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ORIGINAL ARTICLE

Experimental Study of Scouring Pattern due to Circular Submerged jet in Shallow Ambient Fluid

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ABSTRACT
Hydraulic jets have found universal use in various fields of engineering and industry nowadays. Among the applications of various kinds of jets, this article draws on a study of downstream scour patterns for circular jets in low-depth receiving fluids. The tests are conducted in a flume with a width of 150, a height of 100, and a length of 600 centimeters. In each test, the flow rate, length, depth and width for the scour was measured and recorded by means of measurement instruments.
Keywords: Hydraulic jet, Sediment Scouring, Submerged jet.

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INTRODUCTION

Todays, hydraulic jets have found worldwide use in various fields of engineering and industry; they can be used in water and wastewater treatment plants, diluents, the transfusion of contaminants into rivers and oceans, lowering water energy and recently in dredging sediment washing deposits from rivers and reservoirs. Sedimentation, an important setback for hydraulic structures, can be addressed in two ways: First, the structure should be designed in a way that minimizes sedimentation. The second way is to remove the sediments by means of mechanical or hydraulic methods. In 1981, Rajaratnam studied scours brought about by submerged wall jets. Furthermore, Jenkins et al. in 1981 and Dellaripa and Bailard in 1989 studied the use of submerged jets in order to eliminate sediments from navigation locks. Through building a laboratory model, Sequeirosa et al. [1] examined the value of shear stress attritional caused by effect of planar jets and circular jets. Mehraeen et al. [2] concluded that the less the angle with the horizon, the vaster the scour patterns. Ahadian et al. [3] studied the factors effective on the flow of submerged jets in stationary receiving water reservoirs. Furthermore, Ahadiyan and Mousavi Jahromi [4] conducted a study on the trajectory geometric characteristics of submerged jets. The studies conducted so far cover the turbulence power of jets, their distribution and diffusion in the receiving fluid, and the scour brought about by planar and circular jets.

MATERIALS AND METHODS

Laboratory Model setup

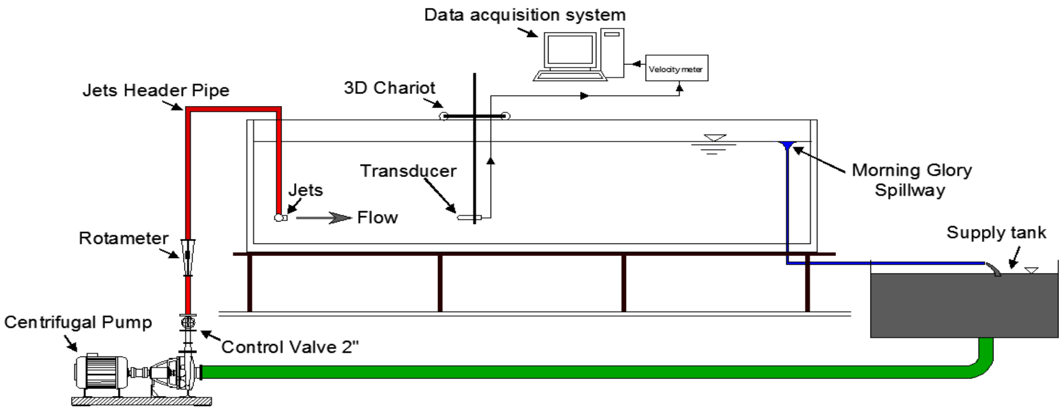
Since the present research aims to study downstream scours of jets by means of a physical model, a laboratory model was built and expanded to facilitate the tests concerned in this research. To plan for the tests of the research, they were all done at a constant nozzle's diameter of 1 centimeter, constant particles diameter, and three submersion levels of 10, 30 and 50 centimeters, and soil gradation of d_{95} with four different flows. Table 1 shows the plan of the tests conducted for this research.

Table.1 List of test scenarios

Submergence Depth(Cm)	Nozzle Discharge(lit/min)	Sediment Diameter	Jet NO
10 30 50	1.6 2 2.5 3	D_{95}	1

12 scour tests were considered according to the table above. Then, based on the test scenarios, a laboratory flume was built. The equipment built and used for the tests consisted of reservoirs for the water supply reservoir, the floor pump to transfer water to the test flume, the jet water supply reservoir and the jet grouting centrifugal pumps, the test flume, the baffled apron drops the morning glory spillway for downstream side of the flume end and the related discharge system and equipment, two- and three-dimensional chariot carriers to measure scour dimensions, a nozzle with a diameter of 10 millimeters, a flume floor drainage system to drain sediments from the flume floor, the bed material, the jet flow distribution system, a rotameter to measure flow rates, a laser distance meter to record scour patters (made by the German company BOSCH). Figure 1 displays the flume flow diagram, in which the red path represents the jet influx path, the green part of the line shows the suction of the pumps, the blue pipes represent the morning glory baffled apron drops spillway and the related discharge pipes for the fixation of the water level balance.

