unit of net cross-sectional area required of the masonry used in construction by the project documents, and upon which the project design is based. Whenever the quantity f'_m is under the

radical sign, the square root of numerical value only is intended and the result has units of pounds per square inch.

stearate Salt or ester of stearic acid that functions as a water repellent by forming a "soap" within the pores of the material. Stearates are generally classified as film formers, but can be considered penetrants in modified form.

stone

building stone, Natural rock of adequate quality to be quarried and cut as dimension stone as it exists in nature, and used in the construction industry.

cast stone An architectural precast concrete building unit intended to simulate natural cut stone.

cut stone Stone fabricated to specific dimensions.

dimension stone Natural stone that has been selected, trimmed, or cut to specified or indicated shapes or sizes, with or without one or more mechanically dressed surfaces.

fieldstone Natural building stone as found in the field.

flagstone A flat stone, thin in relation to its surface area, commonly used as a stepping stone, for a terrace or patio, or for floor paving. Usually either naturally thin or split from rock that cleaves readily.

stone masonry Masonry composed of natural or cast stone.

stone masonry, ashlar -- Stone masonry composed of rectangular units having sawed, dressed, or squared bed surfaces and bonded by mortar.

ashlar pattern -- A pattern bond of rectangular or square stone units, always of two or more sizes. If the pattern is repeated, it is patterned ashlar. If the pattern is not repeated, it is random ashlar.

coursed ashlar -- Ashlar masonry laid in courses of stone of equal height for each course, although different courses may be of varying height.

random ashlar -- Stone masonry pattern of rectangular stones set without continuous joints and laid up without drawn patterns. If composed of material cut to modular heights, discontinuous but aligned horizontal joints are

discernible.

stone masonry, rubble Stone masonry composed of irregular shaped units bonded by mortar.

coursed rubble Masonry composed of roughly shaped stones fitting on approximately level beds, well bonded, and brought at vertical intervals to continuous level beds or courses.

random rubble Masonry wall built of unsquared or rudely squared stones irregular in size and shape.

squared rubble Wall construction in which squared stones of various sizes are combined in patterns that make up courses as high as, or higher than, the tallest stones.

story pole A marked pole for measuring masonry coursing during masonry construction.

stress Intensity of force per unit area.

stretcher A masonry unit laid with its greatest dimension horizontal and its face parallel to the wall face.

strike (1) To remove excess concrete from the top of the form by screeding. (2) To remove excess mortar from the surface of a joint by cutting it flush with the unit surface using the edge of a trowel. See also **tooling**.

string course A horizontal band of masonry, generally narrower than other courses, extending across the facade of a structure and in some structures encircling such decorative features as pillars or engaged columns.

stringing mortar The procedure of spreading enough mortar on a bed to lay several masonry units.

structural clay tile Hollow masonry building units composed of burned clay, shale, fire clay, or combinations of these materials.

end-construction tile Tile designed to be laid with the axis of its cells vertical.

facing tile Tile for exterior and interior masonry with exposed faces.

fireproofing tile Tile designed for protecting steel structural members from fire.

side-construction tile Tile intended for placement with the axis of the cells horizontal.

structural concrete All concrete used for structural purposes, including plain and reinforced concrete.

suction See **initial rate of absorption**.

surface bonded masonry Bonding of masonry units by parging with a thin layer of fiber-reinforced mortar.

surface bonding mortar A product containing hydraulic cement, glass fiber reinforcement with or without inorganic fillers, or organic modifiers in a prepackage requiring only the addition of water prior to application.

T

temper (1) In hydraulic setting compounds, to bring to a usable state by mixing in or adding water. (2) To moisten and mix mortar to a proper consistency.

tendon Steel element such as wire, cable, bar, rod, or strand, or a bundle of such elements, used to impart prestress forces to concrete or masonry.

terra cotta A fired clay product used for ornamental work.

thermal storage capacity The ability of a material, per square foot of exposed area, to absorb and store heat. Numerically, the density times the specific heat times the thickness.

thermal inertia Lag time required for a mass to heat or cool.

thermal mass Dense material capable of absorbing and storing heat.

thermal resistance The reciprocal of thermal transmittance (expressed by the notation R).

