Countermeasures of abutment scouring-An experimental approach

Zaka Ullah Khan[1*], Afzal Ahmed[1], Ghufran Ahmed Pasha[1]

[1]*Department of Civil Engineering, University of Engineering and Technology Taxila,47050, Pakistan*

Abstract

Local scouring around the bridge abutment is one of the main causes of bridge failure across the world which causes interruption of social interaction, economical loss in the form of repairing and in severe case the loss of lives. In this research countermeasures of abutment scouring is analysed by providing collar and hooked-collar on vertical-wall and wing-wall abutments separately in open channel laboratory flume. The results of scouring reduction are compared. The collar of width 2.25 times the length of abutment is used, whereas, hooked-collar of height 2.5cm is used. It is resulted that maximum reduction in abutment scouring is 83% in the presence of hooked-collar on vertical-wall under the sediment bed level and 74.2% scouring is reduced with hooked-collar on wing-wall at sediment bed level. Hence, hooked-collar is found as an effective scouring reducer for vertical-wall and wing-wall abutments.

Keywords: *Short abutment; Local scour; Collar; Hooked collar; Countermeasure*.

1. Introduction

Local scouring near the bridge piers & abutments is a significant and critical process that leads to bridge failure [1]. The phenomenon of local scouring is very similar at both bridge piers and abutments [2]. Therefore, it becomes essential to predict local scouring of the bridge piers & abutments, in an accurate & precise way. Otherwise, the local scouring will result in collapse of the whole bridge structure causing a serious death toll and injuries as its aftermath [3]. Local scour at bridge abutment occurs at its upstream face due to downward flow. The scour hole becomes deeper and wider as a result of horseshoe vertex at base of abutment [4]. The local scouring problem have been studied by many hydraulic researchers under different flow conditions. Based on the research carried out, several methods have been introduced and implemented to counter local scouring around the bridge piers & abutments [5]. There are two categories of countermeasure techniques around the bridge abutments for the local scouring: armoring and flow modification techniques [6]; [7]. The armouring techniques are such as, riprap stones around the bridge abutment, gabions, cable-tied blocks, and concrete-mats or bags. The flow modification techniques are spur dike, parallel-wall, or application of collar and hooked-collar on bridge abutments [8]. Collars and hooked-collars were previously investigated to study the scouring round the bridge piers [6]; [9]; [10]. The application of collar on the abutment was also analysed previously where the collar of width of 2.25La (La is length of short abutment) was applied resulting that collar on vertical-wall under bed level, and on wing-wall abutments at bed level can reduce more scour depth [11]. Khosravinia et al., (2018) also used collar having width greater than length of abutment resulting in lag time onset scouring and reduction in scouring within the range of 9% to 37%. Various sizes of collar around abutments at different levels and sediment dimensions were tested and it was resulted that depth of scour hole reduces with increase in collar width, however, no valuable effect was found due to sediment size [12]. The parameters including height, diameter and protection range of the collar were also investigated in the past. It was concluded that, with the increase in collar height, the effect of protection decreases and with the increase in external collar diameter, the effect of protection increases. Moreover, it was suggested, that anti-scour collar is more efficient to protect the scouring of bridge piers & abutments [9]. The efficiency of collars for scour reduction of piers & abutments was examined by [13]; [14]; [15]; [16]; [17]; [4]; [18]; [19]. They found that width and elevation of collar were the most important factors for collar efficiency. It was indicated from experiments that application of collar at smaller levels in relation to the sediment bed level, enhanced its effectiveness because of the flow infiltrated below the collar and scoured bed materials in less portion (Tanaka et al. 1967); [20]; [21]. From experimental study, it was found that changing only abutment length did not affect time development of local scour depth significantly [22]. The elevation of collar on abutment with reference to sediment bed level, plays an important role as a scour depth reducer [11]. It was analysed that collar application is useful to restrict the direct collision of down flow and bed material. The effects of erosion were diverted away from abutment and reduction of scour depth occurred in the proximity of abutment [13].

*Corresponding author. Tel.: +92 3459798780; fax: NA
E-mail address: zaka.uk65@gmail.com

The application of hooked-collar on short abutments (La/Y < 1, where, La is bridge short abutment length and Y is flow depth) for reducing scour depth has not been studied previously. Therefore, in this research the impact of simple collar & hooked-collar upon the scouring of short abutments of bridge, is investigated and the results of local scouring around the short abutments with no protection and protection of collar and hooked-collar, are compared.

