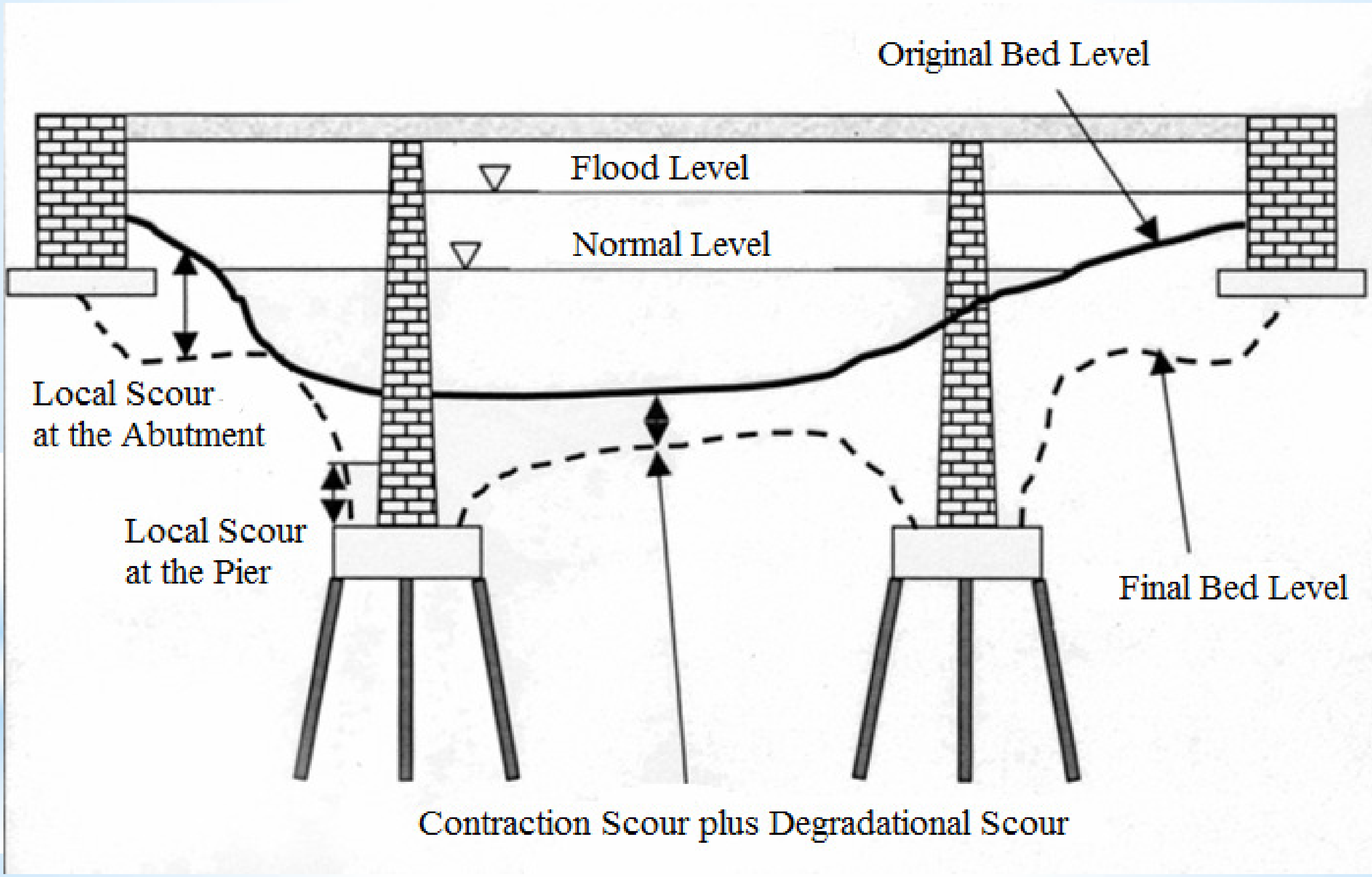
Pressure-Flow Scour

OR

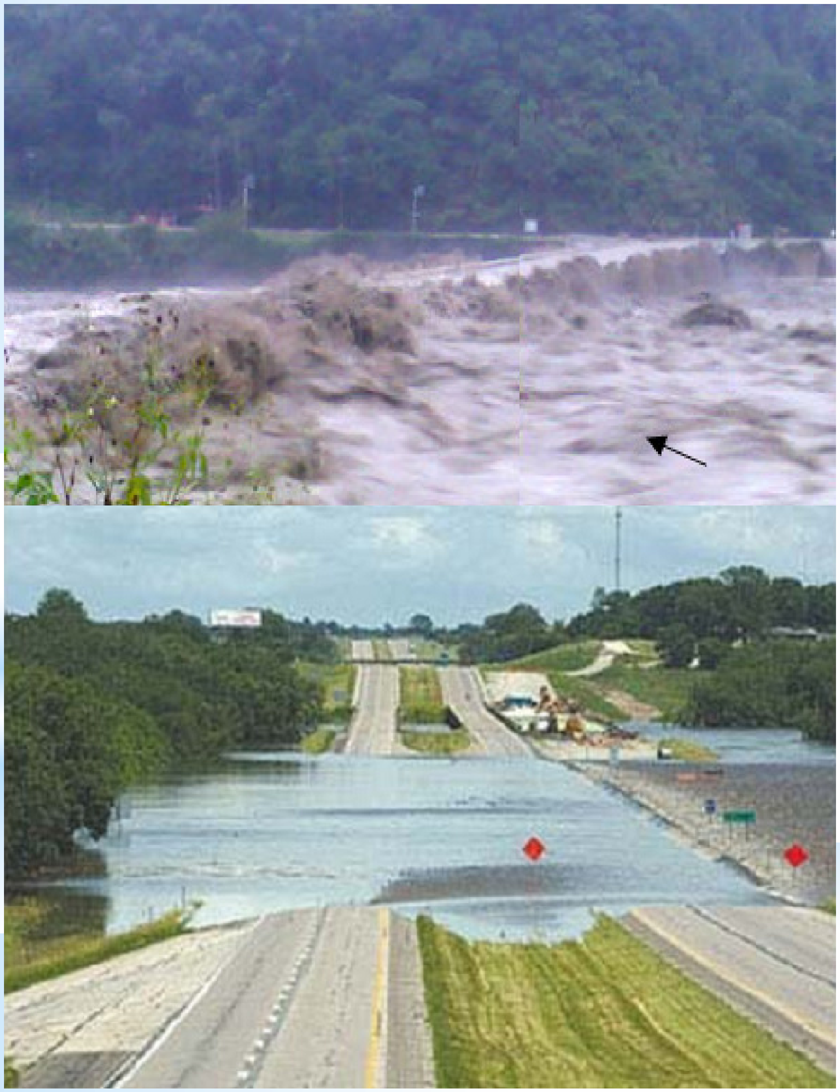
Vertical-Contraction Scour

Free Surface Flow Scour



Pressure-flow scour conditions occur when the water-surface elevation of the river exceeds the bottom elevation of the bridge deck's structural members.

