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Experimental Study of Local Scour Depth around Cylindrical Bridge Pier

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***Abstract*—**The failure of bridges due to excessive local scour during floods poses a challenging problem to hydraulic engineers. The failure of bridges piers is due to many reasons such as localized scour combined with general riverbed degradation. In this paper, we try to estimate the temporal variation of scour depth at nonuniform cylindrical bridge pier, by experimental work conducted in hydraulic laboratories of Gaziantep University Civil Engineering Department on a flume having dimensions of 8.3 m length, 0.8 m width and 0.9 m depth. The experiments will be carried on 20 cm depth of sediment layer having d_{50}=0.4 mm. Three bridge pier shapes having different scaled models will be constructed in a 1.5m of test section in the channel.

***Keywords*—**Scour, local scour, bridge piers, scour depth.

I. Introduction

SCOUR around bridge pier is usually widely divided into general scour, contraction scour and local scour. General scour happens without the existence of bridge. The contraction scour results from the acceleration of the flow due to the constriction of channel, while local scour happens by the turbulence around bridge obstacles such as pier and abutment. According to statistic, "60% of all bridge failures result from scour and other hydraulic related causes. In this regard, scour is the primary cause of bridge failure in the United States" [9]. As demonstrated in Fig. 1, the strong vortex motion caused by the existence of the pier entrains bed sediments within the locality of the pier base.

The movement of vortices at pier base continues to create a hole and interacts with the flow from upstream, develops into a complex vortex system. The vortex then spreads downstream along the sides of the pier. This vortex shape is often referred to as horseshoe vortex because of its great similarity to a horseshoe [9]. The numerical and experimental studies have been done to study and predict the behavior of the rivers and to measure the maximum depth of scour in equilibrium condition. Based on the difference of the approach flow sediment transportation pattern, the local scour was divided into clear-water scour and live-bed scour [2].

Clear-water scour occurs when there is no moving or transmission of bed material from upstream to downstream of the pier [10]. When there is moving of particles from upstream into the crossing or encroachment, this is called live bed scour. Therefore, the study on the phenomena of pier scour has become a topic of continued interest to the investigators, many researchers worked on investigation of scour depth numerically or experimentally. Review of the important experiments and field studies was given by [1], [3]-[5], [7], [8].

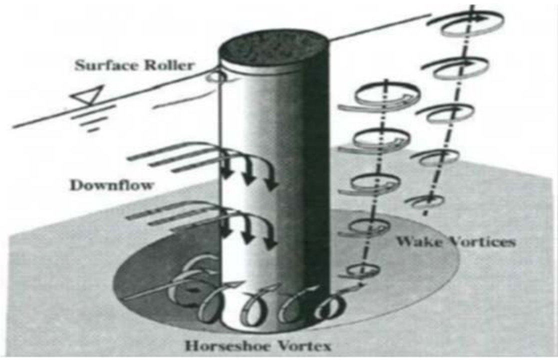

Fig. 1 Vortex motion around a pier [7]

Fig. 2 General View of the Laboratory Flume

A. *Scour Process*

Upon reaching a certain flow velocity in the channel, the sediment particles close to the pier begin to move; scour is initiated. The eroded particles will follow the flow pattern and carried from the front of the pier towards the downstream. Upon an increase in the flow velocity, more and more particles will get dislodged, forming a scour hole increasing in size and depth. Eventually, a maximum scour depth is attained which corresponds to a flow velocity being close to the critical velocity U=Ucr, for initiation of sediment of sediment transport in the channel. For nonuniform sediments, the larger size is less likely to be eroded and an armoring layer forms itself in the scour hole. A subsequent further increase in the flow velocity, U<Ucr, is responsible for a transport of sediments in and out of the scour hole, but the scour depth remains essentially constant. Thus, an average equilibrium

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scour depth, ds, establishes itself, being slightly smaller than the maximum scour depth.

II. Experimental Setup

The experiment in this study was conducted in a circulating flume as shown in Fig. 2. Length of the flume is about 8.3 m, width is 0.8 m, and depth is 0.9 m with glass sides and iron bottom. The study section was setup about 2.8 m from inlet of the flume which is filled with sand medium size of the particles d_{50}=4 mm and gradation coefficient σg=1.15, the thickness of the sand is 20 cm with a test section of 1.5 m. The shape of the samples is circular with a diameter of 5 cm, 7.5 cm and 11.1 cm respectively. The circulating flow system is served by a pump with capacity of 25 L/sec located at the right of the flume and there is a valve to control the flow in the flume. The pump withdraws the water from a sump at the downstream of the flume. At the end of the flume, there is a rectangular weir to measure the flow rate and there is a point gage to measure the depth of the scour hole.

