MUTUAL INTERFERENCE OF BRIDGE PIERS ON LOCAL SCOUR

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Abstract:

Local Scour around isolated bridge pier has been extensively studied by several investigators, but scanty work is available on scour around bridge piers founded on close proximity .The work reported herein is concerned with an extensive experimental study of local scour around bridge piers aligned in different arrangements at varied pier spacings .The objective of present study is to investigate the effect of mutual interference of bridge piers on local scour. Based on the concept that maximum local scour occurs at incipient flow condition, the clear water scour experiments in present study were conducted at flow intensity equal to 0.95 under steady uniform flow conditions. Making the isolated pier scour depth as a base for evaluation of mutual interference, few experiments were also conducted at isolated pier of the same diameter and with the same flow conditions. In all, more than 40 experiments were conducted under the same flow conditions by varying pier spacings in tandem, lateral and staggered arrangement. The data on temporal scour depth, equilibrium scour depth, size of the scour holes and areal extent of scour for varied spacing between the piers located in tandem, lateral and staggered arrangement are collected which may provide a very useful information to the bridge engineers. Mathematical models were then developed to quantify the effect of mutual interference of piers on scour depth. Present study reveals that the piers at close proximity, if designed merely as an isolated pier, may lead to bridge failure.

Introduction

The removal of sediment from around the bridge pier or abutment located in a flowing water body is referred as local scour. The problem of scour around an isolated pier has been extensively studied and also documented by several investigators, however, scouring due to a single pier has been more thoroughly investigated (Chabert and Engeldinger, 1956; Laursen and Toch, 1956; Shen et al, 1969; Melville, 1975, Hjorth, 1975; Breusers et al, 1977; Ettema, 1980; Baker, 1981; Jain, 1981; Raudkivi and Ettema, 1983; Melville and Sutherland, 1988; Kothyari et al, (1992a,b) ; Melville 1997 and others), than the case of more hydraulically interacting piers(Elliot, 1978; Hannah, 1978; and Breusers and Raudkivi, 1991).

The presence of several piers can lead to the occurance and development of a scour process that is quite different from one which occurs around a single pier. Four mechanisms of scour (reinforcing, sheltering, shed vortices and compressed horseshoe vortices) have been recognized to occur at piers group (Hannah, 1978) which make the scour phenomenon more complex and which can modify the depth and shape of the scour hole around the piers. Based on the extensive research carried out over the years various equations have been developed for the estimation of equilibrium scour depth at the bridge piers, however, most of the equations have been derived for the case of a single isolated pier. In the light of above discussion it can be concluded that if a bridge pier is merely designed and constructed on the basis of such equations, it may lead to the bridge failure.

In this scenario to ensure the stability of the bridge piers the need of a study on the effect of mutual interference of bridge piers on local scour assumes significance, which is the subject of present study. In order to study the effects of mutual interference due to the presence of a group of piers on local scour, a series of clear water scour experiments under steady uniform flow conditions has been conducted considering different configurations of pier arrangements and equations have been developed for the estimation of scour depth at group of piers.

Experimental Programme

The experiments were performed in 75.6 cm wide rectangular re-circulating tilting flume. Table 1 shows the various flow parameters considered in present study.

Table 1. Flow Parameters

Discharge Q (l/s)	Depth of flow Y_0 (cm)	Average flow velocity V (m/s)	Flow Froude Number F	Pier Froude Number F_P	Particle Froude Number F_d	Flow Reynold No. R_e	Pier Reynold No. R_{ep}	Shear Velocity U_* (m/s)	Critical shear velocity U_{*c} (m/s)	Pier size b(mm)	Sediment size d_{50} (mm)
41.0	14.0	0.39	0.33	0.685	3.94	39551	12887	0.053	0.226	33.0	1.00

Experimental Procedure:

Before the start of each experimental run, the model piers were set vertically at the desired locations in the flume sediment bed. The sediment bed around the model piers was fairly leveled and the water was then allowed to flow slowly over the sediment bed in the flume and the steady uniform flow conditions were achieved by operating the inlet supply valve and the tailgate. The experiments were run for eight-hour duration during which scour depths at the nose of the pier were measured at regular interval of time to study the temporal variation of scour depth.

At the end of eight hours, the water supply to the flume was stopped gradually and the water from the flume was drained off carefully so that the scour holes and the scour patterns around the piers developed by the flow were not disturbed. After the water was drained off from the flume, the detailed measurements of the scoured area around the piers were then made and thereafter, the photographs of the scour patterns were taken.

