ISSN (Online) : 0974-5645
ISSN (Print) : 0974-6846
Indian Journal of Science and Technology *Vol 8(2), 185–190, January 2015*
DOI : 10.17485/ijst/2015/v8i1/52576

The Effect of Collar on the Size of Proper Riprap Cover around the Cylindrical Bridge Piers in the Rivers Bend

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Abstract

Riprap of bridge piers is placed to eliminate local scour and to secure the pier from failure. However, riprap surfaces frequently rupture to protect bridges pier during deluges despite arrangement of riprap particles around its foundations. Improper design of proper extent for riprap cover greatly reduces the riprap efficiency in local scour control. Therefore, in this research in order to determine the proper size of riprap cover at the angle of 60° of river bend, some experiments were carried out under clean water conditions in a flume of 180°. The effect of collar presence around the pier and also different size of collar on proper size of riprap were examined in different experiments. The results showed that the presence of collar around the cylindrical bridge pier decreased the proper size of riprap as 26% compared to the pier without collar. Moreover, as the collar diameter increased, the size of riprap cover decreased which is economically affordable.

Keywords: Bend, Bridge, Collar, Pier, Riprap, Scour

1. Introduction

The main factor in local scouring on the river bed, consists of a series of secondary flows which comprise wake vortex system, trailing vortex system, horseshoe vortex system and bow wave vortex. Wake vortex system acts as a vortex and moves the bed sediments upward to the floor[1]. This systems strength depends on the piers shape and water velocity. This System does not exist. Practically, trailing vortex system is of little significance and often occurs in completely submerged piers. Horseshoe vortex system forms due to fragmentation in the piers upstream flow. In other words, the system forms when high pressure gradient is created by the collision between the water flow and the pier[2]. Posey[3], Odgaard and Wang[4], Graziano et al[5], Chiew[6], Bertoldi and Kilgore[7], McCorquodale et al[8], Parola[9], Jones et al[10], Melville and Hadfield[11] and others, have introduced different methods of scour reduction.

Pier protections against local scour can be classified generally in two methods; flow changing methods and armoring methods to enhance the ability of the bed material to resist erosion.

Flow altering devices that have been used to reduce the power of the eroding agents, i.e., the downflow and horseshoe vortex, to erode the bed material. This is normally achieved by placing an extended base plate or collar at or around the bed level. Some designers have used streamlined piers with the objective of reducing the large pressure field around the pier, thereby preventing three-dimensional boundary layer separation, and hence, formation of the horseshoe vortex. Armoring devices include: Cable-tied blocks, tetrapods, dolos, placed riprap rocks, flexible mattresses, grout mats and bags (which are fabricated from geotextiles and filled with grout in situ), anchors (used in conjunction with mats and cable-tied blocks), and high density particles etc. around pier foundation[12].

The use of riprap stones to deal with pier scour problems is very common in civil engineering practice. The extensive studies including experiments and field studies have been conducted. Also, many equations for the

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riprap size to protect bridge piers against scour have been proposed. Especially, Melville and Coleman[13] compared the published equations and concluded that the Parola[9] equations lead to conservatively large riprap relatively to the other equations. Lauchlan and Melville[14] summarized the following recommendation of other design criteria for riprap protection at bridge piers (Figure 1).

- Thickness of riprap layer, $t_R = 2d_{r50}$ to $3d_{r50}$
- Lateral extent of riprap layer, $3b$ to $4b$
- Synthetic filter: the lateral extent should be about 75% of the lateral extent of the riprap layer.
- Stone filter layers: as an alternative to synthetic filters
- Thickness of stone filter layers, $t_f = d_{r50}$

One of the problems of using riprap is riprap rupture over the time. Many researchers have been conducted on the size and thickness of riprap stable[3,9,13-21]. Lauchlan and Melville[14], Chiew and Lim[21] and Lim and Chiew[22] also searched about riprap properties under live-bed local scour. The rupture mechanisms as represented by Chiew[19] were confirmed. Unger and Hager[23] divide the rupture of a riprap surfaces into three causes: Rolling, Undermining and Sliding failure. Rolling essentially according to shields involving a small sediment size ratio, for a riprap whose size is close to the bed sediment. Undermining as the typical failure mode occurring for riprap diameters much larger than the bed sediment. Instead of being transported, riprap elements sink into the bed sediment. Because a riprap filter was absent, undermining occurred at the location with the largest surface deformations. Sliding once an interface scour has developed along the riprap periphery. In this case the instability at the edge of the coarse riprap layer stones and finer bed material initiates the formation of local scour hole, which affects the stability of riprap layer. The primary objective for the present study was to determine the efficiency of collars

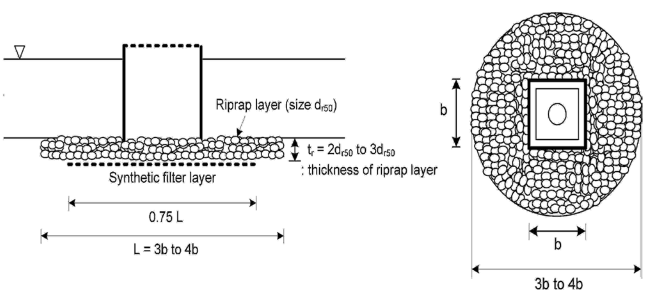

Figure 1. The example of recommendations for riprap replacement at bridge piers.

