

SIMULTANEOUS EFFECT OF COLLAR AND ROUGHNESS ON REDUCING AND CONTROLLING THE LOCAL SCOUR AROUND BRIDGE ABUTMENT

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Abstract

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Investigation of local scour around hydraulic structures particularly bridges is of crucial importance in river engineering. Bridge destruction mostly occurs as a result of scour phenomenon around piers and abutments, not because of structural weaknesses. Hence, finding a solution to reduce scour depth is momentous. In this study which was conducted in the conditions of clear water scour, the effect of local roughness and collar and also impact of using them simultaneously around bridge abutment were evaluated. The results demonstrated that the existence of roughness causes a reduction in the severity of scouring process and its final depth and the use of collar leads to a delay in the scouring process in addition to the ultimate reduction in the scour depth, which in case of using them simultaneously, scour depth decreases by about 83%.

Keywords: local, scour, bridge, abutment, roughness

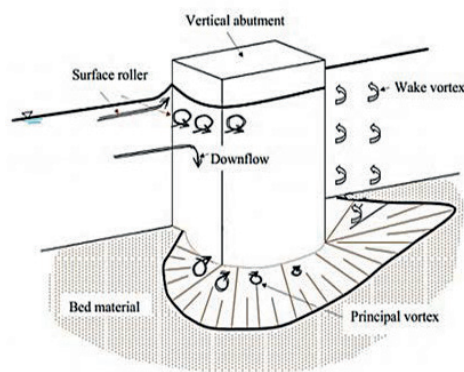
INTRODUCTION

Bridges are among the most important and most widely used river structures and are used for different cases. Study of local scour around hydraulic structures especially bridges is of great importance in river engineering. According to the statistics provided by various countries, it can be said that bridge destruction mostly occurs as a result of scour phenomenon around piers, not because of structural weaknesses. Scour is a natural phenomenon that is created because of river flows or flood waters, the result of which is erosion by water flow leading to transferring and grinding the materials from the floor, coasts and around the bridge piers and abutments. The depth caused by the bed erosion relative to the initial bed is called scour depth. Also, the empty space and created niche due to leaching of sediments from the bottom of the river bed is referred to as scour hole. In the study

of 383 cases of bridge destruction, it has been reported that 57% of bridge destruction is due to damages in abutments, which shows the importance of scour investigation and prediction in abutments (Raudkivi and Ettema, 1983).

Fig. 1 shows the flow field around a bridge abutment. The factors affecting the scour around the bridge abutment can be divided into down flow, bow wave vortex, primary vortex (horseshoe vortex), secondary vortex and wake vortex.

Bridge destruction resulting from the scouring of bridge foundation or abutment has increasingly encouraged the researchers to study the scour phenomenon around bridge abutments and to provide the methods for controlling and reducing the scour. In the past several decades, many studies have been conducted by people such as Melville (1992), (Molinas and Wu, 1998), (Dey and Barbhuiya, 2005) and Melville *et al.* (2006),



1: Flow field around a bridge abutment

to identify the mechanism, scour development and scour phenomenon around the abutment. Methods of scour reduction have been analyzed by various researchers, each of which has advantages and disadvantages. Methods of reducing the local scour are classified into two groups: 1) method of strengthening the bed; 2) methods of altering the flow pattern.

In strengthening methods, various materials are placed on the bed, coasts and adjacent to the spur dike in order to increase the ability and resistance of the bed of parapets against scour. Among these methods in the study of abutments, we can refer to the use of coarse materials or riprap by Morales, (Ettema and Barkdoll, 2008), joined betty blocks by Przedwojski (1995) and bags containing sand or geo-bag by Korkut *et al.* (2006).

In the methods of altering the flow pattern, scour control is done by reducing the flow power. Among these methods are submerged vanes and collars and use of cable and slot.

