TIME DEVELOPMENT OF SCOURING AROUND A BRIDGE PIER PROTECTED BY COLLAR

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In clear-water condition scouring around an unprotected pier, first develops very fast but the rate of scouring is reduced as the scour hole becomes deeper. Different definitions are given in the literature for the time of equilibrium. In this paper, time development of scouring around a circular and rectangular pier protected by a collar is studied. A collar 3 times wider than the pier diameter, or pier width, was used at the streambed level. It is shown that application of a collar affects the time development of scouring considerably. In the circular pier, in contrast with an unprotected pier the rate of scouring at the upstream face of the pier, was very low at the first 30 hours. After this time the rate of scouring increased again. In the rectangular pier no sign of scouring was observed upstream of the pier after 52 hours. However, very slow development of scouring was measured at two sides of the collar. This shows that collar is more effective on a rectangular pier compared to a circular one. It is also shown that collar is more effective in slowing down the scour development than a wider foundation with a similar width and elevation.

1 *Introduction*

There are so many bridges over waterways in the world. At many of these bridges, erosion of channel beds has developed around the pier foundations. As a result, a high percentage of bridge failures in recent years have been attributed to scouring (Johnson and Ayyub 1996). Pier scour is the erosion of the streambed in the vicinity of pier foundation due to complex vortices system. This system consists of a horse shoe vortex initiated from the down flow at the upstream face of the pier, and wake vortices which shed from sides of the pier (Breusers and Raudkivi 1991).

In clear-water condition scouring first develops very fast but the rate of scouring is reduced as the scour hole becomes deeper (Figure 1). Maximum depth of the scour hole increases with shear stresses on the bed material. Since in clear-water condition the maximum depth of the scour hole is reached asymptotically with time, an equilibrium time of scour should be defined. In live-bed condition depth of the scour hole reduces and fluctuates as bed forms pass over the scour hole (Raudkivi 1998) (Figure 1). It can therefore be said that maximum depth of the scour hole occurs at the threshold of bed material motion. It can also be concluded that the equilibrium or final depth of local scour is rapidly attained in live-bed conditions, but rather more slowly in clear-water conditions (Melville and Coleman 2000).

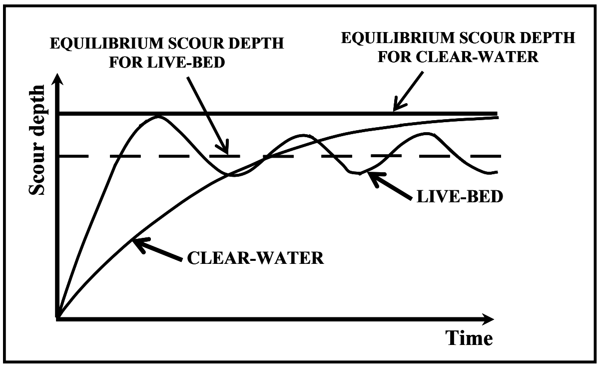

Figure 1. Scouring in clear-water and live-bed conditions (Raudkivi, 1998).

The effect of collar in reducing scour depth is previously studied on circular piers by Tanaka and Yano (1967), Ettema (1980), Chiew (1992) and Kummar et al (1999), and on rectangular piers by Zarrati et al (2004). In the present work, time development of scouring around piers protected by a collar in clear-water condition is studied.

2 *Application of collar*

Collar diverts the down flow and protects the riverbed from its direct impact. Wider collars are more effective as they protect a larger area around the pier. Lowering the elevation of a collar also increases its efficiency as less flow penetrates below the collar resulting in a weaker down flow (Tanaka and Yano1967, Zarrati et al 2004).

In addition to lowering the scour depth, application of a collar reduces the rate of scouring. Mashahir and Zarrati (2002) in their work on rectangular piers showed that rate of scouring reduced considerably when a collar was installed at the streambed level. As in clear water condition maximum depth of scouring is reached very slowly, and existence of a collar further reduces the rate of scouring, it is necessary to define a time that equilibrium scour depth is reached. Chiew (1992) in his studies on scour protection at bridge piers by slot and collar defined the equilibrium time of scour as a time when change in depth of the scour hole is less than 2% of the pier diameter after 8 hours. In study on time scale for local scour at unprotected circular piers Melville and Chiew (1999) defined the equilibrium time of scour as the time when scour depth did not change by more than 5% of the pier diameter over a period of 24 hours. Both of these studies were conducted in clear water condition.

