EFFECT OF COLLAR ON TEMPORAL DEVELOPMENT OF SCOUR AROUND BRIDGE ABUTMENTS

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In this study, an investigation related to the reduction of scour around a vertical-wall bridge abutment by using rectangular collars has been carried out for the case of clear-water flow condition over uniform sediment particles. The primary cause of local scour around abutment is a spiraling vortex flow structure called the principal vortex. The growth of the vortex can be arrested by retaining the vortex on a rigid surface by a collar plate, and therefore, the excessive scouring around the bridge abutment can be prevented. The primary objective of this study is to determine the time varying development of scouring around the bridge abutment by using collars of different sizes and at different elevations. Development of scouring with and without collar was studied and observed scouring values were compared to each other. Experimental results showed that in addition to reduction of scour depth, a collar was very effective in reducing the rate of temporal development of the scour hole. Comparison of the results of this study with the previous studies showed that the effectiveness of a collar increases with lowering its elevation and widening it.

1 Introduction

Failure of bridges to scouring is common occurrence and each year a significant amount is spent to repair or reconstruct bridges whose piers and/or abutments have been under – cut. Because of failure experiences many researchers have worked on scour phenomena during the last decades (Rajaratnam and Nwachukwu, 1983; Melville, 1992 and 1997). Most of the methods stated in the above mentioned papers deal with the determination of design scour depth at bridge piers and abutments using design discharges for steady flow cases. However, the flow in a river during a flood is unsteady. The time required by the design discharge to scour to its full potential is generally much larger than the time for which it runs. Therefore, for realistic estimation of scour depth in case of flood flows the temporal variation of the scour depth becomes significant for design purposes (Yanmaz and Altınbilek, 1991; Kohyari et. al., 1992,a and b; Melville and Chiew, 1999; Kothyari and Ranga Raju, 2001; Oliveto and Hager, 2002; Coleman et. al., 2003).

One of the methods used for control of scouring around the bridge pier is to install a collar around the pier. Collar diverts the down flow and protects the riverbed from its direct impact. Chiew (1992) showed that, the collar has the effect of shielding the sediment particles from erosion by the down flow. Kumar et. al. (1999) investigated that larger diameter at or nearer the bed are more effective. Singh et. al. (2001) obtained 91% reduction of scour by using a collar-plate of twice diameter of the pier and plate elevation 0.1D below the average bed level. Mashahir and Zarrati (2002) concluded that the collar is very effective in slowing down the development of scouring around a rectangular pier based on the studies conducted with and without collar.

In this study, which is a part of continuing Ph.D. research, collar-plates which arrest growth of a vortex by forming a rigid surface around the abutment, are placed at various levels to the abutment and time variation of local scour depth around the abutment is observed under clear-water flow conditions.

2 Experimental Set-Up

Since the maximum scour depth occurs at the threshold condition, all experiments were conducted under clear water flow conditions, $U_*/U_{*c}<1$, where U_* is the shear velocity of the approach flow and U_{*c} is the value of U_* at the threshold. The threshold of bed material motion was found by experiment when the abutment was not installed at the discharge of 0.05 m^3/s with the corresponding flow depth of 100 mm. The value of

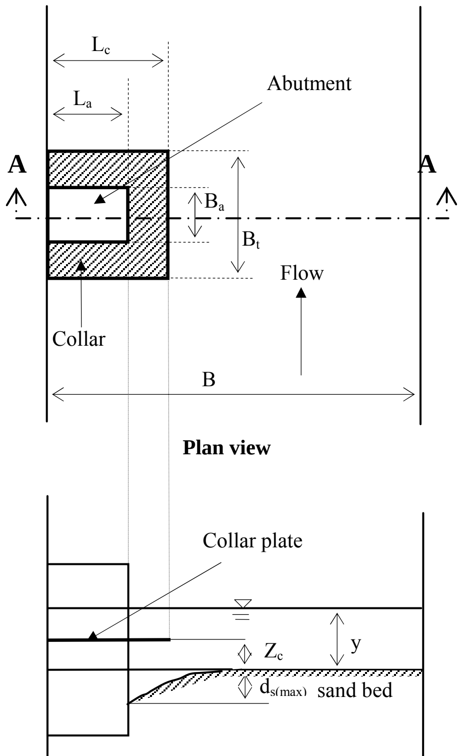

Figure 1. Definition sketch of collar-abutment arrangement

the ratio U_*/U_{*c} in these experiments was about 0.90. A rectangular flume with transparent walls, 30 m long, 1.5 m wide and having a bottom slope of 0.0001 was used in the experiments. The working section of the flume, which was located 15 meters downstream from the flume entrance, in the form of a recess below its bed was 1.50 m wide, 10 m long and 0.50 m deep. The mobile bed was made of uniform sand having a median diameter of d_{50}=1.48 mm and a distribution ratio of σ_g=1.28. The flow was supplied from a water tank by a pump and measured by a sharp-crested rectangular weir. The depth of the flow and the bed profile measurements were conducted by a point gage with a vernier scale to an accuracy of ±0.1 mm. Figure 1 shows a definition sketch with a typical view of a collar-abutment arrangement used in this study. The abutment used was rectangular in plan view, having the length of L_a=0.20 m and the width of B_a=0.10 m.

