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European Journal of Experimental Biology, 2012, 2 (5):1827-1832

European Journal of Experimental Biology
Pelagia Research Library
ISSN: 2248 –9215
CODEN (USA): EJEBAU

Maximum depth of scour by impinging circular turbulent jet

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ABSTRACT

In this paper result of experiments on scour due to impinging circular jet is presented. The effect of parameters like: drop height, jet diameter, jet velocity and tail water depth on maximum depth of scour was investigated. It was found that by increasing jet velocity and drop height, depth of scour increases. While increasing tail water depth decreases the depth of scour. A new equation for prediction of maximum depth of scour is introduced.

Keywords: Depth of scour, circular jet, dimensional analysis, culvert.

INTRODUCTION

Study on scour of bed is of considerable importance in the field of hydraulic engineering.[1] Most often the flow downstream of hydraulic structures is of the form of turbulent water jet, such as the flow from spillway, downstream of gates, at the outlet of culverts and over the drops. Due to the complex nature of these flows and their interaction with sediment bed, study on scour due to water jet has been mainly empirical.

Different investigators have reported extensive studies on the outlet scour. [1, 2, 3, 4, 5, 6] have investigated the scour due to vertically impinging circular jets. Studies on scour due to horizontal circular wall jet were carried out by: [7…13]. Scour due to obliquely impinging jet was studied by [14…19].

This paper presents the results of an experimental study on the scour of sand bed particles by impinging circular turbulent water jet. [11] Maximum depth of scour was correlated with stability number, drop height and outflow jet diameter.

DIMENSIONAL ANALYSIS

Figure 1 shows the schematic view of scour due to impinging circular jet [6]. Maximum depth of scour d_s is influenced by: velocity of outflow jet V, drop height H_c, outflow jet diameter D, mean sediment size d_{50}, acceleration due to gravity g, density of sediment ρ_s and density of water ρ. Therefore:

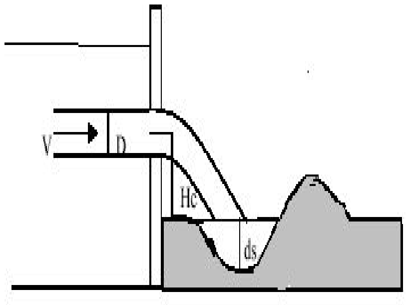

Figure 1.Schematic view of scour due to impinging circular jet

$$d_s = f(V, H_c, D, d_{50}, g, \rho, \rho_s) \quad (1)$$

Using the method of dimensional analysis, Eq. (1) can be written as:

$$\frac{d_s}{H_c} = f\left(SN, \frac{H_c}{D}, \frac{T_w}{D}\right) \quad (2)$$

in which SN is densimetric Froude number given by:

$$SN = \frac{V}{\sqrt{gd_{50}\left(\frac{\rho_s - \rho}{\rho}\right)}} \quad (3)$$

By combining the first two terms in the right hand side of Eq. (3) one can write:

$$\frac{d_s}{H_c} = f\left(\frac{SND}{H_c}, \frac{T_w}{D}\right) \quad (4)$$

The correlation between parameters of Eq. (4) can be obtained by using the experimental data.

MATERIALS AND METHODS

Experiments were conducted in a tilting re-circulating type flume with a length of 13m, width of 0.6m and depth of 0.6m. A schematic view of the flume is shown in Fig. 2. Horizontal culverts, for establishing circular jet, were made of PVC and installed at the distance of 6m from upstream end of flume.[18] Different flow conditions were applied in order to have various values of outflow jet velocity. The drop height H_c was measured from centerline of culvert to original bed level. The sand particles used for the bed had a mean diameter d_{50} of 1.4mm, density of 2.605 and geometric standard deviation of $\sigma g = 1.3$. Sediments were filled up to a thickness of 0.20m at the downstream of culvert. A sluice gate at the end of flume was used to control the tail water depth.[3] Discharge was measured by volumetric method. Depth of flow and bed profile was measured by a point gauge with an accuracy of ±0.1mm. The duration of experimental runs was kept equal to 22hrs in which the change in scour hole was observed to be no more detectable. Experiments were conducted for various values of drop height, outflow jet diameter, out flow jet velocity and tail water depth. Table 1 shows the range of parameters studied.[7]