In order to have uniform flow before and after the bridge pier, a ramp was constructed and fixed to the upstream and downstream of the test section of the flume. Experiments were carried out at fix discharges and details of the experimental conditions were given in Table I. Long time duration of 1 hour is chosen in the experiments for each run. The variation of local scour depth with time is measured at various times by stopping the experiments and running it again.

In this study, different size of sediment was tested to determine the d50.

TABLE I
RESULTS OF EXPERIMENTAL WORK

run	D (cm)	h (cm)	t (min)	Q (m/sec)	A	V
A1	5	2.5	15	0.00629	0.02	0.31
A2	5	4.4	30	0.0166	0.0352	0.471
A3	5	5.4	30	0.02263	0.044	0.514
A4	5	5.7	30	0.02519	0.0464	0.542
B1	11	2.5	30	0.00629	0.02	0.314
B2	11	4.4	40	0.0166	0.0352	0.471
B3	11	5.4	35	0.02263	0.044	0.514
B4	11	5.8	30	0.02519	0.0464	0.542
C1	7.5	2.5	50	0.00629	0.02	0.3145
C2	7.5	4.4	30	0.0166	0.0352	0.4715
C3	7.5	5.4	30	0.02263	0.044	0.514
C4	7.5	5.8	50	0.02519	0.0464	0.542

*A: code for 5 cm circular pier, *B: code for 11.1 cm circular pier *C: code for 7.5 cm circular.

III. Results and Discussions

In this study, the experiments were carried with 5, 7.5, and 11.1 cm circular piers with four discharges. Experimental conditions are shown in Table I. The present experimental results are compared with the results of [1]. They have derived empirical equation for predicting the maximum equilibrium local scour depth by using the experimental results of [6].

$$d_s = 1.35\, kD^{0.7}y^{0.3} \qquad (1)$$

where ds=equilibrium scour depth; K=1 for circular pier; D= pier diameter; y=depth of flow.

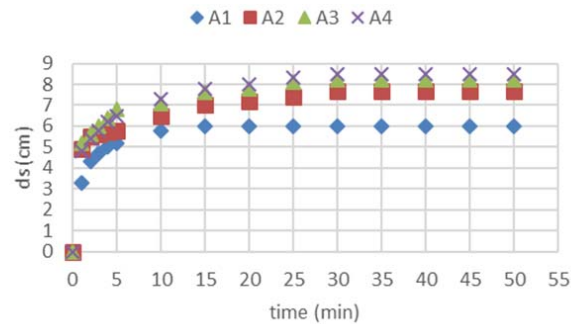

Fig. 3 Evolution in scour depth according to different time for sample (A)

In Fig. 3, there are four experimental run for each pier at different discharges. Fig. 3 shows that maximum scour depth reaches in equilibrium after 15 minutes for lower discharge and increased by increase of discharge for the pier diameter of 5 cm.

Fig. 4 shows time variation of local scour depth for pier diameter of 7.5 cm at different discharges. It is clear that there is a variation in maximum scour depth but the effects of the diameter is small on scour depth in that test.

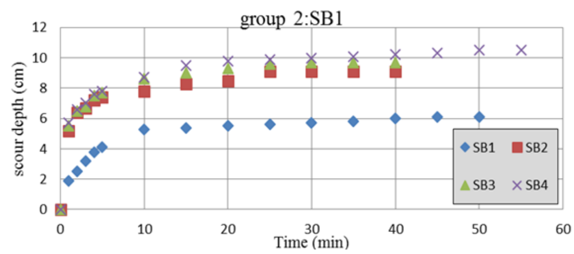

Fig. 4 Evolution in scour depth according to different time for sample (B)

Fig. 5 shows time variation of local scour depth for pier diameter of 11.1 cm at different discharges. It may be concluded that, local scour depth increases with increasing discharge.

