Ghodsian, Masoud; Melville, Bruce W.; Coleman, Stephen

Scour Caused by Rectangular Impinging Jet in Cohesiveless Beds

Scour Caused by Rectangular Impinging Jet in Cohesiveless Beds

Masoud Ghodsian *, Bruce Melville ** and Stephen Coleman ***

* Professor, Water Engineering Research Center, Tarbiat Modares University, Tehran, Iran

** Professor, Department of Civil and Environmental Engineering, The University of Auckland, New Zealand

*** Associate Professor, Department of Civil and Environmental Engineering, The University of Auckland, New Zealand

I. Abstract

In this paper result of experiments on scour due to impinging rectangular jet in uniform cohesive bed material is presented. The effect of the tailwater depth, water and sediment discharge on the depth of scour was investigated. It was found that the depth of scour is a function of the densimetric Froude number, the ratio of drop height to tailwater depth and the ratio of sediment discharge to water discharge. Increasing the sediment load in the water jet leads to a decrease in the scour depth. It was found that the depth of scour increases with increasing the discharge. The depth of scour initially increases by increasing the tailwater depth and then decreases.

II. Introduction

Flow over and through hydraulic structures often occurs in the form of jets. The jet velocities are usually high enough to produce sizeable, even dangerous, scour holes. Several investigators have studied the scour due to a free overfall jet, including Damle (1966), Doddiah (1953), Robinson (1971), Rajaratnam and Beltaos(1977), Rajaratnam(1980), Abt et al. (1984), Mason (1989), Mason and Arumugam (1985), Ruff et al. (1987), Blaisdell and Anderson (1988), Amanian (1993), Afify and Gilberto (1994), Doehring and Abt (1994), Stein and Julien (1994), Azar (1998), Hoffmans (1998), Martins (1999), Ojha (1999), Mahboubi (2000), Ghodsian and Azar (2001,2002), Ghodsian (2002), Najafi (2003), Ghodsian and Najafi (2003), Tajkarimi (2004) and Bombardelli and Gioia (2005).

The results of an experimental study on depth of scour due to a free overfall jet are presented in this paper

III. Dimensional analysis

The scour depth d_s due to a free-falling jet depends on many variables, including unit discharge of flow q, velocity of outflow jet V, unit discharge of sediment load in the jet q_s, drop height H_c (measured from the centre of the jet to the bed), cross-sectional dimensions of the jet, density of water ρ, median sediment size d_{50}, density of sediment ρ_s, tailwater depth Y_t and acceleration due to gravity g. In this study, the hydraulic radius R of the jet cross section used to characteristic the jet size. Therefore:

$$d_s = f\left(R, Y_t, d_{50}, \rho, \rho_s, g, V, H_c, q, q_s\right) \qquad (1)$$

Using dimensional analysis, Eq. 1 can be written in the following form:

$$\frac{d_s}{Y_t} = f\left(\frac{Y_t}{H_c}, Fr_d \frac{R}{H_c}, \frac{q_s}{q}\right) \qquad (2)$$

in which Fr_d is the densimetric Froude number given by:

$$Fr_d = \frac{V}{\sqrt{g d_{50}(S_s - 1)}} \qquad (3)$$

where S_s is specific gravity of the sediment.

IIV. Experiments

The experiments were conducted in a re-circulating flume with a length of 40m, width of 0.83m and depth of 1.0m. A rectangular free overfall jet of 0.072m width was established 5m from the upstream end of the flume (Figure 1). The bed of the flume downstream from the jet was raised in order to create a 0.3m deep and 3m long test section. The test section was filled with a uniformly-graded sediment with a median diameter of d_{50}=0.62 mm. A sluice gate was used to control the tailwater depth. Discharge was measured by a calibrated sharp-crested triangular weir at the entrance to the jet approach channel. Initially, a thin protective metal sheet was placed on the sediment bed downstream of the jet. The flume was slowly filled until the desired tailwater level was reached. The jet-scour experiments were started when the protective sheet was rapidly removed. At the end of the experiments, the scour profile was measured using the depth sounder.

Initially, experiments were run with a clear-water jet flow and thereafter with a successively-increased sediment load to the jet. Sediment having the same size as that of the bed material (d_{50} = 0.62mm) was added to the jet using a hopper (see Fig. 1). Experiments were run for varying water and sediment discharges and tailwater conditions. The duration of experimental runs was set to 2hr. It was observed that most of the scour had occurred after 2hr. Table 1 shows the range of data studied.

