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ABSTRACT

Bridge failures are generally resulted from scour of the bed material around bridge piers and abutments during floods. In this study, scour phenomenon around bridge abutments and collars, located at abutments as scour countermeasures, were experimentally investigated.

Based on the results of 97 experiments conducted, the effect of various sizes of collars which were located around the abutments at different elevations, on the scour reduction at bridge abutments was determined. The results were compared with previous studies, and the effect of the sediment grain size on the performance of abutment collars was emphasized. It was noticed that when the collar width was increased and it was placed at or below the bed level, the reduction in the maximum local scour depth increases considerably. It was also seen that the change of the sediment size did not affect the optimum location of the collar at the abutment, which yields the maximum scour reduction around the abutment.

INTRODUCTION

There are numerous works, experiments and case studies given in the literature about pier scour and abutment scour concept. The statistical data show that in a bridge failure case, the main reason of the failure is most probably the pier or abutment scour (Melville 1992, Kandasamy and Melville 1998).

In the literature there are many studies related with the pier scour and its countermeasures. For bridge pier countermeasures, the NCHRP 24-7 (1998) project final report named "Countermeasures to Protect Bridge Piers from Scour" has reviewed nearly all the literature in this aspect and also has given recommendations and design suggestions for a number of countermeasures. Also, the Federal Highway Administration has developed several comprehensive technical manuals for dealing with the problem of bridge scour. Moreover, a field survey of pier countermeasures was carried out across the United States (Li, Kuhnle, and Barkdoll 2006). However, the scour at bridge abutments has received less attention, and especially the future works on countermeasures for abutment scour are greatly needed.

The literature review shows that the researchers studied the collars mainly to reduce the local scour at bridge piers. The researchers like Dargahi (1990), Chiew (1992, (b)), Kapoor and Keana (1994), Kumar et. al. (1997), Singh et. al. (2001), Mashahir and Zarrati (2002), and Borghei et al. (2004) all investigated the reducing effect of the collars on the local scour at bridge piers.

There are fewer researchers studying the countermeasure effect of collars on bridge abutment scour. Kayatürk (2005) conducted experiments in a rectangular channel with glass side walls, 30.0 m long, 1.0 m deep and 1.5 m wide, with erodible uniform sand having a median diameter of d_{50} = 1.48 mm under clear water conditions. The tests showed that with a flow depth of 0.10 m and a flow rate of 0.050 m^3/s, the bed material would be at incipient motion condition. The ratio of the shear velocity in these experiments to the critical shear velocity calculated from Shield's diagram was about 0.90. Kayatürk (2005) tested vertical wall abutments having rectangular plan view with a constant width of B_a = 10 cm and five different lengths perpendicular to the flow direction L_a = 7.5 cm, 15 cm, 20 cm, 25 cm and 35 cm. For rectangular collars of widths, B_c = 2.5 cm, 5.0 cm, 7.5 cm and 10 cm were tested with each abutment at various elevations from the bed level, Z_c = -5 cm, -2.5 cm, ±0.0 cm, 2.5 cm and 5.0 cm, for a time period of 6 hours. Based on the experimental results Kayatürk (2005) stated that the efficiency of a collar was a function of its size and its vertical location on the abutment. As the size of the collar increases, the scour depth decreases. If the ratio of the abutment length to the flow depth $L_a/y > 1$, the efficiency of the collar increases with decreasing L_a/B_c and the elevation of the collar shifts in downward direction from the bed level, as long as the clear water flow conditions are satisfied, regardless of the flow depth. If $L_a/y < 1$, the collar, which is placed at the bed level ($Z_c/y = \pm 0.00$), gives higher performance than those having other Z_c/y values. Instead of full-collars, the partial collars can be used to provide maximum reduction in the scour depth from an economical point of view (Kayatürk, 2005).

