River Scour

River Scour is the result of the erosive action of flowing water, excavating and carrying away material from the bed and banks of streams and from around the piers and abutments of bridges or hydraulic structure.

Total scour at any river section considers two primary components:

1. **General scour** of the river bed
2. **Localized scour** due to the cross structure

General scour is scour that occurs irrespective of the existence of the bridge (or any hydraulic structure), and includes long-term degradation or aggradation of the river.

Localized scour is scour that is directly attributable to the existence of the hydraulic structures/bridges, and includes scour owing to flow contraction and the local flow field developed at a pier and/or abutment and hydraulic structure.

Thus, localized scour is composed of:

Contraction scour

Local scour

These three scour components (general scour, contraction scour and local scour) are added to obtain the total scour at a pier or abutment.

This assumes that each component occurs independent of the other.

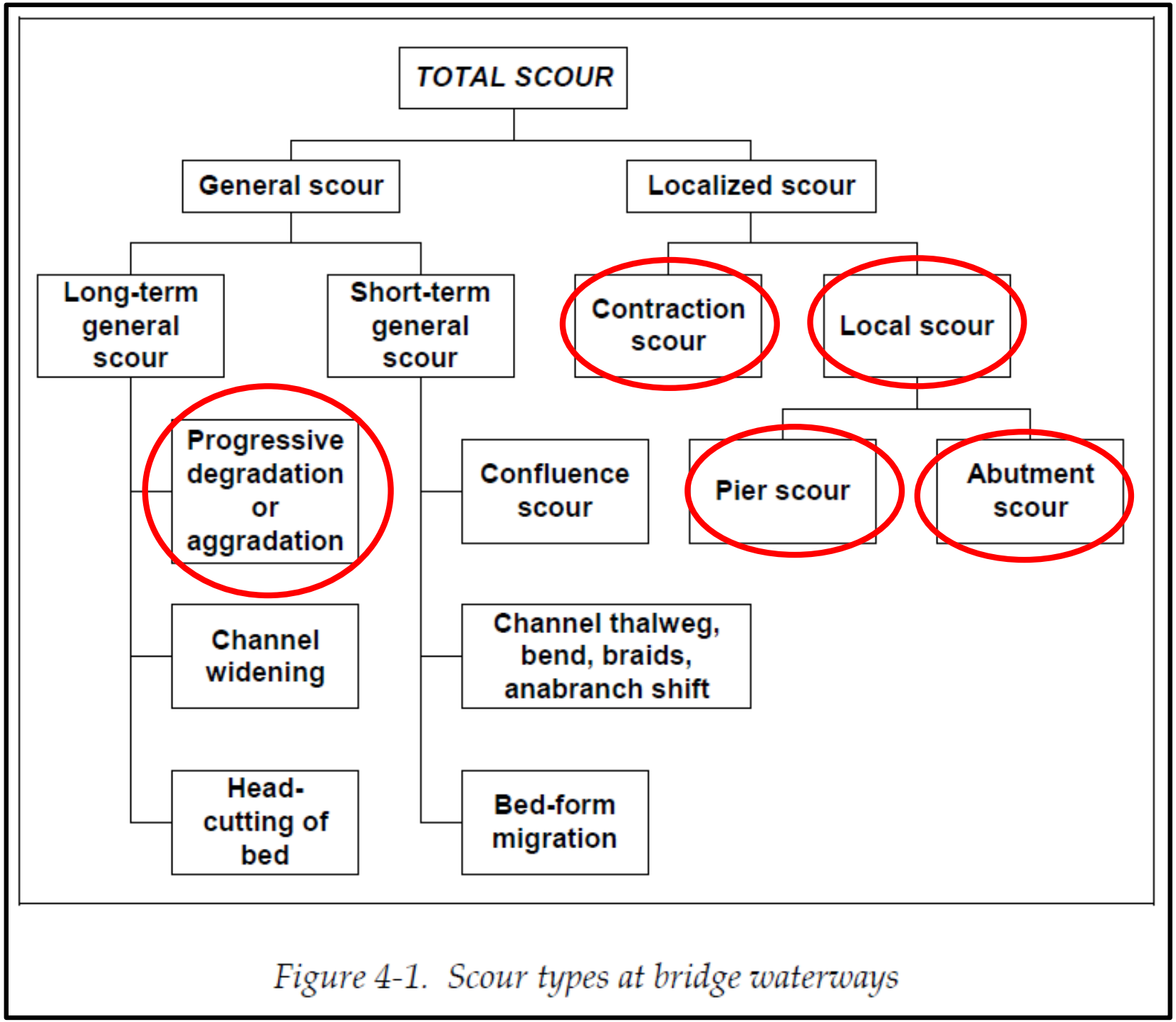


Figure 4-1. Scour types at bridge waterways

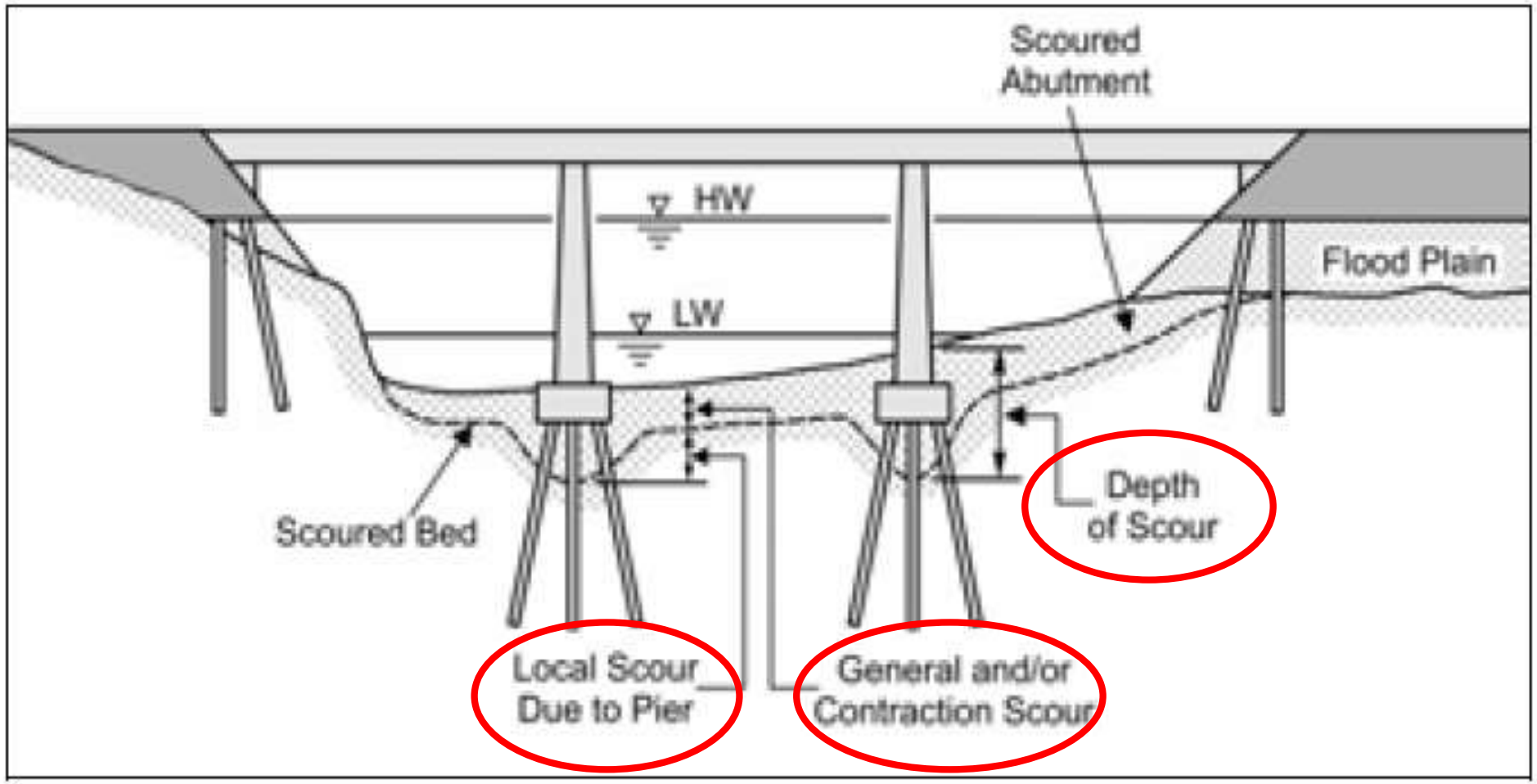


Figure 4-2. Scour types at a bridge opening

River Scour

General Scour: Aggradation and Degradation

Aggradation and degradation are long-term streambed elevation changes due to natural or man-induced causes which can affect the reach of the river on which the bridge is located.

Localized Scour: Contraction Scour

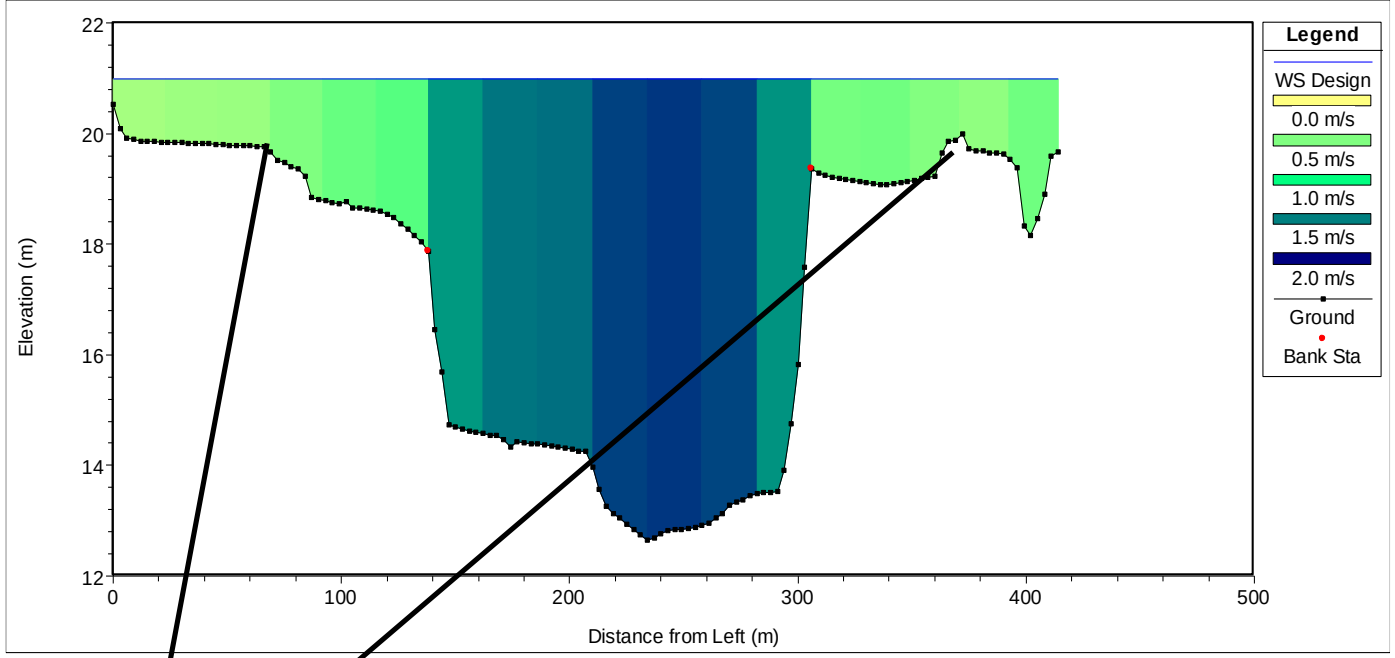
Contraction scour is a lowering of the streambed across the stream or waterway bed at the bridge. This scour occurs because the flow is constricted by the bridge and its approaches. This lowering may be uniform across the bed or non-uniform, that is, the depth of scour may be deeper in some parts of the cross section.

Contraction scour results from contraction (or constriction) of the flow, which results in removal of material from the bed across all or most of the channel width.

Contraction scour is different from long-term degradation in that contraction scour occurs in the vicinity of the constriction or bridge (and not along the longitudinal profile).

Local Scour

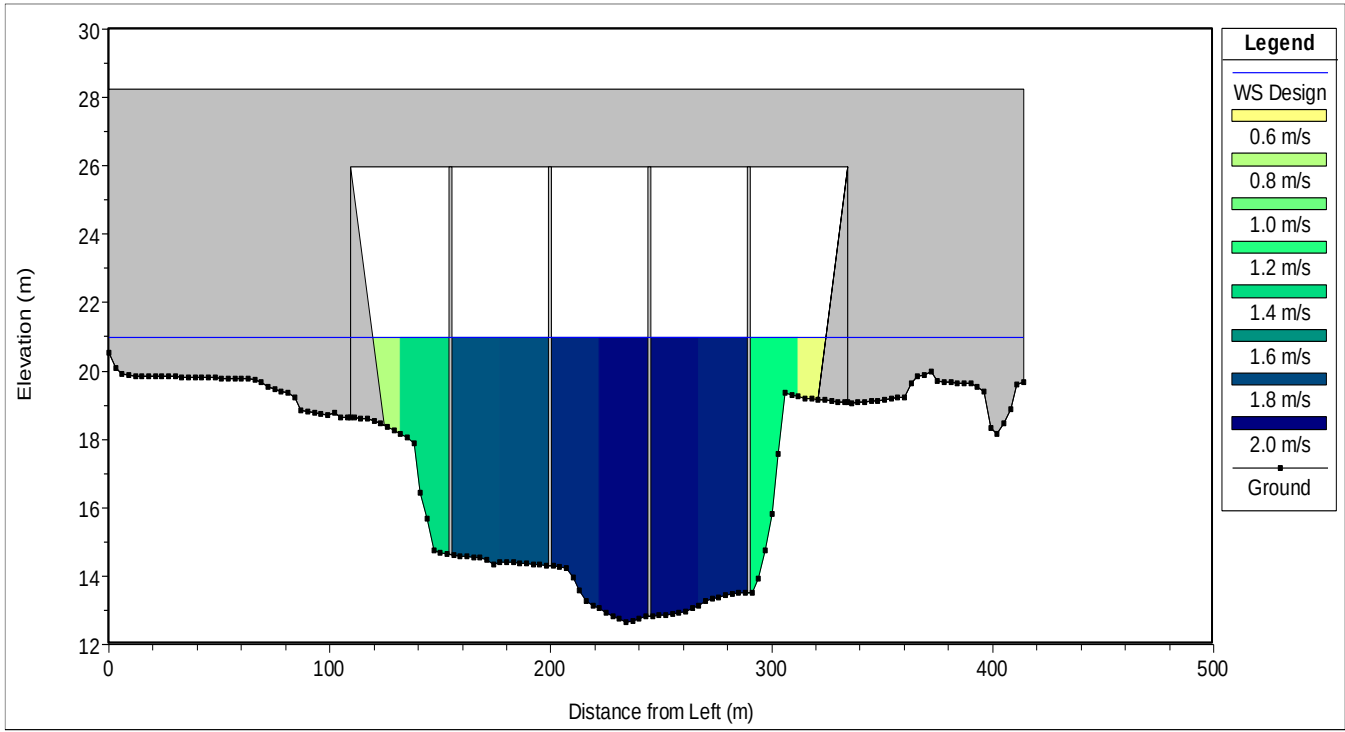
Local scour involves removal of material from around piers, abutments, spurs, and embankments. It is caused by an acceleration of flow and resulting vortices induced by obstructions to the flow.