TABLE 1. RANGE OF EXPERIMENTAL DATA

Parameter	Range
Y_t	9.4-20.3
Fr_d	7.19 – 9.36
Q_s	0 - 14
d_s/Y_t	0.11 – 1.3

V. RESULTS

In all the experiments it was observed that the scour hole is roughly circular in plan with most of the eroded material being deposited as a ridge downstream from the scour hole. However limited deposition occurs also on the sides of the scour hole (Fig.2). The effect of discharge on longitudinal and lateral scour profile, for Q_s=0, is shown in Figs. 3 and 4, respectively. These figures show that under the stronger flow of Q = 2.97L/s, which is associated with more longitudinal flow velocity, more sediment is transported downstream with deposition on the sides of the scour hole being sparse. It is evident that by increasing discharge the dimensions of scour hole and ridge formed at the downstream of scour hole increases.

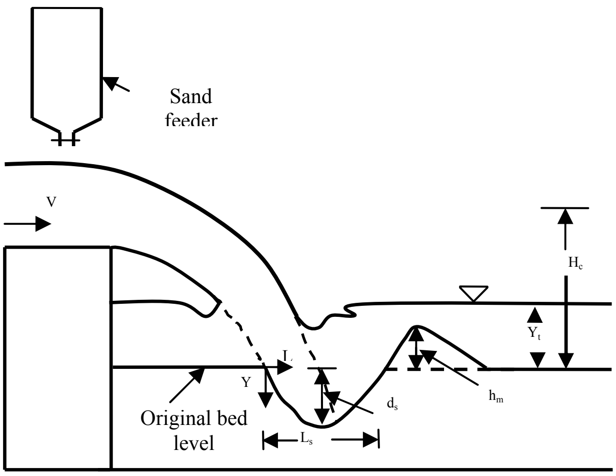
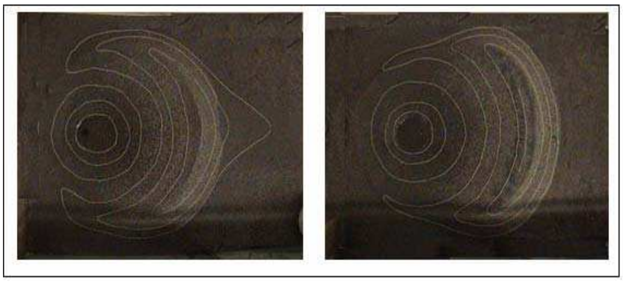


Fig 1. Schematic view of scour due to impinging jet



a) Q=1.45(L/s) b)Q=2.97 (L/s)

Fig. 2 Typical scour hole formed for two values of discharge; Y_t=9.4cm and Q_s=0

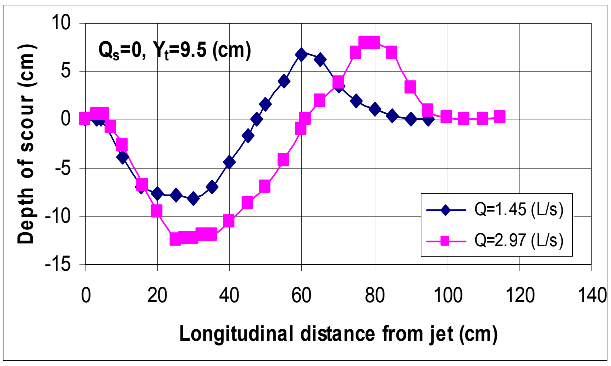


Fig. 3 Effect of discharge on longitudinal scour profile

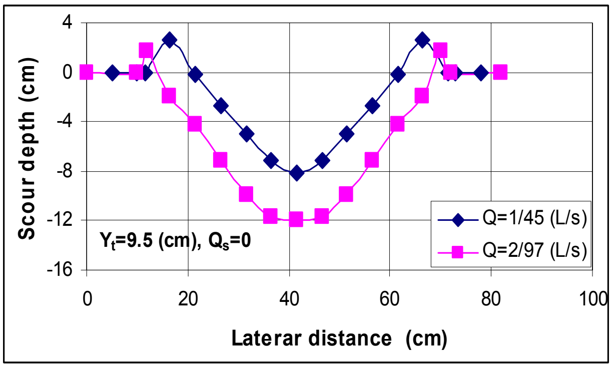


Fig. 4 Effect of discharge on lateral scour profile

The influence of the tailwater depth Y_t and discharge Q on the depth of scour d_s is demonstrated in Fig. 5, for which drop height H_c=27.6cm and sediment transport rate Q_s = 0. It is evident from these figures that increasing tail

