SCOUR REDUCTION BY USING A COLLAR AROUND A PIER GROUP

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ABSTRACT:

Attempts have been made by several investigators to reduce scour depth using several devices around bridge piers, such as sacrificial piles placed upstream of the pier, slots through the pier, riprap and gabion placed around the pier and collar around the pier. Following successful application of collar by earlier researchers on circular and rectangular piers for reduction of scouring, the present study examines experimentally the effectiveness of a collar on a group of two circular cylindrical piers for the reduction of scour depth. The experiments were conducted in clear-water scour conditions at flow intensity 0.95. Two piers of 4.15 cm diameter with clear spacing between them equal to two pier diameter with and without collar were tested at 0°, 15°, 30° and 45° angles of attack. The size of the collar and its placement on the bed was decided on the basis of well-established research work of earlier investigators. Present study reveals that the application of collar to the group of two circular cylindrical piers aligned at 0^o, 15^o, 30^o $45^{\ o}$ angles of attack, produces 87.05 %, 58.97 %, 51.85%, and 48.4 % reduction in the maximum scour depth respectively.

***Key Words*: Bridge, pier, piers group, collar, scour**

INTRODUCTION:

Scour around bridge piers as a result of flooding is the most common cause of bridge failure (Richardson and Davis, 1995; Johnson and Dock, 1996; Lagasse *et al*., 1995). The potential cost including human toll and monetary cost of bridge failure due to scour damage has highlighted the need for better scour prediction and protection methods. The devices to control the local scour at bridge piers can be grouped in two categories.

(i) Armoring devices

In armoring device, the streambed resistance is increased by placing the rip-rap and gabions around the piers. Several researchers (Brice *et. al*.., 1978; Croad, 1993; Parola, 1993; Yoon *et. al*., 1995; Chiew, 1995; Worman 1989, (Lim and Chiew, 1996 and 1997); Lim, 1998; Chiew and Lim, 2000; Lim and Chiew, 2001), have attempted to determine the size and extent of the riprap layer.

(ii) Flow altering devices

Using flow-altering device, the shear stresses on the riverbed in the vicinity of pier, are reduced by altering the flow pattern around a pier, which in turn reduces the scour depth at the pier.

Many flow altering devices have been attempted by several investigators to reduce the depth of scour around a pier (Schneible, 1951; Chabert and Engeldinger, 1956; Thomas, 1967; Tanaka and Yano, 1967; Ettema, 1980; Odgard and Wang, 1987; Chiew, 1992; Gupta and Gangadharaiah, 1992; Chiew, 1992, Vittal *et. al.*, 1994; Melville and Hadfield, 1999; Kumar *et. al.*, 1999; and Zarrati *et. al.*, 2004, 2006). Indeed flow altering devices can be more economical, especially when the riprap material in required amount is not available near the bridge site or is expensive.

Application of Collar:

Reduction of scouring by indirect method can be achieved by using a slot in the pier (Chiew, 1992; Vittal *et. al.*, 1994 and Kumar *et. al.*, 1999). However, floating debris may block a slot. In addition to this, its construction is difficult. A collar around the pier diverts the down flow and shields the streambed from its direct impact. The scour reduction efficiency of collars has already been established in earlier studies (Zarrati *et. al.*, 2004 and 2006; Kumar *et. al.*, 1999); Chiew, 1992; Ettema, 1980; Tanaka and Yano, 1967; Thomas 1967; Schneible, 1951). Encouraging results achieved by the application of collar in aforementioned studies have, therefore, rekindled an interest to examine experimentally the effectiveness of application of a collar to a group of two circular cylindrical piers aligned in line with the flow, and skewed at 15°, 30° and 45°to the flow.

EXPERIMENTAL PROGRAM

Experiments were performed in an 11 m long, 0.756 m wide and 0.55 deep rectangular tilting flume at Civil Engineering Department, AMU, Aligarh, and U.P., India. The uniform sediment having a median size of 0.95 mm and standard deviation, σ_g as defined below, less than 1.2, was filled in test section in the flume in a thickness of 0.25 m.

$$\sigma_g = \left(\frac{d_{84}}{d_{16}} \right)^{0.5}$$

The arrangement of piers group with collar in the flume is shown in Fig.1.

Two smooth circular cylinders made up of mild steel, 4.15 cm in diameter, were used as pier models. In all experiments, the clear spacing between the two piers was maintained at two times the pier diameter. The effective width of piers group was chosen so that the effects of flume sidewalls and sediment size on the depth of scour were negligible (Shen *et. al.*, 1966; Ettema, 1980 and Melville, 1997). The sediment gradation used here was such that the effect of sediment size distribution on scour depth was also negligible (Ettema, 1980; Raudkivi and Ettema, 1977).

