CHAPTER-3

SCOUR TYPES AND PARAMETERS AFFECTING THE SCOUR

3.1. SCOUR TYPES

Total scour at a bridge pier or abutment consist of three components:

1. Long term aggradation and degradation of the river bed
2. General scour at the bridge
   a. Contraction scour
   b. General scour
3. Local scour at the piers or abutments.

3.1.1 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. Aggradation involves the deposition of material eroded from the channel or watershed upstream of the bridge, where as degradation involves the lowering or scouring of the stream bed due to a deficit in sediment supply from stream.

3.1.2 Contraction Scour

Contraction scour of a river involves the removal of material from the bed across all or most of the channel width in the bridge reaches due to the increased velocities and shear stress on the bed. Contraction scour often occurs when the bridge embankments encroach on the floodplain or into the main channel. There are two types of contraction scour to be considered. Live bed scour occurs when there is transport of
bed material in the upstream reach into the bridge cross section. With live-bed contraction scour the area of the contracted section increases until, the transport of sediment out of the contracted section equals the sediment transported in. Clear water scour occurs when there is no bed materials transport from the upstream reach into the downstream reach, or the materials being transported in the upstream reach is transported through the downstream reach mostly in suspension and at less than capacity of the flow.

3.1.3 General Scour

General scour is a lowering of the streambed across the stream or waterway bed at the bridge. 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. General scour may result from contraction of the flow, which results in removal of material from the bed across all or most of the channel width, or from other general scour conditions, such as, flow around bends where the scour may be concentrated near the outside of the bend. General scour is different from long-term degradation, in that general scour may be cyclic or related to the passing of the flood.

3.1.4 Local Scour

The basic mechanism causing local scour at bridge piers and abutments is the formation of vortices at their base. The vortex removes bed material from the base of the obstruction. As the sediment transport rate, which is outgoing from the scour hole is higher than that coming into, a scour hole develops. As the depth of the scour increases, the strength of the vortices is reduced. On the other hand, there are vertical
vortices downstream of the structure called wake vortices. Generally, depths of local scour are much larger than general or contraction scour depths, often by a factor of ten (Federal Highway Administration, 2001).

![Fig.-3.1 Types of scour that can occur at a bridge.](image)

### 3.2. SCOUR MECHANISM

Flow pattern and mechanism of scouring around a pier and an abutment is a complex phenomenon resulting from the strong interaction of the three-dimensional turbulent flow field around the bridge foundations and the erodible sediment bed. Piers and abutments are usually considered as similar in case of scour phenomena (Laursen, 1962; Melville, 1997); but in the abutments case, the presence of the incoming wall boundary layer generates a more complex flow field than that observed at piers. Moreover, the scour depth at the abutment was found to be less than that at the equivalent pier due to the boundary layer effects induced by the channel wall (Kothyari and Ranga Raju, 2001).

The basic mechanism causing local scour at piers is the formation of horseshoe vortex at their base (Fig. 3.2). The horseshoe vortex 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 or abutment. Upon reaching a certain flow velocity in the channel,
the sediment particles close to the cylinder begin to move and thus scour is initiated.
The eroded particles will follow the flow pattern and are carried from the front of the
cylinder towards the downstream. Upon an increase in the flow velocity, more and
more particles will be dislodged, forming a scour hole increasing in size and depth. The
action of the vortex removes bed material from around the base of the obstruction. 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. The horseshoe vortex extends downstream, past
sides of the pier for a short distance before losing its identity and becoming part of the
general turbulence.

In addition to the horseshoe vortex around the base of a pier, there are vertical
vortices downstream of the pier called the wake vortex (Fig. 3.2). 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.
Therefore, immediately downstream of a long pier there is often deposition of material.

Eventually, for live-bed local scour, equilibrium is re-established between bed
material inflow and outflow and scouring ceases. For clear-water scour, scouring
ceases when the shear stress caused by the horseshoe vortex equals the critical shear
stress of the sediment particles at the bottom of the scour hole. Generally, the
equilibrium of final depth of local scour is rapidly attained in live-bed conditions, but
rather more slowly in clear-water conditions.
Fig. 3.2 Flow and scour pattern at a circular pier (after Melville and Coleman, 2000).

Fig. 3.3 Schematic diagram of flow field at an abutment (after Kwan, 1988).

Dargahi (1990) carried out an experiment to investigate by means of flow visualization and measurements, the coupling between the flow field and local scouring. The general development of the scour pattern observed upstream of the pier along the plane of symmetry with respect to time.
Melville (1975) mapped the flow field in a scour hole for three different stages of the scour process during one set of conditions. The stages were: (1) flat-bed or no scour stage at \( t = 0 \); (2) intermediate stage at \( t = 0.5 \) hour, and (3) equilibrium condition. At each stage a cast was made of the bed, the surface of the cast was coated with sand from the experiment and the flow conditions were re-established. Flow measurements were made using a hot-film anemometer with direction indicated by a piece of cotton on the rod. Fig. 3.4 shows an example of Melville's measurements for the intermediate stage. Velocities along the sides of the hole were weak and a grove or lip exists at the base of the cylinder where velocities are highest, indicating this is the most important area of sediment removal.

