River Scour

Clear-Water and Live-Bed Scour

If the mean velocity (V) in the upstream reach is equal to or less than the critical velocity (Vc) of the median diameter (d_{50}) of the bed material, then contraction and local scour will be clear-water scour.

If the mean velocity is greater than the critical velocity of the median bed material size, live-bed scour will occur.

In clear bed scour, the scour holes develops deeper and reaches a stable condition whereas in live bed condition, the scour depth fluctuate about an equilibrium value due to the presence of both the erosion and deposition process.

Due to the sedimentation the scour depth in live bed scour is generally less than the scour depth in case of clear water condition.

When sediment particles are present in the flow, they can partially absorb the energy of the water, reducing the force available to erode the riverbed material. Moving sediment can create bedforms like ripples or dunes, which can further disrupt the flow and limit the potential for deep scour. In a live bed (where sediment is actively moving), the scour depth tends to stabilize as the rate of sediment removal balances the rate of sediment deposition.

River Scour

Clear-Water and Live-Bed Scour

There are two conditions for contraction and local scour: clear-water scour and live-bed scour.

Local scour can occur when the rest of the river bed is stable and no bed sediment transport occurs. This condition is referred to as clear-water scour. Clear-water scour occurs when there is no movement of the bed material in the flow upstream of the crossing (structure).

At the pier or abutment the acceleration of the flow and vortices created by these obstructions cause the bed material around them to move. This occurs when the bed material sediment transport in the uncontracted approach section is negligible or less than the carrying capacity of the flow.

Live-bed scour occurs when there is transport of bed material from the upstream reach into the crossing. This occurs when bed material is already being transported into the contracted bridge section from upstream of the approach section (before the contraction reach).

The limiting scour then corresponds to the equilibrium between the sediment transport into the scour hole and out of the scour hole. For this condition, the scour depth may fluctuate with time as dunes pass by the scour hole.

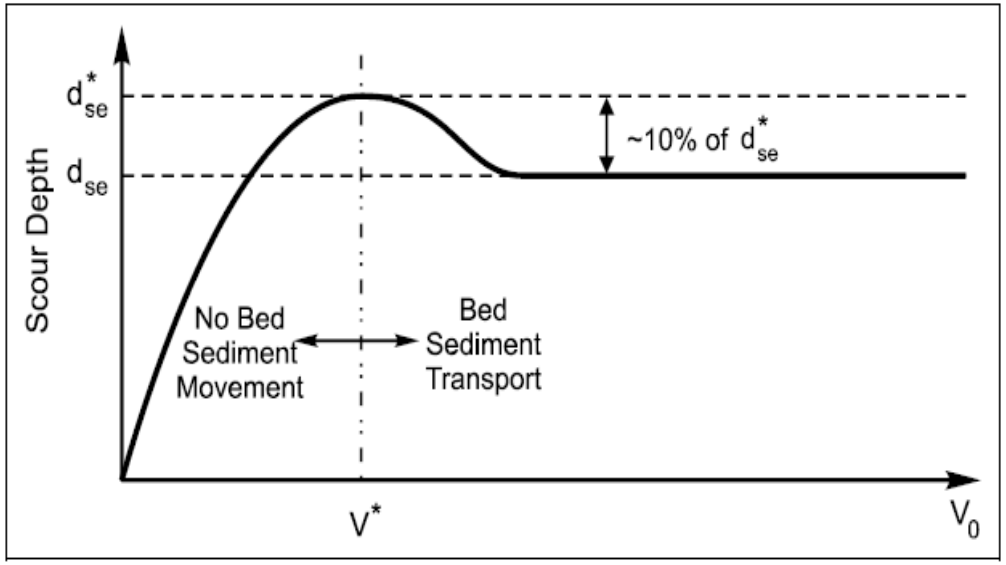


Figure 4-5. The variation of maximum pier-scour depth with flow velocity and bed sediment transport

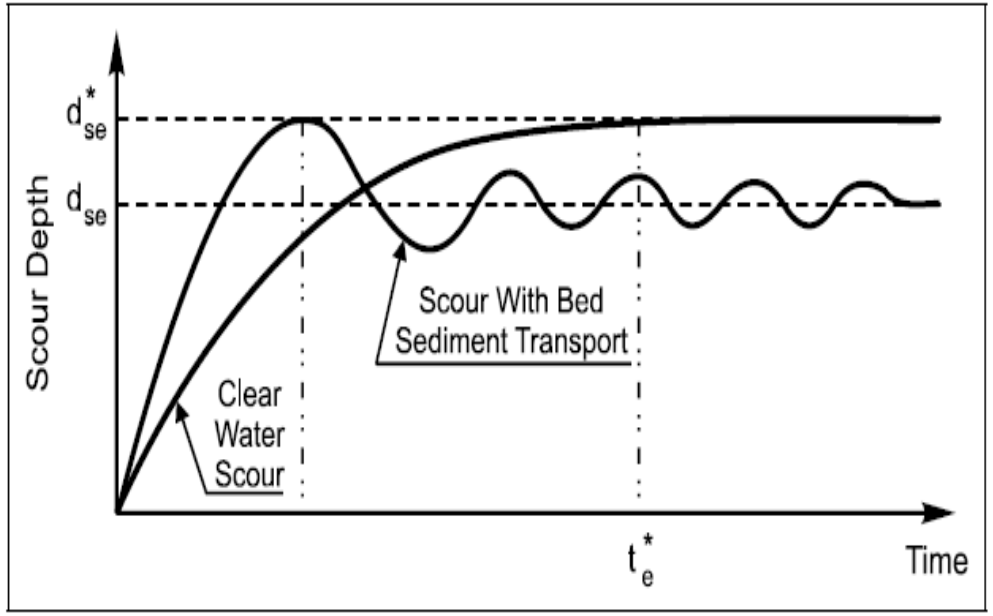
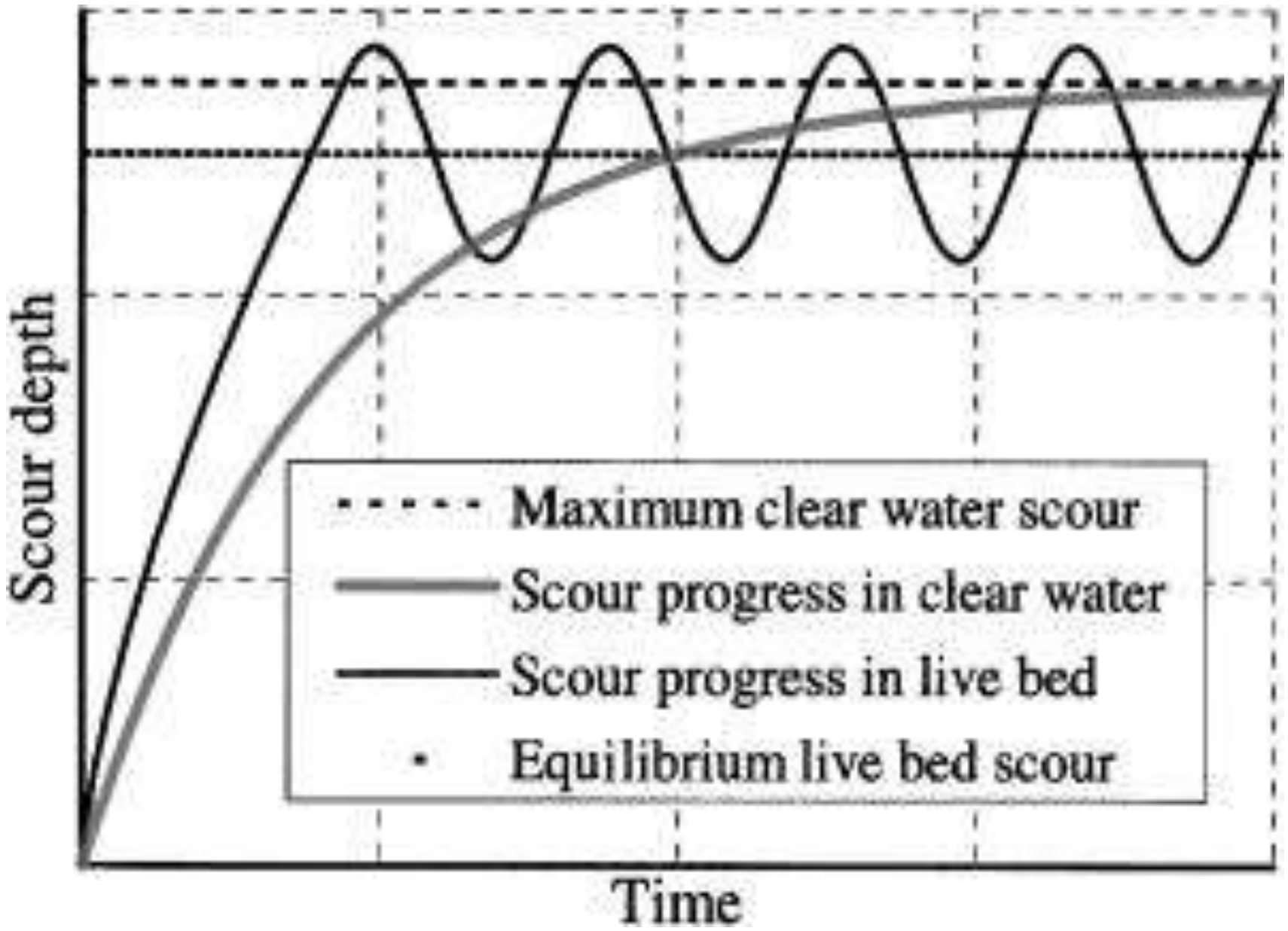


Figure 4-6. The time development of pier scour for clear-water conditions (e.g., pier on a floodplain) and for conditions when the waterway transports bed sediment


Scour depth
Time
Maximum clear water scour
Scour progress in clear water
Scour progress in live bed
Equilibrium live bed scour

Live-bed or Clear-water Determination

Clear-water: Vc > mean velocity

Live-bed: Vc < mean velocity

$$V_c = 10.95\, y_1^{1/6}\, d_{50}^{1/3}$$ (Laursen, 1963)

Where:

