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EXPERIMENTAL WORK TO ESTIMATE BRIDGE PIER SCOURING AROUND ROUND NOSED RECTANGULAR PIER AND PROTECTION AGAINST SCOURING USING RIPRAPS

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ABSTRACT

Local scour around bridge pier is the main factor for the failure of the bridge structure like bridge piers, abutments etc. in the alluvial channel. The protection of the bridge pier can be done by using riprap, collars, vertical vanes, slots, etc. around the scour pattern/depth. The phenomenon of local scour around the bridge pier depends upon discharge, depth of flow, pier shape, pier geometry, pier shape factor, type of sediment particles. The scouring pattern around bridge pier is studies around round-nose bridge pier in non-uniform sediments having two different standard deviation, in clear-water scour condition. The scour prevention in the present study is done by using a suitable size of riprap along with a layer of geonet to avoid the failure of riprap. The scour depth is measured in three different pier models, one in round-nose rectangular pier, another tapered in elevation i.e. narrowing upwards ad the last circular pier. It is observed that the maximum scour occurs around circular pier rather than round-nose rectangular pier in both type of non-uniform sediment. The reduction of scour can be observed when the layer of riprap is placed around the scour depth around bridge piers.

Key words: Scour, Round-nosed Rectangular Pier, Riprap

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1. INTRODUCTION

In flowing water the removal of sediment around and near the structures of bridges is governed which is termed as ‘Scour’. The removal or lowering of the riverbed level is caused by the erosive action of flowing water, around the piers and abutments of bridges the excavation and carrying away the bed material is done by the erosive action of the flowing water (Richardson et al., 2001). The amount of the reduction of bed level around the ridge pier is termed as ‘scour depth’. Scour around the pier or apparent structure caused by the erosive action can result in structural failure and abutments and can result in loss of life and property.

Local scour is divided into two categories according to the sediment transport conditions: Live-bed scour and Clear-water scour. When the sediment is continuously supplied or transported from upstream of the river bed to the subjected area of the scour is termed as live bed scour condition. This condition occurs when the shear stress create by the flow of water along the stream exceed the critical stress i.e. ($\tau_0>\tau_c$), bed load transport along the streamline develops. The rate of scour hole is rapidly increased with respect to time at first, then it decreases with respect to time. The equilibrium condition is reached when the rate of sediment load entering the scour hole is equal to the rate of sediment load going out. When there is no bed load transport fluctuations or alterations of flow is not been observed. According to Rudkivi (1977), in live bed conditions average maximum scour depth, average equilibrium scour depth and average minimum equilibrium scour depth are defined and it is different for clear-water scour condition. Clear water scour condition prevails when the bed material at the upstream side of the bridge structure has no motion. In clear water scour condition the shear stress created by the flow of water along the stream line is smaller than the critical stress i.e. ($\tau_0<\tau_c$). In clear water condition the mean approach flow velocity is less than the critical velocity i.e. ($V_0<V_c$). Yanmaz (2002)suggested that the degree of scour depends upon the flow properties and is affected by inertia of flow and pier geometry.

Due to flooding the bridge piers are affected by scour which results in failure of the bridges. (Lagasse et al., 1995; Johnson and Dock, 1996; Richardson and Davis, 1995; Melville and Hadfield, 1991). Due to the failure of bridges loss of property and life can been seen, moreover the repair works of the bridges are costly so the bridge piers are needed to be protected during the flood conditions. Following are the measures by which the bridge piers can be protected:

- Using Ripraps
- Scour reduction using Slots
- Reduction of scour using Collar
- Foundation Caissons
- Delta wings like Passive Device
- Submerged Vanes
- Tetrapots as artificial Riprap

The most common practice used for the protection of bridge pier is by using riprap stone as armouring devices. Large stones of different shapes are placed at the scour hole to stop the scouring action formed by the horseshoe vortex. The horseshoe vortex is the primary parameter that affects the scour formation, by using riprap stone of known mean diameter (D_{50}), and by required thickness the effect of horseshoe vortex can be reduced.