2. Research Methodology

2.1 Channel description and Preparation

Hydraulic laboratory in the Department of Civil Engineering at University of Engineering and Technology (UET) in Taxila was used to carry out experimental work. All experiments were performed on a rectangular channel of length, width and depth are 20m, 1m and 0.75m respectively (Fig. 1). The side walls and bed of the channel were made up of transparent glass and concrete foundation respectively. The bed of the channel was prepared with sand material upto 0.30 m depth having size, D_{50} = 0.88 mm, standard deviation of sediment particle size distribution, σg = 1.20, relative density, G = 2.56 and was levelled horizontally [10]. The sand bed should be appropriately levelled, in order to avoid the unwavering water level in test section. The level of water was controlled by an movable tail-gate, installed at the channel's extreme downstream end, and discharge by flow control valve, fixed at the start of the channel.

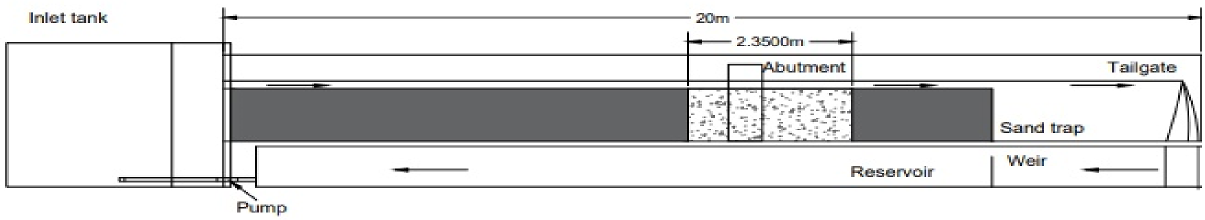

Fig. 1 Schematic View of Experimental Channel in Lab: (Side View)

2.2 Experimental Procedure

Vertical-wall abutment (Fig. 2) was installed at the centreline of the channel at 4.4 m distance downstream of the channel entrance. When the water was allowed to flow in the test section, around the bridge vertical-wall abutment the sediments started to scour. Scouring around vertical-wall abutment was recorded at constant flow rate (Q) of 0.0252cumecs. The flow depth was kept almost constant i.e.; 15cm to obtain short abutment criterion ($La/Y \leq 1$), by using tailgate. The total number of trials were total 14 where each trial was run for 6 hours, as the major part of scouring (60-85%) occurs during first 6-7 hours of experiments [11]. After draining out water from channel, the resultant scouring in the vicinity of vertical-wall abutment was measured with point gauge. After measuring depth of scour hole nearby vertical-wall abutment, the bed of channel was again levelled for next run of wing-wall abutment of 45° (Fig. 3). Then rectangular collar on vertical-wall and wing-wall abutments as shown in Fig. 4 and Fig. 5 respectively were tested as a countermeasure at three different elevations. The scour depths of vertical-wall & wing-wall abutments were measured at different points around the wetted perimeter of the abutment. The collar width was kept 2.25 times the length of bridge abutments. Then hooked-collar on vertical-wall & wing-wall abutments (Fig. 6 and Fig. 7) were tested as a scouring countermeasure at three different elevations (at bed level, above and below bed levels).

For each run, the maximum percentage reduction in the scour depth (Rds) in the surrounding of wing-wall (45°) and vertical-wall abutments was calculated as;

$$R_{ds} = \frac{Ds - Ds*}{Ds} \times 100\ \% \quad (1)$$

D_s= maximum scour depth without protection of collar or hooked-collar on abutment, D_s*= maximum scour depth with protection of collar or hooked-collar in each run.

Fig. 2 Vertical-wall Abutment

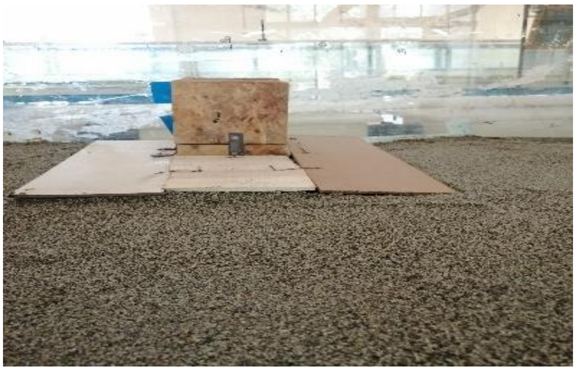

Fig. 5 Wing-wall Abutment with collar (at bed level)

Fig. 3 Wing-wall Abutment

Fig. 6 Vertical-wall Abutment with Hooked-collar (at bed level)