In the present study, time development of scouring around a circular pier with and without a collar are measured and compared. These results are also compared with time development of scouring around a rectangular pier protected by a collar. The present study was carried out to see how a collar affects the scouring rate and the definition for the time of equilibrium.

3 *Experimental procedure*

To study the temporal variation of scouring around a pier with and without a collar, experiments were carried out in a 10 m long, 0.75 m wide, and 0.55 m deep flume. A collar with an effective width '*W*' equal to three times the pier diameter '*D*' was installed at the streambed level (Figure 2). Size and elevation of the collar was selected based on the previous experience. Wider collars are more effective, but construction of collars wider than 3 times the pier diameter is considered impracticable. Also, the efficiency of a collar increases at lower elevations (Tanaka and Yano 1967, Zarrati et al 2004).

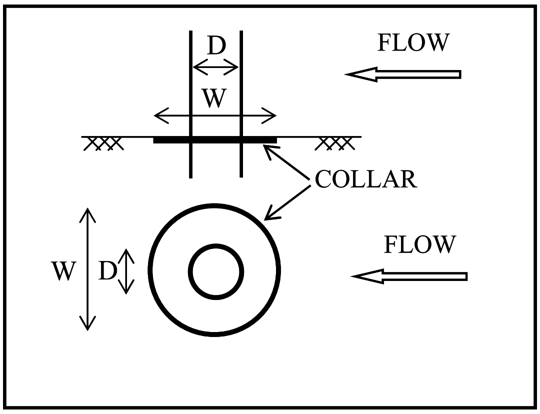

Figure 2. Position of collar around a circular pier.

A point gauge was used to measure scour depth in the flume. A periscope installed inside the pier, was used to measure development of the scour hole at the pier's perimeter. The circular pier used in this study was 0.04 m in diameter. The flume had a working section in the form of a recess below its bed that was filled with sediment and located 6 m downstream from the flume entrance. Median size of the sediment was 0.95 mm, with geometric standard deviation of sediment grading, less than 1.2. All tests were conducted at incipient sediment motion, which maximum depth of the scour hole is expected (Breusers and Raudkivi 1991).

The threshold of sediment motion was found by experiment when the pier was not installed. The ratio of shear velocity in these experiments to the critical shear velocity calculated from shields' diagram was about 0.92.

4 *Time development of scouring around a circular pier*

Scouring around an unprotected circular pier started simultaneously at the downstream of the pier under action of wake vortices, and upstream face of the pier due to the down flow. The scour hole upstream of the pier was then developed under the action of horseshoe vortex. This experiment was carried out for 44 hours in which variation in scour depth was less than 2% of pier diameter in the last 8 hours. Maximum depth of the scour hole was measured 92 mm.

When the collar was attached to the circular pier at the streambed level, in the beginning of the experiment, scouring started downstream of the pier due to action of wake vortices. These vortices were so strong that at the first 30 minutes a 2 cm deep scour hole was formed downstream of the collar. At this time no sign of scouring was observed due to the down flow and horseshoe vortex at the upstream face of the pier. Later in the experiment two grooves were formed at two sides of the collar and moved towards upstream, along the rim of the collar until they joined each other at the front edge of the collar. By penetration of flow beneath the front edge of the collar the rate of scouring increased. The maximum scour depth was 67.5 mm at the upstream face of the pier after 90 hours and variation of the scour depth was less than 5% of the pier diameter in the last 24 hours. Temporal variation of scour depth at the upstream face of the circular pier, with and without a collar is showed in Figure 3. In this figure Y_s is depth of the scour hole at time *t* and Y_{se} is equilibrium depth of scour.