Li, Kuhnle and Barkdoll (2006) have conducted some laboratory experiments with collars at a vertical-face wing wall abutment placed at the main channel edge, an abutment configuration typical of older bridges on smaller streams. To mitigate the abutment scour, flat, horizontal, steel collars were attached around a wing-wall abutment ending at the main channel edge under clear-water flow conditions in a laboratory flume channel. It was found that these collars were able to protect the bridge abutment efficiently by eliminating secondary vortices that ordinarily would cause local scour. The minimum collar dimensions that eliminated the local scour were a flow perpendicular width of 0.23 L_a (L_a is the abutment length perpendicular to the flow direction) and a flow parallel length of 0.7 times the flow parallel abutment width. It was determined that a vertical location of 0.08 y (where y is the main channel flow depth) below the mean bed sediment elevation gave the best results of scour reduction. In addition, the collar did not only reduced the scour magnitude near the abutment, but also retarded the development of the scour hole.

This review exposes that there is a gap in the literature related to the use of collars to mitigate abutment scour. Although there are some studies conducted and presented, there is a need for further investigation of this phenomenon.

The aim of this study is to investigate the effect of the grain size of the bed material on the performance of collars on reducing the local scour depth at the base of the abutments. For this reason, a series of experiments were conducted at the laboratory under clear water flow conditions with vertical abutments and collars of various sizes using almost uniform sand of d_{50} = 0.90 mm and the results obtained were compared with those of Kayatürk (2005) to see they are valid or not for finer bed materials.

EXPERIMENTAL SETUP

The experiments were conducted in a 1.5 m wide, 1.0 m deep and 30 m long, flume with glass side walls and a bed slope of $S_0 = 0.001$. The working section, in which the abutments were located, was 10 m long with a recess on the bed 0.50 m deep and was situated 10 m downstream from the entrance of the flume. The recess was filled with uniform sediment with a diameter of 0.90 mm.

The longitudinal cross-sectional view of the flume is shown in Figure 1.a. The flume had a closed-loop water system and the flow to the flume was supplied from a constant-head water tank by a pump. A gate was mounted at the tail end to adjust the flow depths.

The flow discharge was measured with a sharp-crested rectangular weir mounted at the upstream section of the flume. By means of bricks and sheet-iron strainer placed between brick walls, located at the entrance of the channel as a filter, turbulence of the flow was reduced and the uniform flow conditions were maintained which were required for upstream head measurements. The scour depths were also measured with a point gage to an accuracy of ±1 mm. The tip of the gage was painted with white paint and for each measurement the painted tip penetrated the sandy bottom of the scour hole until it could no longer be seen.

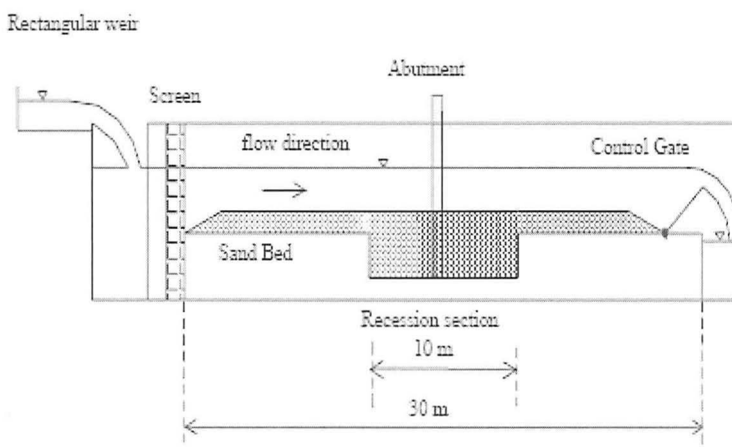

Figure 1.a. The longitudinal cross-section of the experimental setup

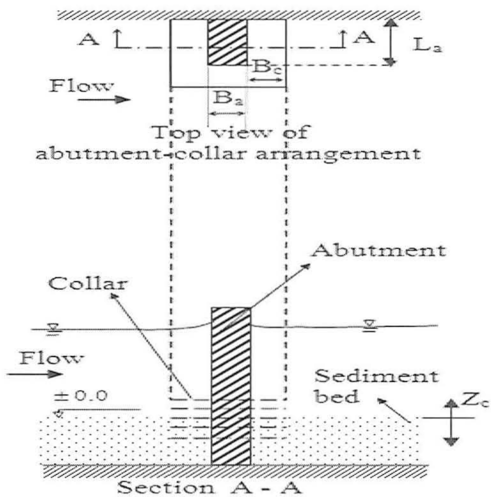

Figure 1.b. Abutment-collar arrangement

The abutments and collars used in this study were manufactured from 3 mm thick Plexiglas at the laboratory (Figure 1.b.).