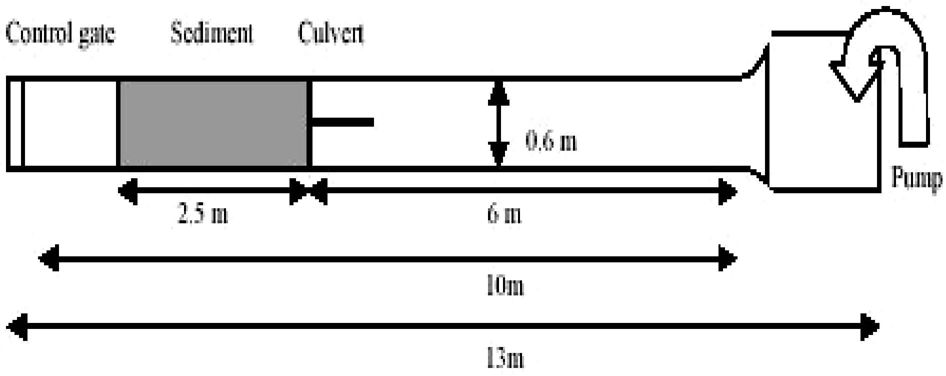

Figure 2.Schematic view of the flume

Table 1. Range of parameters studied

d (m)	U (m/s)	H_c (m)	T_w (m)	T_w/D	H_c/D	SN	d_s (mm)
Present study							
.022-.046	0.55-1.7	0-0.30	.02-0.30	0.5-10	0-12	4.5-14.5	1.41
[9]							
0.1	1.25-3.3	0-0.4	$\leq 0.5D$	≤ 0.5	0-4	9-25	1.86

RESULTS

Figures 3 to 5 shows the variations of relative scour depth d_s/H_c and SN for different values of relative outflow jet diameter H_c/D when relative tail water depth T_w/D = 0.5 to 10 respectively. It is evident that by increasing SN, the value of d_s/H_c increases. Moreover, by increasing the relative outflow jet diameter H_c/D, the relative scour depth d_s/H_c increases. The experimental data of [8] is also depicted in Figs. 3 to 6 and shows a similar trend and good agreement with present data [1].