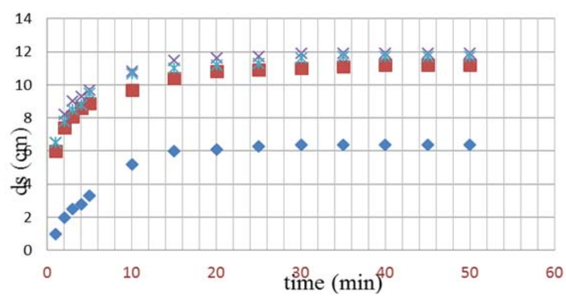

Fig. 5 Evolution in scour depth according to different time for sample (C)

Figs. 3-5 show that equilibrium scour depth increases when approaching discharge to the pier increases. The reason is that the kinetic energy of the flow increases and destructive effect of the flow increases. Many bridges are collapsed during the flood season. Because of this, the pier should be designed for maximum predicted discharge.

Variation of discharge with local scour depth of the present experimental results is shown in Fig. 6 and compared with the results of (1) with pier diameter of 5 cm. There are some discrepancies between our results and result of [1]. The reason of this variation may be the experimental conditions and limitation of [1] are not clear in their study.

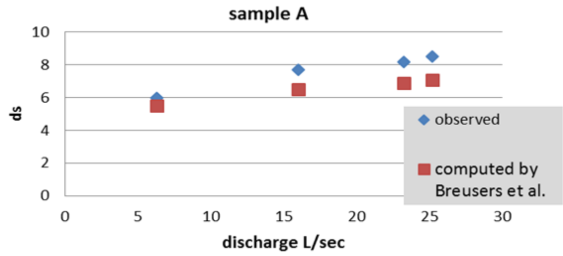

Fig. 6 Comparison between observed and computed of scour depth for sample A

Fig. 7 shows the variation of present experimental results of local scour with discharge. In contrast to Fig. 6, there is no discrepancy between our experimental results and [1] except one point where the discharge less than 10 lt/s. One can say that, Fig. 8 is in good agreement with (1).

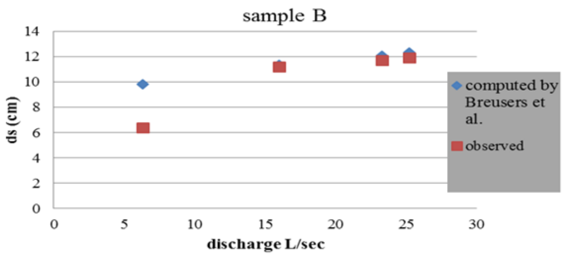

Fig. 7 Comparison between observed and computed of scour depth for sample B

(a)

(b)

Fig. 8 (a) (b) Experimental work show the pier bridge sample A

Fig. 8 shows bathymetry of our experimental work of 5 cm pier diameter. It is seen that, there is an accumulation of sediments in the downstream of the pier and scour around the pier. This picture also shows that the present local scour is live bed scour, because erosion happens at the upstream side of the pier.

Fig. 9 also shows the bathymetry of our experimental work of 11.1 cm pier diameter. The deposition and scour are clearly seen.

(a)

(b)

Fig. 9 (a) (b) Experimental work show the pier bridge sample B

Fig. 9 also shows the bathymetry of our experimental work of 11.1 cm pier diameter. The deposition and scour are clearly seen.

Figs. 10 and 11 show the bathymetry of the scoured bed for 5 cm pier diameter. Scour depth is 8.5 cm at upstream of the pier from the top of the undisturbed sediment bed which is 20 cm. There is erosion at the downstream and upstream but the erosion in the upstream was higher than downstream.

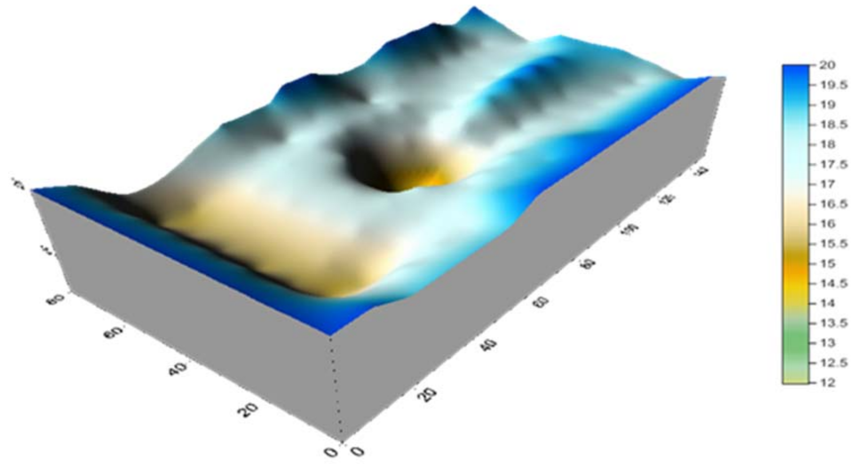

Fig. 10 Bed bathymetry for experimental Run A4 (Scale is cm)

