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Scour Depth at River Confluence of Unequal Bed Level

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Abstract: The flow and sediment patterns at river junctions have been studied by many researchers. Most of the studies have conducted in river junctions of equal bed level. For the case of unequal river bed level only few studies can be found in the literature and a relation for prediction of scour depth has not been developed yet. Therefore it is the main purpose of this study to conduct experimental tests to investigate the effect of river bed discordance on scour depth. The study conducted under different flow discharge, variable river bed level and different lateral channel width. Analyses of data have shown that for discharge ratio larger than 0.74, as the river bed discordance increases, the scour depth increases too and vice versa for the discharge ratio less than 0.74. In this study an equation has been developed to predict the scour depth.

Key words: River confluence, bed discordance, scour hole, sediment, junctions

INTRODUCTION

The location where two rivers combined is defined as river confluence. Due to three dimensional flow structure at this location, especially due to the downstream mixing of flow, a deep scour hole is developed which can damage the river banks and structures nearby. Therefore, this phenomenon has attracted the attention of many researchers over the past three decades. The most important and notable studies are Ashmore and Parker (1983), Best (1988), Biron *et al.* (1993, 1996, 2002), Mosley (1976), Boyer *et al.* (2006) and Ghobadian and Shafai Bejestan (2007). Most of these studies emphasis on river confluences of the same bed level. Biron *et al.* (1993) have conducted some field measurement in a 60° river confluence of unequal bed level. They concluded that no scour depth has been observed and that the river morphology is different than for the case of the same level bed. Boyer *et al.* (2006) also measured field data in a 65° river confluence of unequal bed level. They concluded that river bed discordance can change the bed shear stress distribution.

The experimental data of Biron *et al.* (1996) have shown that the flow patterns for unequal bed level is different than for the case of equal river bed level. They found that for the case of equal bed level, the flow velocity vector is parallel to the bed while for the case of unequal bed level the direction of flow velocity vectors are toward the water surface. Ghobadian and Shafai Bejestan (2007) conducted extensive experimental studies on river bed confluence. Most of their tests conducted on equal bed level. The results found from their study were that as the downstream densimetric Froude number, the discharge ratio and the angle of river confluence increases, the scour depth increases. On the others hand, as the river width ratio increases or the sediment sizes increases, the scour depth is reduced. Based on a few tests they found that river bed discordance can have significant effect on the scour depth. They developed relation for predicting scour depth at river junction of equal bed level. The literature review reveals that the scour depth at river junction of unequal bed level has not been studied in the past, therefore it is the main purpose of this study to conduct experimental tests and to determine the effects of river bed discordance, discharge ratio and width ratio on the scour depth at river confluence.

DIMENSIONAL ANALYSIS

Before conducting experimental test, a general relationship has to be developed. This was done by dimensional analysis. In the case of scour hole at river confluence it can be shown that the scour depth (H_s), depends on the flow discharge in the main and in the lateral channels Q_1 and Q_2, respectively), the width of main and lateral channel (B_1 and B_2, respectively), the angle of river confluence (θ), the bed slope (S_o), the flow velocity and flow depth downstream of confluence (V_3 and D_3, respectively), the river width downstream of confluence (B_3), the bed material size (d_{50}) and the river bed discordance (Z). or one may write:

$$H_s = f(Q_1, Q_2, Q_3, B_1, B_2, B_3, \theta, S_0, V_3, d_{50}, Z, \rho, g, \mu) \quad (1)$$

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In which ρ and μ are the flow density and viscosity, respectively and g is the acceleration of gravity. Equation 1 can be written in the following non dimensional from using the Buckingham theory:

$$H_s/d_{50} = f\,(Q_2/Q_1, B_2/B_1, \theta, S_0, F_{g3}, R_{e3}, W_{e3}, Z/B_3) \qquad (2)$$

