Conference Paper, Published Version

Beg, Mubeen; Jamil, Mohd.

Scour Reduction Using Collar around Piers Group

Scour Reduction Using Collar around Piers Group

Mubeen Beg*, Mohd. Jamil**

*Sr. Lecturer Department of civil Engineering, Z.H. College of Engg. & Tech., AMU, Aligarh, U.P. India

**Professor Department of civil Engineering, Z.H. College of Engg. & Tech., AMU, Aligarh, U.P. India

Several methods have been attempted to reduce scour depth 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 on circular and rectangular piers for reduction of scouring, the present study examines experimentally the effectiveness of a collar on a group of circular cylindrical piers. The experiments were carried out in clear-water scour condition with flow intensity 0.95 and the group of piers aligned in line with the flow, and skewed at 7.5°, 10° and 15° to the flow, without collar and with a collar fixed at sediment bed level. It is worth to mention that application of collar on the group of the piers studied in this work is extremely successful in producing 100 percent reduction in the scour depth up-to 7.5°angles of attack of flow. At 15° angle of attack, application of collar gives 79.3 percent reduction in scour depth.

INTRODUCTION

Scour is the process of lowering of river -bed due to removal of the bed material by erosive action of flowing water. The presence of an obstruction like a pier in an alluvial channel leads to the formation of horseshoe vortex at upstream and sides of the pier and also wake vortices at the downstream side of the pier because of flow separation at the sides. As a result, the flow gets modified, bed shear stress increases around the pier and scour takes place in the vicinity of the pier. Enlargement of the flow cross-section due to the scour eventually reduces the shear stress around the pier. The term ' local scour' is used to emphasize the fact that the lowering of the river- bed occurs only in the vicinity of the pier.

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; Melville and Coleman, 2000). 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. A large depth of foundation is required 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.

Various methods have been attempted to control scouring around bridge piers, such as using riprap around the pier, slots through piers, sacrificial piles in front of a pier, piers group and collars. Countermeasures to control the local scour at bridge piers can be grouped in two categories;

(1) Armoring devices:

In this device, the streambed resistance is increased by placing the riprap and gabions around the piers. Several researchers (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), Maynord, S.T. (1995),' have attempted to determine the size and extent of the riprap layer.

(2) Flow altering devices:

Using flow altering devices, 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.

Attempts have been made by several investigators to reduce the depth of scour around a pier using armoring and flow altering devices i.e., by placing the riprap around the pier (Brice et al., 1978;Croad, 1993; Parola,1993; Yoon et al., 1995; Worman 1989, (Lim and Chiew, 1996 and 1997); Lim, 1998; Chiew and Lim, 2000; Lim and Chiew, 2001), providing an array of piles in front of the pier(Chabert and Engeldinger, 1956 and Melville and Hadfield,1999), a collar around the pier (Schneible, 1951;Thomas 1967; Tanaka and Yano 1967; Ettema 1980; Chiew, 1992; Kumar et al., 1999, Zarrati et al. 2004), submerged vanes(Odgard and Wang 1987), a delta-wing-like fin in front of the pier (Gupta and Gangadharaiah, 1992), a slot through the pier(Chiew, 1992, Kumar et a., 1999) and partial pier-groups (Vittal et al. 1994)

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.

Flow pattern and Mechanism of Scouring:

The performance of any scour protection device around bridge piers depends on how does the device counter the scouring process. Flow mechanism of scouring around a bridge pier is very complex and has been investigated by various researchers (Chabert and Engeldinger, 1956; Hjorth, 1975; Melville, 1975; Melville and Raudkivi, 1977; Dargahi, 1990; Ahmed and Rajaratnam, 1998 and Graf and Istiarto, 2002).

As the approach flow velocity goes to zero at the leading face of the pier, it causes an increase in pressure. As the flow velocity decreases from the surface to the bed, the dynamic pressure on the pier face also decreases downwards. As a result, a vertically downward pressure gradient is developed on the leading face of the pier which drives the flow down the pier, like a vertical jet. When this down-flow impinges the streambed, it digs a hole in front of the pier, and rolls up and by interaction with the coming flow forms a complex vortex system and a scour hole forms around the pier.