Figure.1 Jet grouting flow diagram



- **Dimensional Analysis**

Considering the parameters affecting the phenomenon of scours caused by jets, and in order to obtain dimensionless equations in this research, a dimensional analysis of the parameters effective in the phenomenon was conducted. The dimensionless equations were extracted for this phenomenon according to Equation.1 and by means of the dimensional analysis of the parameters mentioned above:

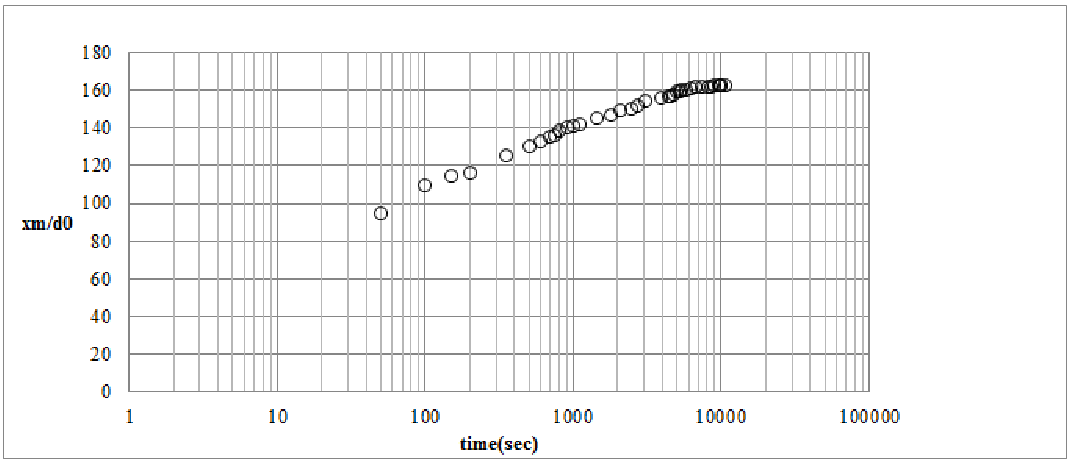
$$f\left(\frac{U_0\rho d_0}{\mu}, \frac{U_0}{\sqrt{gd_0}}, \frac{U_0}{\sqrt{g\frac{\Delta\rho}{\rho}d_{95}}}, \frac{H}{d_0}, \frac{X_{max}}{d_0}, \frac{y_{max}}{d_0}, \frac{Z_m}{d_0}, \frac{U_m}{U_0}, \frac{X_{max}}{D_{95}}, \frac{Z_{max}}{D_{95}}\right) = 0 \qquad (1)$$

In Equation 1, the first parameter is the Reynolds number for the jet output, the second parameter represents the Froude number for the jet output, the third parameter indicates the densimetric Froude number of the sediment particles, the fourth parameter involves the jet submersion number, the fifth parameter is the dimensionless ratio of the maximum jet longitudinal profile, the sixth parameter is the maximum scour width ratio, the seventh parameter represents the maximum scour depth ratio, the eighth parameter is the dimensionless ratio of the central jet flow velocity to the initial speed, the ninth parameter consists of the ratio of maximum length to the average diameter of the sediment particles, and the tenth parameter is the ratio of maximum scour depth to the average diameter of the sediment particles. It should be noted that the tests were planned so that the Reynolds number for the jet flow would fall into the turbulent flow range at all times; therefore, the Reynolds number has been eliminated from the results presented.

The equilibrium time

Before starting sedimentation tests, the equilibrium time test was used for the sediments existing on the bed used for the tests. In order to conduct these tests, the flow was cut at certain time intervals and the parameter x_m was measured. This part of the tests was highly time-consuming; each test took 6 hours. Thus, based on the results displayed in Diagram 1, the balance time for each test is approximately 3 hours.

Diagram.1 The equilibrium time test for sediments



RESULTS AND DISCUSSION

The Variables Measured

The flumes for the tests and the manner the tests were conducted in have been previously discussed. In this section, the data measured based on the test scenarios and the conducted dimensional analysis will be presented. In this research, the jet Froude number range was 18 to 34, the densimetric Froude number for the sediment particles was 35 to 68; the jet Reynolds number at the time tests were being conducted was in a 5600-106100 range.

