ISSN 1996-3343

Asian Journal of Applied Sciences

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Asian Journal of Applied Sciences 5 (4): 192-204, 2012
ISSN 1996-3343 / DOI: 10.3923/ajaps.2012.192.204

Buried Wing Versus Wing Wall as Abutments and Spur Dykes Scour Countermeasure

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ABSTRACT

Scour is the main damage cause of abutments, piers, spur dykes and the hydraulic structures built in the river bed. By examining flow around the vertical wall abutment, it was observed that before the formation of scour hole, the streamlines at upstream of the abutment were deflected towards the noise abutment and the down flow in upstream face of abutment was negligible. As the Scour hole in the vertical wall abutment develops the down flow increases. Preventing formation of the hole in the upstream face of the vertical wall abutment using buried wing as a new approach it can be expected that the down flow as well as scouring effect reduces. Employing three types of abutment (vertical wall, wing wall and buried wing) with nine different flow depth-discharge in clear water condition the experiment were done. Results showed comparing with vertical wall abutment the buried wing abutment decreases the scouring depth by 19-31.2% and the wing wall abutment by 6-26% in similar condition. In spite of ease of implementation and lower cost the buried wing has a better performance related to wing wall in scouring control.

Key words: Abutment, spur dyke, scour, countermeasure, buried wing

INTRODUCTION

Bridge scour is a destroying phenomenon which makes huge damages every year. About 50 to 60 bridges fail are reported yearly in United States, with 60% of the failures being associated with the effects of flow hydraulics, including scour at the bridge abutment (Ballegooy, 2005). According to Melville (1992), 29 out of the 108 bridge failures in New Zealand between 1960 and 1984 were attributed to abutment scour. Large damage reported for roading expenditure in New Zealand due to abutment failure (Melville, 1992).

To protect bridge pier and abutments scour countermeasures were used. There are limited researches on the effectiveness of this method. Two major countermeasure techniques used to prevent local scour at bridge piers and abutments which can be classified as river bed armoring and river training structures. Armoring countermeasures for bridge abutments include riprap, cable-tied blocks, gabions, foundation extensions, geo-bags, grout-filled bags, etc. Difficulties encountered with armoring at abutments include movement of sands through the armor and an inability to keep the armor in place. In addition, armor can fill a portion of the waterway beneath the bridge that causes additional contraction scouring. River training structures include spur dikes, guide banks and bendway weirs. These methods basically perform to alter the flow alignment and transfer the scour potential away from the vicinity of bridge abutments (Johnson *et al.*, 2001; Ballegooy, 2005; Li *et al.*, 2006).

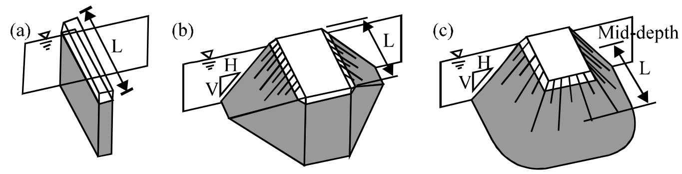

Fig. 1(a-c): Common abutment shapes (Melville and Coleman 2000). (a) Vertical-wall, (b) Wing-wall and (c) Spill-through

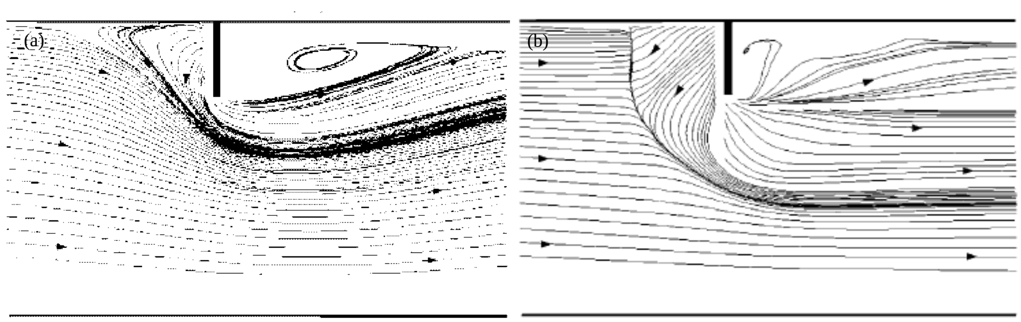

Fig. 2(a-b): Computed near-bed streamlines (Nagata *et al.*, 2005). (a) Initial scouring stage (at t = 1 min) and (b) Equilibrium scouring stage

90° spur dykes are similar to vertical wall abutment but usually they are longer, therefore more risk of scouring can be expected. Three common shapes of abutment are vertical wall, wing wall and spill through (Fig. 1a-c). The abutment can locate in all types of channels, in single channel (without Floodplain), in floodplain and in floodplain and in main channel (Melville, 1995; Ettema *et al.*, 2004).

Kwan and Melville (1994), Mayerle *et al.* (1995), Ouillon and Dartus (1997), Biglari and Sturm (1998), Barbhuiya and Dey, (2003), Nagata *et al.* (2005) and Zhang *et al.* (2009) are among researchers that studied flow around abutments and spur dykes. By computing near-bed streamlines at the initial scouring and equilibrium stages Nagata *et al.* (2005), mentioned "at the initial scouring stage, the streamlines are seen concentrated near the nose of the spur dike while at the equilibrium stage, the separation region extends laterally further beyond the spur dike following the growth of the vortex as the scour hole evolves" (Fig. 2a,b). They also investigated the relationship between the flow pattern and the bed scouring process. Figure 3 shows computed and measured velocity vectors in the longitudinal sections in upstream face of spur dyke. They found vertical flow immediately upstream from the spur dike is less pronounced at the initial scouring stage at t = 1 min. As the scour hole develops, strong downward flow along the upstream face of the spur dike and near-bed flow directed towards the upstream part of the scour hole become evident". Good agreements between the numerical results of Nagata *et al.* (2005) and the experimental results of Michiue and Hinokidani (1992) which obtained at the equilibrium stage shown in (Fig. 3b, c) can be seen. A growth in time of the vortical flow upstream from the spur dyke face had a significant influence on the near-bed flow patterns (Nagata *et al.*, 2005).