2. EXPERIMENTAL SETUP

The experiment work were performed in re-circulating tilting flume 10 m long, 0.30 m wide and 0.50 m in Hydraulics Laboratory of BharatiVidhyapeeth College of Engineering, Pune, Maharashtra, India. The working station of the flume is fitted with sediment to a uniform depth of 0.10 m at the bottom of the flume along length to provide same elevation as in bed level in the recess. Non cohesive river bed sand is used as sediment in the experimental work. Two samples of sediments are prepared of d50 = 0.63 mm and Geometric standard deviation σg = 2.0 and d50 = 0.63 mm and Geometric standard deviation σg= 2. V is the approach velocity of flow calculated from the current meter and the discharge and flow depth is calculated from the downstream channel. During the experimental work discharge is adjusted by inlet valve and outlet gate.

Using Shields chart for threshold condition of uniform sediments in water (Melville and Sutherland 1998) the shear velocity V_{*c} is converted to mean shear velocity V_c by the logarithmic form of velocity profile given in the equation below.

$$\frac{V_{ca}}{V_{*ca}} = 5.75 \log\left(5.53 \frac{D}{d_{50a}}\right) \qquad (1)$$

The horseshoe vortex is the primary parameter that affects the scour formation, by using riprap stone of known mean diameter (D_{50}), and by required thickness the effect of horseshoe vortex can be reduced. Lagasse et al. (2006) suggested that the riprap that is used for protection purpose should be of required stone size to overcome the shear failure of the pier. As per HEC-23 (Lagasse et al. 2001), the sizing of the riprap D_{50} is determined using the standard Isbash formula.

$$D_{50} = \frac{0.692(KV)^2}{(S_S - 1)2g} \qquad (2)$$

As per Koerner (1998), the geotextile/geonet used should have a permeability which is more than 4 times greater than that of the bed material. The effective size of the geotextile/geonet filter should be less than d_{90} of the bed material, approximately 2 mm. Lauchalan and Melville (2001) recommended the following design criteria for protection of bridge pier by riprap.

Lateral extend of riprap layer = $3b\ to\ 4b$

Thickness of riprap layer, $t_R = 2D_{50}\ to\ 3D_{50}$

Figure 1 gives the detail recommendation for riprap layer around bridge pier suggested by Lauchalan and Melville (2001)