Cross-section at bridge site without bridge

Floodplain

Cross-section at bridge site with bridge



Computed hydraulic parameters at the bridge location for 'without bridge' condition for a design discharge of 2285 m^3/s

Parameter	Main Channel	Left Overbank	Right Overbank
Flood Level (m PWD)	16.27	16.27	16.27
Flow Area (m^2)	1562	156	137
Hydraulic Depth (m)	8.18	1.87	1.70
Velocity (m/s)	1.38	0.43	0.40
Discharge (m^3/s)	2163	67	55

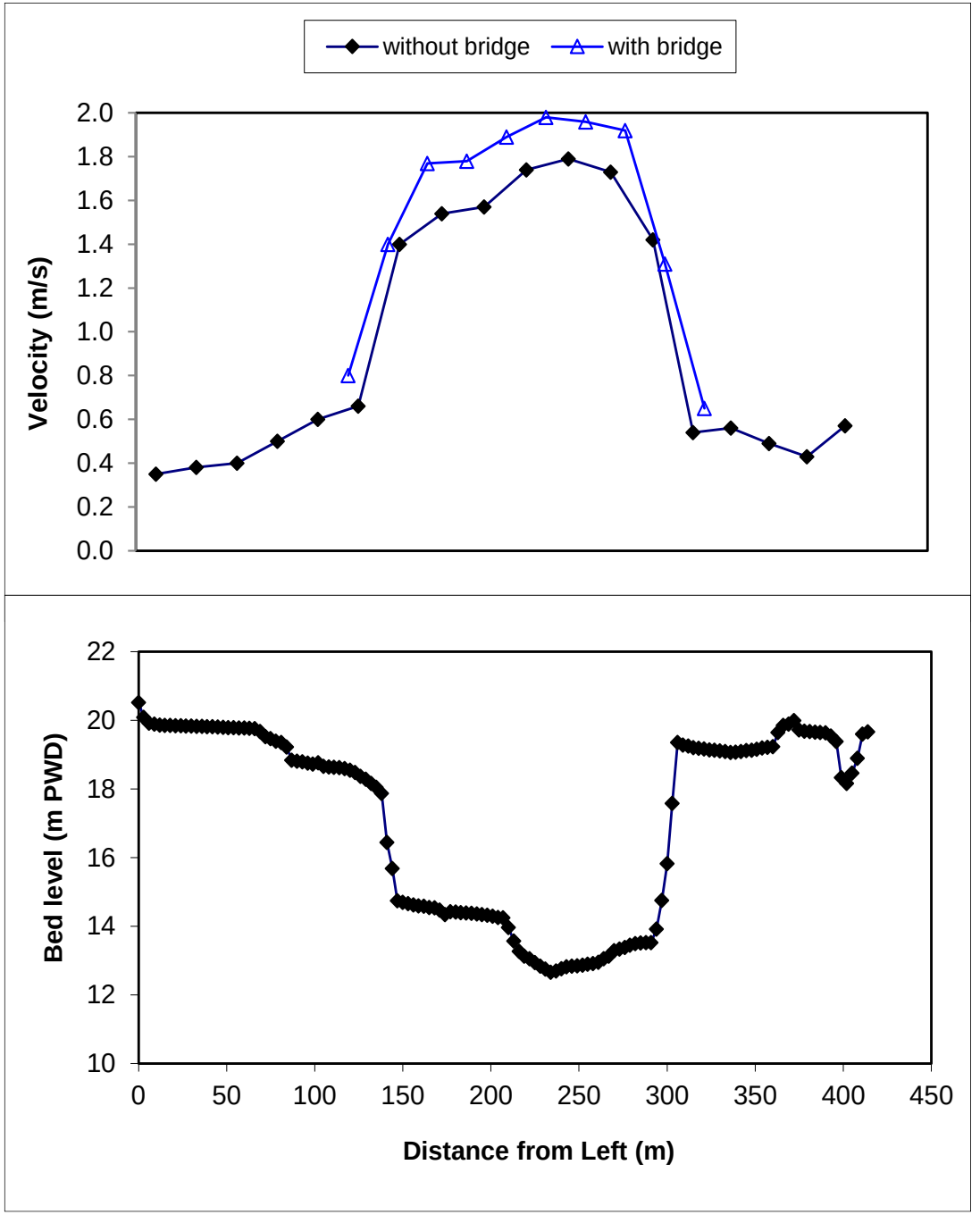
$Q_{floodplain}$

Change in A and V

Hydraulic parameters of the main channel of the bridge section for with and without bridge conditions for a design discharge of about 2285 m^3/s

Parameter	With Bridge	Without Bridge	Difference
Bridge Opening (m)	350	---	---
Flood Level (m)	16.28	16.27	0.01
Flow Area (m^2)	1496	1562	66
Hydraulic Depth (m)	8.18	8.18	0.00
Average Velocity (m/s)	1.43	1.38	0.05
Discharge (m^3/s)	2144	2163	19

Change in the velocity due to contraction at bridge site



River Scour

Scour at Bridge Piers and Abutments

The basic mechanism causing local scour at piers or abutments is the formation of vortices at their base. The horseshoe vortex at a bridge pier results from the pileup of water on the upstream surface of the obstruction and subsequent acceleration of the flow around the nose of the pier. The action of the horseshoe vortex removes bed material from around the base of the pier.

The transport rate of sediment away from the base region is greater than the transport rate into the region, and consequently, a scour hole develops.

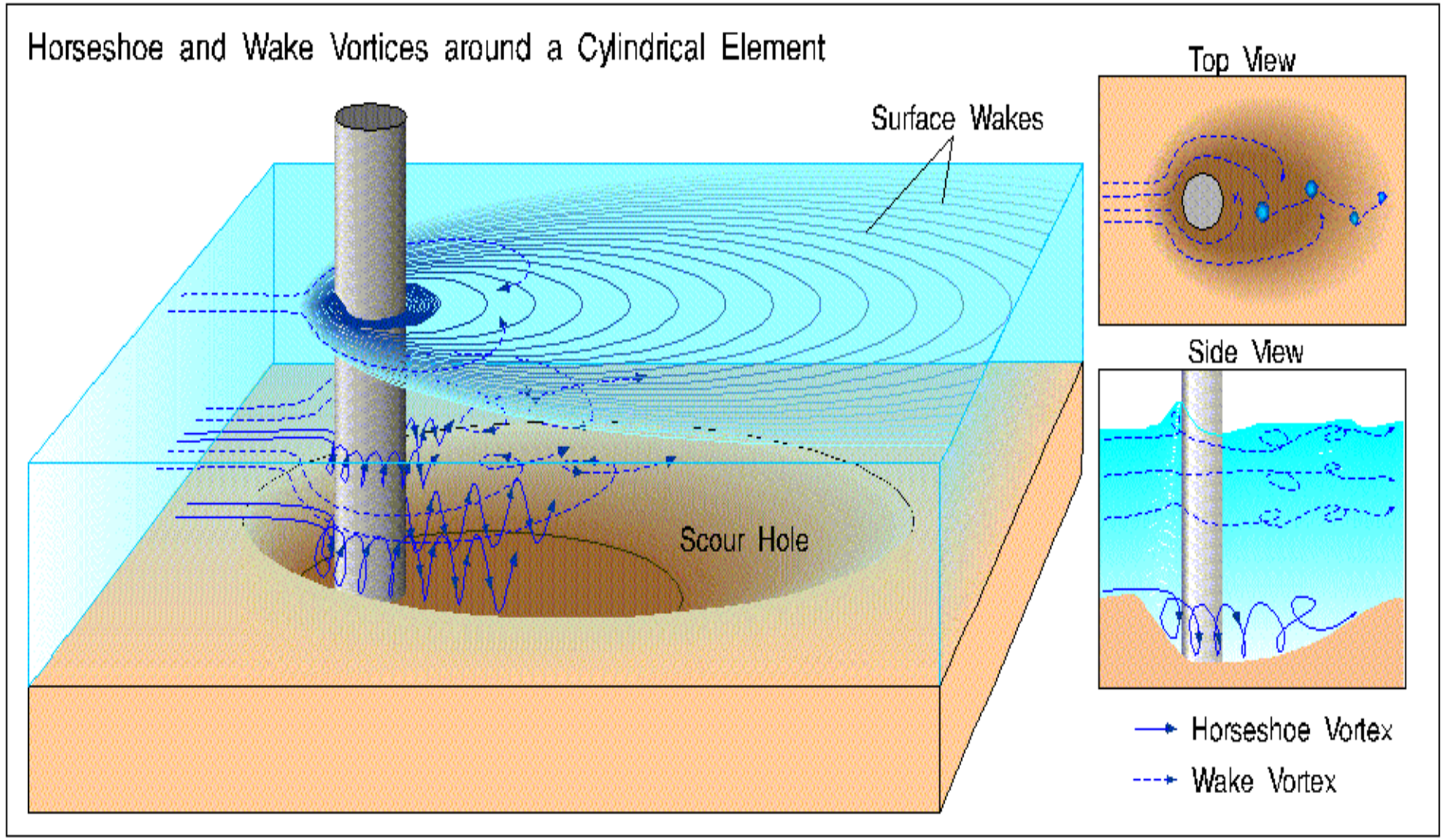
As the depth of scour increases, the strength of the horseshoe vortex is reduced, thereby reducing the transport rate from the base region. Eventually, equilibrium is reestablished between bed material inflow and outflow and scouring ceases.

In addition to the horseshoe vortex around the base of a pier, there are vertical vortices downstream of the pier called the wake vortex. Both the horseshoe and wake vortices remove material from the pier base region.

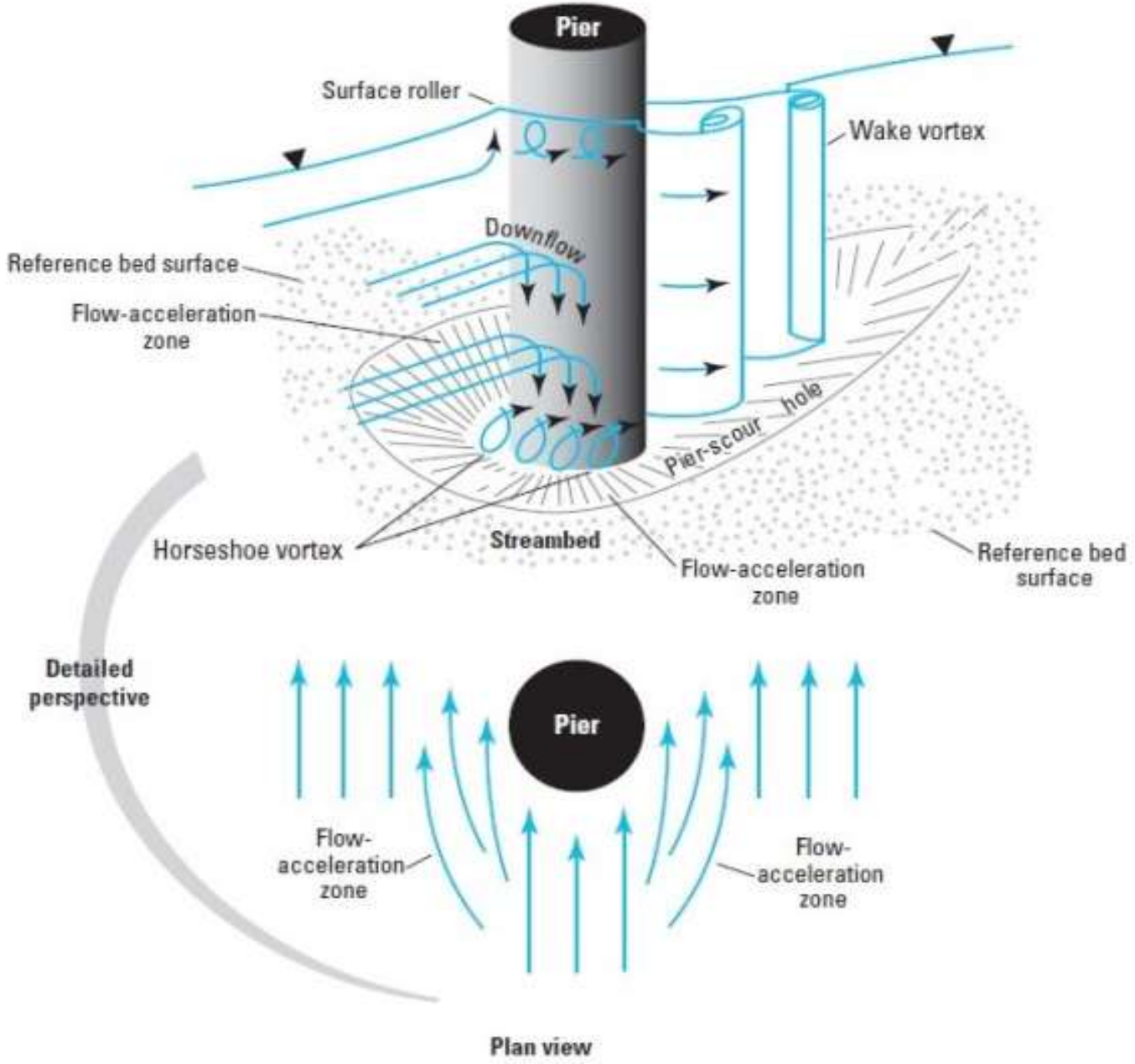
However, the intensity of wake vortices diminishes rapidly as the distance downstream of the pier increases.