In the initial stage of the scouring the streamlines at upstream of vertical wall or spur dyke divert to the noise of them and they shape a wing at wing wall abutment. Dead zone of flow formed in upstream and downstream region of abutment (Fig. 2a). Therefore, putting wing at upstream

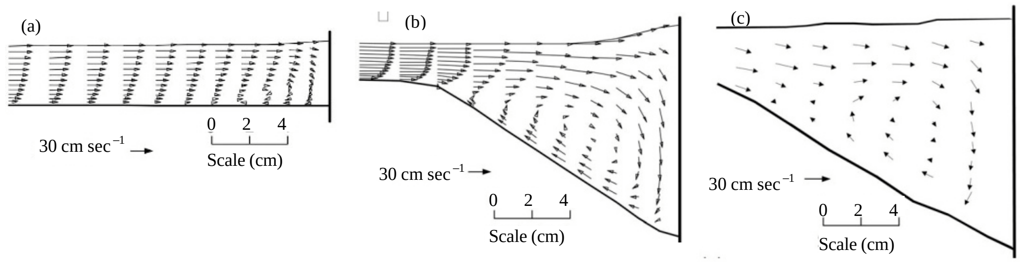

Fig. 3(a-c): Velocity vectors at longitudinal sections in upstream face of spur dyke (Nagata *et al.*, 2005). (a) Computed results at initial scouring stage (at t = 1 min), (b) Computed results at equilibrium stage and (c) Experimental results at equilibrium stage observed by Michiu and Hinokidani (1992)

dead zone of vertical wall did not seem very efficient. But the final scour of wing wall abutment was less than the one at vertical wall. Compare with previous researches for flow around abutment, experiment observation using sawdust in wet and dry case (dry sawdust for surface streamlines and wet sawdust for near-bed streamlines) and also how sediment moves one can conclude that wing only able to prevent development of hole toward upstream of vertical wall. Therefore, buried wing can prevent development of hole toward upstream of vertical wall.

Burid wing are similar to submerged vanes. Odgaard and Kennedy (1983) used submerged vanes for river bend bank protection. Odgaard and Mosconi (1987), Odgaard and Wang (1991a, b), Wang *et al.* (1996) and Barkdoll *et al.* (1999) also proposed use of submerged vanes for sediment management in stream bank, water intake and at lateral diversions. Johnson *et al.* (2001) employed of vanes in main channel for control of scour at vertical wall abutments in floodplain. Lie *et al.* (2006) used of parallel wall for control scour in abutment. Ghorbani and Kells (2008) studied effect of submerged vanes on the scour occurring at a cylindrical pier.

MATERIALS AND METHODS

Experiments were conducted in compound channel with a 1.5 m wide, 14 m long and 0.7 m deep with slope of 0.001. Flood plains' width were 58.5 cm and the main channel had trapezoidal cross section with the bottom width of 9 cm and 12 cm at the top part with depth of 9 cm (Fig. 4). The flume was located in the hydraulic laboratory of Soil Conservation and Watershed Management Research Institute (SCWMRI) of the Agricultural Research and Education Organization in Tehran-Iran.

Since, the abutment scouring was in the floodplain, the main channel was made up of steel to establish a fixed bed. In order to create a roughness approximately equal to the flood plains, the metal's surface was covered with a layer of stone mortar powder. Sediment with uniform aggregation and mean sediment grain size (d_{50}) of 0.84 mm was used between section A and B and d_{50} of 10 mm at the other parts of the flood plain. The abutment's length and width are 20.5 cm and 10 cm, respectively and was made up of waterproof wood. The model abutment was located 7 m downstream of the inlet tank in order to reach a fully developed flow at the abutment's upstream. Water was pumped from the main tank into a pool located in the upstream of the flume and passes through dissipaters before entering the flume. A schematic diagram of the flume is shown in (Fig. 4a-c). In order to adjust the depth of water, a tailgate which is located at downstream of the