The present experimental program was performed in the following phases under the same hydraulic, sediment and pier conditions as shown in Figures 1 A-E:

Phase I: Single Pier:

In this series of experiments a 33 mm diameter circular galvanized iron pier model was inserted centrally and vertically into the sediment bed in the flume at a distance of 3.5 meters from the inlet of the flume projecting well above the water surface.

Phase II: Piers in Tandem Arrangement

In this series of experiments two numbers of 33 mm diameter smooth circular model piers of galvanized iron were located in the direction of flow centrally and vertically in the sediment bed in the flume at varying relative pier spacing X/b= 0,1,2,4,6,8,10,12.2,15,20 and 25, where X is the clear distance between the two consecutive piers. In all experiments of this series the upstream pier was located at a distance of 3.5 meter from the inlet of the flume and only the downstream pier was moved to set it at the desired pier spacing in the next experiment.

Phase III: Piers in Lateral Arrangement

In this series of experiments, two smooth circular pier models of galvanized iron were set vertically in the sediment bed in the flume at varying relative lateral spacing between them, Z_c/b =0, 1,2,3,4,5,6,7,8,9and 10 where Z_c is the clear distance between the two consecutive piers and b is the pier width. The two piers were so located in the sediment bed that the line joining the centers of the two piers was at right angles to the flow direction and the centers of the two piers were located at equidistance from the center of the flume width.

Phase IV: Piers in Staggered Arrangement

In this series of experiments, two circular galvanized iron pier models of 33 mm diameter were set vertically in the sediment bed of the flume at a constant spacing between them equal to 8 times the pier diameter and at varying angles of attack $\alpha = 0, 7.5, 15, 30$ and 45 degrees. The two piers were so located in the sediment bed at a pier spacing $Z_c/b = 8$,and angle of attack α so that the perpendicular distance of their centers from the longitudinal central line of the flume was equal.

Collection of Experimental Data

During the experimental runs, the temporal variation of scour depth at single pier and piers in tandem, lateral and staggered arrangement, have been measured and recorded. At the end of each experiment, when the water from the flume was drained off, the scoured area around the piers and the region of deposition downstream of the piers was surveyed by a point gauge and the levels of the bed around the piers were recorded. In each experimental run, the normalized equilibrium scour depths (ds/dsi) at the piers were measured as shown in tables 2, 4, and 6. Due to space limitation of the paper, all the data collected in present study cannot be presented; therefore, data for a few cases are presented in this paper.

Data for Single Pier

Normalized equilibrium scour depth dsi/b = 2.175
Length of the scour hole = 49.5.0 cm
Width of the scour hole w = 25.0 cm

Data for Piers in Tandem Arrangement

The data collected for the tandem arrangement of piers are shown in table 2 and 3.

Table 2. Normalized Scour Depths (ds/dsi) at various relative pier spacings X/b

Relative pier spacing X/b	Front Pier (ds/dsi)	Rear Pier (ds/dsi)

0	1.00	0.83
1	1.150	0.88
2	1.16	0.93
4	1.13	0.92
6	1.06	0.97
8	1.071	0.96
10	1.06	0.93
12.5	1.04	0.81
15	1.03	0.84
20	1.02	0.81
25	1.01	0.86

Scour holes widths at various pier spacings were measured and recorded as shown in table 3.

Table 3. Scour Hole Widths w/b at Front Pier Various Relative Pier Spacings

Relative pier spacings (X/b)	0	1	2	4	6	8	10	12.5	15.0	20	25
Relative width of scour holes (w/b)	7.6	7.6	7.6	8.2	8.03	7.88	7.73	6.7	7.3	7.4	7.6

Data For Piers in Lateral Arrangement

The data collected for this pier arrangement are shown in table 4, and 5.

Table 4. Normalized Scour Depths at Various Relative Lateral Pier Spacings Z_c/b

Relative lateral pier Spacing Z_c/b	0	1	2	3	4	5	6	7	8	9	10
Normalized equilibrium scour depths ds/dsi	2.11	1.38	1.18	1.04	1.03	1.02	1.02	1.01	1.00	1.00	1.00

Table 5. Scour Hole Widths at Various Relative Lateral Pier Spacings Z_c/b

Relative ier spacings Z_c/b	0	1	2	3	4	5	6	7	8	9	10
Relative width of scour Holes (w/b)	8.26	13.65	9.09	10.65	11.14	12.33	12.81	8.75	8.4	7.6	7.6

Length of the scour hole = 38.2 cm

Data for Piers in Staggered Arrangement

The data collected for staggered arrangement of piers are shown in tables 6.

