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PREDICTION OF LOCAL SCOUR AROUND BRIDGE PIERS

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Abstract: Scour is a natural phenomenon caused due to the erosive action of flowing stream on alluvial beds which removes the sediment around or near structures located in flowing water. It means the lowering of the riverbed level by water erosions such that there is a tendency to expose the foundations of a bridge pier. It 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. Prediction of likely scour depths is an important aspect of the design bridge piers. While detailed guidance is available for the scour design of some bridge piers. In this study, the use of collars for reducing the effects of local scour at a bridge pier is presented together with the time aspect of the scour development. The overall objective of the research is to study the temporal development of the scour for a pier fitted with a collar and a pier without a collar. The study was conducted using a physical hydraulic model operated under clear-water conditions in cohesion-less bed material. The time development of the scour hole around the model pier with and without a collar installed was compared with similar studies on bridge piers. The depth of the scour hole increases as the duration of the increased flow that initiates the scour increases.

Keyword: Scour, Scour depth, design scour, River, Bridge pier, River bed, Sediment, Collar etc.

I. INTRODUCTION

Local scour at piers is the main reason for the collapse of bridges founded in alluvial sediments (Melville and Coleman 2000). Hence, extensive studies have been carried out, mostly focused on equilibrium scour depth, as it is an upper limit for the time-dependent scour depth. Although the equilibrium scour is conceptually simple (in clear-water, the depth to which the scour process tends). the desired flow conditions are established and the scour is allowed to develop and eventually reach equilibrium, but even after a few weeks, evolution of the scour may still be observed, prompting formulas (models) that do not consider equilibrium scour (Oliveto and Hager 2002). Besides their human toll, bridge failures cost millions of dollars each year in direct expenditure for replacement and restoration in addition to the indirect expenditure related to the disruption of transportation facilities (Lagasse and Richardson 2001). Moreover, while a lot of work has been done to develop equations for predicting the depth of scour, many researchers have also worked extensively to understand the mechanism of local scour. Raudkivi and Ettema (1983), Ahmed and Rajaratnam (1998), Chiew and Melville (1987) and Breusers et al. (1977), among others, are some of the researchers that have worked on pier scour. Local scour around bridge piers was studied by Shen and Schneider (1969) while Breusers et al. (1977) gave a state of the art review on local scour around circular piers. Current research areas include understanding the scour processes, temporal development of scour, predicting scour in cohesive soils, parametric studies of local scour, and prediction of scour depth at various types of hydraulic structures. For example, Ansari et al. (2002) studied the influence of cohesion on scour around bridge piers. Ahmed and Rajaratnam (1998) investigated the flow around bridge piers in their laboratory study on flow past cylindrical piers placed on smooth, rough and mobile beds. Lim and Chiew (2001) presented a parametric study on riprap protection and failure around a cylindrical bridge pier with uniform bed sediments.

Failure Type	Number of Failure	Percentage
Hydraulics	1027	58%
Collision	224	13%
Overload	220	12%
Fire	52	3%
Deterioration	116	7%
Earthquake	19	1%
Other	111	6%
Total	1769	100%

A. Reduction of Scour

Reduction of scour depth around foundations of bridge pier is an important part in tackling the problems associated with scour. Since complete protection from scour may prove to be highly expensive, reducing the depth of scour so as not to expose the foundations shall be of extreme importance in controlling the overall stability of the piers. Many authors have in the past attempted to reduce the scour by employing various techniques. Collars are also used on bridge piers to reduce local scouring. The basic function of a collar is to divert the down flow and hence to protect the riverbed from its direct impact.