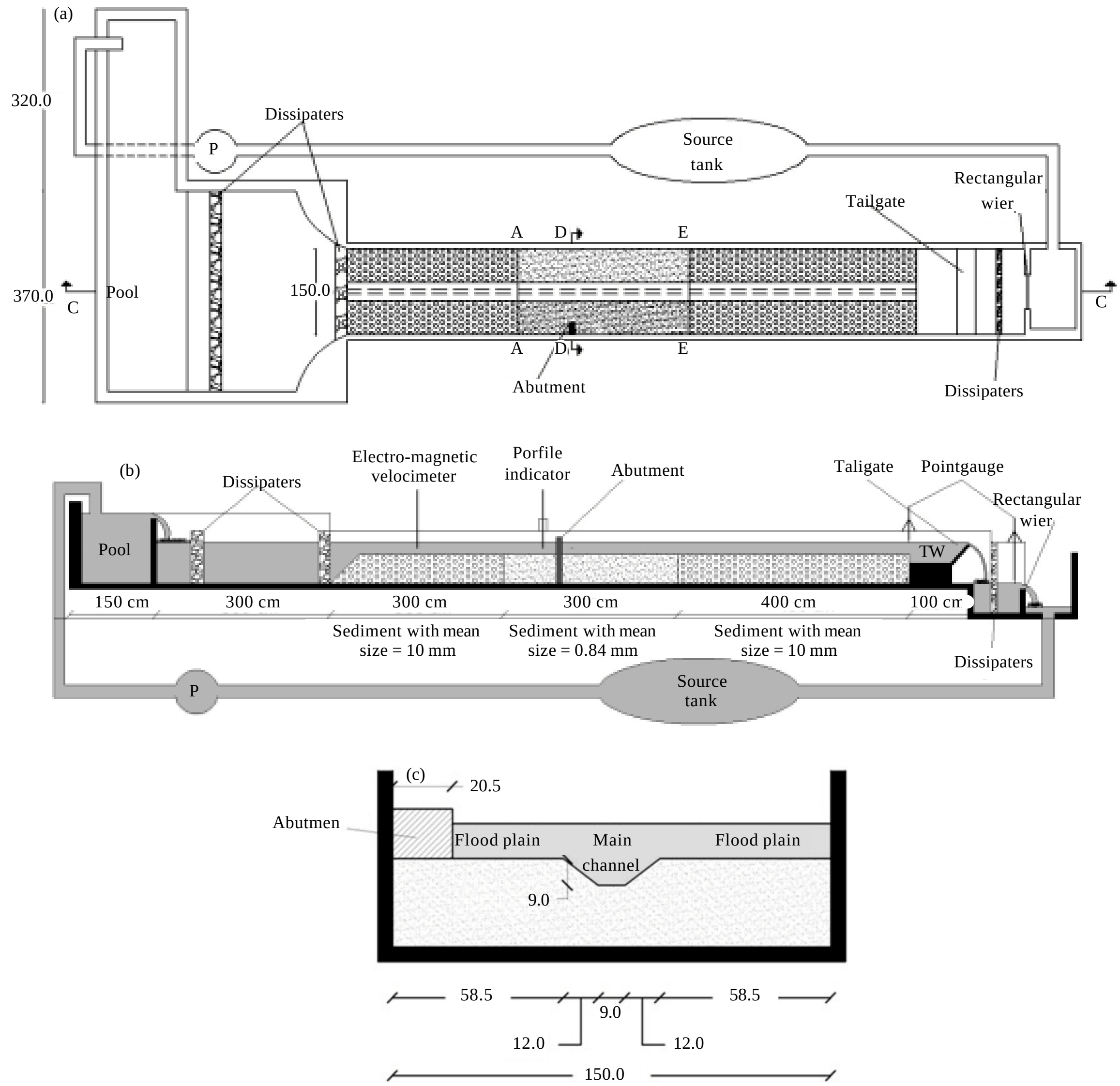

Fig. 4(a-c): Schematic diagram of the flume. (a) Plan of flame (X-Y), (b) Section C-C (X-Z) and (c) Section (D-D) (Y-Z)

flume was used. Discharge was measured with calibrated rectangular weir which accomplished to a point gauge with 0.1 mm accuracy located on the weir. Water depth and Changes bed formation around the abutment were measured by the Delft's profiler-indicator. To control water depth at tailwater (T_w) during the test, also a pointgauge with 0.1 mm accuracy was used. An electro-magnetic velocimeter was applied to measure flow velocity.

The buried wing is defined as a wing which its top level located at channel the bed level. The buried wing was placed on the nose of abutment with 45 degree angle. The vane which used in the buried wing abutment was made of galvanized sheet with 2 mm thickness.

This study is carried out in three different Experimental setup i.e., vertical wall abutment (VW), wing wall abutment (WW) and buried wing abutment (BW) (Fig. 5a-c). In each of these

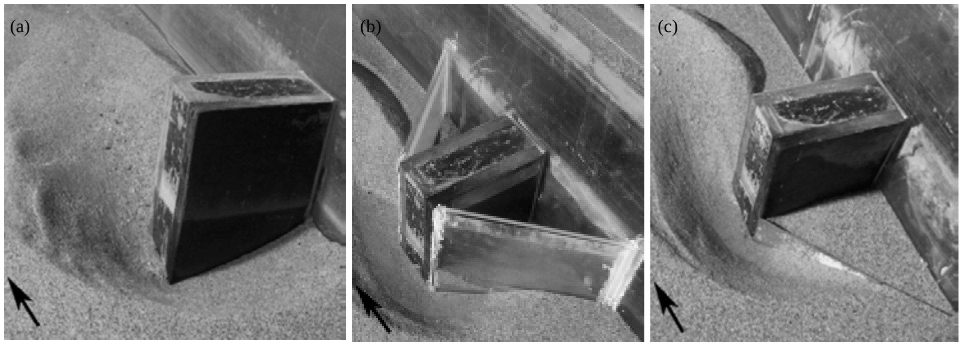

Fig. 5(a-c): Different experimental setup. (a) Vertical wall abutment (VW), (b) Wing wall abuntment (WW) and (c) Buried wall abutment (BW)

Table 1: Hydraulic condition

Test condition	Q (Lit sec^{-1})	y_F (cm)	y_m (cm)	U_F (m sec^{-1})	U_m (m sec^{-1})	Fr_F	Fr_m	U_{CF} (m sec^{-1})	U_{cm} (m sec^{-1})	U_F/U_{CF}	U_m/U_{cm}
1	23.5	4.0	13.0	0.27	0.43	0.43	0.38	0.28	0.34	0.96	1.27
2	30.0	6.5	15.5	0.24	0.36	0.30	0.29	0.30	0.35	0.80	1.03
3	30.0	7.0	16.0	0.23	0.33	0.28	0.26	0.31	0.35	0.76	0.95
4	30.0	7.5	16.5	0.22	0.30	0.25	0.24	0.31	0.35	0.70	0.87
5	33.3	7.5	16.5	0.23	0.34	0.27	0.27	0.31	0.35	0.75	0.98
6	36.9	7.5	16.5	0.28	0.39	0.32	0.30	0.31	0.35	0.90	1.11
7	44.3	10.0	19.0	0.27	0.33	0.27	0.24	0.32	0.36	0.82	0.93
8	44.3	11.0	20.0	0.25	0.28	0.24	0.20	0.33	0.36	0.76	0.79
9	44.3	12.0	21.0	0.23	0.26	0.21	0.18	0.33	0.36	0.69	0.72

where, Q: Flow discharge, y_f: Flow depth on floodplain, y_m: Flow depth on main channel, U_f: Mean velocity of flow on floodplain, U_m: Mean velocity of flow on main channel, Fr_f: Flow Froude number on the floodplain, Fr_m: Flow Froude number on main channel, U_{cf}: critical flow velocity at the threshold of sediment motion on floodplain, U_{cm}: Critical flow velocity at the threshold of sediment motion on main channel

cases nine different hydraulic conditions were applied that presented in Table 1. Using Shields diagram Critical shear velocity (U_{*c}) was obtained about 0.02 m sec^{-1} (Miller *et al*., 1977). By applying Eq. 1, one can find the critical velocity (U_c) for different hydraulic conditions which is presented in Table 1.

