PARALLEL WALLS AS AN ABUTMENT SCOUR COUNTERMEASURE

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Scour at bridge abutments can cause damage or failure of bridges and result in excessive repairs, loss of accessibility, or even death. To mitigate abutment scour, clear-water laboratory experiments in a compound channel with an erodible main-channel bad and rigid floodplain were performed using parallel walls. These experiments will aid in developing design guidelines for scour countermeasures for well vegetated or rigid banks and floodplain. Two types of parallel walls were tested: the first was made of a solid thin wood plate and the second was made of piled rocks. For solid parallel walls, a series of rectangular straight plates of different length attached to the upstream end of a wing wall abutment parallel to the flow direction were employed. The velocity was 90% of its incipient motion value for bed sediment movement. The bed material was sand with a mean diameter of 0.8 mm. All the plates were seated at the bottom of the bank slope and were even with the abutment face parallel to the flume wall. It was found that straight plates thus situated are able to move the scour hole from the upstream abutment corner and are efficient as a countermeasure to prevent scour there. As the length of the plate increased, the scour at the abutment declined and as the plate reached 1.1L, where L is the length of the abutment perpendicular to the flow, the scour depth at the abutment was minimum. It was also found that a triangular-shaped or submerged end could reduce the scour at the upstream end of the plate.   For parallel rock walls, various values of wall length and protrusion length into the main channel were tested. It was found that a wall that does not protrude into the main channel with a length of 0.5L length minimizes scour at the abutment where L is the length of the abutment perpendicular to the flow.

1 Introduction

Scour at bridge abutments can cause damage or failure of bridges and result in excessive repairs, loss of accessibility, or even death. There are many countermeasures that have been proposed, but parallel walls are singled out in this paper as being a new and attractive alternative. Previous work on the related topic of guidebanks includes Spring (1903), Lagasse et al. (1999, 2001), and Richardson and Simons (1984).

This study focuses on abutments on a rigid floodplain and banks whose face is even with the toe of the main channel. This situation is common in well-vegetated, smaller stream with older abutments. While typical guidebanks have an ellipcital upstream end, a parallel wall does not and, therefore, would be less expensive due to the difficulty of construction of the elliptical shape. The efficacy of parallel walls without the elliptical end, was, therefore, tested here.

2 Experimental Procedure and Results

All of the experiments were conducted in a flume located in the hydraulic laboratory at the National Sedimentation Laboratory, Oxford, MS. The flume channel was 30 m long, 1.2 m wide, and 0.6 m deep, and it was supported in the center at two points and on the ends by four screw jacks that allow the channel slope to be adjusted. The model abutment was located over a 3 m long, 1.2 m wide, by 1.2 m deep recessed section of the flume 22 m downstream from the inlet tank.

The channel section of the experiments is illustrated in Figure 1. It was a compound channel consisting of an asymmetric floodplain of width 320 mm next to a main channel that has a bank slope of 1:1 (H:V). The height between the top of the floodplain and the main channel bed, y_m, was 80 mm. The rigid floodplain was made of galvanized steel plate and glued down onto the flume bottom. A thin layer of the 0.8 mm sand was glued to the floodplain and bank side slope.
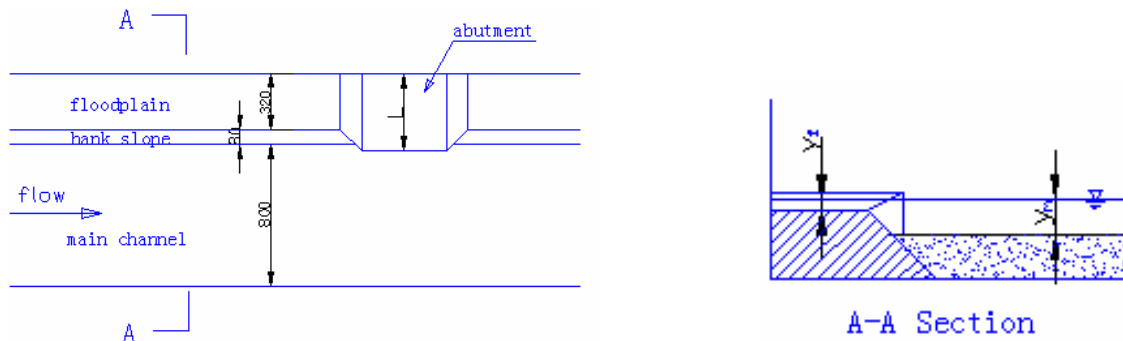
Figure 1: Dimension Sketch for Experimental Compound Channel (mm).