![Flow field inside the scour hole (Melville, 1975)](image)

Fig. 3.4 Flow field inside the scour hole (Melville, 1975)

Melville also found that a strong downflow develops at the leading edge, and that the velocity at the bottom of the hole decreases as equilibrium is reached. He
observed that as the scour hole grows the diameter of the horseshoe vortex increases and the centre of the vortex moves away from the cylinder. The circulation associated with the vortex initially increases rapidly and then slows and approaches a constant value as equilibrium is reached.

It has been observed that in the free surface flow around an obstruction, such as a bridge pier, downwash motions, horseshoe vortices and vortex shading are formed and the turbulence is intensified in front, around and behind the piers. In addition, a uniquely shaped scour hole on the loose bed around a pier is seen. Experimental studies have found that both the flow and the sediment transport processes during the scour hole development are highly complex.

3.3. CAUSES OF SCOUR

Stream and channel instability resulting in river erosion and changing angle of attack can contribute to bridge scour. Debris can also have a substantial impact on bridge scour in several ways. A build up of material can reduce the size of the waterway under a bridge causing contracting scour in the channel. A build up of debris on the abutment can deflect the water flow, changing the depth of local scour. Debris might also shift the entire channel section around the bridge causing increased water flow and scour around the bridge and also scour in another location. During flooding, although the foundations of a bridge might not suffer damage, the fill behind the abutments may scour. This type of damage typically occurs with single span bridges with vertical wall abutments.
3.4. PARAMETERS AFFECTING SCOUR AROUND BRIDGE PIERS

A number of papers have been published since 1940 on various aspects of scour around bridge pier. Based on the experimental work and some theoretical analysis it is found that the following factors affect the scour depth at the bridge pier.

1. Whether the incoming flow is clear water flow or it carries sediment: clear water flow occurs when $u_*/u_{*c}$ is less than unity, while for sediment transporting flow $u_*/u_{*c}$ is greater than unity. Here $u_*=\sqrt{g}yS_b$ is the shear velocity of flow and $u_{*c}$ is the shear velocity at which bed material starts moving, $y$ is the depth of flow in the river and $S_b$ is the river slope.

2. Effect of change in depth of flow: experiments by Melville and Sutherland have shown that when (depth of flow/pier width) ratio i.e., $y/D$ is greater than 2.6, scour depth does not depend on the depth of flow; for smaller depths, the scour depth depends on the depth of flow.

3. Effect of shape of pier nose: the shape of the pier nose affects the strength of horse-shoe vortex as well as the separation of the flow around the bridge pier; hence it affects the maximum scour depth.

4. Effect of angle of inclination of pier on scour depth: when the axis of the pier makes an angle $\Theta$ with the general direction of the flow, two major changes take place in the flow field. Except in the case of cylindrical pier, the separation pattern is drastically changed resulting in change in vortices. Secondly, the open width between the piers, perpendicular to the flow direction reduces as the angle of inclination $\Theta$ increases.

5. Effect of opening ratio on scour depth: the opening ratio $\alpha$ is defined as $\alpha=[(B-D)/B]$, where B is centre to centre spacing of the piers and D is the pier...
width. When $D$ is very small compared to $B$, $\alpha$ is close to unity and flow around one pier does not affect the other.

6. Effect of bed material characteristics: in the case of non-cohesive materials, the characteristics of the bed material that affect the scour depth are sediment density, median size $d_{50}$ of the bed material, its standard deviation and stratification. For all practical purposes the density of natural sediments can be taken as 2.65, a constant value.

7. Stratification: Ettema (1980) and Kothyari (1990) have studied the effect of the bed material on scour depth in case of clear water scour. It is concluded that the stratification, in which a relatively thin coarse top layer covers a thick fine bottom layer, is the critical condition. Once the top coarse layer is scoured away, scour depth will rapidly increase.

8. Effect of flow parameters: based on certain theoretical analysis, physical reasoning and analysis of experimental data, investigators have arrived at the basic flow parameters to which the dimensionless scour depth is related. Thus Breusers et al. (1977), Laursen and Toch (1956), Laras (1963) and Ettema (1980) consider $D/y$ as important parameters and hence they related $d_{sc}/y$ to $D/y$. Thus according to Breusers et al. (1980)

$$d_{sc}/y = 1.4(D/y) \quad (3.1)$$

Where; $d_{sc}$ = clear water scour below bed level

$y$ = average depth of flow

$D$ = pier width or pier diameter.