$$\frac{U_c}{U_{*c}} = 5.75\log\left(5.53\frac{y}{d_{50}}\right) \tag{1}$$

where, y is approaching flow depth and d_{50} is mean sediment grain size. Experiments were carried out in clear water condition. In Table 1 the amount of U/U_c for different hydraulic conditions in the flood plain and main channel were also computed. Tests were designed so that different conditions of Froude number and U/U_c in experiments to be covered. The aim of this research was investigation about BW and its comparison with VW and WW for similar condition.

RESULTS AND DISCUSSION

Scouring at the VW abutment was begun from the nose of the abutment. When the hole at the nose was created, sediment at upstream face moved to the hole and then to the downstream. This

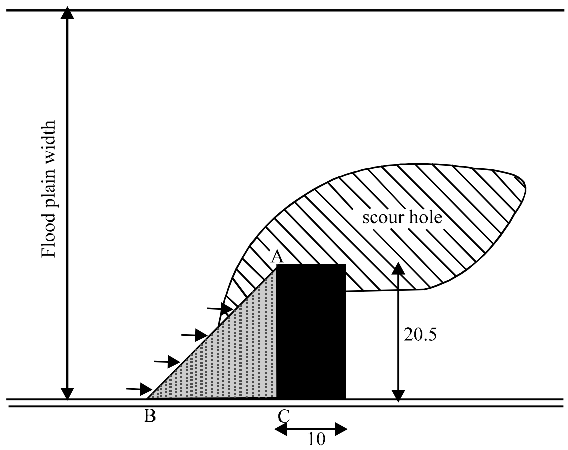

Fig. 6: Schematic diagram of buried wing abutment

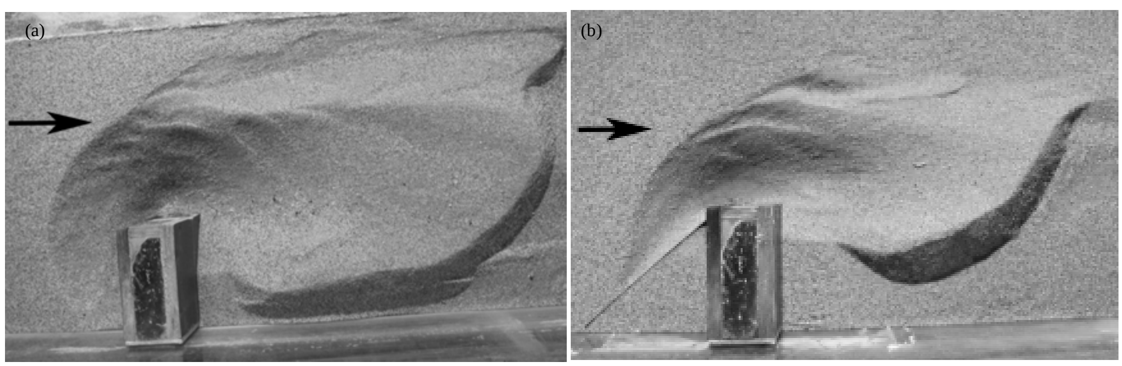

Fig. 7(a-b): Bed deformation after of test. (a) Vertical wall abutment. (Q = 44.3 Lit sec^{-1}, y = 10 cm) and (b) Buried wing abutment (Q = 44.3 Lit sec^{-1}, y = 10 cm)

phenomenon could cause development of the hole. At the initial scouring stage, the down flow had small velocity. As the hole developed to the upstream face of abutment, the velocity of down flow was increased this caused more scouring.

The BW was employed to prevent development of scour hole to region ABC (Fig. 6). Using BW at upstream face of abutment prevents sediment motion to the nose of abutment and sediments at ABC region would be fixed. Thus scouring hole would not develop to the upstream face of abutment. Therefore, down flow in upstream face of abutment could decrease, as a result principal vortex would be reduced. These could cause a reduction of scouring.

In WW the streamlines that shown in Fig. 6 after reaching the wing (line AB) change its direction toward scouring hole and enter into the hole. Then passing from the maximum depth of scour it increases the depth. But in BW as shown in Fig 6 and 7a and b the streamlines pass over the buried wing (line AB) and enter to region ABC. When they exit from ABC region due to difference in scour hole level with this region they would pass from the maximum depth and would not effect on depth increase.

The maximum scour depth measured by use of the profiler indicator during the experiments. Figure 8 shows the maximum scour depth (d_s) during time for all abutment shapes and hydraulic conditions mentioned. At the beginning development of the scour the rate of scour depth is high for both VW and BW but as soon as the buried wing appears the rate of scour depth decreases.

Also it was observed that the maximum scour depth occurred near the abutment nose during the experiment for both the VW and BW. As it is shown in Fig. 9a and b, for all tests, at WW maximum scour depth initially occurs in point S. Then, for different hydraulic conditions WW the maximum scour depth can moves towards the abutment nose. In test 3 and 4 of WW the maximum scour depth were not transferred to the abutment nose. Using Table 1, it can be found that in discharge of 30 Lit sec^{-1} and depth 7 cm and 7.5 cm the maximum scour depth would not move. It was also found that at the end of the experiment in these cases the maximum scour depth was lower than other cases.