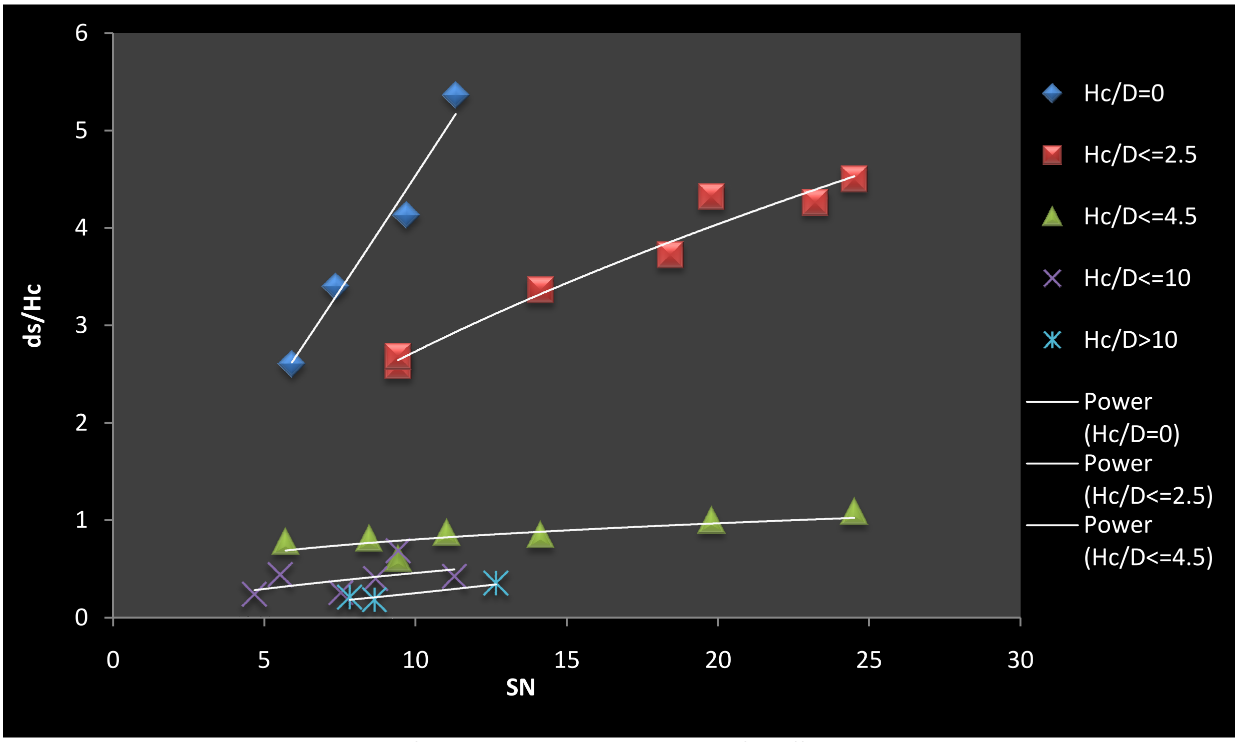

Figure 3.Variations of relative scour depth ds/Hc and SN for different values Hc/D when Tw/D = 0.5

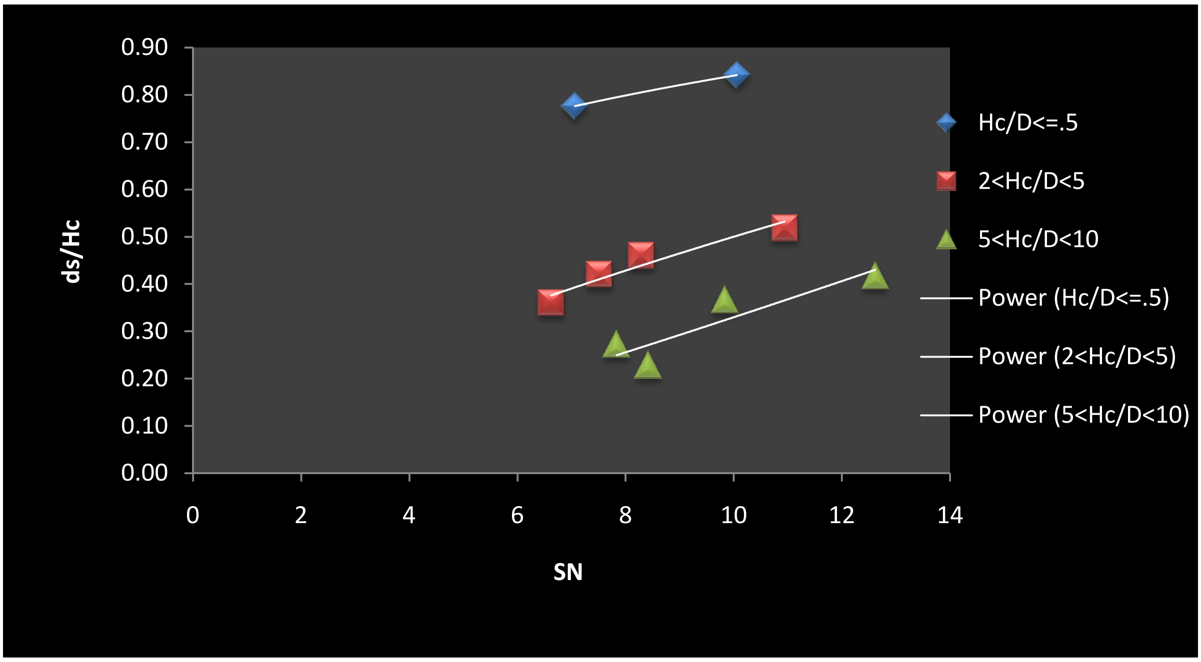

Figure 4.Variations of relative scour depth ds/Hc and SN for different values Hc/D when 2<=Tw/D <5