B. Scour Reduction using Collar

When a collar is installed around the pier, the direct impact of the down flow on the streambed is prevented, which not only causes reduction in the maximum scour depth but the rate of scouring is also reduced considerably. Reduction in the rate of scouring reduces the risk of pier failure when the duration of flood is low. The scour reduction efficiency of collars has already been established in earlier studies (Zarrati, 2006; Zarrati, 2004; Kumar, 1999; Chiew, 1992;

Ettema, 1980; Tanaka and Yano, 1967; Thomas 1967; Schneible, 1951). Chiew (1992) also tested a collar with an effective width of three times the pier diameter. Kumar, (1999) performed a series of experiments on effectiveness of collar for control of scouring around circular bridge piers. They concluded that with a collar at the bed when B is 4 times pier width, there will be no scour in front and sides of the pier, but a deep scour hole forms at the pier's rear. For the use of collars around piers Kumar, (1999) derived design relationship in Equation (1).

$$\left(\frac{ds_p - ds_c}{ds_p}\right) = 0.057\left(\frac{B}{D}\right)^{1.612}\left(\frac{H}{Y_0}\right)^{0.837} \quad (1)$$

where:

ds_p = depth of scour on pier without a collar; ds_c = depth of scour on pier with a collar;

B = diameter of collar; D = diameter of circular pier; H = elevation difference between water surface and collar surface; Y_0 = depth of water above bed elevation.

Ettema, 1998), Zarrati, (2004) also performed some experiments with varying angles of attack. A pier fitted with a collar is shown in Fig.1.

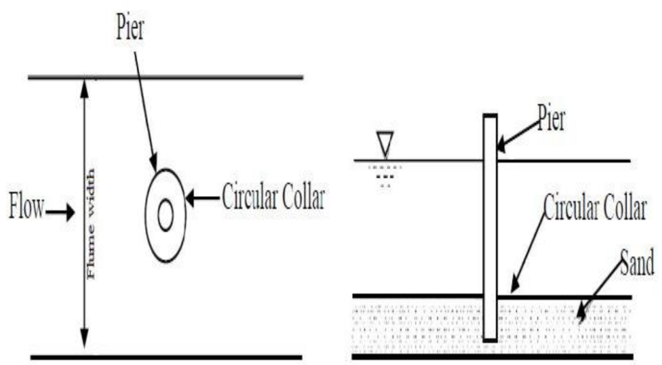


Fig.1 Schematic Illustration of a Pier Fitted With a Collar

Zarrati, (2006) examined experimentally the scour depth reduction efficiency of collar around a group of two circular piers aligned with the flow (Fig.2a) and transverse to the flow (Fig.2b).

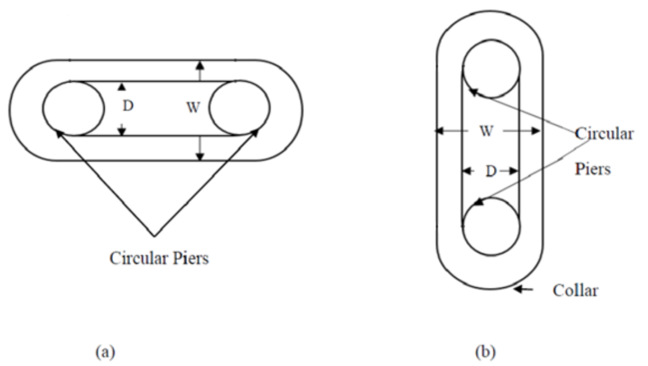


Fig.2 Group of two Piers with Collar aligned with the Flow and Transverse t the Flow

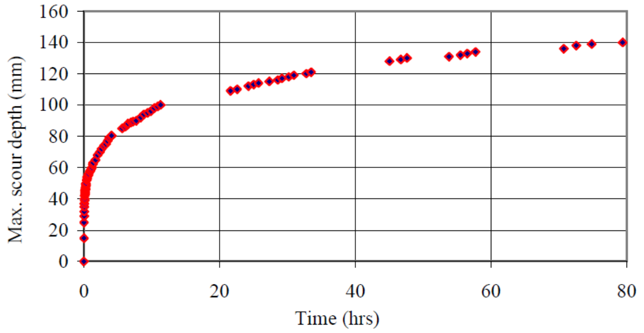
The space between two piers was covered with riprap. The data showed that in the case of two piers in line, combination of continuous collars and riprap results in the most significant scour reduction.

