Journal of Scientific Research and Development 2 (7): 322-325, 2015
Available online at www.jsrad.org
ISSN 1115-7569

Experimental investigation the impact of collar installation on the Cylindrical Bridge Piers in the Rivers Bend

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Abstract: Bridges destruction by many factors such as scour and other natural and human factors brings a lot of life and property damage every year. For this reason, many researchers have focused on studying the scour phenomenon in recent years and provided different methods to control this phenomenon. In this study, the effect of collar on reducing scour around the bridge pier was examined. For this purpose, three oval collars with a thickness of 3 mm were used. In the experiments, a cylindrical pier 21 mm in diameter and five different flow rates were used. The results showed that in the case of using the collar associated with increasing flow rate, the volume of scour has increased. However, this amount has decreased as compared to the control experiments. Also, the large collar had the maximum reduction in scour compared with other collars.

Key words: Scour; Bridge pier; Collar; Laboratory model

1. Introduction

Scour is a natural phenomenon caused by water flow in rivers and waterways. Scour is the result of water erosion effect that removes the particles from the bed and banks of waterways as well as around the bridges piers and their bearings, which leads of erosion (Nohani et al., 2012). Bridge piers are an essential structural component of bridges; their failure may have significant consequences on an important infrastructural element. Bridge piers may be subjected to scour by severe hydraulic conditions, or when the bed sediment size is relatively small, resulting in a large scour hole exposing the entire bridge foundation (Nohani et al., 2012). These reports reflect the importance of investigations in connection with scour around the piers. The flow pattern and mechanism of scour around the bridge piers is very complex and has been studied by many researchers (Dargahi, 1990). The collision of water flow to the bridge pier and its separation are considered as principal and important causes of local scour around the bridge piers. By water collision to the pier, a downward flow is created that after hitting the bed, will collide the mainstream and create the horseshoe vortex. Flow separation behind the pier also creates the wake vortex (Breusers and Raudkivi, 1991). In general, the scour of the bed's particles is achieved by the interaction of the following forces:

1. The driving force caused by the flow that acts to separate the particles from the river's bed
2. The resistance force due to the friction of the particles and the particles weight that resists against the particles motion and prevents the separation of the particles from the bed

Collar is a plate that is placed in different levels on the pier (base) and usually close to the pier surroundings. The collar thickness should not be too much, since it creates barriers against the flow and increases the scour (Alabi, 2006). Many researchers have studied the effect of using collar to reduce the scour around the bridge piers. Chobert and Engeldinger (1956) examined the impact of circular collar on scour reduction of the bridge piers and concluded that placement of the collar at the height of the 0.4D below the bed with a diameter of D3 can reduce scour nearly as 60% that the "D" is the diameter of the bridge pier. Nohani (2015) investigated the effect of collar on the size of proper riprap cover around the cylindrical bridge piers in the rivers bend. 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. Zarati et al. (2006) studied the performance of independent and collars with beaching in scour reduction around the piers group. The results showed that designing two piers in a line and combination of continuous collars and beaching will lead to a 50-60% reduction of the scour depth in the front and rear of the piers. They also found that using independent collars has a better performance than the continuous ones. Kumar et al. (1999) examined the use of collars to reduce local scour in the bridge piers. The results indicated that by increasing the size of collar and reducing the height of the collar to the bottom (bed), the collar performance will increase. Masjedi et al. (2010) examined the local scour reduction around the bridge piers by using collar at 180 degrees arc. The

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results showed that by increasing the collar size, the scouring will much reduce. The minimum scour depth occurs with a collar with a width three times of the pier diameter that has been installed at 0.1level under the bed.