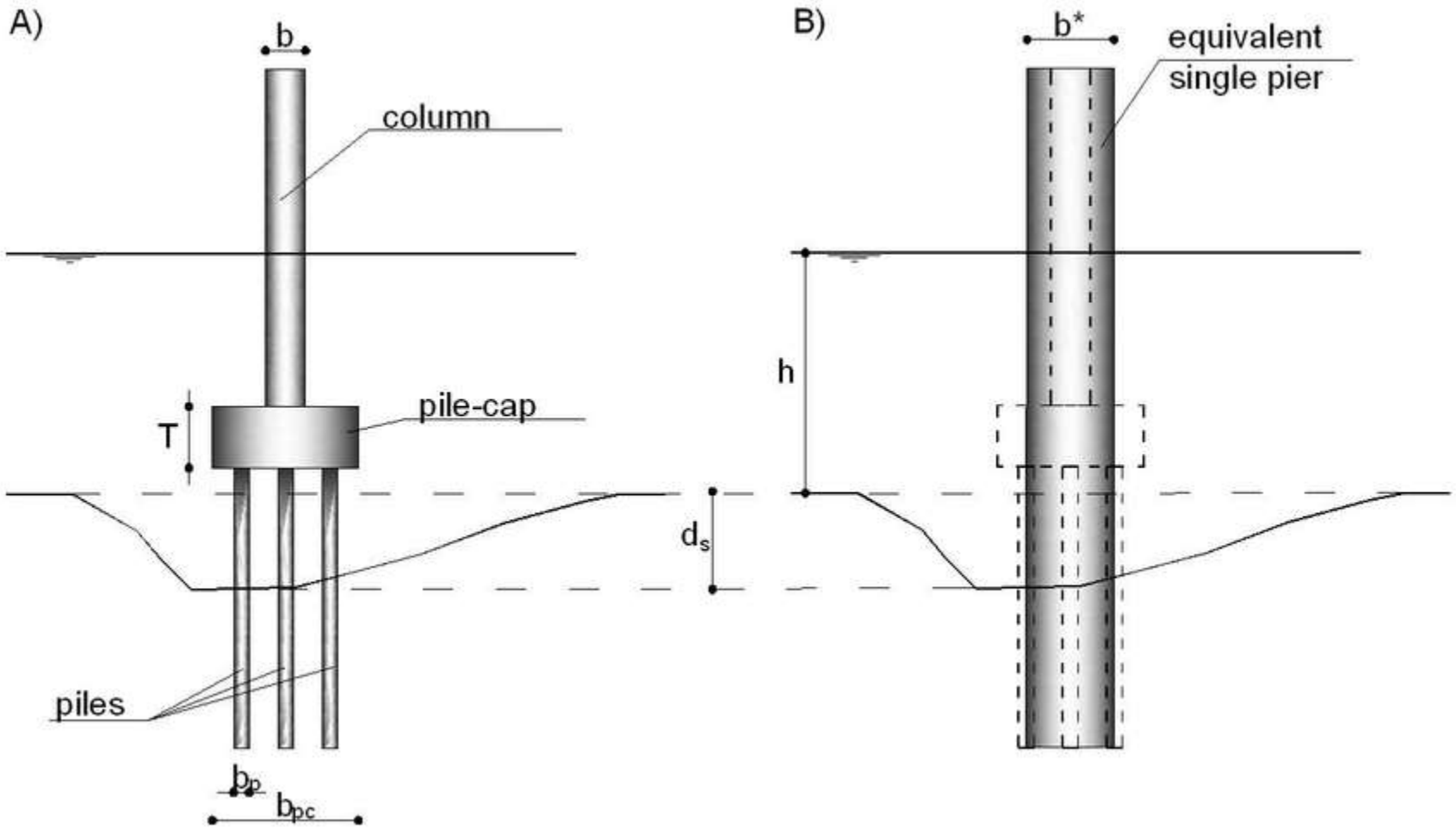
y_1 =depth of flow in the upstream of bridge

d_{50} = median diameter of bed material

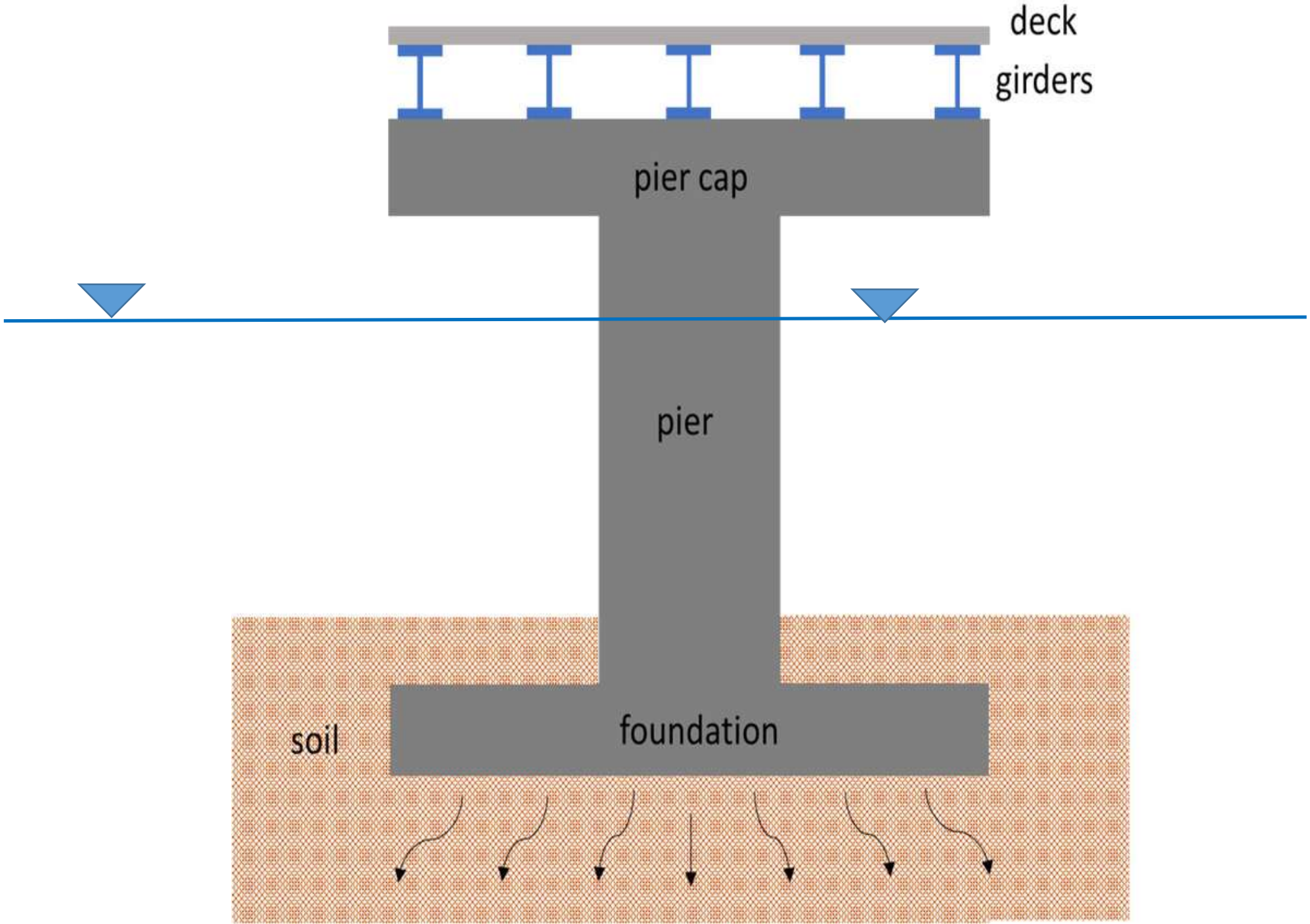
Estimation of Scour depth

Normal and Complex Pier

A complex pier is frequently composed of up to three elements, referred to as column, pile-cap and piles (or pile group), while a simple (normal) pier is assumed to be a single column (normally cylindrical) .



Normal Pier



Complex Pier



Why Complex Pier

Structural Robustness: Complex piers combine multiple elements (typically a pier stem, pile cap, and pile group) to transfer significant vertical and horizontal loads from the bridge deck down to stable soil or rock layers. Standard structures crack under the immense weight of long-span and multi-lane. A horizontal load is any lateral force (such as wind, earthquakes, water currents, or vehicle braking) that acts parallel to the ground and threatens to overturn or shear a bridge structure. Complex piers handle these forces by utilizing a wide pile cap and deep pile groups to transform destructive lateral tilting into manageable vertical forces.

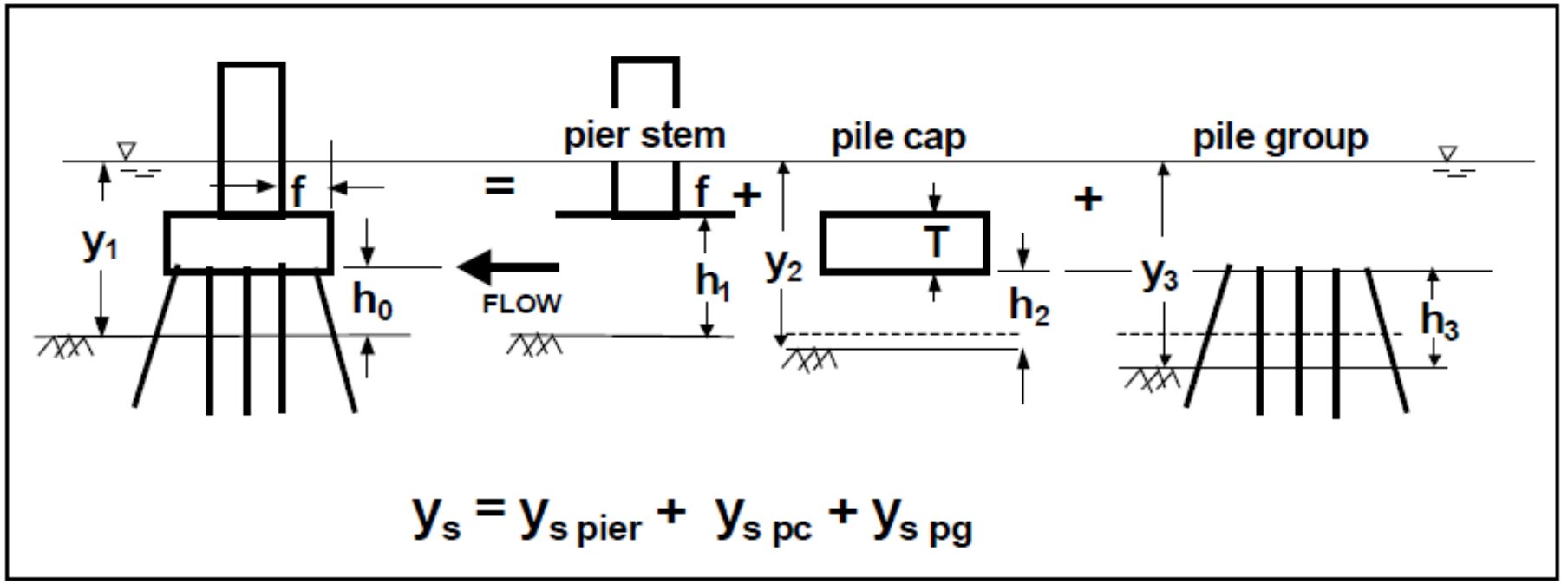
Deep Water Limits: Standard piers rest directly on shallow foundations. They cannot reach the deep, stable bedrock needed when bed soil is weak (unconsolidated eroded or deposited bed material). Complex piers can be deep enough to bypass weak soil and resist scouring.

Ship Collision Protection: In navigable waterways, the pile cap is often positioned near the water surface to protect the pier stem from ship impacts. A single concrete column lacks the physical footprint and mass to absorb or deflect the impact of a moving cargo ship.

Seismic Resistance: Complex pier design is chosen for superior stability in seismic zones, offering increased strength against environmental forces. Standard piers lack the flexible, multi-layered design needed to absorb shifting soil forces and prevent snapping during high-magnitude earthquakes.

Complex pier

Pile foundation is generally preferred as pier foundation because of low bearing capacity of river bed soil and to provide adequate support for the high dead load of the bridge superstructure.



