SLOTTED PIER AS A SCOUR CONTROL MEASURE

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Abstract— Scour is result of the erosive action of flowing water, excavating and carrying away material from bed and banks of streams and other waterways. Scour is one of the major causes of failure of bridges across the world. The estimation of correct depth of scour below the stream bed is very important since that determines the depth of foundation. In this study an attempt has been made to study the effectiveness of slotted pier as a scour control measures. The provision of slot in the pier helps in reducing the strength of the horseshoe vortex due to the reduction of effective diameter of the pier. Furthermore, the passage of water through the slot reduces the intensity of adverse pressure gradient upstream of the pier. The slot helps to pass most of the flow through it and only the balance is left to cause much reduced scour damage. For this, a rectangular slot is provided on the pier, above bed level and behavior of scour around the pier was observed by conducting model test under clear water
Index Terms—Bridge piers, Scour reduction, scour depth with time, pier diameter.

I. INTRODUCTION

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. Construction of bridge requires careful planning and in depth study and no undue risk should be taken in design and construction. The most common cause of bridge failures is from floods, scouring bed material from around bridge foundations. Scour is the engineering term for the erosion caused by water of the soil surrounding a bridge foundation (piers and abutments). During the spring floods of 1987, 17 bridges in New York and New England were damaged or destroyed by scour. In 1985, 73 bridges were destroyed by floods in Pennsylvania, Virginia, and West Virginia.

The 1973 national study for the Federal Highway Administration (FHWA) of 383 bridge failures caused by catastrophic floods showed that 25 percent involved pier damage and 75 percent involved abutment damage. A second more extensive study in 1978 indicated that abutment scour problems also have the same responsibility as that of local scour for failure of bridge foundation.

II. OBJECTIVE OF THE STUDY

Many bridges failed around the world because of extreme scour around pier and abutment. The failure of bridges due to scour will result in economical loss and may also result in losses of human life. In an extensive study of bridge failures in United States, it reported that damage to bridges and highways from regional floods in 1964 and 1972 amounted about $100,000,000 per event. A large depth of foundation is require for bridge piers to overcome the effect of scour which is a costly proportion. Therefore, for safe and economical design, scour around the bridge piers is required to be controlled. So in this study an effort have been made to reduce the depth of scour by using a rectangular slot through pier, which helps to pass most of the flow through it because of a favorable pressure gradient and balance would be left to cause much reduced scour damage. The basic principle of a slot is either to divert the down flow away from the bed, or to reduce the down flow impinging on the bed. When the slot is placed near the bed, the oncoming flow at the bottom boundary layer accelerates through the slot as a horizontal jet.

III. METHODOLOGY

A laboratory model study has been carried out in a flume channel of 19.25m long, width 1000mm and the depth is 1300mm and observations are made for local scour around slotted and solid bridge piers of different diameters. The experiments were conducted till the scouring process stopped or the change in scour depth was small enough to be neglected. The sand bed is used as bed material and local scour depth was observed for different approach velocity. For each and every set of experiments the pumps were started and water collected at the inlet tank and discharged through the flume channel and finally returned back to the main reservoir through recirculation channel. The pumps are run for up to six hour period and scour depth are measured after every hour interval. The process was continued till scouring reaches a stable condition. The test were conducted for different diameter viz. 3.81cm (1.5″), 5.08cm (2″), 7.62cm (3″) solid and slotted pier and also for different opening ratio of slot at different velocity.

IV. LITERATURE REVIEW

The provision of slot to reduce the power of the horseshoe vortex includes create a conduit for passing the flow through the pier of the bridge. Tanaka and Yano (1967) and Chiew (1992) have studied the effect of providing slots through the body of circular piers on scour depth. Chiew (1992) conducted experiments with two distinct locations of the slots. Kumar et al. (1999) carried out research to determine the scour reduction efficiency of slots of different lengths and aligned at different angles to the flow. The application of slot to control scour in a group of circular bridge piers in a direct canal was studied by Heidarpoor, et al. (2003) findings revealed that the group of bridge piers has a great impact on the depth of scouring on the front part of the pier compared with an individual pier. A.T. Monakada and et. al. (2009) by examining effect of a rectangular slot (width 1.8cm and varied height) observed that a slot in the pier considerably reduces the scour depth. When the slot length increases from the water surface to the bed Level, the efficiency was between 48% and 85%. Therefore, the slot location is a parameter that has a direct effect on the scour depth, with the best location near the bed.

IV SCOUR MECHANISM

The basic mechanism causing local scour at a pier is the formation of vortices at their base. The formation of these vortices results from the pileup of water on the upstream surface and subsequent acceleration of the flow around the nose of the pier. The action of the vortex removes bed material from around the base of the pier. When the transport rate of the sediment away from the pier caused by the vortex is greater than the transport rate of sediment into the region around the pier, a scour hole develops. As the depth of the scour hole increases and widens, the strength of the vortices is reduced, thereby reducing the transport rate of sediment out of the scour hole. At the same time, the widened scour hole is able to capture a greater amount of the bed load moving past the pier. Eventually, an equilibrium condition is established and scouring process can be ignored.