2. Materials and methods

The experimental model was used to study the impact of collar on scour depth, which includes the following information. The channel was 10 m in length, 25 cm in width and 30 cm in depth. The channel floor and walls were made of Plexiglas**.** A triangular 60 degrees flume was used at the end of channel to measure the flow rate. Water transfer was performed with a pump with a maximum flow rate of 10 liters per second. A stilling basin was used at the beginning of the channel to reduce the flow turbulence. The experiments' range was filled with non-cohesive uniform sediments with an average diameter of 1 mm. The Raudkivi and Ettema (1983) criterion ($\frac{W}{D} \geq 6.25$) was used to avoid the lack of channel walls impact on the scour depth, where W is the channel width and D is the diameter of the pier. Consequently, a pier with a diameter of 22 mm was chosen**.** To avoid the impact of the average particle size of the bed on scour depth, the Ettema (1980) measure ($\frac{D}{d_{50}} > 20 - 26$) was used**.** Five different flow rates were considered to see the impact of flow rate on scour according to the hydraulic conditions. To avoid the influence of the flow depth on scour**,** the current depth must be greater than 3 times of the pier diameter ($\frac{y}{D} > 3.5$) (Chiew and Melville, 1987). Thus, the flow depth was considered equal to 7.5 cm in all the experiments. Three collars with different dimensions were used in the tests. The large to small diameters ratio of the collars were as 1, 1.2 and 1.3. The lengths of the collars were the same at the pier upstream and equal to the pier diameter and different in the downstream. The ratio of the collar downstream to the pier diameter was equal to 1, 1.5 and 2. Since the maximum depth of scour occurs in the clear water conditions, thus, all experiments were performed under the same conditions.

3. Results and discussion

At the beginning, a long-term test was carried out to determine the time period of doing the tests. The test was performed within 5 hours, and the scour depths at different times were recorded. Fig. 1 shows the time development graph of the scour depth. According to the Fig., around 85% of the scour depth has occurred at the first 100 minutes of the test, and since the aim of doing experiments was not to achieve the equilibrium scour depth, therefore, the time of doing all the experiments was considered as 100 minutes.

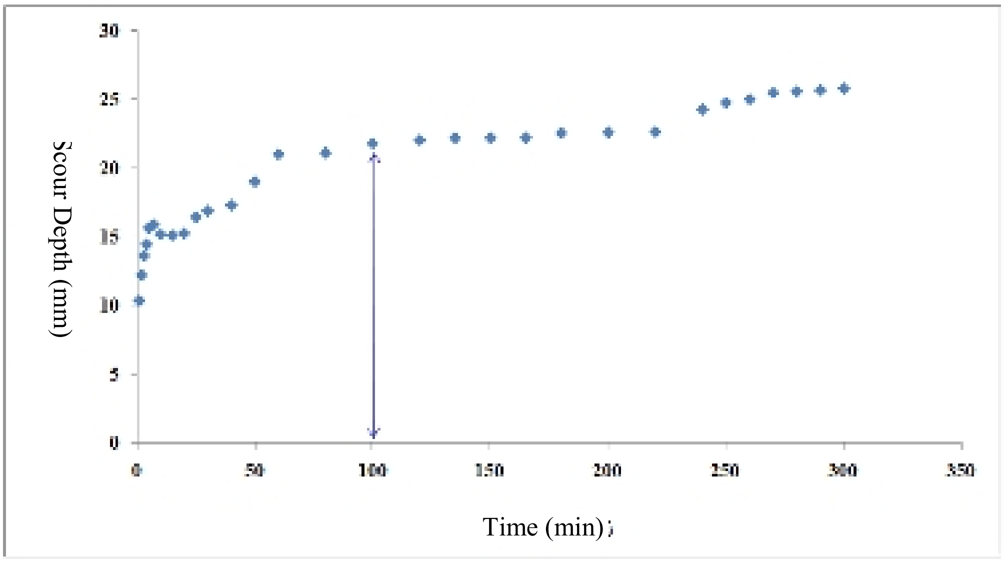

Fig. 1: Time changes of scour depth in the case of pier without collar

After determining the time of the experiments, the control experiments were done. In experiments without collar (control experiments), first, the scouring was began in the area between the pier nose up to a 45 degree angle at both sides of the pier than to the longitudinal axis at upstream under the influence of the horseshoe vortex. Sediments removed from the scour hole were accumulated as a stack at two sides of the pier and gradually transferred to the downstream. With the arrival of these ridges to the pier end, the process of erosion and sediment transfer from the front and around the pier were significantly increased by the horseshoe vortex, the flows on both sides of the pier and the wake vortexes on the back of the pier. With deepening of the scour hole, its walls were collapsed and the cavity expanded to the surroundings. In control experiments, the effect of five different flow rates on local scour around the pier was examined. With the increase in the flow rate, the scour depth also increased. The diagram slope is steeper at initial moments of the test than the last moments. This means the scouring occurs more rapidly in the first moments, and over the time and by reducing the power of the horseshoe vortex, its intensity will reduce. Fig. 2 shows the graph of flow rate influence on scouring around the pier. It can be seen in the Fig. that by increasing the time, the depth of scour has become more and reaches to a constant value at about 100 minutes. In fact, it is when the balance time occurs. Also with increased flow rate, the flow velocity around the pier would increase, and therefore, the speed and power of the downward flow and horseshoe vortex would be higher. With increased power of these forces, the scour depth would increase as well. Figs. 2, 3, 4, 5 and 6 show the changes in scour volume with time for the pier with different collars (where, L is the length of collar at the pier downstream and D is the pier diameter).