Scour components at a complex pier configuration

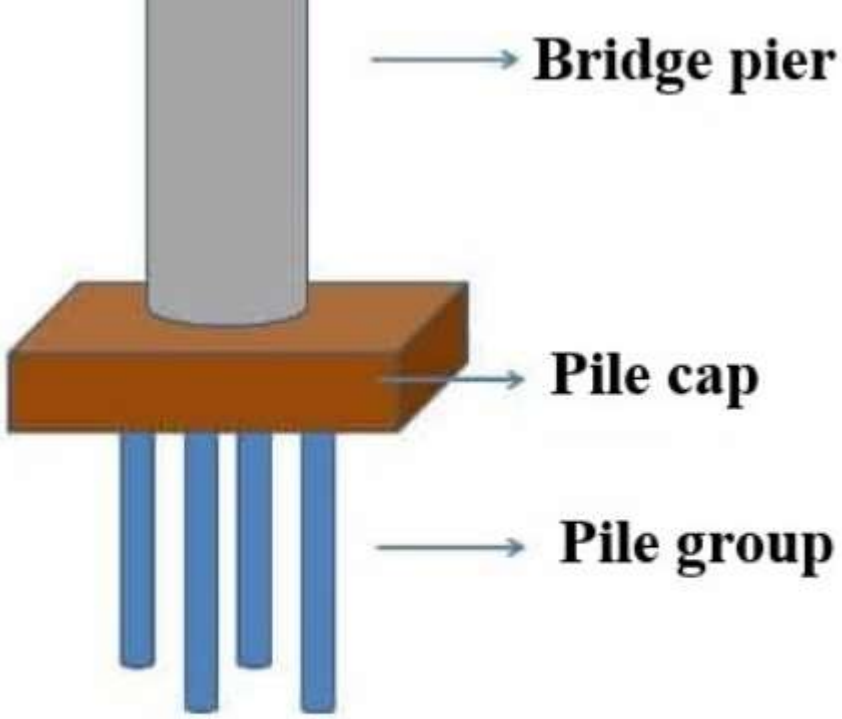


Figure 3.7: Components of a complex pier

Complex pier

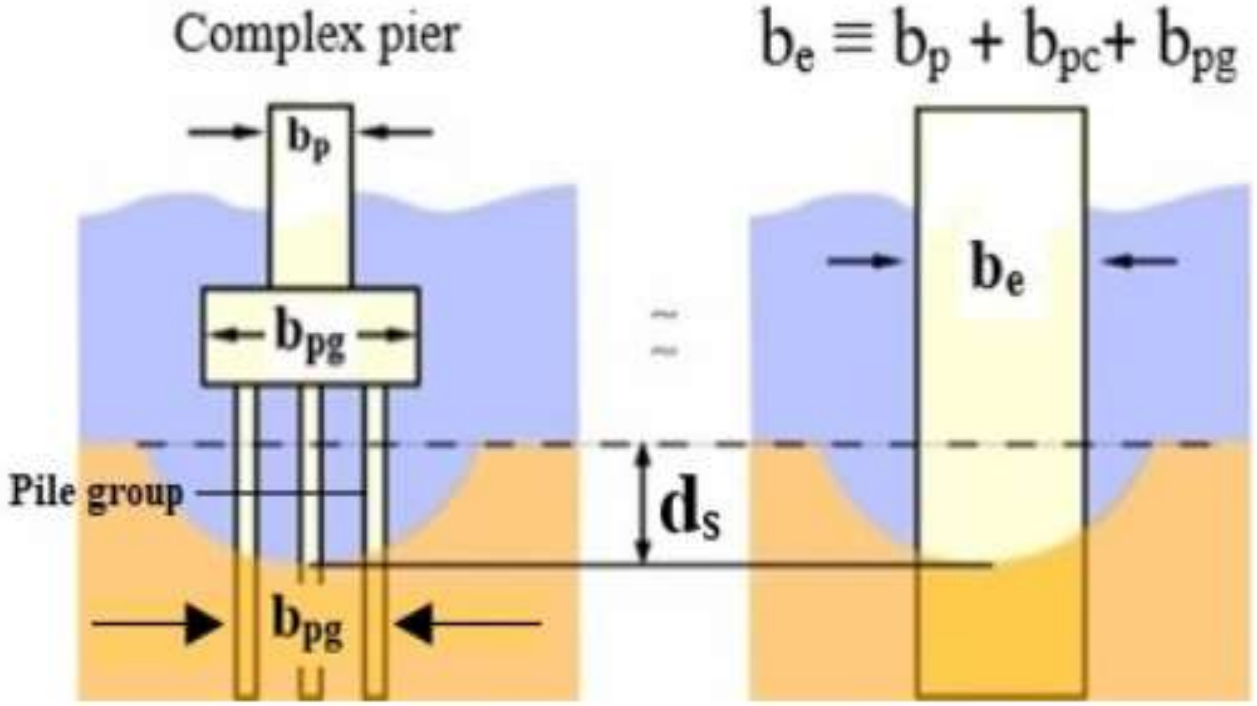


Figure 3.8: Definition sketch for total effective diameter for complex pier.

River Scour

Complex Pier

For piers founded on a slab footing (wider than the pier), caisson or pile cap, the footing, cap or caisson with the top below the general bed level can be effective in reducing the local scour depth through interception of the down flow (horseshoe vortex).

However, if the top of the wider foundation element comes to the bed level, or even above, the scour depth is increased.

At footing, caisson or pile cap foundations, four cases of local scouring can occur (Figure):

Case I: where the top of the footing, cap or caisson remains buried below the base of the scour hole;

Case II: where the top of the footing, cap or caisson is exposed within the scour hole below the general bed level;

Case III: where the top of the footing, cap or caisson is above the general bed level; and

Case IV: where the top of the footing, cap or caisson is at or above the water surface level.

For Case I, the local scour is unaffected by the presence of the footing, cap or caisson, while for Case II, the local scour typically is reduced from that at a simple pier, due to interception of the downward flow.

For Case III and IV, the influence of pile cap together with the uniform portion of the pier will work as complex pier and effective pier diameter needs to be estimated.

Effective Pier Diameter (b_e)

$$b_e = b\left(\frac{d+Y}{d+b^*}\right)+b^*\left(\frac{b^*-Y}{b^*+d}\right)$$

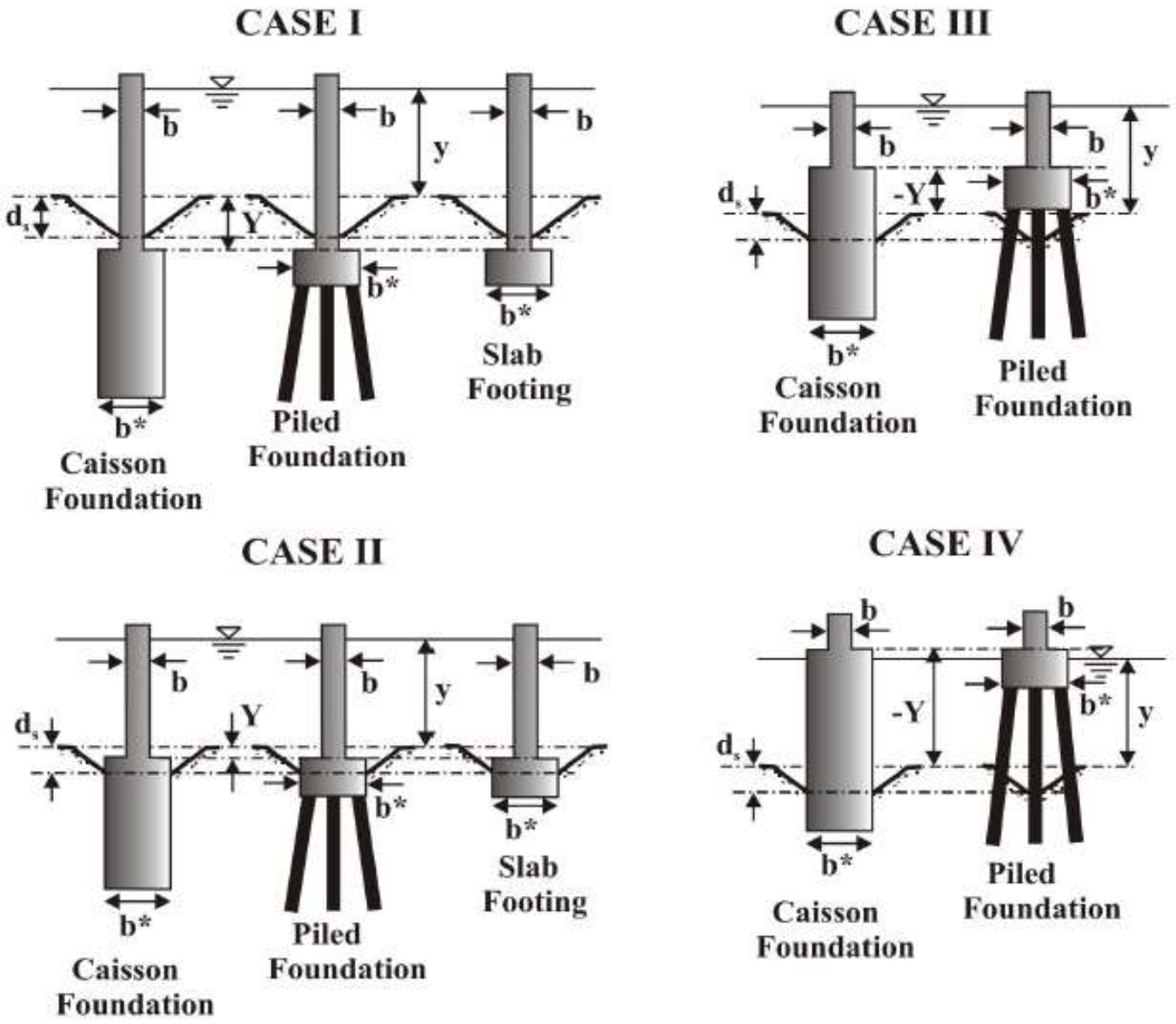
d_s = scour depth

Y = distance between bed and top of pile cap/caisson

y = depth of flow

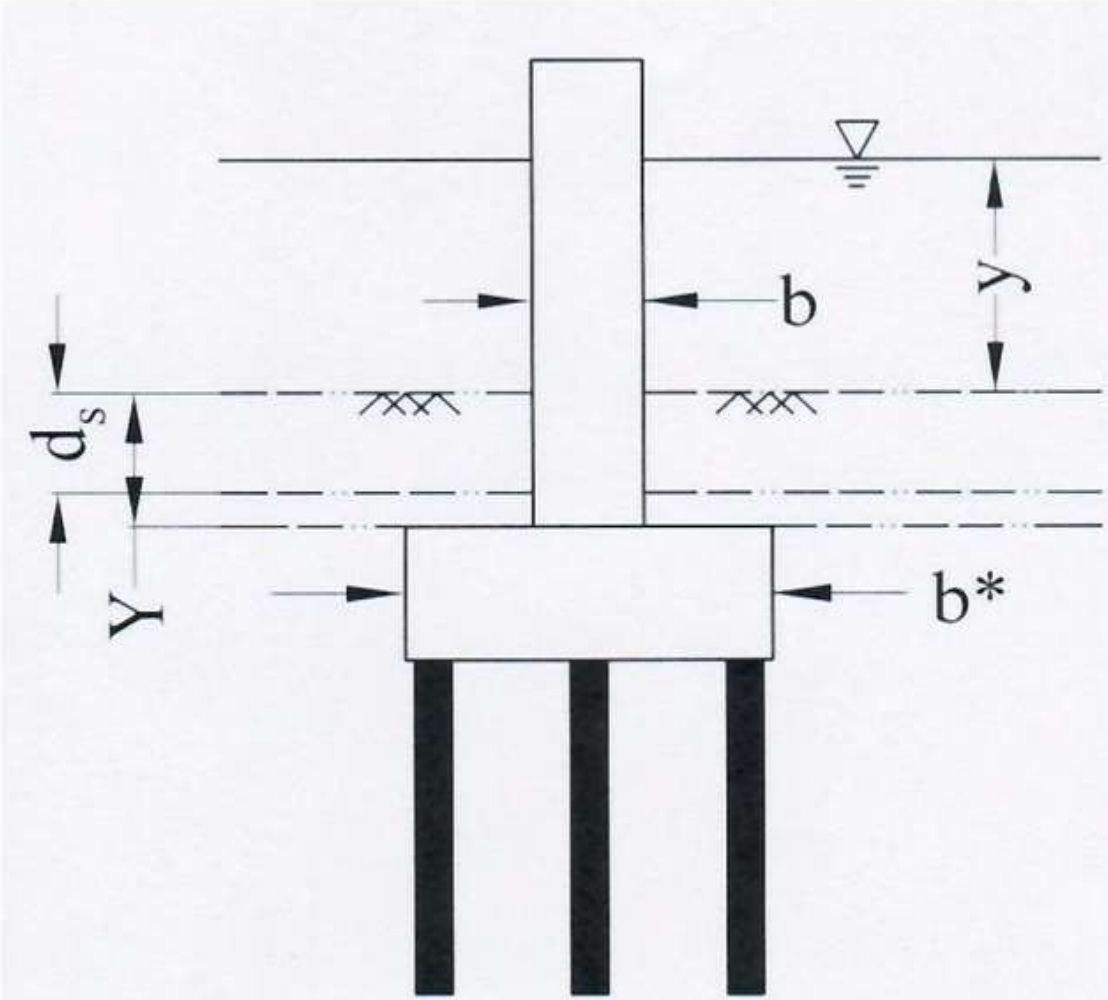
Cases

1. $d_s < Y$
2. $d_s > Y$
3. Y is 0 or – ve (pile cap/caisson above or at bed level
4. Y is – ve (pile cap/caisson above water level)