Fig. 4 Vertical-wall Abutment with collar (at bed level)

Fig. 7 Wing-wall Abutment with Hooked-collar (at bed level)

3. Result

3.1 Scouring without collar or hooked-collar protections

The wing-wall (45°) & vertical-wall abutments were initially tested without any protection. It was found that sediments creeping motion to flow in downward direction, started in the scour hole at the upstream edge of the abutments. The abutment suspended sand particles were deposited far in downstream due to decrease in velocity. The scour hole of vertical-wall abutment as shown in Fig. 8 was wider than wing-wall abutment. Longitudinal profiles of scour hole of vertical-wall & wing-wall abutments are shown in Fig. 11 and Fig. 12 respectively. The maximum scour depth nearby vertical-wall and wing-wall abutments were 118mm and 93mm respectively as mentioned in Table 1.

3.2 Scouring with collar protection

The longitudinal profiles of unprotected vertical-wall & wing-wall abutments in comparison with collar protected vertical-wall & wing-wall abutments at different elevations (At bed, below, and above) are shown in Fig. 13 and Fig. 14 respectively. The maximum percentage reduction in scour depth of vertical-wall abutment having collar at below the sediment level and for wing-wall abutment with collar at bed level, are 78.9% and 65.6% respectively as mentioned in

Table 1. Hence, it is found that for vertical-wall abutment, collar below bed level and for wing-wall abutment, collar at bed level have high reduction of scour depths.

3.3 Scouring with hooked-collar protection

The longitudinal profiles of unprotected vertical-wall & wing-wall abutments in comparison with hooked-collar protected vertical-wall & wing-wall abutments at different elevations (At bed, below, and above) are shown in Fig. 15 and Fig. 16 respectively.
The maximum percentage reduction in scour depth for vertical-wall abutment with hooked-collar below the sediment level and for wing-wall abutment with hooked-collar at bed level are 83% and 74.2% respectively (Table. 1). Hence, it is found that, by using hooked-collar on the vertical-wall abutment at below the sediment bed level, and on wing-wall abutment at bed level, have better results of scour depth reduction as compared to only protection of collar.

Fig. 8 Scouring of unprotected Vertical-wall abutment

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Fig. 9 Scouring of Vertical-wall abutment protected with collar

Fig. 10 Scouring of vertical-wall abutment protected with hooked-collar

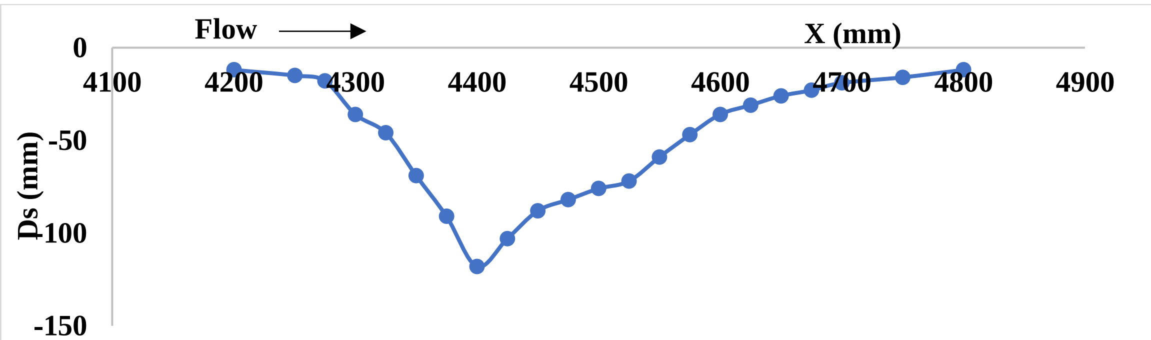

Fig. 11 Longitudinal profile of scour hole of unprotected Vertical-wall abutment (VW)

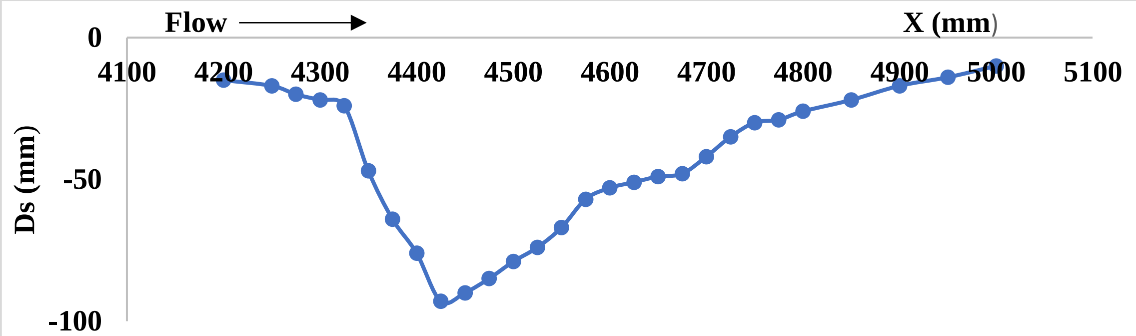

Fig. 12 Longitudinal profile of scour hole of unprotected Wing-wall abutment of 45° (WW)

