EFFECT OF COLLAR LENGTH ON TIME DEVELOPMENT OF SCOURING AROUND RECTANGULAR BRIDGE PIERS

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The process of local scouring at bridge piers is time dependent. Using of a collar around a pier for scour protection reduces the rate of scouring considerably. Collars are horizontal plates which are attached to a pier. Collars acts as a barrier to the down flow and prevent its direct impingement into the streambed. In the present work collars with 3 different lengths (25, 35 and 45 cm) and constant width equal to 3 times the pier width were installed around a rectangular pier 5 cm wide and 15 cm long. Pier model had a circular nose and tail and was made from clear Perspex. Collars were installed at the streambed level and all tests were conducted at the threshold of bed material motion where maximum depth of scour hole is expected. Long time tests were carried out to study the development of the scour hole around the pier. Results of the present study showed that the collar length is an important factor that affects the rate of scouring. In experiments with 25 cm and 35 cm collars, the flow undermined the collar and penetrated below its upstream edge after 8 and 24 hours respectively. After this time, development of scouring was accelerated due to the action of horseshoe vortex. In the experiment with 45 cm collar, flow could not penetrate below the upstream edge of the collar after 185 hours. Therefore, scouring at the upstream region of the pier did not occur.

Key Words : *Bridge pier, scouring, Protection, Collar, Time development*

1. INTRODUCTION

Local scour around a pier results from a complex vortex system which forms around the pier. These vortices consist of a horseshoe vortex initiated from the down flow at the upstream face of the pier and wake vortices downstream of the separation point at the sides of the pier. Numerous methods have been studied to control local scouring around bridge piers. In general, these methods can be divided into two types: i-armoring the bed and ii-changing the flow pattern around the pier to reduce the shear stresses on the streambed material. To change the flow pattern various devices are used which include: collar attached to the pier[1,2,3,4,5)], sacrificial piles placed upstream of the pier[6)], slots[3,4)] and Iowa vanes[7)]. Collars are plates, which are attached to a pier, act as a barrier to the down flow, and prevent its direct impingement into the streambed. Tanaka and Yano (1967), Ettema (1980), Chiew (1992) and Kummar et al. (1999) studied the effect of collar in reducing local scour depth around a circular pier. In these studies, collars with a width equal to 2 to 4 times the pier diameter were installed around the pier and their efficiency was measured. Efficiency of collars around rectangular piers was studied by Zarrati et al. (2004), in which collars with a total width 2 to 3 times the pier width (W/D=2 & 3, Fig.1) were used to control scouring.

Collars are found to be very effective in reducing the rate of scouring and postponing the time that maximum scour depth occurs[8]. In contrast with an unprotected pier, where scouring starts at the upstream face of the pier with a high rate, with a collar installed at the streambed level, scouring is first observed at downstream of the collar. Wake vortices are obviously responsible for formation of this scour hole. Two scour holes also develop simultaneously at two sides of the collar, which are then extended very gradually towards upstream along the rim of the collar. These holes are then joined at the upstream edge of the collar. After the scour hole develops at the upstream edge of the collar, flow penetrates below the collar. Penetration of flow below the collar forms the down flow and horseshoe vortex below the collar as a result of it scouring accelerates[5].

In the present study, collars with different lengths are installed around a rectangular pier and their effect on development of scouring is examined.

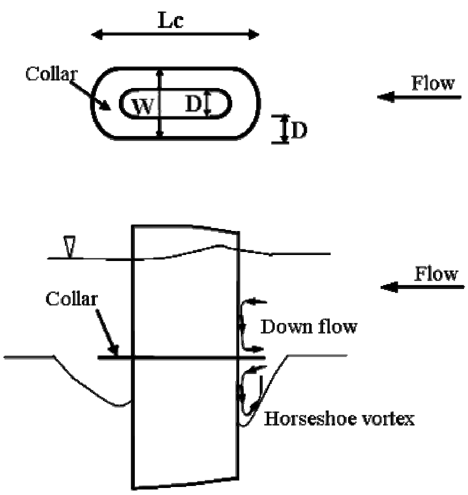

Fig.1 Collar around the rectangular bridge pier.

2. EXPERIMENTAL SETUP

The experiments were carried out in a flume, 10 m long, 0.74 m wide and 0.6 m deep. The flume had a working section in the form of a recess below its bed, which was filled with sediment and was located 6 m downstream from the flume entrance. Median size of the sediment was 0.95 mm. The pier model was 5 cm wide and 15 cm long and was located aligned with the flow. This pier model had a circular nose and tail and was made from clear Perspex. Three different Perspex collars with 25 cm, 35 cm and 45 cm length were used in these studies, all installed at the streambed level (Fig.2). Total width of all collars 'W" was constant and equal to 3 times the pier width in all these tests.