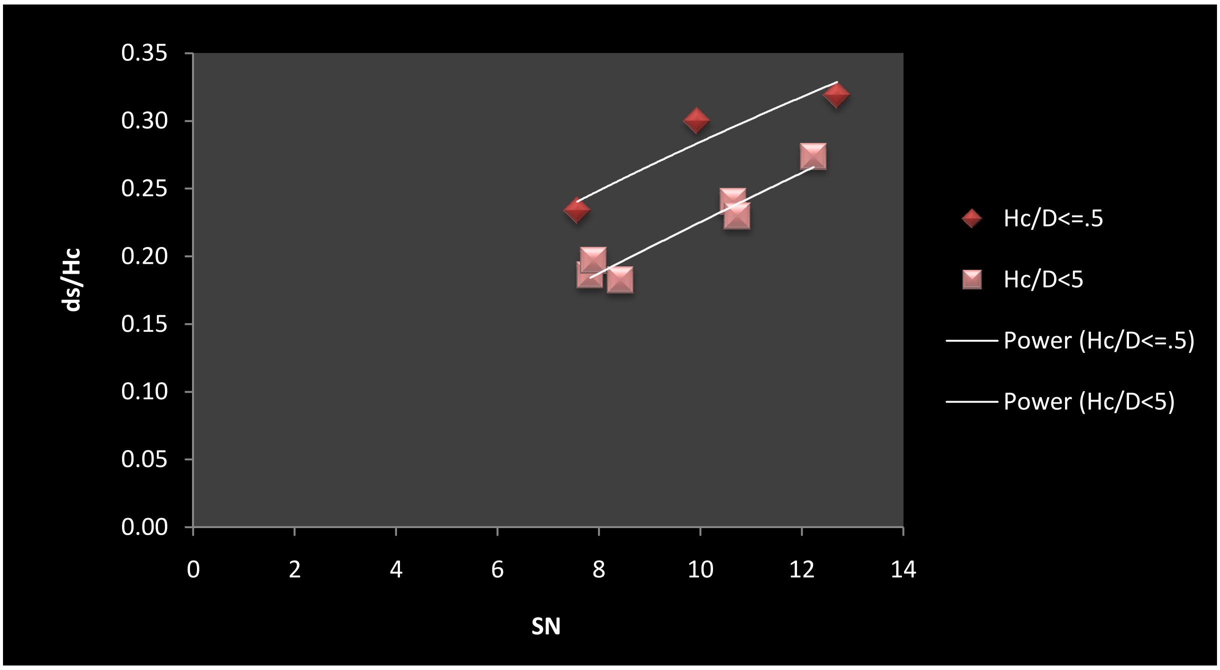

Figure 5.Variations of relative scour depth ds/Hc and SN for different values Hc/D when 5<=Tw/D <10

In accordance with Eq. (4), the experimental data is shown as variations of relative scour depth d_s/H_c with SND/H_c for various values of relative tail water depth. It is clear that by increasing SND/H_c, the relative scour depth increases and by decreasing relative tail water depth T_w/D, the relative scour depth d_s/H_c increases. Analysis of experimental data indicates that the relative scour depth d_s/H_c can be expressed as:

$$\frac{d_s}{Hc} = a\left(\frac{T_w}{D}\right)^b \left(\frac{SND}{H_C}\right)^C \qquad (5)$$

By using least square method it was found that:

a = 0.293 , b = -0.26 and $c = 0.575(Tw/D)^{-0.466}$

With these values, Eq. (5) reads:

$$\frac{d_s}{Hc} = 0.293\left(\frac{T_w}{D}\right)^{-0.26}\left(\frac{SND}{H_C}\right)^{0.575(Tw/D)^{-0.466}} \tag{6}$$