The study of Gurram *et al.* (1997) have shown that for subcritical flow river bed slope has no effects on flow pattern in river confluence. In present study, the confluence angle was kept constant equal to 60° and flow conditions were such that the Reynolds number (R_{e3}) and Weber number (W_{e3}) have no affect on flow characteristics. In this study the tests were conducted under constant sediment size an the flow velocity an depth at the downstream of the junction were such that the value of densimetric Froude number (F_{g3}) was constant in all the tests. Therefore the general non dimensional relation for this study is:

$$H_S/d_{50} = f\,(Q_2/Q_1, B_2/B_1, Z/B_3) \qquad (3)$$

MATERIALS AND METHODS

To reach the goals of this study, experimental tests were conducted during summer in the Hydraulic Laboratory of Shahid Chamran University. The experimental set-up consist of a main flume (9 m length, 35 cm width and 50 cm height), a lateral flume (3 m length, 35 cm width and 50 cm height). Few tests are conducted for lateral flume width equal to 25 cm. At the upstream end of each flume a stilling box has been installing to reduce the kinetic energy of the incoming flow. Flow Discharge in the main pipe measured by an electronic flow meter with accuracy of ±0.01 L sec^{-1}. Flow discharge in the main flume was measured by a V-notch weir installed at the upstream of the flume. The flow discharge in the lateral flume was calculated by subtracting the flow discharge of the main pipe and the main flume. Two valves installed in two entrance pipes to control the flow discharge. A slide gate at the downstream of confluence controls the water surface in the main flume. The lateral flume is connected with angle of 60° to the main flume. Figure 1 shows the plan view of the experimental set-up.

Experimental procedure: A piece of plexi glass was placed at the end of lateral channel then sediment was placed on the bed of lateral flume up to the top level of the plexi glass. The same sediment also was placed on the bed of the main flume. The final bed surface of lateral flume was higher by the amount of (Z) than the main flume bed surface. Three different values of (Z/B_3) were tested in this study. After fixing the bed, the pump was started and flow was allowed to enter the main flume very slowly. During the filling of the flume, the slide gate was kept closed. When the flow depth in both flumes were high enough to assure that sediment will not move, the flow discharge gradually was increased in both flumes till reaches the desired flow discharge. At the same time the slide gate was opened gradually to reduce the tail water

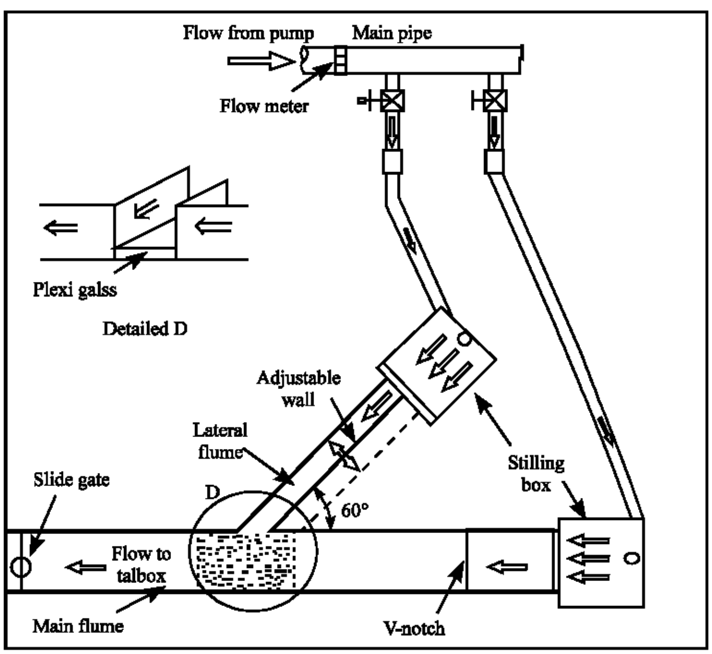

Fig. 1: Plan view of the experimental set-up

Table 1: Range of variables used in this study

Parameters	Range of variables
B_r Br	0.714, 1.0
d_{50}	1.95 mm
Z/B_3	0.057, 0.114, 0.171
Q_r	1.25, 1.0, 0.74, 0.50, 0.25

depth until it reaches to the desired flow depth. This situation was kept constant for almost one hour. Ghobadian and Shafai Bejestan (2007) kept the duration of test much longer but they found that 98% of scour depth occur at first hour of the test. After this time, the pump was shut down and both flumes were drained then the bed topography was measured by point gage with accuracy of ±0.1 mm. In this study total of 30 tests were conducted. The range of variables are shown in Table 1.