The horseshoe vortex deepens the scour hole in front of the pier until the shear stress on the bed material at the base of the pier becomes less than the critical shear stress. The separation of the flow at the sides of the pier causes so-called wake vortices. These vortices are unstable and shed alternatively. These vortices act as little tornadoes, lifting the sediment from the bed.

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; Kumar et al., 1999. However, a slot may be blocked by floating debris. 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; Kumar et al., 1999;Chiew, 1992; Ettema, 1980;Tanaka and Yano, 1967; Thomas 1967; Schneible, 1951). Kumar et al. (1999) performed a series of experiments on effectiveness of collar for control of scouring around circular bridge piers. Zarrati et al.(2004) conducted a series of experiments using a collar for control of scouring around rectangular pier having a collar with the same width all around the pier. The piers are sensitive to the angle of attack of flow and scour depth around them increases rapidly with an increase in angle of attack (Laursen and Toch, 1956; Ettema et al., 1998). Zarrati et al. (2004) conducted experiments on rectangular piers with varying angles of attack. A scanty information however, is available in literature about the application of collars on group of piers.

Following successful application of collar plates on piers for reduction of scouring, in this paper the effectiveness of collar plate on a group of piers was studied experimentally

EXPERIMENTAL PROGRAMME

It is well known that experimental methods are helpful in understanding and analyzing the behavior of complex flow situations which otherwise cannot be subjected to purely theoretical analysis. Therefore, it was planned to conduct laboratory experiments to study the application of collar on piers group for scour depth reduction.

Experiments were conducted in a rectangular re-circulating tilting flume, 11.0 m long, 75.6 cm wide and 55.0 cm deep located in the Hydraulics laboratory of Civil Engineering Department, Z.H. College of Engineering and Technology, AMU Aligarh, India. Water was supplied to the flume from a constant head overhead tank, which got its supply from the laboratory water supply system. Flow straightners were provided at the upstream end of flume to ensure uniformly distributed flow across the width of the flume and minimum turbulence in the flow. Water supply into the flume was regulated by operating a valve in the water supply pipeline. A calibrated bend meter was used for measuring discharge passing through the flume. Water surface level and bed level in flume were measured using a point gauge mounted on a trolley which could be moved over adjustable rails mounted on the two walls of the flume. The rails were kept parallel to the flume bed. A tailgate was provided at the downstream end of the flume, which was operated to adjust the depth of flow in the flume. A transition of wooden block was fitted tightly at the entrance of the flume to ensure smooth flow without disturbing the sediment bed in the flume. A sediment trap was provided at the downstream end to collect sediment coming from the upstream bed.

Sediment was filled in the flume to a constant thickness of 25 cm in the rest section. At the entrance of the flume, graded layers of glass beads, followed by a transition block of wood, were placed to obtain a smooth flow without disturbing sediment bed in the flume. A sediment trap was provided at the outlet of the sand bed. As such, water flowing out of the flume was clear and virtually sediment free.

The piers group model was comprised on five galvanized iron smooth circular cylinders, one cylinder of 4.15 cm at the center and two cylinders of 3.3 cm and 2.15cm on either side of 4.15 cm cylinder. All the five cylinders were joined in a group to give a form similar to lenticular pier. The aspect ratio (length/width) of this piers group was equal to 3.61. The size of the piers group was so selected that the blockage effect on scour depth in the flume was insignificant. Experiments were conducted in uniform non-ripple forming sediment bed of median diameter d_{50} equal to 0.95 mm and standard deviation (σ_g = 1.15) in steady state clear-water scour condition at flow intensity (U/U_c) of 0.95. The experiments were conducted in three phases. In first phase, a series of experiments was conducted with 4.15 cm diameter single isolated cylinder to form the basis for comparison with the piers group model at 0^o angle of attack. In second phase, the experiments were conducted at piers group model without collar aligned at 0^o, 7.5oand 15^o to the flow. In third phase the experiments were conducted with same piers group model fixed with collar plate at bed level at the same angles of attack as in phase second. All the experiments were conducted under same hydraulic and sediment conditions.