The wing-wall abutment model was made of steel. The dimensions of the model are shown in Figure 2. The abutment terminated on the bank slope of the main channel as illustrated in Figure1, which corresponds to the type III abutment of Melville (1992). The height between the top of the floodplain and the top of the abutment was 60 mm.
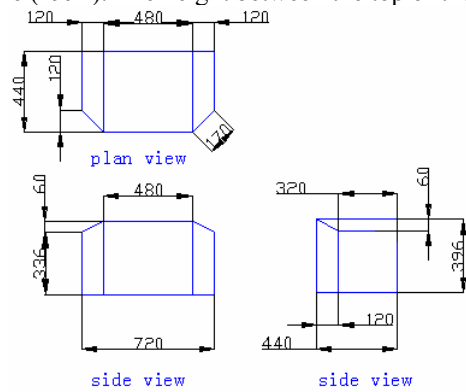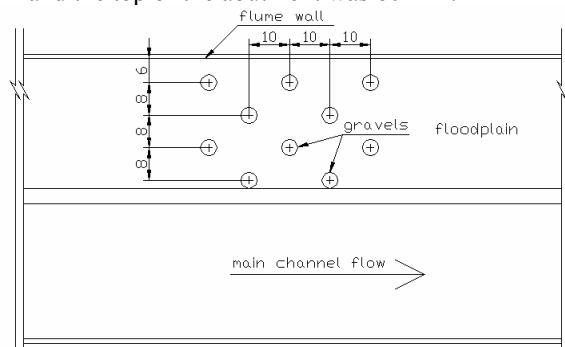

Figure 2: Dimensions of Abutment Model (mm).

Figure 3: Scheme of staggered placement of gravel on floodplain to provide roughness. Gravels were placed throughout the floodplain (cm).

The bed material used in the experiments had a diameter of 0.8 mm in both the floodplain and the main channel. The standard deviation of the gradation curve of the material σ_g is $\sigma_g = [D_{84}/D_{16}]^{1/2} = 1.37$. According to Shields diagram, the critical shear velocity of the bed sediment is 1.995 cm/s. The steel floodplain was first primed and painted and then the same size sands of median diameter 0.8 mm were sprinkled onto the surface of it to provide roughness. The floodplain was further roughened using gravel rocks of average diameter of 4.5 cm that were placed in a staggered arrangement on the floodplain (Figure 3).
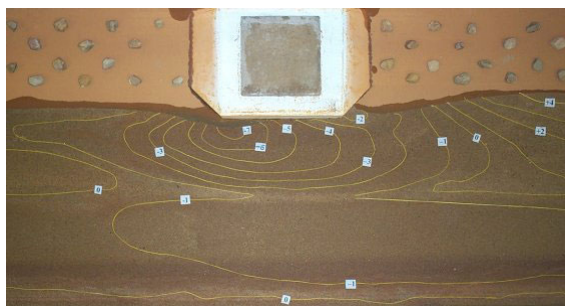

Figure 4: String contour of the baseline test, y_m = 13.2 cm, y_f = 5.2 cm, Q = 0.0442 m³/s, time = 4800 minutes. Flow is from left to right with a staggered arrangement of gravel on the floodplain.
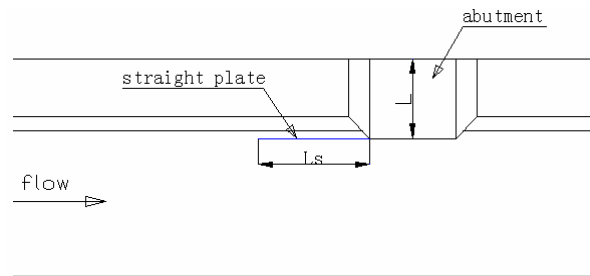

Fig. 5: A sketch of the straight plate cases with varying length L_s.