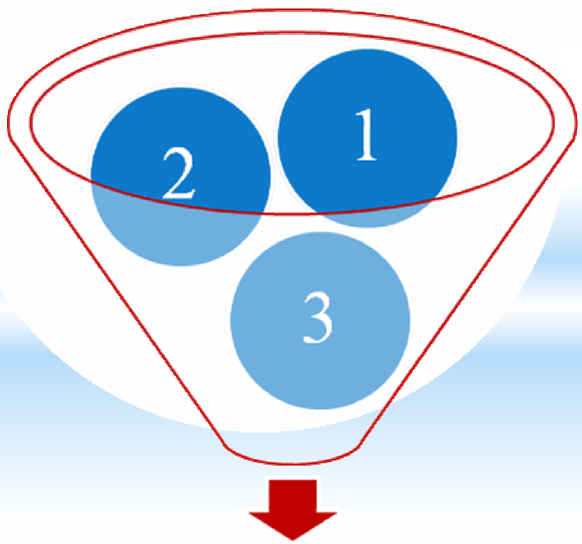
Totally submerged flow



Partially submerged flow

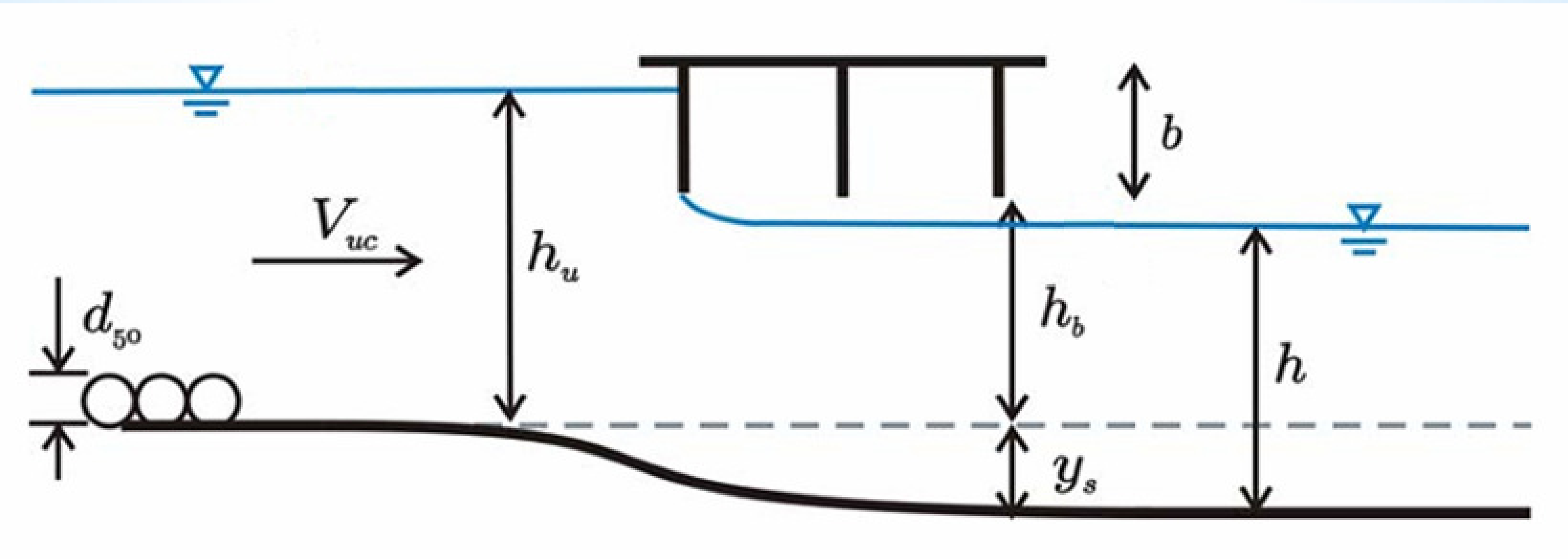
- **Flow Classification**

The tailwater surface elevation



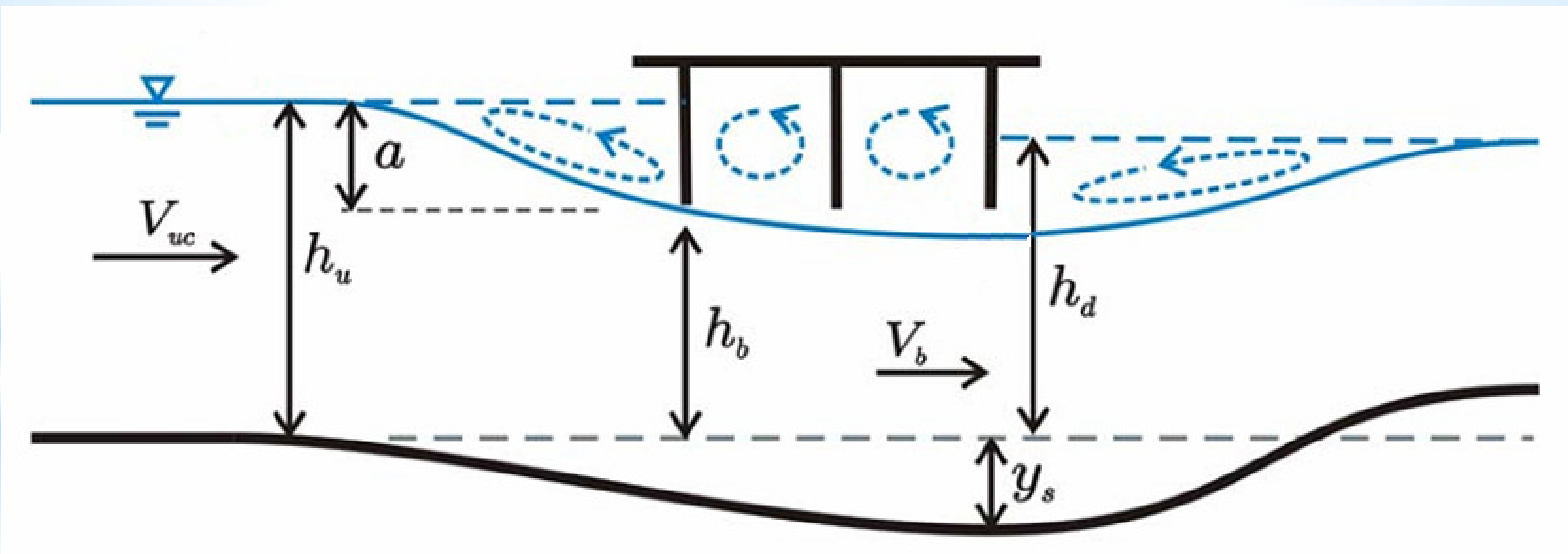
Case 1

- ✓ If the downstream low chord of a bridge is unsubmerged , the bridge operates as an inlet control **sluice gate**. The scour is independent of the bridge width and continues until a uniform flow and a critical bed shear stress are reached.