Water was allowed to flow over the level sediment bed slowly and the flow was adjusted using the inlet valve and the tailgate to achieve steady and uniform flow condition. Before the start of each experiment, the pier was inserted in the test section vertically in desired positions. The area around the piers models was leveled.

The scour depths were measured with the help of point gauge at various time intervals. It was observed during the experimental runs that the water depth was maintained at a sensibly constant elevation. All the experiments were conducted under same hydraulic and sediment condition. The experiments were run for sufficient time.

The range of variables used in the present study is given in Table 1.

TABLE: 1

SEDIMENT AND HYDRAULIC DETAILS

Pier type	Size of pier (cm)	Pier aspect ratio	H (cm)	U (m/s)	D_{50} (mm)
Circular	4.15	-	14	0.40	0.95
Piers Group model	-	3.61	14	0.40	0.95

Temporal measurements of scour depth at nose and other point at the pier mode were made during the experimental runs. After the completion of the experimental run, the flow was gradually stopped and the flume was drained off very carefully so that the scour hole and scour patterns developed by the flow around the pier were not disturbed. Thereafter, the scoured area was surveyed with a point gauge. The curves for temporal variation of scour depth and maximum scour depth versus angles of attack curves were plotted for the two phases of experiments. The mathematical models were also developed to predict the maximum scour depth. To overcome the difficulty of observing the development of the scour hole, strong light source was used which permitted the observation of the phenomenon as it progressed.

Experiments were performed in the following phases:

Phase I: Isolated Pier:

A series of experiments was first performed on 4.15 cm diameter single cylinder to form a basis against which the scour depth at piers group could be compared.

Phase II: Piers group without collar:

Experiments were conducted using a piers group model, comprising on five galvanized iron smooth circular cylinders, one cylinder of 4.15 cm at the center and two cylinders of 3.3 cm and 2.15cm on either side of 4.15 cm cylinder as shown in Fig. 1. In this phase, the experiments were performed on piers group aligned at 0°, 7.5oand 15° to the flow without using collar plate.

Phase III: Piers group with collar:

In this phase, experiments were conducted by applying a collar plate around the piers group as shown in Fig.1.

Fout! Objecten kunnen niet worden gemaakt door veldcodes te bewerken.

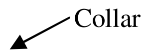

Fig. 1 Piers group with and without collar

The collar was fixed at the sediment bed level. Before the start of each experimental run, the pier model was located centrally and vertically into the sediment bed in the flume. The pier model was installed at a distance of 3.5.metres from the inlet of the flume projecting well above the water surface. The area around the pier model was leveled. The water from the supply pipe line was allowed to flow over the leveled sediment bed slowly with the help of the inlet valve in the supply line. As steady uniform flow conditions were established, the experimental run was started

During the experimental runs ,the scour depth was measured at the nose of the pier and at other points around the model pier at regular time intervals of 5,10,15,30,60,120,180,240, 300,360,420 and 480 minutes with the point gauge. The mean approach flow depth was kept constant as 14 cm throughout the experiments. At the end of the experimental run, the water supply was gradually stopped and the water was drained off from the flume with extreme care that there was no disturbance in the scour hole and the scour patterns around the pier. Detailed measurements of scoured area around the pier were then made in static condition. Finally, the photographs of the scoured area around the pier were taken

Results and Discussion

The temporal development of scour depth around piers group with and without collar aligned at different angles of attack, are presented in figures 2 and 3 respectively. It is evident from these figures that application of collar around piers group, not only causes reduction in the maximum scour depth but also 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 variation of scour depth around piers group with and without collar versus angles of attack has been plotted in figure 4 which shows that at piers group without having collar around it the scour depth remains

