Experimental Study on Scour Due to Simultaneous Wall and Impinging Circular Jet

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Abstract: *In this study the scour mechanism and the effect of some of the important parameters such as jet velocities, impinging jet distance from the upstream wall and tailwater depth on the longitudinal scour profile due to 3d simoultaneous wall and impinging jet are investigated experimentally. Experiments were conducted in a channel 10 m long, 1 m height and 0.57 m width. For generating jet flow, two pipes with 1 cm inside diameter and 2 m long were used. Uniform sediment with median size of 1.05 mm was used as the bed material. The experiments showed that the jet distances, jet velocities and tailwater depth have significant effect on scour hole profile. Depending on the jet velocities, tailwater depth and the distance of the impinging jet from the upstream wall, two types of longitudinal scour profiles are observed.*

Keywords: *Wall jet, impinging jet, scour, experimental study*.

1. INTRODUCTION

The scour hole formation due to jets can cause the structural failure of the hydraulic structure located near the influential region of the jet. Estimating the scour hole dimensions and finding the effect of different parameters on scour hole dimensions help the researchers for better understanding of the scour formation due to jets. Extensive researches were performed for understanding the effects of the tailwater depth, jet velocity, sediment characteristics on scour hole dimensions. Most of the previous researches were performed for only wall jet or impinging jet.

Rajaratnam and Berry (1977), Lim (1995), Aderibigbe & Rajaratnam (1996), Ade & Rajaratnam (1998) and Sui *et al*. (2008) stated that the main parameter that effect on scour hole dimensions is densimetric Froude number of the jet.

Tailwater depth effect on scour hole dimensions due to impinging and free falling jets were investigated by Ghodsian *et al*. (2006) and Aderibigbe & Rajaratnam (1996). The critical tailwater depths were introduced by Aderibigbe & Rajaratnam (1996), Ghodsian *et al*. (2006) that beyond the critical value by increasing or decreasing the tailwater depth the scour hole dimensions decreases. Also Ali & Lim(1986), Faruque (2004), Sarathi *et al*. (2008) and Mehraein *et al*. (2010) stated that there is a critical tailwater depth that by increasing or decreasing the tailwater from the critical value the scour hole dimensions due to 2D and 3D wall jet increases.

Because of the formation of the armour layer the scour hole in the non uniform sediment by the jets have smaller dimensions as compare to the uniform sediment. This trend observed for scour hole that is formed due to wall jet or impinging jet (Aderibigbe & Rajaratnam (1996), Mih & Kabir (1983), Ranjbar (2006)).

Most of the previous researches assumed that the effect of the sediment size on scour hole dimensions can be considered by the densimetric Froude number (Rajaratnam (1981), Mazurek & Rajaratnam (2002) and Rajaratnam & Mazurek (2003)). The effect of the sediment size on scour hole dimensions was studied by Sui et al. (2008) among others.

Effect of the ratio of the jet diameter to median diameter of the sediment was investigated by Sarathi *et al*. (2008). They found that this parameter has effect on scour hole dimensions in temporal evaluation of the scour hole dimensions but the scour hole dimensions are more or less independent of this parameter in the equilibrium condition.

Lim (1995) showed that the scour hole depth decreases by decreasing the expansion ratio but the scour hole length increases and he also found that when expansion ratio is smaller than 5 the expansion ratio has effect on scour hole dimensions due to wall jets.

A few studies were performed on the scour formation due to wall and impinging jets and wall and offset jet (Uyumaz (1988) and Dey & Eldho (2009)). Uyumaz (1988) stated that the maximum depth of scour is smaller when there is simultaneous flow under and over a gate, as compared to the cases of flow only under or over a gate. Dey & Eldho (2009) investigate the effect of the space of two offset jets on scour hole dimensions. Their results show that in the intermediate jet distance the scour depths and volumes are minimum.

Review of literature, to the knowledge of authors show that no research is performed for understanding the effect of the different parameter on scour hole dimensions due to simultaneous wall and impinging jets. In the first step of this research the scour mechanism due to simultaneous wall and impinging jet was investigated then the effect of the different parameters on longitudinal scour profiles at the equilibrium states are studied.

2. EXPERIMENTAL SETUP AND PROCEDURE

Experiments were performed in a channel 0.58 m wide, 10 m long and 1 m deep. For measuring the flow discharge, a Heinrich flowmeter was used. This flowmeter can measure the discharge in the range of 0.25 m^3/hr to 2.5m^3/hr. For creating the jets the flow was pumped from a tank into a straight steel pipes with 2m length, 1, 2 cm inner diameter. Sediment basin with a minimum thickness of 0.4m and length of 2.5 m was located at the downstream of jet. The median grain size of sediment was 1.05 mm and the standard deviation $\sigma_g = \sqrt{\frac{d_{84}}{d_{16}}} = 1.25$ so the sediment is nearly uniform. The specific gravity of sediment density was 2.65. The gradation curve of sediment used is shown in Figure 1.