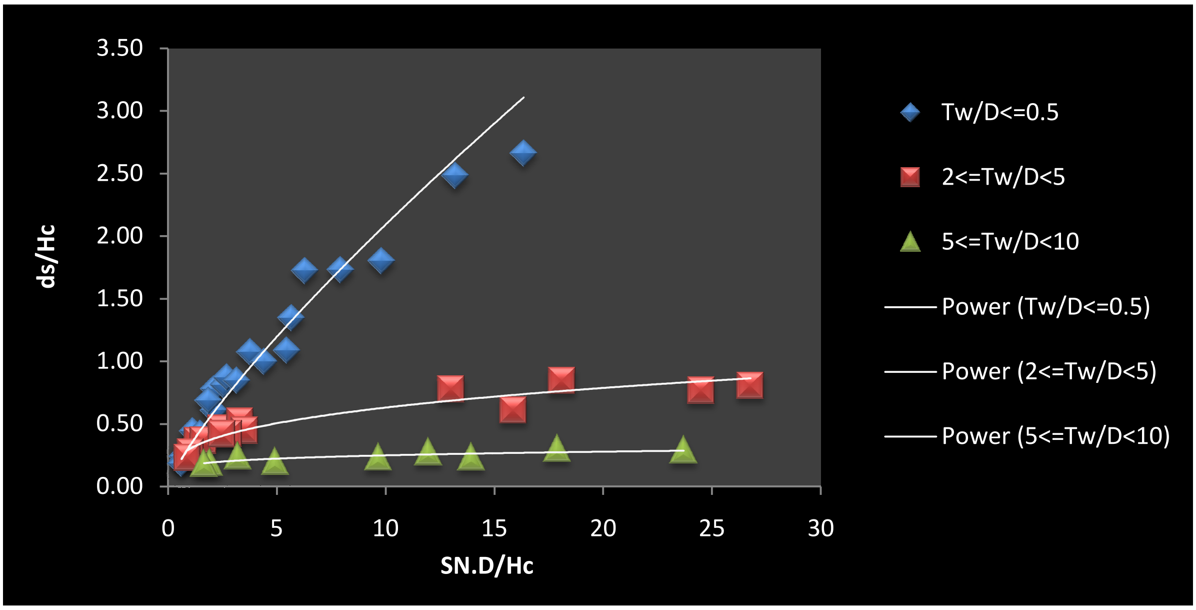

Figure 6.Variations of relative scour depth ds/Hc with SND/Hc for various values of relative tail water depth

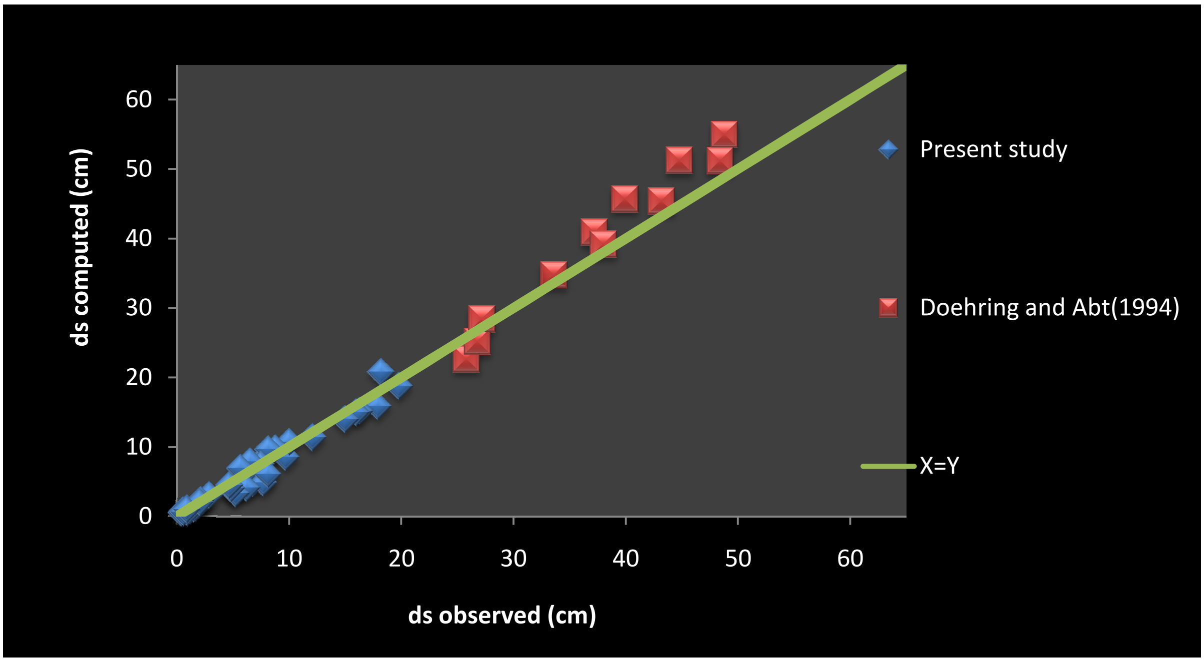

Figure 7. Comparison of observed and computed values of relative scour depth ds/Hc using Eq. (6).

The average percentage error due to Eq. (6) is 5.8 %. Figure 7 shows comparison of observed and computed values of relative scour depth d_s/H_c using Eq. (6). The present data and data of [8] are depicted in Figure (6). It is clear that the majority of data points fall within error band of ±20%. Hence one can expect to have acceptable results using Eq. (6). However, more data with wider range is required to verify the generality of this equation.

CONCLUSION

Based on the results of this experimental study on the scour of sand bed particles by impinging circular turbulent jet, the following conclusions could be derived:

The maximum depth of scour is a function of mainly the stability number SN and relative tail water depth T_w/H_c. By increasing the stability number, the relative scour depth increases and by increasing the relative tail water depth, the relative scour depth d_s/H_c decreases.[17] A new equation for estimation of maximum depth of scour due to impinging circular turbulent water jet is developed.

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