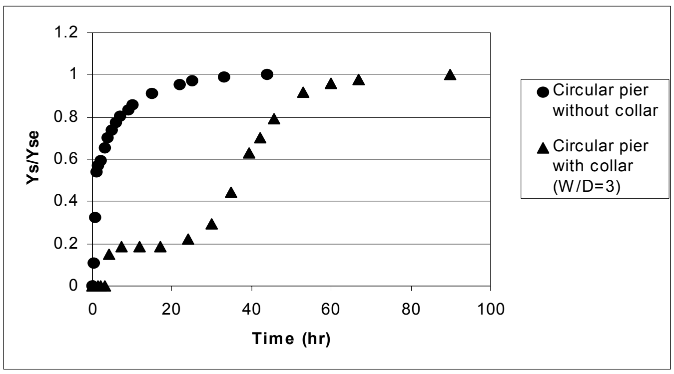

Figure 3. Time variation of scour depth at the upstream face of the circular pier with and without a collar.

According to the results shown in Figure 3, it can be seen that existence of collar has reduced the rate of scouring considerably. With a collar scouring at the upstream face of the pier is zero after about 4 hours from the beginning of the experiment and only 30% of the maximum scouring occurred after 30 hours; whereas in this time 98% of scouring has occurred in unprotected pier. It can also be seen that scour depth at the upstream face of the pier did not change for 10 hours at the first stages of scour development. Scouring however, accelerated after 30 hours. This is the time when flow penetrated below the collar and undermined it. After this time development of scouring is similar to the unprotected pier with a milder slope. In this stage of scouring, time of equilibrium similar to an unprotected pier can be defined.

Based on Figure 3, in the case of pier without a collar 70% and 90% of the equilibrium scour depth occurred after 10% and 30% of the time of equilibrium respectively. These results agree with the Melville and Chiew (1999) experiments. They concluded that 90% of the equilibrium scour depth, developed after 30% of the time of equilibrium. In the case of pier with collar, 20% and 90% of the equilibrium scour depth, developed after 10% and 55% of the time of equilibrium respectively.

Time development of scouring around a circular pier with a collar at streambed level and with size of *W/D=2*, was studied by Ettema (1980). Result of this work is compared with the present study with *W/D=3* in Figure 4. It can be seen from this figure that how the width of the collar affects the time development of the scouring.

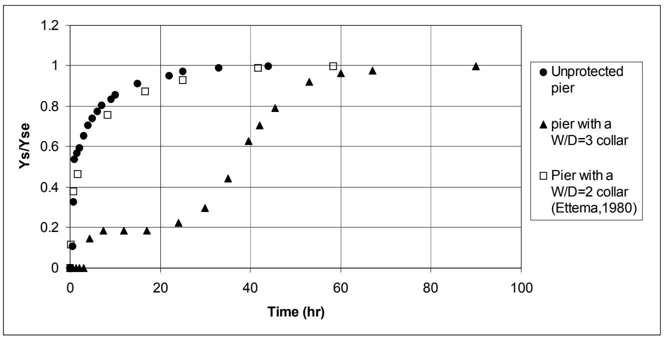

Figure 4. Time development of scouring with collars of different sizes.

Melville and Raudkivi (1996) studied the effect of foundation geometry on pier scour. From this study, time development of scouring around a circular pier with its foundation at the streambed level, and 2.7 times wider than pier diameter, is compared with the results of the present study in Figure 5. In this figure t_e is time of equilibrium. Scour variation at an unprotected circular pier is also shown in this figure for comparison. It can be seen that while a wider foundation at the streambed level does not reduce the rate of scouring, a collar with about the same width reduces the rate of scouring.

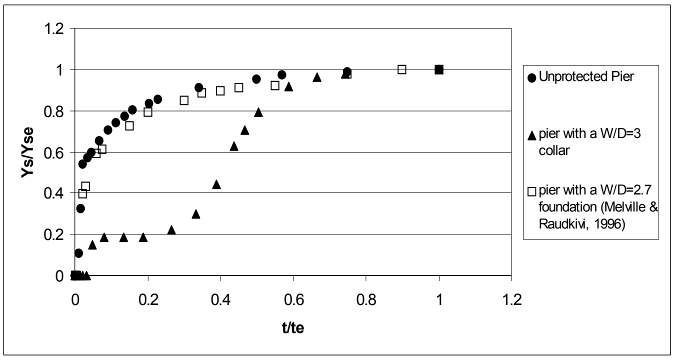

Figure 5. Comparison of the rate of scouring around a pier protected by a collar, and a pier with a wide foundation.