Tests were conducted at the threshold of bed material motion where maximum depth of scour hole is expected[9]. 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 for which finer materials may move, but the elevation of the bed would not reduce more than 2 to 3 mm during the period of the experiment. These tests showed that with 0.12 m flow depth and 0.032 m3/s discharges, bed material would be at incipient motion. The ratio of shear velocity in these experiments calculated from flow depth and energy slope to the critical shear velocity calculated from Shields diagram was about 0.92.

It should be noticed that the shear velocity applied to the streambed affects the time development of scouring. By increasing the ratio of shear velocity to Shields' critical shear velocity, the area of high shear stress around the collar increase. Consequently, the scour hole at the rim of the collar develops faster towards the upstream[10].

Flow depth was measured with a point gauge with 0.1 mm accuracy. Discharge was measured with a calibrated sharp crested weir installed at the downstream end of the flume.

To find the maximum depth of scouring, experiments were continued until the variation of scour depth was negligible. This time was found based on Melville and Chiew (1999) definition. According to this definition when depth of the scour hole does not change by more than 5% of the pier diameter over a period of 24 hours, equilibrium condition is achieved.

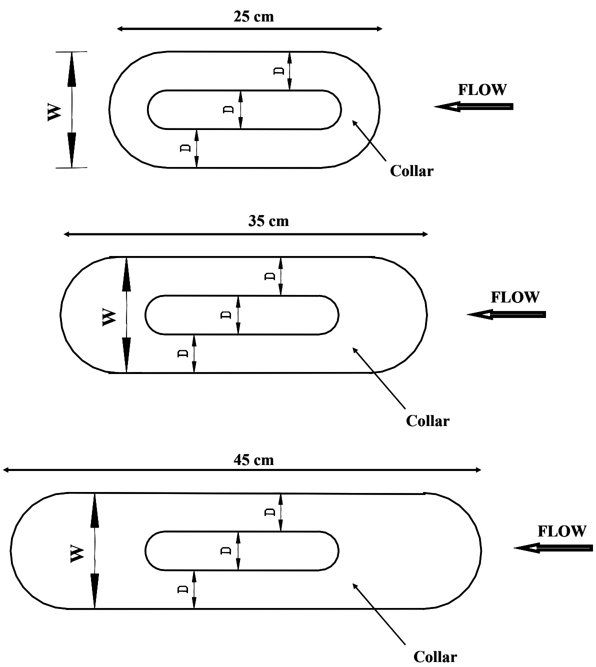

Fig.2 Collar with different lengths around the rectangular pier.

3. RESULTS OF EXPERIMENTS AND DISCUSSION

In a preliminary test, scouring around the pier without any protection was measured. The test was conducted for 45 hours and maximum scouring was measured at the upstream face of the pier. The ratio of maximum scour depth to the pier width was equal to 2.16 (Table 1). This result was in agreement with the empirical equations (for example Melville and Sutherland, 1988). The scour hole around the pier was also symmetric, showing the evenness of flow and correct setup of the experiment. Also, time development of scouring in this test is shown in Fig.3. Based on this Figure, 70 and 90 percent of the scouring occurred in first 0.8 and 5 hours respectively.

In the next stage of experiment, a 25 cm long collar was installed around the pier at the streambed level. With the collar in place, scouring started at downstream of the collar by the action of wake vortices. At this time, no sign of scouring was observed due to the down flow and horseshoe vortex at the upstream face of the pier. Two scour holes were also developed simultaneously at two sides of the collar, which were then extended towards upstream along the rim of the collar while their depths were increasing gradually. These scour holes joined each other at the front edge of the collar after 6 hours of experiment. When the scour hole developed at the upstream edge of the collar, flow penetrated below the collar, undermined it and as a result, scouring accelerated. In this experiment after 8 hours, the collar was completely undermined and separated from the bed. The ratio of maximum scour depth to the pier width was measured 1.63 at the upstream face of the pier and was reached after 55 hours. Reduction of the maximum scour depth in this test was therefore 25% in comparison with the unprotected pier (Table 1). Based on time development of scouring in this experiment which shown in Fig.3, 70% and 90% of the maximum scour depth occurred after about 13.8 and 19 hours respectively, comparing with 5 hours in unprotected pier. This shows the efficiency of collar in postponing the development of scouring compared with an unprotected pier.