- ✓ This case occurs only for upstream slightly submerged conditions.
- ✓ Since the flow condition under the bridge in this case is an open channel flow.



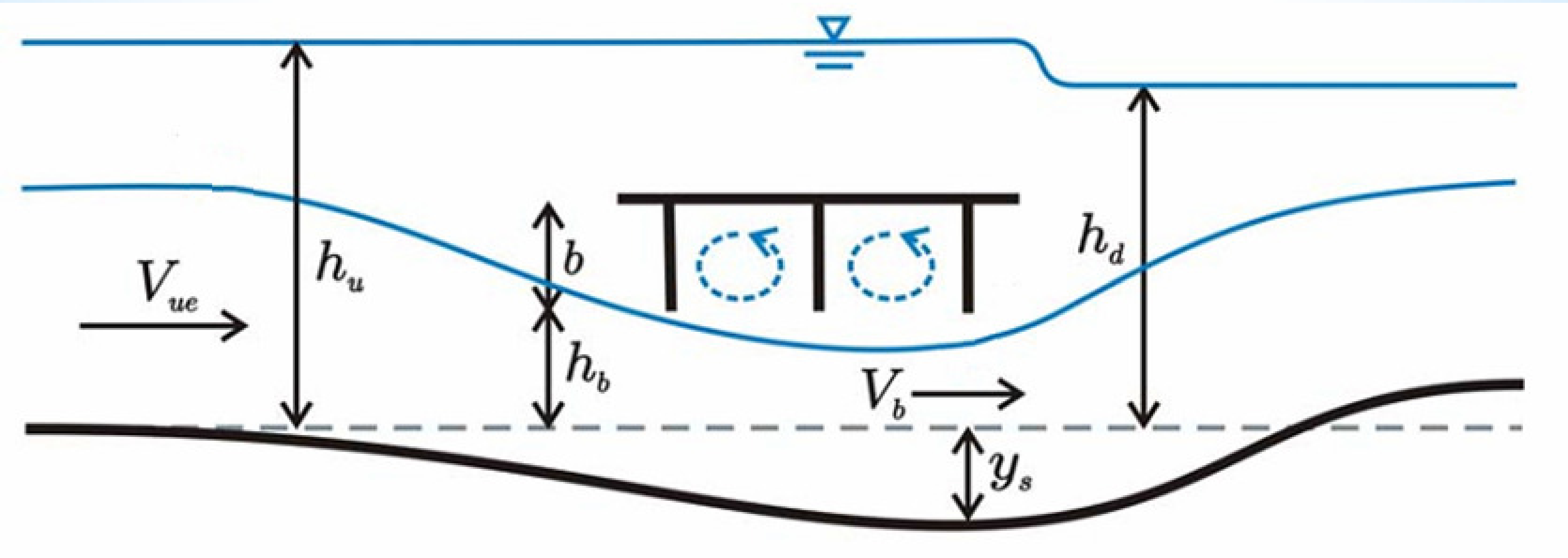
Case 2

- ✓ If the downstream low chord is partially submerged, the bridge operates as an outlet control **orifice**, and the bridge flow is rapidly varied pressure flow.