3 Baseline Experimental Results

The baseline test was carried out under conditions of y_m = 13.2 cm, y_f = 5.2 cm, and Q = 0.0442 m^3/s. From figure 4 it can be seen that the maximum scour, 7.77 cm, took place at the upstream corner of the abutment. This scour depth will be used as the baseline scour depth for abutment scour without any countermeasures.
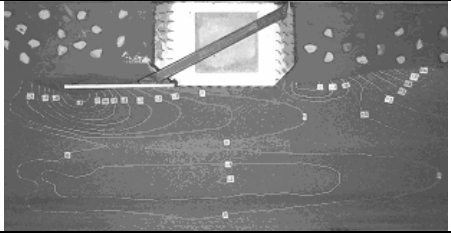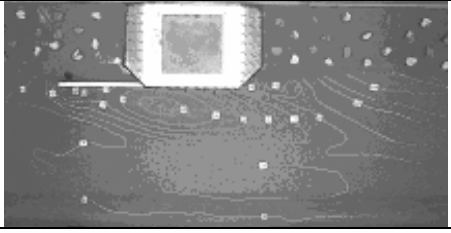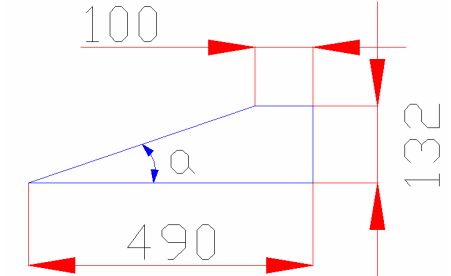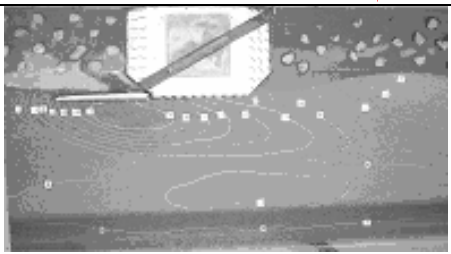
4 Solid Parallel Wall Experimental Results

A series of rectangular straight plates of different lengths, L_s, attached to the upstream end of the abutment parallel to the flow direction were tested (Fig. 5) to assess parallel wall feasibility. Although somewhat impractical to build a solid wall in the field, it could be done in areas where rock is scarce. In these cases, the flow depth on the floodplain, y_f, was equal to 5.2 cm and the flow depth in the main channel, y_m, was 13.2 cm. The velocity ratio U/U_c was about 0.9 in the center of the entire channel. Table 1 gives results of the solid wall experiments.

Table 1: Straight plate experimental results (run time-4800 min., Q=0.038 m^3/s).

Straight plate length (Ls)	Maximum scour depth at abutment (cm)	Scour reduction rate (%)	Maximum scour at the countermeasure (cm)
0.3L, rectangular	6.25	19.6	8.65
0.5L, rectangular	4.01	48.4	8.10
0.6L, rectangular	2.95	62.0	7.71
0.7L, rectangular	2.15	72.3	7.83
0.8L, rectangular	1.43	81.6	7.62
1L, rectangular	0.33	95.8	7.71
1.2L, rectangular	-0.40	105.1	8.30
1L, bank high, submerged	4.00	48.5	5.50
1.2L, with upstream 0.4L submerged 4.3 cm deep in water	1.74	77.6	7.80
Triangular upstream end	4.63	40.4	6.83

All the solid parallel walls were seated on the bank slope of the main channel and aligned with the abutment face parallel to the flume wall. The top of each wall was the same height as the top of the abutment except in one case, in which the wall height was 5.2 cm lower than the flow surface, and also in another case where the wall was partially submerged about 4.3 cm in the flow. It was found that, in general, walls attached to the upstream end of the abutment were able to move the scour hole upstream from the abutment corner and therefore, was efficient as a scour countermeasure. It was also found that as the length of the wall increased, the scour at the abutment declined. Table 2 shows photographs of the topographic maps of the scoured region after 4800 minutes.

