Comparative Study of Scouring Around Bridge Piers

P. Sreeja and Supradeep Singh

Abstract Excessive scouring around bridge piers is one of the main causes for bridge failures. Scour is not easily noticeable because it is hidden under the channel flow. Scour around a bridge pier is a challenging problem to planners and hydraulics researchers because of the adaptation of some empirical formulas. The basic reason of such adaptation of empirical formulas is due to lack of monitoring of such complex problem, and hence, the mechanism of scouring is not fully understood. Most of these scour prediction empirical formulas was based primarily on flume experiments. Thus, the knowledge of precise maximum scour depth for a given hydraulic and geotechnical condition is essential for proper design of foundation of the bridge piers as under predicted scour depth will lead to bridge failures, and over prediction of scour depth will lead to unnecessary construction costs. Since most of the scour prediction equations are based on laboratory experiments, it is important to analyse the hydraulic characteristics of the river before and after the construction of the bridge. In this study, analysis has been carried out to understand the influence of different parameters such as sediment size and the shape of the pier using different empirical equations. In India, Indian codes for scour estimation uses Lacey's regime equation for scour depth estimation for the hydraulic design of bridges, which are having certain limitations. Thus, the objective of this study is to obtain a better understanding of the mechanism which causes scouring by considering hydraulic and geotechnical characteristics. Therefore, in the present study, an attempt has been made to investigate the effect of different parameters on scour around bridge piers. The results obtained were compared with equations and models used by other researchers and found that Lacey's equation is giving over predicted values than other empirical equations.

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1   Introduction

Scour at a bridge pier is the formation of a hole around the pier due to erosion of soil
by flowing water [1]. The scour depth around the bridge piers may vary depending
upon the flow depth, angle of attack, pier size, pier shape and characteristics of
the sediments. Numerous researchers have studied the scour mechanism but mostly,
the model studies were made with lot of simplifications and empirical formulas
associated with it [2]. But field investigations in this area are needed to understand
the actual scouring mechanism. Such a study would be helpful in the efficient design
of bridge foundations and strengthening of bed material if required.

1.1   Critical Appraisal of the Reviewed Literature

In laboratory model studies, internal flow characteristics do not truly represent proto-
type bridge pier scouring in rivers in view of large-scale distortion of the models [3,
4]. Hence, there is a need to evaluate the applicability of empirical scour equations
to different site conditions and check its generality. There is also a need to evaluate
whether the predicted maximum scour depth results in highly uneconomical and over
conservative results.

1.2   Objective of the Study

The present research is concerned with the study of local scour around a bridge pier.
The main aim of the study is to understand the scouring pattern for a river-bridge
system in India (Saraighat Bridge, Guwahati). To address this objective, the present
research has the following scope:

1. To model the river reach under unsteady flow conditions using computer software
   package HEC-RAS.
2. To critically evaluate the empirical equations for scour depth determination for
   its generality.

2   Methodology

The primary concern is pier scour which is calculated using one dimensional model
(Hec-Ras) for high flood discharge. Aggradation and degradation are long-term

stream bed elevations which change due to natural or manmade causes. Contraction scour in the bridge channel involves the removal of materials from the bed, where the flow area of the stream is reduced either by natural contraction of the stream channel or by a bridge. General scour is the general decrease of the stream bed during the passage of the flood wave. Local scour involves the removal of bed materials around the structure located in the moving water.

2.1 River Flow Modelling

The river flow modelling is done for scour depth determination around bridge piers using Hec-Ras. Upstream end of the river system is modelled by using stage hydrograph, flow hydrograph and boundary conditions of stage and flow hydrograph. In unsteady flow model, the Saint-Venant equation is used.

Some of the commonly used equations for scour depth determination can be summarised as follows:

Lacey's [5] equation is given by

$$d_s = 0.47k \left(\frac{Q}{f}\right)^{0.33} - h \tag{1}$$

where d_s is the scour depth, Q is the discharge, h is the depth just upstream of the pier, k is the correction factor for local scour depth, and f is the silt factor.