RESULTS AND DISCUSSION

Effect of discharge ratio (Q_r) on relative scour depth (H_s/d_{50}): As it can be shown from Eq. 3, the discharge ratio in which here is defined as the ration of lateral discharge (Q_2) to the main flume discharge (Q_1) has a significant effect on the scour depth. To see how varies the scour depth with the value of Q_r, Fig. 2 and 3 were plotted. Figure 2 shows the variation of H_s/d_{50} versus Q_r for width ratio of 0.714 and Fig. 3 for width ratio equal to one. As it can be shown from Fig. 2, 3, as Q_r increases the scour depth increases. The results indicate that the ratio of river bed discordance to width of main channel in the downstream of junction (Z/B_3) has not shown significant difference in scour depth when the value of Q_r is less than about one. However, when the discharge ratio is larger than one, the scour depth for unequal bed level is larger than for equal bed level. The rate of increase of scour depth is not the same for three different bed discordances. As it can be seen the scour depth is much higher when the ratio of river bed discordance to the width of main channel in the downstream of junction (Z/B_3) is equal to 0.171. This is because as Q_r increases the separation zone dimensions in the main channel increases. This will increase the magnitude of maximum velocity and bed shear stress causing deep scour hole. The same conclusion has been stated by other investigators such as Ghobadian and Shafai Bejestan (2007).

Effect of width ratio (B_r) on relative scour depth (H_s/d_{50}): Another important parameter which previous studies have shown that can affect the scour depth significantly is the ratio of lateral flume to the main flume width (B_r). To see this effect Fig. 4 and 5 have been plotted from the experimental test data. Figure 4 shows variation of Hs/d_{50} versus B_r for (Z/B_3) equal 0.057.

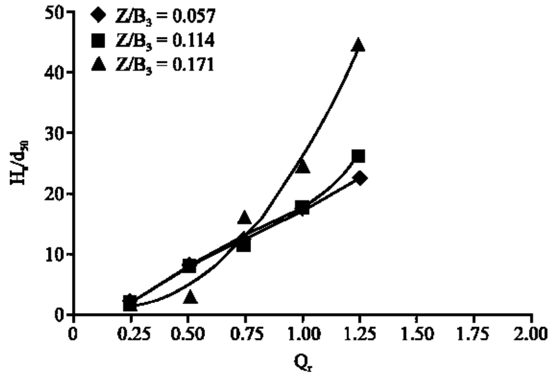

Fig. 2: Variation of relative scour depth versus discharge ratio for different bed discordance (B_r = 0.714)

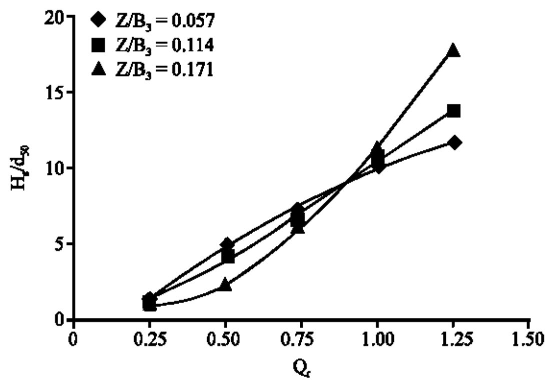

Fig. 3: Variation of relative scour depth versus discharge ratio for different bed discordance (B_r = 1)

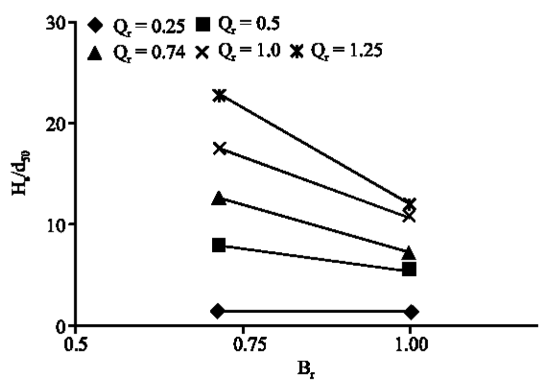

Fig. 4: Variation of relative scour depth versus width ratio for different discharge ratio (Z/B_3 = 0.057)

