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Experimental Study on Scour due to Submerged Vertical Impinging Circular Jet

Rahul Shakya[1], V.K. Sarda[2] and Manendra Singh[3]

[1]Research Scholar, Department of Civil Engineering, National Institute of Technology Hamirpur, Himachal Pradesh-177005, E-mail: `rshakya@nith.ac.in`

[2] Professor (Retd), Department of Civil Engineering, National Institute of Technology Hamirpur, Himachal Pradesh-177005, E-mail: `sardavk@yahoo.com`

[3] Assistant Professor, Department of Civil Engineering, National Institute of Technology Hamirpur, Himachal Pradesh-177005, E-mail: `manendra@nith.ac.in`

Abstract. In this paper, the laboratory study of the scour has been carried out in cohessionless and cohesive sediments by submerged vertical circular impinging jet. The scour tests were performed using cohessionless sediments (sand and fine gravel) and cohesive sediments (38% clay, 52% silt, 10% fine sand). The characteristics of scour like maximum static scour depth, temporal variation of scour depth, radius of scour and dune height were obtained. An ANN model for predicting the scour holes dimensions from the hydraulic properties of the jet and the properties of the sediments was also developed.

In case of cohesionless sediments, temporal variation of scour depth has been quantified by testing the functional relationships available in the literature and new working relations have been proposed for estimation of equilibrium scour time. Scour parameters have been analyzed using the data collected in the present study and that available in literature. In case of cohesive sediments, maximum static scour depth has been analyzed with varying flow jet conditions. Working relations have been proposed to study the effect of various jet parameters and the maximum static scour depth and maximum volume of scour. The proposed equations have been validated by using the data collected in present study and the data reported in the literature. The data collected in present study has been analyzed in dimensional and non-dimensional form to generate an ANN model to determine maximum scour depth and their performance has been evaluated using coefficient of correlation.

Keywords: Static scour depth; Temporal variation; Coefficient of correlation; ANN model.

1 Introduction

The process of lowering of river bed level due to removal of bed material in the vicinity of hydraulic structures by erosion action of flowing water is termed as scour. Most often the flow downstream of hydraulic structures is of the form of water jet, such as the flow from spillway, downstream of gates, at the outlet of culverts and over the drops [1].

Study of scour by jets is important for assessing the stability of such structures that may be affected by erosion of the downstream bed [2]. Hydraulic jets have several uses in present world such as to inject industrial pollutants or effluent into the rivers and seas or for sediment management in run-off reservoirs and intakes etc. Most often the flow downstream of hydraulic structures is in the form of water jet, such as the flow from spillway, downstream of gates, at the outlet of culverts and over the drops. An understanding of the role of the various parameters that affect the scouring process and the jet behaviour during scour is very important. The exploratory examination on scour because of submerged vertical jet in uniform soil was first led by Rouse [3]. In addition to the safety of hydraulic structures, understanding of the jet behaviour during scour is also important because of the increasing use of jets in other applications.

2 Experimental Setup

A rectangular steel tank 1.24 m long and 1.24 m wide, with depth 0.84m, was used, which could be filled with the desired sediments upon which submerged vertical circular jet was intended to be impinged. It was ensured that the tank's boundary was sufficiently large so that it would not have any influence on scour process. The impinging jet was produced by a nozzle of diameter 0.0162m located at the bottom of a cylindrical pipe of diameter 0.75'' i.e. 1.90 cm which was connected with an inlet, regulated by a valve to control the flow rate or discharge from the constant head arrangement provided in the lab. The nozzle could be located at any desired height above the prepared sediment bed. Nozzle was mounted on a steel bar which can be fixed at desirable height on the guide bars provided on the sides of the steel tank. The jet discharge is measure by using calibrated venturimeter provided in the inlet pipe. The experimental setup for scour under submerged circular vertical water jet in cohesionless sediment channel bed is shown in Fig. 1. The Fig. 2 shows the experimental setup used for the cohesive.