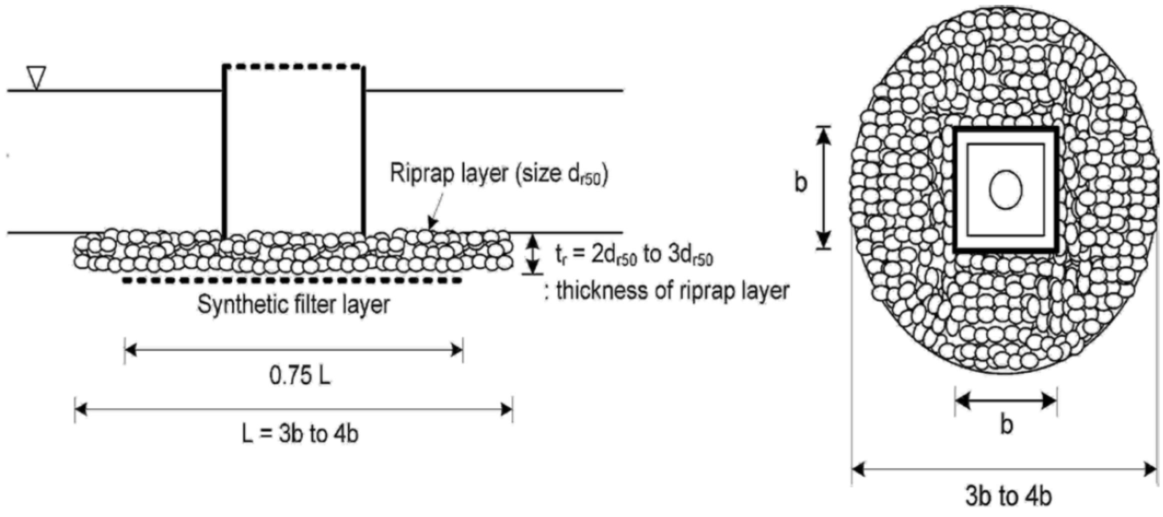

Figure 1 Recommendation for riprap layer around bridge pier (Lauchalan and Melville, 2001)

3. RESULTS AND DISCUSSTIONS

3.1. Experimental Procedure

The bed level is elevated by 10 cm by using false bed and sediment zone 1 m long, 30cm wide and 10 cm deep. It is prepared of 5m from the upstream side of flume and is filled with sediment particles. The round-nose rectangular pier and circular pier is placed vertically at the middle and entire portion of sediment zone (test section). Before starting the experiment work, level the sediment bed along the length of sediment zone by using trowel. Then to start the experiment work, the tilting flume is filled with water gradually to the required depth by adjusting the outlet gate. The flow discharge was slowly increased to the required value to maintain the clear-water scour condition ($V/V_c < 1$). Using Pigmy Type Current Meter the flow velocity was measured by lowering the current meter at the upstream side of the pier. Non cohesive river bed sand is used as sediment in the experimental work. Two samples of sediments are prepared as d_{50} = 0.63 mm and Geometric standard deviation σ_g = 2.0 and d_{50} = 0.63 mm and Geometric standard deviation σ_g = 2.5. During the experiment, the location and magnitude of the maximum scour is measured at the upstream side of the pier by using the pointer gauge with the accuracy upto 0.1 mm. Rate of scouring is maximum in the first hour. The run time for all the experiment is of 3 hrs. The downstream gate is elevated at 45^0 throughout the experimental procedure for all pier types.

3.2. Experimental Data

The results of temporal variation of scour depth in non-uniform sediments for the three different piers. Scour depth measurements were carried out with the help of Vernier Pointer Gauge for three hour duration run.Using Shields chart for threshold condition of uniform sediments in water (Melville and Sutherland 1998) the shear velocity V_{*c} is converted to mean shear velocity V_c by the logarithmic form of velocity profile given in the equation below. Table 3.1 shows the maximum scour formed along the three bridge pier model placed in two sediment standard deviation of σ_g= 2.0 and 2.5 and figure 2 and 3 shows the temporal variation of scour depth with respect to time.

$$\frac{V_c}{V_{*_c}} = 5.75 \log\left(5.53 \frac{D}{d_{50}}\right) \quad (3)$$

Table 2 Maximum scour depth around the piers having σ_g= 2.0 and 2.5

Sr. No	Pier Model	σ_g	Maximum Scour Depth (mm)	Approach Velocity (V)	Critical Velocity (V_c)	$\frac{V}{V_c} < 1$
1	Rectangular Pier	2.0	37.7	0.15	0.293	0.51 < 1
2	Rectangular Pier Narrowing Upwards	2.0	25.4	0.15	0.293	0.51 < 1
3	Circular	2.0	40.4	0.15	0.293	0.51 < 1
4	Rectangular Pier	2.5	34.5	0.245	0.299	0.82 < 1
5	Rectangular Pier Narrowing Upwards	2.5	22.7	0.245	0.299	0.82 < 1
6	Circular	2.5	38.2	0.245	0.299	0.82 < 1