Laursen and Toch [6] equation is given by

$$d_s = 1.35b^{0.7}y^{0.3} \tag{2}$$

where d_s is the maximum predicated depth of local scour, b is the pier width, and y is the flow depth.

Jain (1981) equation is given by [7]

$$d_s = 1.84b \left(\frac{y}{b}\right)^{0.3} (\text{Fr}_c)^{0.25} \tag{3}$$

where d_s is the scour depth, Fr_c is the critical Froude number, y is the depth flow b, and is the pier width.

CSU equation [8] will give maximum pier scour depth and is recommended for both live and clear-water pier scour computation, which is given by

$$\frac{Y_S}{a} = 2.0K_1K_2K_3K_4 \left(\frac{Y_1}{a}\right)^{0.35} \text{Fr}_1^{0.43} \tag{4}$$

where Y_S is the scour depth, Y_1 is the flow depth directly upstream of the pier (m), K_1 is the correction factor of the pier nose shape, K_2 is the correction factor for the angle

of attack of the flow, K_3 is the correction factor for bed condition, $K_4 = 0.4(V_R)^{0.15}$ is the correction factor for armouring by bed material size, and a is the pier width.

Froehlich's pier equation [9] is given by

$$y_s = 0.32\varnothing \left(a'\right)^{0.62} y_1^{0.47} \text{Fr}_1^{0.22} D_{50}^{-0.99} + a \tag{5}$$

where y_s is the pier scour depth; $\varnothing$ is the correction factor for pier nose shape; a' is the projected pier width with respect to the direction of the flow; y_1 is the depth immediately at upstream of the pier; Fr_1 is the Froude number at the upstream of pier; D_{50} is the bed material grain size at which 50 per cent is finer; a is the pier width.

Gumbel's method is used for determining the design flood for different return periods, and the corresponding flood values are used in the river flow modelling for the determination of scour depth.

$$x_T = \bar{x} + K\sigma_{n-1} \tag{6}$$

where x_T is the value of T year flood event; $\bar{x}$ is the mean of the maximum instantaneous flow; σ_{n-1} is the standard deviation of the maximum instantaneous flow.

3   Results and Discussion

The various results obtained from the work done for the determination of depth of scour around bridge piers of Saraighat Bridge in Brahmaputra river for a high flood flow condition at different sections using Hec-Ras software.

The peak flow in the Brahmaputra River from a single gauging station at Pandu Port has been determined using the Gumbel's method and found to be 74,856.736 m³/s corresponding to return period of 50 years. Water surface profile and velocity profile of the river corresponding to these flows have been computed using Hec-Ras for three conditions, namely (i) without the bridge, (ii) with the existing bridge and (ii) with two parallel bridges.

3.1   River Flow Analysis for the Existing Data

Velocity profile of the river without any bridge, with the existing bridge and the two bridges together are determined for the existing data obtained from Gammon India Ltd and return period 50 years. Figure 1 represents the comparison of velocity profile of the river without bridge, with the existing bridge and the two bridges together.
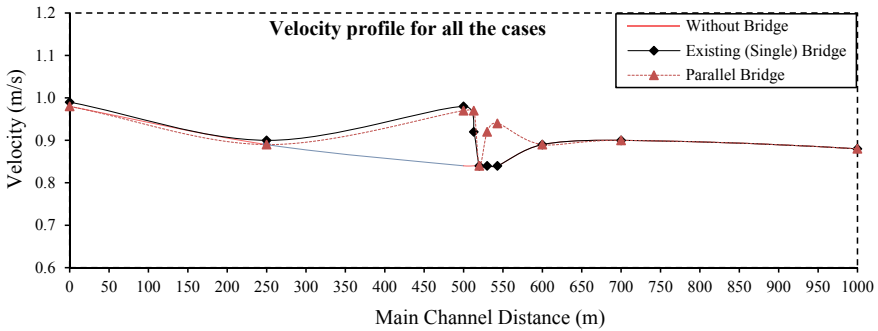
Fig. 1 Comparison of longitudinal velocity profiles in the river with different cases