The lengths oh the abutments rectangular in plan were the same as those used in Kayatürk's study (2005) as being 35 cm, 25 cm, 20 cm, 15 cm, and 7.5 cm with a constant width of 10 cm (Table 1.). According to Oliveto and Hager (2002), and Kayatürk (2005), the effect of the stream wise abutment length on the development of the scour hole is small and can be neglected. Four different collars of widths, B_c = 2.5 cm, 5.0 cm, 7.5 cm and 10 cm, were tested with each abutment (Table 1).

EXPERIMENTAL PROCEDURE

All tests were conducted under the clear water flow conditions at U_*/U_{*c} = 0.90, where U_* is the shear velocity of the approach flow and U_{*c} is the value of U_* at the threshold of grain motion. The threshold flow depth of bed material motion, y_c = 5.3 cm, was calculated from the Shield's diagram. Then, the result for y_c was confirmed with the experimental observation when the abutment was not installed. Finally, the flow depth satisfying the ratio of U_*/U_{*c} = 0.90 was calculated as y = 4.25 cm, and the experiments were conducted by using this flow depth, which corresponds to upstream Froude and Reynolds numbers of 0.41 and 43439, respectively.

After locating the abutment in place in the flume without or with a collar, the experiments were started by filling the channel with water without disturbing the leveled surface of sediment bed until the water depth was adjusted to satisfy the ratio of U_*/U_{*c} = 0.90, by making use of the control gate placed at the far downstream of the flume. When the corresponding flow depth (y = 4.25 cm) and discharge (Q =

0.017 m^3/s) were achieved and the flow regime was checked as being uniform by making use of line meters attached to the glass side walls of the flume, the experiment was started. The scour hole was obtained by performing a 6-hour continuous run under clear water conditions and both the maximum scour depth and the scour formation at the abutment site were investigated. The maximum scour depth at the end of a 6-hour continuous run was determined with the help of a mirror by estimating the distance between the zero level of the mirror and the current level of the channel bed. At the end of each experiment, the flume was carefully drained and sand bed level was straightened and compacted for the next experiment with a special apparatus, which was made of steel plate welded on a steel frame. Before the straightening and compaction of the channel bed, the longitudinal cross-sectional bed profile in front of the abutment face, where the maximum scour depth occured, was gauged and recorded in the flow direction. The frame used for straightening could slide from the beginning to the end of the flume over steel rails which were mounted on the glass side walls.

As the efficiency of the collar is also a function of its vertical location on the abutment, collars of different sizes were placed at different elevations on the abutments (Z_c) as; at the bed level, 1.0 cm and 2.0 cm above the bed level and also 1.0 cm and 2.0 cm below the bed level. In Table 1, all collars used are classified considering their sizes and also abutment types.

Table 1. Abutment and collar sizes used in the tests

Z_c (cm) = +2.0, +1.0, ±0.0, -1.0, -2.0 (with respect to the channel bed)			
Type	L_a (cm)	Case	B_c (cm)
1	7.5	a	10.0
		b	7.5
		c	5.0
		d	2.5
2	15	a	10.0
		b	7.5
		c	5.0
		d	2.5
3	20	a	10.0
		b	7.5
		c	5.0
		d	2.5
4	25	a	10.0
		b	7.5
		c	5.0
		d	2.5
5	35	a	10.0
		b	7.5
		c	5.0
		d	2.5

Maximum Scour Reductions around the Abutments with Collars

The total number of the experiments conducted; with abutments of lengths: L_a = 7.5 cm, 15 cm, 20 cm, 25 cm and 35 cm, collars of widths: B_c = 2.5 cm, 5.0 cm, 7.5 cm and 10 cm, and finally collar locations of Z_c = -2.0 cm, -1.0 cm, ±0.0 cm, 1.0 cm and 2.0 cm is 97. The experiments for the abutment length of 7.5 cm with the collar widths of 10 cm, 7.5 cm, and 5 cm at the elevation of Z_c = -2.0 cm have not been performed. The reason is that the propagation of the scour depth in the vertical direction is stopped during the experiments for Z_c = -1.0 cm, meaning that there is no sense or need to locate collars below this limiting level. The bed profiles obtained at the end of these experiments and the maximum scour depths around the abutments for each experiment were determined. Then, the scour depths around abutments with and without collar were compared to see the percent reduction in the scour depth.