Table 2: Photographs of selected straight plate tests (flow from left to right, run time=4800 min., Q=0.0379 $\pm$ 0.003m^3/s).

Parallel wall description	Photographs
L_s = 1.2L, y_m = 13.2 cm, y_f = 5.2 cm.	
L_s = 1.0L with the top of the wall submerged 5.2 cm in the water. y_m = 13.2 cm, y_f = 5.2 cm.	
A sketch of the dimension of the triangular wall (mm).	
triangular end was tested. y_m = 13.2 cm, y_f = 5.2 cm.	

5 Discussion of Plate Length

Fig. 6 is a plot of the scour depths at the upstream corner of the abutment and the maximum scour depth in the vicinity of the upstream end of the wall versus the length of the wall in terms of the abutment length, L_s. It is seen that as the length of the wall increases from 0.3L to 1.2L, the scour at the abutment decreases rapidly. There is no scour at the abutment corner in 4800 minutes of running when the wall reaches a length of 1.1L. The length of the wall is vital to its success as a countermeasure. If the wall moves the scour hole far enough upstream, the scour hole at the upstream end of the wall will have no impact on the abutment corner and the countermeasure will be considered successful. Otherwise, the abutment corner will still be in the scour region and may be subject to collapse.
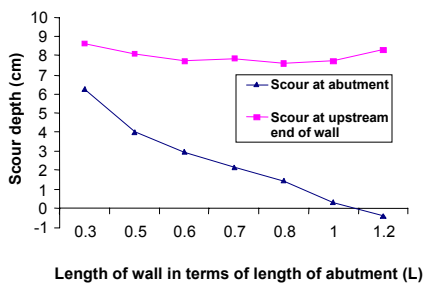

Fig. 6: Scour depth at both abutment and upstream end of wall versus length of wall in terms of wall length.

