Ministry of Science and Technology
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Hydraulic Design of Bridge

(CE 5016 Design of Hydraulic Structures)

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Introduction

- The afflux (rise in upstream water level) depends on the type of flow (sub critical or supercritical).
- To minimize scour and choking problems, the flow is assumed as sub critical flow condition for the most bridge design.
- The establishment of afflux levels is extremely important for the design of upstream dykes and other protection works and also for the location of safe bridge deck levels.
- The permissible upstream stage level and downstream water level can be established by back water computation.

Back water levels

Short contraction

- Bridge with only few piers may be relatively less important in back water problems.
- The change in water level Δh can be obtained by the energy equation between sections 1 and 2.

$$\Delta h = K_B \frac{V_2^2}{2g} + S_0 \frac{L}{\sigma} - \alpha_1 \frac{V_1^2}{2g}$$

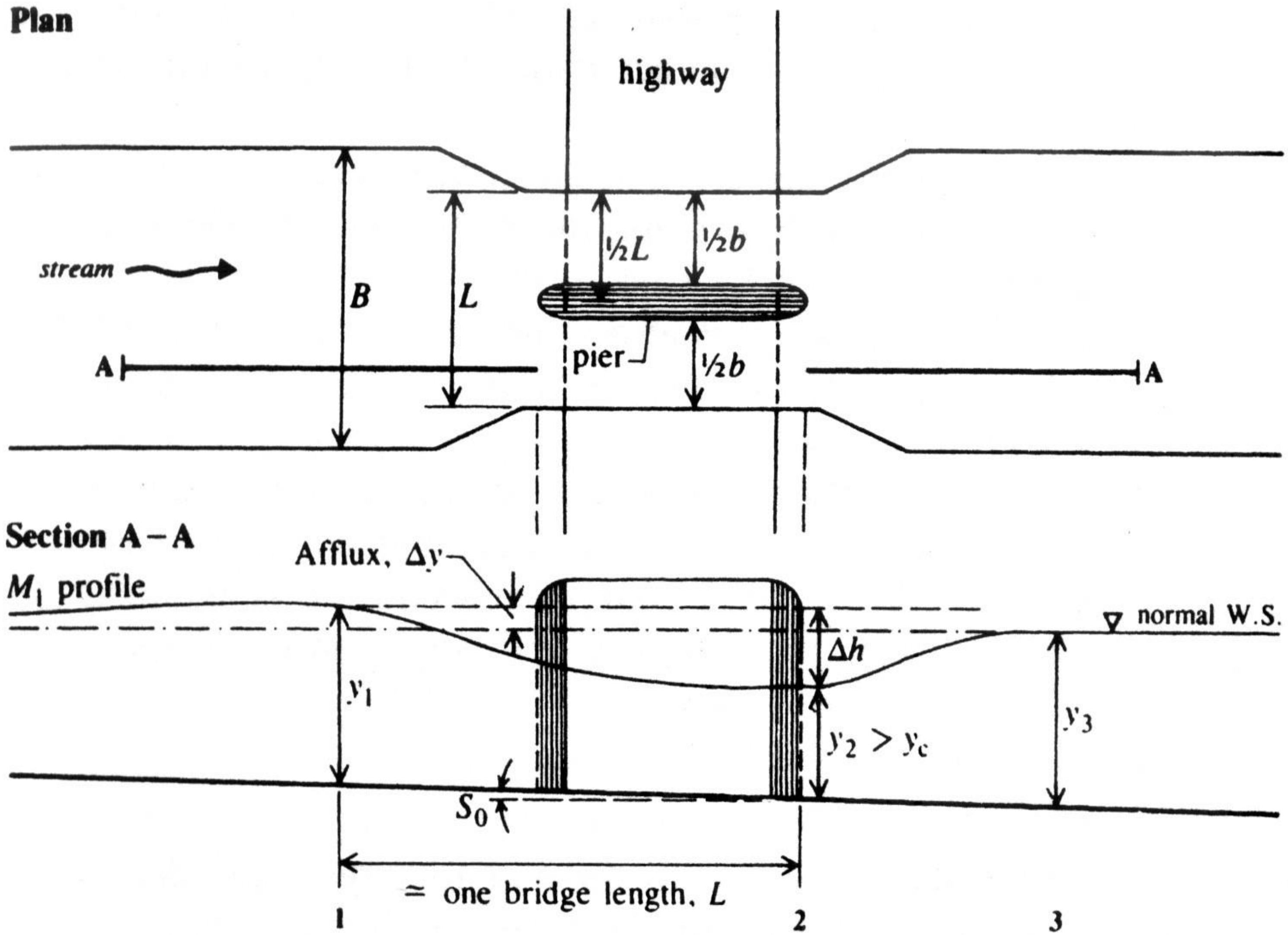

Fig. 10.10 Flow profile through bridge with contracted channel of relatively short length (subcritical flow)