In Figure 2, the overall effect of abutment length, collar width and the location of the collar on the reduction of maximum scour depth can be seen according to the results of this study. Figure 3 is provided to show the same graph for the Kayatürk's results (2005). Each line given in the figures corresponds to a constant L_a/B_c value. According to the plot of Kayatürk (2005), at small values of L_a/B_c which is less than about 2.0, maximum reductions in scour depths are mainly obtained when the collars are located at the bed level, $Z_c/y = \pm 0.0$. For greater values of L_a/B_c, maximum reduction in scour depths are mostly observed when the collars have the value of Z_c/y = -0.50. This figure also clearly shows that scour reduction capacity of a collar increases as the width of the collar increases, and decreases with increasing abutment length. Collars are generally more effective in reducing the scour depth around the abutment when they are located below the sand bed, $-0.50 < Z_c/y < -0.25$, compared to the cases of above the sand bed, $0.0 < Z_c/y < 0.50$, for the value of $L_a/B_c > 2.0$. The trend lines of the data points in Figure 2 also imply that at Z_c/y values less than –0.50, higher reductions in the maximum scour depths around the abutments can be obtained than those given in the figure for Z_c/y = -0.50. For design purposes when the optimum value of Z_c/y is required, the one close to the bed level but having adequate scour reduction capacity should be selected (Kayatürk, 2005). When Figure 2 is compared to Figure 3 it is clearly seen that the general trends of the data of the same abutment and collar are very similar. At small values of L_a/B_c, which is less than and equal to 2.0, the maximum reductions in the scour depths are mainly obtained when the collars are located at the bed level, $Z_c/y = \pm 0.0$. For the range of L_a/B_c between 2 and 5, the maximum reduction in the scour depths is observed for Z_c/y values between -0.24 and -0.47. But, it has a fluctuating behavior. For L_a/B_c values greater than and equal to 5, the optimum Z_c/y occurs at Z_c/y = -0.47, which is similar to the results of Kayatürk (2005). One additional observation can be summarized as, the increase in the collar width increases the scour reduction performance of the collar, whereas the increase in the abutment length decreases this efficiency. This holds true for both studies.

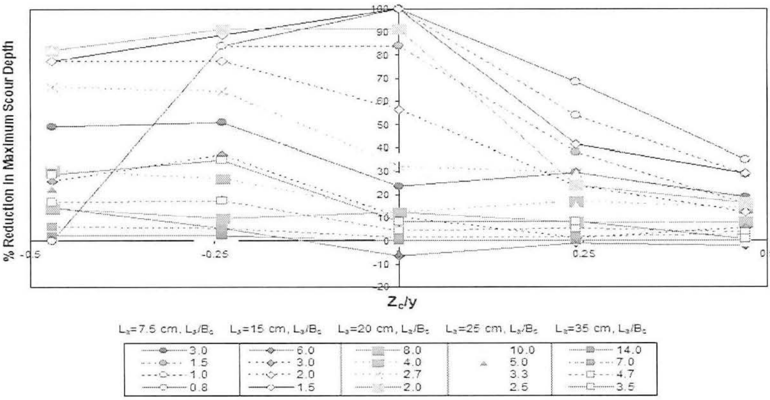

Figure 2. Effect of collar size and elevation on the maximum scour depth around the abutments of various lengths ($Q = 0.017\ m^3/s$, $y = 4.25$ cm, $d_{50} = 0.90$ mm)