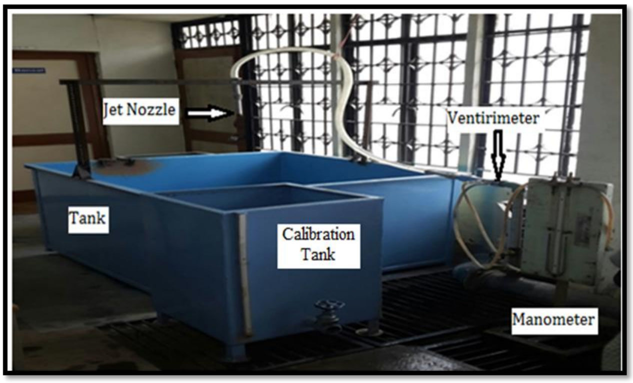

Fig.1. Experimental setup for scouring in cohessionless sediment

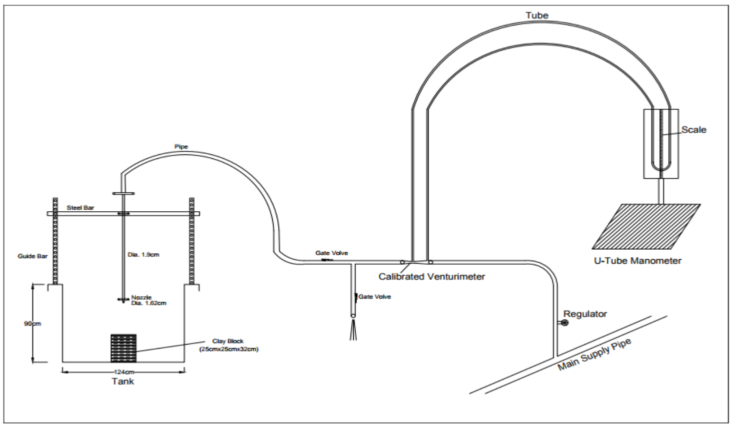

Fig. 2. Definition sketch of setup for scouring in cohesive sediments

3 Materials and Methods

3.1 Cohesionless sediment

Cohesionless sediment (fine gravel) was used for the preparation of channel bed having sediment size (d_{50}) as 3.34 mm and specific gravity as 2.65. Total 16 experiments were conducted with four different jet velocities i.e. 1.57m/s, 2.23m/s, 2.87m/s and 3.94m/s and four different impingement heights 5cm, 9cm, 18cm and 32cm.

3.2 Cohesive sediment

Locally available soil was used having mean particle size (d_{50}) of 0.0015 mm and specific gravity of 2.67 and 90% of which passed through 75-micron sieve (IS Sieve No. 200). Total 9 experiments were conducted with three different jet velocities i.e. 1.57m/s, 2.23m/sand 2.87m/s using three different impingement heights of 5cm, 9cm and 18cm from the original bed level in case of cohesive sediments.

4 Results and Discussion

4.1 Temporal variation of Scour depth

The variation of static scour depth during experimental runs was observed until there was no change or a very small change in its values (1mm or less than 1mm). Most of the scouring (about 75%) occurs in the starting 45 minutes from commencement of the experimental run [4]. The equation 1 has been proposed by applying multi-linear regression on the data collected from the present study to express the equilibrium scour time in dimensionless form.

$$\frac{T_s}{H/U} = 31.71\left(\frac{d}{H}\right)^{0.500}\left(\frac{d_{50}}{H}\right)^{-0.148}\left(\frac{U}{\sqrt{gH}}\right)^{0.945} \tag{1}$$

From Eq. (1), the value of R^2 was found to be 0.935.
Where T_s= time required to reach the maximum scour depth; H= height of jet from the bed level; U= jet velocity; d= diameter of jet; d_{50}= mean size of sediments; g= gravitational constant; R^2= coefficient of correlation.

4.2 Relation for maximum static scour depth

In case of each experimental run, the depths of static scour was measured. The following Eq. 2 has been proposed by applying multi-linear regression on the data collected from the present study to express the equilibrium scour time in dimensionless form:

$$\frac{d_{sms}}{H} = 0.468\left(\frac{d}{H}\right)^{1.098}\left(\frac{d_{50}}{H}\right)^{-0.391}\left(\frac{U}{\sqrt{gH}}\right)^{0.516} \tag{2}$$

From Eq. (2), the value of R^2 was found to be 0.945.
Computed maximum scour depth has been compared with available literature. The Fig. 3 shows the comparison between the observed and calculated value of d_{sms}/H. It can be seen from Fig. 3 that most of the data point collected from present study was found to be similar with data of the previous researchers [5, 6].