Long Contraction

- Bridge has a number of large piers and/or long approach embankments contracts the water width.
- The backwater effect is considerable.
- Afflux is entirely created by the presence of piers and channel contraction.
- Momentum and continuity equations between sections 1 and 3 result in

$$\Delta y / y_3 = \{A + [A^2 + 12 C_D (b/B) Fr_3^2]^{\frac{1}{2}}\} / 6$$

where

$$A = \{C_D (b/B) + 2\} Fr_3^2 - 2$$

Yarnell's empirical equation

$$\Delta y / y_3 = K Fr_3^2 \left(K + 5 Fr_3^2 - 0.6\right)\left(\alpha + 15\alpha^4\right)$$

where

$$\alpha = 1 - \sigma = 1 - b / B$$

K is a function of the pier shape shown in Table

e.g. for semicircular nose and tail, K=0.9

for square nose and tail , K=1.25

(for piers with length to breadth ratio = 4)

This equation is valid only if σ is large, i.e. the contraction cannot set up critical flow conditions between piers and choke the flow.

If the flow becomes choked by excessive contraction the afflux increases substantially.

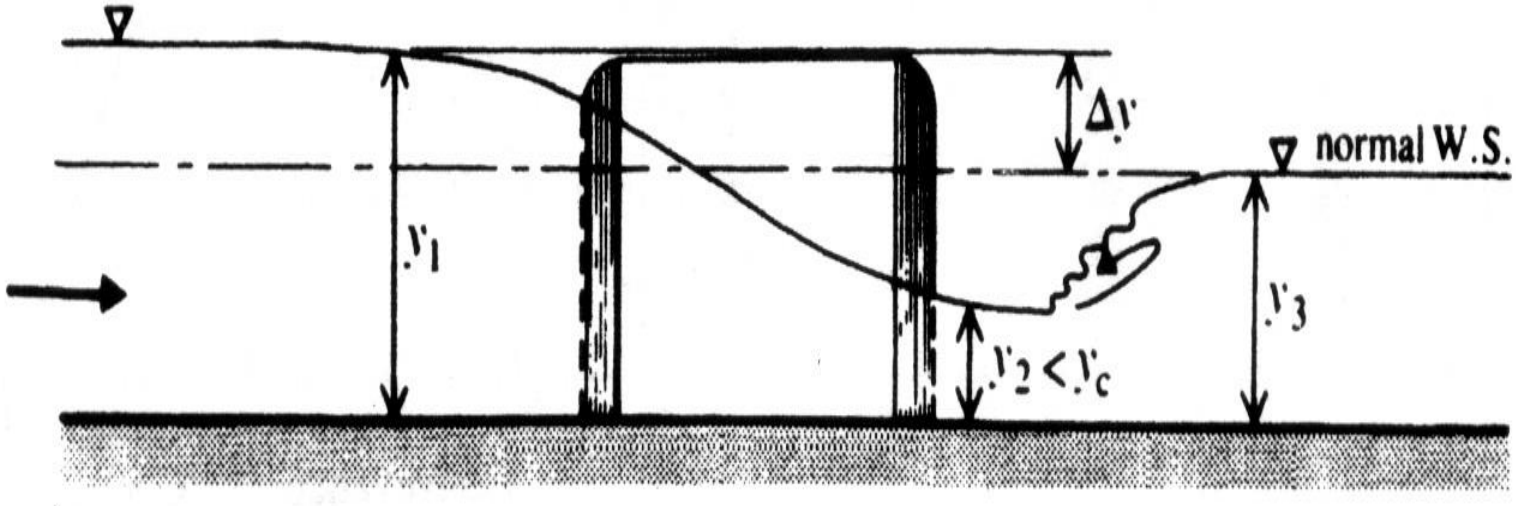

Fig. 10.11 Flow profile with choked flow conditions

The limiting values of σ (assuming uniform velocity at section 2)for critical flow at section 2 can be written as

$$\sigma = (2 + 1/\sigma)^3 Fr_3^4 / (1 + 2Fr_3^2)^3$$

the energy loss between sections 1 *and* 2

$$E_1 - E_2 = C_L \frac{V_1^2}{2g}$$

where C_L *is a function of pier shape*

0.35 for square-edged piers

0.18 for rounded ends

(for pier length width ratio =4)