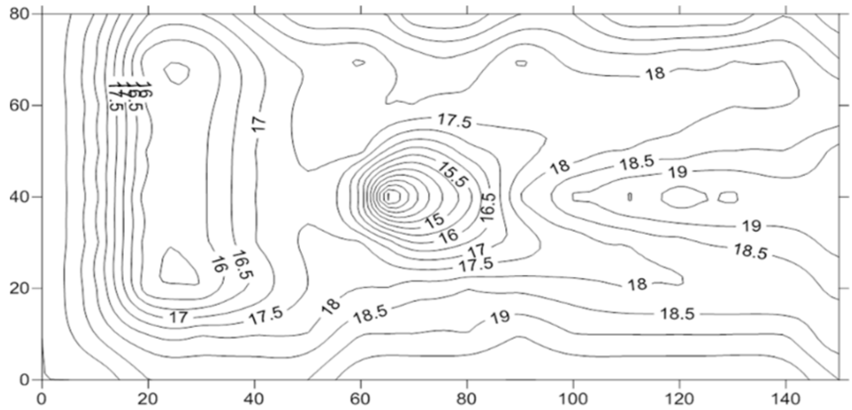

Fig. 11 Topographic bed for Experimental Run A4 (Scale in cm)

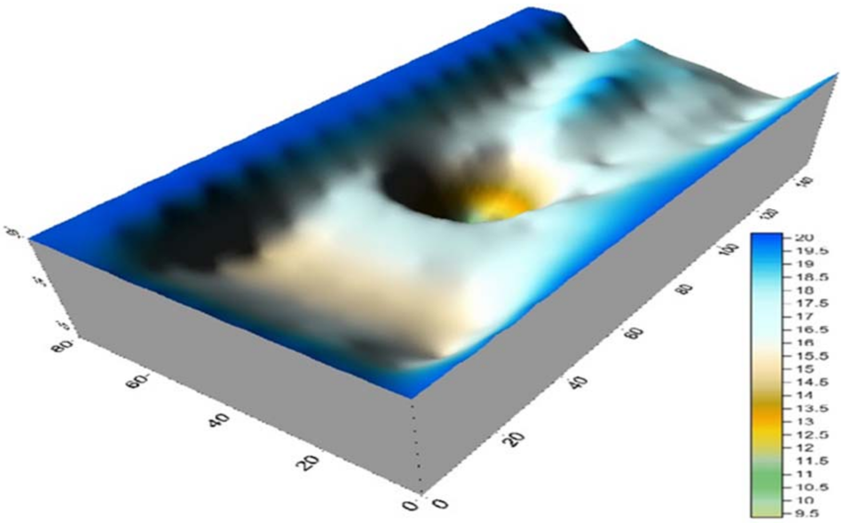

Fig. 12 Bed bathymetry for experimental Run B4 (scale is cm)

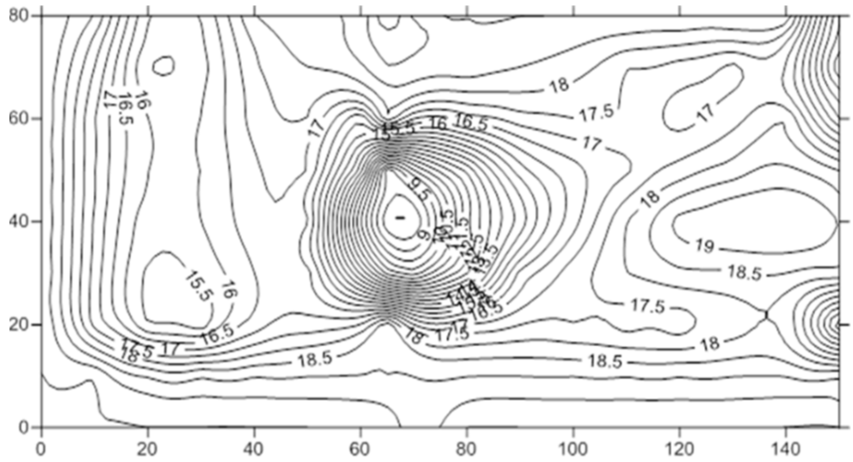

Fig. 13 Topographic bed for experimental Run B4 (scale in cm)