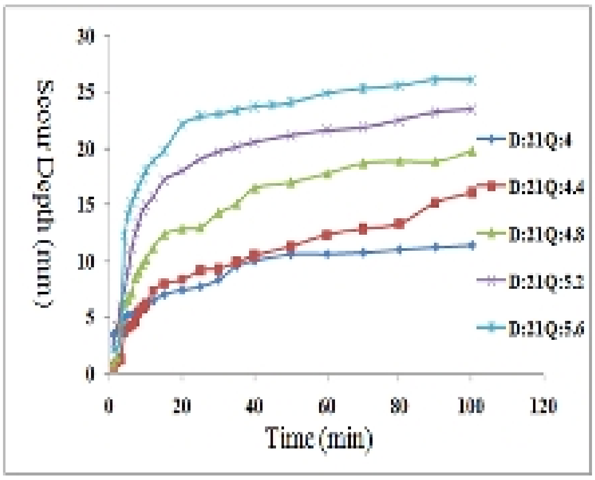

Fig. 2: Impact of flow rate on scour depth with time

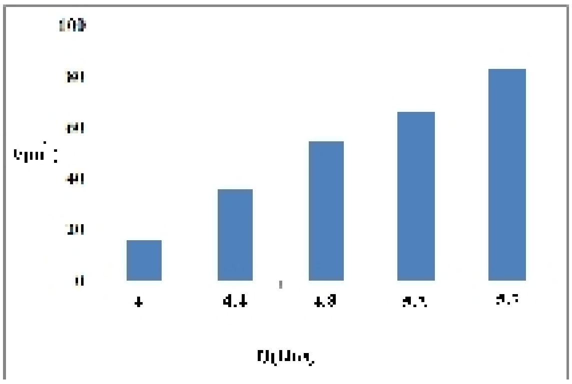

Fig. 4: Changes in scour cavity volume with flow rate changes for a pier with collar $\frac{L}{D} = 1.5$

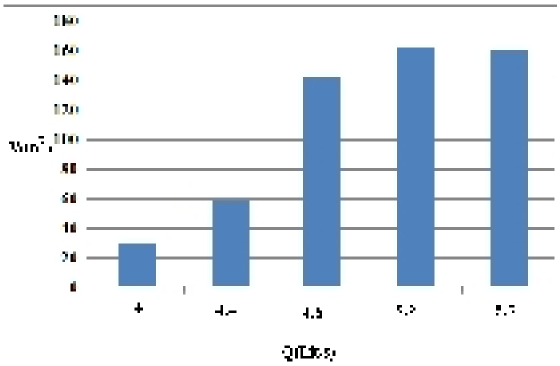

Fig. 3: Changes in scour cavity volume with flow rate changes for a pier with collar $\frac{L}{D} = 1$

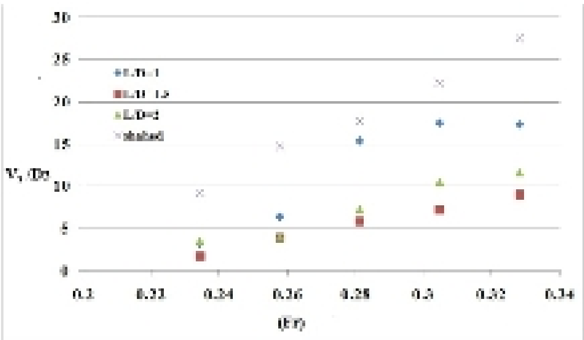

Fig. 6: Changes in scour cavity volume with Froude number at the pier with different collars and control experiment