through-wall flashing A water-resistant membrane or material assembly extending totally through a wall and its cavities, positioned to direct any water within the wall to the exterior (ASTM D1079).

tie See **connector, tie**.

tolerance The allowable deviation from a value or standard; especially the total range of variation permitted in maintaining a specified dimension in machining, fabricating, or constructing a member or assembly (ASTM E631).

tooling The act of compacting and shaping a mortar joint.

toothing Constructing the temporary end of a wall with the end stretcher of every alternate course projecting. Projecting units are toothers.

trowel

concrete trowel A flat, broad-bladed steel hand tool used to finish concrete, or to apply, shape and finish plaster.

mason's trowel A trowel having a flat, triangular steel blade in an offset handle used to pick up and spread mortar. The narrow end of the blade is called the "point"; the wide end, the "heel."

troweled finish A concrete finish provided by smoothing the surface with power-driven or hand trowels, or both, after the float finishing operation. *Note:* A troweled finish is smoother than the floated finish. (ASTM C1127)

tuckpointing See **pointing**.

U

UBC Uniform Building Code.

ultraviolet resistance Resistance to degradation by ultraviolet radiation.

unbonded tendon A tendon that is permanently prevented from bonding to the concrete or masonry after stressing.

unit masonry Construction of brick or block that is set in mortar, dry-stacked, or mechanically anchored.

unreinforced masonry (1) Masonry whose tensile resistance is considered in design and the resistance of any reinforcing steel present is neglected. (2) Masonry constructed without steel reinforcement, except that which may be used for bonding or reducing the effects of dimensional changes due to variations in moisture content or temperature.

V

vapor barrier See **vapor retarder**.

vapor migration The movement of water vapor from a region of high vapor pressure to a region of lower vapor pressure (ASTM D1079).

vapor permeability (1) The property of a material that permits migration of water vapor under the influence of a difference in vapor pressure across the material. (2) The ability of a material to transmit water vapor through a thickness of 1 inch. It is measured in perm-inches.

vapor permeance Time rate of water-vapor transmission through a unit area of a flat material or construction induced by unit vapor-pressure difference between the two specified surfaces, under specified temperature and humidity conditions (ASTM E631). See **perm**.

vapor pressure (P_v) The partial pressure of the water vapor in an air-vapor mixture. It is determined by the dewpoint temperature or by the dry bulb temperature and the relative humidity of the mixture. The units are psi or inches of mercury.

vapor resistance The reciprocal of vapor permeance. A rating of the resistance of a material to the passage of water vapor. The unit of measure is a rep.

vapor resistivity The reciprocal of vapor permeability. A measure of the resistance of a one inch thickness of material to the passage of water vapor. The unit of measure is rep/inch.

vapor retarder (1) Material or system that impedes the transmission of water vapor under specified conditions (ASTM E631). (2) A layer of material or a laminate used to appreciably reduce the flow of water vapor into the roofing system (ASTM D1079). (3) Material or construction that retards water vapor migration, generally not exceeding 1 perm for ordinary houses in non-extreme climates (ASTM E241). (4) A layer of material which appreciably reduces the diffusion of water vapor. A material, film or coating made for this use is generally expected to have a vapor permeance of 1 perm or less. See also **air barrier**.

veneer A single facing wythe of masonry, anchored or adhered to a structural backing, but not designed to carry structural loads.

vermiculite Micaceous aggregate used in lightweight insulating concrete, concrete masonry units and plaster. (2) Insulation composed of natural vermiculite ore expanded to form an exfoliated structure.

vibrator A machine used to eliminate trapped air

bubbles and consolidate freshly placed concrete or masonry grout.

virtual eccentricity The eccentricity of a resultant axial load required to produce axial and bending stresses equivalent to those produced by applied axial loads and moments. It is normally found by dividing the moment at a section by the summation of axial loads occurring at the section.

vitrification Progressive reduction in porosity of a ceramic composition as a result of heat treatment, or the process involved.

vousoir One of the truncated, wedge-shaped masonry units which forms an arch ring.