Scour at a cylindrical pier

The “horseshoe vortices” remove material from the base of the pier and creates a scour hole.

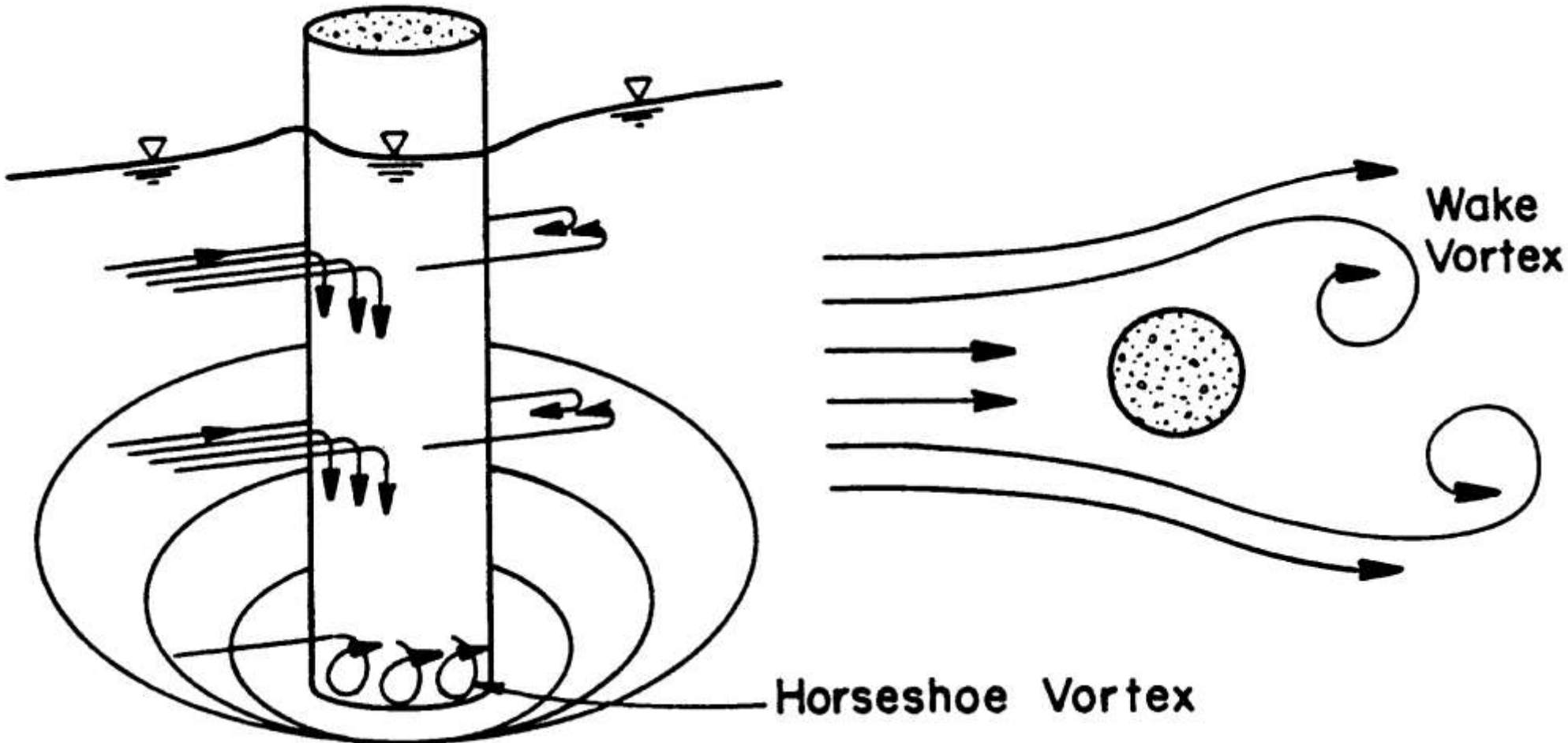


Scour at a cylindrical pier



Factors which affect the magnitude of local scour depth at piers and abutments are:

(1) velocity of the approach flow, (2) depth of flow, (3) width of the pier, (4) size and gradation of bed material, (5) angle of attack of the approach flow to a pier or abutment, and (6) shape of a pier or abutment.



River Scour

Factor affecting scour depth

Flow velocity affects local scour depth. The greater the velocity, the high is the erosive force and deeper is the scour.

Flow depth also has an influence on the depth of local scour. An increase in flow depth can increase scour depth by as much as a factor of 2 or greater for piers. With abutments, the increase is somewhat less depending on the shape of the abutment. The relation between depth of flow (y) and pier width (b_p) is shown in figure.

Pier width has a direct influence on depth of local scour. As pier width increases, there is an increase in scour depth. There is a limit to the increase in scour depth as width increases. The relation between depth of flow (y) and pier width (b_p) is shown in figure.

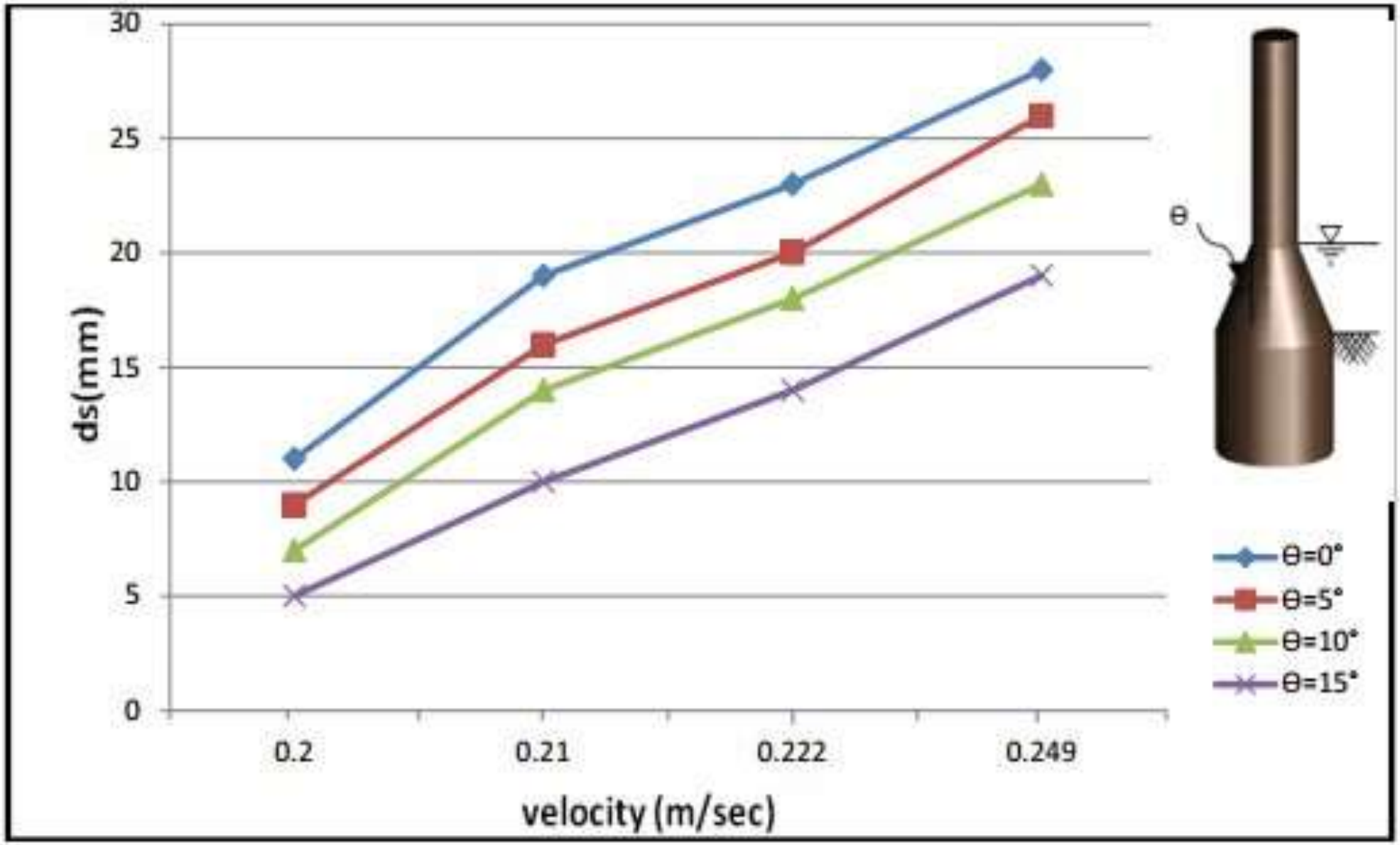
For narrow piers ($Y/b_p > 1.4$) scour depth increases proportionally with pier width and for wide piers ($Y/b_p < 0.2$) scour depth increases proportionally with flow depth. For intermediate lengths (medium pier width and medium depth of flows), the scour depth depends on both pier width and depth.

Bed material characteristics such as size, gradation, and cohesion can affect local scour. The relationship is shown in figure.

Angle of attack of the flow to the pier or abutment has a significant effect on local scour. Abutment scour is reduced when embankments are angled downstream and increased when embankments are angled upstream.

Shape of the nose of a pier can have up to a 20 percent influence on scour depth. Streamlining the front end of a pier reduces the strength of the horseshoe vortex, thereby reducing scour depth. A square-nose pier will have maximum scour depths about 20 percent greater than a sharp-nose pier and 10 percent greater than either a cylindrical or round-nose pier.

Effect of velocity on scour depth (shape of pier)



The commonly used scour depth-velocity relationship is:

$ds \propto (V/Vc)^n \times D$ (y)

Where:

ds = equilibrium scour depth

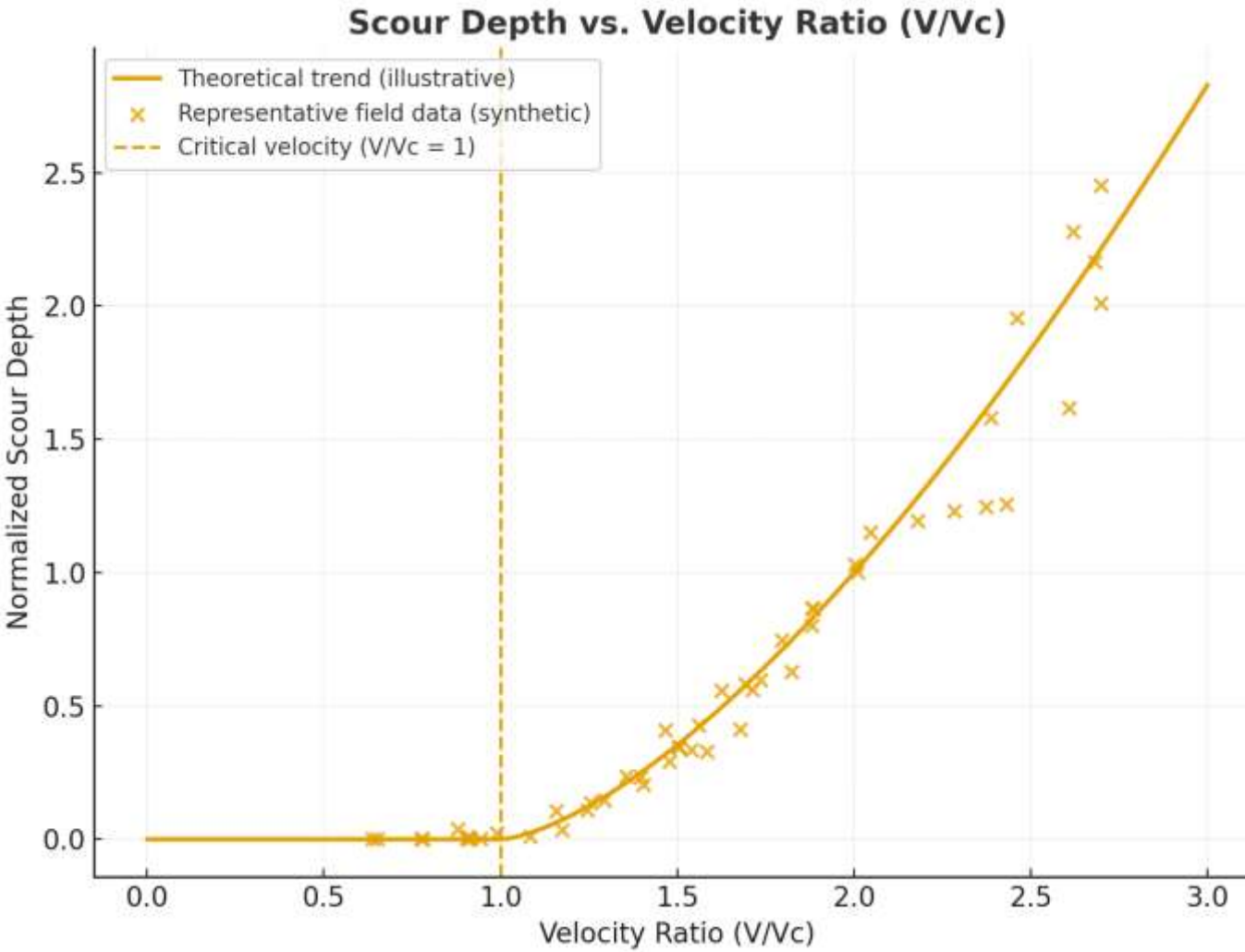
V = approach velocity

Vc = critical velocity

D = pier width or flow depth(y)

n ≈ 1–2 (depending on flow conditions)