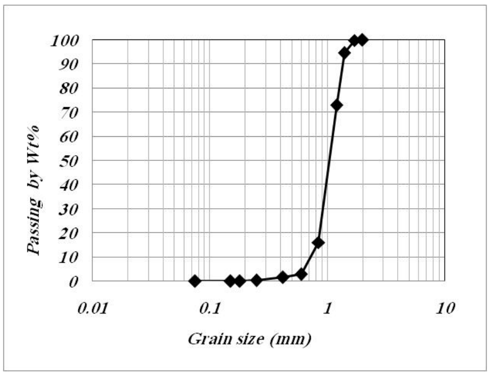

Figure 1. Grain size distribution curve

Schematic view of the scour hole and experimental facilities are shown in figure 2. Each experiment was performed in two steps. In the first step the predetermined values of the tailwater depth (Y_t), the distance of the impinging jet (x_p) and the discharge of the jets were adjusted. Valves number 1, 2 are completely opened and valve number 5 was completely closed. In this step, valves 3, 4 were used for regulating the discharge. At the end of step 1, the pumps were turned off and the sediment bed was leveled. In the second step of experiments, by closing the valves number 1, 2 and opening valve number 5, the channel was filled. After the tailwater depth reached to the specified value the secondary valve was closed and valves number 1 and 2 were opened simoultainously and the scour process began. When valves number 1 and 2 were opened the discharge of the jets also were checked for assuring the jet velocity. A sluice gate was located at the end of the main channel to control the tailwater depth. Tailwater depth and bed profile were measured by a digital point gauge having an accuracy of ± 0.01 mm.

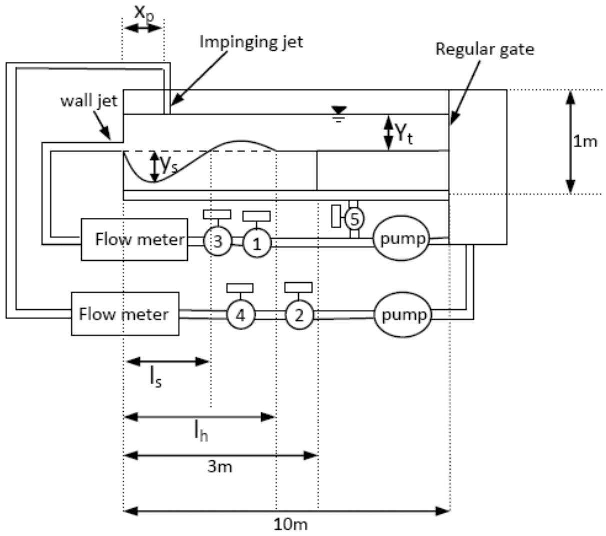

Figure 2. Schematic view of the scour hole and experimental facilities

The scour hole dimensions were measured in static and dynamic conditions. In static measurments the pupms were turned off and after the channel drainage the scour profiles were measured. In dynamic measurments while running the pumps the maximim depth of scour were measured.

3. RESULTS AND DISCUSSION

Different researchers used different method for estimating the equilibrium time of the scour hole. Day *et al*. (2001) stated that the scour hole dimensions reached to the equilibrium state when, the variation of the scour depth does not exceed from the median sediment size within 1 hr duration of the experiments. In order to obtain the equilibrium time for experiments, some long duration experiments (96 hrs) were performed for different tailwater depths, different locations of the impinging jet from the upstream wall and different jet velocities. In this study the equilibrium time of the scour was selected as the time when the scour depth reached to 90% of long duration scour depth. Figure 3 shows that the equilibrium time of the scour depths for Y_t=3 cm, Y_t=11 cm are t=24 hrs and t=18 hrs respectively.