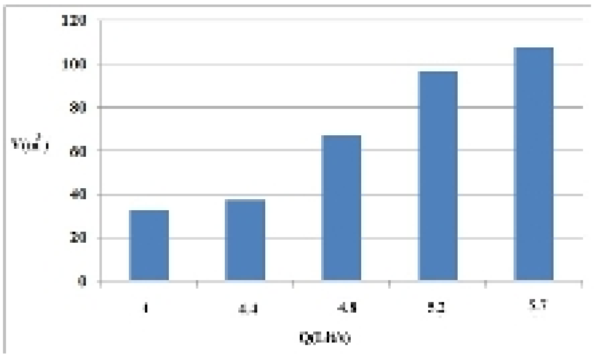

Fig. 5: Changes in scour cavity volume with flow rate changes for a pier with collar $\frac{L}{D} = 2$

As can be seen in these Figs, despite the collars around the pier, the volume of scour cavity has increasing as the pier without collar by increased flow rate; however, but the value is less than the case without the collar, which indicates the effect using collar on reducing scouring around the pier. By installing collars around the pier, the direct confrontation of the downward flow to the bed and erosion caused by local tensions around the pier are avoided. By installing the collar, the first signs of scouring were observed at the pier downstream due to wake vortices functioning. In this case, unlike the case without collar, the horseshoe vortex was not initially observed. With the functioning of the wake vortex, some grooves were created on both sides of the pier, and over the time, the grooves expanded towards the upstream and downstream. By developing the horseshoe vortex, the scour cavity gradually expanded as well. Fig. 6 shows the variation of scour cavity with the Froude number. As can be seen in the Fig., as the Froude number increases, the volume of scour cavity will also increase. In Fig. 7, the comparison between changes in the scour cavity volume with the flow rate at the pier with different collars and the volume of scour in the case of pier without collar is shown. As can be seen in the Fig., the volume of scour cavity in case of using collars with different dimensions has shown reduction compared to the case without collar, which indicates the impact of using collar on reducing scour. According to Figs. 6 and 7, we can conclude that the collar with dimensions of shown reduction (where L is the length of collar at downstream and D is the pier diameter) has had the greatest impact on reducing scour. Also, with increased collar size, its effectiveness in reducing scour has increased. However, this increase partly influences the scour reduction, and since then, it would have no effect.

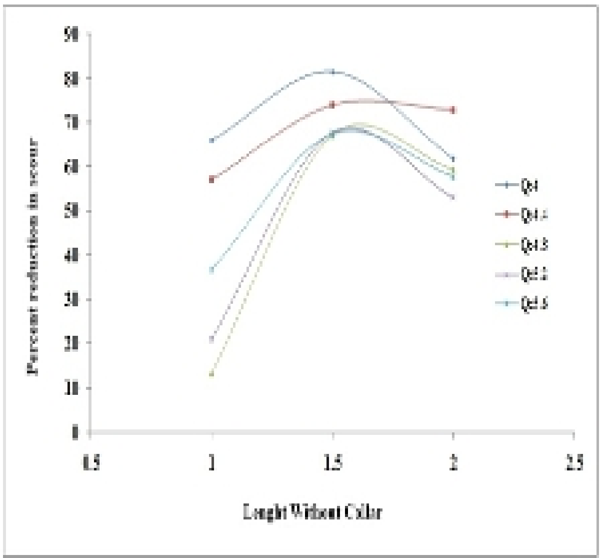

Fig. 7: Comparison of changes in the volume of scour with flow rate at pier with different collars with the case without collar

4. Conclusions

In this survey, three collars with the dimensionless ratio of the collar length of the downstream pier to the pier diameter ($\frac{L}{D}$) equal to 1, 1.5 and 2 were used to investigate the reduction of local scour around the cylindrical bridge pier. The results showed that in general, using collar around the pier is effective in reducing scour**.** Regarding the shape of the collar, one can say in general that the oval collar has had more impact on reducing scour**.** The maximum reduction was related to the large collar with the dimensionless ratio of the collar length of the downstream pier to the pier diameter equal to 1.5. The reduction value in the flow rate of 4 liters per second was equal to 80%. The lowest decrease was related to the collar with dimensions of $\frac{L}{D} = 1$ at flow rate of 4.8 liters per second, equal to 13%.

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