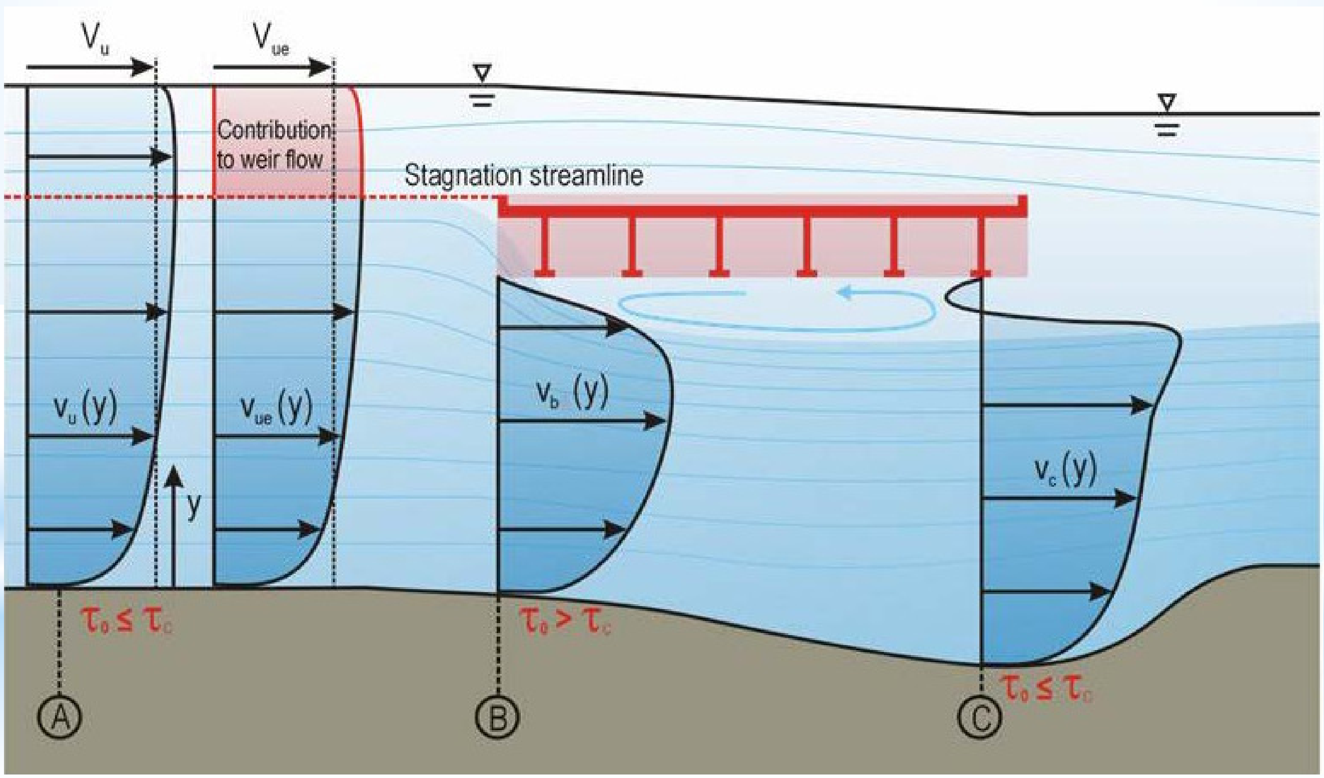


Case 3

- ✓ If the bridge is totally submerged, it operates as a combination of an **orifice** and a **weir**.
- ✓ Only the discharge through the bridge affects scour depth.



- ✓ As shown in figure, shear stress applied by the flowing water is less than the critical shear stress in the approach, as is required for clear water approach conditions.
- ✓ However, if there is sufficient contraction, this relationship will reverse at section B, initiating scour.
- ✓ At section C, a scour hole will form to increase conveyance until the applied shear is less than or equal to critical shear Stress.



Velocity distributions in Case 3

Evaluation of Pressure-flow Scour

Flow Structure and Turbulent Conditions

Sediment Transportation

Bed forms

Umbrell et al.(1998)