C. Scour test results:

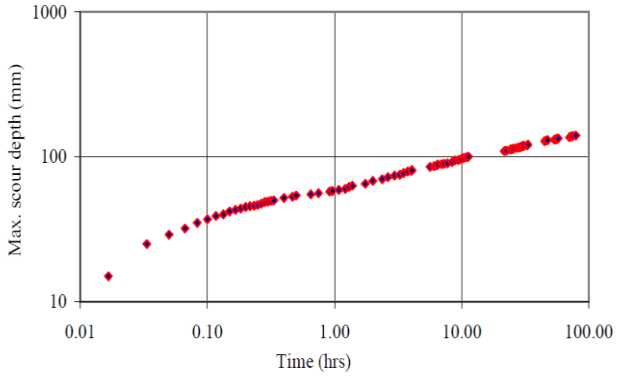
In the tests, the time development of scour as well as the efficacy of using a collar as a countermeasure was studied. For the tests, a 115 mm pier diameter was used for the case where no collar was fitted to the pier and for the case where a collar was used. The tests were conducted under clear-water conditions at a flow intensity, (U/Uc= 0.89). In this work, the temporal development of scour at a circular pier fitted with or without a collar was experimentally studied using a physical hydraulic model. The study was performed under clear-water conditions using a uniform cohesion-less bed material and a circular pier. The principal objective of this study is to carry out a much longer test than found in the literature with a view to evaluating the time development of the local scour pier collar for mitigating the depth of scour that would otherwise occur at a bridge pier, and the assessment of the occurrence of an equilibrium scour condition, if achieved, or of the implications of not achieving such a condition in respect of interpreting the results obtained from a physical hydraulic model study. Also to be assessed as part of this study are some of the equilibrium scour depth prediction equations as well as some definitions of equilibrium scour depth found in the literature.

D. Pier without a collar

For this test, the effect of the scouring process was noticed immediately upon starting the test. Fig. 3 shows the time development of the maximum scour for the 115 mm diameter pier. As the results show, the maximum scour depth increases with time. However, an equilibrium scour condition was not reached before the test was stopped at about 80 hours. The test was stopped because the scour was about to penetrate through the thickness of the sand layer in the flume. The log-log plot of the temporal development of scour depth has been included to show that the equilibrium scour is not being approached as indicated by the continuous increase of the slope of the plot in Fig. 3(b). The scour rate versus time for the test is shown in Fig.4. The scour rate is defined as the change in scour depth per change in time (mm/hour). Even though equilibrium was not attained, the rate of scour is low by the end of the test. The scour rate, which was 240 mm/hr during the first three minutes of the test, was drastically reduced to about 0.2 mm/hr by the end of the test as depicted in Fig. 4. The slope of a straight line fitted to the figure is 0.833. Being a negative slope denotes that the scour rate decreases with time. After the 80-hour test duration, the maximum scour depth was 140 mm. As the data show, about 70% of the maximum depth of scour was attained within the first 12 hours, which corresponds to approximately 15% of the total test duration.



(a) Arithmetic scale



(b) Log-log scale

Fig.3. Temporal development of scour depth for the 115 mm pier without a collar:

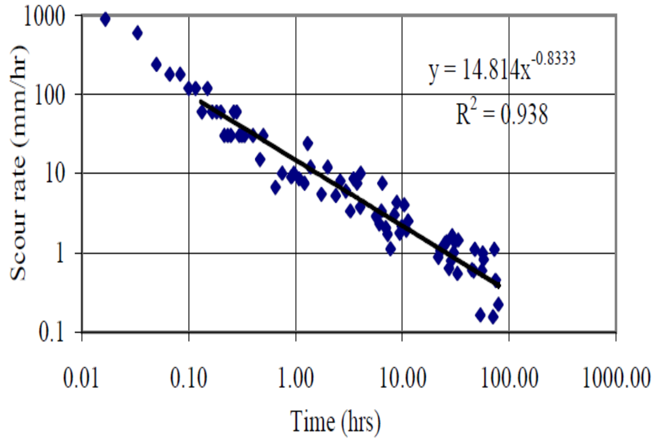
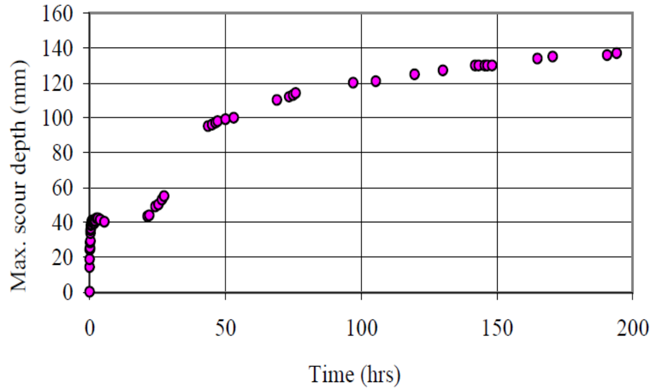