Maximum scour depth was known as an indicator to report the amount of scouring. In order to compare scouring control methods this parameter was also examined. In this research another parameter introduce to report the amount of scouring i.e. the appeared abutment area (AAA). Since, the instability of the abutment occurs when the sediment moves from it and the sediments would be removed. The stability of the abutment cannot be reported only by one specific point as the maximum scour depth. In Table 2 for all test maximum scour depth, AAA, percents reduction

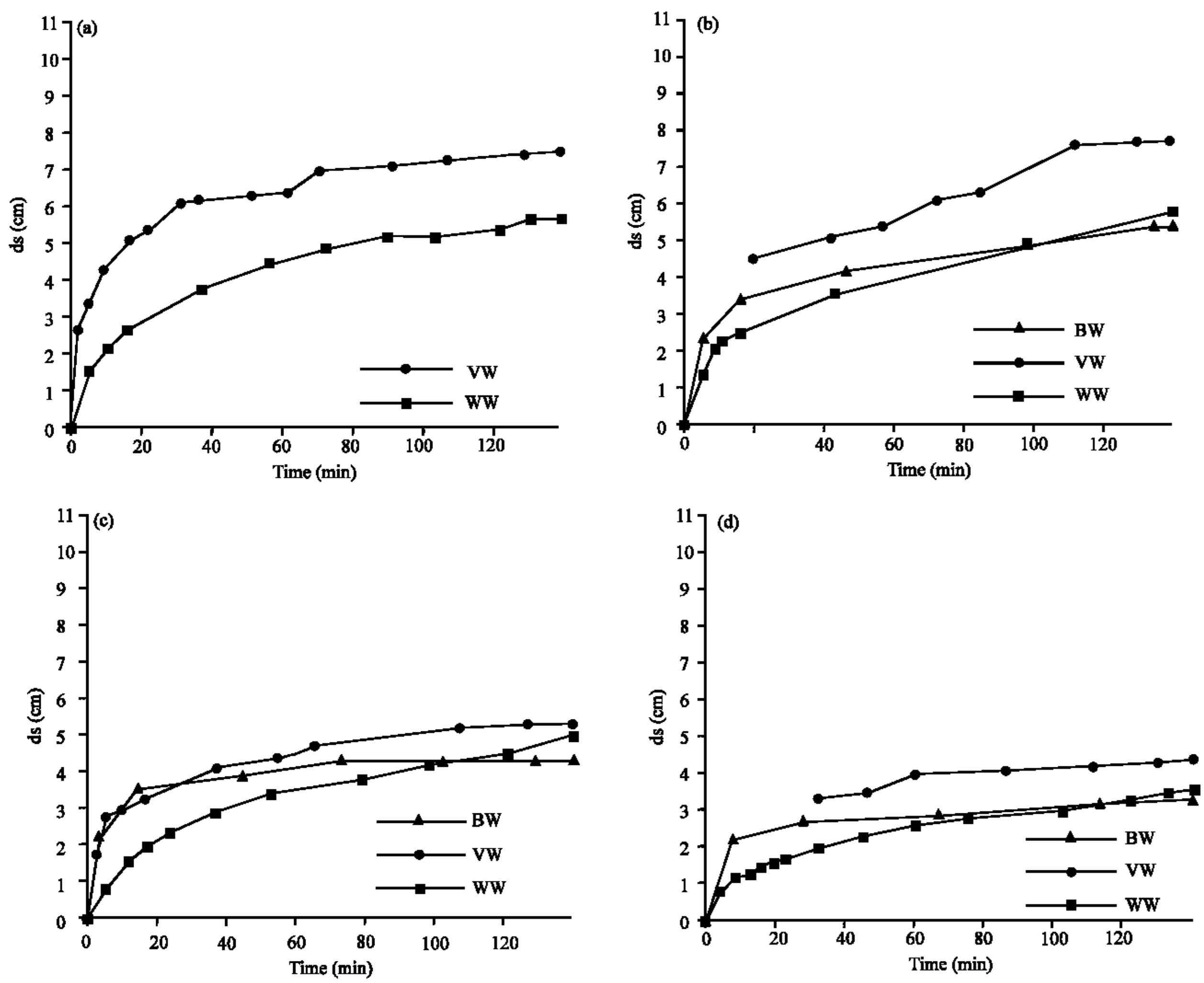

Fig. 8(a-i): Continued