V. SCOUR PROTECTION MEASURE CONSIDERED IN THIS STUDY

There are many approaches available for scour protection measure, but all are economically expensive and construction cost is also more. In our experiment we have used an approach for scour protection measure using rectangular slot on the pier, which helps to pass most of the flow through it because of a favorable pressure gradient and balance would be left to cause much reduced scour damage. The basic principle of a slot is either to divert the down flow away from the bed, or to reduce the down flow impinging on the bed. Considering that, experimental study were conducted with provision of vertical slot on the piers at different velocities and at different opening ratio as scour control measures. Experiments were run under a clear water scour regime on sand bed for a period of 6 hour and the observations were taken at one hour interval.

VI. OBSERVATION

A model bridge arrangement has been made in such a way that the pier axis is perpendicular to the direction of flow of water. The experiment have been conducted using the circular pier of different diameter 3.81cm (1.5″), 5.08cm (2″), 7.62cm (3″) and slotted pier with percentage of opening are 26.24 %, 39.37%, 35.43 %, 49.21%, 32.80 % and 52.49 % of width. The observations were done at four locations, location- U_1 and U_2 just along the upstream face and location D_1 and D_2 along the downstream face of the pier. The observations are made at every 1 hour of interval and the experiments were conducted till the scouring process stopped or change in scour depth was small enough to be neglected. Scour observations were made at all the 4 points under clear water at different diameter and velocity for solid and slotted pier with different opening ratios and observations were explained in the graph

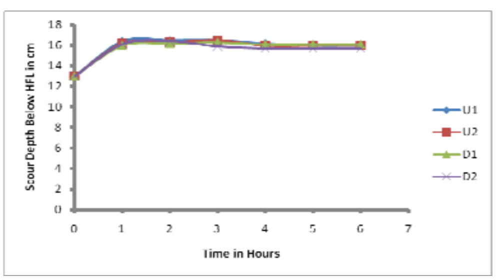

Fig.1: Scour depth behavior for solid pier

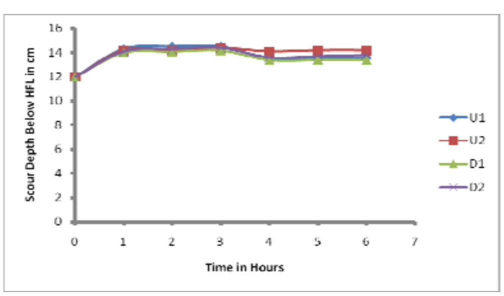

Fig.2: Scour depth behaviour for slotted pier

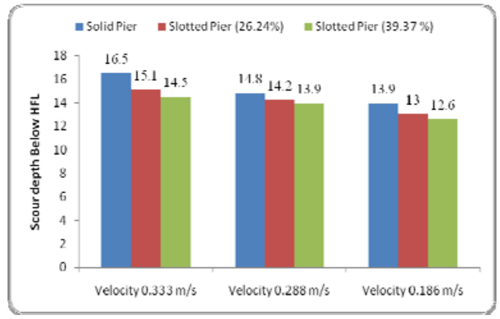

Fig.3: Variation of scour depth at different velocity for pier Diameter 3.81 cm

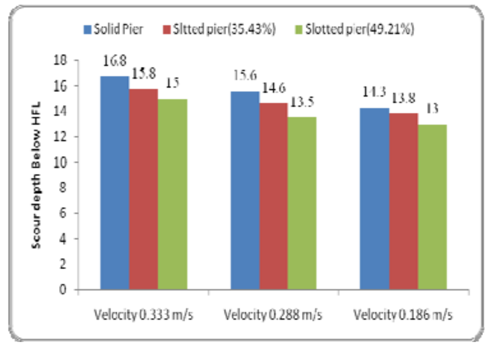

Fig.4: Variation of scour depth at different velocity for pier Diameter 5.08 cm

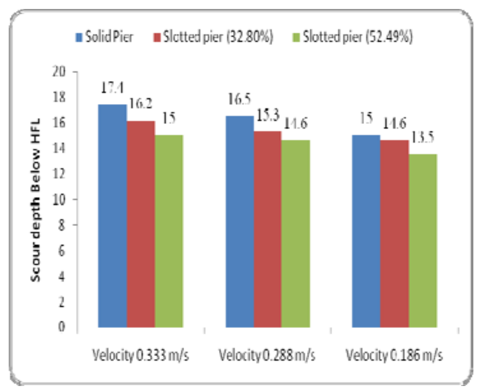

Fig.5: Variation of scour depth at different velocity for pier Diameter 7.62 cm

From above Fig. it was observed that the provision of slot on the pier reduces the scour depth, also observed that scour depth is inversely proportional to the size of slot on pier. Using laboratory data as input, analysis were made for calculation of anticipated scour depth by using current evaluation practices. For the analysis the approach like IRC-78-2000, HEC-18, U.C. Kothiyari methods are adopted and calculated results are compared with experimental results.