(with different diameter) in proper riprap cover which can be applied in the certain rivers bend.

2. Materials and Methods

Experiments were conducted in a rectangular cross section of a 180-degree flume bend of Plexiglas materials under clear water condition and using nonadhesive sediments. Table 1 represents the model details including length, height, width, etc. The pier model was made from a circular 60-mm-diameter pipe of Teflon plastics and was placed in the test section. Pier diameters were selected so that the effect of flume sidewalls and sediment size on the depth of scour hole becomes negligible[24].

Scouring in non-cohesive sediments which have a diameter less than 0.7 mm a long with the movement of bed particles in upstream pier is similar to live bed situation. To riddance the effect of sediment particle size on local scouring depth, the dimensionless parameter of b/d_{50} (pier diameter to mean diameter of bed materials) must be bigger than 25[24]. In this study, experiments were filled with a 150mm-thick fine materials of 1mm average diameter and specific gravity of 2.66. Clear water scouring occurs under $U < 0.95U_c$ (U average flow velocity U_c threshold velocity for bed sediments) condition[25]. The threshold of bed material motion was found by experiment when the pier was not installed. Threshold of material motion was defined as a condition such that although finer bed materials move. The riprap particles with median size, d_{r50} = 2.58 mm, 3.68 mm, 4.38 mm and 5.35 mm were selected. Riprap height in all tests was equal to $3d_{r50}$ to prevent winnowing failure[19]. Experiments for stable riprap size around the pier without a collar were covered with a riprap layer. Different discharges and flow depths were tested to find the rupture condition for each riprap particle. Short duration tests were conducted. In these tests, the movement of the first riprap grain in 16 minutes was assumed as the rupture criterion[19]. Experiments in a specific discharge started with the higher flow depth and if after 16 minutes instability of riprap layer did not occur, flow depth was decreased about 6 mm. The experiment continued until instability was observed in the riprap surface. When rupture occurred, the proportion of $U/U_{c(d_{r50})}$ was recorded (U is the undisturbed velocity upstream of the pier and $U_{c(dr50)}$ is the critical failure velocity). The experiments were repeated for different

Table 1. Details of the Physical hydraulic model

Discharge	Angle	Depth	Radius of curvature to Channel	Width	Length	Length	Radius	Length	Length
Be Use	Bend Maximum	Channel (m)	Width $\left(R_c / w_t\right)$	Channel (m)	Bend Foreign	Bend Internal	Curvature Central	Channel Output	Channel Input
31	180	0.45	4.67	0.6	9.74	7.84	2.8	5.5	9.1

riprap sizes, discharge and depth. The extension of the riprap layer in two cases (riprap failure and stable) showed in Figure 2.

According to Figure (2a) due to improper model of riprap cover around the pier, local bed scour is observed around it. In this situation, uplifting vortex will develop behind the pier and create scour at the end of riprap extent. The damage which is caused in this case is edge failure. Even if the riprap aggregate is not heavy enough, when the extent and shape of riprap cover around the pier are not appropriate and sufficient, riprap failure is probable.

In The experiments were performed in combination with the collar and the riprap, the Collars with widths of W = 2b and W = 3b were placed at the stream bed level to study their efficiency for stable riprap size. Tests procedure was similar to what explained in previous Tests. The experiment continued until instability (shear failure) was observed in the riprap layer. When failure occurred, flow velocity was recorded as the critical velocity of the riprap grains. The experiment was then repeated for various riprap sizes, flow discharge and depth. Then to determine the proper cover for stable riprap layer around the pier with collar, tests were conducted. Tests were performed in the threshold of bed materials motion. Various patterns were tested with 2.58 mm aggregates for 72 hours, similar to the case without collar. All tests to study a suitable range of riprap and stability were conducted in the 60-degree position because of in this position the vortex flow is a maximum amount[26].