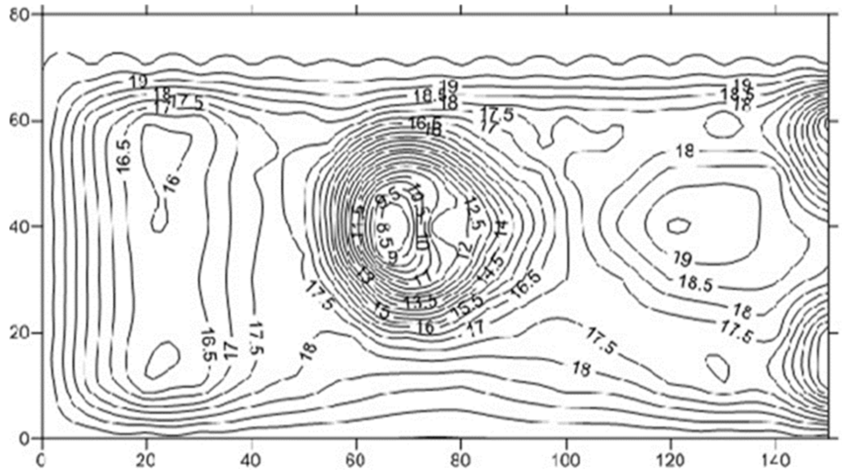

Fig. 14 Graph of topographic bed for Experimental Run C4

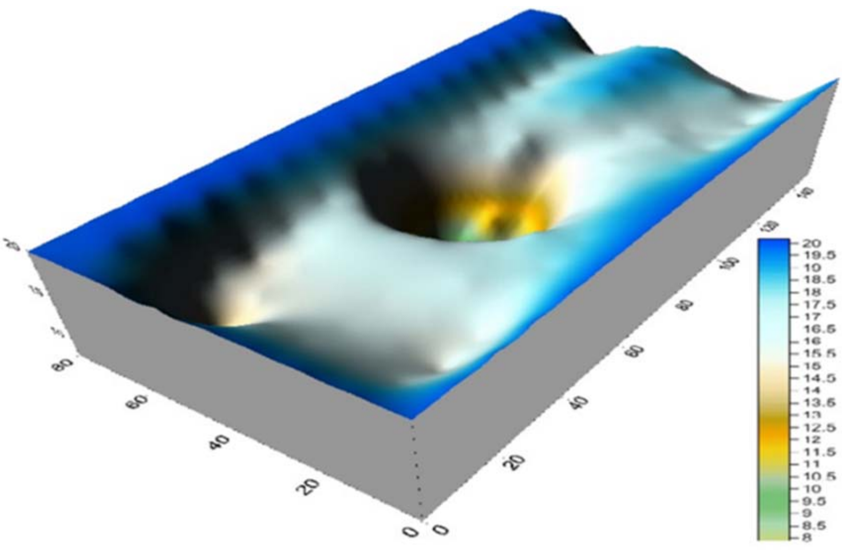

Fig. 15 Bed bathymetry for experimental Run C4 (scale is cm)

Figs. 12 and 13 show the bathymetry of the scoured bed for 7.5 cm pier diameter. Scour depth is 10.5 cm at upstream of the pier from the top of the undisturbed sediment bed which is 20 cm. There is erosion at the downstream and upstream. The erosion at the upstream of the pier is higher than downstream of the pier.

Figs. 14 and 15 show the bathymetry of the scoured bed for 11.5 cm pier diameter. Scour depth is 11.9 cm at upstream of the pier from the top of the undisturbed sediment bed which is 20 cm. There is erosion at the downstream and upstream. The erosion at the downstream of the pier is higher than upstream of the pier.

IV. Conclusions

1. The present experimental results show that there is a relation between depth of scour and pier diameter where the depth of scour increases with increase of pier diameter for the same sediments size and discharge.
2. Our experimental study also show that there is a relation between the size of the sediments and maximum scour depth with decreasing the mean size of the sediments the maximum scour depth increases.
3. Our experimental results show that the deposition is not occurred at high discharges. Scour is occurring as live bed scour.

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