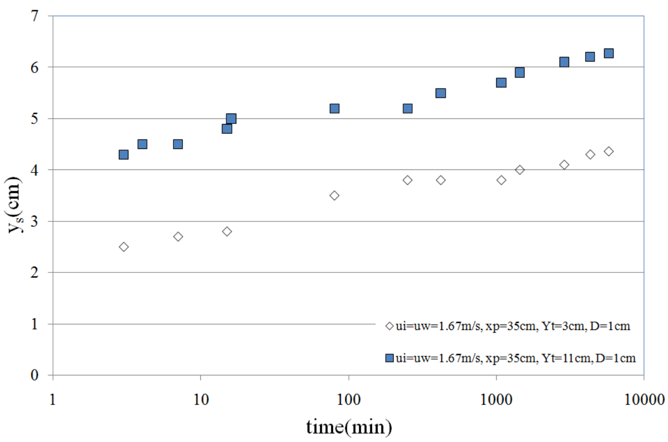

Figure 3. Variation of depth of the scour depth with time for different values of Y_t, u_w=u_i=1.67 m/s, x_p=5 cm

The distance of the impinging jet from the upstream wall also depend on temporal variations and the equilibrium time of the scour hole depth (Figure 4). When $x_{p=}$50 cm the digging and refilling was observed in impinging jet scour hole region. Initially two separate scour holes formed by wall and impinging jet. The scour depth due to impinging jet increased to 5 cm and after few minutes from beginning of the experiment (after about 9 minutes) by reaching the ridge of the wall jet scour hole to the location of the impinging jet the sediments on the ridge of the wall jet entered to the scour hole of the impinging jet. As a result the scour hole depth the scour hole depth (refilling phase in figure 4) decreases. The process of the entering the sediment to the impinging jet region continues a single scour hole was formed by the wall and impinging jet (digging phase in figure 4). When x_p=5 cm the scour hole due to wall and impinging jet attached to each other from beginning of the experiments forming a single scour hole, so the above processes (digging and refilling phases) was not observed in this condition. Because of the digging and refilling process and entering the scoured sediment by the wall jet to the scour hole due to impinging jet, the equilibrium time of the scour depth is t_{eq}= 4 hrs for x_p=50cm and when x_p=5cm the equilibrium time is 2 hrs. By comparing the equilibrium times of the scour hole for different values of the velocity jets, because of the longer duration of the digging phase for u_i=u_w=1.67 m/s, the equilibrium time of the scour depth increases for this condition to 16 hrs.

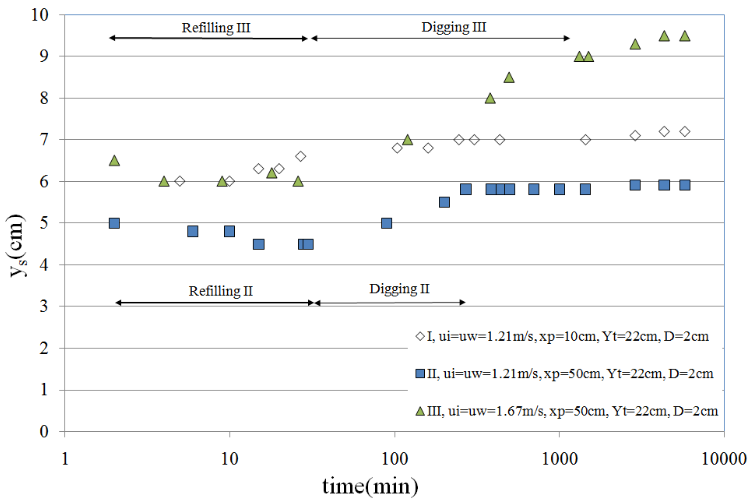

Figure 4. Variation of the depth of the scour depth with time for different values of x_p when u_w=u_i=1.67m/s, Y_t=11cm

4. DESCRIPTION OF THE SCOURING PROCESS

Immediately after opening valve number 3 and 4 the scour process was began and the sediment was moved away from its position. Most of the sediment was transported downstream as suspended load and after some hours from the beginning of the experiments most of the sediment was transported downstream in the rolling and sliding condition. In the equilibrium state of the scour hole when x_p=5 cm the turbulence bursting process was observed in the whole of the scour hole especially in the longitudinal second half part of the scour hole. In the equilibrium state of the scour hole when x_p=35 cm some sediment remains in suspended form in the impinging jet region (second scour hole region). The sediment was moved to the upstream face of the ridge and because of the ridge height and the slope of the ridge the sediments slide down and entered again into the second scour hole. In this condition the scour hole depth in static and dynamic conditions are different. In the equilibrium state of the scour hole two types of longitudinal scour profile were observed (Figure 5). The first type of scour hole has only one local maximum and the second type of scour hole has two maximum local scour depths. In the second type of the scour hole the first scour hole formed by the wall jet and the second scour hole formed by the impinging jet. The first type of scour hole were observed when D=1 cm, 3<Y_t<11 cm, x_p=5 cm and u_w=u_i=1.67 m/s. When Y_t=18 cm, u_w=u_i=1.67 m/s and D=1cm the second type of the scour hole were observed for x_p>=25 cm. So when u_i and u_w remain constant, the type of the scour hole depend on the tailwater depth and the distance of the impinging jet from the upstream wall. The impinging jet behaves like an obstacle against the wall jet development in longitudinal direction, a part of the wall jet mass deviates to the right side of channel and the other part deviates to the left side of channel. in this case more of the sediment deposits near the channel walls as compare to the centerline of the wall jet pipe (u_i=u_w=1.67 m/s, x_p>15 cm, 3cm<Y_t<18 cm). Figure 6 show that the height of the ridge has a local minimum value at y=0cm (centerline of the pipe) and reached the maximum value at y=3cm and then decrease again by increasing y value.