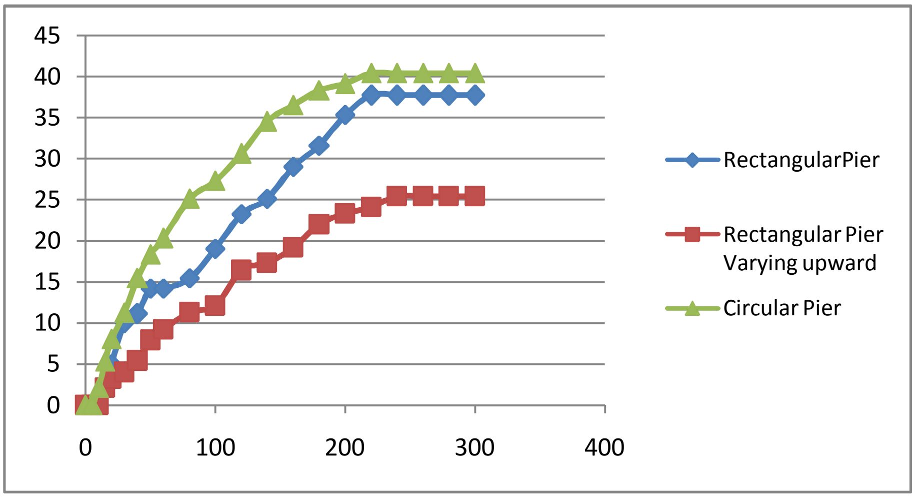

Figure 2 Temporal Variation in scour depth with σ_g = 2.0

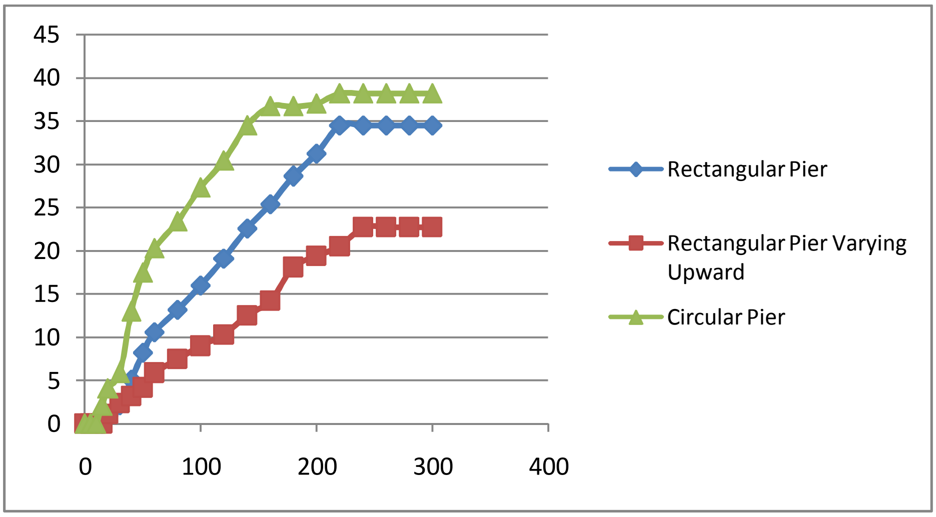

Figure 3 Temporal Variation in scour depth with σ_g = 2.5

The horseshoe vortex is the primary parameter that affects the scour formation, by using riprap stone of known mean diameter (D_{50}), and by required thickness the effect of horseshoe vortex can be reduced.

Lagasse et al. (2006)suggested that the riprap that is used for protection purpose should be of required stone size to overcome the shear failure of the pier.

As per HEC-23 (Lagasse et al. 2001), the sizing of the riprap D_{50} is determined using the standard Isbash formula

$$D_{50} = \frac{0.692(KV)^2}{(S_S - 1)2g} \tag{3}$$

Lauchalan and Melville (2001)recommended the following design criteria for protection of bridge pier by riprap.