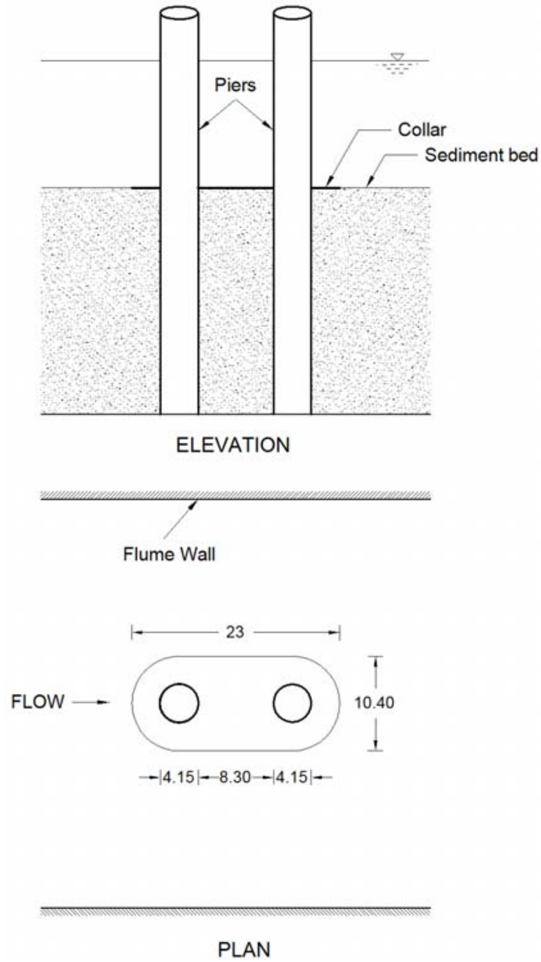


Fig. 1 Arrangement of piers group with collar in the flume

Since the maximum depth of scour occurs at the threshold of bed material motion, all the tests were conducted just below this condition (Raudkivi, 1991).

The threshold of the sediment motion was found by experiment when the pier models were not installed. The threshold of sediment motion was defined as a condition for which finer materials may move, but the elevation of the sediment bed would not lower more than 2 to 3 mm during the period of experiments. These tests showed that with 0.14 m flow depth and 0.041 m^3/s discharge, bed material would be at incipient motion. In these experiments, the ratio of shear velocity calculated from flow depth and energy slope to the critical shear velocity calculated from Shields diagram, was about 0.95. A collar plate having a width equal to 2.5 times the model pier diameter, as shown in Fig. 1, was used in present investigation.

The experiments were conducted in two phases under the same hydraulic, pier and sediment conditions.

In first phase, the experiments were performed without collar, by installing the two piers at clear pier spacing of two-pier diameter aligned at 0°, 15°, 30° and 45° angles of attack.

In second phase, the experiments were performed with collar using the same model piers placed at the same clear pier spacing and at the same angles of attack to the flow as in phase first. As established by earlier studies that the collar is most effective when placed at the bed level, in present study experiments were conducted with a collar having a width equal to 2.5 times the pier diameter and fixed at the bed level.

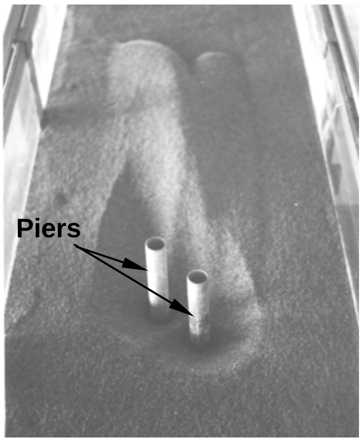
Initially, few tests were run for 18 hours, however, as about 90 percent of the total scour depth occurred in the first 4 hours and after 10 hours, the rate of scour was insignificant, therefore, remaining experiments were carried out for 10 hours duration. After each experiment, the flume was drained off very carefully so that the scour hole was not disturbed. Thereafter, the extent of the scoured area was measured by a point gauge with 0.1 mm accuracy at several points around the pier. Photograph as shown in Fig. 2, taken at the end of experimental run for the case of 45° angle of attack depicts the scour and deposition patterns around the group of piers without collar and with collar respectively. Chiew (1992) explains that when general sediment transport occurs, troughs of migrating bed forms may expose the pier beneath the collar and lower the collar's effectiveness. Therefore, the performance of collars in live-bed conditions needs further attention and research. Collar was installed at the initial bed-level for all experiments.

