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Downstream scour of combined flow over weirs and below gates

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ABSTRACT: Some of the weir's disadvantages can be solved if they combined with sluice gates. One disadvantage of the sluice gates is they retained the floating materials which can be solved if they combined with the weirs. Such a flow, which often appears in form of jets, may have considerable hydraulic potential to scour on the downstream side of the structure; a scour hole is formed. Since the scour hole develops rather rapidly, the researchers take interest in the equilibrium scour depth, h_s, and the length of scour hole, L_s. In this study, the scour characteristics of scour hole downstream of combined free over weir and below gate was investigated experimentally. For comparison of results, the maximum depth of scour in weir only and sluice gate only was also investigated. The results show by decreasing the y/a and w/a (y is the gate opening, w is the head over weir and a is the vertical distance between the gate top and the weir bottom), the ratio of h_s/y_0 (h_s is the maximum depth of scour and y_0 is the upstream water depth), increases. The comparison of results shows that the main part of scour in combined flow is due to flow over weirs.

Keywords: Scouring, Combined flow over Weirs and below Gates, Clear Water, and Dimensional analysis

1 INTRODUCTION

Weirs and gates are the common and important structures which are used in controlling and adjusting the flow in irrigation channel. Weirs widely used for flow measurements. One of the weirs demerits is they need to be cleaned of sediment and trash periodically. Sluice gates are used extensively for flow control and water measurement for long time. One disadvantage of the sluice gates is they retained the floating materials. In order to maximize their advantages, weirs and gates can be combined together in one device, so that water could pass over the weir and below the gate simultaneously. Figure 1 shows this structure, this compound device create a new hydraulically condition in compression with weir or gate, each other alone.

The combined weir and gate systems can be used in minimizing sedimentations and depositions. Several works can be found in combined overflow and underflow that the first idea of simultaneous flow over the weir and under the gate was introduced by Majcherek (1984).

Negm (1995, 1996) analyzed the characteristics of the combined flow over contracted weirs and below contracted gates of rectangular shape with unequal contractions. Alhamid (1999) studied combined flow over V-notch weir and below contracted rectangular gate. This study covered both free and submerged gate flow conditions, under different weir-gate dimensions. Based on dimensional analysis and using non-linear regression analysis, discharge equation was developed for both free and submerged gate flows. Ferro (2000) reported the results of an investigation carried out to establish the stage-discharge relationship for a flow simultaneously discharging over and under a sluice or a broad-crested gate. Negm et al. (2002) conducted some experiments to study the characteristics of the combined flow over the sharp-edged rectangular weir and below the sharp-edged rectangular gate with contractions. He introduced a general dimensionless relationship for predicting the discharge of the combined flow. Samani and Mazaheri (2007) presented a new physically-based approach for estimating the stage discharge relationship of combined flow over the weir and under the gate for semi submerged and fully-submerged conditions.

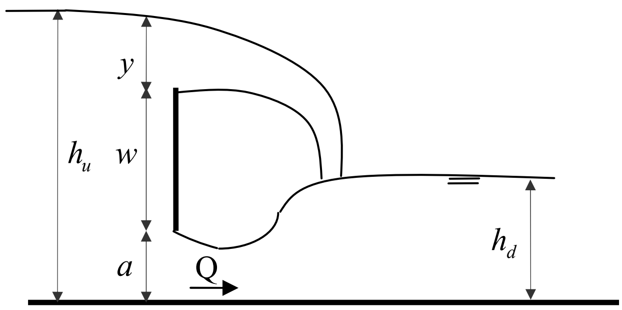

Figure 1 Definition sketch for combined free flow over weirs and under gates.

Determination of shape and maximum depth of scouring in downstream of combined weir and gate could be very useful to select the best controlling structure in aspect of bed stability.

Most of the previous study focus on discharge coefficient of combined flow over the weir and under the gate and only a few information available on local scouring downstream of this structures. Uyumaz (1998) by conducting the experiments concluded that in the case of discharge over the gate, the depth of scour is greater than in the case of discharge under the gate.

In this study the maximum scour depth downstream of weirs, sluice gates and combined structures of them for submerged condition were studied experimentally. This study is focused on determination of main source of scouring downstream of combined structures.