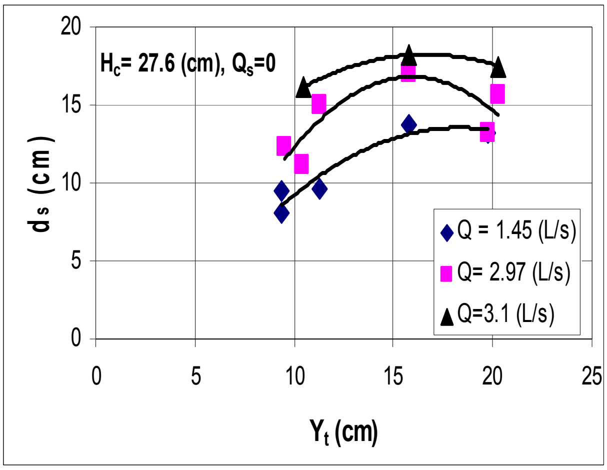


Fig. 5 Effect of tailwater depth and discharge on depth of scour

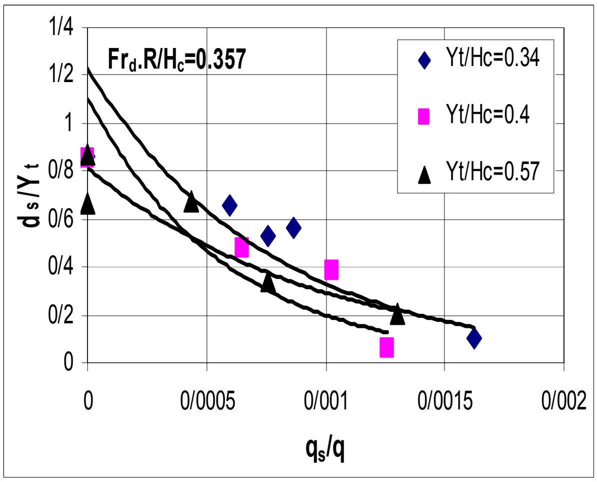


Fig. 7 Variations of d_s/Y_t with q_s/q for different values of Y_t/H_c

water depth increases the scour depth initially, reaches to a maximum and then decreases. For low values of tailwater depth, the scour depth is governed by the tailwater depth, increasing with larger depth. The decreasing depth of scour at high values of tailwater depth is attributed to the increasing dissipation of the energy of the jet flow for this case.

The influence of the sediment load of the jet on the scour depth is depicted in Fig. 6 for Q = 1.45L/s and three values of tailwater depth, Y_t=9.45cm, 11.3cm and 15.8cm respectively. When the jet is carrying sediment ($Q_s > 0$), the scouring potential of the jet is reduced, and the depth of the scour decrease.

The influences of the parameters q_s/q and Y_t/H_c on relative scour depth d_s/Y_t are shown in Fig. 7 for $Fr_d.R/H_c$= 0.357. The effect of q_s/q in reducing scour depth is clear from this figure. In summary, the scour depth developed below a free-falling jet is reduced in size when the jet carries a sediment load.

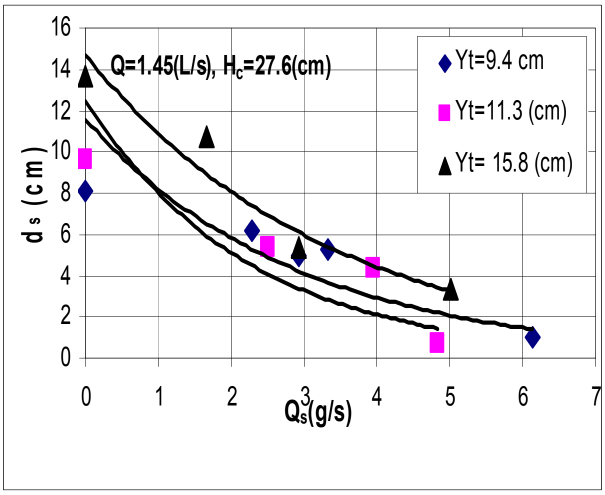


Fig. 6 Effect of sediment load on depth of scour

VI. CONCLUSIONS

The conclusions from this experimental study are:

- The sediment carried by a jet reduces the scouring potential of the jet as compared to a clear-water jet, as a result, the depth of scour decreas.
- With increasing tailwater depth, the depth of scour initially increases, reach a maximum value and thereafter decrease.
- With increasing discharge, the dimensions of scour hole and ridge height increases.
- With increasing sediment load in the jet flow, depth of scour decreases.
- Depth of scour is influenced by the parameters Fr_dR/H_c, Y_t/H_c and q/q_s.