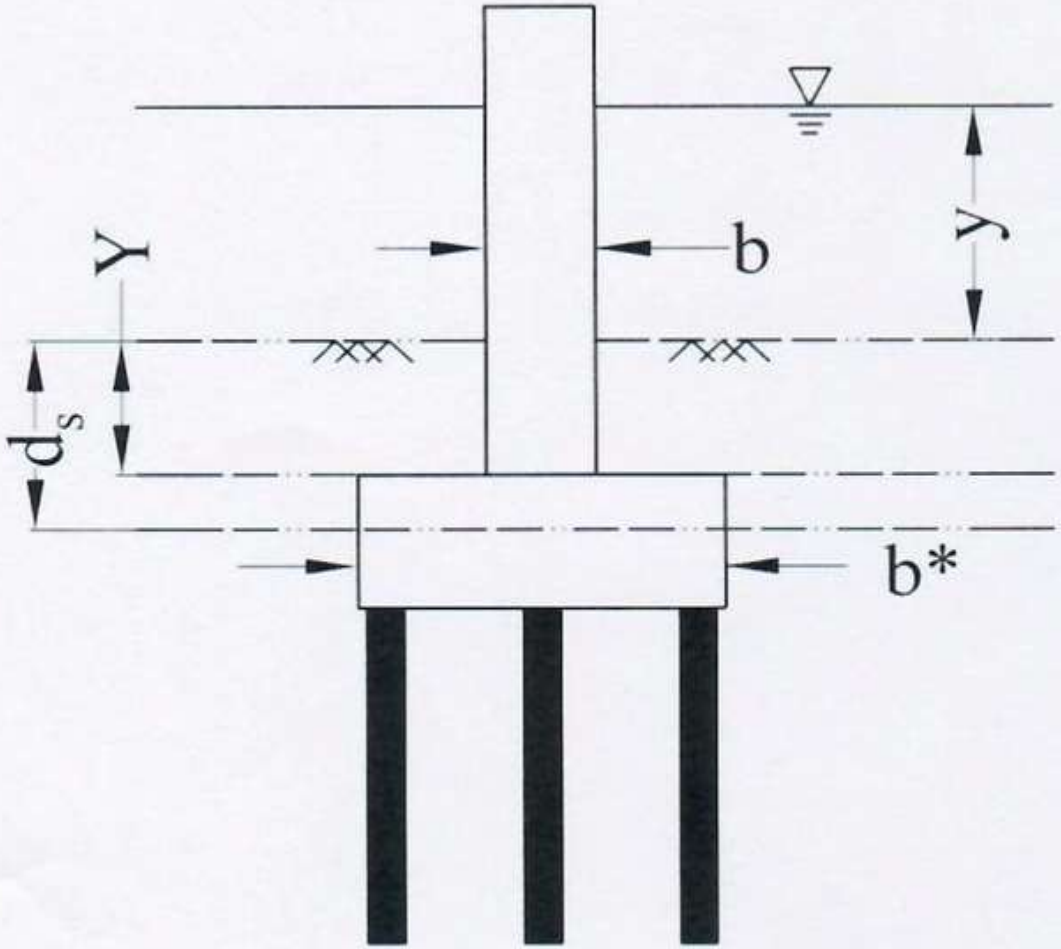


b_e= effective diameter b = pier diameter b^* = pile cap width y = flow depth and d = hydraulic depth

Normal pier



Case -1



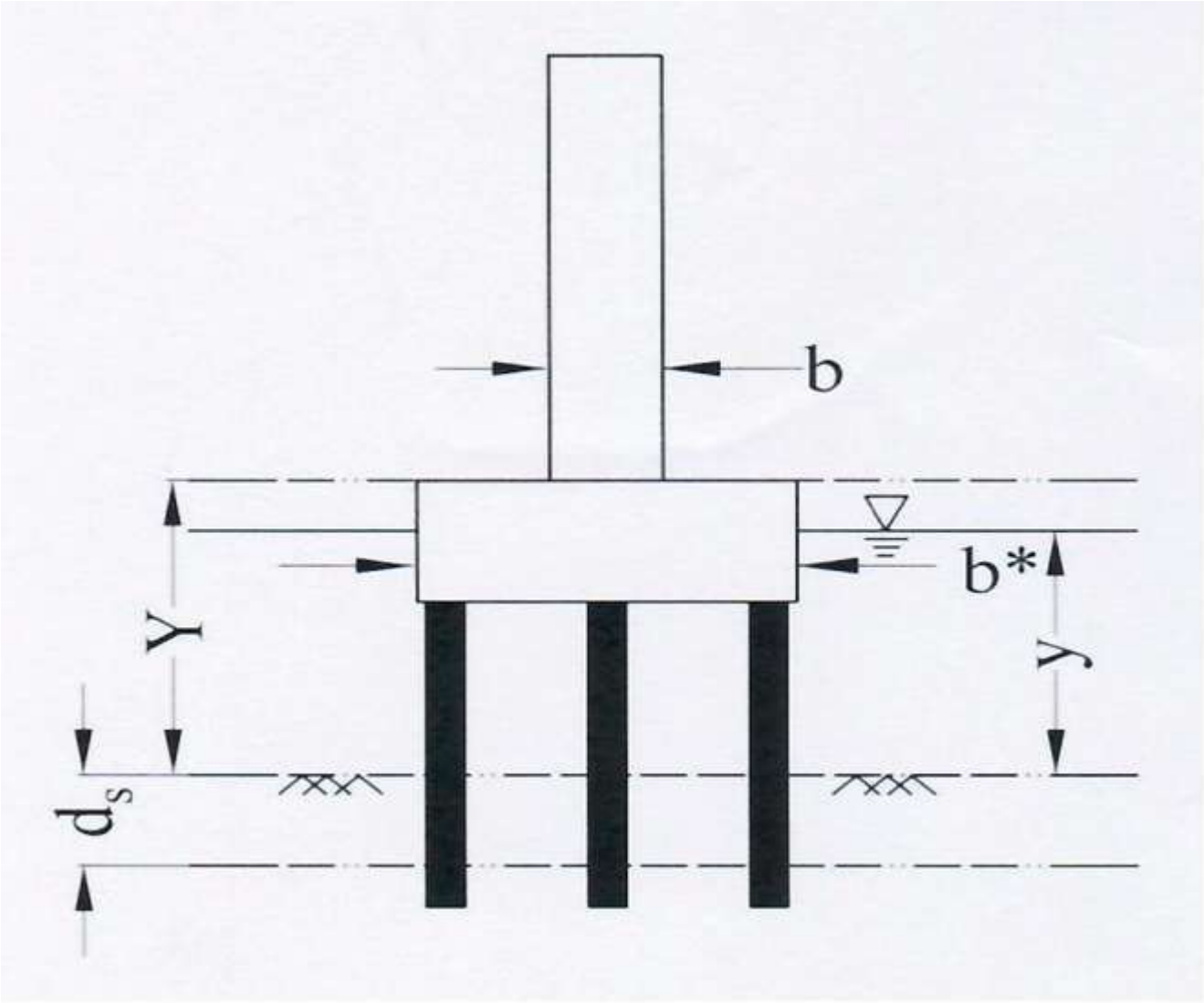
Case -2

Complex pier

Conditions:

Y >= y

Y < y



Cases -3 and 4

Estimation of Scour

Reference	Equation number	Notes
Laursen [1963]	At the threshold condition: $d_s / b_p = 1.34(h / b_p)^{0.5}$ (9.4)	applicable for clear-water scouring
Neill [1987]	At the threshold condition: $d_s / b_p = K_s$ (9.5)	K_s =1.5 for round nose and circular pier and =2.0 for rectangular piers
Jain and Fischer [1980]	At the threshold condition: $d_s / b_p = 1.86(h / b_p)^{0.5}$ (9.6)	applicable for clear-water scouring condition
Chitale [1988]	At the threshold condition: $d_s / b_p = 2.5$ (9.7)	applicable for clear-water scouring condition
Melville [1997]	At the threshold condition: $b_p/h<0.7$: $d_s / b_p = 2.4$ $0.7<b_p/h<5$: $d_s / b_p = 2(h / b_p)^{0.5}$ $b_p/h>5$: $d_s / b_p = 4.5(h / b_p)$ (9.8)	the shape correction factors for square nosed and sharp nosed are 1.1 and 0.9, respectively
Richardson and Davis [1995] (HEC-18)	At the threshold condition: $d_s / b_p = 2 * K_s K_\theta K_3 K_4 (h / b_p)^{0.35} * Fr\text{^}^{0.43}$ (9.9)	the shape correction factors for square nosed and sharp nosed are 1.1 and 0.9, respectively. Applicable for tidal and clear water

For complex piers, effective pier diameter, b_e is to be used instead of b_p.

b_p = pier diameter and d_s = scour depth below the initial bed level; h = hydraulic depth

River Scour

Estimation of Scour

The equation given by **HEC-18** (Richardson and Davis, 1995) is widely used in USA and other parts of world for scour depth estimation. The relationship of scour depth with flow depth and pier width is developed with correction factors involving pier nose shape, angle of attack of flow, bed condition, and particle size of soil. The HEC-18 equation is also used by the United States Federal Highway Administration (FHWA).