Lateral extend of riprap layer = $3b\ to\ 4b$

Thickness of riprap layer, $t_R = 2D_{50}\ to\ 3D_{50}$

Figure 4 gives the detail recommendation for riprap layer around bridge pier suggested by Lauchalan and Melville (2001)

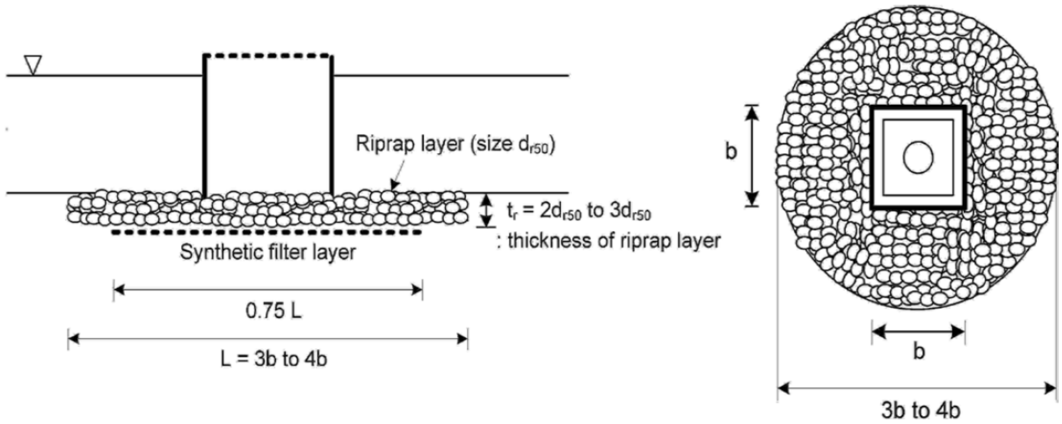

Figure 4 Recommendation for riprap layer around bridge pier (Lauchalan and Melville, 2001)

Table 3 below shows the effect of riprap protection work around the pier having a layer of geofabric/geonet, the runs were performed for around 3 hours and correspondingly readings were taken. The thickness of the riprap was kept the same for circular and rectangular bridge piers.

Table 3 Riprap status around the piers

Sr. No	Time (min)	Size of Riprap, D_{50} (mm)	Thickness of Riprap Layer, t_R (mm)	Lateral Extend of Riprap (mm)	Scour of Riprap	Riprap Status
1	0	9.1	18.2	150	0	Intact
2	5	9.1	18.2	150	0	Intact
3	20	9.1	18.2	150	0	Intact
4	40	9.1	18.2	150	0	Intact
5	60	9.1	18.2	150	0	Intact
6	100	9.1	18.2	150	0	Intact
7	140	9.1	18.2	150	5	Intact
8	180	9.1	18.2	150	5	Intact
9	220	9.1	18.2	150	10	Intact
10	260	9.1	18.2	150	10	Intact
11	300	9.1	18.2	150	12	Intact

4. CONCLUSIONS

The following conclusions are based on the experimental work on scour development around the round-nosed rectangular pier, circular and round-nosed rectangular pier with varying upwards. The three models were tested in the tilting flume with respect to bed level of non-uniform sediments having standard deviation values as 2.0 and 2.5.

The Scour depth around bridge piers for non-uniform sediments for 300 minutes runs was found to be more in circular pier, and less in rectangular pier with and without batter.

It was also observed that when the round-nosed rectangular pier tapered in elevation. i.e. narrowing upwards is placed in the sediment sample the scour depth decreases as compared to simple rectangular pier having round nose.

The horseshoe vortex developed around the rectangular piers creates smaller stresses at the bed material which results in less scour depth

In the case of circular pier the horseshoe vortex developed around the pier creates more stresses at the bed material which results in more scour depth.

The scour depth varies with time more at the initial stage but later it decreases for longer time duration.

Along the upstream side of the pier maximum scour depth is observed due to the vortex formation.

Also at the downstream side of the pier coarser sediment particles is found.

When the layer of riprap was placed along the scour depth the ripraps are intact to each other and the dislodgment is minimised by the geotextile/geonets by placing it over the riprap cover.

The scour of ripraps was still found after 140 minutes but was less as compared to without protection around the piers.

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