As to the application of non-submerged plates to reduce the scour depth around the bridge abutment, we can mention the experimental study of Johnson *et al.* (2001) which was conducted for a short vertical abutment located in the river floodplain area. They examined different options of resting the non-submerged plates inside the main channel to analyze its impact on the scour of the main channel bed. The results indicated that the plates keep the flow away from the site of abutment and consequently, the scour hole is transferred from the foot of abutment to the middle areas of the river although the scour depth increases.

One of the provided methods is to install a protective collar adjacent to the abutment. A collar is a circular or rectangular steel sheet attached to the bridge piers or abutments, which may be installed at different levels from the bed. Additionally, a collar is a plate with low thickness to create change in the flow pattern around the abutment and consequently control the scour dimensions.

Li (2005) carried out a research into the effect of collar on reducing the scour around the abutment

of wing wall in the state of clear water. They found that the collar size is the most effective parameter in the rate of scour depth. Further, they came to the conclusion that the scour depth decreases by 75 %. Kayaturk (2004) conducted a study regarding the impact of collar performance on the development of the scour around long rectangular abutment on the eve of the movement of bed particles. Experiments were performed in a channel with a width of 1.5 meters and longitudinal slope of 0.0001 and velocity ratio of $v/v_{*c} = 0.9$ (in the state of clear water). By installing the collar of different sizes at variable levels, they found that better results are achieved through the placement of the collar at the level lower than the bed. According to these experiments, when the collar is placed at the level of 50 mm below the bottom of the channel, scour is reduced by 67 %. Dargahi (1990) investigated the scour on collars and revealed that the collar should not be too thick since great thickness of the collar causes to create a barrier against the flow and increases the scour. His results suggested that the collar cannot prevent horseshoe vortex formation, but has an effective role in scour reduction if set in a good place relative to the bed level.

Khozaymehnezhad *et al.* (2012) evaluated the performance of symmetrical and asymmetrical collars and concluded that with the increasing of dimensions in both modes, better performance will be achieved. Ardeshtir *et al.* (2012) in their experiments demonstrated that the existence of collar with different sizes decreases the scour by 63 % and 100 % and also delays the scour time. Moreover, they studied the influence of different collars, placement level and their sizes in the two types of rectangular and trapezoidal abutments and came to this conclusion that when the symmetrical collar is placed below the bed level, it has the best performance in reducing the scour depth.

Another solution for the control and reduction of local scour, which has been proposed in this study as a new method, is the creation of local roughness on bridge abutment which is implemented in the form

of spherical and angular rings during concrete-casting to create bumps on the pier.

In the following, the equation to calculate the scouring process in abutment has been presented by Coleman *et al.* (2003):

$$\frac{d_{st}}{d_s} = \exp \left[-0.07 \left(\frac{V_c}{V} \right) \ln \left(\frac{t}{t_c} \right)^{1.5} \right] \quad (1)$$

The objectives of this research include investigating the effect of the placement level of circular collar relative to the bed (level of higher than the bed, on the bed and lower than the bed) and collar size on reducing the scour depth around the short semicircular abutment. Besides, in this study, by using the roughness created on semi-spherical abutment, the impact of these roughness's particularly the effect of the distance between them on the rate of scour reduction in the abutment are investigated. Finally, simultaneous application of collar and roughness with the best performance in scour reduction is dealt with it.

MATERIALS AND METHODS

Experiments have been conducted in an experimental channel with a length of 7 m, width of 0.32 m and height of 0.36 m. A pump has the duty of transferring water from the main tank to the channel, whose maximum discharge is 11 liter per second. The channel is equipped with a volume-time tank, with the help of which one can measure the discharge. An adjustable weir in the downstream regulates the water depth in the channel. The area for conducting the experiments in the channel has 1 m length and 10 cm bed height, which is 4 m away from the beginning of the channel. Flume length in the upstream of the location of the abutment has been chosen in such a way that flow is fully developed. In the upstream and downstream of this site, Teflon platforms were installed with a length of 1 m and height of 0.1 m (Fig. 2).