This shows that scour depth increases with velocity ratio, V/Vc



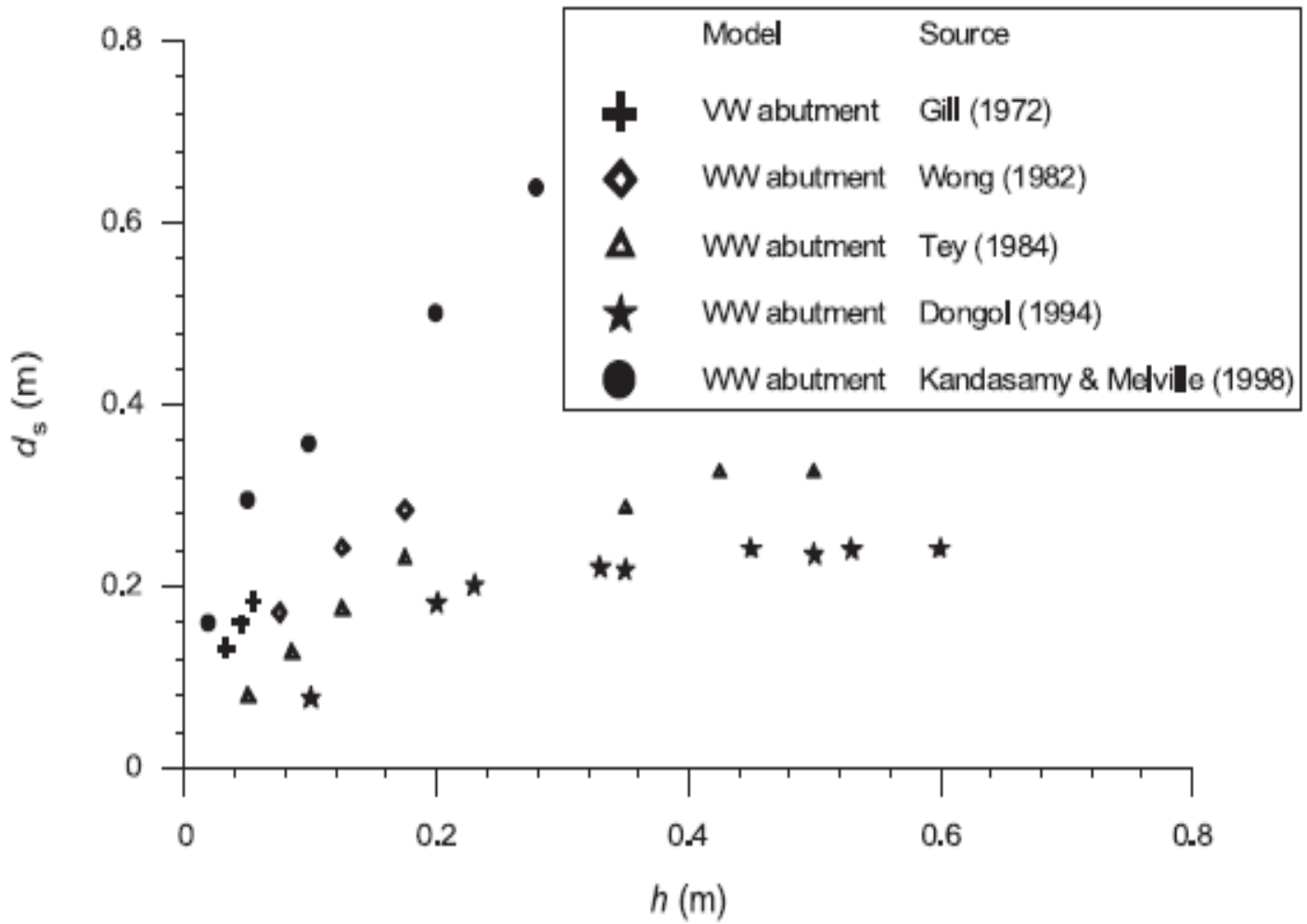
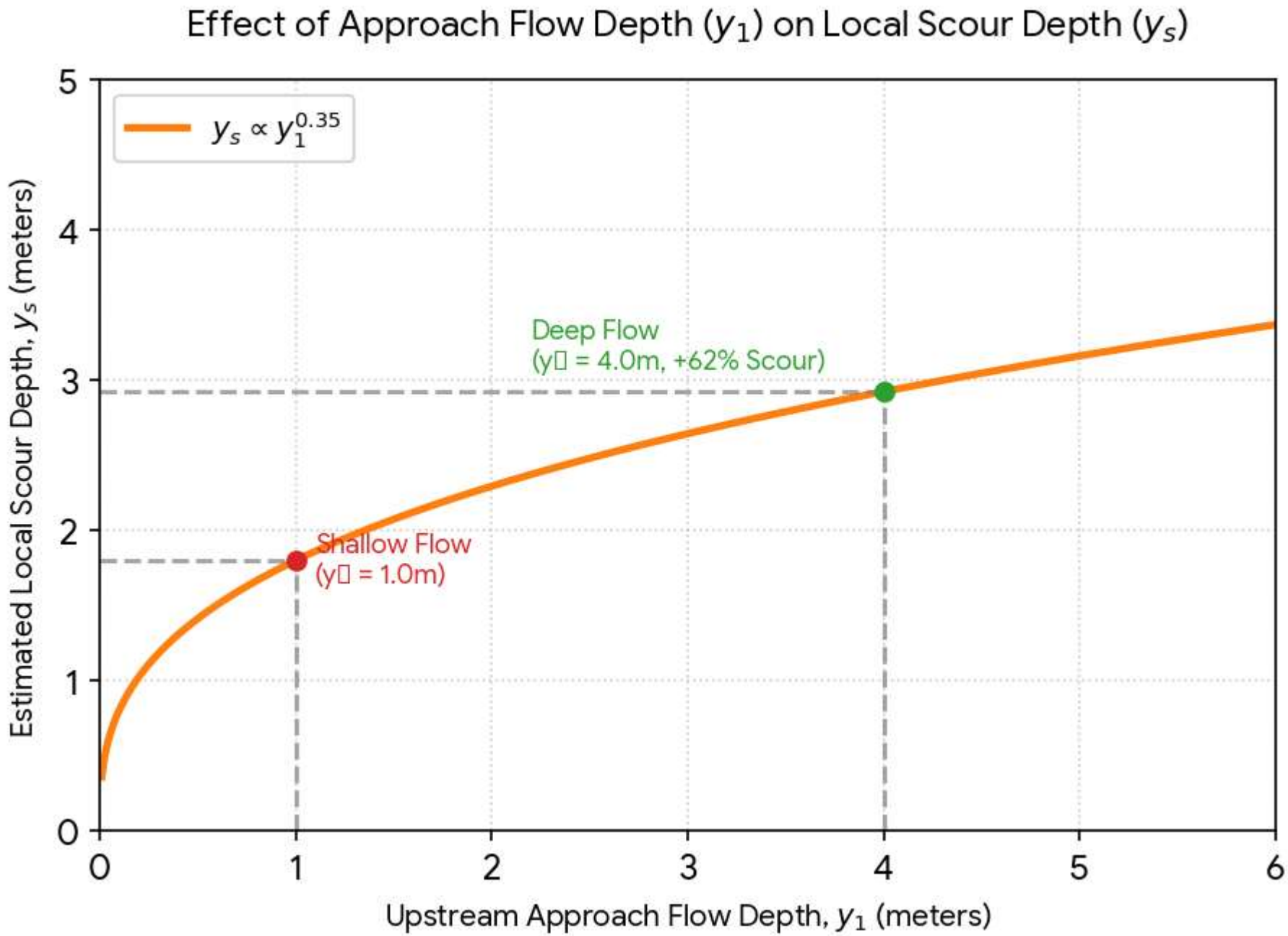
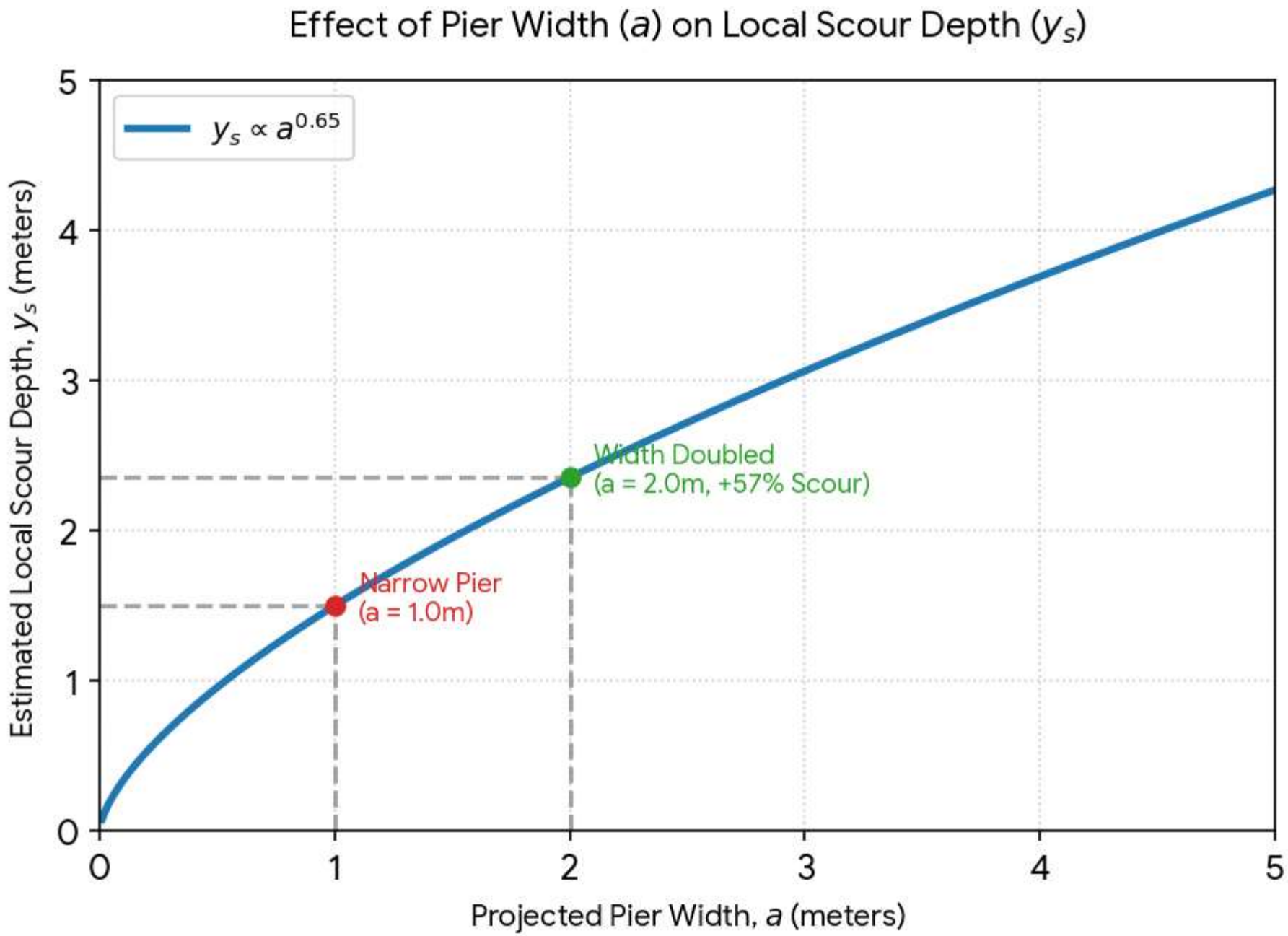
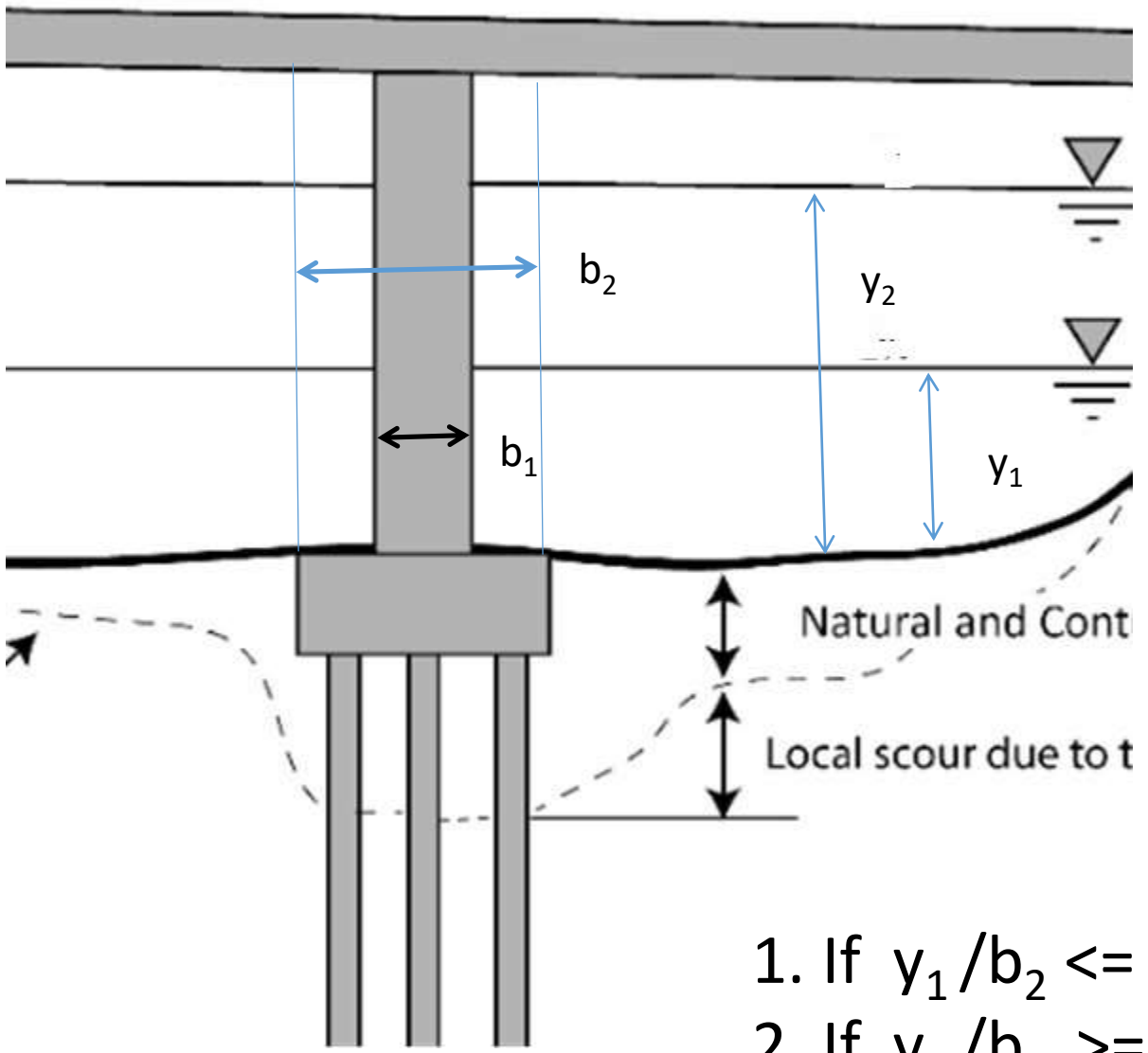


Figure 8. Variation of scour depth d_s with flow depth h.