5 *Time development of scouring around a rectangular pier*

Mashahir and Zarrati (2002) studied the development of scouring around a rectangular pier with and without a collar. The pier model was 5cm wide and 25cm long. They found that when a collar with *W/B=3* was installed at the streambed level, where *B* is the pier width (Figure 6), scouring started at the downstream end of the collar under the action of wake vortices. Two scour holes were also formed along two sides of the collar. This experiment was continued until 52 hours when change in the maximum scour depth, which was at two sides of the collar, was less than 2% of the pier width after 8 hours (Chiew 1992). In this time scouring did not reach the pier perimeter. However they mentioned that very slow extension of the scour hole towards the pier is possible which may takes many days to develop and further study is needed to find the ultimate extension of the scouring.

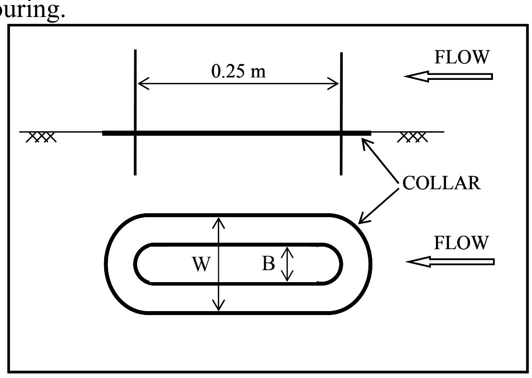

Figure 6. Position of collar around a rectangular pier.

Time development of scouring in this experiment at two sides of the collar and upstream face of the pier are compared with rate of scouring at the upstream face of the circular pier in Figure 7. It can be seen that in the rectangular pier, scouring started at the sides of the collar from the beginning of the experiment and developed very gradually. No sign of scouring could be seen at the upstream face of the pier after 52 hours. In the circular pier though existence of the collar has reduced the rate of scouring at the first 30 hours, the rate of scouring has increased again. This shows more effectiveness of collar on the rectangular pier. Since the rate of scouring is very slow in the rectangular pier protected by a collar, it seems that in this case much longer time should be allowed before it is ensured that scouring is reached to its final extension and equilibrium condition.

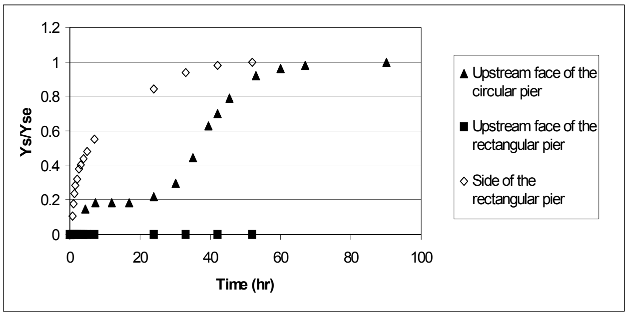

Figure7. Comparison of scouring rate at a rectangular and a circular pier.

6 *Conclusions*

In addition to reducing the depth of the scour hole, application of a collar reduces the rate of scouring to a great extend. In this work time development of scouring is studied around circular and rectangular piers. A collar with an effective size equal to 3 times the pier diameter or pier width, installed at the streambed level is used in this study. It is shown that with a collar, rate of scouring at the upstream face of the circular pier is very slow at the first 30 hours of experiment. In this test only 30% of the maximum scouring occurred after 30 hours; whereas in this time 98% of scouring occurred in unprotected pier. However, rate of scouring increased again after this time. Collar was more effective in the rectangular pier, and no sign of scouring was observed after 52 hours at the upstream face of the pier. It is also shown that a collar is more effective in reducing the scour rate than the pier foundation with a similar width and in the same elevation.

Acknowledgment

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