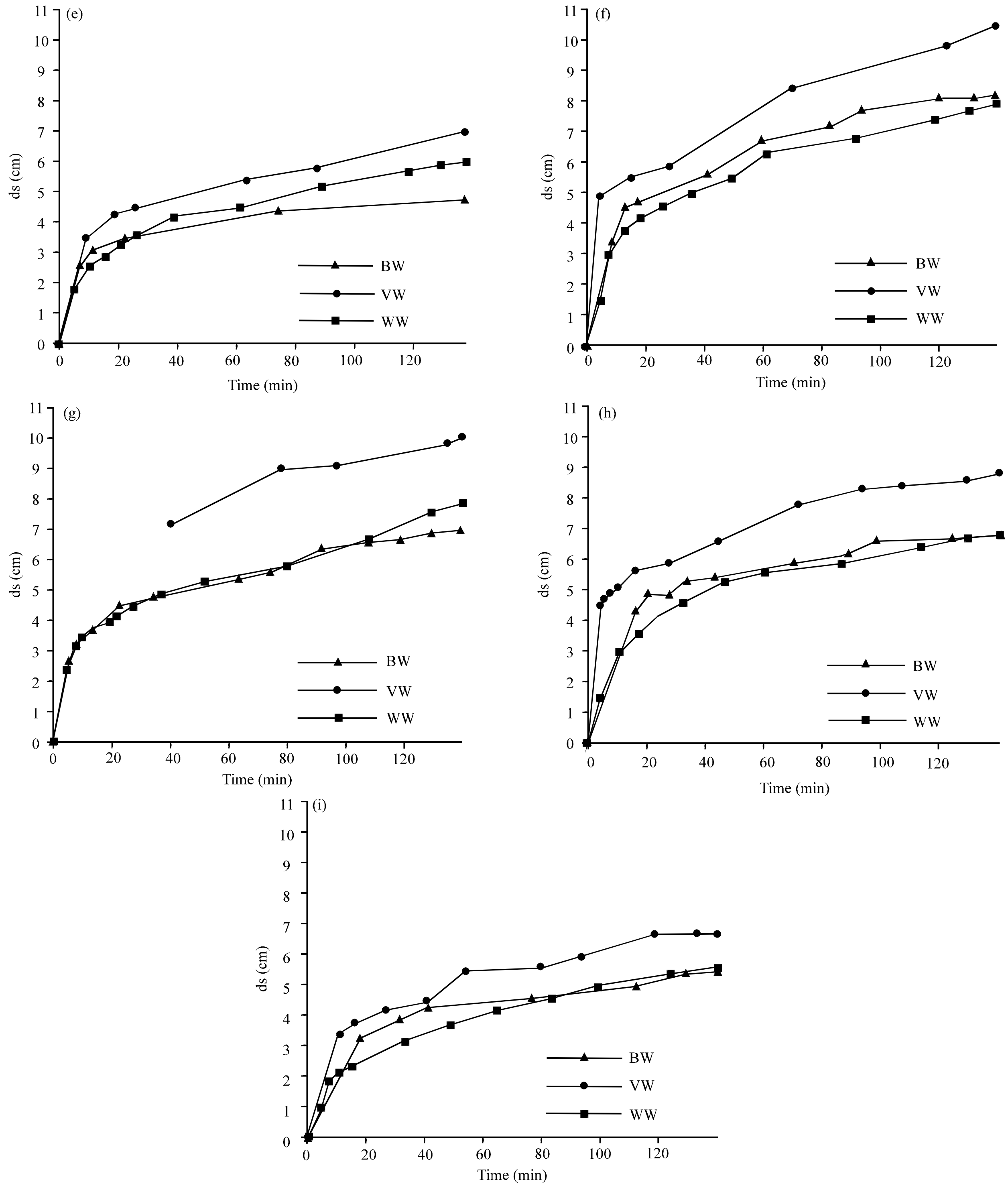

Fig. 8(a-i): Time development of scouring

in AAA and d_s for WW and BW compare to VW were reported (R%). In tests 3 and 4 of WW the maximum scour depth was not occurred at the abutment nose, therefore smaller area of the abutment would appear. Figure 10 shows percent reduction in AAA for WW and BW compare to VW.

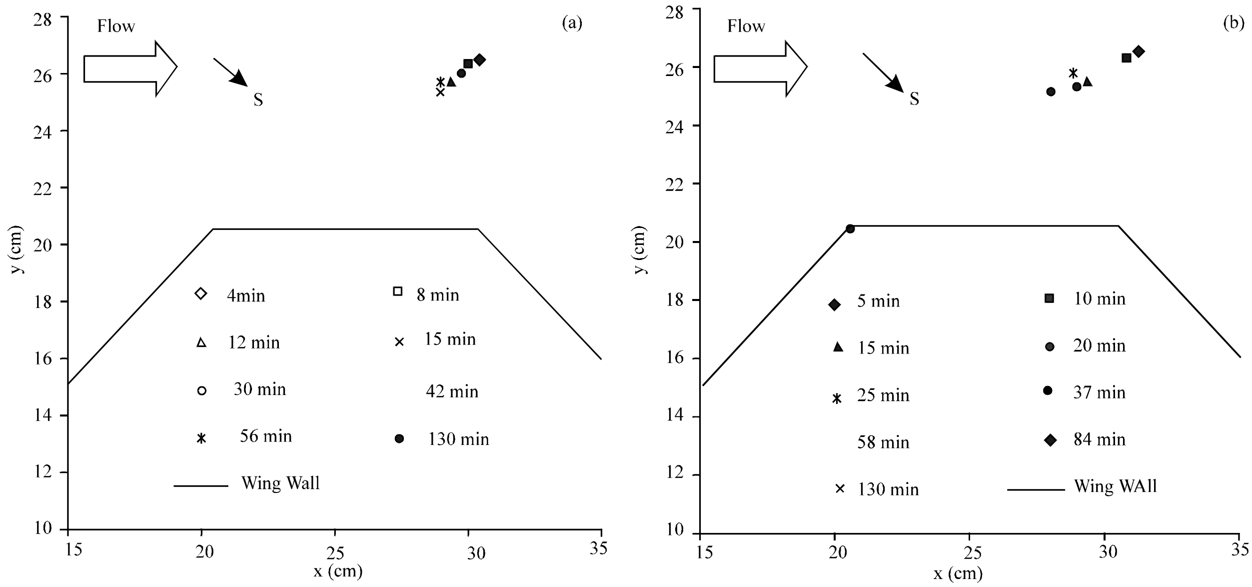

Fig. 9(a-b): Location of the points of maximum scour depth (a) Q = 30 Lit sec^{-1}, y = 7.5 cm and (b): Q = 33.3 Lit sec^{-1}, y = 7.5 cm

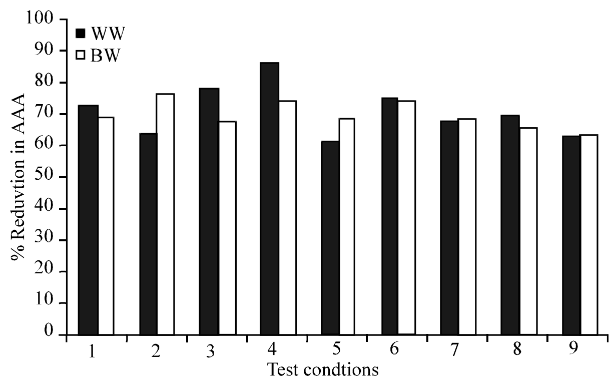

Fig. 10: Reduction in Appeared Area Abutment (AAA)