The scour hole was obtained by performing a 6-hours continuous run under clear-water condition with the flow depth of y=100 mm corresponding to the discharge of Q=0.05 m^3/s first without collar and then with collars. At the end of the tests both maximum scour depths and scour holes at the abutment site were investigated.

Four different collar widths B_c=0.025 m, 0.050 m, 0.075 m and 0.10 m were tested. Since the effectiveness of the collar on the development of the scour hole is also a function of its vertical location on the abutment, all collar types were tested at various

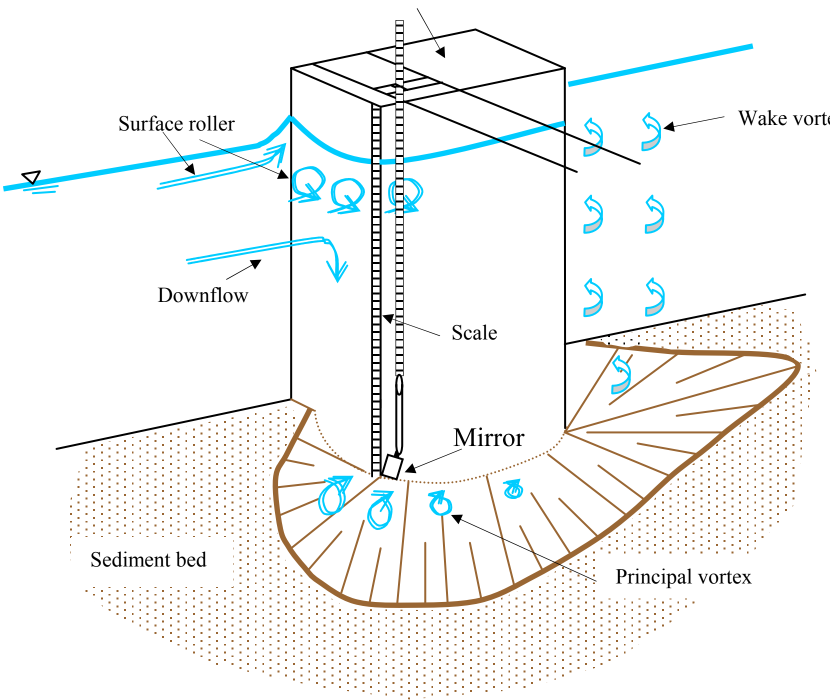

Figure 2. Definition sketch of flow and scour measurement around the abutment

elevations; at the bed level, 0.025 m and 0.050 m above the bed level and 0.025 m and 0.050 m below the bed level.

In the experiments, the maximum scour depths around the bridge piers d_s, were measured against time t, relative to the initial bed level using a vertical scale attached to the interior wall of hollow plexiglas abutment with stick having a small inclined mirror at its end.

3 Analysis of Results

In this study, the maximum scour depths around an abutment –with and without collar- were measured and time development of the scour hole was followed during the scouring process. The effectiveness of the collar widths and elevations in reducing scour depth was investigated. Studies have shown that, due to the presence of a collar, it does not matter what the dimensions and elevations are, the depth of the scour hole is reduced significantly. The effect of location of the collar of constant width, B_c=100 mm, on the time development of scouring around the abutment is shown in Figure 3. From this figure it is seen that, as the vertical distance between the collar plate and the bed level, Z_c, which is measured from bed, increases in upward direction, the maximum scour depth approaches towards the maximum scour depth value of the abutment that has no collar.

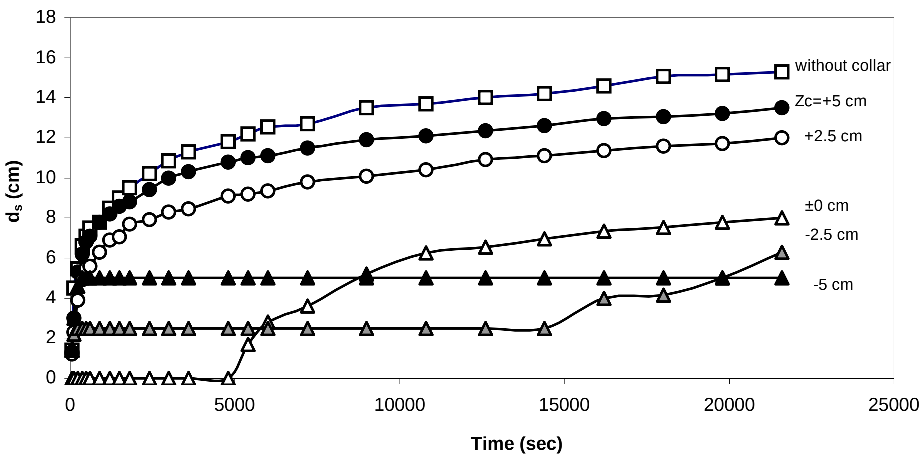

Figure 3. Time development of scouring around the abutments of B_c=100 mm with and without collar for various values of Z_c