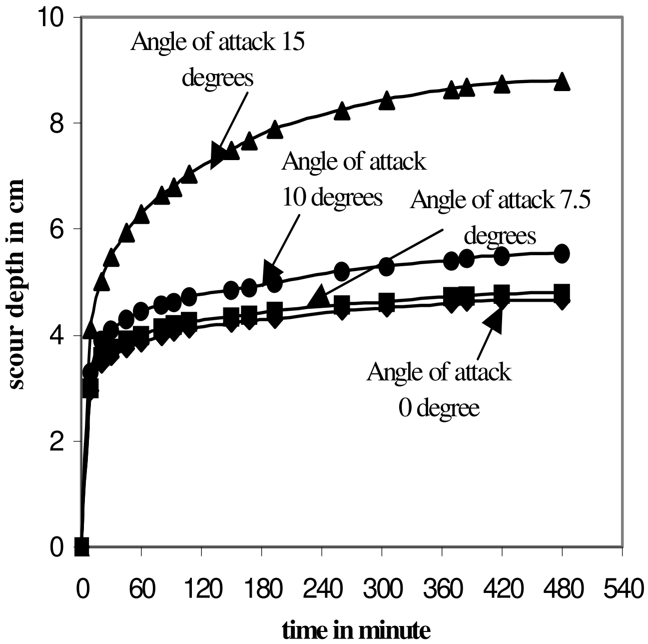

Fig.2 Temporal variation of scour depth at piers group without collar.

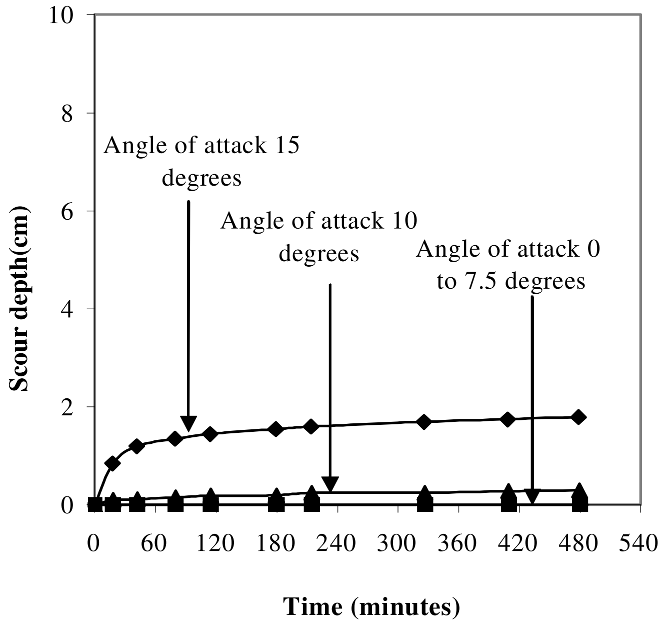

Fig. 3 temporal variation of scour depth at piers group with collar

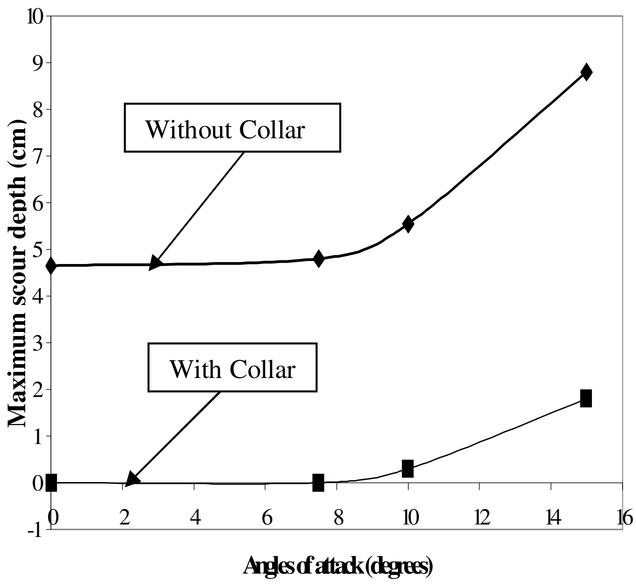

Fig. 4 Angle of attack versus maximum scour depth with and without collar at piers group