Table 2: Reported maximum scour depth and AAA

Test condition	ds (VW) (cm)	ds (BW) (cm)	ds (WW) (cm)	AAA (VW) (cm^2)	AAA (BW) (cm2)	AAA (WW) (cm2)	R% AAA (BW)	R% AAA (WW)	R% ds (BW)	R% ds (WW)
1	7.7	5.8	5.7	142.20	44.21	39.30	69	72	24.7	26.0
2	7.7	5.3	5.8	134.36	31.60	48.68	76	64	31.2	24.7
3	5.3	4.3	5.0	77.50	24.98	16.90	68	78	18.9	5.7
4	4.3	3.3	3.6	42.90	11.10	5.95	74	86	23.3	16.3
5	7.0	4.8	6.0	109.75	34.33	42.45	69	61	31.4	14.3
6	10.5	8.2	7.9	237.85	61.40	58.70	74	75	21.9	24.8
7	10.0	7.0	7.9	194.02	60.79	62.90	69	68	30.0	21.0
8	8.8	6.8	6.8	171.78	58.03	52.30	66	70	22.7	22.7
9	6.8	5.5	5.6	106.68	39.59	39.80	63	63	19.1	17.6

Figure 11a-i show the scour hole in cross section at the maximum scour depth location. It can be seen that the scour hole at the VW is much larger than the WW and BW, thus the VW abutment area appeared increases. Comparing with VW employing WW and BW can decrease AAA about 70%.

By comparing cross sections, it is obvious that BW's scour hole is equal to or less than the WW's scour hole. Thus, BW can be used instead of WW.