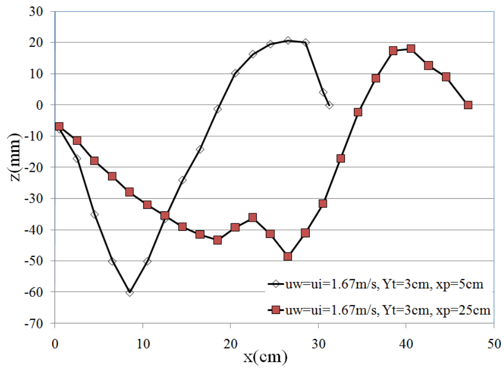

Figure 5. Types of longitudinal scour profile

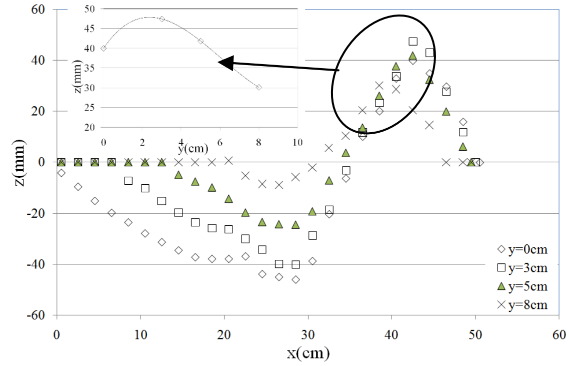

Figure 6. Longitudinal profile of the scour hole for different distance from the centerline of the pipe (u_i=u_w=1.67m/s, Y_t=11cm, x_p=25cm)

The deviation of the wall jet to the channel side wall was observed in low tailwater depth (Y_t=3cm). A typical asymmetric plan profile of the scour hole is shown in Figure 7. The deviation of the wall jet to the channel side wall in low tailwater depth was also reported by previous researchers such as (Sarathi *et al*. (2008), Kantoush (2008), Mehraein *et al*. (2010)).

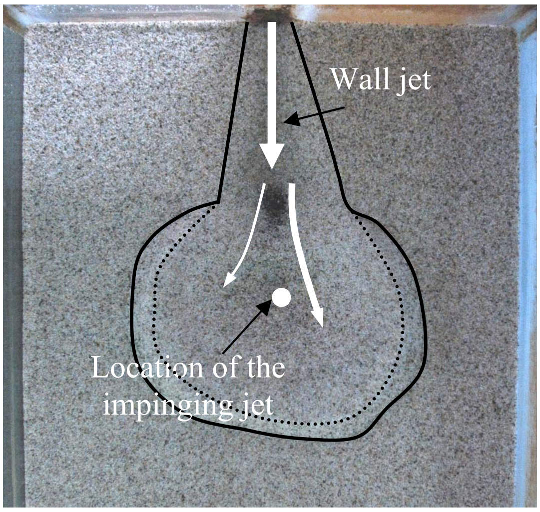

Figure 7. Asymmetric scour hole profile Y_t=3cm, u_i=u_w=1.67m/s, x_p=25cm

Figure 8. shows effect of the distance of the impinging jet from the upstream wall on longitudinal scour hole profile. When x_p=5 cm because of the effect of the upstream wall a recirculation flow were observed near the upstream wall and a small scour (2.3cm) was observed in front of the upstream wall. When x_p>=10cm a small scour was not observed and effect of the upstream wall omitted on impinging jet. By increasing the distance of the impinging jet from the upstream wall the scour hole depth decreases. The scour hole profile due to only wall jet is also shown in figure 8. The scour length (l_s) and the distance of the end of the ridge from the upstream wall (l_h) increase by increasing the distance of the impinging jet (x_p) from upstream wall. Because of the restriction effect of the impinging jet on the longitudinal development of the wall jet, for all values of x_p the scour length (l_s) and the distance of the end of the ridge from the upstream wall (l_h) are smaller when the impinging jet and wall jet works simultaneously as compare to the wall jet.