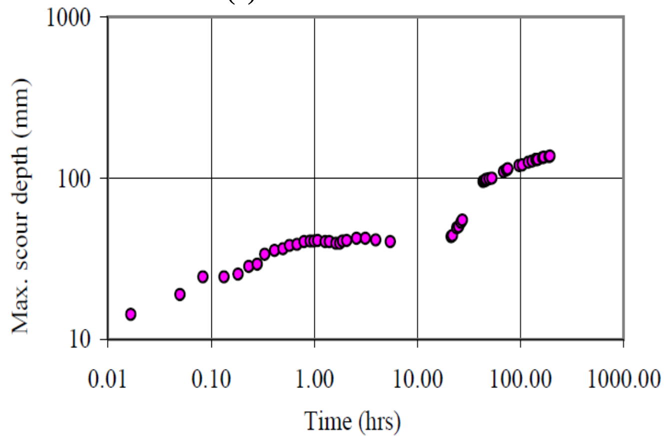
Fig. 4. Scour rate with time for the 115 mm pier without a collar

E. Pier fitted with a collar

For this test, a collar was positioned at the level of the channel bed in accordance with the recommendations of earlier researchers (e.g., Ettema 1980; Kumar et al. 1999). Scour was first noticed to occur at the edge of the collar on either side of the collar toward the downstream portion of the collar. As sediment material was being removed from beneath the collar at the upstream side of the pier, deposition was taking place in the grooves that had formed around the periphery of the collar. The maximum scour depth, which had been located within the grooves, gradually decreased as more sediment material was scoured from below the collar.



(a) Arithmetic scale



(b) Log-log scale

Fig. 5. Temporal development of scour depth for the 115 mm pier with a collar

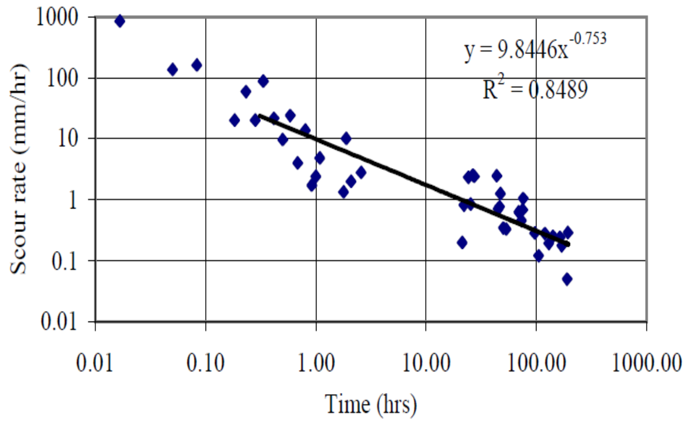
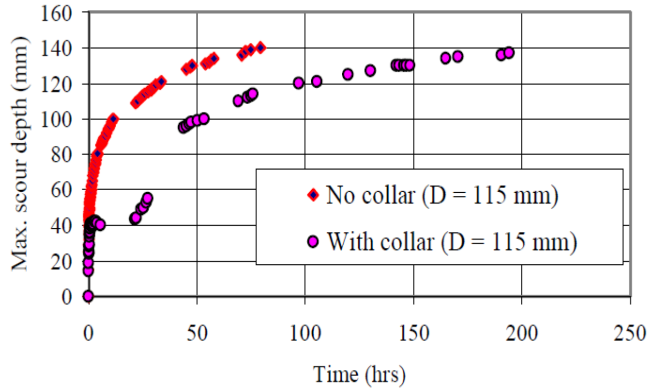
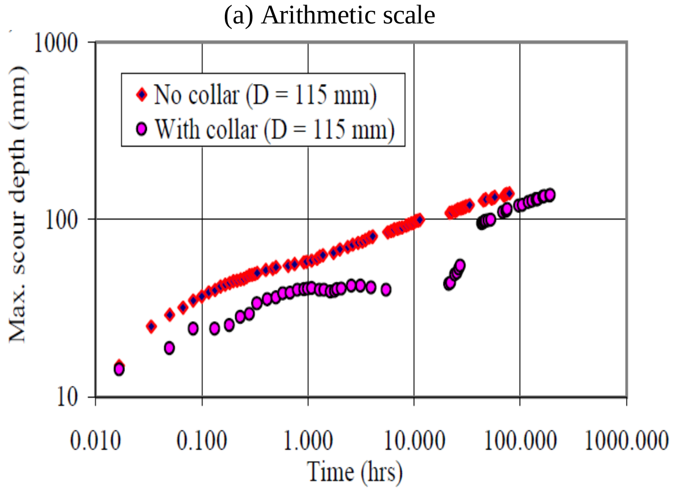