First phase: Experiments without collar

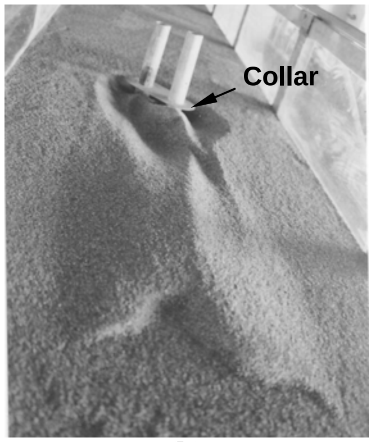
In this phase, four tests were conducted on the group of two piers without collar and aligned at 0°, 15°, 30°and 45°angles of attack to the flow keeping the clear spacing between the two piers equal to two pier diameters.

Second Phase Experiments with Collar

In this phase, a collar was skirted around the group of two piers and four tests were conducted with this collar fitted piers group aligned at 0°, 15°, 30° and 45° angles of attack to the flow keeping the same clear spacing between the two piers as that what was kept in the experiments conducted in phase first.



(a)



(b)

Fig. 2 Photo views showing the scour and deposition patterns around piers group aligned at 45° angle of attack (a) Without Collar (b) With Collar.

RESULTS AND ANALYSIS

The scour depths measured at upstream, downstream, right and left faces of the upstream and downstream piers with and without collar are given in Tables 1 and 2 respectively. For piers groups with and without collar, the location of occurrence of maximum scour depth around piers is mentioned in Table 3 and 4 respectively. The percentage reduction in the maximum scour depth due to the application of collar to the piers group is given in Table 5.and also illustrated in Fig. 3. The results given in Table 3 indicate that as the angle of attack increases, the point of occurrence of maximum scour depth moves from the upstream to downstream along the downstream edge of the collar.

For the case of piers group without collar, Table 4 infers that at 0°and 15° angles of attack the maximum scour depth occurs just near the nose of upstream pier while at 30°and 45°angles of attack, the point of occurrence of maximum scour depth moves towards the right face of the downstream pier.

Fig. 3 reveals that the rate of reduction in scour depth due to application of collar is faster between 0° and 15° angles of attack; however, it decreases beyond 15° angle of attack. It clearly indicates that the scour depth reduction efficiency of collar decreases as the angle of attack increases.

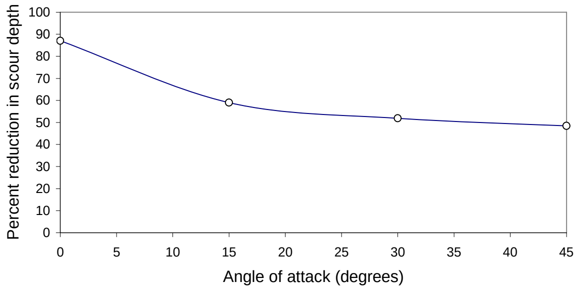


Fig. 3 Percent reduction in scour depth with angle of attack

Table 5 clearly indicates that application of collar produces 87.05%, 58.97%, 51.85% and 48.4% reduction in maximum scour depth at 0°, 15°, 30° 45° angles of attack respectively.

Table-1: Scour Depth at Upstream and Downstream Piers of Piers Group with Collar at Various Angles of Attack

Angle of attack A	Maximum scour depth at upstream and downstream piers (centimeters)							
	UPSTREAM PIER				DOWNSTREAM PIER			
	Nose of pier	Rear* side of pier	Right* face of pier	Left face of pier	Nose of pier	Rear side of pier	Right* face of pier	Left* face of pier
0°	0.4	0.0	1.25	1.25	0.0	0.0	0.1	0.1
15°	3.5	0.0	4.0	1.45	0.0	1.85	2.35	1.2
30°	2.05	0.0	5.2	0.0	0.0	1.5	1.5	1.95
45°	5	3.7	4.55	4.3	5.65	4.3	5.5	5.2

* While observing towards downstream

Table-2: Scour Depth at Upstream and Downstream Piers of Piers Group without Collar at Various Angles of Attack

Angle of attack A	Maximum scour depth at upstream and downstream piers (centimeters)							
	UPSTREAM PIER				DOWNSTREAM PIER			
	Nose of pier	Rear side of pier	Right* face of pier	Left* face of pier	Nose of pier	Rear side of pier	Right* face of pier	Left* face of pier
0°	9.65	7.6	9.1	9.1	8.05	8.1	7.1	7.1
15°	9.75	7.9	9.4	9.1	8.9	7.25	8.3	8.7
30°	10.8	9.25	10.3	10.0	10.6	8.85	10.2	10.0
45°	10.15	8.85	9.95	9.9	10.95	9.2	10.5	10.45

* While observing towards downstream

Table-3: Location of Maximum Scour Depth around Piers Group with Collar at Various Angles of Attack.