Downstream Nozzle Scour Patterns

This section concerns the main purpose of this research – downstream nozzle scour patterns. In 1976, Rajaratnam showed that the effect of Reynolds numbers in creating scour holes caused by planar jets is negligible if its amount is more than 3000. According to Equation (2), the nozzle downstream scour pattern is directly related to the densimetric Froude number.

$$\frac{X_{max}}{d_0}, \frac{y_m}{d_0}, \frac{z_m}{d_0}, \frac{x_{ym}}{d_0}, \frac{H_m}{d_0}, \frac{x_m}{d_0}, \frac{H}{d_0} = f(Fr_d) \quad (2)$$

Based on the study conducted by Jenkins et al. (1981), x_m and y_m – defined as scour radius parameters – are regarded as the most important parameters involved in the development of flow patterns. In his research, Jenkins defines x_m as r_m, and calls it the scour radius. Furthermore, the two parameters x_m and y_m are also considered to be the main parameters involved in the determination the number of series and parallels influential in downstream jet scour patterns. In this research, having sketched all of the parameters involved in Equation 2, the results obtained by Jenkins et al. was confirmed; and the other parameters, $\frac{z_m}{d_0}$, $\frac{x_{ym}}{d_0}$, were also found to be affected by them, and thus increased by the same proportion.

Moreover, another effective parameter which was affected in this research by submersion levels is $\frac{H}{d_0}$, which will be studied. Having conducted the balance time test and determined the influential parameters according to Equation 2, tests were begun with submersion depths 50 times the nozzle diameter and various Froude numbers were tested for this level. Diagram 2 shows the longitudinal scour profile for submersion depths of 50 on the central axis of the jet. According to Figure 2, depth of scour hole and sediment stack increase with higher Froude numbers.

Figure.2 The image of the scour pattern at a submersion depth of 30

To quantify the longitudinal scour profile for the nozzle with various submersion levels, sediment particle Froude numbers have been displayed in Diagrams 2 to5.

Diagram.2 Longitudinal scour profiles along the nozzle x-axis for $50=\frac{H}{d_0}$

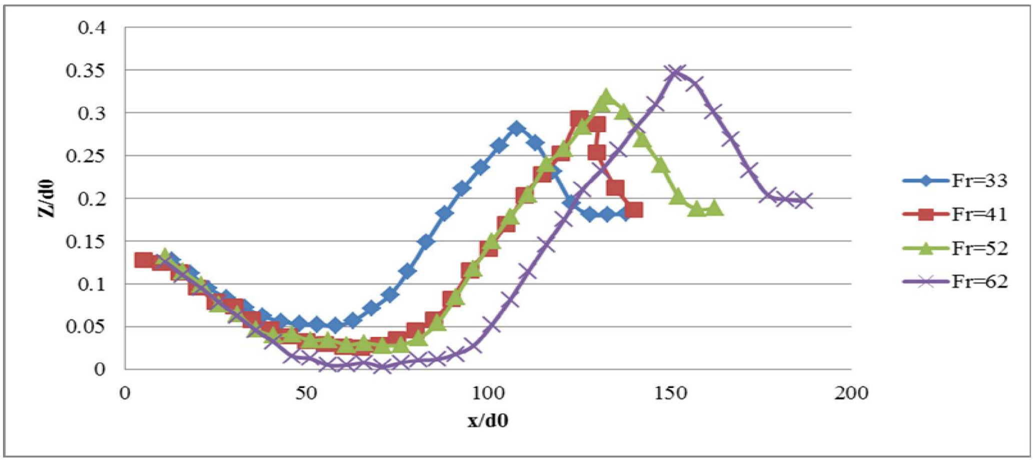


Diagram.3 comparison of longitudinal scour profiles along the nozzle x-axis for $30=\frac{H}{d_0}$

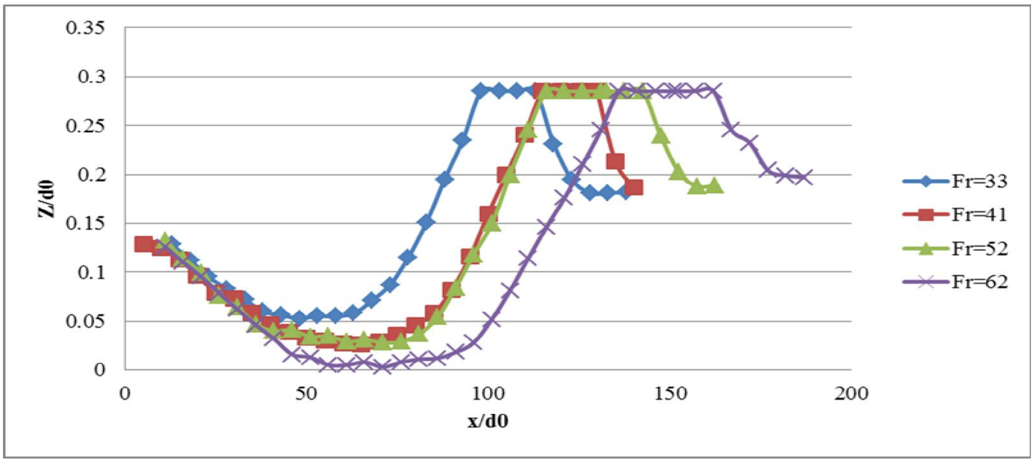


Diagram.4 comparison of longitudinal scour profiles along the nozzle x-axis for $h/d_0=10$