To eliminate the influence of the channel walls on local scour, according to (Raudkivi and Ettema, 1983), the distance of abutment axis to the front wall

of the channel over the abutment length should be greater than 6.25 m. Based on this criterion and with a little more consideration, the length of abutments is equal to 30 mm ($L = 30$ mm) and they are made of Teflon plastic, and short semicircular abutments have been used in all experiments. Given the point that abutments should not be submerged in water, their length has been considered to be 33 cm. additionally, according to these researchers, the average diameter of the particles should be more than 0.7 mm in order to prevent the ripple formation during the test.

Melville (1992) stated that when geometric standard deviation of particles is less than 1.3 m, the effect of the heterogeneity of particles on scour depth can be ignored. Therefore, considering the above criteria, the distance between the platforms was filled with cohesion less sediments with an average diameter of 0.75 mm, specific weight of 2.65 m and geometric standard deviation of 1.2 m. For having fixed flow characteristics along the channel, the sediment chosen for the test site was bonded on platforms.

Since maximum scour depth occurs in the condition of clear water flow and particle motion threshold, all tests were performed under these circumstances. Particle motion threshold is determined by conducting an experiment at a time when the abutment has not been installed in the channel. Particle motion threshold is applied to the conditions in which despite the motion of fine particles, the bed surface does not change during the test more than 2–3 mm. Thus, the ratio of flow velocity to the critical velocity (v/v_c) is equal to 0.95 and the flow depth has been obtained to be 12.5 cm.

In this study, to investigate the impact of collar on the scouring mechanism and its temporal changes, parameters such as collar size in two sizes of 1.5 L and 2 L and also collar placement level relative to the channel bed (on the bed, 0.2 L under the bed and 0.2 L above the bed) were examined and analyzed. Fig. 3 shows the manner of collar's connection to the abutment.

Further, the position of roughnesses to each other has been shown in Fig. 4. In order to investigate



2: A view of the experimental channel

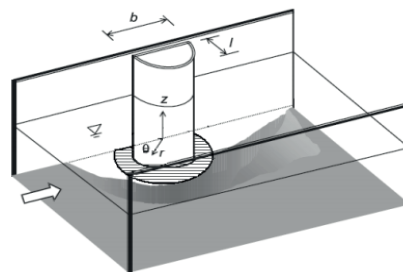
the effect of determining the proper distance between the roughnesses on the scour depth control and reduction, a total of 4 experiments were conducted according to Tab. I. Roughness height and depth have been fixed throughout all tests.

RESULTS AND DISCUSSION

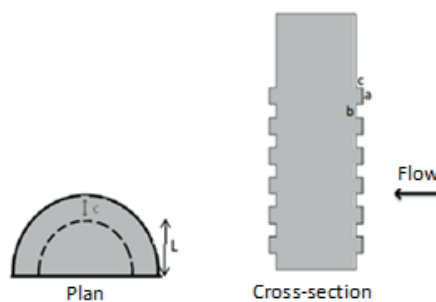
Considering the importance of the equilibrium time and reviewing the studies conducted, it is revealed that researchers have used different criteria for the equilibrium time of the scour. Kumar *et al.* (1999) considered the scour equilibrium time as the time 3 hours after which the scour depth changes for less than 1 mm. Vittal *et al.* (1994), selected the time 6 hours after which the scour depth changes for less than 1 mm as the scour equilibrium time. Kumar *et al.* (1999), provided a new definition for the equilibrium time. According to their definition, equilibrium time depends on the pier diameter and is the time in which the scour hole develops to the depth where the speed of increasing the scour is not higher than 5 % of the pier diameter

within 24 consecutive hours. Since the objective of this study is to compare the temporal development of the scour hole of control abutment with abutments containing roughness, Kumar's criterion for the equilibrium time was chosen. Taking into account this criterion, the equilibrium time was obtained to be 24 hours.