Effect of Approach Flow Depth (y_1) on Local Scour Depth (y_s)
$y_s \propto y_1^{0.35}$
Deep Flow
(y□ = 4.0m, +62% Scour)
Shallow Flow
(y□ = 1.0m)
Estimated Local Scour Depth, y_s (meters)
Upstream Approach Flow Depth, y_1 (meters)
0
1
2
3
4
5
6


Effect of Pier Width (a) on Local Scour Depth (y_s)
$y_s \propto a^{0.65}$
Estimated Local Scour Depth, y_s (meters)
Projected Pier Width, a (meters)
Width Doubled
(a = 2.0m, +57% Scour)
Narrow Pier
(a = 1.0m)
0
1
2
3
4
5



1. If y_1/b_2 <= 0.2 then y controls (wide pier)
2. If y_2/b_1 >= 1.4 then b controls (narrow pier)

For wide piers

d_s / b_p = constant x (y / b_p) or $d_s \alpha y$

For narrow piers:

d_s / b_p = constant or $d_s \alpha b_p$

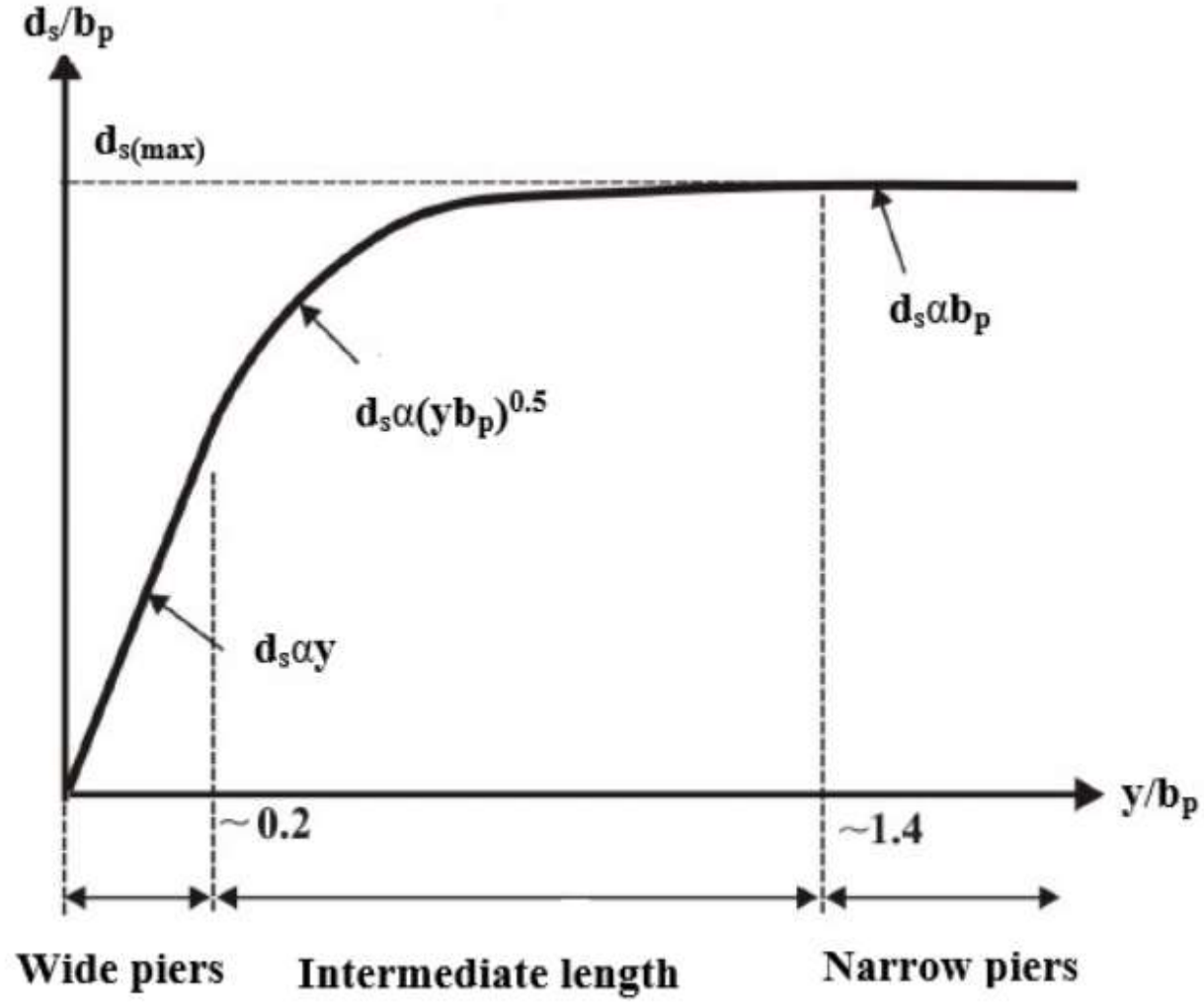


Figure 2.4: Local scour depth variation with flow shallowness (Melville, 2008)

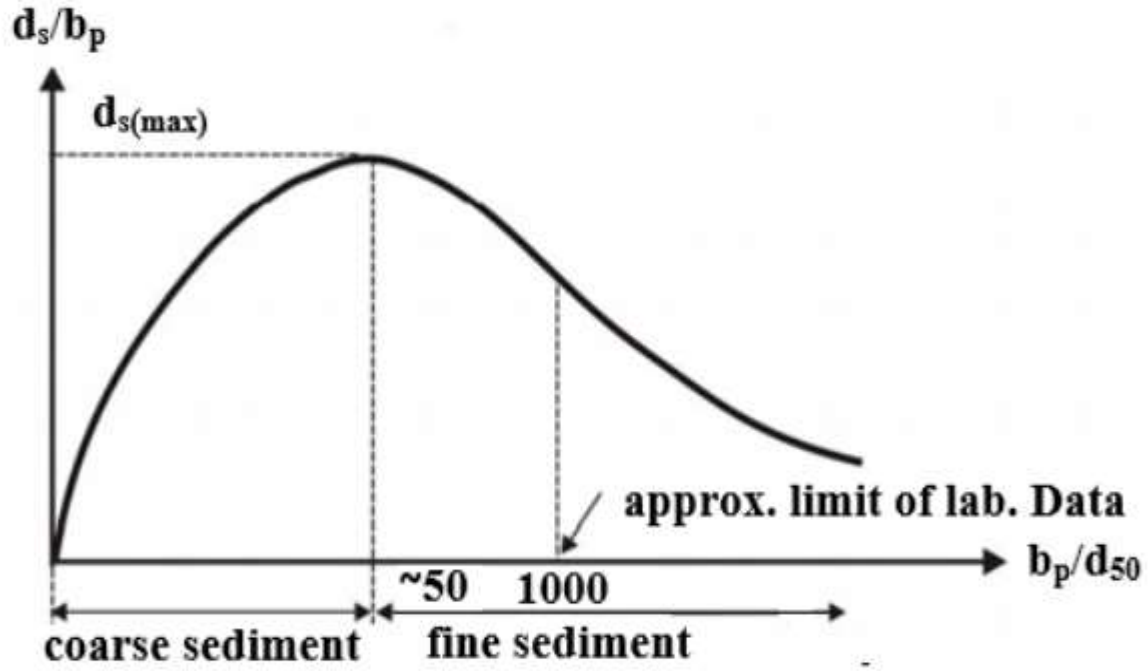


Figure 2.5: Local scour depth variation with sediment coarseness (Melville, 2008)

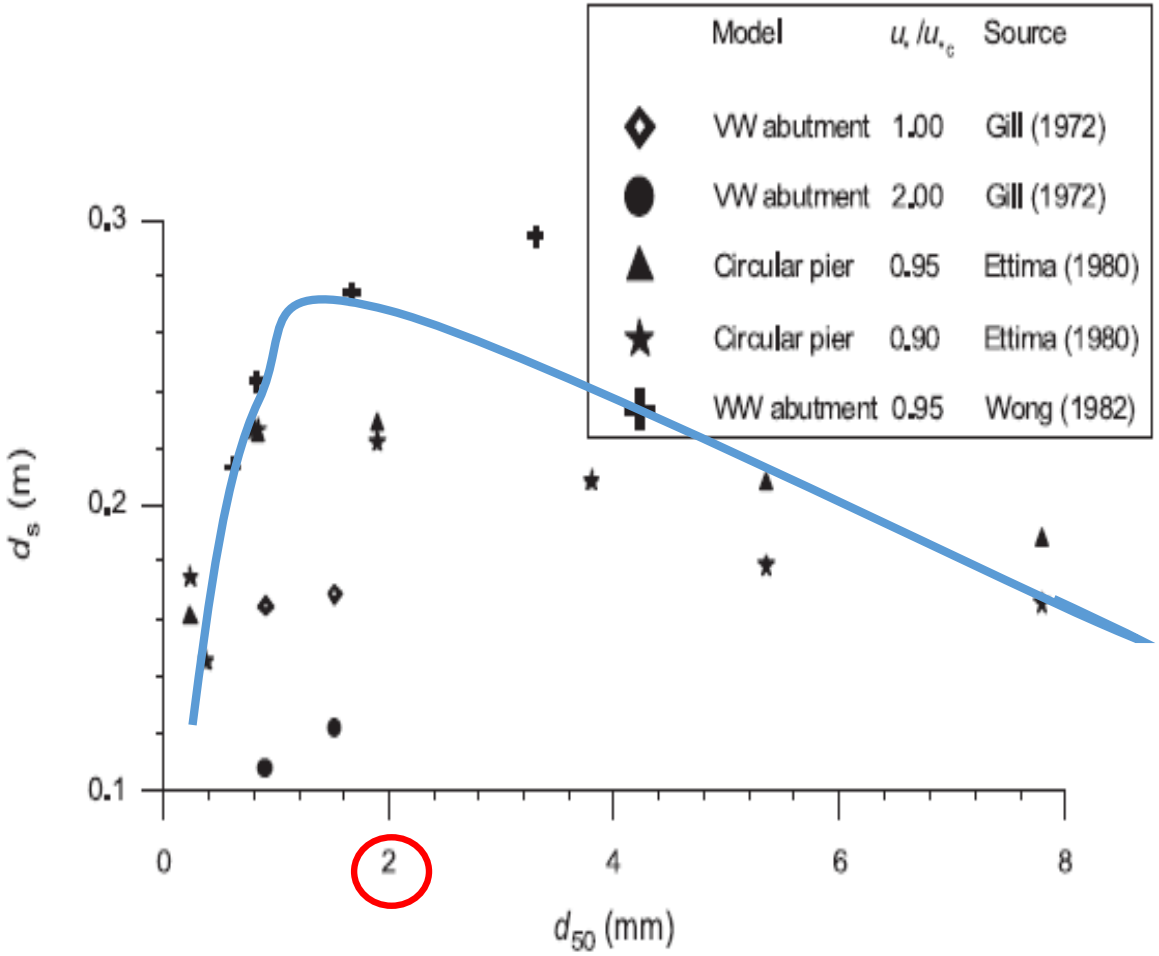


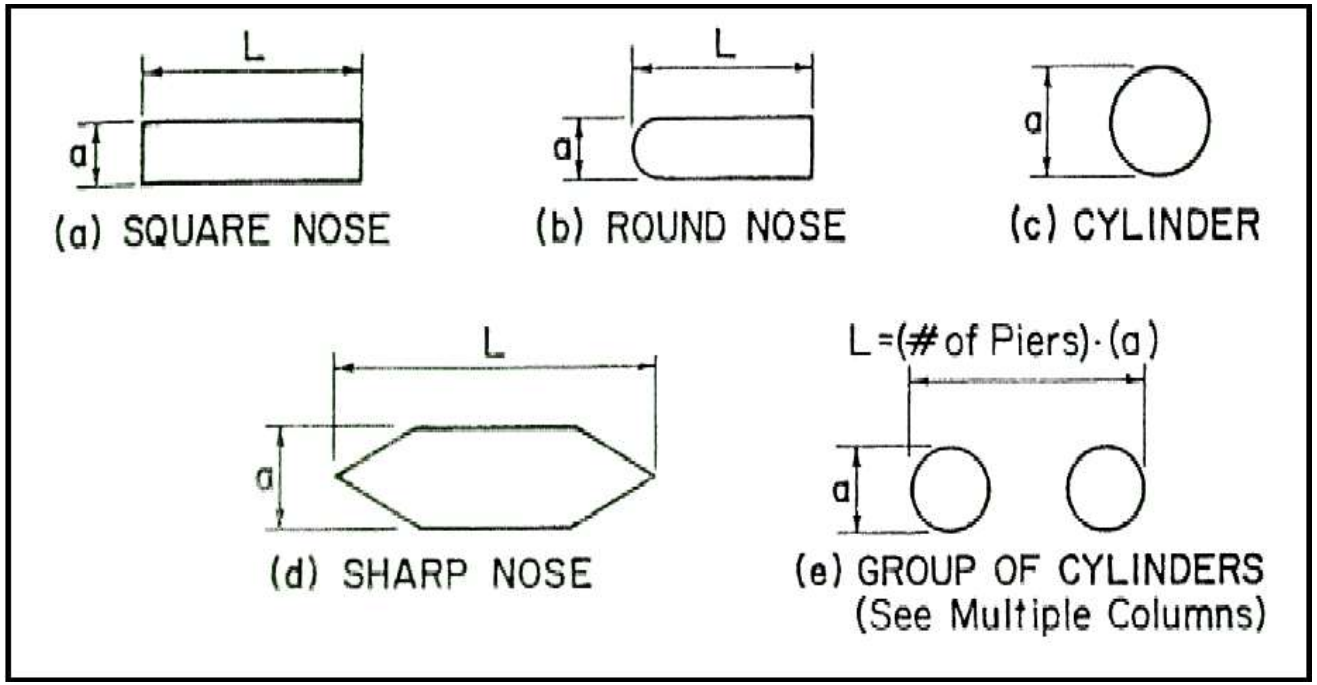
Figure 10. Variation of scour depth d_s with sediment size d_{50}.