2 MATERIALS AND METHODS

2.1 Dimensional *Analysis*

Figure 2 shows the parameters affecting the local scour downstream of combined weir and gate. The maximum depth of scour depth h_s, depends on:

(1) Parameters related to geometry of channel: width of channel (B).

(2) Parameters related to geometry of structure: vertical distance between the gate top and the weir bottom (w), gate opening (a) and head over the weir (y).

(3) Parameters related to bed sediment: median size (d_{50}), sediment density (ρ_s) and bed slop (S_0).

(4) Parameters related to fluid properties: density (ρ_w); dynamic viscosity (μ); gravitational acceleration (g).

(5) Parameters related to approaching flow condition: flow depth (h_u), flow discharge (Q) and mean flow velocity (U).

Thus the process may be expressed by the functional relationship:

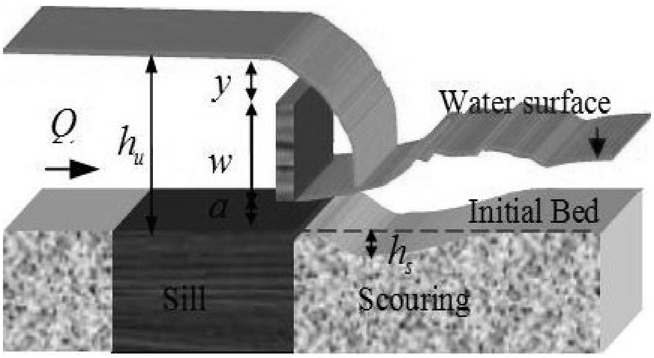

Figure 2 Definition sketch for scour downstream of combined weir and gate.

$$h_s = f(Q, U, w, a, h_u, y, B, S_0, d_{50}, \rho_w, \rho_s, \mu, g) \tag{1}$$

$$\frac{h_s}{h_u} = \xi\left(\frac{w}{y}, \frac{a}{y}, Fr\right) \tag{2}$$

In the case of weir structures (a=0), the following relation can be obtained by the same procedures:

$$\frac{h_s}{h_u} = \xi\left(\frac{w}{y}, Fr\right) \tag{3}$$

Figure 3 shows the effective parameters on scouring downstream of sluice gates. The following dimensionless parameters can be found by using Buckingham π-theorem:

$$\frac{h_s}{h_u} = \xi\left(\frac{a}{h_u}, Fr\right) \tag{4}$$

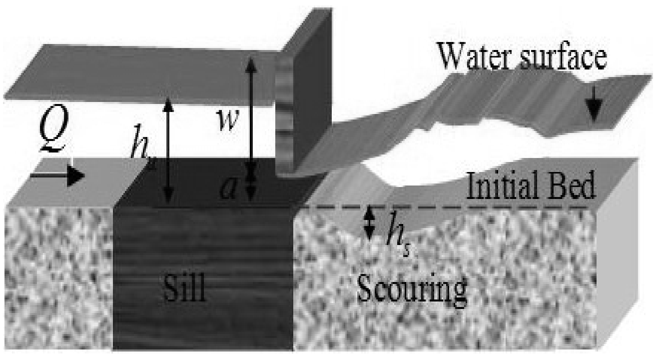

Figure 3 Definition sketch for scour downstream of gate.

2.2 *Experiments Setup*

The experiments were conducted in a straight rectangular channel at the hydraulic laboratory of Gorgan University in Iran. The channel was 3.7 m long, 0.12 m wide and 0.17 m deep with bed slope, S_0, of 0.0001.

The bed material consists of uniform sediment by median size of 1.5 mm and σ=1.3. The 8 cm layer of uniform sand was placed on the bed along the channel. The combined weir and gate was installed at a section 1.4 m from the inlet. The sand bed surface was properly leveled by a plate attached to the instrument carriage. The flume was first filled slowly with water until the pump started to reach a desired flow rate and then the tailgate was adjusted to reach a suitable flow depth. Each experiment was continued to reach an equilibrium condition. In order to find out the time required to achieve equilibrium state, i.e. When the maximum scour depth is approximately time invariant, the primarily experiments were performed for 360 minutes. Figure 6 shows the variation of maximum scour depth against time. As seen in Figure 6, almost 90 percent of maximum scour depth was achieved beyond the 120 minutes.

During each run of experiment, the maximum depth of scour was measured at given time intervals. At the end of each experiment, the water was drained slowly and bed topography was measured with digital point gauge.