References

[1] Abt S.R., Kloberdanz R.L. and Mendoza C., 1984, Unified culvert scour determination, *J. Hydr. Engrg., ASCE*, 110(10), 1363-1367.

[2] Afify, M. and Gilberto E. U., 1994, Plunge pool scour by inclined jets, Hydraulic engineering 94- 1040-1044.

[3] Amanian, N., 1993, Scour below a flip bucket spillway, PHD dissertation, civil and environmental engineering, Utah state university, Logan, Utah, 250.

[4] Azar, F.A., 1998, Scour downstream of pipe culvert, M.S. Thesis, Tarbiat Modares University, Tehran, Iran, 120.

[5] Blaisdell F.W. and Anderson C.L., 1988, A comprehensive generalized study of scour at cantilevered pipe outlets, *J. Hydr. Res.*, IAHR, 26(4), 357-376.

[6] Bombardelli, F. A. and Gioia, G., 2005, Towards a theoretical model of localized turbulent scouring, Proc. of the 4th IAHR sypms. on river, costal and estuarine morph dynamics-RCEM, Urbana, Illinois, USA, 931-936.

[7] Damle, P.M., 1966, Evaluation of scour below ski-jump buckets of spillways, Proc. golden jubilee symp., Poona, India., 154-164.

[8] Doddiah, D., 1953, Scour from jets, proc. IAHR/ASCE conference, Minnesota; 161-169.

[9] Doehring, F., and Abt, S.R., 1994, Drop height influence on outlet scour, *J. Hydr. Engrg., ASCE*, 120(12), 1470-1476.

[10] Ghodsian, M., 2002, Scour hole geometry downstream of a culvert, 13th APD-IAHR Conference, Singapore, 272-275.

[11] Ghodsian, M. and Azar F.A., 2001, Effect of sediment gradation on scour below free over fall spillway, 3 rd

International Symposium on Environmental Hydraulics, Arizona State University, USA, on CD Ram.
[12] Ghodsian, M. and Azar F.A., 2002, Scour hole characteristics below free over fall spillway, *Int. J. of Sediment Research*, 17(4), 304-313.
[13] Ghodsian, M., and Najafi, J., 2003, Maximum depth of scour by impinging circular turbulent jet, 30th congress of IAHR, Greece, 353-359.
[14] Hoffmans, G. J. C. M., 1998, Jet scour in equilibrium phase, *J. Hydr. Engrg., ASCE*, 124(4), 430-437.
[15] Mahboubi, E., 2000, Effect of sediment size on scour due to free falling jet, M.S. Thesis, University of Science and Technology, Tehran, Iran, 130.
[16] Martins, K. J., 1999, Scour caused by rectangular impinging jets, Ph.D Thesis, Colorado State University, Forth Collins, USA, 403.
[17] Mason, P.J., 1989, Effects of air entrainments on plunge pool scour, *J. Hydr. Engrg., ASCE*, 115(3), 385-399.
[18] Mason, P.J., and Arumugam, K., 1985, Free jet scour below dams and flip buckets, *J. Hydr. Engrg., ASCE*, 111(2), 220-235.
[19] Najafi, J., 2003, Scour downstream of pipe culvert, M.S. Thesis, Tarbiat Modares University, Tehran, Iran. 110.
[20] Ojha, C.S.P., 1999, Outlet scour modeling for drop height influence, *J. Hydr. Engg., ASCE*, 125(1), 83-85.
[21] Rajaratnam, N., 1980, Erosion by plane turbulent jet, *J. Hydr. Res., IAHR*, 19(4), 339-358.
[22] Rajaratnam, N., and Beltaos, S. , 1977, Erosion by impinging circular turbulent jets, *J. Hydr. Div., ASCE*, 103(10), 1191-1205.
[23] Robinson A.R., 1971, Model study of scour from cantilevered outlets, *Trans., ASAE*, 14, 571-581.
[24] Ruff, J.F., Abt, S.R., Doehring, F.K., and Donnell, C.A., 1987, Influence of culvert shape on outlet scour, *J. Hydr. Engrg.*, ASCE. 113(3), 393-400.
[25] Stein, O.R., and Julien, P.Y., 1994, Sediment concentration below free overfall, *J. Hydr. Engrg., ASCE*, 120(9), 1043-1059.
[26] Tajkarimi, D., 2004, Analysis of scour due to free falling jet and application of neural network.", M.S. Thesis, Tarbiat Modares University, Tehran, Iran.

Keywords: scour, jet, densimetric Froude number, tailwater depth.