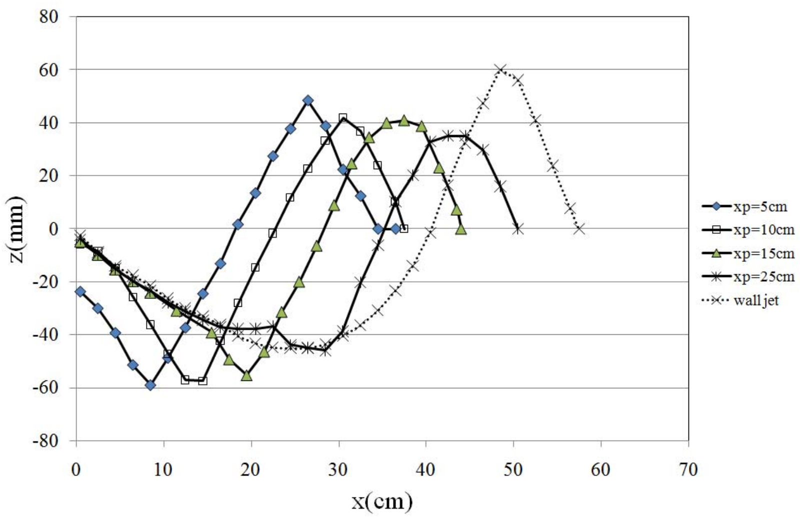

Figure 8. longitudinal scour profiles for Y_t=11 cm, u_i=u_w=1.67 m/s

Figure 9 shows effect of the tailwater depth on longitudinal scour profile in static and dynamic measurements.

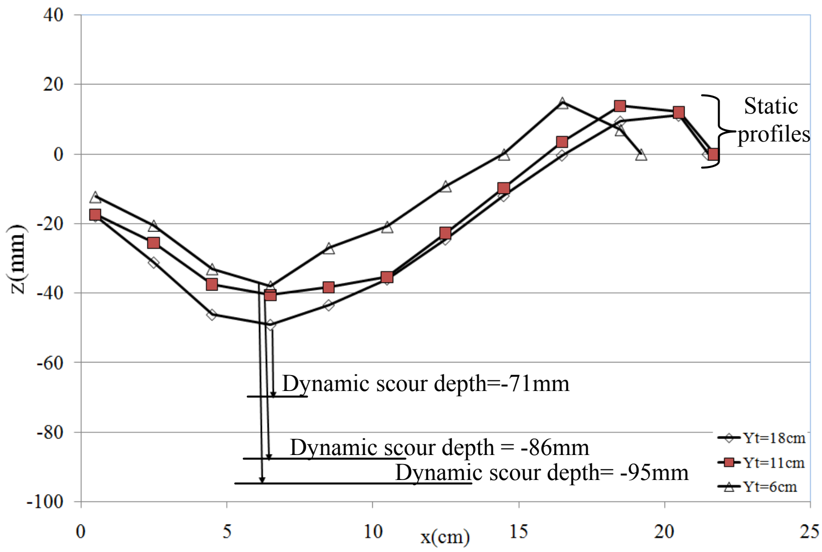

Figure 9. Longitudinal scour profiles for x_p=5 cm, u_i=1.67 m/s, u_w=3.34 m/s

In the experiments, small scour was also observed in front of the upstream wall. In static measurement the scour depth decreases by decreasing the tailwater depth because of deposition of the suspended after the pumps were turned off the sediments deposited in the scour hole. By increasing the tailwater depth the impinging jet diffuses more in tailwater depth and the amount of the suspended sediments was smaller than the lower tailwater depth. In dynamic measurement because of the diffusion of the jets in the tailwater depth the scour depth decreases by increasing the tailwater depth. The scour length (l_s), the distance of the end of the ridge from the upstream wall (l_h) increases by increasing the tailwater depth (Y_t). The ridge heights slightly decrease by increasing the tailwater depth.

5. CONCLUSIONS

The present study deals with local scour due to simultaneous wall and impinging jet. The results show that the equilibrium times of the scour hole depend on the tailwater depth and the distance of the impinging jet from the upstream wall. According to the observation two types of the longitudinal scour holes profile were observed. The scour depth (y_s) decreased by increasing the tailwater depth (Y_t) and distance of the impinging jet pipe from the upstream wall (x_p).

Effect of the distance of the impinging jet (x_p) from the upstream wall (x_p) and tailwater depth (Y_t) on the scour hole dimensions were investigated. The scour hole length (l_s) and the distance of the end of the ridge (l_h) increase by increasing the tailwater depth and the distance of the impinging jet from the upstream wall (x_p).

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