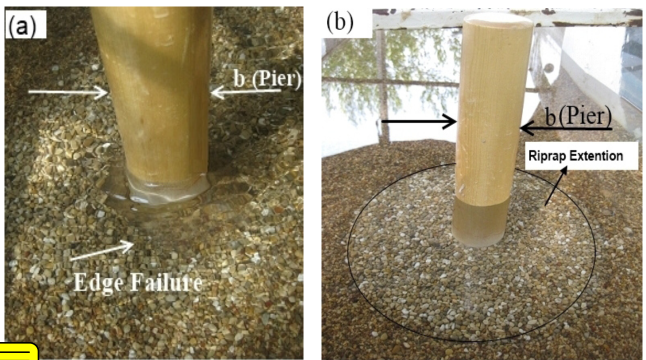

Figure 2. Extension of the riprap layer; a) Failure, b) Stable.

3. Result

Figure 3 shows the proportion of $U / U_{c(d_{r50})}$ plotted against, relative riprap diameter d_{r50} / y_c for stable riprap particle in the 60-degree position. Figure 3 shows that on all tests, as the riprap relative size become increases, the threshold conditions is reached at a higher critical velocity ratio; also, by increasing the d_{r50} / y_c, the distance of the points representing critical velocity ratio approach together. At 60-degree position in contrast to straight channels, the maximum velocity occurs adjacent the bed and accordingly causes reduction in the stability of riprap.

Figure 4 present the final pattern for stable riprap layer without collar. The proposed extent includes circular shape.

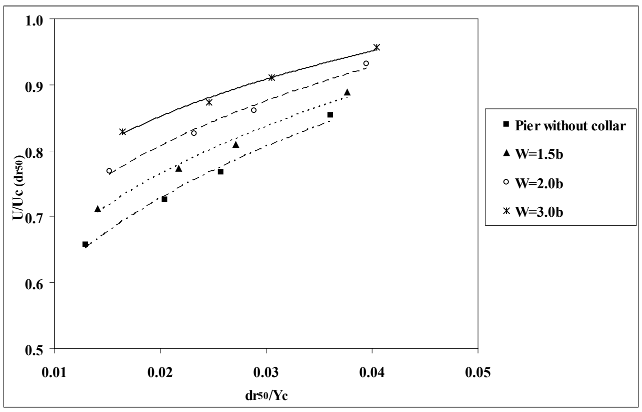

Figure 3. Critical velocity ratio against relative riprap diameter.

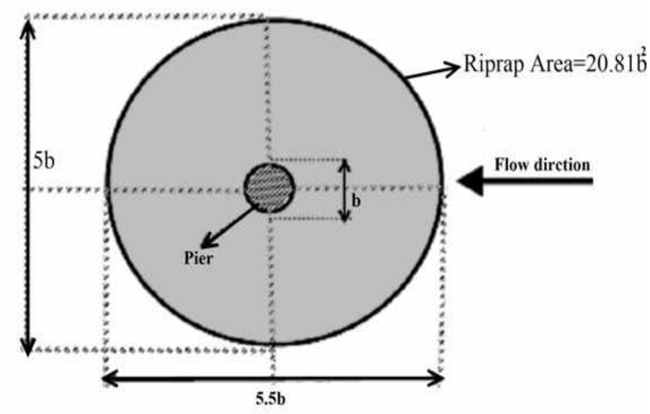

Figure 4. Final extension of the riprap layer without collar protection.

Figure 5 present the final pattern for stable riprap layer with collars of W = 1.5b, W = 2b and W = 3b, respectively. The proposed extents include two half ellipsoids which form an oval shape.

Results indicate that using a large collar has tangibly (0.95b) eliminated the riprap in front of the pier (Figure 5,c) while in the pier without collar the presence of riprap is necessary as far as 2.25b in front of the pier and this distance for the pier with small and medium collars reduces to 1.5b and 1b, respectively. So that for the small, medium, and large collars respectively 34%, 55%, and 57% of the riprap cover in front of the pier are reduced compared to the pier without the collar. Moreover, the presence of the large collar has decreased the riprap extent along the pier (1.65b) more than that of the small collar (1.87b). The reason that the riprap extent along the pier with small collar is more than that of the pier with large collar is the greater power of horseshoe vortices, so that in the large collar the strength of this scouring factor is reduced. Moreover, in the pier without protective collar, due to the direct effect of horseshoe vortex on the cover of both sides of the pier, the need to increase the cover is more tangible in order to ensure lack of riprap failure and to deal with horseshoe vortex. Ultimately, with regard to the above Figures behind the pier, the small collar had nearly no effect on the riprap extent compared to the pier without collar (2.75b) and the large collar has increased this extent (3.2b). Finally, with respect to the changes trend of riprap extent in above Figures, it is observed that the presence of collar