Table 6. Normalized Equilibrium Scour Depths at Piers Located in Staggered Arrangement

Angle of attack α (degrees)	Normalized equilibrium scour depths ds/dsi	
	Front Pier	Rear Pier
0	1.05	0.83
7.5	1.06	0.85

15	1.181	0.911
30	1.125	1.151
45	1.14	1.23

Development of Mathematical Models for Scour Depth Estimation at Group of Piers

To develop mathematical models for the estimation of scour depth at single pier and piers located in tandem, lateral and staggered arrangement, dimensional analysis has been carried out on the parameters affecting pier group scour and then regression analysis has been performed on the dimensionless parameters using the present experimental data as given below.

Scour Depth Model for Single Pier

In order to prove the present experimental conditions, it is proposed to compare the results of scour depth due to single circular model pier dsi obtained in present study with the scour depths obtained from clear- water scour predictors of Laursen and Toch (1956), Breusers et al (1977), Jain (1981), Melville (1997) and HEC- 18 design scour equation as shown in Table 7.

Table 7. Scour depth at Single Pier

Scour depth dsi/b observed in present study	Scour depth dsi/b predicted by Laursen and Toch. Equation	Scour depth dsi/b predicted by Breusers et al. equation	Scour depth dsi/b predicted by the equation of Jain	Scour depth dsi/b predicted by the equation of Melville	Scour depth dsi/b predicted by HEC -18 equation
2.175	2.082	3.54	2.152	2.28	2.08

Scour Depth Model for Piers Located in Tandem Arrangement

Model for Scour Depth at Front Pier

$$ds/dsi = 1..0 + 0.45\,(X/b)^{0.75}\exp\{-X/b)\}^{0.6} \qquad (2)$$

Model for Scour Depth at Rear Pier

$$ds/dsi = 0.80 + 4 \times 10^{7}(X/b + 6)^{0.4}\exp((X/b + 6)^{0.94} + 0.20\tanh\{1.67 \times 10^{-3}(X/b - 16)\ (X/b)^{0.8}\exp(X/b - 16)^{-1/30}\} \qquad (3)$$

Scour Depth Model for Piers Located in Lateral Arrangement

$$ds/dsi = \coth(k_1 X/b + k_2) \qquad (4)$$

Where k1 and k2 are constants, which are to be the function of particle size d_{50} and Froude number F respectively as given below.

$$K1 = (d_{50}/b)^{0.24} \qquad (5)$$

$$K2 = 0.3\,F^{-0.6} \qquad (6)$$

Scour Depth Model for Piers Located in Staggered Arrangement

Model for Scour Depth at Upstream Pier

$$ds/dsi = 1.0 + 0.142\,\alpha^{0.144} \qquad (7)$$

Model for Scour Depth at Downstream Pier

$$ds/dsi = 0.83 + 0.7\ \alpha^{1.51} \qquad (8)$$

where α is the angle of attack in radians.

Analysis and Discussion of Results

It can be observed in Table 7 that the scour depth observed at single pier in present study is very close to the scour depth predicted by the equation of Jain.

Table 2 shows that at relative pier spacing X/b equal to 0, in tandem pier arrangement (when two piers touching with each other in the direction of flow), the scour depth at front pier was almost equal to that at an isolated pier and at rear pier it was 83 % of the scour depth at isolated pier. At pier spacing of 1.5,4,6,10and 15 the scour depths at front pier were 17 %, 13%, 6%, 5.0% and 3 % more than that at an isolated pier respectively. At rear pier, scour depths were 93%, 97%, 85%, 83% and 86% of the scour depth at an isolated pier at pier spacings of 3,6,12 and 25 respectively. The scour depths at front and rear piers were almost equal to that at an isolated pier at relative pier spacing of 90. In the absence of mutual interference, the length and width of scour hole were approximately equal to 7.5 times and 15 times the pier diameter.

Table 3 shows that upto X/b=2, w/b is 7.6, however at X/b=4, w/b becomes 8.2. As X/b increase further, w/b decreases reaching to 6.7 at X/b equal to 12.5 after which w/b again increases reaching to 7.6 at X/b=25 which is almost equal to the scour hole width at w/b equal to zero.

Table 4 reveals that at pier spacing equal to 0(when two piers touching with each other normal to the direction of flow) in lateral arrangement, the scour depth at the twin piers was 2.11 times as that at isolated pier At pier spacings of 1 , 2 ,3 and 4, the scour depths were 38 % ,18 %,4 % and 3 % more than the scour depth at isolated pier respectively . However, as the pier spacing approached to 8, the scour depth at the two piers was almost equal to the scour depth at isolated pier.The scour holes of the two piers in lateral arrangement were completely free of mutual interference at pier spacing of 10.