W

wale A long horizontal member on formwork used to hold studs in place.

wall (1) A vertical element with a horizontal length to thickness ratio greater than three, used to enclose space.

bearing wall A wall supporting a vertical load in addition to its own weight.

bonded wall A masonry wall in which two or more wythes are bonded to act as a structural unit.

composite wall A multi-wythe wall in which at least one of the wythes is dissimilar to the other wythe or wythes with respect to type of masonry unit.

curtain wall A nonbearing exterior wall, secured to and supported by the structural members of the building.

masonry bonded hollow wall Wall with an internal air space, the facing and backing wythes of which are connected with masonry headers.

multi-wythe wall A masonry wall composed of two or more wythes.

panel wall An exterior non-loadbearing wall wholly supported at each story.

parapet wall That part of any wall entirely above the roof.

partition wall An interior wall one story or less in height. It is generally non-loadbearing. In Canada, partition means an interior wall of one-story or part-story height that is never loadbearing.

pierced wall See **wall, screen**.

perforated wall See **wall, screen**.

prestressed wall Reinforced concrete or

masonry walls in which internal stresses have been introduced to reduce potential tensile stresses in the wall resulting from imposed loads.

retaining wall A wall not enclosing portions of a building, designed to resist the lateral displacement of soil or other material.

screen wall A masonry wall in which an ornamental pierced effect is achieved by alternating rectangular or shaped blocks with open spaces.

serpentine wall A wall that is sine wave in plan.

Single-wythe wall A masonry wall only one unit in thickness.

solid masonry wall A wall built of solid masonry units, laid contiguously, or with the collar joint between the units filled with mortar or grout.

trombe wall A masonry wall that designed to absorb solar heat and release it into the interior of a building.

wall tie See **connector, tie**.

water Water as liquid, vapor or solid (ice) in any combination or in transition (ASTM E241).

water absorption Process in which water enters a material or system through capillary pores and interstices and is retained without transmission.

water infiltration Process in which water passes through a material or system and reaches an area that is not directly or intentionally exposed to the water source.

water leakage Water infiltration that is unintended, uncontrolled, exceeds the resistance, retention or discharge capacity of the system, or causes damage or accelerated deterioration.

water penetration Process in which water enters a material or system through an exposed surface, joint or opening.

water permeation Process in which water enters, flows within, and spreads throughout a material or

system.

water reducing agent A material which increases slump and workability of freshly mixed concrete or mortar without increasing the amount of water.

water repellant A material or treatment for surfaces to provide resistance to penetration by water (ASTM E631).

water retentivity That property of a mortar which prevents the rapid loss of water to masonry units of high suction. It prevents bleeding or water gain when mortar is in contact with relatively impervious units.

water saturation The maximum amount of water a material or system can retain without discharge or transmission.

water vapor Water in the state of an invisible gas, diffused in the air.

water vapor permeance See **vapor permeance**.

waterproof Impervious to water.

waterproofing Treatment of a surface or structure to prevent the passage of liquid water under hydrostatic, dynamic, or static pressure (ASTM C717).

weep hole (1) Opening in mortar joints or faces of masonry units to permit the escape of moisture. (2) A small hole allowing drainage of fluid (ASTM E631).

wind-driven rain Rain driven by the wind.

workability The property of freshly mixed concrete, mortar or plaster that determines its working characteristics and the ease with which it can be mixed, placed, and finished.

workmanship The art or skill of a worker; craftsmanship; the quality imparted to a thing in the process of creating it.

wythe Each continuous vertical section of masonry one unit in thickness.

ASTM Standards

The following reference standards of the American Society for Testing and Materials (ASTM) are related to masonry and concrete products, testing, and construction.

Clay Masonry Units

ASTM C27	Fire Clay and High Alumina Refractory Brick
ASTM C32	Sewer and Manhole Brick
ASTM C34	Structural Clay Loadbearing Wall Tile
ASTM C43	Terminology Relating to Structural Clay Products
ASTM C56	Structural Clay Non-Loadbearing Tile
ASTM C62	Building Brick
ASTM C106	Fire Brick Flue Lining for Refractories and Incinerators
ASTM C126	Ceramic Glazed Structural Clay Facing Tile, Facing Brick, and Solid Masonry Units
ASTM C155	Insulating Fire Brick
ASTM C212	Structural Clay Facing Tile
ASTM C216	Facing Brick
ASTM C279	Chemical Resistant Brick
ASTM C315	Clay Flue Linings
ASTM C410	Industrial Floor Brick
ASTM C416	Silica Refractory Brick
ASTM C530	Structural Clay Non-Loadbearing Screen Tile
ASTM C652	Hollow Brick
ASTM C902	Pedestrian and Light Traffic Paving Brick
ASTM C1088	Thin Veneer Brick Units Made from Clay or Shale
ASTM C1261	Firebox Brick for Residential Fireplaces
ASTM C1272	Standard Specification for Heavy Vehicular Paving Brick