Angle of attack α˚	Location of maximum scour depth
0˚	Along edges of collar near right and left faces of upstream pier (at 3cm from side of upstream pier).
15˚	Along downstream edge of collar (at 10 cm from edge of collar along the line drawn normal to the flow direction from rear face of downstream pier
30˚	Along downstream edge of collar (t a point 5cm from collar edge and at 12.5 cm from a line drawn along flow direction through the center of downstream pier)
45˚	Just near nose of downstream pier

Table-4: Location of Maximum Scour Depth around Piers Group without Collar at Various Angles of Attack

Angle of attack α°	location of maximum scour depth
0°	Nose of front pier
15°	Nose of front pier
30°	At 2.5 cm towards left from left face of downstream pier
45°	1.5 cm towards left from left face of downstream pier

Table-5: Comparison between Maximum Scour Depth at Piers Group with and Without Collar

Angle of Attack α	% Reduction in scour depth due to collar
0°	87.05
15°	58.97
30°	51.85
45°	48.40

Conclusions:

From the data collected in present study it is concluded that the application of collar to the group of two circular cylindrical piers produces 87.05%, 58.97%, 51.85% and 48.4% reduction in maximum scour depth at 0°, 15°, 30° 45° angles of attack respectively. This study shows that the effectiveness of collar in reducing the scour depth around group of two piers decreases as angle of attack increases. It is noteworthy that the use of collar around the group of two produces enthusiastic results, however, the study can be extended for larger duration of time.

References:

1) Brice, J. C., Bloggett, J.C. and others: Countermeasures for Hydraulic Problems at Bridge piers, Vol. 1 and 2,*FHWA-78-162 & 163*, Federal Highway Administration, U.S. Department of transportation, Washington, D.C., 1978.
2) Chabert, J. and Engeldinger, P.: Etude des affouillement autour des Piles des ponts (Study on Scour around bridge piers), *Laboratoire National d'Hydraulique*, Chatou, France, 1956.
3) Chiew Y.M.: Mechanics of riprap failure at bridge piers, *J. of Hydraulic Engineering, ASCE*, vol. 121, No. 9, pp. 635-643, 1995.
4) Chiew Y.M. and Lim, F. H.: Failure Behavior of riprap layer at bridge piers under live-bed conditions, *J. Hydr. Engrg. ASCE*, 126(1), 43-55, 2000.
5) Chiew, Y.M.: Scour Protection at Bridge Piers, *J. Hydr. Engrg., ASCE*, 118(9), 1260-1269, 1992.
6) Croad, R.N.: Bridge pier scour protection using riprap, Central *Laboratories Report No. PR3-0071*, Works Consultancy Services, N.Z., 1993.
7) Ettema, R.: Scour at Bridge Piers, *Report No. 216*, School of Engrg., University of Auckland, Auckland, New Zeeland, 1980.
8) Ettema, R., Mostafa, E.A., Melville, B.W. and Yassin, A.A.: Local Scour at Skewed Piers, *J. Hydr. Engrg., ASCE*, 124(7), 756-759, 1998.
9) Gupta, A.K., and Gangadharaiah, T.: Local scour reduction by a delta wing-lick passive device. *Proc., 8th Congr. of Asia and Pacific Reg.* Div., 2, CWPRS, Pune, India, B471-B481, 1992.
10) Johnson, P.A. and Dock, D.A.: Prababilistic Bridge Scour Estimates, *J. Hydr. Engrg., ASCE*, 124 (7), 750-754, 1996.
11) Kumar, V, Ranga Raju, K.G. and Vittal, N.: Reduction of Local Scour around Bridge Piers Using Slot and Collar, Technical Note, *J. Hydr. Engrg., ASCE*, 125(12), 1302-1305, 1999.