Effect of Pier Shape

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:

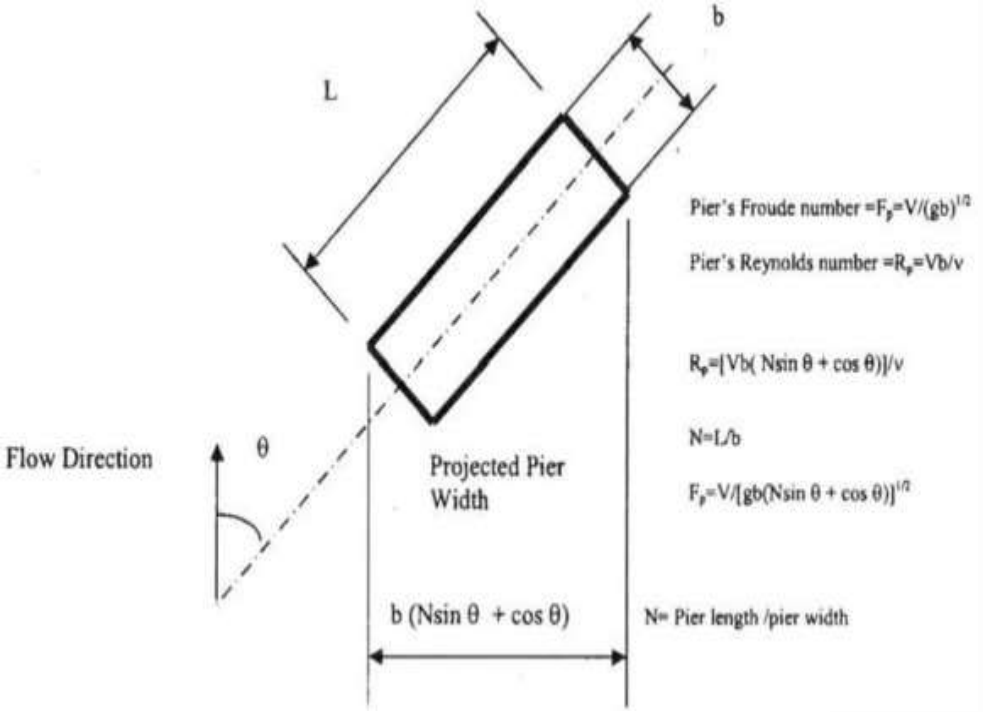
$$\frac{Y_s}{Y_1} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{a}{Y_1}\right)^{0.65} Fr_1^{0.43}$$

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

Effect of Angle of Attack

The angle of attack is the angle between the flow direction and the upstream nose of the pier. An angle of 0 degree indicates the flow is parallel to the pier.



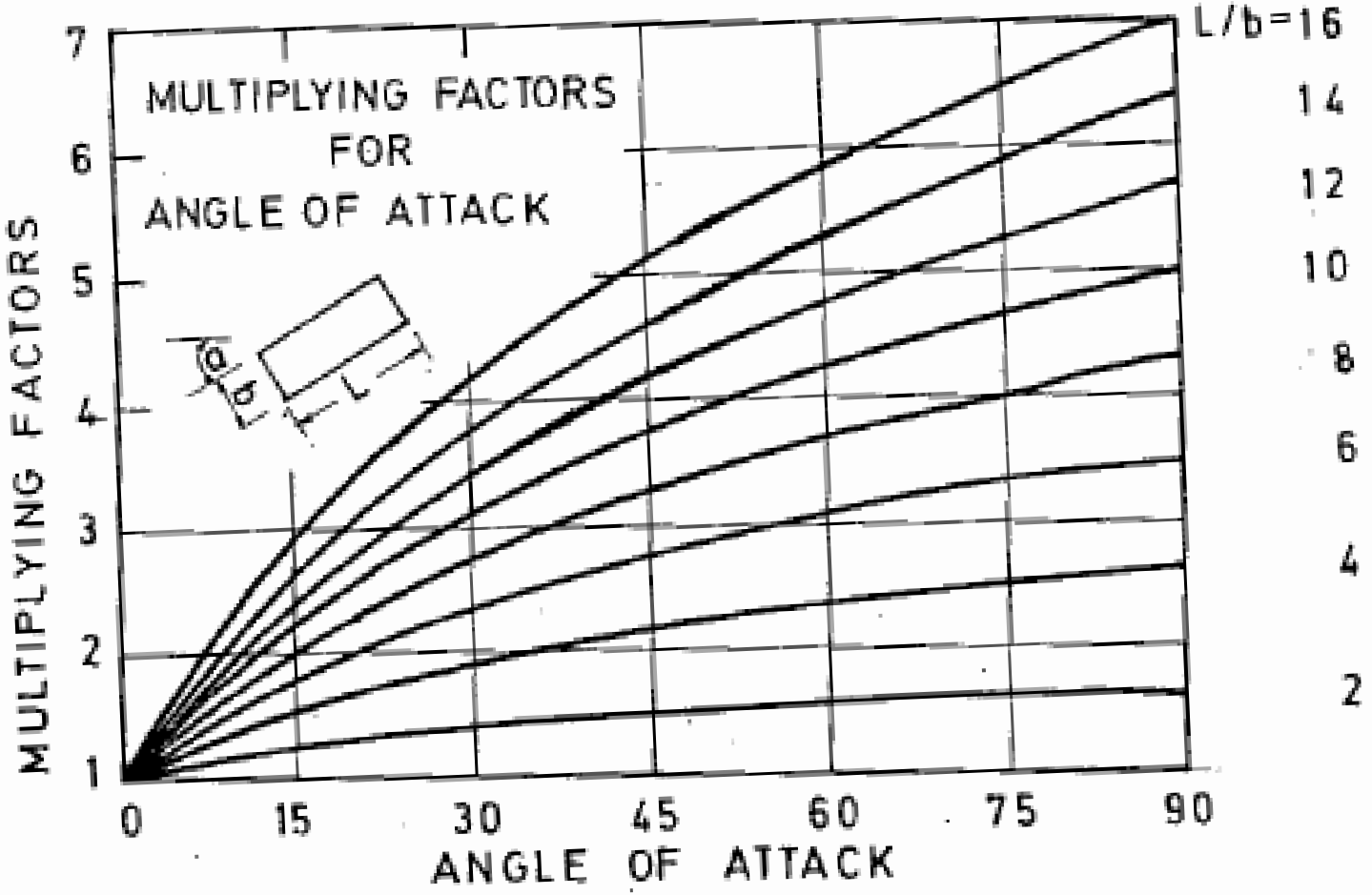


FIG. 2.10 DESIGN CURVES FOR CALCULATING DEPTH OF LOCAL SCOUR AT BRIDGE PIERS.

Angle of Attack

The **angle of attack** is the angle between the approaching river current and the long axis of the bridge pier. When a river does not hit a pier perfectly straight, the flow faces a much wider obstruction. To account for this, the equivalent width of pier that would produce the exact same amount of scour is needed.

K_2 is the Angle of Attack correction factor in equation:

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

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

Table 6.2. 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			

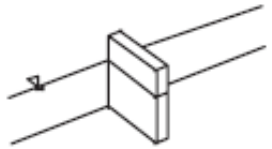
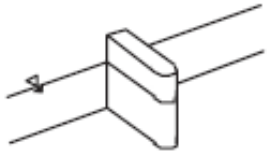
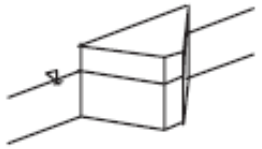
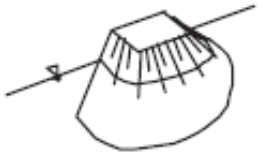
Notes: *K_2 should only be applied when the entire length is subjected to the attack of flow*

K_2 max = 5.0, a = pier width

Abutment scour

Local scour occurs at abutments when the abutment and embankment obstruct the flow. The obstruction of the flow forms a horizontal vortex starting at the upstream end of the abutment and running along the toe of the abutment and forms a vertical wake vortex at the downstream end of the abutment.

Table 1. Abutment shape factors.

Abutment model	Abutment shape	Shape factor, K_s
	Vertical-wall	1·00
	Semicircular ended	0·75
	45° wing-wall	0·75
	Spill-through with slope horizontal : vertical 0·5 : 1 1 : 1 1·5 : 1	 0·60 0·50 0·45

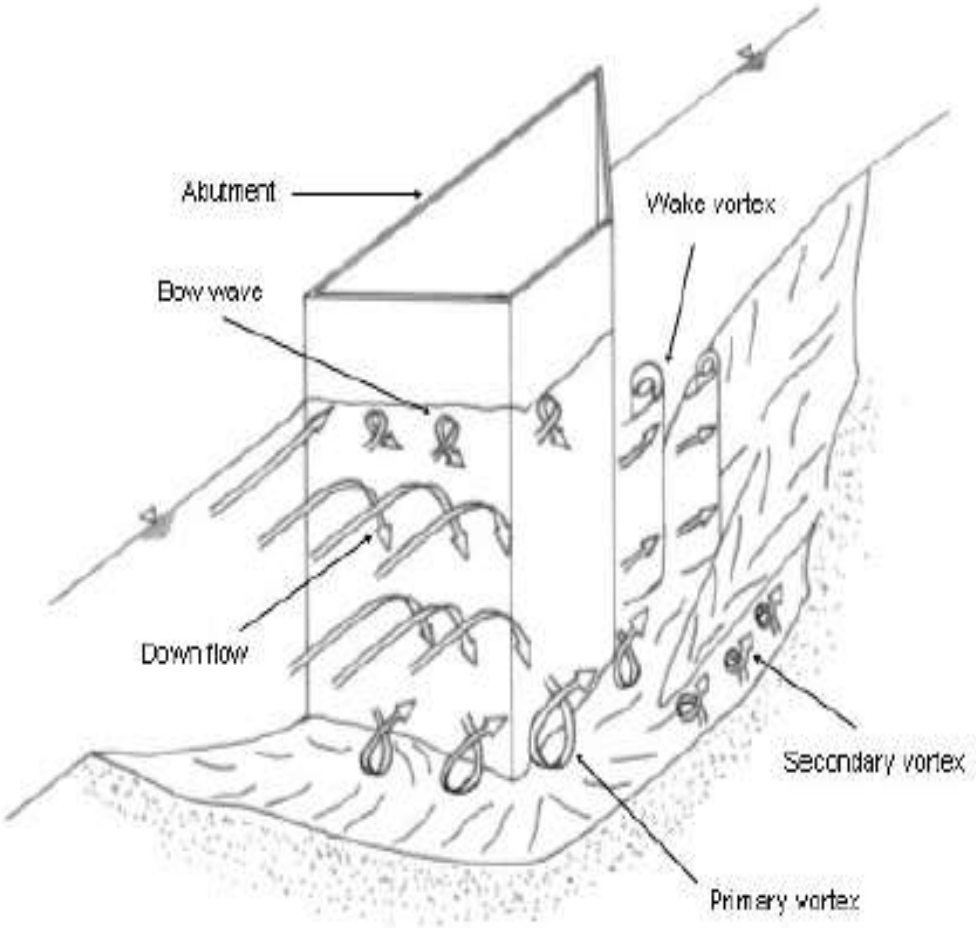
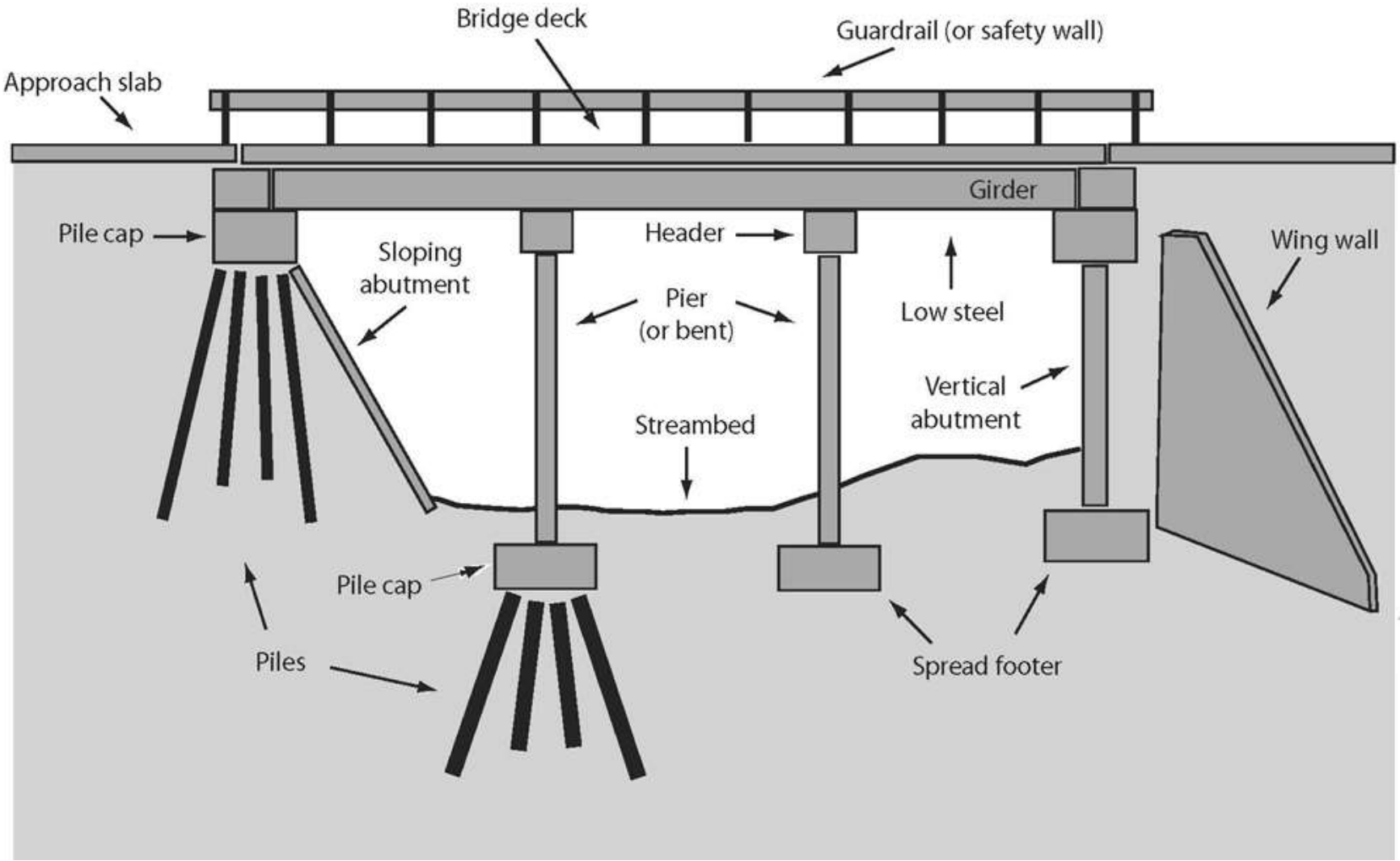
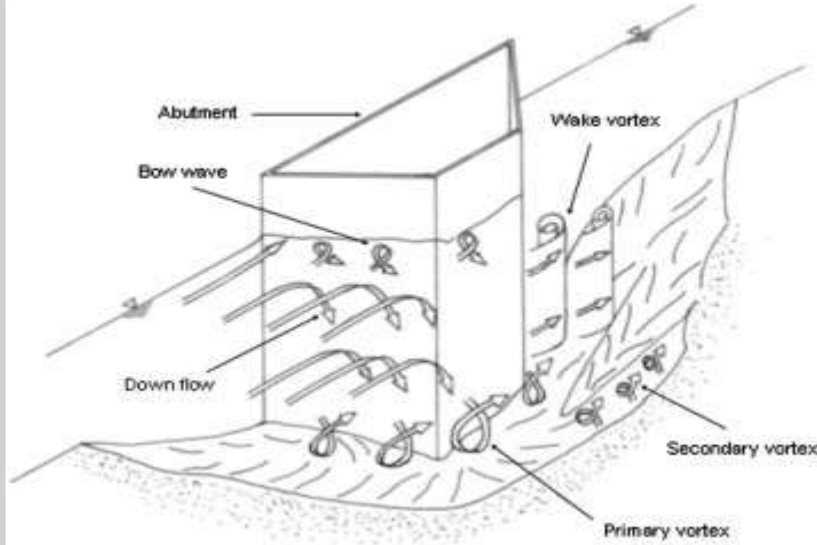
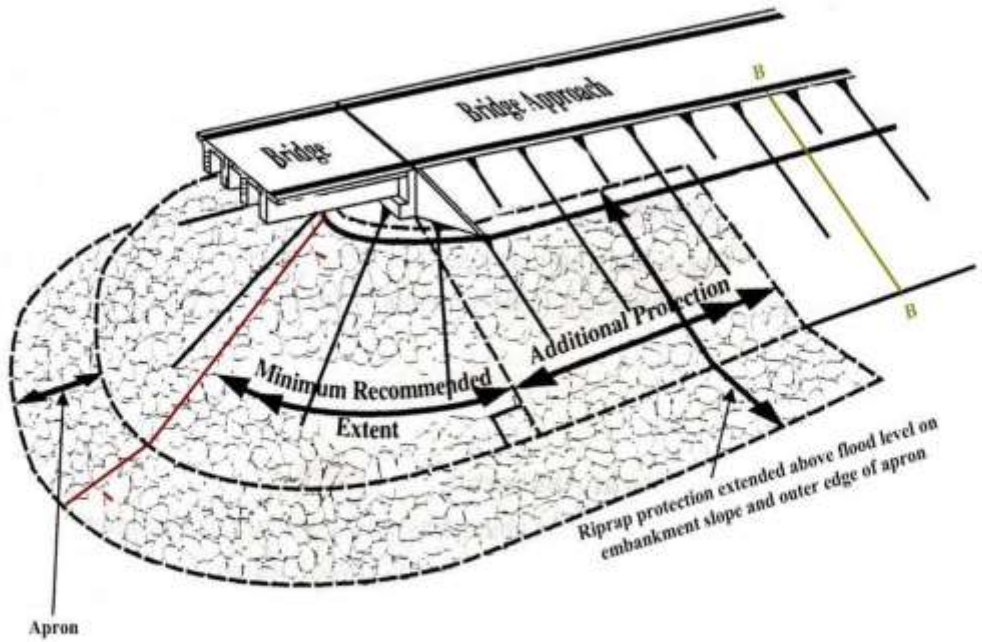