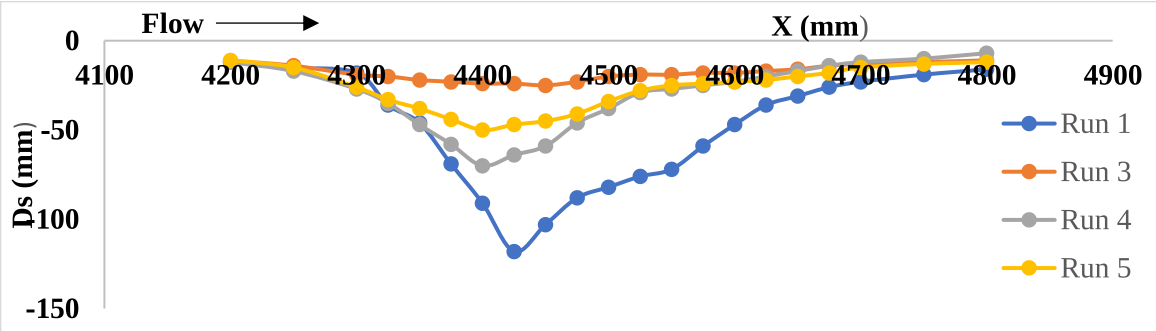

Fig. 13 Comparison of longitudinal profile of unprotected Vertical-wall abutment with collar protected Vertical-wall abutment at different elevations (At bed, below, and above)

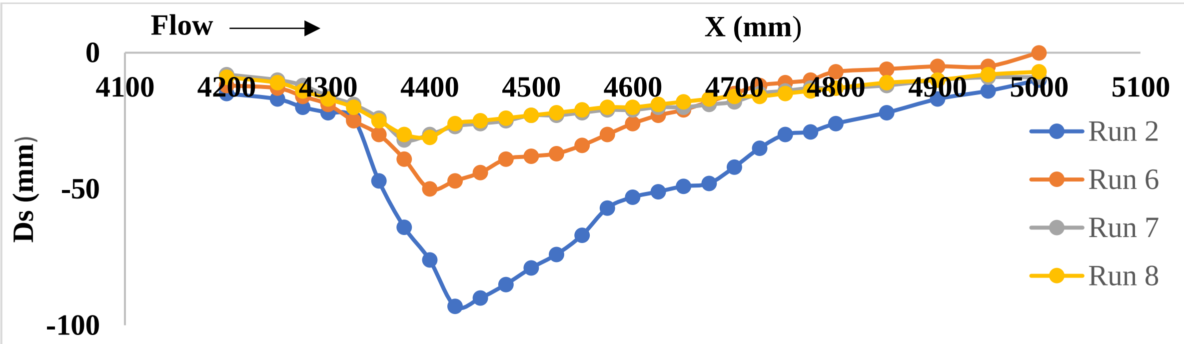

Fig. 14 Comparison of longitudinal profile for unprotected Wing-wall abutment with collar protected Wing-wall abutment of 45° at different elevations (At bed, below, and above)

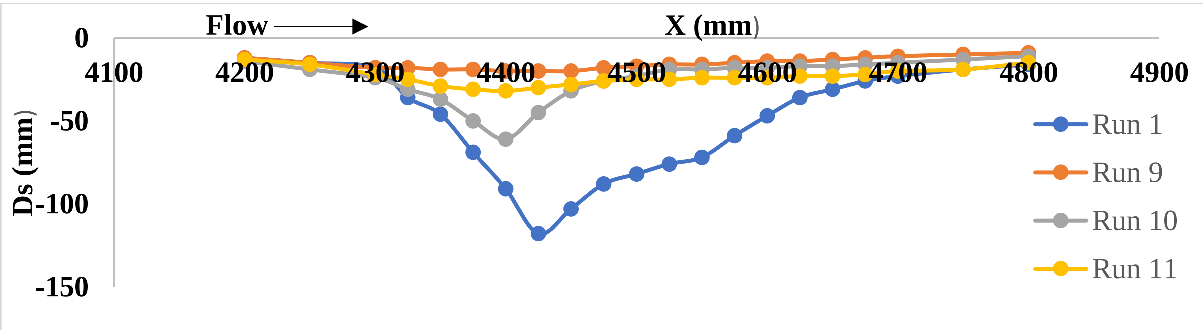

Fig. 15 Comparison of longitudinal profile of unprotected Vertical-wall abutment with hooked-collar protected