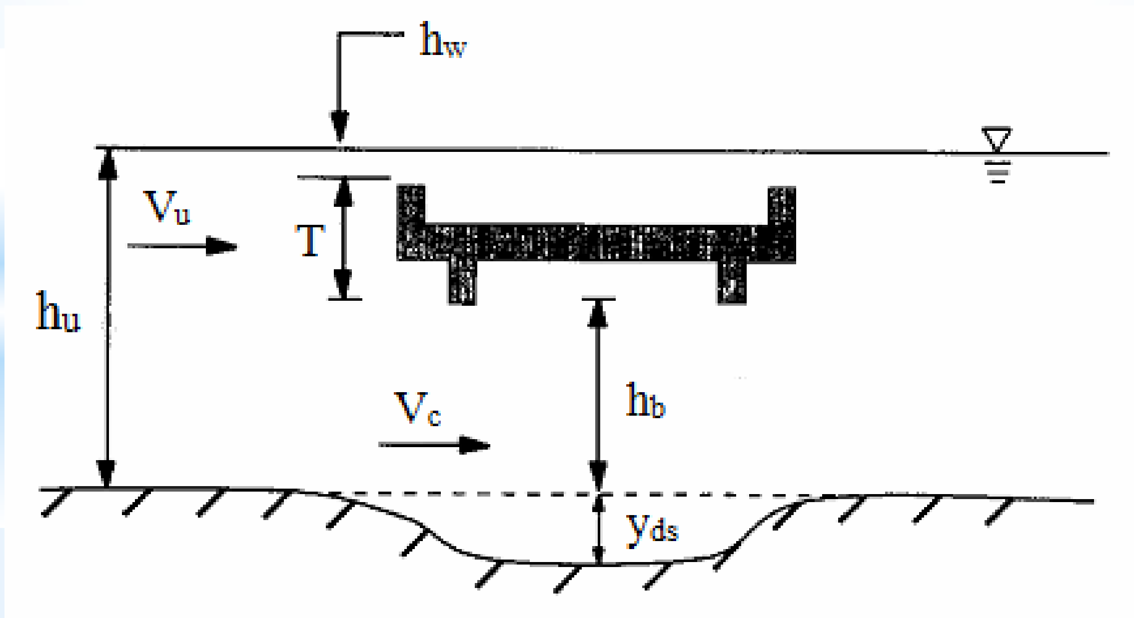
- ✓ Scour caused by pressure flow beneath a bridge without the localized effects of piers or abutments;
- ✓ Clear-water Scour Conditions;
- ✓ Using the mass conservation law, they presented :

$$Q_{total} = Q_{weir} + Q_{submerged}$$

➢ It is assumed that flow velocity over the bridge deck is approximately equal to the approach velocity, Va, and that the flow velocity under the bridge at scour equilibrium is approximately equal to the incipient motion velocity of the approach flow, Vc:

$$V_u h_u B = V_u h_w B + V_c (h_b + y_{ds}) B \quad \rightarrow \quad (h_b + y_{ds}) = \frac{V_u}{V_c}(h_u - h_w)$$

$$\rightarrow \quad \frac{h_b + y_{ds}}{h_u} = \frac{V_u}{V_c}\left(1 - \frac{h_w}{h_u}\right)$$



$$\frac{(h_b + y_{ds})}{h_u} = 1.1021\left[\left(1 - \frac{h_w}{h_u}\right)\frac{V_u}{V_c}\right]^{0.6031}$$

y_{ds}= Maximum equilibrium scour depth,
h_u = Approach flow depth,
h_b = Vertical bridge opening height before scour,
h_w = Depth of weir flow overtopping bridge,
V_u = Average approach flow velocity,
V_c = Critical velocity of the bed material in the bridge opening:

Neill's critical velocity: $V_c = 1.58\sqrt{g\,(s-1)D_{50}}\left(\frac{h_u}{D_{50}}\right)^{1/6}$

Arneson and Abt (1998)

- ✓ The magnitude of total scour at a bridge flowing under pressure flow conditions results from the sum of pressure flow deck scour and pressure flow pier scour;
- ✓ Live-bed Scour conditions;
- ✓ Using techniques of multiple linear regression, partial residual analysis, and a variety of other statistical tests to evaluate the quality of the data, a relationship was developed from the data collected in the laboratory:

$$\frac{y_{ds}}{h_u} = -5.08 + 1.27\left(\frac{h_u}{h_b}\right) + 4.44\left(\frac{h_b}{h_u}\right) + 0.19\left(\frac{V_b}{V_c}\right)$$

V_b = Average velocity of the flow through the bridge opening before scour occurs,

$$q = V_u h_u = V_b h_b$$

$$\frac{y_{ps}}{b} = -0.25 + 3.59\left(\frac{V_u}{\sqrt{gy}}\right) + 0.14\left(\frac{y}{h_b}\right)$$

y_{ps} = equilibrium depth of pressure flow pier scour measured from the mean bed elevation;

b = pier width.

Shen et al.(2012)

- ✓ Scour caused by pressure flow beneath a bridge without the localized effects of piers or abutments;
- ✓ Clear-water Scour Conditions;
- ✓ The theoretical formulation of the model is based on the conservation of mass of the water passing underneath the bridge deck.