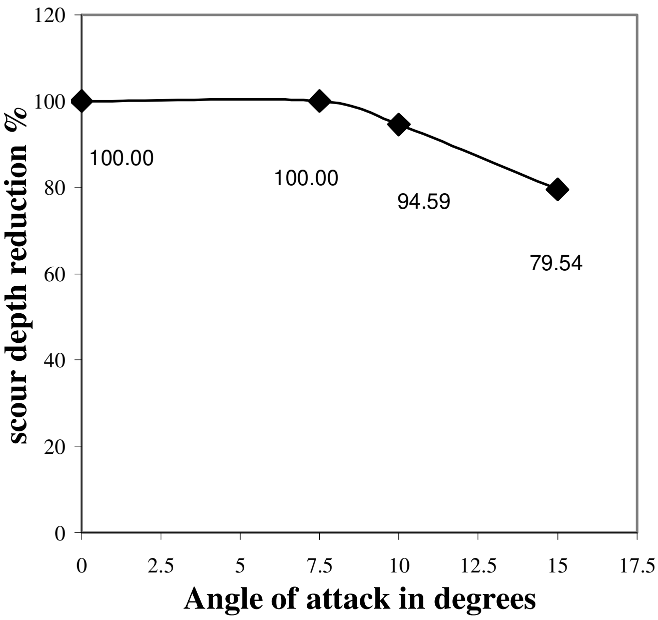

Fig. 5 - Scour depth reduction using collar around piers group

almost constant up-to 7.5 degree angle of attack. From 7.5 to 10 degrees of angles of attack, there is small increase in scour depth. Beyond 10-degree angle of attack, the scour depth increases rapidly. In figure 4 similar trends can be seen in the variation of scour depth around piers group having collar around it.

The efficiency of collar in reducing the depth of scour around pier group can be observed in figure 5. It is worth to mention that application of collar around piers group for angles of attack 0 to 7.5 degrees produces 100 percent reduction in scour depth. As shown in figure 5, the reduction in scour depth at 10 and 15 degrees angles of attack, is 94.59 percent and 79.54 percent respectively.

The use of piers group having no collar around it and aligned at 0 degree angle of attack with the flow yields about 35 percent reduction in scour depth as compared to the scour depth at single isolated 4.15 cm cylinder which has been used in formation of piers group.

Chabert and Engeldinger (1956) conducted experiments on piers group of three circular cylinders at different angles of attack. The piers group had a cylinder of 15 cm diameter at the center and one cylinder of 7.5 cm diameter on either sides of the 15cm cylinder placed at a distance of 15cm from the outer face of the 15 cm cylinder. The aspect ratio of this piers group was equal to 4. The b/d_{50} was equal to 50 where b= diameter of the cylinder at the center of the piers group.

The geometrical form of the piers group, b/d_{50} ratio and piers group aspect ratio used in present study are almost same as that of Chabert and Engeldinger.

The values of relative scour depth (i.e., scour depth at piers group/ scour depth at single isolated central cylinder) obtained from curve of Chabert and Engeldinger from present study, were compared for the case of zero degree angle of attack. A good agreement has been observed. The present study can be very useful in economical design of bridge pier.

Conclusions

Following conclusions are drawn from present study Piers group without having collar around it gives about 35 percent reduction in scour depth as compared to the scour depth around a single isolated maximum size cylinder used in forming the piers group. Application of collar around the piers group produces 100 percent reduction in scour depth at angles of attack up-to 7.5 degrees, 94.79 percent reduction at 10 degree angle of attack and 79.54 percent reduction at 15 degree angle of attack as compared to scour depth at corresponding angles of attack without collar around it. The reduction in scour depth using piers group in present study is in good agreement with the piers group used by Laursen and Toch at zero degree and 15 degree angles of attack The present study can be very useful in economical design of bridge piers.