6 Rock Parallel Wall Experimental Results

A series of rock walls of different lengths L_w and different protrusion lengths, Lp, were tested (Fig. 7) under clear water conditions. The effect of extending the wall out into the main channel was unclear. Extending the wall could divert flow away from the abutment or it could cause scour-inducing eddies. Rock was thought to be less expensive and easier to construct in the field than a solid wall. These structures are similar to guidebanks without the elliptical upstream end (Bradley, 1978). In these experiments, the flow depth on the floodplain (y_f) was equal to 5.2 cm and the flow depth in the main channel (y_m) was 13.2 cm. The velocity ratio U/U_c was about 0.9 in the centerline of the entire channel. The top of each wall was the same height as the top of the abutment so that they were not submerged by the flow.
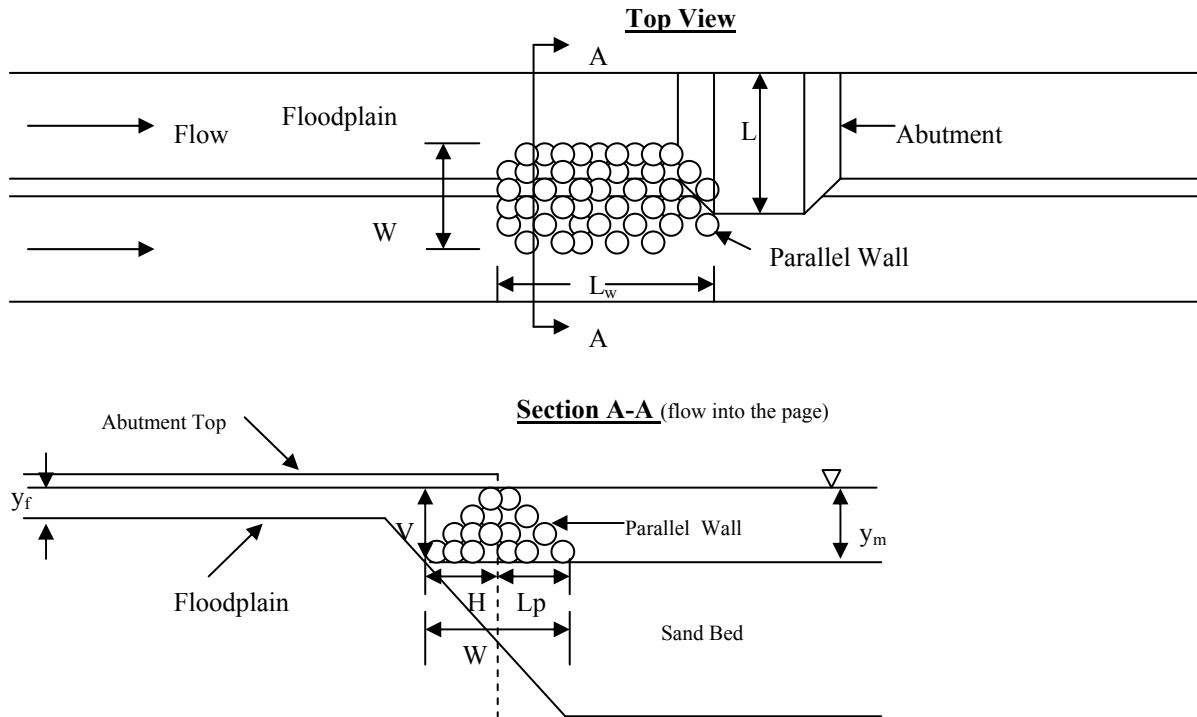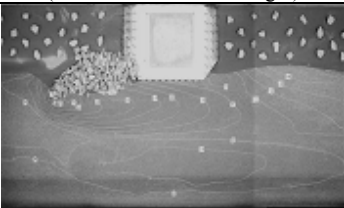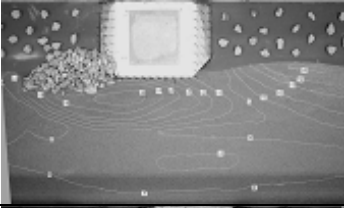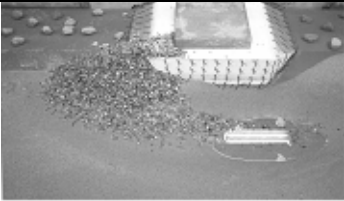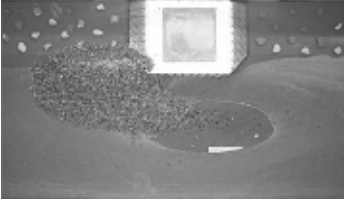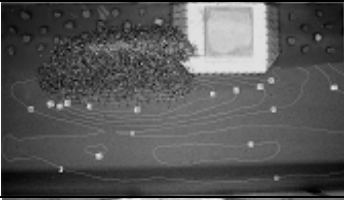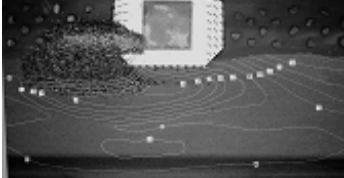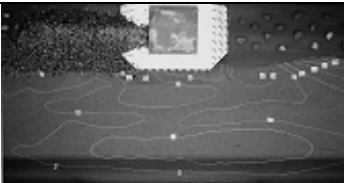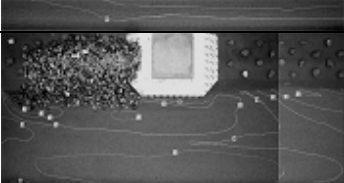

Fig. 7: Definition sketch of parallel wall.