Table 5 shows the scour hole widths at piers located in lateral arrangement at varied pier spacings. At $Z_c = 0$, the width of the scour hole w/b is 8.26, however at $Z_c = 1$, scour hole width becomes 13.6 and at $Z_c = 2$, scour hole width reaches to 9.09. From $Z_c = 3$ to 6 the scour hole width increases and then decreases approaching to 7.6 at $Z_c = 10$

Table 6 shows that at 45^{o} angle of attack, the scour depth at upstream and downstream piers are 1.14 and 1.23 times the scour depth at a single pier respectively. At angles of attack of 7.5^{o} and 15^{o} the scour depths at upstream pier were 1.05 and 1.181 times the scour depth at a single pier and at downstream pier were 0.85 and 0.911 times the scour depth at a single pier.

References

Baker, C.J. (1981), "New Design equations for Scour around Bridge Piers", *J. of Hydraulic Division, ASCE*, Vol. 107, HY-4.

Breusers, H.N.C., Nicollet ,G. and Shen, H.W. (1977). ''Local scour around cylindrical piers.'' *J. of Hydraulic Research*, volume 15 , No.3 , page 211-252.

Breusers, H.N.C, and Raudkivi, A. J. (1991), “ Scouring” *2nd Hydraulic Structures Design Manual, I.A.H.R.*, A. A. Balkema/ Rotterdam – Netherlands.

Chabert , J and Engeldinger , P. (1956.) ‘‘Etude des Affouillement Autour des Piles de Ponts**’’,** *Lab Nat, d’Hydr.* , Chatou , France , October.

Elliot, K.R. and Baker, C.J. (1978), ‘‘Effect of Pier spacing on scour around Bridge Piers’’, *J. of Hydraulic Division, ASCE*, Vol. 3.No.7, pp. - 1105-1109.

Ettema, R.(980), ‘‘Scour at Bridge Piers.’’ Department of Civil Engineering, University of Auckland, New Zealand, *Report No. 216*, February.

Hannah, C. R. (1978) ‘‘Scour at Piles Groups.’’ University of Canterbury, New Zealand, Civil Cylindrical Engineering Research, *Report No.78* page 392.

Hjorth,P. (1975), ‘”Studies on the Nature of Local Scour”, Department of Water Resources Eng., Lund Institute of Technology, *Bulletin Series A*, *No. 46.*

Jain, S.C. (1981), ‘‘Maximum Clear- Water Scour Around Circular Piers.’’ *Journal of Hydraulic Division, Proc. ASCE*, Vol. 107, No.HY-5, May.

Kothyari, U.C., Garde, R.J. and Ranga Raju, K.G. (1992a), “ Temporal Variation of Scour around Circular Bridge piers”, J.of Hydr. Engrg., ASCE , Vol. 118, No. 8, Aug., pp. 1091-1105.

Kothyari, U.C., Garde, R.J. and Ranga Raju, K.G. (1992b), “ Live-Bed Scour around Bridge Piers “, J.of Hydraulic Research, I.A.H.R. , Vol. 30, No. 5, Aug., pp. 701-715.

Laursen, E.M., and Toch, A. (1956), ‘‘Scour Around Bridge Piers and Abutments.’’ *Bulletin No.4*, lowa Highway Reasearch Board.

Melville, B.W. (1975), ‘‘Local Scour at Bridge Sites.’’ University of Auckland, school of Engineering, Auckland, New Zealand, *Report No.117*.

Melville, B.W. and A..J. Sutherland (1988), “Design Method for Local Scour at Bridge Piers”, *J. of Hydraulic Engrg., Proc. ASCE*, Vol. 14, No. 10, October.

Melville, B.W. (1997), “Pier and Abutment Scour – Integrated Approach”, *J. Hydr. Engrg., ASCE*, Vol. 123, No 2, pp. 615-630

Raudkivi, A.J. and Ettema, R. (1983), ‘‘Clear-Water Scour at Cylindrical Piers.,” J. *of Hydr. Engrg., ASCE*, Vol.109. No.3. pp. 338-350.

Shen, H.W., Schneider, V.R. and Karaki, (1966), S.S. (1969), “Local Scour Around Bridge Piers”, *J. of Hydr. Engrg., Proc. ASCE*, Vol. 95, No. HY-6.