When the collar is placed above the bed level, the down flow occurring in front of the abutment is diverted by the collar and therefore the riverbed is protected from its direct impact. As the collar approaches to the bed level the distance between the collar and bed level gets smaller, less flow can penetrate under it and therefore the weaker down flow is formed under the collar. Eventually, the erosion capacity of penetrating flow into this zone gets weaker and that results in less amount of scour around the abutment. But, the effectiveness of the collars above the bed level on the reduction of the scour depth is not as much as the collars placed at or below the bed level. When the collar is placed at bed level, for a certain time period, about 5000 seconds, no scour is observed around the abutment. After this time period the scour hole develops rapidly and then it continues deepening at a slower rate in such a way that the data points fallow almost the same trend of those of abutment having the collar at elevations above the bed level. If the collar is placed below the bed level, the flow sweeps away the bed material over the collar down to the collar level immediately. After that, because of the weaker down flow and lower erosion capacity of the flow, no scour is observed around the abutment for the time periods of 15000 seconds and 21600 seconds for the collars of Z_c=-2.5 cm and –5 cm, respectively. At the end of these time periods the scouring process starts around the abutment of Z_c=-2.5 cm following a trend similar to that of Z_c=±0 cm, while the collar of Z_c=-5 cm doesn't cause any erosion by the end of the experiment. However, from the general trends of the experimental data of various Z_c values given in Figure 3, one can conclude that, if the experiments had been conducted longer than 6 hours, the scour holes might have been observed around the abutment of Z_c=-5 cm. However, it might be stated that the maximum scour depth to be obtained at the end of the extended time period would be much smaller than that of Z_c=-2.5 cm.

Installing the collar at elevations lower than the bed level gives better results. The best location of the collar plate is observed to be 50 mm below the bed level, which results in 67% reduction in the scour depth, compared to the case of abutment having no collar.

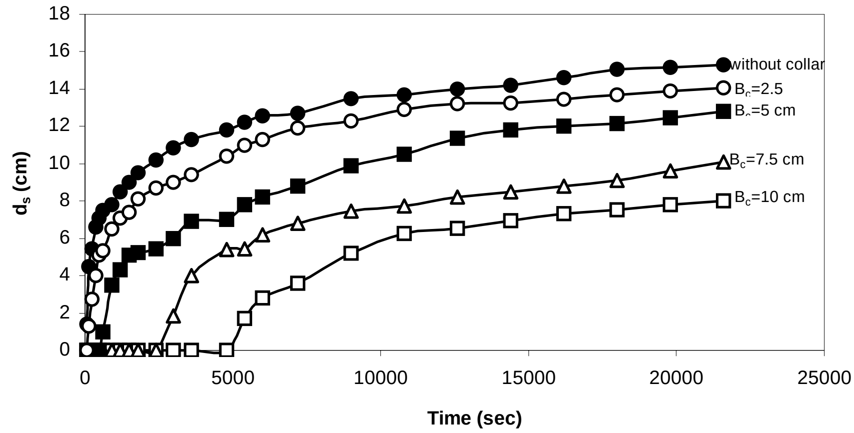

Figure 4. Time development of scour depths of the abutment as a function of collar width for Zc=±0 cm.

Figure 4 shows temporal variation of the scour depth around the abutment as a function of collar width for collars installed at bed level. This figure clearly reveals that as the collar width increases, the scour depth decreases for a given time. This is because with increasing the width of the collar the down flow jet above the collar gets further away from the abutment and more of its energy dissipates before it reaches the streambed. Among the collar widths tested the one of B_c=100 mm causes the maximum reduction in the scour depth about 48 % with respect to the others. At the same time it is also seen from Figure 4 that the collar of B_c=100 mm has the longest time period, about 5000 seconds, over which no scour is observed around the abutment while the corresponding period gets smaller as the width of the collar decreases.

4 Conclusions

In this study time development of the local scour around the abutment with and without collar plates of various sizes and installed at different elevations was studied. It is observed that, while the elevation of the collar plates decreases below the bed material, the local scour depth decreases. When the collar plate is placed above the bed level, it has also reducing scour depth effect but not as much as those to be installed below the bed level.

Increasing the width of the collar plate also affects the maximum scour depth around the abutment.

Using collar at abutments is very effective in slowing down the development of scouring. As floods often last much shorter times than the equilibrium times, this property of collars become important in practice to prevent the abutments against scouring.

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