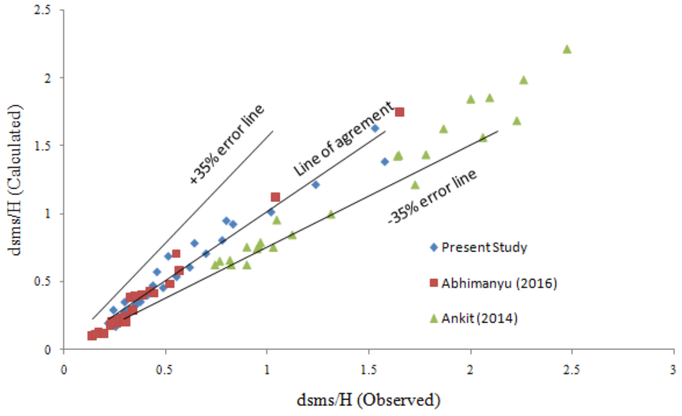

Fig.3. Comparison of observed and computed maximum scour depth

4.3 ANN model for prediction of maximum static scour depth

To assess the performance of the models, the equilibrium scour data consisting of 132 data points collected from experimentally and literature review. The range of these parameters used to generate the ANN model is given below in the Table 1:

Table 1. Range of different parameters for jet scouring

Parameter	Range
Maximum scour depth, d_{sms} (cm)	1.04-49.4
Diameter of nozzle, d (cm)	0.8-12.7
Sediment size, d_{50} (cm)	0.047-0.334
Jet velocity, U_0 (m/sec)	1.29-9.84
Impingement Height, H (cm)	1-53

Network training, testing and validation. The figures 4, 5 and 6 compare the observed and predicted values of scour depth for the training, testing and validation data, respectively. Eighty percent [7] input-output patterns were used for network training while remaining ones were used for testing and validation the trained network.

It can be seen from Figs. 4, 5 & 6 that the values of statistical error parameter i.e. correlation coefficient (r) were found to be 0.9886, 0.9969 and 0.97824 from training, testing and validation stages, respectively. While the correlation coefficient obtained in equation 2 was 0.945 which clearly shows that the ANN model performs most satisfactory in comparison to multi-linear regression, for prediction of scour depth due to submerged circular vertical jet in cohesionless sediments.

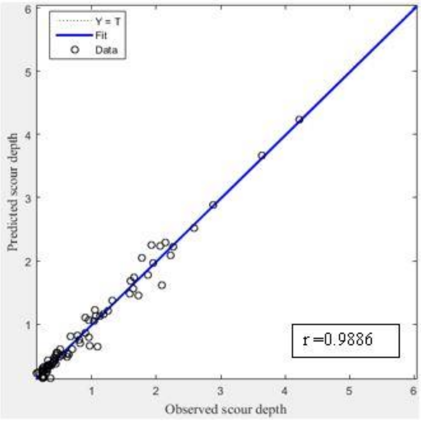

Fig.4. Scatter plot of observed and predicted equilibrium scour depth for training (non-dimensional parameter)

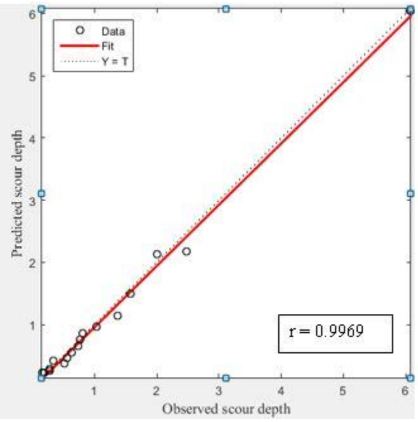

Fig.5. Scatter plot of observed and predicted equilibrium scour depth for testing (non-dimensional parameter)

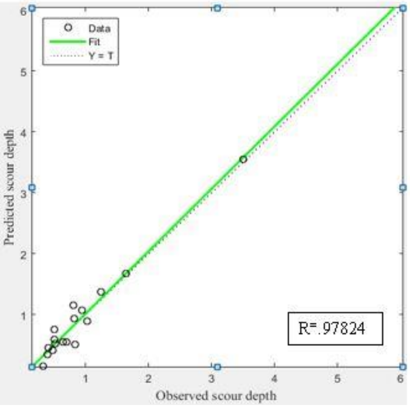

Fig.6. Scatter plot of observed and predicted equilibrium scour depth for validation(non-dimensional parameter)

5 Maximum Scour Depth(d_{smc})-Cohesive Sediments

The data collected from present study was analysed using multi-linear regression, and the following equation has been obtained:

$$\frac{d_{smc}}{H^3} = 0.882\left(\frac{d}{H}\right)^{3.441}\left(\frac{U_0 \rho H}{\tau_c}\right)^{1.592} \tag{3}$$

From Eq. (3), the value of R^2 was found to be 0.967.