Next test was carried out with 35 cm long collar. Similar to the pervious test, two holes at two sides of the collar were developed towards upstream. However since this collar was longer than the collar in the previous test, only after 24 hours the collar was completely undermined and then scouring started and developed at the upstream face of the pier. This experiment was continued for 70 hours and the ratio of maximum scour depth to the pier width was measured 1.6 at the upstream face of the pier. Reduction of the maximum scour depth in this test was therefore 26% in comparison with the unprotected pier (Table 1). It should be noticed that though maximum depth of scouring is similar in 25 cm and 35 cm collars, beginning of scouring at the upstream face of the pier was postponed with longer collar considerably. Time development of scouring in this test is shown in Fig.3. This Figure shows that 70% and 90% of the maximum scour depth occurred after about 30.5 and 35 hours respectively. Comparing of this experiment result with 25 cm collar test it can be concluded that with increasing the collar length, rate of scouring around the pier decreased.

Finally, the collar with longer length of 45 cm was attached to the pier at the streambed level (Fig.2). In this test after 185 hours, flow could not penetrate below the upstream edge of the collar. Therefore, scouring at the upstream face of the pier did not occur (Fig.3). Maximum depth of scouring in this test was

Table 1 Results of experiments.

Length of Collar (cm)	Without collar	25	35	45
Time when scouring begins at the upstream of the pier (hours)	-	8	24	Not observed
Time when 70% of maximum Scour depth occurs (hours)	0.8	13.8	30.5	Not observed
Time when 90% of maximum Scour depth occurs (hours)	5	19	35	Not observed
Ratio of the Maximum Scour Depth to the Pier Width	2.16	1.63	1.6	0.87
Time of Experiment (hours)	45	55	70	185
Reduction of Maximum Scour Depth (%)	-	25	26	60
Location of Maximum Scouring	Upstream face	Upstream face	Upstream face	Sides of the Collar

at the sides of the collar and was 4.35 cm, showing about 60% reduction in scouring (Table 1).
Results of the present study showed that the collar length is a significant factor that affects the rate of scouring. With increasing the length of the collar, beginning of the scouring around the pier perimeter was postponed and maximum depth of scour decreased.

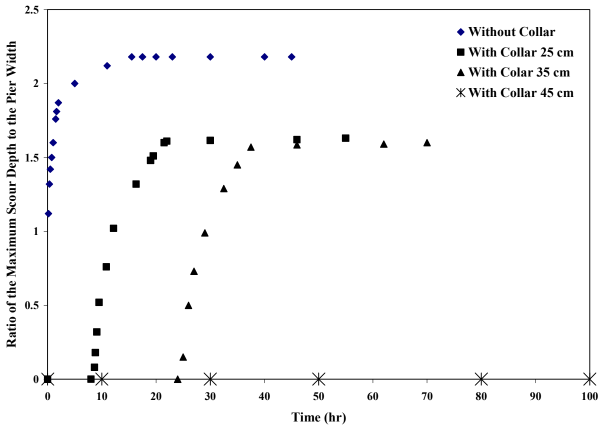

Fig.3 Time development of scouring at the upstream face of the pier without collar and with collar with different lengths.

4. CONCLUSION

In the present work efficiency of collars with constant width but with different lengths were tested on a rectangular pier. The pier model was 5 cm wide and 15 cm long and was located aligned with the flow. Three different collars with 25 cm, 35 cm and 45 cm length were used in these studies, all installed at the streambed level. All the tests were conducted at the threshold of bed material motion to achieve the maximum scour depth.
Results of the present study showed that the collar length is an important factor that affects the rate of scouring. In experiments with 25 cm and 35 cm collars, the flow undermined the collar and penetrated below its upstream edge after 8 and 24 hours respectively. After this time, development of scouring was accelerated due to the action of horseshoe vortex. Maximum reduction of scour depth in these cases was about 25% compared with a pier without any protection. Although 35 cm collar did not change the maximum depth of scouring compared with 25 cm collar, it postponed the beginning of scouring at the upstream face of the pier quite considerably. With 35 cm collar scouring started at the upstream edge of the pier after 24 hours, whereas in unprotected pier 90% of scouring occurred in first 5 hours. This shows the efficiency of collar in reducing the rate of scouring around the pier. In the experiment with 45 cm collar, flow could not penetrate below the upstream edge of the collar after 185 hours. Therefore, scouring at the upstream region of the pier did not occur. Maximum depth of scouring in this test was at the sides of the collar and was 4.35 cm, showing about 60% reduction in scouring.

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