Figure 2. Schematic diagram of flow field at an abutment (after Kwan 1988).


Bridge deck
Guardrail (or safety wall)
Approach slab
Girder
Pile cap
Header
Wing wall
Sloping
abutment
Pier
(or bent)
Low steel
Vertical
abutment
Streambed
Pile cap
Piles
Spread footer


Abutment
Wake vortex
Bow wave
Down flow
Secondary vortex
Primary vortex



[Reproduced from Melville and Coleman (2000)]

Figure 7.2 (a) Layout of abutment with bridge approach.

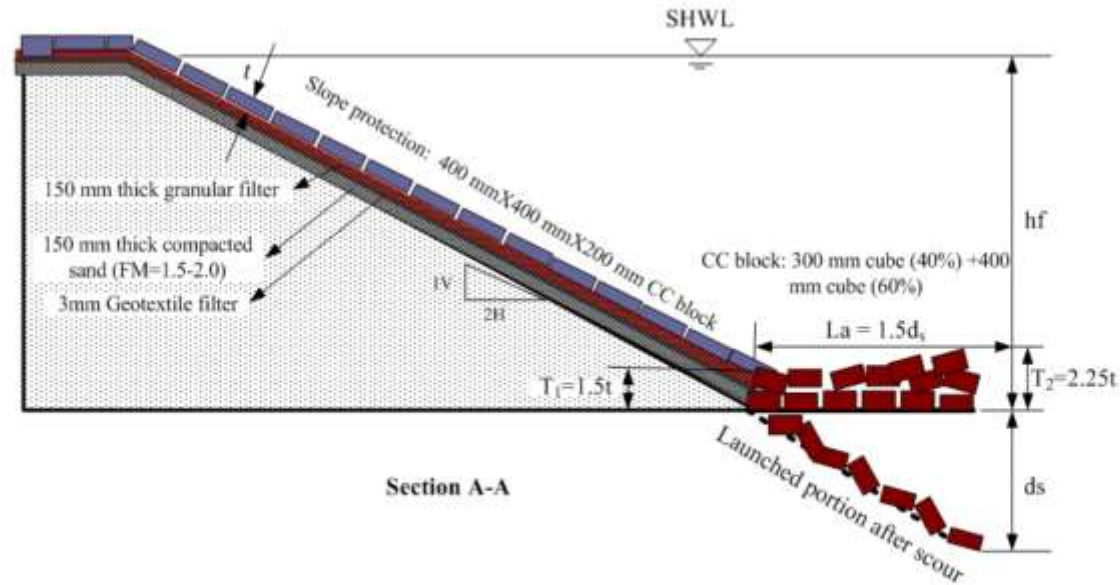


Figure 7.2 (b) Typical abutment protection (t = 450 mm, Apron length (La) = 1.5 times of the scour depth around abutments, T_1 and T_2 are inner and outer edge thickness of apron, respectively).

Table 9.3 Comparison of local scour depth around piers using different formulae

Equation No. and Reference	Scour depth below initial bed level (m)	Scour level, (m) PWD	Scour depth below SHWL (+24.40 m, PWD)
(9.3) Breusers [1965]	3.75	14.49	9.91
(9.4) Laursen [1963]	4.94	13.30	11.10
(9.5) Neill [1987]	4.00	14.24	10.16
(9.6) Jain and Fischer [1980]	6.75	11.49	12.91
(9.7) Chitale [1988]	6.47	11.77	12.63
(9.8) Melville [1997]	5.63	12.61	11.79
(9.9) Richardson and Davis [1995]	6.23	12.01	12.39

Table 9.6 Comparison of local scour depth around abutment using different formulae

Equation No. and Reference	Local scour depth below initial bed level (m)	Scour level, (m) PWD	Scour depth below SHWL (+ 17.40 m, PWD), m
(9.11) Laursen [1963]	2.75	11.63	5.77
(9.12) Melville [1997]	2.63	11.75	5.65
(9.13) Lim [1997]	0.74	13.64	3.76
(9.14) Rahman and Haque [2004]	1.04	13.34	4.06
(9.15) Froehlich [1989]	0.98	13.40	4.00

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.

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.

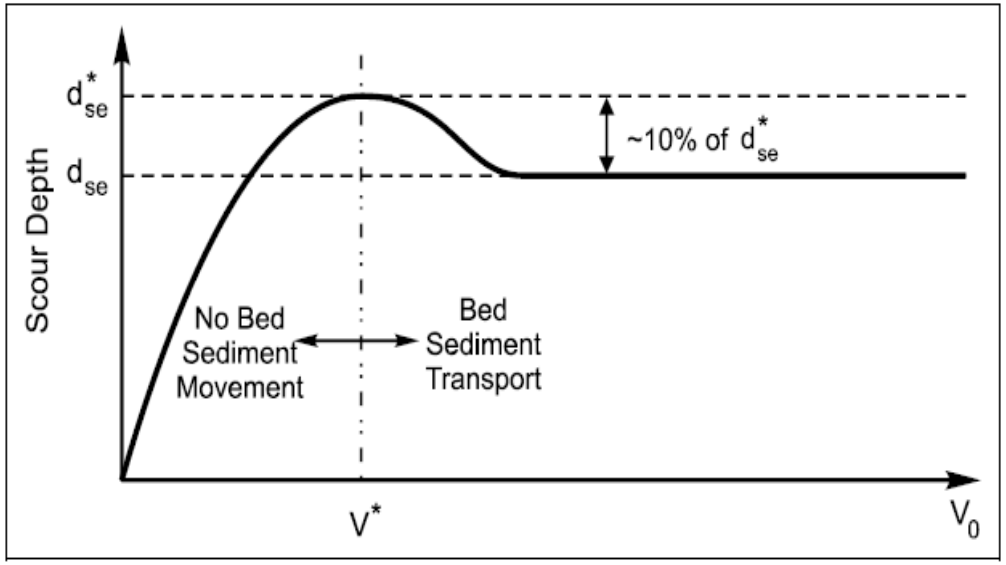


Figure 4-5. The variation of maximum pier-scour depth with flow velocity and bed sediment transport

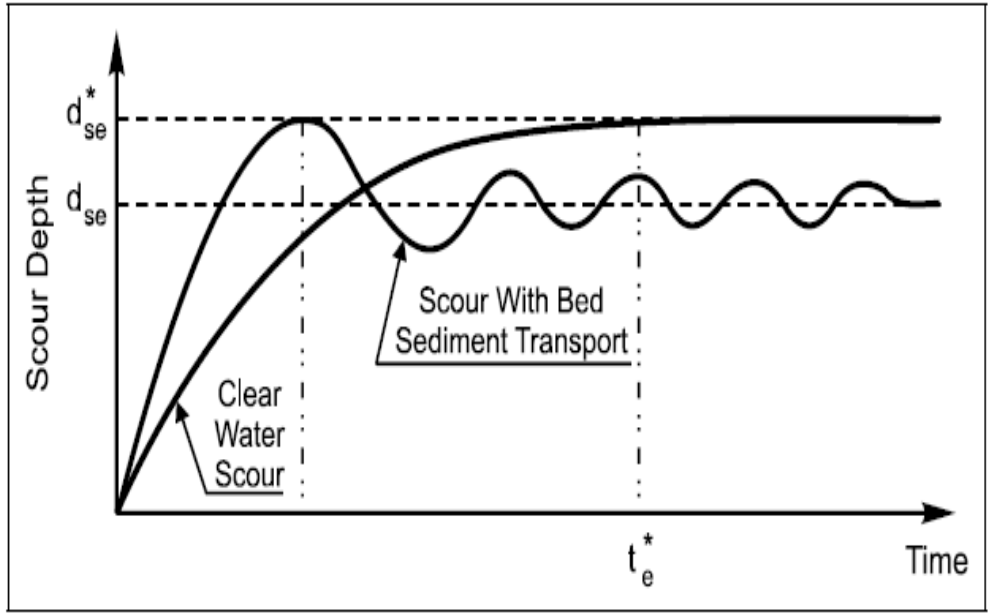
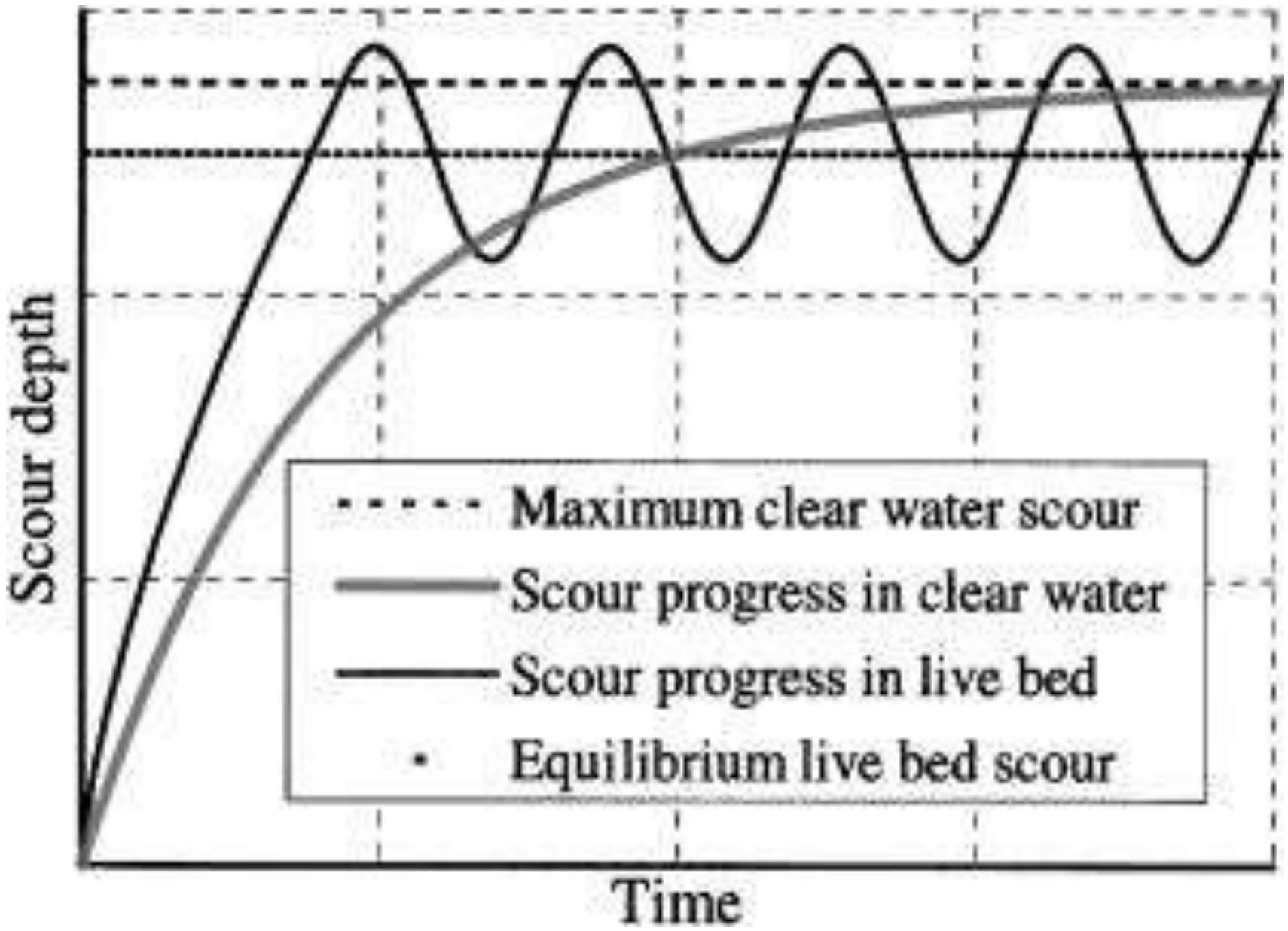