Where d_{smc}= maximum scour depth in cohesive soil; H= height of jet from the bed level; U_o= jet velocity; d= diameter of jet; τ_c= critical shear stress of soil; ρ= density of fluid (water).

Implementations and results. To assess the performance of the models, the equilibrium scour data consisting of 45 data points, collected from experimentally and literature review. The range of these parameters used to generate the ANN model is given below in the table 2:

Table 2. Range of different parameters for jet scouring

Parameters	Range
Maximum static scour depth, (d_{smc})	0.35-18.49 (cm)
Diameter of nozzle, (d)	0.4-1.62 (cm)
Critical Shear stress of soil, (τ_c)	257-300
Jet velocity, (U_0)	1.57-25.86 (m/sec)
Impingement Height, (H)	4-18 (cm)

Network Training, Testing and Validation. To assess the performance of the models, the equilibrium scour data consisting of 45 data points, have been collected from experimentally and literature review. Eighty percent input-output patterns were used for network training while remaining ones were used for testing and validation the trained network.

It can be seen from Figs. 7, 8 & 9 that the values of correlation coefficient (r) were found to be 0.98761, 0.9982 and 0.9887 from training, testing and validation stages, respectively. While the correlation coefficient obtained in equation 3 was 0.967 which clearly shows that the ANN model performs most satisfactory in comparison to multilinear regression, for prediction of scour depth due to submerged circular vertical jet in cohesionless sediments also.

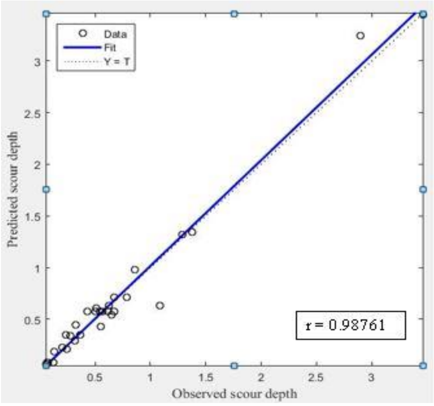

Fig.7. Scatter plot of observed and predicted equilibrium scour depth for training (non-dimensional parameter)

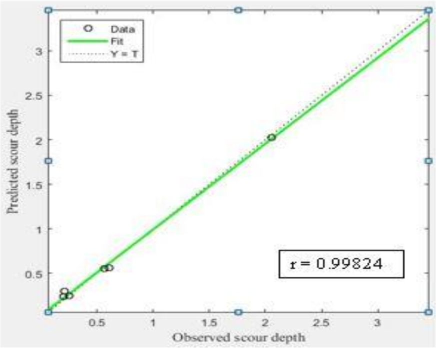

Fig.8. Scatter plot of observed and predicted equilibrium scour depth for testing(non-dimensional parameter)

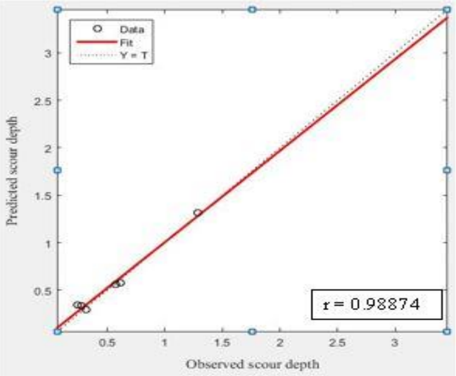

Fig.9. Scatter plot of observed and predicted equilibrium scour depth for validation(non-dimensional parameter

6 Conclusions

In case of cohessionless sediments the equilibrium scour time (T_s) is the function of jet velocity and jet impingement height. In cohesive soil, the scour hole radius is distinct for scour by jets as compare to that in cohessionless sediments. In cohesive soil the form of erosion was mass erosion i.e. removal of the soi1 in the form of chunks that varied in size. There was no "ridge" that formed outside the scour hole. As well, the maximum scour depth typically did not fall along the jet centre line. The ANN Model gives better results in analysis as compared to Regression model analysis in both cases.

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