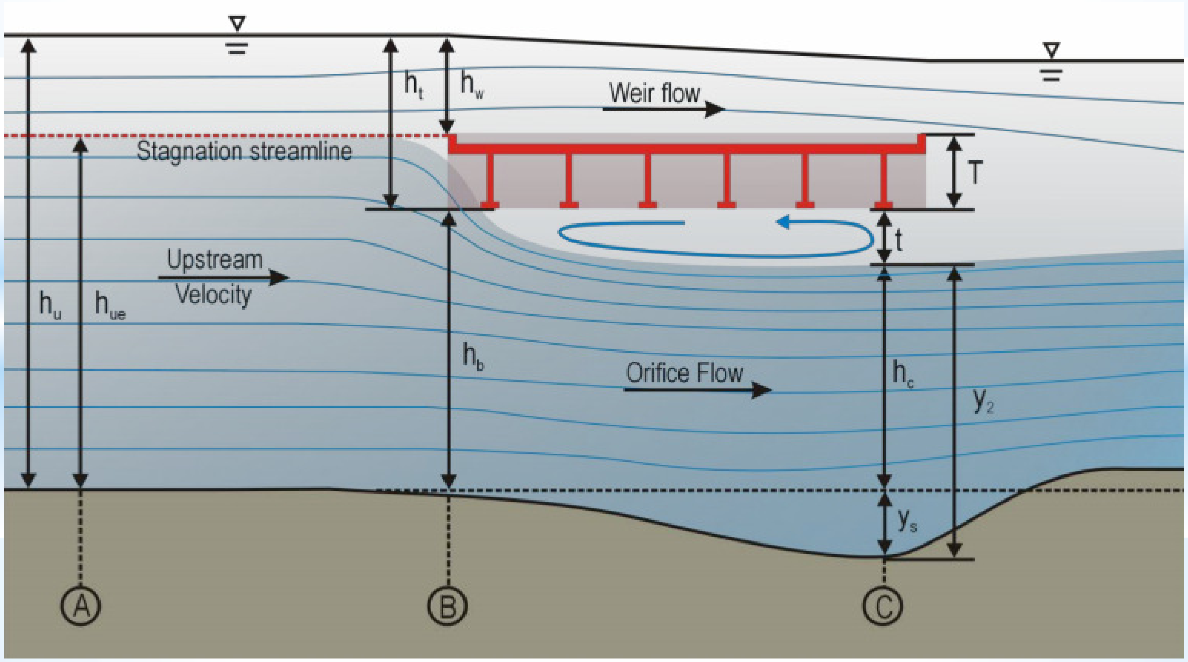
$$q = V\ h \quad \rightarrow \quad V_{ue} h_{ue} = V_b h_b = V_c \left(h_c + y_{ds} \right)$$

$$h_c = h_b - t \quad \rightarrow \quad V_{ue} h_{ue} = V_c \left(h_b - t + y_{ds} \right)$$

$$Laursen's\ \ critical\ \ velocity \quad \rightarrow \quad V_c = K_U h^{1/6} D_{50}^{\ 1/3}$$

$$at\ \text{section}\ C : h = h_b - t + y_{ds} \quad \rightarrow \quad V_{ue} h_{ue} = K_U \left(h_b - t + y_{ds} \right)^{1/6} D_{50}^{\ 1/3} \left(h_b - t + y_s \right)$$

$$\rightarrow \quad h_b + y_{ds} = \left(\frac{V_{ue} . h_{ue}}{K_U . D_{50}^{\ 1/3}} \right)^{6/7} + t$$



$$\frac{t}{h_b} = 0.5\left(\frac{h_b . h_t}{h_u^2}\right)^{0.2}\left(1 - \frac{h_w}{h_t}\right)^{-0.1}$$

t = Separation zone thickness,

h_t = Flow depth above the bottom of the bridge superstructure,

h_{ue} = The effective approach flow depth

V_{ue} = Effective approach velocity directed under the bridge,

T = The bridge superstructure thickness,

n = Exponent used for the power law velocity distribution, For fully developed turbulent flows, n may be taken as one-seventh,