It was found that (a) the walls which were set back onto the floodplain such that the feet of the walls were even with the abutment (no protrusion length, Lp) were very effective in protecting the abutment, (b) those walls whose feet protruded into the main channel beyond the abutment (protrusion length, 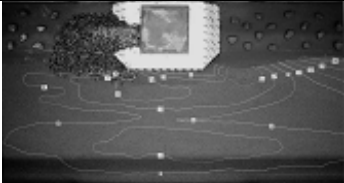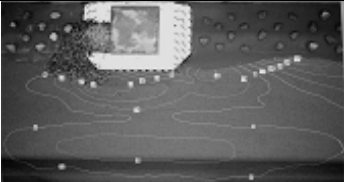Lp, greater than zero) tended to produce significant scour in the bridge crossing and potentially threaten the middle and downstream abutment end, and (c) for zero protrusion length, Lp, the protection efficiency of the walls were not sensitive to the lengths of the wall unless the wall was extremely short, for instance, 0.25L, then the protection efficiency would drop significantly. Overall, the straight wall is an efficient and practical countermeasure to prevent scour at the abutment.

Table 3: Experimental data of straight stone walls (Q = 0.0385 $\pm$ 0.003m^3/s, t = 4800 min.).

Wall description	Photographs (All flow is from left to right)	Maximum scour at abutment (cm)	Scour reduction(%)
Gravel diameter 40-70 mm, Lw=1.3L, wall end slope H:V=13.2/13.2, a varying side slope of H:V=6.6/13.2 at upstream and zero at the abutment. Lp=0.		1.05	86
Gravel diameter 40-70 mm, Lw=0.61L, wall end slope H:V=36/13.2, a varying side slope of H:V=6.6/13.2 at upstream and zero at the abutment , Lp=0, used the scoured wall of previous run.		3.32	57
Gravel diameter 6.7~9.5 mm, Lw=.5L, wall end slope H:V=30/13.2, side slope H:V=18/13.2, Lp=0.5W.		0.2	97
Gravel diameter 6.7~9.5 mm, Lw=0.5L, wall end slope H:V=30/13.2, side slope H:V=18/13.2, Lp=0.5W.		5.21	29
Gravel diameter 6.7~9.5 mm, Lw=L, wall end slope H:V=30/13.2, side slope H:V=18/13.2, Lp=0.5W.		5.06	35
Gravel diameter 6.7~9.5 mm, Lw=1.5L, wall end slope H:V=30/13.2, side slope H:V=18/13.2, Lp=0.25W.		0.45	94
Gravel diameter 6.7~9.5 mm, Lw=0.5L, wall end slope H:V=30/13.2, side slope H:V=18/13.2, Lp=0.25W.		5.3	32
Gravel diameter 6.7~9.5 mm, Lw=L, wall end slope H:V=30/13.2, side slope H:V=18/13.2, Lp=0.25W.		2.35	70

Gravel diameter 6.7~9.5 mm, Lw=1.5L, wall end slope H:V=30/13.2, side slope H:V=18/13.2, Lp=0.		1.9	76
Gravel diameter 6.7~9.5 mm, Lw=L, wall end slope H:V=30/13.2, side slope H:V=18/13.2, Lp=0.		1.95	75
Gravel diameter 6.7~9.5 mm, Lw=0.5L, wall end slope H:V=30/13.2, side slope H:V=18/13.2, Lp=0.		2	74
Gravel diameter 6.7~9.5 mm, Lw=0.25L, wall end slope H:V=30/13.2, side slope H:V=18/13.2, Lp=0.		2.8	64
Gravel diameter 6.7~9.5 mm, Lw=2L, wall end slope H:V=30/13.2, side slope H:V=18/13.2, Lp=0.		2	74
Gravel diameter 19~50 mm, Lw=1.5L length, stone wall end slope H:V=30/13.2, side slope H:V=17/13.2, Lp=0.		0.3	96