From Fig. 1, it is seen that for cross-sectional area (without bridge), the velocity is reducing from 0.89 to 0.84 m/s for the channel with a chainage of 250–543 m. This is so caused because the natural flow area is increasing from 19,183.8 to 22,555 m². Now, for the existing bridge that is at the channel distance of 500 m, the velocity is increasing from 0.90 to 0.98 m/s and again decreasing to 0.90 m/s at a channel distance of 513 m. This abrupt change in the velocity is caused due to the sudden contraction of the flow area due to the presence of piers. After crossing the piers, the velocity reduces as the flow area increases and finally attains its stability. Again some variation of velocity is also seen in the downstream direction this is caused because of the variation of the cross-sectional area of the Saraighat River. For the parallel bridge, it is seen that the velocity is abruptly increasing twice that is at channel distance 500 m and again at channel distance 530 m. This is so occurring because the flow area is contracted by the piers due to the presence of multiple bridges.

3.1.1 River Flow Analysis for a Return Period of 50 Years

From Fig. 2, it is seen that for cross-sectional area (without bridge), the velocity is reducing from 0.92 to 0.89 m/s from the channel distance 250 to 543 m. This is so caused because the natural flow area is increasing from 19,183.8 to 22,555 m². For the existing bridge that is at the channel distance of 500 m, the velocity is increasing from 0.92 to 1.01 m/s and again decreasing to 0.97 m/s at a channel distance of 513 m. This abrupt change in the velocity is caused due to the sudden contraction of the flow area due to the presence of piers. After crossing the piers, the velocity reduces as the flow area increases and finally attains its stability. Again some variation of velocity is also seen in the downstream direction; this is caused because of the variation of the cross-sectional details of the river. For the parallel bridges, it is seen that the velocity is abruptly increasing at channel distance 500 and 530 m because the flow area is contracted by the piers due to the presence of multiple bridges

The scouring around the bridge piers have been computed using different empirical equations in the case of cohesionless soil with different sediment particles as listed
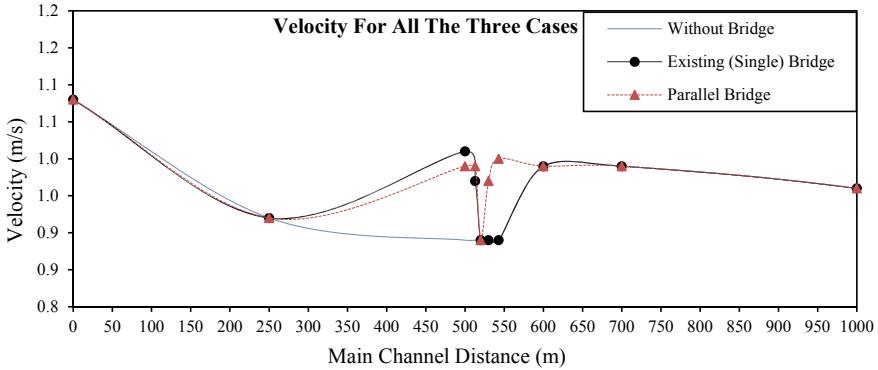
Fig. 2 Comparison of longitudinal velocity profiles in the river with different cases

in table. Different scours such as local scour, contraction scour and total scours have been estimated.

Different grain sizes at different piers of Saraighat Bridge

Pier number	1	2	3	4	5	6	7	8	9	10	11	12
Particle size d_{50} (mm)	0.38	0.37	0.28	0.02	0.32	0.32	0.25	0.32	0.32	0.08	0.71	0.32
Particle size d_{95} (mm)	0.88	0.68	0.62	0.07	0.71	0.75	0.48	0.52	0.48	0.32	1.6	0.63