Figure 4-6. The time development of pier scour for clear-water conditions (e.g., pier on a floodplain) and for conditions when the waterway transports bed sediment


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

River Scour

The Local Scour Process

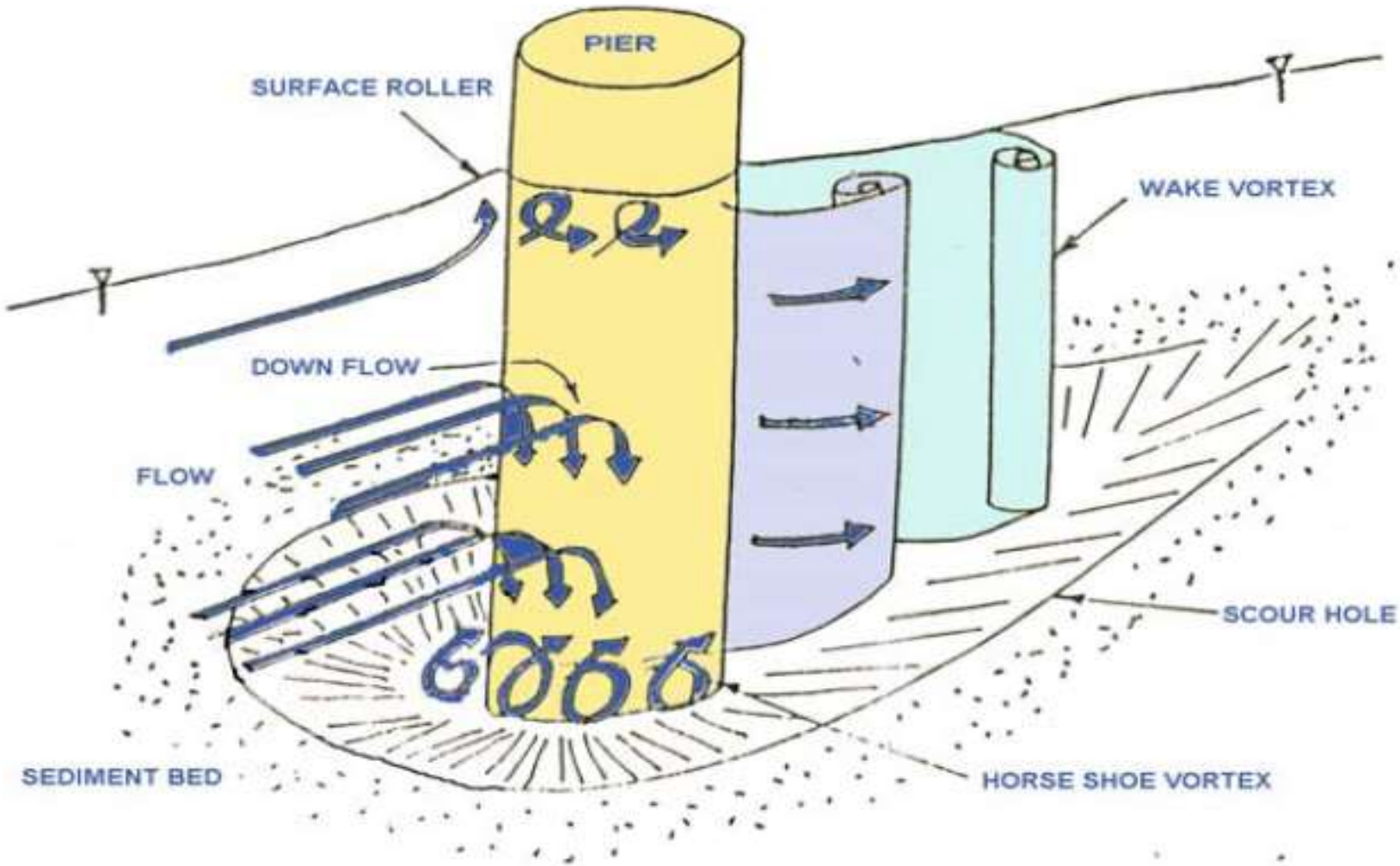
Local scour develops as a hole around the pier, and involves a complex local flow field causing sediment erosion. Usually, the scour hole is deepest at the leading edge of the pier, because of downward flow into the scour hole and the formation of a vortex that in plan looks horseshoe-shaped.

The pier locally blocks the approach flow, inducing a pressure field that leads to a three-dimensional separation of the flow close to the pier. This separated shear layer rolls up along the obstruction to form a vortex system in front of the element which is swept downstream by the river flow. Viewed from the top, this vortex system has the characteristic shape of a horseshoe and thus called a horseshoe vortex (figure).

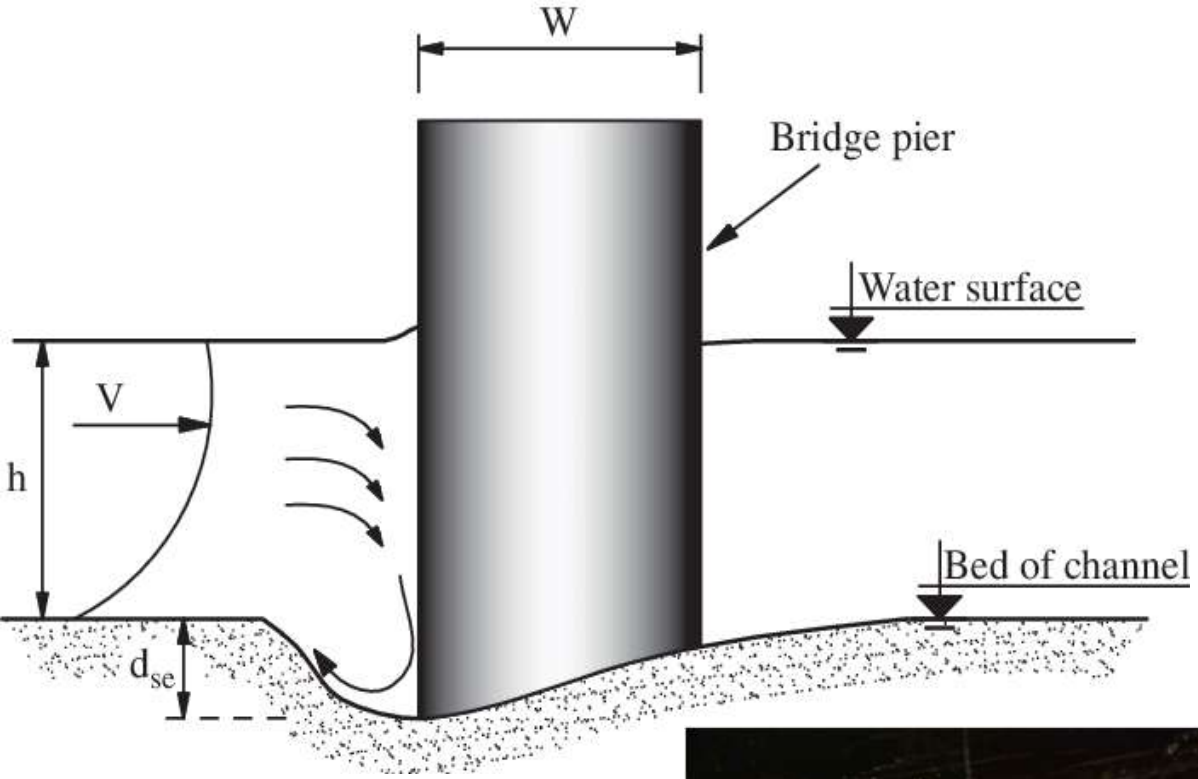
The formation of the horseshoe vortex and the associated downward flow around the bridge element results in increased shear stress and hence a local increase in sediment transport capacity of the flow. The temporal variation of scour and the maximum depth of scour at bridge elements therefore mainly depend on the characteristics of flow, pier and river-bed material.

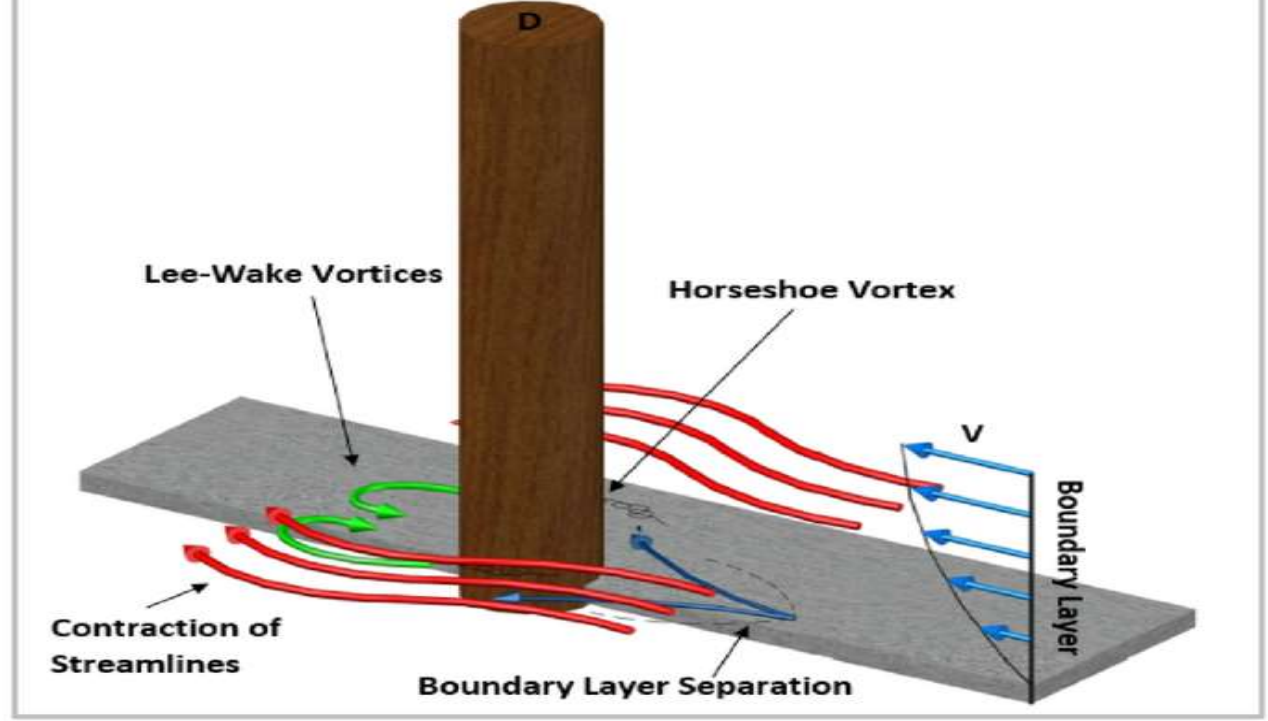
Finally the vortex breaks up and diffuses into the flow.

An additional vortex system is formed by flow separation from the sides of the pier. The flow forms shear layers that roll up into concentrated vortices with vertical axes. On being shed from the pier, these vortices form a clearly visible vortex trail downstream of the pier. These vortices increase the scouring action along the line of their movement by sucking bed sediment into their lower pressure core.



FLOW STRUCTURE AT A BRIDGE PIER





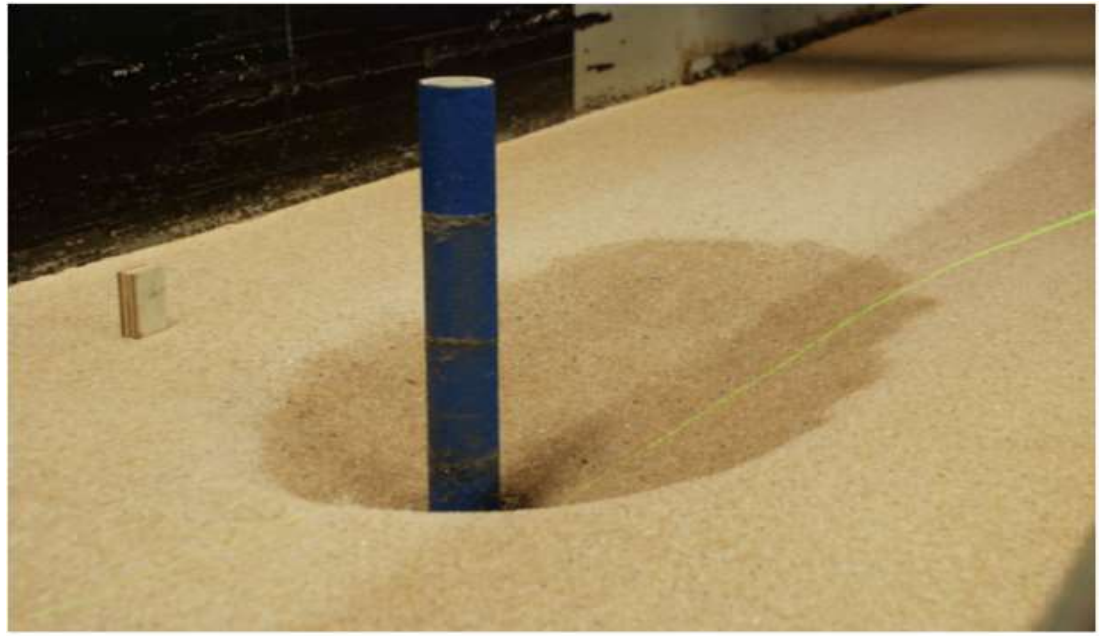


Figure 2: Experiment of scour hole formation around a single pier.