Acknowledgement

The authors are highly thankful to The Department of Civil Engineering Z.H. College of Engineering and Technology, Aligarh Muslim University, U.P., India, for providing the necessary facilities in hydraulics laboratory for the successful completion of this work.

References:

[1] Ahmed, F., and Rajaratnam N. (1998). ‘ Flow around bridge Piers’, Am. Soc. Civ. Engrg., J. Hydr. Engrg., 124(3),288-300.

[2] Brice, J. C., Bloggett, J.C. and others (1978).” 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.

[3] Breusers, N.H.C. and Raudkivi, A.J.(1991). “Scouring”, 2nd Hydraulic Structures Design Manual, IAHR, A.A. BALKEMA/ROTTERDAM, The Netherlands.

[4] Chabert, J. and Engeldinger, P. (1956). Etude des affouillement autour des Piles des ponts (Study on Scour around bridge piers), Laboratoire National d’Hydraulique, Chatou, France.

[5] Chiew Y.M. (1995),’ Mechanics of riprap failure at bridge piers’, j. of Hydraulic Engineering, ASCE, vol. 121,No. 9, pp. 635-643.

[6] Chiew, Y.M.(1992), Scour Protection at Bridge Piers”, J. Hydr. Engrg., ASCE, 118(9), 1260-1269.

[7] Chiew Y.M. and Lim, F. H. (2000), ‘Failure Behavior of riprap layer at bridge piers under live-bed conditions,” J. Hydr. Engrg., ASCE, 126(1),43-55.

[8] Croad, R.N. (1993), ‘ bridge pier scour protection using riprap,’ central laboratories report no. PR3-0071, works consultancy services, N.Z.

[9] Dargahi, B.(1990), “ Controlling Mechanism of Local Scouring”, J. Hydr. Engrg., ASCE, 116(10), 1197-1214.

[10] Dey, S. (1997).”Local Scour at Piers”, part I: a review of developments of research,’ IRTCES, Int. J. Sediment Res., 12(2),23-44.

[11] Dey, S., Bose, S.K., and Sastry, G.L.N. (1995). ‘Clear Water scour at circular piers: a model.,’ Am. Soc. Civ. Eng., J. Hydr. Engrg., 121(12), 869-876.

[12] Ettema, R.(1980). Scour at Bridge Piers, Report No. 216, School of Engrg., University of Auckland, Auckland, New Zeeland.

[13] Ettema, R., Mostafa, E.A., Melville, B.W. and Yassin, A.A.(1998),"Local Scour at Skewed Piers,“ J. Hydr. Engrg.,ASCE, 124(7), 756-759.

[14] Graf, W.H. and ISTIARTO, (2002), 'Flow pattern in the scour hole around a cylinder', journal of hydraulic research, vol. 40, No v. 1, pp. 13-20.

[15] Graf, W. H.,and Yulistiyanto, B.(1998)" Experiments on flow around a cylinder; the velocity and vorticity fields, Int. Ass. Hydr. Res., J. Hydr. Res., 36(4), 637-653.

[16] Gupta, A.K., and Gangadharaiah, T. (1992). "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.

[17] Hjorth, P.(1975). Study on the Nature of Local Scour, Dept. Water Resources, Lund Inst. Of Tech., Bulletin Series A, No. 46.

[18] Istiarto,I.(2001). 'Flow around a cylinder on a mobile channel bed.' Ph.D. Thesis, no. 2368, EPFL., Lausanne, Switzerland.

[19] Johnson, P.A. and Dock, D.A. (1996). " Prababilistic Bridge Scour Estimates", J. Hydr. Engrg., ASCE, 124(7), 750-754.

[20] Kumar, V, Ranga Raju, K.G. and Vittal, N.(1999)."Reduction of Local Scour around Bridge Piers Using Slot and Collar", Technical Note, J. Hydr. Engrg., ASCE, 125(12), 1302-1305.