Live-bed and Clear-water Scour Determination by CSU (Richardson 1990 eq.): HEC 18

$$\frac{Y_s}{Y_1} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{a}{Y_1}\right)^{0.65} Fr_1^{0.43}$$

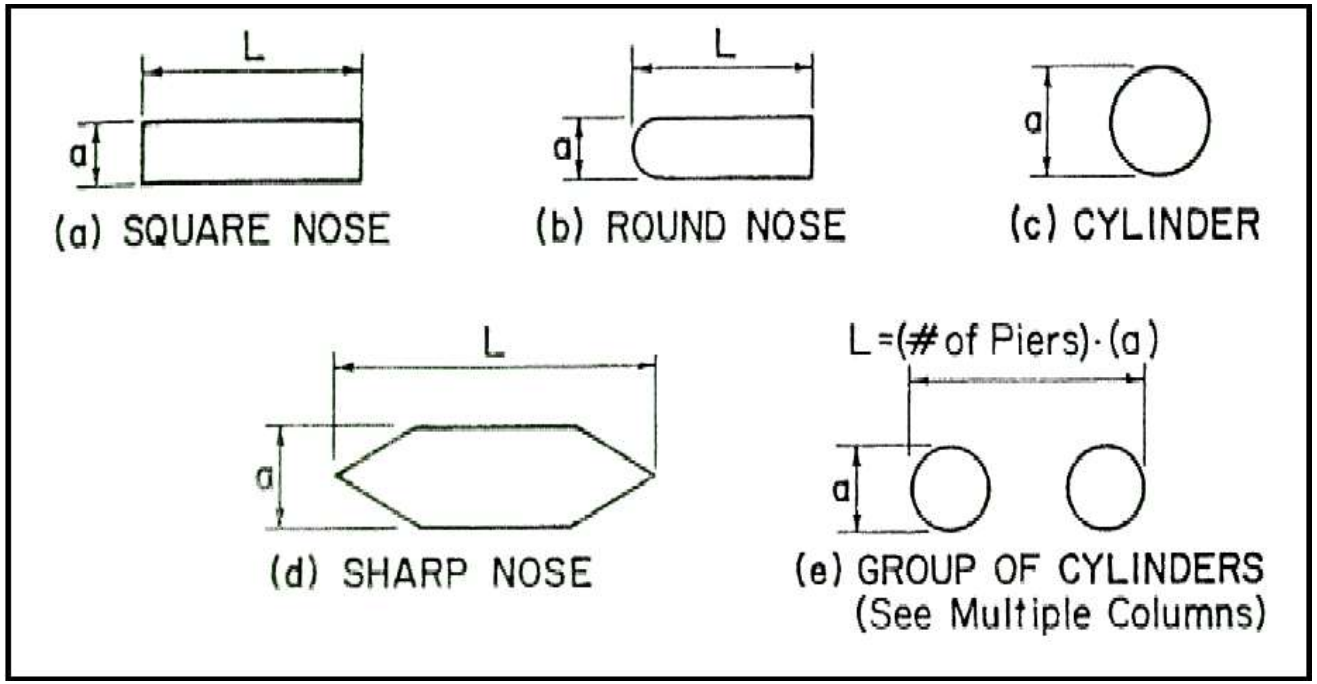
where:

Ys = Scour depth
Y_1 = Flow depth directly upstream of the pier
K_1 = Correction factor for pier nose shape
K_2 = Correction factor for angle of attack of flow
K_3 = Correction factor for bed condition
K_4 = Correction factor for armoring by bed material size
a = Pier width
Fr_1 = Froude number directly upstream of pier

Common Pier Shapes

To be used for determining the K_1 (Pier Nose Shape correction factor) in equation:

$$\frac{Y_s}{Y_1} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{a}{Y_1} \right)^{0.65} Fr_1^{0.43}$$



K_1 is the Pier Nose Shape correction factor in equation:

$$\frac{Y_s}{Y_1} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{a}{Y_1}\right)^{0.65} Fr_1^{0.43}$$

Table 6.1. Correction Factor, K_1, for Pier Nose Shape.	
Shape of Pier Nose	K_1
(a) Square nose	1.1
(b) Round nose	1.0
(c) Circular cylinder	1.0
(d) Group of cylinders	1.0
(e) Sharp nose	0.9

For angle of attack < 5 deg. For greater angles, K_1=1.0 and K_2 dominates

K_2 is the Angle of Attack correction factor in equation:

$$\frac{Y_s}{Y_1} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{a}{Y_1}\right)^{0.65} Fr_1^{0.43}$$

$$K_2 = (\cos\theta + (L/a)\sin\theta)^{0.65}$$

Table 6.2. Correction Factor, K_2, for Angle of Attack, θ, of the Flow.			
Angle	L/a=4	L/a=8	L/a=12
0	1.0	1.0	1.0
15	1.5	2.0	2.5
30	2.0	2.75	3.5
45	2.3	3.3	4.3
90	2.5	3.9	5.0
Angle = skew angle of flow L = length of pier, m			

Notes: *K_2 should only be applied when the entire length is subjected to the attack of flow,* *K_2 max = 5.0*

K_3 is the Bed Condition correction factor in equation:

$$\frac{Y_s}{Y_1} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{a}{Y_1}\right)^{0.65} Fr_1^{0.43}$$

Table 6.3. Increase in Equilibrium Pier Scour Depths, K_3, for Bed Condition.		
Bed Condition	Dune Height m	K_3
Clear-Water Scour	N/A	1.1
Plane bed and Antidune flow	N/A	1.1
Small Dunes	3> H ≥ 0.6	1.1
Medium Dunes	9> H ≥ 3	1.2 to 1.1
Large Dunes	H ≥ 9	1.3

For round nose piers aligned with the flow, the maximum scour depth is limited as follows:

ys ≤ 2.4 times the pier width (a) for Fr1 ≤ 0.8

ys ≤ 3.0 times the pier width (a) for Fr1 > 0.8

K_4 is the Correction Factor for armoring by bed-material size in equation:

K_4 min = 0.4

If D_{50} < 2mm or D_{95} < 20mm, then K_4 = 1.0

If D_{50} >= 2mm and D_{95} >= 20mm then

$$\frac{Y_s}{Y_1} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{a}{Y_1} \right)^{0.65} Fr_1^{0.43}$$

$$K_4 = (V_R)^{0.15}$$

where $$VR = \left[\frac{V_1 - V_{icD_{50}}}{V_{cD_{50}} - V_{icD_{95}}} \right] > 0$$

$$V_{icDx} = 0.645 \left(\frac{D_x}{a} \right)^{0.053} V_{cDx}$$

$$V_{cDx} = K_u Y_1^{\frac{1}{6}} D_x^{\frac{1}{3}}$$

V_{icDx} = Approach velocity required to initiate scour at the pier for grain size D_x
V_{cDx} = critical velocity for incipient motion for grain size D_x
y_1 = Depth of flow just upstream of the pier, excluding local scour, m (ft)
V_1 = Velocity of the approach flow just upstream of the pier, m/s (ft/s)
D_x = Grain size for which x percent of the bed material is finer, m (ft)
a = Pier width (ft)
K_u = 6.19 SI Units
K_u = 11.17 English Units

Example: Normal Pier Scour

Pier Width (d): 1.5 m
Approach Flow Depth (Y): 3.0 m
Approach Velocity (V): 2.0 m/s
Pier Nose Shape (K1) : 1 (Assuming a standard round-nosed pier).
Angle of Attack (K2): 1 (Assuming the pier is perfectly aligned with the flow)
Bed Condition (K3): 1.1 (Plane bed / small dunes condition)
Bed Armoring (K4): 1 (Assuming a standard sandy bed with no coarse armoring material)

$$\frac{Y_s}{Y} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{d}{Y}\right)^{0.65} Fr_1^{0.43}$$

Putting values of Ks – all 1 except K3 = 1.1

$Y_S = 3 \times 2 \times 1.1 \times (1.5/3)^{0.65} \times (2/[9.81 \times 3]^{0.5})^{0.43}$

$Y_S = 3 \times 2 \times 1.1 \times 0.64 \times 0.65 =$ **2.75 m**

Example: Complex Pier Scour

Pier Width (d): 1.5 m
Approach Flow Depth (Y): 3.0 m
Approach Velocity (V): 2.0 m/s
Pier Nose Shape (K1) : 1 (Assuming a standard round-nosed pier).
Angle of Attack (K2): 1 (Assuming the pier is perfectly aligned with the flow)
Bed Condition (K3): 1.1 (Plane bed / small dunes condition)
Bed Armoring (K4): 1 (Assuming a standard sandy bed with no coarse armoring material)
Pile cap: 7 m x 11 m placed at bed level

$$\frac{Y_s}{Y} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{d}{Y}\right)^{0.65} Fr_1^{0.43}$$

Putting values of Ks – all 1 except K3 = 1.1

$Y_S = 3 \times 2 \times 1.1 \times (5.35/3)^{0.65} \times (2/[9.81 \times 3]^{0.5})^{0.43}$

$Y_S = 3 \times 2 \times 1.1 \times 1.46 \times 0.65 =$ **6.26 m**

Equivalent pier diameter

$$b_e = b\left(\frac{d+Y}{d+b^*}\right) + b^*\left(\frac{b^*-Y}{b^*+d}\right)$$

$d_e = 1.5\,[(3+0)/(3+7)] + 7\,[(7-0)/(3+7)]$
$d_e = 1.5 \times 0.3 + 7 \times 0.7 = 5.35$ m

For the complex pier the scour depth is 2.28 times higher than the normal pier.

River Scour

Estimation of Scour Depth:

Lacey–Inglis method (Normal Pier)

From the analysis of field data of Indo-Gangetic plain, Lacey (1929) gave the following relation for scour depth:

$$D_{LQ} = 0.47(Q/f)^{1/3}$$

Here D_{LQ} is the normal scour depth in m below the design flood level, *Q* the design flood discharge in m^3/sec and *f* the Lacey's silt factor related to the median size of bed material d_{50} (in mm) by the equation:

$$f = 1.76 \sqrt{d_{50}}$$

Inglis (1944) collected data from bridges on alluvial rivers in India and found that maximum scour depth below the highest flood level (HFL), D_{se}, when expressed in terms of computed depth of flow in the river D_{LQ} gave:

$$D_{se} = K\, D_{LQ}$$

where K varied from 1.76 to 2.59 with a mean value of 2.09. Hence, the maximum scour depth according to Inglis is:

$$D_{se} = 2.0\, D_{LQ}$$

River Scour

Example

Calculate the scour depth for the 110 m bridge over the Kumar River with a discharge of 380 m^3/sec from the following data:

Hydraulic depth: 4.11 m

Sediment size : 0.17 mm

Pile cap width: 4.2 m

Assume that the 1 m diameter pier with pile cap would be at the bed level.

Solution

Considering a complex pier:

$$b_e = b\left(\frac{d+Y}{d+b^*}\right)+b^*\left(\frac{b^*-Y}{b^*+d}\right)$$

Equivalent pier diameter, b_e is – (considering pile cap at bed level; Y = 0)

Hence, b_e = 1[4.11/(4.11+4.2)] + 4.2[4.2/(4.2+4.11)] = 2.617 m

The scour depths computed by different methods are shown in table.

References	Local Scour Depth (m)
Breusers [1965]	3.66
Laursen [1963]	4.39
Neill [1987]	3.93
Jain and Fischer [1980]	6.10
Chitale [1988]	6.54
Melville [1997]	5.65
HEC-18 [2012]	6.28



Considering normal pier:

$f = 1.76 \sqrt{d_{50}} = 1.76\ (0.17)^{0.5} = 0.7257$

$D_{LQ} = 0.47(Q/f)^{1/3} = 0.47\ (380/0.7257)^{1/3} = 3.79$ m

Estimated scour depth is: $D_{se} = 2.0\ D_{LQ} = 2 \times 3.79 = 7.58$ m (from Design flood level)

Approaches Towards Bridge Pier Scour Protection

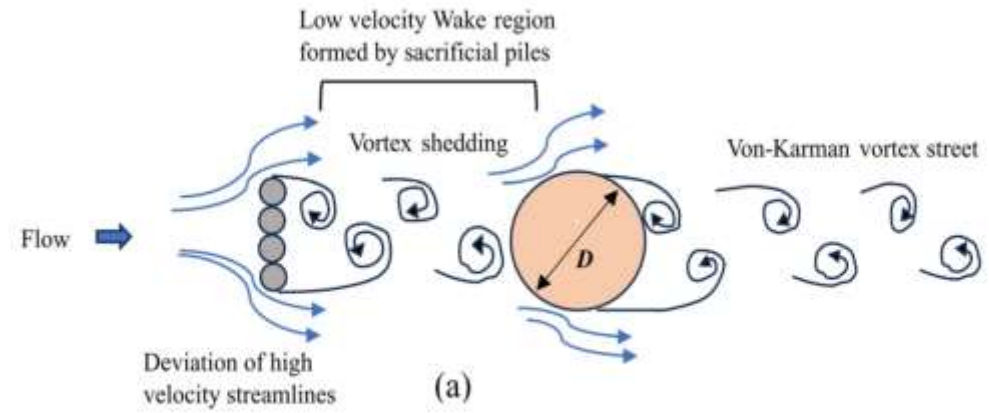
Numerous scour countermeasures have been introduced and they are classified in two groups:

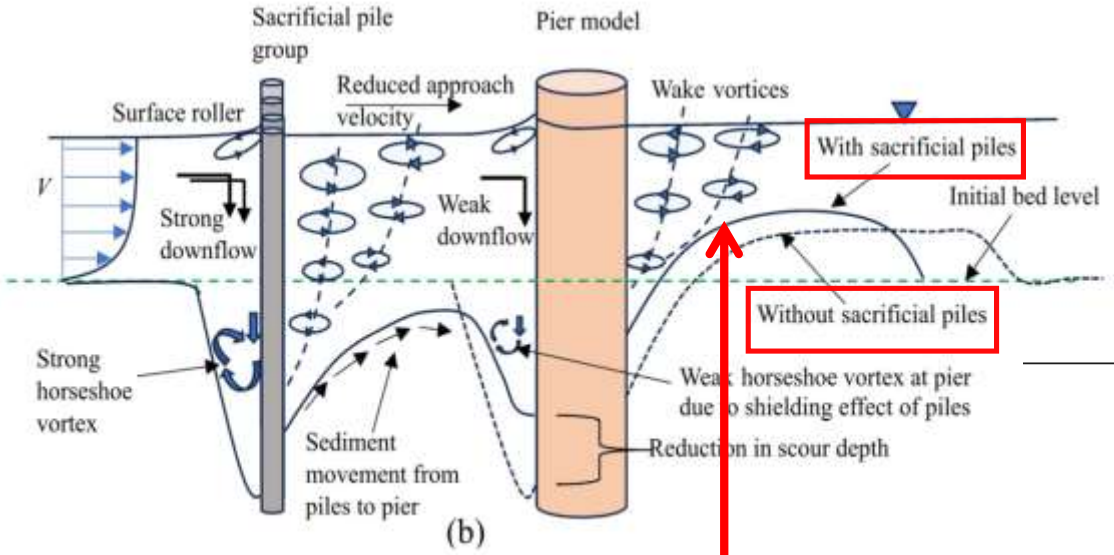
(a) Armoring countermeasures and
(b) Flow altering countermeasures

The armoring countermeasures withstand the increased erosive forces of flow that occur around a bridge pier due to a hydraulic condition by acting as a resistant layer to hydraulic shear stresses providing protection to the more erodible materials underneath. They include ripraps, wire gabions, concrete blocks, geo-bags etc.

The flow altering countermeasures deflect the approaching flow or to divert downward flow for reduced erosive power of flow. They include collars and sacrificial piles.

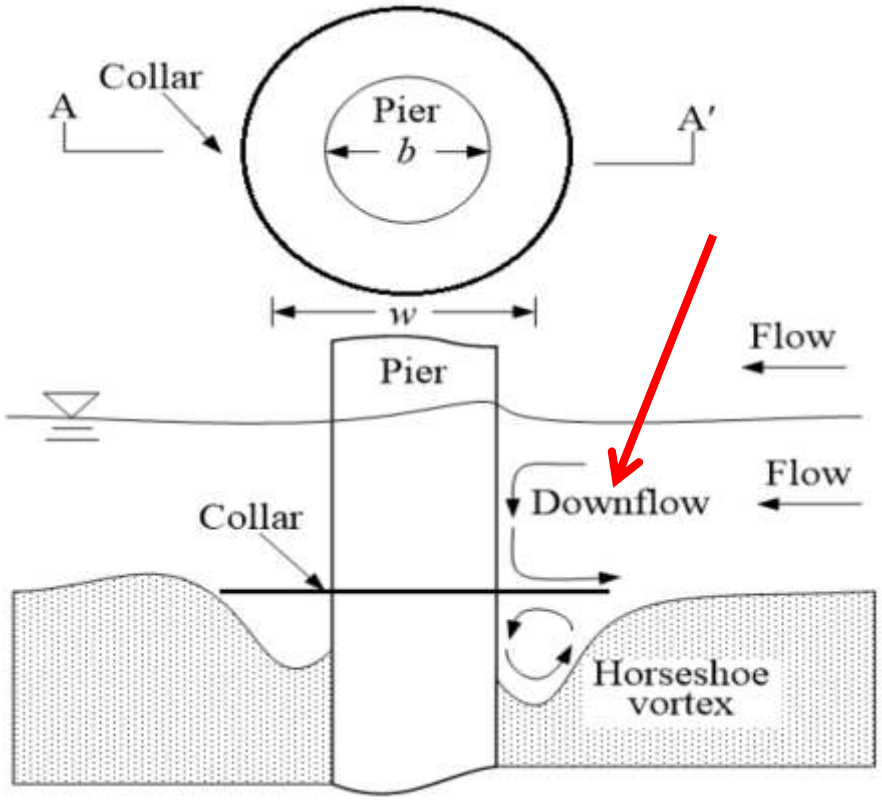
Collars shield bed material from the downward flow and horseshoe vortices. Collars are devices attached to the pier at some level usually close to the bed. It is a thin protective disc made of steel or concrete and extends around the outside edge of the pier with the main objective of protecting the bed from the scouring effect of the down-flow at the pier and the associated horseshoe at the base of the pier. The concept behind using collar is that it will sufficiently deflect the down flow vortex which results in reduction of scour.
Sacrificial piles protect the pier from scouring by suppressing the approaching flow, causing a wake region downstream resulting in weakened forces of the flow, and deflecting the high velocity flow, respectively. These piles of small diameter are placed upstream of a bridge pier are found to reduce the local scouring around the pier. The effectiveness of these sacrificial piles in reducing the local scour depends on the number of piles, the size of the piles relative to the pier, the protrusion of the piles, and the geometric arrangement of the piles.



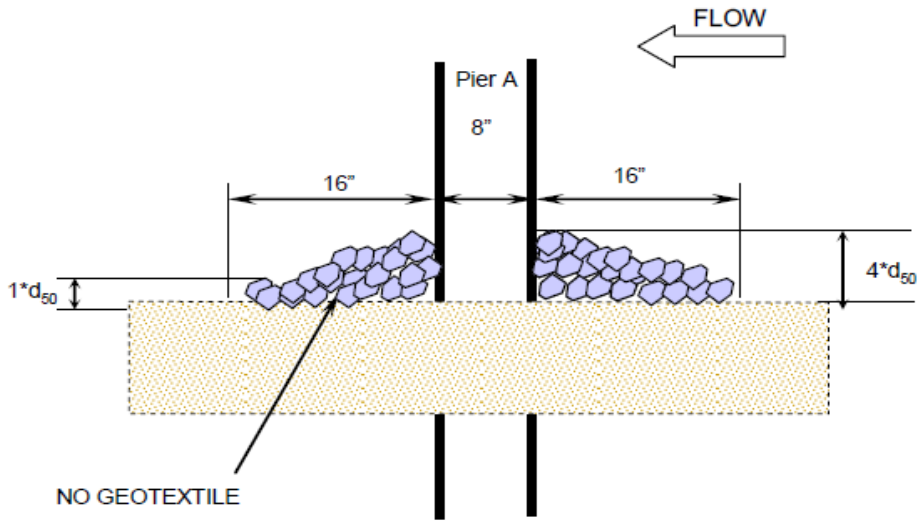


Sacrificial Pile

Collar



Riprap/Gabion



d_{50} riprap = 1.2"

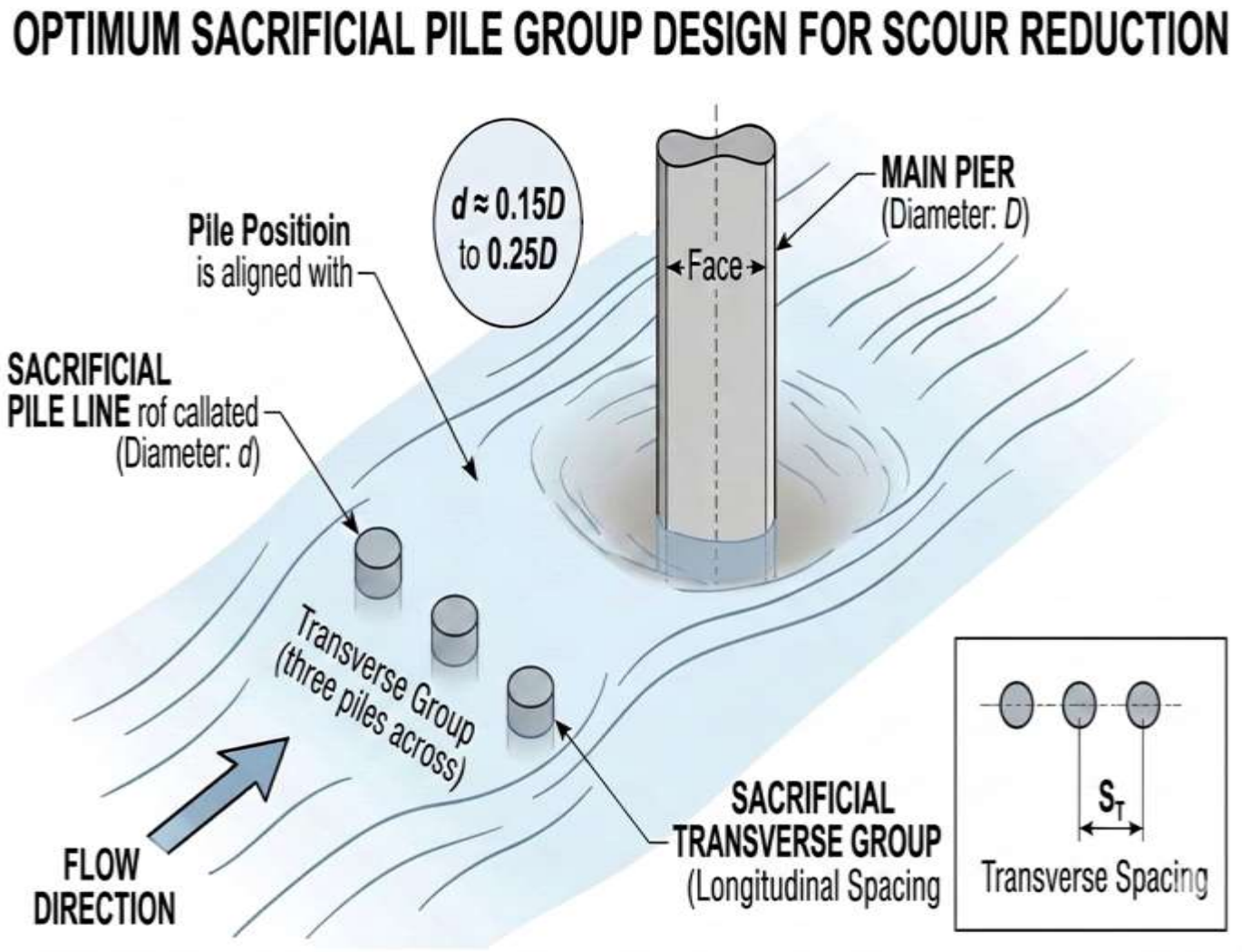
Features of Sacrificial Pile

Size (diameter): d – 0.2 to 0.5 D
Height (Length) - 0.6 Y
Number - 3 to 6
Distance between Pier and Pile - 1 to 3 D
Spacing between piles – 2d to 3d
Effectiveness – 20% - 60% reduction
(depends upon number of piles used)

D = Pier diameter
d = Pile diameter
Y = Depth of flow

Why not used in Bangladesh?