Cementitious Masonry Units

ASTM C55	Concrete Building Brick
ASTM C73	Calcium Silicate Face Brick (Sand-Lime Brick)
ASTM C90	Loadbearing Concrete Masonry Units
ASTM C129	Non-Loadbearing Concrete Masonry Units
ASTM C139	Concrete Masonry Units for Construction of Catch Basins and Manholes
ASTM C331	Lightweight Aggregates for Concrete Masonry Units
ASTM C744	Prefaced Concrete and Calcium Silicate Masonry Units
ASTM C936	Solid Concrete Interlocking Paving Units
ASTM C1319	Concrete Grid Paving Units

Natural Stone

ASTM C119	Terminology Relating to Dimension Stone
ASTM C406	Roofing Slate
ASTM C503	Marble Dimension Stone
ASTM C568	Limestone Dimension Stone
ASTM C615	Granite Dimension Stone

ASTM C616	Quartz Based Dimension Stone
ASTM C629	Slate Dimension Stone

Mortar and Grout

ASTM C5	Quicklime for Structural Purposes
ASTM C91	Masonry Cement
ASTM C144	Aggregate for Masonry Mortar
ASTM C150	Portland Cement
ASTM C199	Pier Test for Refractory Mortar
ASTM C207	Hydrated Lime for Masonry Purposes
ASTM C270	Mortar for Unit Masonry
ASTM C404	Aggregates for Masonry Grout
ASTM C476	Grout for Masonry
ASTM C658	Chemical Resistant Resin Grouts
ASTM C887	Packaged, Dry, Combined Materials for Surface Bonding Mortar
ASTM C1142	Extended Life Mortar for Unit Masonry
ASTM C1329	Mortar Cement

Concrete

ASTM C33	Concrete Aggregates
ASTM C94	Ready-Mixed Concrete
ASTM C150	Portland Cement
ASTM C260	Air-Entraining Admixtures for Concrete
ASTM C330	Lightweight Aggregates for Structural Concrete
ASTM C387	Packaged, Dry, Combined Materials for Mortar and Concrete
ASTM C494	Chemical Admixtures for Concrete
ASTM C595	Blended Hydraulic Cements
ASTM C618	Fly Ash and Raw or Calcined Natural Pozzolan for Use as Mineral Admixture in Portland Cement Concrete
ASTM C685	Concrete Made by Volumetric Batching and Continuous Mixing
ASTM C845	Expansive Hydraulic Cement
ASTM C928	Packaged, Dry, Rapid Hardening Cementitious Materials for Concrete Repairs
ASTM C989	Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
ASTM C1017	Chemical Admixtures for Use in Producing Flowing Concrete
ASTM C1107	Packaged, Dry, Hydraulic Cement Grout
ASTM C1157	Performance Specification for Hydraulic Cements
ASTM C1240	Silica Fume for Use as a Mineral Admixture in Hydraulic-Cement Concrete, Mortar and Grout
ASTM D98	Calcium Chloride

Reinforcement and Accessories

ASTM A82	Steel Wire, Plain for Concrete Reinforcement
ASTM A153	Zinc Coating (Hot-Dip) on Iron or Steel Hardware
ASTM A165	Electro-Deposited Coatings of Cadmium on Steel
ASTM A167	Stainless and Heat Resisting Chromium-Nickel Steel Plate, Sheet and Strip
ASTM A184	Fabricated Deformed Steel Bar Mats for Concrete Reinforcement
ASTM A185	Steel Welded Wire Fabric, Plain for Concrete Reinforcement
ASTM A307	Carbon Steel Bolts and Studs, 60,000 psi Tensile Strength
ASTM A416	Uncoated Seven-Wire Stress-Relieved Steel Strand for Prestressed Concrete
ASTM A421	Uncoated Stress-Relieved Steel Wire for Prestressed Concrete