- Skewed bridges produce greater affluxes.
- Yarnell found that
  - ►10° skew bridge gave no appreciable changes
  - ►20° skew produced about 250% more afflux values.
- Martin-Vide and Piró recommended for bakwater computation of arch bridges that
  - ►K=2.3m-0.345

    where “m” is the ratio of the obstructed and channel areas for 0.324<m<0.65

(b) Discharge computation

For sub critical and near critical flows,

- Nagler proposed the equation

$$Q = K_N b(2g)^{\frac{1}{2}} \left(y_3 - \theta \frac{V_3^{\,2}}{2g} \right) \left(h_3 + \beta \frac{V_1^{\,2}}{2g} \right)^{\frac{1}{2}}$$

- d'Aubuisson suggested the approximate formula

$$Q = K_A b_2 y_3 \left(2gh_3 + V_1^{\,2} \right)^{\frac{1}{2}}$$

- Chow presents the series the design charts produced by Kindsvater, Carter and Tracy.

(c) Scour depth under the bridge

- minimum stable width of an alluvial channel is $W = 4.75\sqrt{Q}$
- If bridge length< W , the normal scour depth under the bridge is

$$D_N = R_s (W / L)^{0.61}$$

$$where$$

$$R_S = 0.475 (Q / f)^{0.33} \; when \; W \leq actual \, waterway \, width$$

$$R_S = 1.35 (q^2 / f)^{0.33} \; when \; W > actual \, waterway \, width$$

- The maximum scour depth is
  - ►for single span bridge with straight approach, more than 25% of the normal scour
  - ►for multispan structure with curved approach, more than 100% of the normal scour
- If the constriction is predominant, the maximum scour depth is

$$D_{\max} = R_S (W / L)^{1.56}$$

(d) Scour around bridge piers

- Several formula based on experimental results have been proposed to predict the "maximum" or "equilibrium" scour depth around bridge piers.

$$y_s / b' = \phi\left(y_0 / b', Fr, d / b'\right)$$

where

$$y_s = scour\ depth\ below\ general\ bed\ level$$

$$b' = pier\ width$$

$$y_0 = upstream\ flow\ depth$$

$$d = se\dim ent\ size$$

$$Fr = Froude\ number$$

(e) Scour protection works around bridge piers

- To minimize the scour and to prevent undermining of the foundations, the protective measures have to be taken.
- Piers with base diaphragms (horizontal rings) and multiple cylinder type piers have been found to minimize the scour considerably.
- The normal practice for protection of the foundation is to provide thick layers of stone or concrete aprons around the piers.
- A riprap protection in the shape of a longitudinal section of an egg with its broader end facing the flow is recommended for a cylindrical pier.▪

Example

A road bridge of seven equal span lengths crosses a 106m wide river. The piers are 2.5m thick, each with semicircular noses and tails, and their length-breadth ratio is 4. The streamflow data are given as follows: discharge=500cumecs; depth of flow at downstream of the bridge = 2.50m. Determine the afflux upstream of the bridge.

- It has a number of large piers.

Therefore back water computation is made for long contraction.

$$y_3 = 2.5m, \quad V_3 = \frac{Q}{A} = \frac{500}{106 \times 2.5} = 1.887\, m/s$$

$$Fr_3^2 = \frac{V_3^2}{2g} \Rightarrow Fr = \frac{V_3}{\sqrt{gy_3}} = \frac{1.887}{\sqrt{9.81 \times 2.5}} = 0.381$$

$$The\ \lim iting\ value\ \sigma = \left(2 + \frac{1}{\sigma}\right)^3 Fr_3^4 \left(1 + 2Fr_3^2\right)^3 \Rightarrow \sigma = 0.55$$

$$\alpha = 1 - \sigma = 1 - \frac{b}{B},$$

$$The\ provided\ value\ of\ \sigma\ is\quad \frac{b}{B} = \frac{15.5 - 2.5}{106/7} = \frac{13}{15.5} = 0.839 > 0.55$$

subcritical flow condition exists between the piers.

$$\therefore\ \sigma = 0.839$$

$$\alpha = 1 - \sigma = 1 - 0.839 = 0.161$$

K=0.9 (for semicircular nose and tail)

$$\frac{\Delta y}{y_3} = KFr_3^2\left(K + 5Fr_3^2 - 0.6\right)\left(\alpha + 15\alpha^4\right)$$

$$\frac{\Delta y}{2.5} = 0.9 \times 0.381^2\left(0.9 + 5 \times 0.381^2 - 0.6\right)\left(0.161 + 15 \times 0.161^4\right)$$

$$\Delta y = 5.41 \times 10^{-2} m = 54.1 mm$$

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