PHYSICAL MODEL STUDY OF SCOURING EFFECTS ON RAFT FOUNDATION OF BRIDGE PIERS

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ABSTRACT: Construction of raft foundation is one of the economical and viable options for bridge piers in Maharashtra. The objective of the present study to evaluate the scouring behavior of bridge pier constructed with raft foundation through physical model tests. In the on-going series of experiments being conducted at IIT Bombay, a horizontal masonry flume constructed at the Hydraulics Laboratory of IIT Bombay was used. The flume is 11m long, 2m wide and 1.3m deep, having a PCC floor. At a distance of 6m from the upstream end of the flume, a Perspex window of length 3m is provided, which facilitates the observation of scour and flow behavior. Using the Froude’s similarity, the model scale was chosen as 1:10. The pier model is made of steel. The raft model is made of marine plywood sheets. The water from the sump is pumped into an inlet tank and re-circulated. The experiments were conducted for a range of discharges and the results are presented. It was observed that majority of scour occurs at the upstream end of the pier only. The provision of raft foundation reduces the scour to a large extent especially along the sides of the pier.

INTRODUCTION

Scour at bridge piers may be defined as a localized lowering in the bed elevation around the pier or loss of support to the bridge pier. This lowering is caused by the three-dimensional boundary layer separation at the pier, resulting in erosion of bed material by the local flow structure, which is characterized by a high level of turbulence and vortices. One of the main concerns about the stability of bridge foundations is the occurrence of scour around piers. The foundation strata for the bridge structures while executing bridge projects, varies from exposed hard rock to pure sand for considerable depth. If good founding stratum is not available in a shallow depth, the construction of small bridges becomes uneconomical. Majority of the rivers in Maharashtra have thick sandy beds, where raft foundation is a feasible solution.

Chiew [1,2] showed that by placing a one-fourth diameter wide slot near the water surface or the bed level, it is possible to reduce the clear-water scour depth by as much as 20%. A one-half-diameter-wide slot placed near the water surface can reduce the clear-water scour depth by as much as 30% [3]. When a slot placed near the bed is combined with a collar, the study showed that the combination is capable of eliminating scouring altogether.

As per the IRC: 89-1997, 78-2000 [4, 5] whenever adoption of shallow foundations for bridges becomes economical, in order to restrict the scour, floor protection has to be provided. The floor protection will comprise of rigid raft with cutoff walls and a flexible apron, to check scour, washing away or disturbance by piping action. Maximum velocity of the flow should be less than 2m/s and the intensity of discharge should be limited to 3m$^3$/m. The rigid raft shall be provided under the bridge extending for a distance of at least 3m on upstream side and 5m on downstream side of the bridge pier. The rigid raft shall be enclosed by cutoff walls with a minimum of 2m on the upstream side and 2.5m on the downstream side. The rigid raft shall be continued over the top width of cutoff walls. Flexible apron of 1m thickness comprising of loose stone boulders, weighing at least 40kg, shall be provided beyond the cutoff walls for a minimum distance of 3m on the upstream side and 6m on downstream side. Cement concrete blocks, or wire crates filled with stones can also be used in place of boulders.

Ugalmugale and Namjoshi [6] have discussed about the design and construction of two major bridges (submersible) across River Bawanthadi and high level bridge across river Kanhan where innovative methods were developed during execution.

Borde and Jangde [7] have concluded that raft foundation is a most economical solution in the case of weak soils where open foundation is not possible. Raft foundations can be most effectively used on small streams and rivers. In rural road development programmes where such structures are required in large number, lot of economy can be achieved. Span lengths up to 10m are suitable for adopting raft foundations since longer spans would make foundation uneconomical. In Maharashtra, the major rivers, like Godavari and Wainganga have been bridged with raft foundations. Raft foundations are equally good for submersible bridges.

Dey and Sen [8] have done extensive studies to determine the scour depth in boulder-bed Rivers under high stream
velocities. If the pier is fitted with a circular collar of diameter three times the pier diameter at the river bed level, the reduction in scour depth is 100%.