Figure 5 and 6 show the same variation for (Z/B_3) equal 0.114 and 0.171, respectively. From these figures it can be seen that as B_r increases, the scour depth decreases. This is because for a constant discharge ratio, as the value of width ratio increases the flow velocity in the lateral flume decreases and thus the separation zone

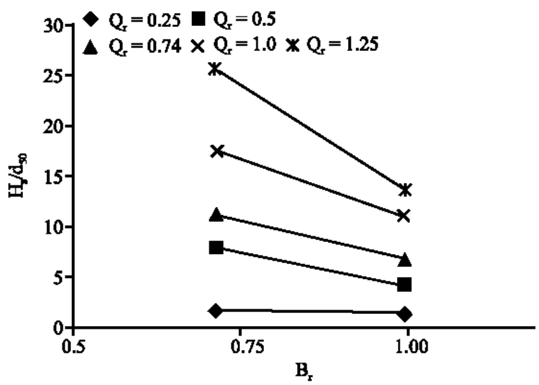

Fig. 5: Variation of relative scour depth versus width ratio for different discharge ratio (Z/B_3 = 0.114)

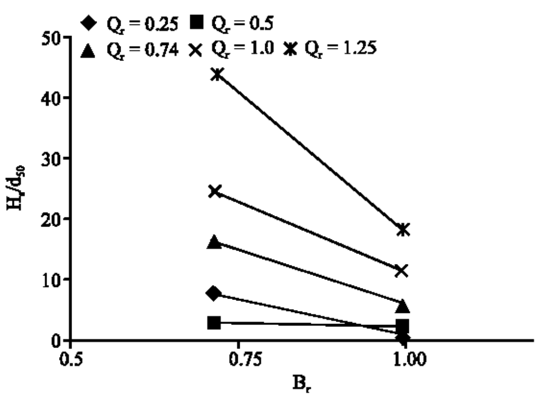

Fig. 6: Variation of relative scour depth versus width ratio for different discharge ratio (Z/B_3 = 0.171)

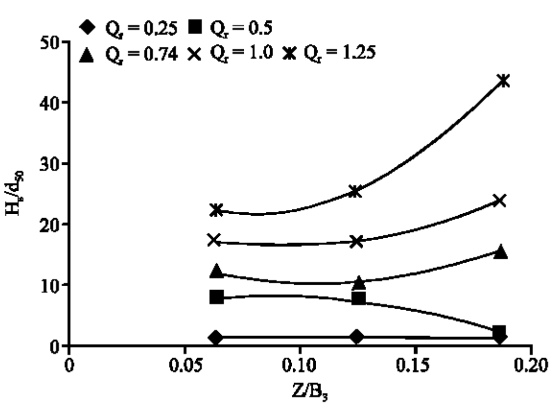

Fig. 7: Variation of relative scour depth versus relative bed discordance or different discharge ratio (B_r = 0.714)

in the junction decreases which eventually causes to decrease the scour depth. For small flow discharge ratio (Q_r less than 0.74) B_r has no significant effect on scour depth.

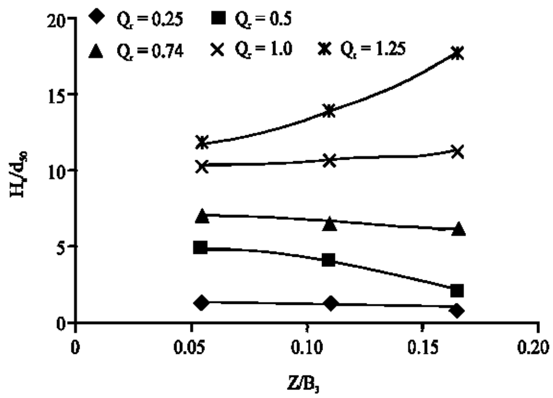

Fig. 8: Variation of relative scour depth versus relative bed discordance or different discharge ratio (B_r = 1)