The experiments were conducted in 3 phases, i.e. weir structure only, gate structure and combined structures experiments.

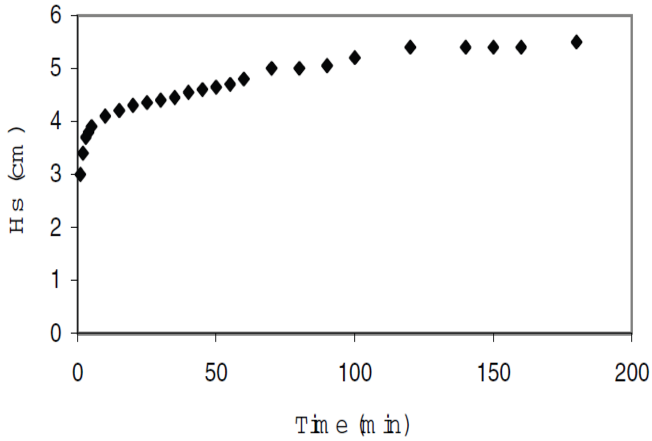

Figure 4 Variation of scour depth against time for Q=0.82L/s and w=3cm.

3 RESULTS AND DISCUSSION

3.1 The weir *structures* scour

A series of experiments have been carried out using four different weir heights, w=2, 3, 4 ,5 cm, and four different flow discharges, Q=0.48, 0.53, 0.7, 0.82 L/s. Figure 5 shows the scouring of the bed and conceptual model of flow pattern downstream of weir structures. The local scouring was formed downstream of structure and the scoured sediment is accumulated as a ridge in downstream of scour hole.

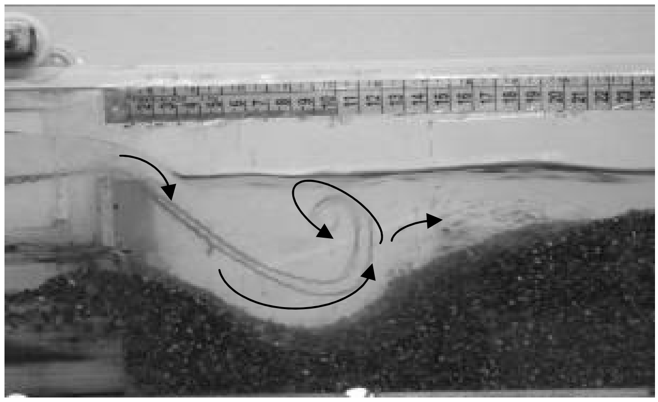

Figure 5 Scouring downstream of weir structures.

Fig. 6 shows the variation of h_s/h_u against w/y for various Froude numbers. It is clear that for a given Froud number, the ratio of h_s/h_u increases when w/y increases. Also by increasing the Froude number, the maximum depth of scour increases.

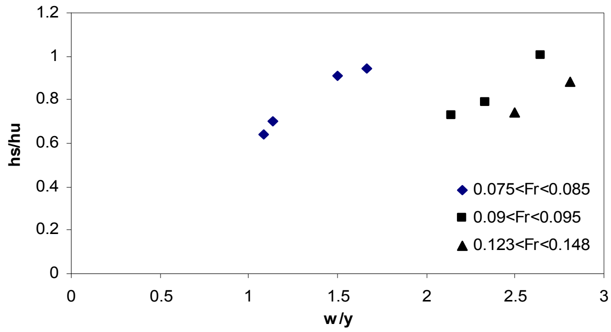

Figure 6 Variation of h_s/h_u against w/y

3.2 The gate *structures* scour

In the second phase of experiments, the scour downstream of gate structure was considered. The scour pattern in downstream of gate is shown in figure 7. It is clear that depth of scour downstream of gate structures is less than the scour downstream of weir structure.

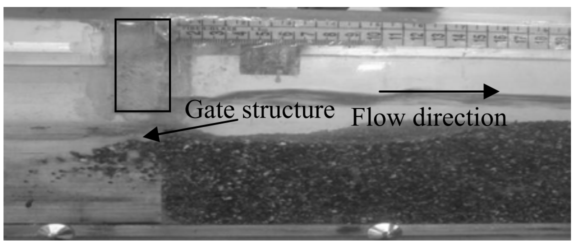

Figure 7 Scouring downstream of gate structures.