1. Extremely high scour depth (60+ m)
2. Risk on navigation



Pier scour counter measures in Bangladesh are generally deep piling (safety factor) and geo-bags, riprap and concrete blocks.

Case Study on Bridge Scour

Field-Based Evaluation of Local Scour in Complex Piers of a Bridge on the Dhaleswari River
M.R. Islam, M. Sc Thesis, IWFM, BUET, 2018
http://lib.buet.ac.bd:8080/xmlui/bitstream/handle/123456789/5439/Full%20Thesis.pdf?sequence=1&isAllowed=y

Dhaleshwari Bridge

The Dhaleshwari bridge is constructed over the Kaliganga River connecting the western part of the Sadar Upazila and growth centers in Ghior with the Upazila headquarter and is located at 23°50'48.00"N latitude and 89°59'56.07"E longitude.
The length of the Dhaleshwari bridge is 297 m.
The bridge has 8 complex pier, 9 spans with a length of 33 m each.
Pier width is 1.5 m.
The length and breadth of the pile cap are 11 m and 7 m, respectively.
There is a pile group below the pile cap - eight piles of 1.0 m diameter are being constructed in two rows (four number of piles in each row).

Left Abutment
Pier 1
Pier 2
Pier 3
Pier 4
Pier 5
Pier 6
Pier 7
Pier 8

Bridge pier
Bridge Pier
Pile cap

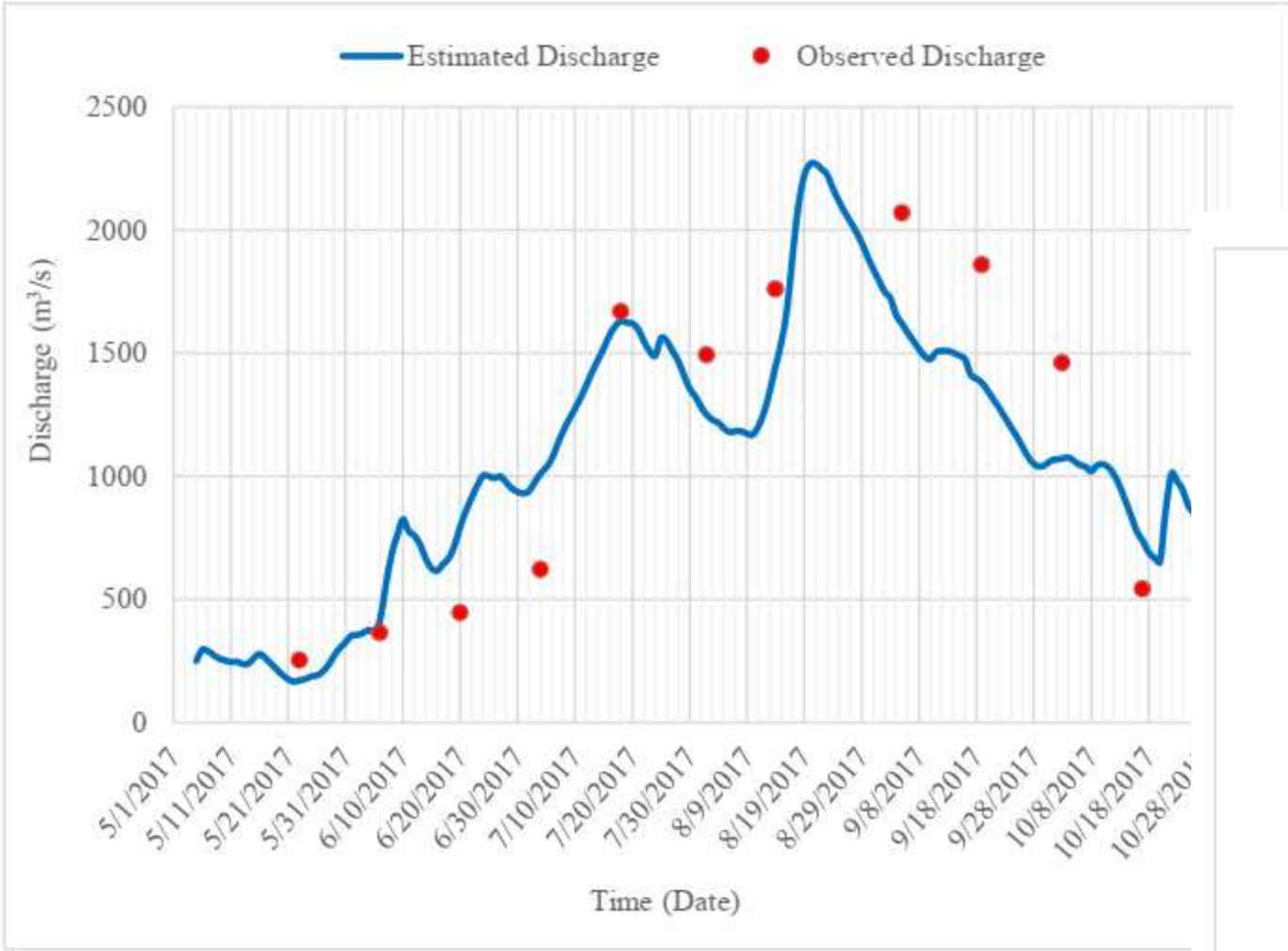


Figure 3.6: Estimated discharge hydrograph of the Kaliganga River at Taraghat year of 2017 (solid line) along with observed discharges (red dots)

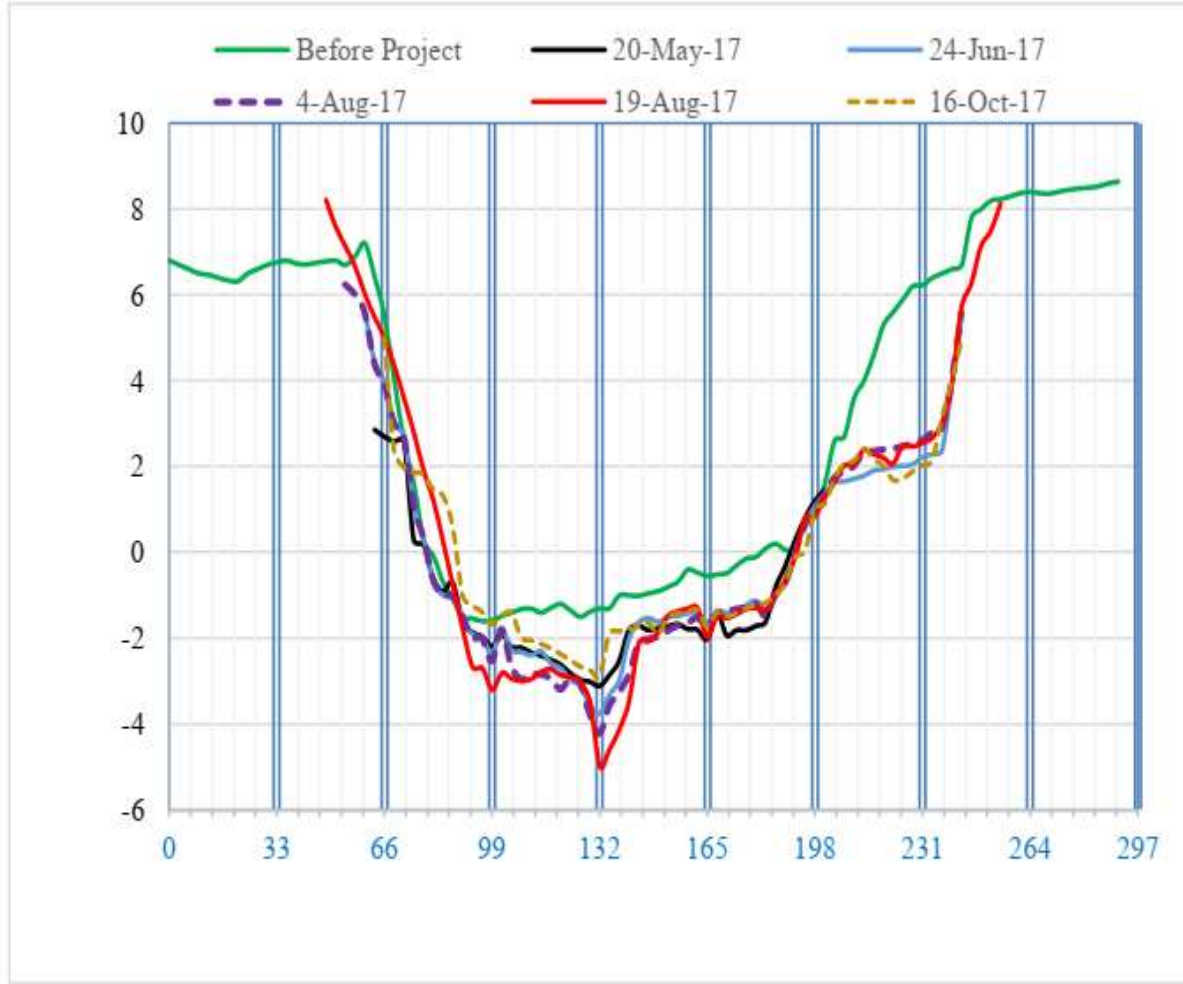


Figure 4.1: Scour holes around bridge piers (piers are located at distances of 33, 66, 99, 132, 165, 198, 231 and 264 m from the left abutment)

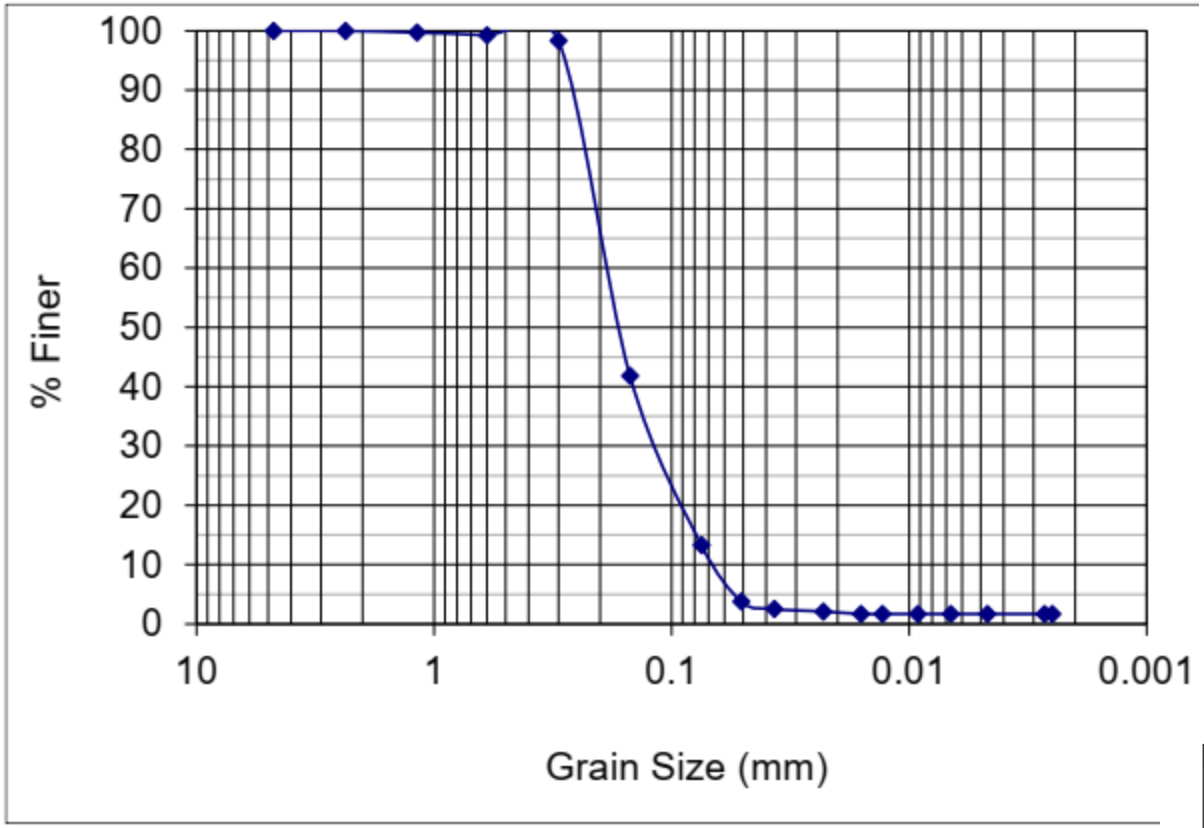


Figure C1: Grain size distribution curve of the bed sediment of the Dhalesw near the Dhaleswari bridge site.