7 Discussion of Stone Wall Length

The length of the rock wall is a very important parameter that may affect the efficiency and cost of the stone wall as a countermeasure of abutment scour. Fig. 8 is a plot of scour depth at bridge abutment versus stone wall length for different wall protrusion lengths. It can be seen from the plot that for protrusion lengths Lp, of 0.25W and 0.5W, increases of wall lengths can reduce scour at the abutment significantly. However, for the case of no protrusion, increases of wall lengths do not show obvious effects in reducing scour at the abutment except when the wall is extremely short.
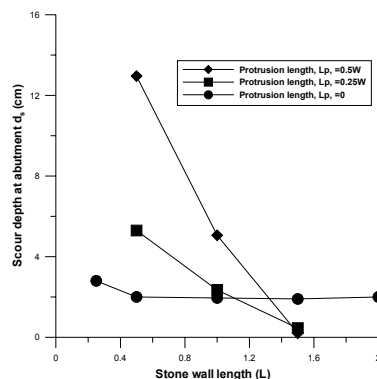

Fig. 8: Plot of scour depth at bridge abutment versus rock wall length for different wall protrusion length.

Fig. 9 is a plot of the maximum scour depth caused by the wall in the channel versus rock wall length for different wall protrusion lengths. It is seen from this plot that for the 0.25W and 0.5W protrusion lengths, increases in wall lengths can significantly reduce the maximum scour depth that is induced by the presence of the walls. While for walls with protrusion length of zero, increases in wall length result in essentially no reduction in scour depth when wall lengths are greater than 0.5L.
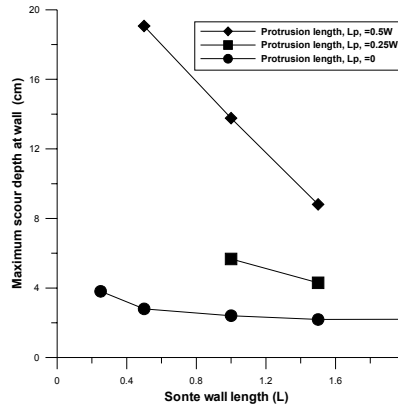

Fig. 9: Plot of the maximum scour depth caused by the wall in the channel versus stone wall length for different wall protrusion lengths.

From the analysis above it can be concluded that for walls with 0.25W and 0.5W protrusion lengths, increasing wall length increases the level of protection and walls of 1.5~2L length provide the maximum scour reduction. For those walls with no protrusion, since the increase in wall length does not significantly improve the scour reduction rate, therefore it is recommended that 0.5L is the optimum length to protect the abutment.

8 Conclusions

1. A solid parallel wall attached at the upstream corner of the abutment parallel with the flow can be used as a countermeasure against abutment scour. The length of the solid wall should be 1.1L for minimum scour at the abutment.
2. Parallel rock walls attached at the upstream of the abutment can also be used as countermeasures against scour at the abutment. The foot of the wall should not protrude into the main channel beyond the abutment and a wall length of 0.5L will provide the sufficient protection at the lowest cost.

Acknowledgement

References

Bradley, J.N. (1978) "Hydraulics of Bridge Waterways", Hydraulic Design Series No. 1, U.S. Dept. Transportation, Federal Highway Administration, 2nd Ed., Washington, D.C.

Lagasse P. F., Richardson E. V., and. Zevenbergen L. W. (1999). "Design of Guide Banks for Bridge Abutment Protection". Stream Stability and Scour at Highway Bridges. *Reston, VA: ASCE*, 0-7844-0407-0, pg. 856.

Lagasse, P. F., Zevenbergen, L. W., Schall, J. D., Clopper, P. E. (2001). Bridge Scour and Stream Instability Countermeasures. Publication No. FHWA NHI 01-003, Hydraulic Engineering Circular No. 23, U. S. Department of Transportation, Federal Highway Administration. Pages 2.7, 2.9, 4.6, 6.16 - 6.18, Design Guidelines 1, 9, 10.

Melville, B.W. (1992). "Local Scour at Bridge Abutments" ASCE Journal of Hydraulic Engineering, Vol. 118, No. 4, April, 1992.

Richardson, E.V. and Simons, D.B. (1984). "Use of spurs and guide banks for highway crossing: Proc. Transportation Research Record 2nd Bridge Engrg. Conf. v2 p.184.

Spring, F.J.E. (1903) "River training and control of the guide bank system," Technical Paper No. 153, Railway Board, Government of India, New Delhi.