[21] Laursen, E.M. and Toch, A.(1956)."Scour around Bridge Piers and Abutments, Iowa Highway Research Board, Bulletin No. 4, Ames, iowa, U.S.A.

[22] Lim and Chiew, (2001). Parametric study of riprap failure around bridge Piers, J of Hyd Research, Vol. 30, No. 1, pp. 61-72.

[23] Lim, F.H. (1998),'Riprap protection and its failure mechanisms', A thesis submitted to the School of civil and structural enginerring, Nanyang technological university,sigapore in fulfillment of the requirements for the degree of doctor of philosophy.

[24] Lim F.H. and Chiew, Y.M.(1996),stability of riprap layer under live-bed conditions' proc., Ist Inter. Conf. On new/emerging concepts for rivers, RiverTech'96, Vol.2, 830-837.

[25] Lim, F.H. and Chiew, Y.M. (1997),' Failure behavior of riprap layer around bridge piers,' proc., 27th conf. of IAHR, Managing water, coping with scaracity and abundance, 184-189.

[26] Maynord, S.T. (1995),"Gabion mattress channel protection design", J. of Hydraulic Engineering, ASCE, vol. 121, No. 7, pp. 519-522.

[27] Melville, B.W. and Coleman, S.E., (2000)," Bridge Scour", Water Resources publications, LLC, Highlands Ranch,CO,572 pp.

[28] Melville, B.W. and Raudkivi, A.J.(1997)." Flow characteristics in Local Scour at Bridge Piers", J. Hydr. Research IAHR, 15, 373-380.

[29] Melville, B.W. (1975). 'Local scour at bridge sites.' Report No. 117, University of Auckland, School of Engineering, New Zeeland.

[30] Melville, B.W. and Raudkivi, A.J.(1977).' Flow characteristics in local scour at bridge piers.' Am.Soc. Civ. Eng., J. Hydr. Engrg., 15(4), 373-380.

[31] Melville, B.W. and Hadfield, A.C.(1999)., "Use of Sacrificial Piles as Pier Countermeasures", J. Hydr. Engrg., Vol. 125, No. 11 , pp 1221-1224.

[32] Odgaard, A.J., and Wang, Y. (1987). "Scour prevention at bridge piers." *Hydr. Engrg.* 87, R.M. Ragan, ed., National Conference, Virginia, 523-527.

[33] Parola, A.C.(1993),"Stability of riprap at bridge piers", J. Hydr. Engrg. ASCE, 119, 1080-1093.

[34] Posey, C.J. (1974),'tests of scour protection for bridge piers,' J. Hydr. Engrg., ASCE, 100(12),1773-1783.

[35] Raudkivi, A.J. (1991).' Scour at bridge piers.' In Scouring, Ed. H. Breusers and A.J.

[36] Raudkivi, A.A. Balkema, Rotterdam. NL.

[37] Richardson, E.V. and S.R. Davis (1995). "Evaluating scour at Bridges," Hydraulic Engineering Circular No. 18 (HEC-18), Publication No. FHWA-IP-90-017, Third Edition, Federal Highway Administration, Washington, D.C.

[38] Schneible, D.E. (1951). "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.

[39] Tanaka, S. and Yano, M.(1967). " Local Scour around a Circular Cylindere", Proc. 12the IAHR congress, delft, The Netherlands,3,193-201.

[40] Vittal, N., Kothyari, U.C. and Haighghat, m.(1994)." Clear water scour around Bridge piers Group", ", J. Hydr. Engrg. ASCE, 120(11), 1309-1318.

[41] Worman, A. (1989)," Riprap Protection Without Filter Layers", ", J. Hydr. Engrg. ASCE, 115(12), 1615-1629.

[42] Yoon, T.H., Yoon, S.B. and Yoon, K.S. (1995)." Design of riprap for Scour Protection around Bridge Piers", 26th IAHR Congress, U.K., Vol. 1., pp. 105-110