The total scour calculated for observed flow data and 50 years return flow for the existing bridge have been shown in Figs. 3, 4, 5, 6, 7 and 8 which show the total scour depth for the parallel bridge.
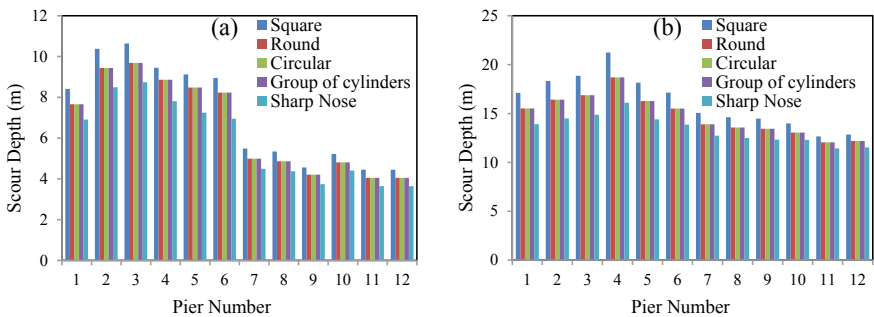

Fig. 3 Total scour depth around the existing bridge using the observed flow data with **a** CSU equation and **b** Froehlich equation
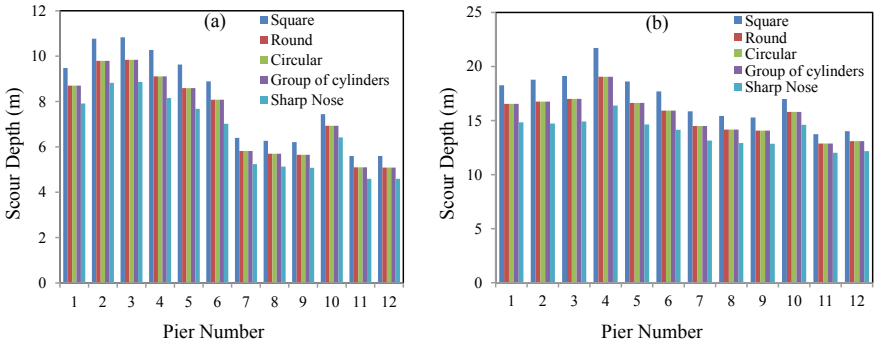
Fig. 4 Total scour depth around existing bridge using the 50 years return period flow with **a** CSU equation and **b** Froehlich equation
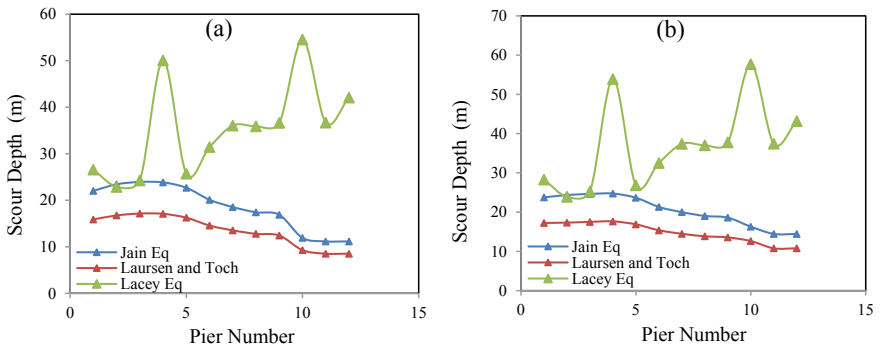

Fig. 5 Total scour depth around the existing bridge using the **a** observed flow **b** 50 years return period flow
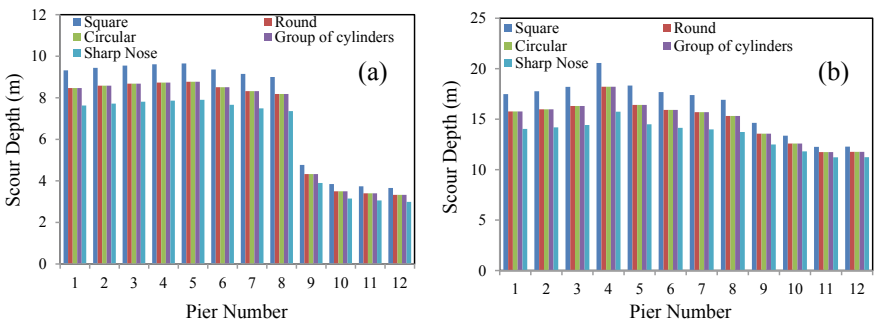