Effect of (Z/B_3) on relative scour depth (H_s/d_{50}): To see how the scour depth varies with variation of (Z/B_3), Fig. 7 and 8 were plotted which show variation of relative scour depth versus (Z/B_3) ratio for width ratio of 0.714 and 1.0, respectively. Figure 7 shows that when the discharge ratio is less than 0.5, the bed discordance has no significant effect on scour depth. When the discharge ratio is greater than 0.5, as the (Z/B_3) increases the scour depth increases too. Figure 8 show the same trend when the width ratio is 0.74.

SCOUR DEPTH PREDICTION

To develop a relation for predicting the scour depth, the experimental data were applied. By analyzing these data by SPSS-14 and MINITAB-14 software, the following equation is developed:

$$H_s/d_{50} = 25.75*(Z/B_3)^{0.52}*B_r^{-2.416}*Q_r^{2.11}+1.73 \quad (4)$$
$$R^2 = 93.65\% \quad F_{r3} = 0.39$$

To investigate the accuracy of Eq. 4, observed values of scour depth have drawn versus the predicted values obtained from Eq. 4 and the results are showed in Fig. 9. As it can be shown, all data are between the 95% confidence band which is proven that Eq. 4 can be applied for prediction of scour depth at river confluence of unequal bed level

To compare the results of this study with the study of Ghobadian and Shafai Bejestan (2007), Fig. 10 was plotted. Figure 10 shows variation of H_s/d_{50} versus discharge ratio (Q_r). The line is the results of Ghobadian and Shafai Bejestan (2007) for equal bed level. The results show that for low discharge ratio, the scour depth is decreasing as (Z/B_3) increases. However when the bed discordance is high and the ratio of discharge in the lateral flume to the

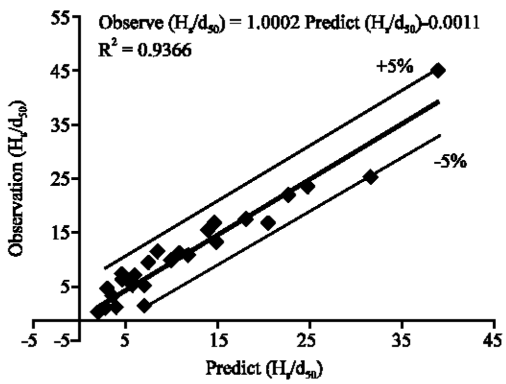

Fig. 9: Observed value of scouring versus predicted values by Eq. 4

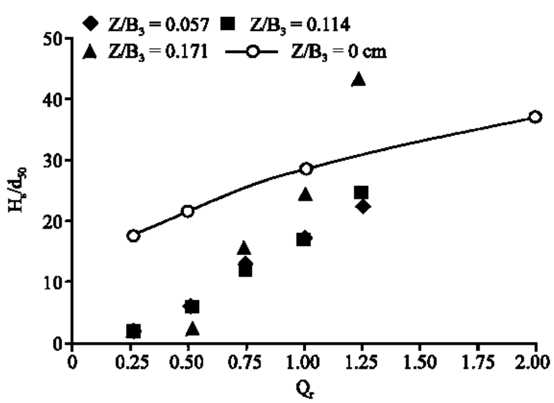

Fig. 10: Compare the results of this study (bed discordance) with concordance depth

discharge in the main flume is greater than 1.25, the scour depth at bed discordance junction is higher than at equal river bed junction.

CONCLUSION

In this study, experimental tests were conducted to investigate the effect of river bed difference at river junction on the magnetite of scour depth. The analysis of the experimental data has proven that generally bed discordance can reduce the scour depth compare with the case of unequal river bed level junctions. However, when the bed discordance is high and the ratio of discharge in the lateral flume to the discharge in the main flume is greater than 1.0, the scour depth at bed discordance junction is higher. An equation is presented to predict the scour depth of unequal bed level of river bed junctions.

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