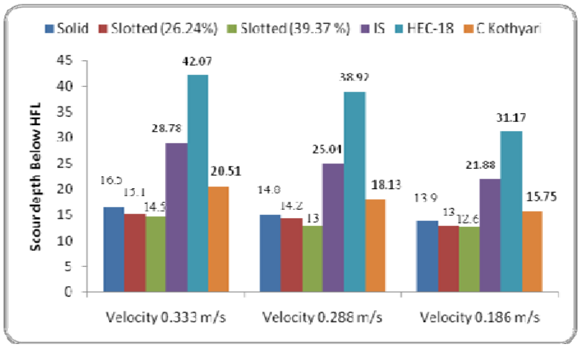

Fig.6: Scour depth evaluated using different approach for pier diameter 3.81 cm

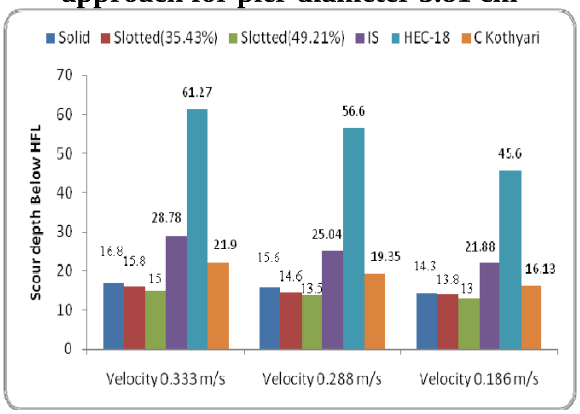

Fig.7: Scour depth evaluated using different approach for pier diameter 5.08 cm

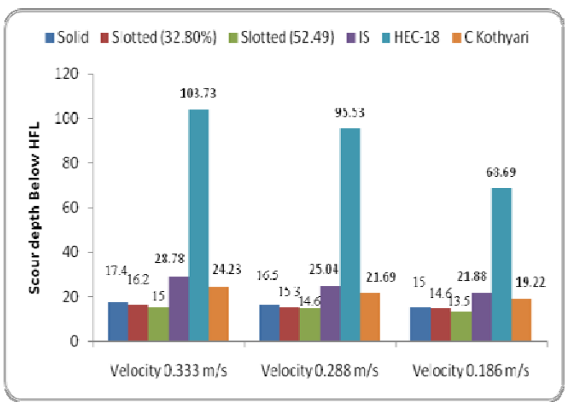

Fig.8: Scour depth evaluated using different approach for pier diameter 7.62 cm

VII. SCOUR DEPTH PREDICATION EQUATION

Development of Regression based model for prediction of equilibrium scour depth in slotted pier:

Using the observed data from laboratory physical models and considering flow velocity (v), pier diameter (d), opening ratio (O_R) and shape of pier as parameters for circular pier, non-linear regression analysis is done by using "XLSTAT" software and the following equations are formulated for estimation of clear-water scour depth around bridge piers.

$$D_{sc}=15.14-0.31v+0.56d-1.84\text{x}10^{-2}\text{x}O_R+8.73\text{x}10^{-3}\text{x}v^2-2.41\text{x}10^{-2}\text{x}d^2\text{x}6.23\text{x}10^{-4}\text{x}O_R^2$$

Where,

D_{sc}= Scour depth below HFL in meter

v= Approach velocity in m/s

d=Pier diameter in meter

Inaccuracy of the equation may arises in different situation, as they are based on limited data obtained from laboratory physical models.

Validation of proposed equation using field data

For validation of proposed equation, the field data used in this study was obtained from American Journal of Environmental Sciences 1(2):119-125,2005 ISSN 1553-345X © Science Publications, 2005. The field data mainly include the discharge, water depth, mean approach velocity, silt factor and maximum observed local scour depth.

The comparison between the measured scoured depths and computed scour depths using proposed equation shows that they are in agreement. The study shows that the proposed formula appear to give a reasonable estimate of local scour depth for solid as well as slotted pier.

VIII. CONCLUSION

From the model study as well as from the analysis of laboratory data and different approaches for scour depth determination, the following conclusion are drawn.

1. For the same approach velocity, bed material and pier diameter, the scour depth reduces due to the provision of slot on pier.
2. Increase in width of slot in the pier reduces the intensity of adverse pressure gradient upstream of the pier, which results in further reduction on scour depth
3. The proposed regression based model for slotted as well as solid pier appears to give a reasonable estimate of the local scour depth.
4. The intensity of scour is greater in the upstream face of the pier than in the downstream face.

5. The rate of scour is maximum at initial period and reduces with time, but the process continues for long time and time to reach equilibrium scour depth varies widely. A practical equilibrium is reached within a relatively short time and after which the increase in the depth and extent of scour becomes virtually imperceptible.

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