With regard to Fig. 5, it was found that 90 % of the equilibrium depth of the scour is obtained after passing 8 hours from the beginning of the test. Thus, the time of conducting the experiments is usually selected to be less than the scour equilibrium time. In this research, 8 hours were considered as the stop time of the experiments in order to compare different methods of controlling the scour. In Fig. 5, the horizontal axis is time in minutes and the vertical axis is the scour depth at any moment over the abutment length. In other charts, the horizontal axis shows the ratio of time to eight-hour equilibrium time (t/t_e) and the vertical axis represents the ratio of scour whole depth at any moment to the abutment length (d_s/L).



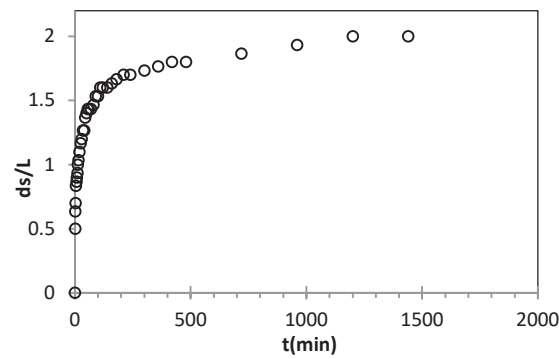
3: Manner of collar's connection to the abutment



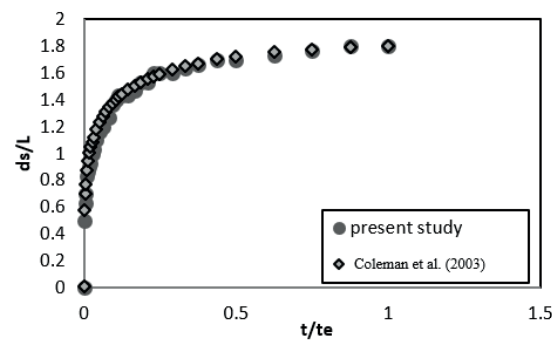
4: A schematic plan of the roughnesses on the abutment

I: Dimensions of the sharp edge roughnesses

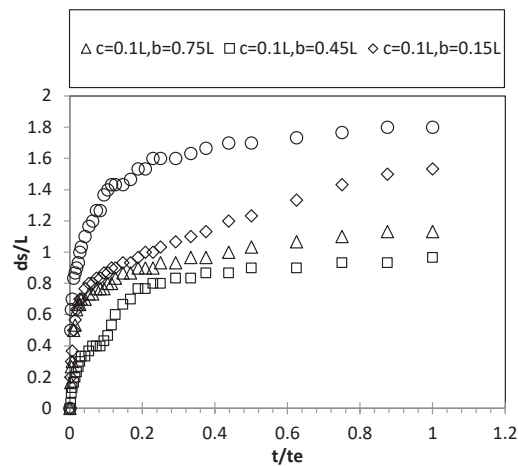
Test No.	a (roughness height)	b (distance between roughnesses)	c (roughness depth)
Unit	meter	meter	meter
1	0	0	0
2	0.05 L	0.15 L	0.1 L
3	0.05 L	0.45 L	0.1 L
4	0.05 L	0.75 L	0.1 L



5: Scouring process of control abutment against time



6: Comparing the results of scouring with the findings of other researchers



7: Effect of the distance of roughnesses on the scouring process

In Fig. 6, temporal development of dimensionless scour depth for the bridge abutment has been compared with the results obtained by Coleman, (Lauchlan and Melville, 2003) in the conditions of clear water scour. This comparison indicates the good conformity of the scouring process in this research with another study. As is evident from the Figure, scouring expands with more speed at the beginning of time, but reaches relative equilibrium with the passage of time