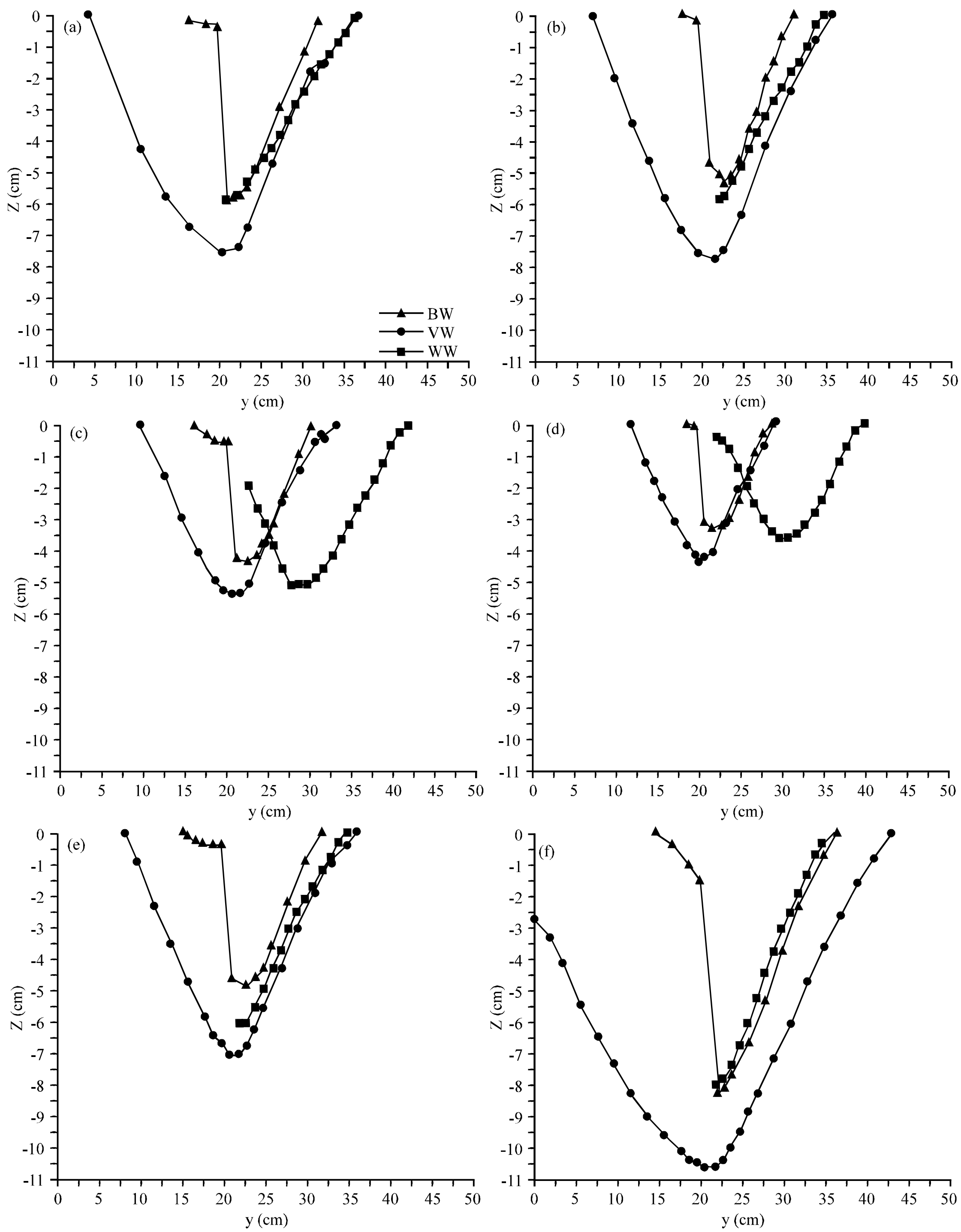

Fig. 11(a-i): Continued

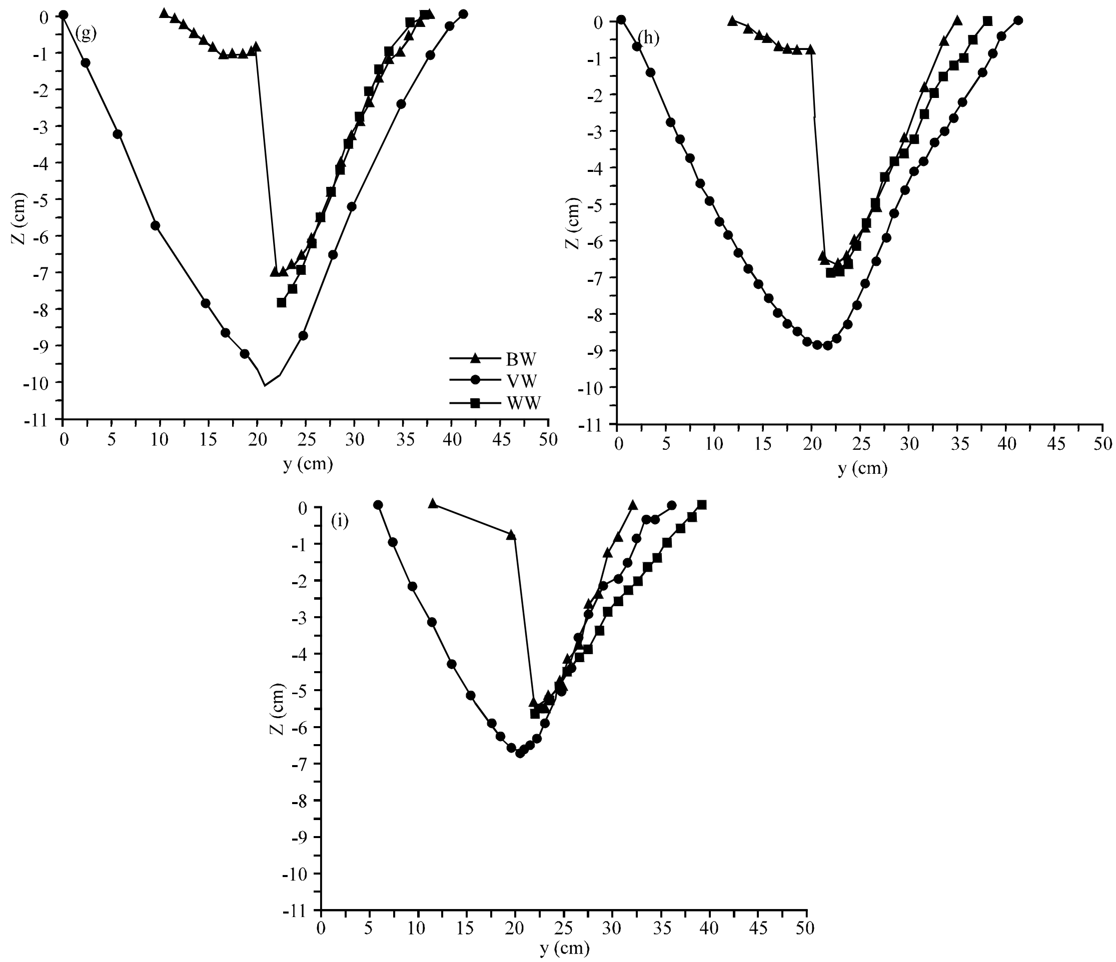

Fig. 11(a-i): Scour hole in cross-section at the maximum scour depth location

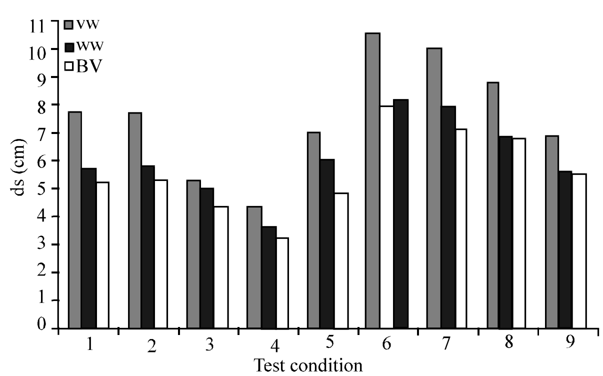

Fig. 12: Maximum scour depth (ds) after the experiment

Comparing with VW the BW decreases the scouring depth by 19 to 31.2% and the WW by 6-26%. In spite of ease of implementation and lower cost the BW has a better performance related to WW in scouring control. In general the scour depth has the maximum amount at the VW and minimum at the BW (Fig. 12). They have also the capability of implication for built VW and spur dyke.

CONCLUSIONS

In this research a new and convenient method (BW) for countermeasure scour of VW and spur dyke was introduced. Comparing with VW the BW decreases scouring depth by 19-31.2% and the WW by 6-26%. In this research parameter introduce to report the amount of scouring i.e., the Appeared Abutment Area (AAA). Comparing with VW using BW and WW can decrease AAA about 70%. In general the scour depth has the maximum amount at the VW and minimum at the BW. Therefore, BW has a better performance related to WW in scouring control.

NOTATION

The following symbols are used in this study:

AAA	=	Appeared area abutment
BW	=	Buried wing abutment
d_s	=	Maximum scour depth
d_{50}	=	Mean size of sediments (size for which 50% ofthe sediments are smaller by weight)
Fr_f	=	Flow Froude number on the floodplain
Fr_m	=	Flow Froude number on main channel
Q	=	Flow discharge
R	=	Reduction percent
t	=	Time of experiments
T_w	=	Tail water
U	=	Mean velocity of flow
U_{*c}	=	Critical shear velocity
U_c	=	Critical flow velocity at the threshold of sediment motion
U_{cf}	=	Critical flow velocity at the threshold of sediment motion on floodplain
U_{cm}	=	Critical flow velocity at the threshold of sediment motion on main channel
U_f	=	Mean velocity of flow on floodplain
U_m	=	Mean velocity of flow on the main channel
VW	=	Vertical wall abutment
WW	=	wing wall abutment
y	=	Flow depth
y_f	=	Flow depth on floodplain
y_m	=	Flow depth on main channel

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