Fig. 6 Total scour depth around parallel bridge using the observed flow data with **a** CSU equation and **b** Froehlich equation
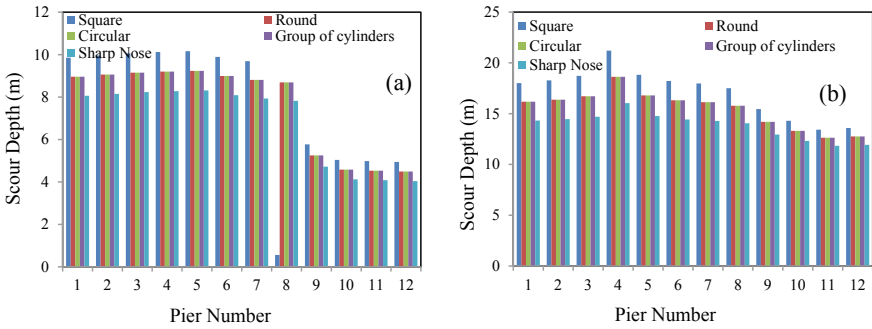
Fig. 7 Total scour depth around parallel bridge using the 50 years return flow with **a** CSU equation and **b** Froehlich equation
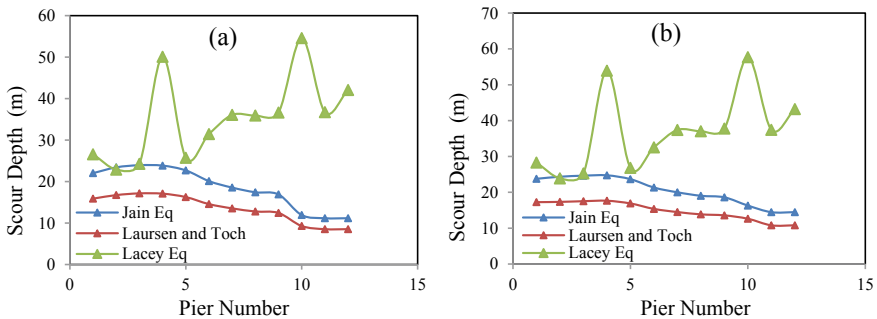

Fig. 8 Total scour depth around the parallel bridge using the **a** observed flow and **b** 50 years return period flow

Hence, it is seen that there is a variation of scour depth at different location of the piers for various kind of data's that is for existing data and 50 years return period using different empirical equations. It is also seen that the scour depth does not follow the same pattern for all the piers at different flow conditions that is for existing data and 50 years return period. This is due to the fact that the contraction scour has also been added with the local scour which is different for different types of piers.

4   Conclusion

In the present study, the empirical equation for scour depth determination has been critically evaluated; the determination of scour depth has also been done for different types of piers with different bed sediments with different pier shapes,; the change in scouring and flow characteristics in a river due to presence of multiple bridges has

also been evaluated. The important observations from the study are summarised as follows:

1. It has been found that while using CSU equation, the grain size effect is not influenced when diameter of the sediments is less than 2 mm.
2. Froehlich considers the effect of grain size when the diameter are less than 2 mm.
3. Jain and Fischer and Larsen and Toch does not considers the effect of grain size of the sediments.
4. It has been also seen that by using Lacey's equation over predicted values are obtained compared to other formula.

From the numerical study, it has been noted that the scour depth increases with the increase in approach flow depth and decreases at greater rate with decrease in flow depth. The decrease in scour depth is due to the interference of the eddies formed around the pier with the downward flow into the scour hole.

4.1 Future Scope of Work

Since the observed data for the scour depth was not available, the validation of the results could not carry out. Study has to be carried out for improving Lacey's equation for using the same for scour determination in the case of cohesive soils.

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