Fig. 6 Scour rate with time for the 115 mm pier with a collar

To further compare the data set in the tests, the time development of the maximum scour depth for the model pier with a collar and the case where a plain pier was used is SHOW IN Fig. 7. In Fig. 7, the data indicated in Fig.3 were plotted together with that of Fig. 5 for easy comparison. As shown in Fig. 7, the time development of local scour can vary depending on whether a collar has been fitted to the pier or not. For the two tests, it can be seen that the time history of the scour is different. For example, after 22 hours, the maximum measured depths were 44 mm and 109 mm, respectively, for the pier protected with a collar and the one without a collar. Ettema (1980) identified three phases of the development of local scour at a cylindrical pier. They are the initial phase, the principal erosion phase, and the equilibrium phase. As defined by Ettema, only the first two phases have been experienced in the tests. An equilibrium phase was not reached. Ettema defined the time to equilibrium scour as the time at which no more than 1 mm of incremental scour was realised within a timeframe of four hours. Since the test durations reported here are greater than some of those reported by Ettema (less than six days), it would seem doubtful if an equilibrium phase is attainable. Therefore, the idea of equilibrium scour condition being achieved within that time frame as reported by Ettema might have been misreported in the literature.



(a) Arithmetic scale



(b) Log-log scale

Fig. 7. Combined temporal development of scour depth

In summary, the time development of scour for a 115 mm diameter pier was studied in the tests for the case where a collar was fitted to the pier and for the plain pier case where no collar was fitted to the pier. It was observed that as the time increased the scour depth also increased. It was observed that the rate of scour decreased as the time increased. The results are in agreement with the work of other researchers such as Ettema (1980), Tanaka and Yano (1967), Chabert and Engeldinger (1956), Thomas (1967) and Chiew and Melville (1992). It was noted that the efficacy of a collar as a countermeasure decreased as the test duration increased. An equilibrium condition was not achieved in the tests.

II. CONCLUSION

The results of the model study indicated that the depth of scour is highly dependent on time. The depth of the scour hole increases as the time increases. The extent of scour observed downstream of the pier also increases as time increases. It was found that the temporal development of the scour hole at a pier is dependent on whether or not the pier is fitted with a collar placed at the bed level. The pathway to equilibrium depth is different depending on whether the pier is fitted with a collar or not. There were two bends in the scour depth-time curve for a case where a collar was fitted to the pier when compared with a single kink in case of a plain pier. With a collar in place, the development of the scour hole is considerably delayed.

Further, it was also found that:

There was a reduction in the scour depth when a collar was used to protect the pier when compared with a plain pier. The scour rate was lower for the case of a test with a collar than when no collar was attached.

III. APPENDIX III.

NOTATION

The following symbols are used in this paper

D	=	pier diameter
ds_p	=	scour depth on pier without a collar
ds_c	=	scour depth on pier with a collar
Y_o	=	Depth of water above bed elevation
H	=	Elevation difference between water surface and collar surface
B	=	Diameter of collar

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