Studies on physically scaled-down models of the pier resting on a raft foundation subjected to different flow conditions in controlled channel flow condition in a laboratory may reveal useful information, which can be used to finalize optimum parameters for the design. Literature review showed that not many model studies have been conducted in Indian conditions to understand the scouring behavior of pier with raft foundations. With an objective of getting better understanding, a physical model study has been undertaken at Department of Civil Engineering, IIT Bombay, sponsored by the Ministry of Road Transport and Highway. Preliminary experiments were conducted to understand the scouring phenomena of simple bridge piers were conducted [9]. In continuation of this project, experiments were conducted on a physical model of pier with raft foundation and some of the results are presented in this paper.

**EXPERIMENTAL DETAILS**

The present study is focused on physical model studies of the scouring behavior at a bridge pier with raft foundation. The experiments were conducted in a horizontal masonry flume constructed at the Hydraulics Laboratory of IIT Bombay. The flume is 11m long, 2m wide and 1.3m deep, having a PCC floor. At a distance of 6m from the upstream end of the flume, a Perspex window of length 3m is provided which facilitates the observation of scour and flow behavior. Using the Froude’s similarity [10,11], model scale chosen is 1:10. The pier model is made of steel. The raft model is made of marine plywood sheets of 12 mm thickness. The water from the sump is pumped into an inlet tank and re-circulated. In the study, a bridge with two spans is considered so that one central pier and two side piers are provided with a raft foundation which extends to the entire width of the flume and was placed in the test section. The water from the sump was pumped into an inlet tank. Adequate stilling arrangements were made to dissipate the energy of falling water. From a big tank, water enters into the channel. A bell mouth arrangement was provided. A wire mesh was provided and pebbles were laid at the entry point to enable smooth entry of water in to the flume. Figure 1 shows the plan view of the test section. Figure 2 shows the schematic diagram of the longitudinal cross section of the flume at the test section.

The bed material used was River sand (d<sub>50</sub> = 0.5mm, specific gravity = 2.93 with 98.1 % sand content). The grain size distribution is shown in Figure 3. The sand used in the present study can be classified as SW according to Unified Soil Classification system [12].

The initial bed levels were recorded using 2D Bed Profiler [13]. Water was allowed into the channel with the discharge being introduced gradually without disturbing the sand bed. The discharge was measured using Ultrasonic Flow Meter. The velocity was measured with a Programmable Electromagnetic Liquid Velocity Meter [14].

The velocity of flow, in the model for the maximum possible discharge, in the model was 0.923m/s, with a flow depth of 210mm. The corresponding values in the prototype are 2.92m/s and 2.1m respectively. The experiments were conducted for a period of 8 hours to attain regime
conditions. Figure 4 shows the vortex formation during the flow at the upstream end of the pier.

After 8 hours, the flow was allowed to stop and the water was drained out. The bed levels after the formation of the scour were also recorded using the 2D bed profiler. The data from the bed profiler were analyzed and scour contours were plotted using Surfer software package.

**RESULTS AND DISCUSSION**

The experiments were conducted with simple piers and piers with raft foundation, for flood discharge conditions. In both cases, the maximum scour was observed at the upstream end of the pier. But provision of raft foundation has helped in reducing the scour depth by approximately 17%, for the same value of discharge, depth and flow velocity. This endorses the fact that provision of raft foundation reduces the damaging power of the horse shoe vortex and thereby the scour.

Figures 5 and 6 show the scour contours with simple pier and pier with raft foundation. For the prototype, the maximum scour depth without raft foundation was 0.93m, whereas the maximum scour depth with raft foundation measured to 0.77 m. For the model, Figures 7 and 8 shows the photographs of the scour hole, with simple pier and pier with raft foundation. Minimal scour was observed at the downstream end of the pier.

Further experiments were conducted for a range of discharges and the results were analyzed. It was observed that majority of scour occurs at the upstream end of the pier. The provision of raft foundation reduces the scour to a large extent especially along the sides of the pier.
CONCLUSIONS
In this study, a 1:10 physical model has been constructed to test the scouring pattern around bridge pier with raft foundation and various parameters affecting it. The experiments were conducted for different depths of flow and discharges. The flow behavior, scour pattern and behavior of the horse shoe vortex were observed. It was observed that maximum scour takes place on the upstream side of the pier, though provision of raft foundation has reduced the scour depth by almost 17%, than the simple pier case. In the next phase, the effect of extending the width of raft foundation to the upstream and downstream side of the pier would be pursued.

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