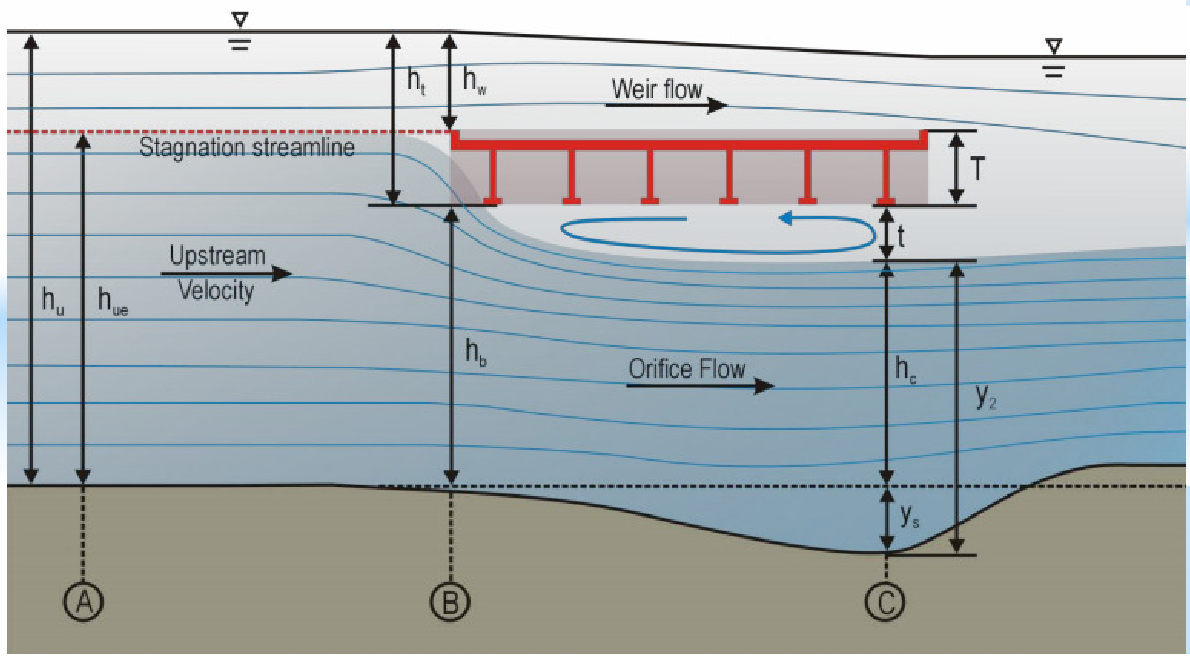
K_U = Constant equal to 6.19 m^2/s

$$h_t = h_u - h_b$$

$$h_w = \begin{cases} h_t - T & for \quad h_t > T \\ 0 & for \quad h_t < T \end{cases}$$

$$h_{ue} = h_b + T$$

$$V_{ue} = V_u \left(\frac{h_{ue}}{h_u}\right)^n$$



Example Problem - Clear-Water Application Including Overtopping

Given:
There are no piers.
Upstream channel width and bridge opening width (W) = 9.7 m
Total discharge = 57.4 m3/s
Upstream channel flow depth (h_u) = 3.7 m
Bridge opening height (h_b) = 2.4 m
Deck thickness = 0.91 m
Bed material D_{50} = 15.0 mm

Determine:

The magnitude of clear-water contraction scour for pressure flow conditions.

Solution: Method of Shen at al.(2012)

$$V_u = \frac{Q}{h_u B} = \frac{57.4}{3.7 \times 9.7} = 1.6\ (m/s)$$

$$V_c = K_U h^{1/6} D_{50}^{\ 1/3} = 6.19 \times (3.7)^{1/6} (0.015)^{1/3} = 1.9\ (m/s)$$

$$V_u < V_c \quad \rightarrow \quad Clear\,Water\,Scour$$

$$h_t = h_u - h_b = 3.7 - 2.4 = 1.3\ (m),$$

$$h_w = h_t - T = 1.3 - 0.91 = 0.39\ (m),$$

$$h_{ue} = h_b + T = 2.4 + 0.91 = 3.31\ (m)\ ,$$

$$V_{ue} = V_u \left(\frac{h_{ue}}{h_u} \right)^n = 1.6 \left(\frac{3.31}{3.7} \right)^{1/7} = 1.57\ (m/s)$$

$$\frac{t}{h_b} = 0.5\left(\frac{h_b . h_t}{h_u^2}\right)^{0.2}\left(1 - \frac{h_w}{h_t}\right)^{-0.1}$$

$$\frac{t}{2.4} = 0.5\left(\frac{2.4 \times 1.3}{3.7^2}\right)^{0.2}\left(1 - \frac{0.39}{1.3}\right)^{-0.1} \quad \rightarrow \quad t = 0.93\ (m)$$

$$h_b + y_{ds} = \left(\frac{V_{ue} . h_{ue}}{K_U . D_{50}^{1/3}}\right)^{6/7} + t$$

$$2.4 + y_{ds} = \left(\frac{1.57 \times 3.31}{6.19 \times (0.015)^{1/3}}\right)^{6/7} + 0.93 \quad \rightarrow \quad y_{ds} = 1.39\ (m)$$