12) Lagasse, P.F., Thompson, P.L. and Sabol., S.A.: Guarding Against Scour, *Civil Engrg. ASCE*, pp. 56-59, 1995.
13) Laursen, E.M. and Toch, A.: Scour around Bridge Piers and Abutments, Iowa Highway Research Board, *Bulletin No. 4*, Ames, IOWA, U.S.A., 1956.
14) Lim and Chiew: Parametric study of riprap failure around bridge Piers, *J. of Hyd. Research*, Vol. 30, No. 1, pp., 61-72, 2001.
15) Lim F.H. and Chiew, Y.M.: Stability of riprap layer under live-bed conditions, Proc., 1st Inter. Conf. On new/emerging concepts for rivers, *RiverTech'96*, Vol.2, 830-837, 1996.
16) Lim, F.H.: Riprap protection and its failure mechanisms, *A thesis* submitted to the School of civil and structural engineering, Nanyang Technological University, Singapore in fulfillment of the requirements for the degree of doctor of philosophy, 1998.
17) Lim, F.H. and Chiew, Y.M.: Failure behavior of riprap layer around bridge piers, *proc., 27th conf. of IAHR*, Managing water, coping with scarcity and abundance, 184-189, 1997.
18) Maynord, S.T.: Gabion mattress channel protection design, *J. of Hydraulic Engineering, ASCE*, vol. 121, No. 7, pp. 519-522, 1995.
19) Melville, B.W.: Pier and abutment scour – an integrated approach, *J. Hydr. Engrg. ASCE*, 123(2), 125-136, 1997.
20) Melville, B.W. and Hadfield, A.C.: Use of sacrificial piles as pier scour countermeasures, *Journal of Hydraulic Engineering, ASCE*, 125(11):1221-1224, 1999.
21) Odgaard, A.J., and Wang, Y.: Scour prevention at bridge piers, *Hydr. Engrg.* 87, R.M. Ragan, ed., National Conference, Virginia, 523-527, 1987.
22) Parola, A.C.: Stability of riprap at bridge piers, J. Hydr. Engrg. ASCE, 119, 1080-1093, 1993.
23) Raudkivi, A.J.: Scour at bridge piers, In Scouring, Ed. H. Breusers and A.J. Raudkivi, *A.A. Balkema, Rotterdam*. NL, 1991.
24) Raudkivi, A.J.: Loose Boundary Hydraulics, 3rd Edition, *Pergamon Press*, 1991.
25) Raudkivi, A.J. and Ettema, R.: Effect of Sediment Gradation on Clear Water Scour, J. Hydr. Div. ASCE, 103(HY10), 1209-1213, 1977.
26) Richardson, E.V. and Davies, S.R.: Evaluating Scour at Bridges, *Rep. No. FHWA-IP-90-017* (HEC-18), Federal Administration, U.S. Department of Transportation, Washington D.C., 1995.
27) Schneible, D.E.: An investigation of the effect of bridge pier shape on the relative depth of scour, M.Sc. *thesis. Graduate College of the State*, University of Iowa, Iowa City, Iowa, 1951.
28) Shen, H.W., *et al*.: Mechanics of local scour, *National Bureau of Standards*, Institute of Applied Technology, U.S. Department of Commerce, Washington, D.C., 1966.
29) Tanaka, S. and Yano, M.: Local Scour around a Circular Cylindere, *Proc. 12the IAHR congress*, delft, The Netherlands, 3, 193-201, 1967.
30) Thomas, Z.: An Interesting Hydraulic Effect Occurring at Local Scour, *Proc. 12th Congress, I.A.H.R., Ft. Coll*ins, Colorado, Vol. 3, pp. 125-134., 1967.
31) Vittal, N., Kothyari, U.C. and Haighghat, M.: Clear water scour around Bridge piers Group, *J. Hydr. Engrg. ASCE*, 120(11), 1309-1318, 1994.
32) Worman, A.: Riprap Protection Without Filter Layers, *J. Hydr. Engrg. ASCE*, 115 (12), 1615-1629, 1989.
33) Yoon, T.H., Yoon, S.B. and Yoon, K.S.: Design of riprap for Scour Protection around Bridge Piers, 26th IAHR Congress, U.K., Vol. 1, pp. 105-110, 1995.
34) Zarrati, A.M., Gholami, H. And Mashahir, M.B.: Application of collar to control scouring around rectangular bridge piers, *Journal of Hydraulic Research, IAHR*, 42(1)97-103, 2004.
35) Zarrati, A.M., Nazariah, M. and Mashahir, M.B.: Reduction of local scour in the vicinity of bridge pier group using collars and riprap, *Journal of Hydraulic Engineering, ASCE*, 132(2): 154-162, 2006.