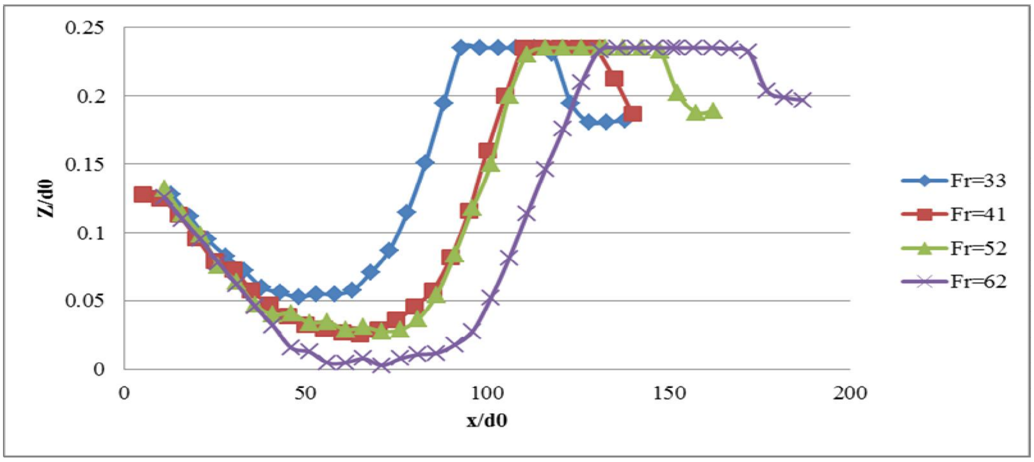
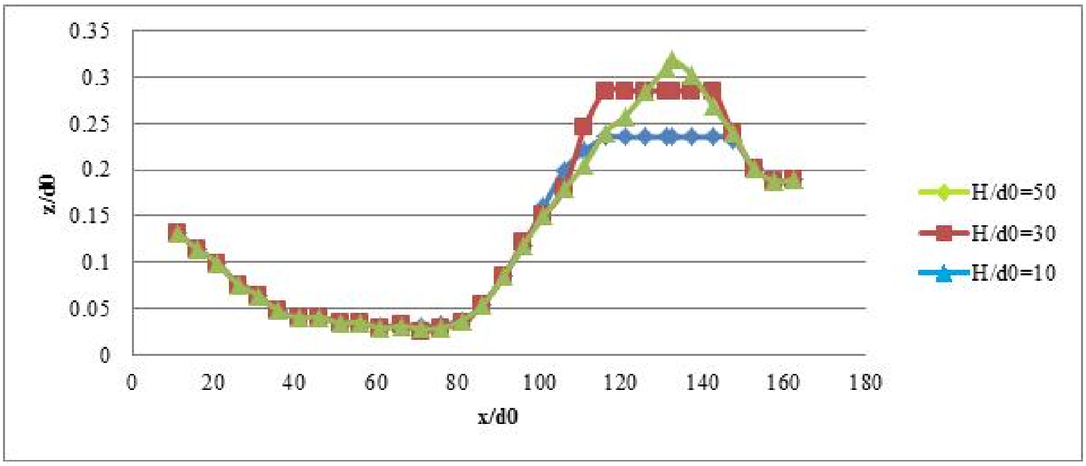


Diagram.5 comparison of downstream scour profiles with changes in submersion depth with a densimetric Froude of 52



According to Diagrams 2 and 5, by changing the depth of submersion from 50 to 100, it is observed that the maximum sediment stack is equal to water level; in other words, in ebb and flow conditions, if the level of the submersion depth is less than the sediment stack, the sediment stack will not be in the form of a summit, and the summit will be flat.

CONCLUSION

This research examined the factors influential on circular jet scour patterns in non-homogeneous sediment particle bed. The results obtained can be summed up as follows:

1. As observed, by changing the depth of submersion from 50 to 100, the maximum sediment stack is equal to water level balances; in other words, in ebb and flow conditions, if the balance of the submersion depth is less than the sediment stack, the sediment stack will not be in the form of a summit, and the summit will be flat.
2. Due to the lack of any significant effects left by the depth of submersion on the dimensions of scour holes, it is recommended that leaching in rivers with ebb and flow be carried out at complete flow, for not only the depth of submersion has no influence, but the movement of the concentrated flow towards downstream is the result of leaching at the beginning of the ebb.
3. The depth of submersion proved to have no significant effect on the scour hole up to 50 times the nozzle diameter.

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