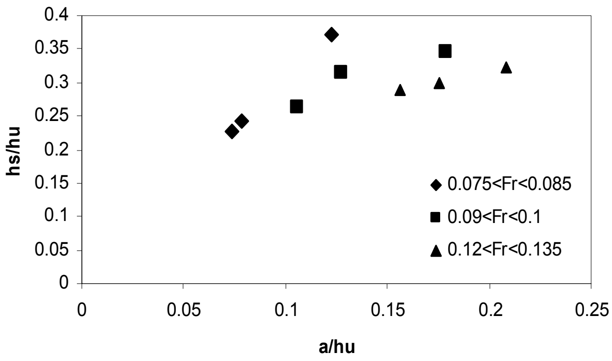

Figure 8 Variation of h_s/h_u against a/h_u

3.3 The *Combined* Weir and Gate structures scour

The scouring downstream of combined flow over the weir and under the gate is shown in figure 9. The conceptual model of flow field downstream of combine flow over the weir and under the gate indicates that there are interactions between the flows over the weir and under the gate and the scour hole cuts and fills alternatively. Figures 10 and 11 show the variation of h_s/h_u against y/a and w/a for Q=0.53, 0.82 L/s and w=3 cm, respectively. It is clear that by decreasing the y/a and w/a, the ratio of h_s/h_u increases (Dehghani and Bashiri, 2009).

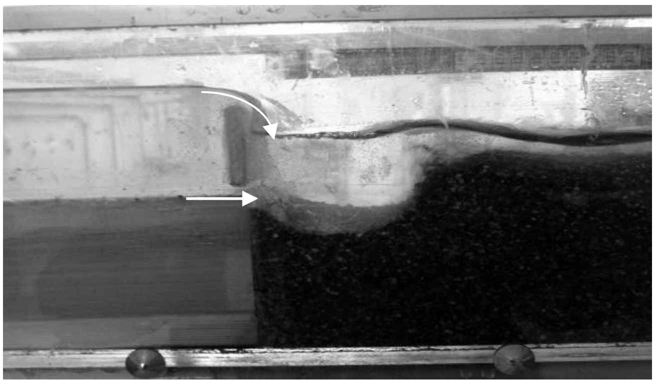

Figure 9 Scouring downstream of combined flow over the weir and under the gate

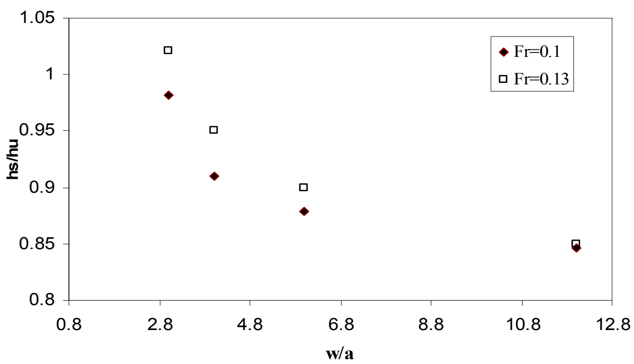

Figure 10 Variation of hs/hu against w/a, for Q=0.53, 0.82 L/s and w=3 cm.

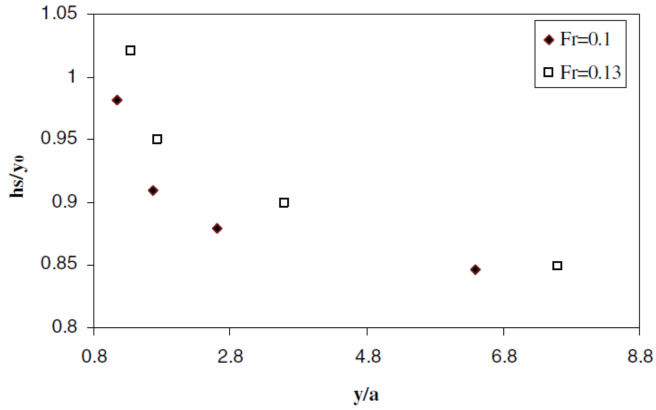

Figure 11 Variation of hs/hu against y/a, for Q=0.53, 0.82 L/s and w=3 cm.