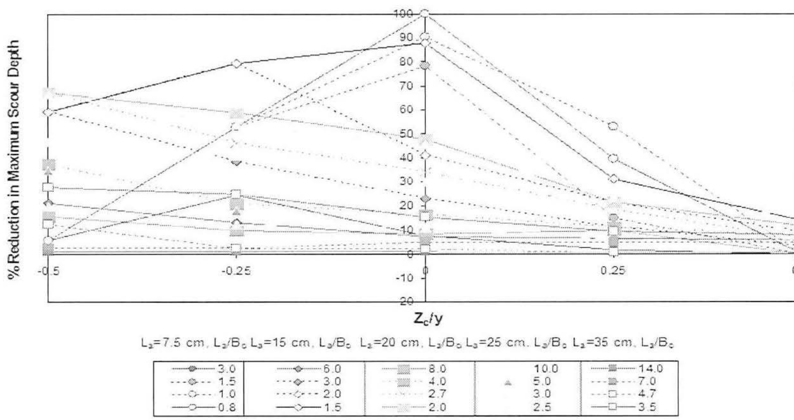

Figure 3. Effect of collar size and elevation on the maximum scour depth around the abutments of various lengths ($Q = 0.050\ m^3/s$, $y = 10$ cm, $d_{50} = 1.48$ mm) (Kayatürk, 2005)

According to the results of the experiments, the locations of the collars having the best scour reduction efficiency for each abutment length and collar width were chosen and presented in Table 2 along with the corresponding values of $\left[(d_s)_{max,c} / y\right]_{opt}$ and $\left[Z_c / y\right]_{opt}$. Here, $(d_s)_{max,c}$ is the maximum scour depth obtained from experiments conducted with collars, %Reduction= $[(d_s)_{max} - (d_s)_{max,c}]/(d_s)_{max}$ where $(d_s)_{max}$ is the maximum scour depth around the abutment without collar.

Table 2. Results of present study and Kayatürk's one (2005)

		RESULTS OF PRESENT STUDY			KAYATÜRK'S RESULTS (2005)		
L_a/B_a	L_a/B_c	$[Z_c/y]_{opt}$	$[(d_s)_{max,c}/y]_{opt}$	$[\%Reduction]_{opt}$	$[Z_c/y]_{opt}$	$[(d_s)_{max,c}/y]_{opt}$	$[\%Reduction]_{opt}$
0.75	3	-0.24	0.73	50.8	-0.25	0.40	24.5
	1.5	0.00	0.24	84.1	0.00	0.12	77.3
	1	0.00	0.00	100.0	0.00	0.05	90.5
	0.75	0.00	0.00	100.0	0.00	0.00	100.0
1.5	6	-0.47	1.79	14.6	-0.50	0.97	23.0
	3	-0.24	1.32	37.1	-0.50	0.50	60.0
	2	-0.24	0.47	77.5	-0.25	0.25	80.0
	1.5	0.00	0.00	100.0	0.00	0.18	86.0
2	8	-0.47	2.26	14.3	-0.50	1.29	16.0
	4	-0.47	1.84	30.4	-0.50	0.96	37.0
	2.67	-0.47	0.89	66.1	-0.50	0.60	61.0
	2	0.00	0.24	91.1	-0.50	0.50	67.0
2.5	10	-0.47	2.64	1.8	-0.50	1.47	20.0
	5	-0.47	2.07	22.8	-0.50	1.19	35.0
	3.33	-0.47	1.79	33.3	-0.50	0.98	46.0
	2.5	-0.47	0.47	82.5	-0.50	0.61	67.0
3.5	14	-0.47	3.04	2.3	-0.50	1.99	1.0
	7	-0.47	2.92	6.1	-0.50	1.95	2.9
	4.67	-0.24	2.56	17.4	-0.50	1.76	12.4
	3.5	-0.24	2.02	34.8	-0.50	1.45	28.0

To determine the optimum locations of the collars for known values of L_a/B_c, the data of $[Z_c/y]_{opt}$ given in Table 2 for both studies are plotted versus L_a/B_c in Figure 4. From this Figure the following classification for L_a/B_c and $[Z_c/y]_{opt}$ can be proposed for the present study:

$[Z_c/y]_{opt} = 0$ for $L_a/B_c \leq 2.0$

$-0.47 \leq [Z_c/y]_{opt} \leq -0.24$ for $2.0 < L_a/B_c < 5.0$

$[Z_c/y]_{opt} = -0.47$ for $5.0 \leq L_a/B_c \leq 14.0$

And for the Kayatürk's one (2005):

$[Z_c/y]_{opt} = 0$ for $L_a/B_c < 2.0$

$-0.50 \leq [Z_c/y]_{opt} \leq -0.25$ for $2.0 \leq L_a/B_c \leq 3.0$

$[Z_c/y]_{opt} = -0.50$ for $3.0 < L_a/B_c \leq 14$

The above relations are valid within the range of L_a/B_c between 0.75 and 14.