Table 4.3: Estimated local scour depth in the Dhaleshwari River near the bridge according to IWFM (2013) (considering pier width, b = 1.5 m)

Equation Name	Scour level (m PWD)
Breusers (1965)	-4.06
Laursen (1963)	-6.92
Neill (1987)	-4.21
Jain and Fischer (1980)	-8.84
Chitale (1988)	-5.71
Melville (1997)	-5.56

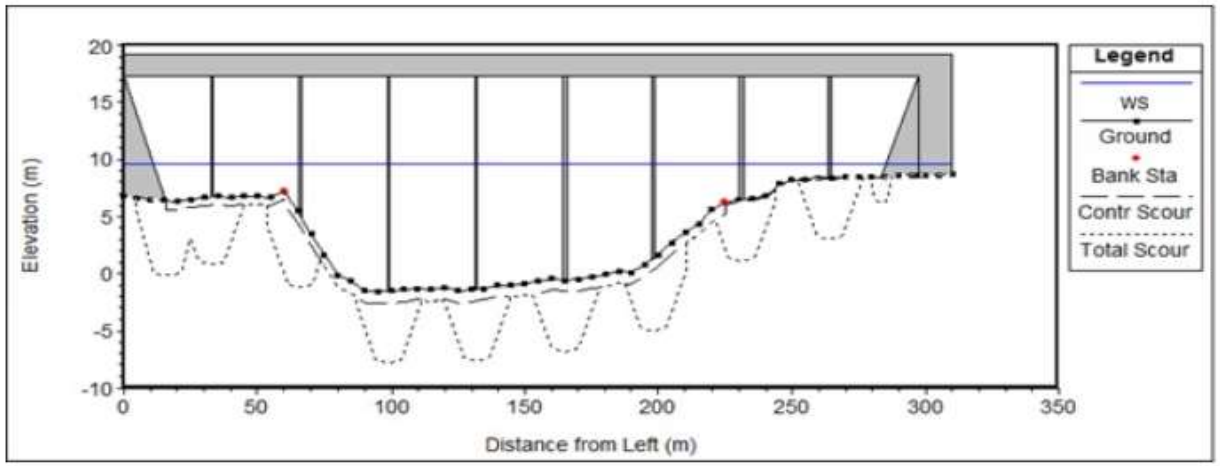
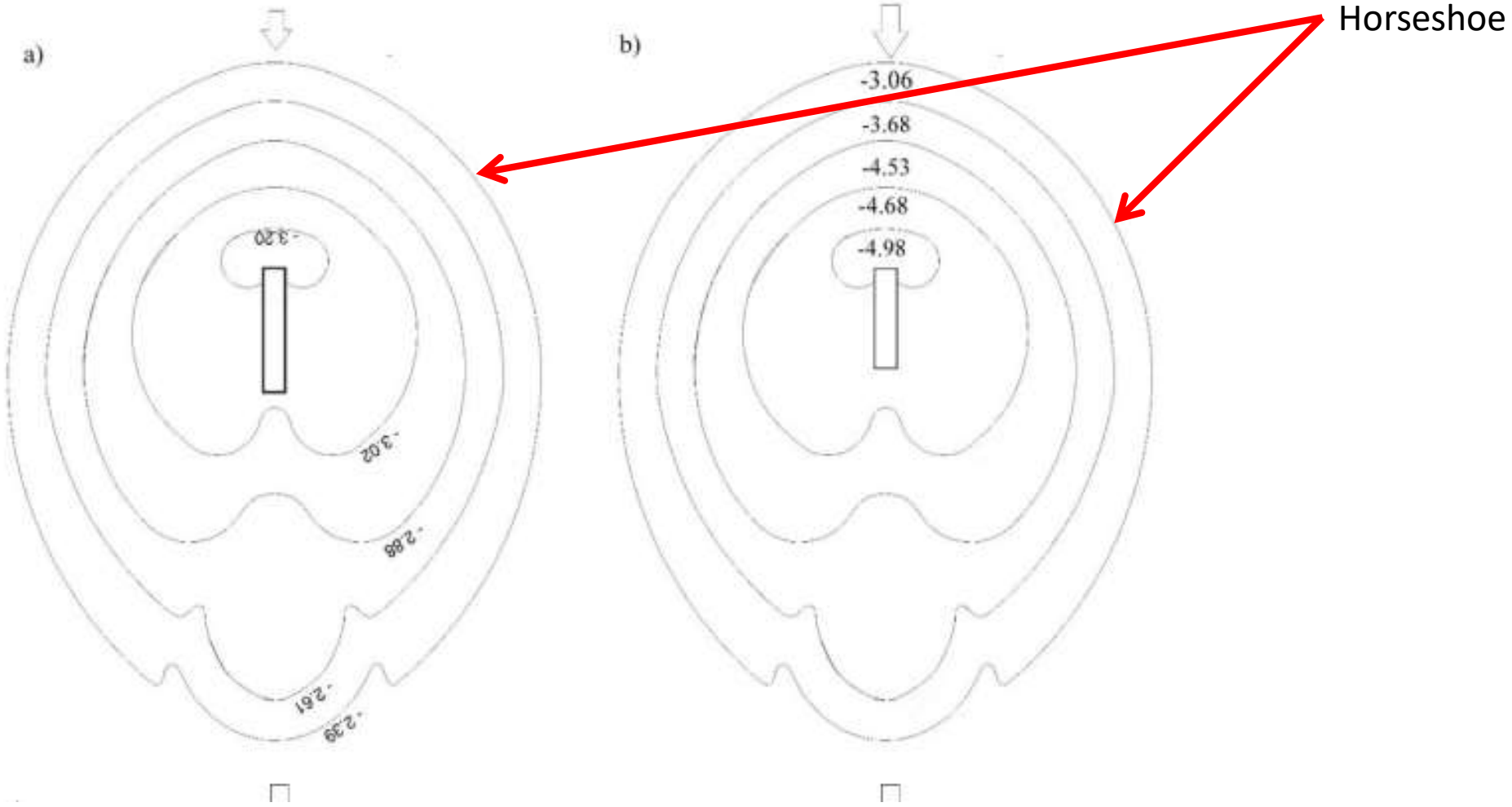
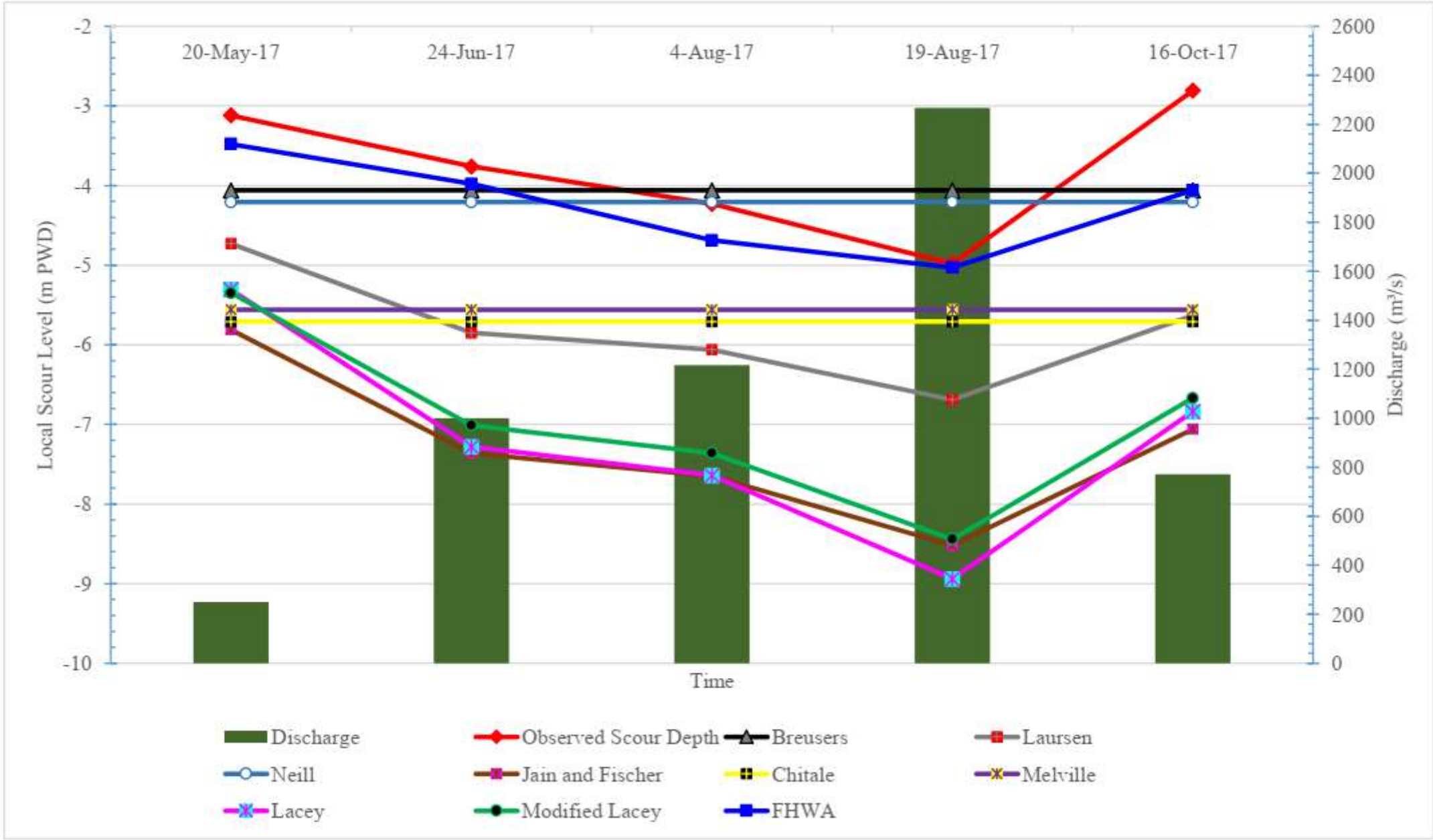


Figure 4.4: Variation of pier scour at the Manikganj Sadar Bridge under design discharge condition with the HEC-RAS model [the maximum local scour is found to be 5.21 m, with 1.5 m pier width]



Figures (a) and (b) showing scour around piers 3 and 4 of Dhaleshwari bridge


20-May-17
24-Jun-17
4-Aug-17
19-Aug-17
16-Oct-17
-2
-3
-4
-5
-6
-7
-8
-9
-10
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Local Scour Level (m PWD)
Discharge (m³/s)
Time
Discharge
Observed Scour Depth
Breusers
Laursen
Neill
Jain and Fischer
Chitale
Melville
Lacey
Modified Lacey
FHWA

Variation of scour depths for rivers of Bangladesh

Based on calculations of scour from 239 bridges spread all over Bangladesh, the formulae of Melville and Coleman, Jain and Fischer, and Richardson (HEC 18) are found to be dominant when deciding the design local scour depth at the complex bridge piers (Mondal, 2022).