By increase of Froude number, the maximum depth of scour (h_s), length of scour (l_1) and sedimentation length (l_2) increase.

The 3D plot of bed change downstream of combined flow over the weir and under the gate is shown in Figure 12.

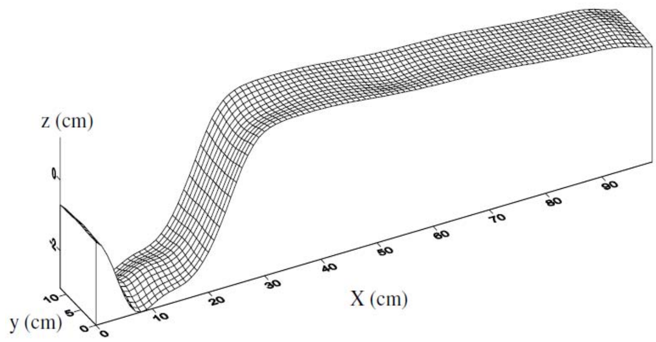

Figure 12 the 3D plot of bed changes at downstream of combined flow over the weir and under the gate

The bed configuration in downstream of combined structures show that the local scouring is formed downstream of structure and the scoured sediment is accumulated as a ridge in downstream of scour hole.

3.4 *Comparison* of Results

Figure 13 shows the comparison of scour depth in downstream of gate, weir and combined gate and weir structures. The results show that in a specific value of Fr, the scour depth is maximum in the case of weir structures and minimum in the case of gate structures. Furthermore, the maximum depth of scour increases with Froude number regardless of the type of structure.

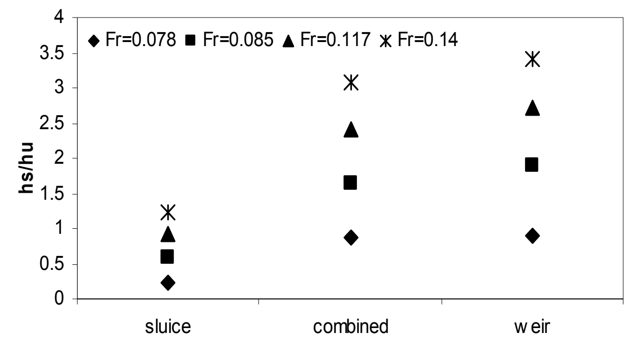

Figure 13 variation of h_s/h_u against different type of structures for various Fr.

Figure 14 also shows the longitudinal profile of scouring along the channel center line. It is found that the length of sedimentation downstream of scour hole is greatest for gate structures.

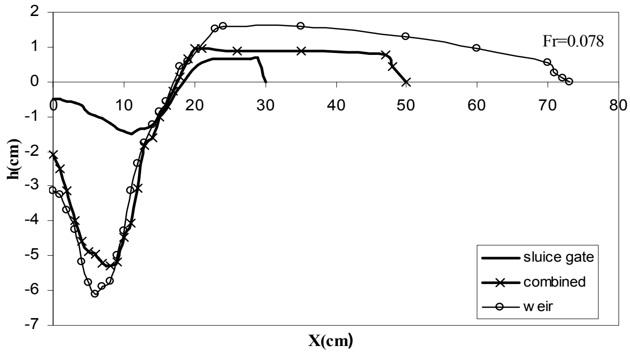

Figure 14 comparison of scouring downstream of gate, weir and combined them

4 CONCLUSIONS

The following results can be concluded:

1. In specific Fr by increasing of weir height, the maximum depth of scouring increases.
2. By decreasing the y/a and w/a (y is the gate opening, w is the head over weir and a is the vertical distance between the gate top and the weir bottom), the ratio of h_s/y_0 (h_s is the maximum depth of scour and y_0 is the upstream water depth), increases.
4. The main part of scour in combined flow is due to flow over weirs.

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NOTATION

B	channel width
d_{50}	median particle size
Fr	flow Froude Number
g	gravitational acceleration
S_0	bed slop
h_u	upstream flow depth
h_s	maximum scour depth
U	mean flow velocity
ρ_w	fluid density
μ	fluid dynamic viscosity
σ	sediment gradation
w	distance between the gate top and the weir bottom
a	gate opening
ρ_s	sediment density
y	head over the weir
Q	flow discharge
ρ_w	flow discharge
l_1	scour length
l_2	sedimentation length