ASTM A496	Steel Wire, Deformed for Concrete Reinforcement
ASTM A497	Welded Deformed Steel Wire Fabric for Concrete Reinforcement
ASTM A615	Deformed and Plain Billet-Steel Bars for Concrete Reinforcement
ASTM A616	Rail-Steel Deformed and Plain Bars for Concrete Reinforcement
ASTM A617	Axle-Steel Deformed and Plain Bars for Concrete Reinforcement
ASTM A641	Zinc Coated (Galvanized) Carbon Steel Wire
ASTM A706	Low-Alloy Steel Deformed Bars for Concrete Reinforcement
ASTM A722	Uncoated High-Strength Steel Bars for Prestressing Concrete
ASTM A767	Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement
ASTM A775	Epoxy-Coated Reinforcing Steel Bars
ASTM A779	Steel Strand, Seven Wire, Uncoated, Compacted, Stress Relieved for Prestressed Concrete
ASTM A780	Practice for Repair of Damaged Hot-Dip Galvanized Coatings
ASTM A884	Epoxy-Coated Steel Wire and Welded Wire Fabric for Reinforcement
ASTM A951	Masonry Joint Reinforcement
ASTM B227	Hard-Drawn Copper-Covered Steel Wire, Grade 30HS
ASTM C171	Sheet Materials for Curing Concrete
ASTM C309	Liquid Membrane-Forming Compounds for Curing Concrete
ASTM C881	Epoxy-Resin-Base Bonding Systems for Concrete
ASTM C1059	Latex Agents for Bonding Fresh to Hardened Concrete
ASTM C1242	Guide For Design, Selection and Installation of Exterior Dimension Stone Anchors and Anchoring Systems
ASTM D994	Preformed Expansion Joint Filler in Concrete (Bituminous Type)
ASTM D1751	Preformed Expansion Joint Fillers for Concrete Paving and Structural Construction (Non-Extruding and Resilient Bituminous Types)
ASTM D1752	Preformed Sponge Rubber and Cork Expansion Joint Fillers for Concrete Paving and Structural Construction

Sampling and Testing

ASTM C31	Making and Curing Concrete Test Specimens in the Field
ASTM C39	Compressive Strength of Cylindrical Concrete Specimens
ASTM C42	Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
ASTM C67	Sampling and Testing Brick and Structural Clay Tile
ASTM C97	Absorption and Bulk Specific Gravity of Natural Building Stone
ASTM C109	Method of Test for Compressive Strength of Hydraulic Cement Mortars
ASTM C138	Unit Weight, Yield, and Air Content (Gravimetric) of Concrete
ASTM C140	Sampling and Testing Concrete Masonry Units
ASTM C143	Slump of Portland Cement Concrete
ASTM C170	Compressive Strength of Dimension Stone
ASTM C172	Sampling Freshly Mixed Concrete
ASTM C173	Air Content of Freshly Mixed Concrete by the Volumetric Method
ASTM C192	Making and Curing Concrete Test Specimens in the Laboratory
ASTM C241	Method of Test for Abrasion Resistance of Stone
ASTM C267	Chemical Resistance of Mortars, Grouts and Monolithic Surfacing
ASTM C426	Test Method for Drying Shrinkage of Concrete Block
ASTM C567	Unit Weight of Structural Lightweight Concrete
ASTM C597	Test Method for Pulse Velocity Through Concrete
ASTM C684	Making, Accelerated Curing, and Testing of Concrete Compression Test Specimens
ASTM C780	Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry
ASTM C803	Penetration Resistance of Hardened Concrete
ASTM C805	Rebound Number of Hardened Concrete
ASTM C856	Petrographic Examination of Hardened Concrete
ASTM C873	Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds

ASTM C880	Flexural Strength of Dimension Stone
ASTM C900	Pullout Strength of Hardened Concrete
ASTM C952	Method of Test for Bond Strength of Mortar to Masonry Units
ASTM C1006	Test Method for Splitting Tensile Strength of Masonry Units
ASTM C1019	Sampling and Testing Grout
ASTM C1064	Temperature of Freshly Mixed Portland Cement Concrete
ASTM C1072	Method of Measurement of Masonry Flexural Bond Strength
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ASTM C1148	Test Method for Measuring the Drying Shrinkage of Masonry Mortar
ASTM C1194	Compressive Strength of Architectural Cast Stone
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ASTM C1218	Water-Soluble Chloride in Mortar and Concrete
ASTM C1262	Evaluating the Freeze-Thaw Durability of Manufactured Concrete Masonry and Related Concrete Units
ASTM C1314	Method of Constructing and Testing Masonry Prisms Used to Determine Compliance with Specified Compressive Strength of Masonry
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ASTM E518	Test for Flexural Bond Strength of Masonry
ASTM E519	Test for Diagonal Tension in Masonry Assemblages
ASTM E754	Pullout Resistance of Ties and Anchors Embedded in Masonry Mortar Joints

Assemblages

ASTM C901	Prefabricated Masonry Panels
ASTM C946	Construction of Dry Stacked, Surface Bonded Walls
ASTM E835	Guide for Dimensional Coordination of Structural Clay Units, Concrete, Masonry Units, and Clay Flue Linings
ASTM C1283	Standard Practice for Installing Clay Flue Lining
ASTM E1602	Guide for the Construction of Solid Fuel-Burning Masonry Heaters

Metric Conversion

TO CONVERT FROM ¹	TO	MULTIPLY BY
LENGTH		
Inch (in.)	Millimeter (mm)	25.4
Inch (in.)	Meter (m)	0.0254
Foot (ft)	Meter (m)	0.3048
Yard (yd)	Meter (m)	0.9144
Mile (mi)	Kilometer (km)	1.6093
AREA		
Square foot (ft ²)	Square meter (m ²)	0.09290
Square inch (in ²)	Square millimeter (mm ²)	645.2
Square inch (in ²)	Square meter (m ²)	0.0006452
Square yard (yd ²)	Square meter (m ²)	0.8361
Acre (A)	Hectare (ha) = 10,000 m ²	0.4047
Square mile	Square kilometer	2.590
VOLUME		
Cubic inch (in ³)	Cubic meter (m ³)	0.00001639
Cubic foot (ft ³)	Cubic meter (m ³)	0.02832
Cubic yard (yd ³)	Cubic meter (m ³)	0.7646
Gallon (gal) Can. liquid ²	Liter	4.546
Gallon (gal) Can. liquid	Cubic meter (m ³)	0.004546
Gallon (gal) U.S. liquid	Liter	3.785
Gallon (gal) U.S. liquid	Cubic meter (m ³)	0.003785
FORCE		
Kip	Kilogram (kgf)	453.6
Kip	Newton (N)	4448.0
Pound (lb.)	Kilogram (kgf)	0.4536
Pound (lb.)	Newton (N)	4.448
PRESSURE OR STRESS		
Kips/square inch (ksi)	Megapascal (MPa) ³	6.895
Pound/square foot (psf)	Kilopascal (kPa)	0.04788
Pound/square inch (psi)	Kilopascal (kPa)	6.895
Pound/square inch (psi)	Megapascal (MPa)	0.006895
Pound/square foot (psf)	Kilogram/square meter (kgf/m ²)	4.882
MASS		
Pound (avdp)	Kilogram (kg)	0.4536
Ton (short, 2000 lb)	Kilogram (kg)	907.2
Ton (short, 2000 lb)	Tonne (t)	0.9072
Grain	Kilogram (kg)	0.00006480
Tonne (t)	Kilogram (kg)	1000
MASS (WEIGHT) PER LENGTH		
Kip/linear foot (klf)	Kilogram/meter (kg/m)	1488
Pound/linear foot (plf)	Kilogram/meter (kg/m)	1.488
Pound/linear foot (plf)	Newton/meter (N/m)	14.593

¹ To convert from SI units to U.S. customary units (except for temperature), divide by the factors given in this table.

² One U.S. gallon equals 0.8321 Canadian gallon.

³ A pascal equals one Newton/square meter; 1 Pa = 1 N/m².

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