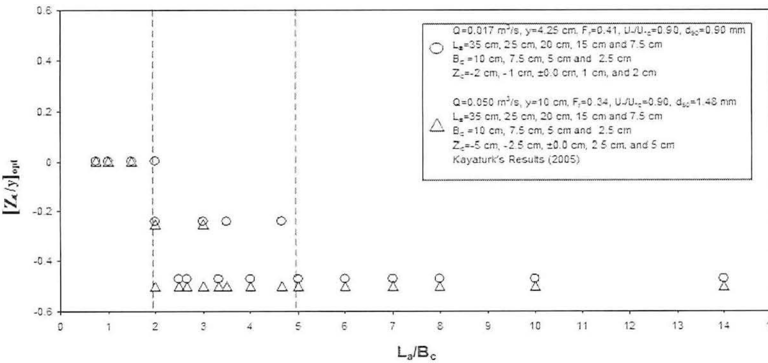

Figure 4. Variation of $[Z_c/y]_{opt}$ with L_a/B_c

Figure 5 shows the variation of $[\%Reduction]_{opt}$ with L_a/B_c (Table 2) for the data of both studies. In the figure it is seen that the best fit lines drawn for all data sets almost coincide to each other. This means that after determining the optimum location of the collar from Figure 4 for a given L_a/B_c, one can also estimate the corresponding $[\%Reduction]_{opt}$ from Figure 5. Consequently, the scour reduction percentages for both sediment sizes are very close to each other. Referring to this figure it can be concluded that to have at least 20% reduction in the maximum scour depth around an abutment, the L_a/B_c value of the abutment must be less than 6, while this value would be less than about 2 to have at least 60% reduction for the Kayatürk's data set (2005). The results for the present data set are almost the same.

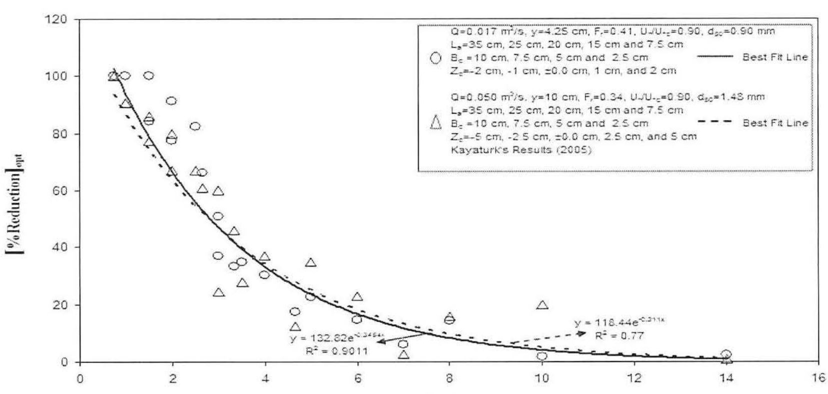

Figure 5. Variation of $[\%Reduction]_{opt}$ with L_a/B_c

CONCLUSIONS

A collar reduces the sediment particles at the bottom of an abutment from erosion by down flow. The efficiency of a collar for reducing scour is a function of its size and its vertical location on the abutment. As the size of the collar increases the scour depth decreases. But, increasing abutment lengths reduce the performance of a collar.