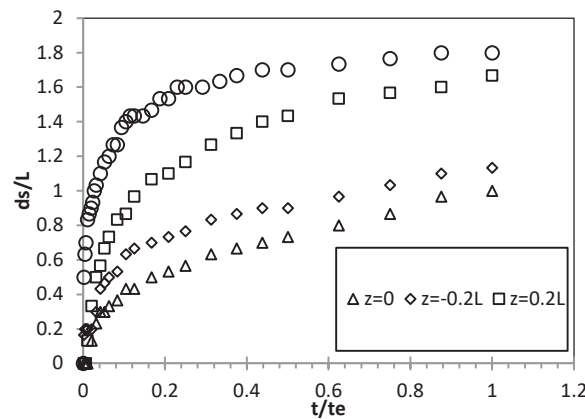
A) Use of roughness

Fig. 7 shows the comparison of temporal development of scour between the control abutment and abutments containing roughness with constant depth ($c = 0.1 L$) and constant height ($a = 0.05 L$) at different distances.

As can be seen in Fig. 7, the existence of roughnesses reduces the power of down flow and since the primary vortexes are created as a result of the down flow, they become weaker and the severity of scouring process and also final scour depth are reduced. Additionally, given the obtained results, it



8: Pictures of modeled abutments containing roughness and the hole created around them



9: Chart of the temporal development of scour for the collar size of 1.5 times as much as the abutment length at different levels

was observed that the amount of final scour depth decreases with an increase in the distance between the roughnesses. The reason for this reduction seems to be that by increasing the distance between the roughnesses, there exists more space between the distances to create down flow and also increase the speed of this flow. When this flow hits the roughness with more speed, it leads to the destruction and depreciation of the flow and this issue causes that with increased distance between the roughnesses, final scour depth is reduced. But this increase in the distance has a maximum value and after this amount, increasing the distance between roughnesses leads to an increase in the scour depth again, which is due to reducing the number of roughnesses or a reduction in the effective surface of roughnesses against down flow.

Therefore, abutment with a roughness depth of $c = 0.1 L$ and the distance of $b = 0.45 L$ between the roughnesses and the height of $a = 0.05 L$ leads to 46 % reduction in the scour rate relative to the abutment without roughness and also best performance.

Fig. 8 depicts examples of the tests carried out on the abutment containing roughness. Part A in this Fig. is related to the abutment with a distance between roughnesses ($b = 0.45 L$) along with its scour hole. Part B and C are respectively associated with abutments with $b = 0.75 L$ and $b = 0.15 L$. As it is clear, Fig. A compared to other two Figures has smaller scour hole in terms of both depth and size.

B) Use of collar

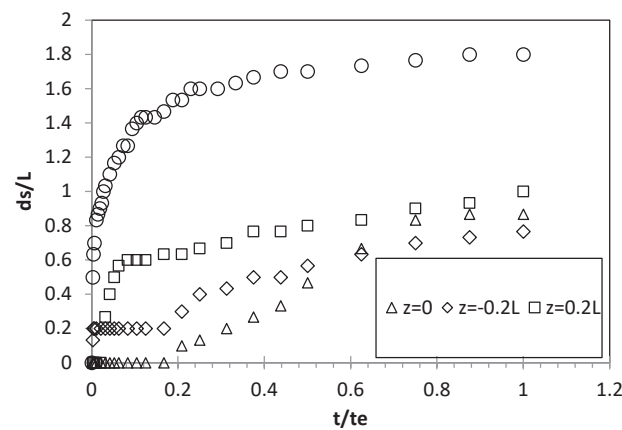
In Fig. 9, charts of the temporal development of scour have been shown for the collar size of 1.5 times as much as the abutment length at different levels.

As can be observed in Fig. 9, for the collar with the size of 1.5 times as much as the abutment length, much delay does not occur at the beginning of scour in each of three placement levels of the collar, but it causes a reduction in the final scour depth and a temporal delay in its process. Also, it is observed that if the collar is placed at the same level as the bed, the greatest amount of scour reduction will be achieved. But the worst state for the position of collar with these dimensions is to be placed higher than the bed level.

In Fig. 10, the same comparison has been made for a collar with the size of 2 times as much as the abutment length.