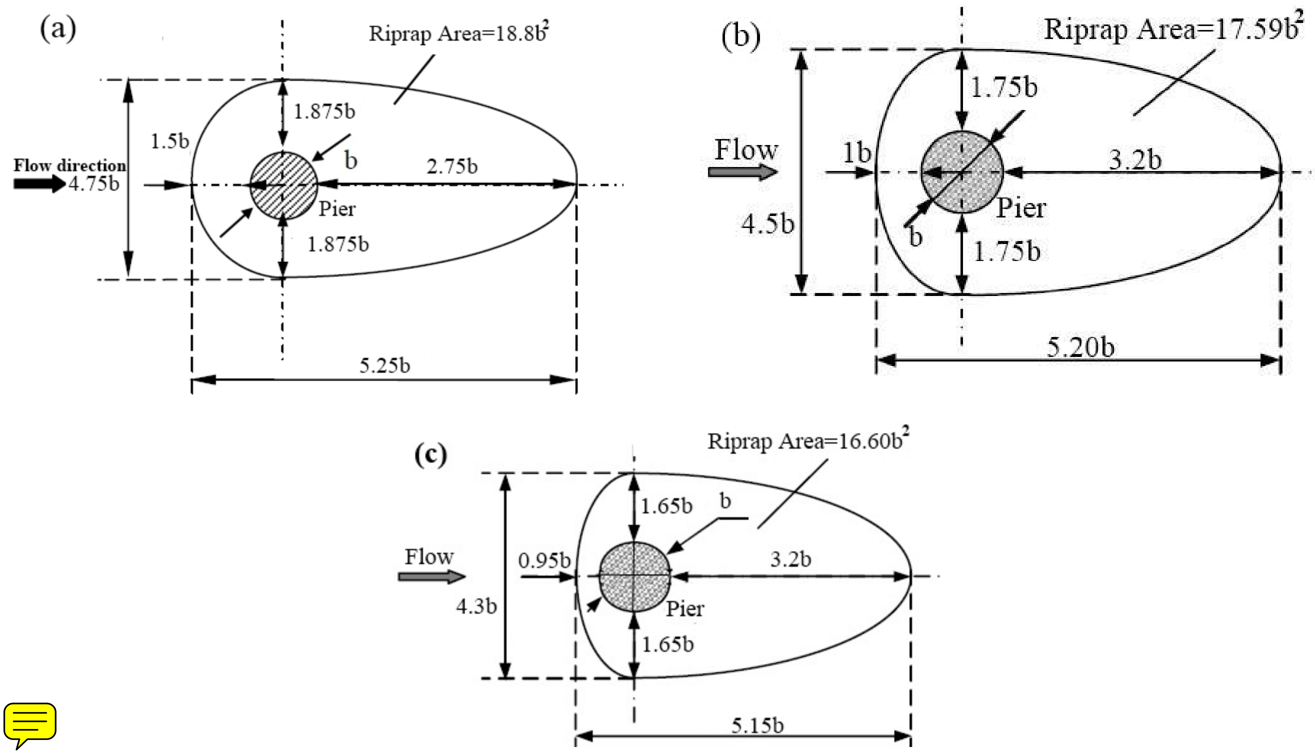

Figure 5. Final extension of the riprap layer with collar; a) W = 1.5b, b) W = 2b, c) W = 3b.

has greatly decreased the proper extent of riprap, so that comparison of the area of riprap extent in above shapes displays the effect of collar and its size on the required riprap cover area. If the area of proper extent of riprap is expressed as a coefficient of b^2, this area for the pier without collar will be $20.81b^2$ and for the pier with small, medium, and large collar will be $18.80b^2$, $17.59b^2$ and $16.61b^2$, respectively. As a result, small, medium, and large collars have decreased the area of riprap extent as 11%, 18%, and 26%, respectively. Furthermore, the area of riprap extent in the pier with large collar in comparison to the pier with small and medium collars has decreased 13%, and 6%, respectively.

4. Conclusion

In the present work, the effect of collar on proper extent of riprap and riprap stability in the vicinity of bridge piers in 180-degree river bends was studied. Four sizes of aggregates and three sizes of collar were used. In experiments which were conducted for stable riprap size, the whole test section area was covered with riprap layer to eliminate the edge failure. Long term tests were also conducted to determine the cover of riprap layer around the pier.

The results show that, using collar in bridge piers increases the riprap stability and greater collars were more effective than smaller collars on increasing the stability. It is concluded that using collar reduced the riprap extent in front and sides of the pier. Based on the experimental data, the riprap Areas with collar widths of W = 1.5b, W = 2b and W = 3b are, respectively, 11%, 18% and 26% less than that for the pier without collar in river bend. It can also be concluded that by using larger riprap grain sizes, the effect of collar on the riprap layer stability decreased. The proposed extent for stable riprap layer without collar includes circular shape but stable riprap layer for pier with collar include two half ellipsoids which form an oval shape.

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