In Kayatürk's study (2005), if $L_a/y > 1$, the efficiency of the collar increases with decreasing L_a/B_c. Also, the elevation of the collar shifts in downward direction from the bed level for increasing L_a/B_c, as long as the clear water flow conditions are satisfied, regardless of the flow depth, that is $U_*/U_{*c} = 0.90$. If $L_a/y < 1$, the collar, which is placed at the bed level ($Z_c/y = \pm 0.00$), gives higher performance than those having other Z_c/y values. In this study, all of the experiments satisfy the condition of $L_a/y > 1$ for all the abutment lengths, which were used. Accordingly, the result derived by Kayatürk (2005) is also satisfied by the results of this study. In other words, according to the general trends of the data presented in Figures 4 and 5, the experiments conducted with a grain size diameter of 0.90 mm provide almost the same results of the experiments conducted with a grain size diameter of 1.48 mm by Kayatürk (2005). In both studies the optimum location of the collar on the abutment, $(Z_c/y)_{opt}$, which will yield the maximum reduction in the scour depth is almost the same for a given L_a/B_c within the ranges tested.

Consequently, it can be stated that the findings of the present study verify that the results of the previous investigation are valid. In order to state a final conclusion about the validity of these findings for other sediments having median diameters different than those; 0.90 mm and 1.48 mm, the similar experiments should be repeated with different erodible material and abutments longer than those used in this study.

REFERENCES

Borghei, S. M., and Nazari, A., (2004). "Experimental Investigation of Sediment Pattern in River Confluence." *6th International Civil Engineering Conference*, Isfahan Technical University, Isfahan, Iran: 247-255.

Chiew, Y. M., (1992). "Scour Protection at Bridge Piers." *J. of Hydr. Eng.*, Vol. 118, No. 9: 1260-1269.

Dargahi, B., (1990). "Controlling Mechanism of Local scouring." *J. of Hydr. Eng.*, Vol. 116, No. 10: 1197-1214.

Kandasamy, J. K., and Melville, B. W., (1998). "Maximum Local Scour Depth at Bridge Piers and Abutments." *J. of Hydr. Eng.*, Vol. 36, No. 2: 183-198.

Kapoor, B. S., and Keana, C. M., (1994). "Experimental Overview to Mechanism of Scour Around A Round Nosed Pier and Effect of Delta Wing like Device on Scour Pattern Around It." *Modeling, Measurement & Control C: Energetics, Chemistry, Earth, Environmental & Biomedical Problems*, v46, Issue number: n3, 1994: 25-44, AMSE Press, Tassin-la-Demi-Lune, Fr.

Kayatürk, Ş.Y., (2005). "Scour and Scour Protection at Bridge Abutments." *Thesis presented to Middle East Technical University*, Ankara, Turkey, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Kumar, V., Raju, K. G. R., and Vittal, N., (1997). "Reduction of Local Scour Around Bridge Piers Using Slots and Collars." *J. of Hydr. Eng.*, Vol. 125, No. 12: 1302-1305.

Li, H., Kuhnle, R. A., and Barkdoll, B. D. (2006). "Countermeasures Against Scour at Abutments." *National Sedimentation Laboratory*, Research Report No. 49, U.S.

Mashahir, M. B. and Zarrati, A. R., (2002). "Effect of Collar on Time Development of Scouring around Rectangular Bridge Piers." *The 5th International Conference on Hydro Science and Engineering*, Warsaw, Poland.

Melville, B. W., (1992). "Local Scour at Bridge Abutments." *J. of Hydr. Eng.*, Vol. 118, No. 4: 615-631.

Oliveto, G., and Hager, W. H., (2002). "Temporal Evolution of Clear-Water Pier and Abutments Scour." *J. of Hydr. Eng.*, Vol. 128, No. 9: 811-820.

Parker, G., C. Toro-Escobar, and R.L. Voight, Jr., (1998). "Countermeasures to Protect Bridge Piers From Scour" User's Guide, Vol. 1, *prepared for National Cooperative Highway Research Program, Transportation Research Board, National Research Council, NCHRP Project 24-7*, St. Anthony Falls Laboratory, University of Minnesota, Minneapolis, MN (revised 7/1/99).

Singh, C. P., Setia, B. and Verma, D. V. S., (2001). "Collar-Sleeve Combination as a Scour Protection Device Around a Circular Pier." *XXIX IAHR Congress Proceedings*, Beijing, China, Vol. 2: 202-210.