As can be seen in Fig. 10, for a collar with larger size, collar position at bed level leads to a delay of 20 % at the beginning of scour. But with increasing the time, collar has better performance below the bed level so that at the end of the trial period, this placement level has the greatest reduction in scour depth. In both states, it is also observed that placement of the collar above the bed surface has the lowest scour reduction, which is because of intensifying the down flow.

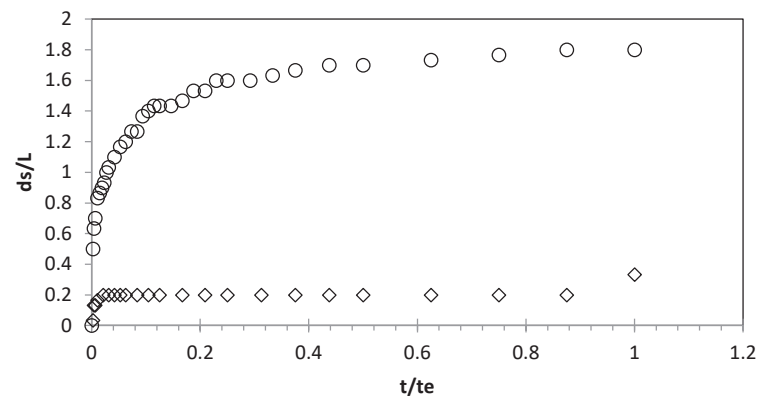
So, it is concluded that the collar with larger size and placement below the surface of the initial bed, while creating the delay time of about 20 % at the beginning of scour, leads to 60 % reduction in the amount of final scour depth and has better



10: Chart of the temporal development of scour for a collar with the size of 2 times as much as the abutment length at different levels



11: Picture of using the collar in abutment and created hole in the experiment



12: Impact of simultaneous use of collar and roughness on reducing the scouring process

performance compared to the collar with smaller size. Fig. 11 shows the picture of the scour hole created around abutment along with a collar with the size of 2 times as much as the abutment length.

In the following, the combined effect of roughness and collar (in their best placement states) is investigated.

C) Simultaneous use of collar and roughness

Fig. 12 shows the comparison of control abutment with the abutment equipped with roughness and collar. According to Fig. 12, simultaneous use of roughness and collar together has caused a long

delay in the scouring process and a sharp decline in the final depth by 83 %. This reduction in the severity of scouring process indicates the impact of roughness against down flow, which reduces its speed when hitting the collar surface. This finally results in flow dispersion with less power and formation of vortices with significantly less power relative to the control abutment.

Fig. 13 depicts a picture of the hole created around abutment at the time of using collar and roughness simultaneously.

In the following, for a better view, Tab. II shows the efficiency of each abutment relative to the control abutment.



13: The hole created around the abutment containing roughness and collar

II: Percentage of the reduction in the final scour depth in abutments

Reduction efficiency (%)	Collar size and placement level	Distance between roughnesses	Abutment
0	-	-	Control
15	-	0.15 L	With roughness
47	-	0.45 L	With roughness
36	-	0.75 L	With roughness
7	1.5 L above the bed	-	With collar
44	1.5 L on the bed	-	With collar
37	1.5 L below the bed	-	With collar
44	2 L above the bed	-	With collar
49	2 L on the bed	-	With collar
60	2 L below the bed	-	With collar
83	2 L below the bed	-	With collar and roughness

CONCLUSION

Based on the results obtained from different experiments on the performance of roughness and collar, it can be concluded that both roughness and collar are considered as effective methods in reducing local scour. The results demonstrate that roughness at its best state reduces the maximum scour depth by 47 % and collar also at its best state decreases the scour depth by 60 %. Further, simultaneous use of roughness and collar methods in abutment, in addition to a long delay in the scouring process, reduces the maximum scour depth by 83 %, which is due to the effect of these methods on the significant reduction in the power of primary vortexes in front of the abutment and wake vortexes at the back of the abutment.

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