Vertical-wall abutment at different elevations (At bed, below, and above)

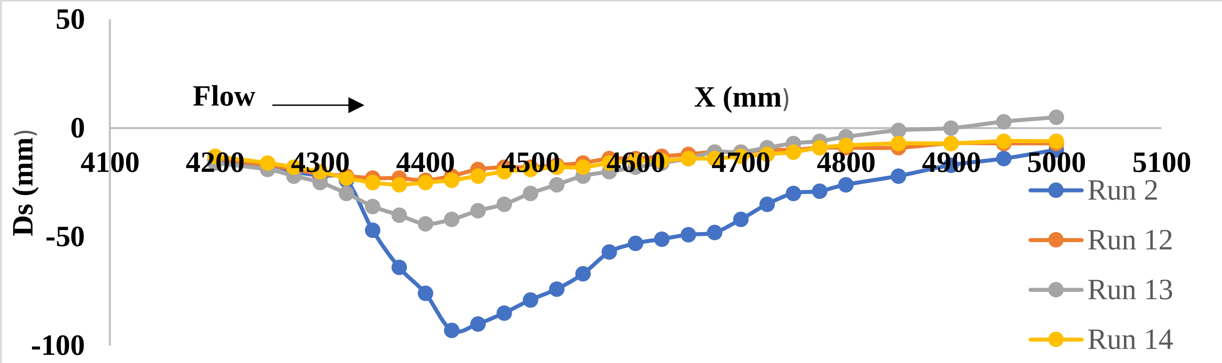

Fig. 16 Comparison of longitudinal profile for unprotected Wing-wall abutment with hooked-collar protected Wing-wall abutment at different elevations (At bed, below, and above)

Table 1. Conditions for collar and hooked-collar experiments at Flow velocity, U=18cm/s, Flow depth, Y=15cm, Length of abutment, La=14cm, Width of collar, Wc=2.25La (31.5cm) and Height of Hook, Hc=2.5cm

Test No	Name	Z_c/Y	Ds_{max}(mm)	R_{ds} (%)	$D_{s\ max}$ location	
					X (mm)	*Z*(mm)
Run 1	*VW*		118		4400	150
Run 2	*WW*		93		4425	150
Run 3	*VW-C*	-0.2	25	78.9	4450	350
Run 4	*VW-C*	0.2	70	40.6	4400	150
Run 5	*VW-C*	0	50	57.6	4400	400
Run 6	*WW-C*	-0.2	32	65.6	4375	150
Run 7	*WW-C*	0.2	50	46.2	4400	150
Run 8	*WW-C*	0	31	65.6	4400	320
Run 9	*VW-HC*	-0.2	20	83	4400	350
Run 10	*VW-HC*	0.2	61	48.3	4400	150
Run 11	*VW-HC*	0	32	72.8	4400	350
Run 12	*WW-HC*	0	24	74.2	4400	350
Run 13	*WW-HC*	0.2	44	52.7	4400	150
Run 14	*WW-HC*	-0.2	26	72	4375	150

VW is vertical-wall abutment, WW is wing-wall abutment, C is for collar, HC is for hooked-collar, Zc is the elevation of collar or hooked-collar with respect to sediment bed level, Dsmaxis the maximum scour depth, Rds is the scour depth reduction.

4. Conclusions

The current research concluded that:

1. The scour depth of short abutments for both wing-wall (45°) and vertical-wall abutments are decreased by providing collar and hooked-collar.
2. The maximum percentage reduction of scour depth of vertical-wall abutment with collar below bed level is 78.90%, while, for wing-wall abutment with collar at bed level it is 65.60 %.

3. The maximum percentage of scour depth reduction in case of vertical-wall abutment with hooked-collar below bed level is 83%, while in case of wing-wall abutment with hooked-collar at bed level is 72.80 %.
4. The use of hooked-collar on short abutments is found to be more efficient technique to reduce the scouring as compared to provide only collar or no protection of abutment.

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