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Experimental Study of Bell-Mouth Intakes on Discharge Coefficient

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ABSTRACT: The strong vortices at the mouth of an intake reduce the discharge efficiency. One of the solutions for controlling the vortex is the use of bell-mouth intakes. Since only general guidance for use of bell-mouth intakes is available a study for the more shapes of mouth of intake is needed. Hence, a comprehensive set of experiments have been carried out using 4 different mouth-shapes of a vertical intake. The results showed that with reducing the radius of curvature of bell-mouth intake, the coefficient of discharge rate increased, and maximum discharge coefficient with four different mouth shape of intake with the radius of curvature of 2d was created.
Keywords: Discharge coefficient, bell-mouth intake, vortex, radius of curvature of mouth of intake.

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INTRODUCTION

For various purposes water is taken from reservoir by the structures named intake. Intake structure controls the flow into conveyance system with the help of gate. When the submergence of an intake is not sufficient, air enters the intake through the air-core vortex and causes some hydraulic problems such as discharge reduction, loss of efficiency in turbines and water conveyance structures. The common solution for avoiding air entrainment is to provide the greater water head than critical submergence. The lowest vertical distance between the water level and upper level of intake that is not associated with a vortex with air entrainment, is called critical submergence.

In all engineering projects, designing of the intakes are handled by two principles; minimizing the cost and maximizing the efficiency. Vortex occurrence in an intake structure can increase critical submergence and decrease discharge coefficient that both of them are not an optimum hydraulic performance.

Several researchers have studied the relationship of vortex occurrence and intake submergence trying to find good guidance for engineers designing any kind of submerged intakes. They were mostly interested in air entraining vortices, as they are the source of biggest destroying occurrence in hydraulic machinery. Hecker (1987) shows that air entrainment takes place at vortex types 5 and 6 (of in total six stages) (Figure 1).

The formation of a vortex may appear at any kind of intake and is independent of its utilization, but the consequences and their importance differ considerably.

Rindels and Gulliver (1987) conducted studies on weak surface vortices at bell-mouth vertical intakes with headrace channel by experimental models. Guide vanes were placed to set the approach angle to the headrace, thirteen experiments were conducted with different approach angles and Froude number ranges between 0.25 and 2.2. Variations of S_C/d with Froude number were provided.

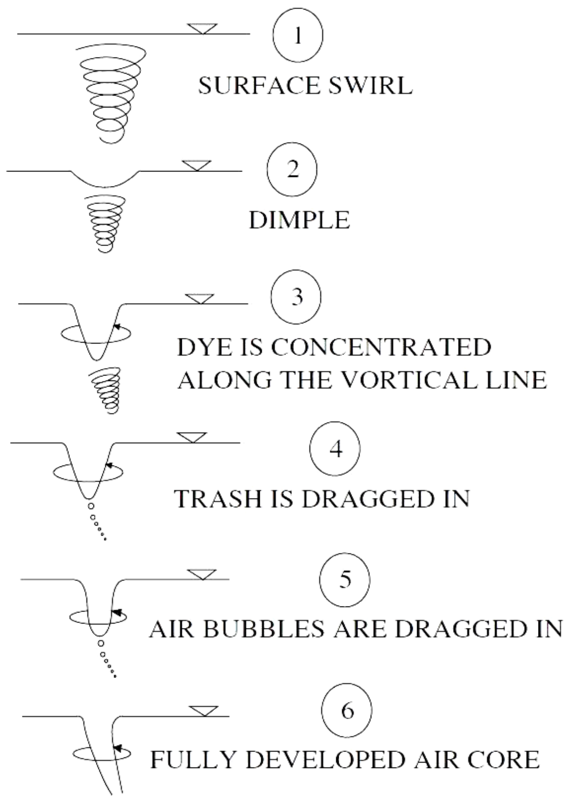

Figure 1. Vortex type classification (Hecker, 1987).

Yıldırım and Kocabas (1995) concentrated studies on critical submergence determination in intakes with air core vortex formation. To form flow area theoretically, a point sink was superposed with uniform channel flow. In their study, the discharge of the point sink was equated to the discharge of the uniform flow to provide continuity in the system. In their experiment, the critical submergence level was set to radius of the imaginary point sink. By both theoretical findings and empirical studies, critical submergence was formulated as:

$$\frac{S_C}{d}=\frac{1}{2\sqrt{2}}\left(C_D\frac{V}{U_\infty}\right)^{0.5}$$

Where S_C/d is critical submergence ratio, C_D is the coefficient of discharge, v is velocity of intake discharge and U_∞ is the uniform canal flow velocity.

Sohn et al. (2009) showed that a vane-type suppressor is effective to prevent vortex formation. A circular flat plate with porous wall was used by Mahyari et al. (2010). With increasing of submergence, discharge is reduced. In the bell-mouth intakes with reducing cross section, the flow velocity increases and pressure decreases in the centre axial of the intake. In this condition until the pressure of centre axial of intake is not less than atmospheric pressure the air core is not formed. So the phenomenon of vortex, in effect of interaction mouth shape of intake, intake submergence and fluid properties such as viscosity and surface tension is formed. Hitherto, there are not so investigations about critical submergence in tank with bell-mouth port, so the aim of present research is to study critical submergence and discharge coefficient in a cylindrical tank with bell-mouth drain port. In the following parts, the critical submergence is determined experimentally without any vortex suppressor and then discharge coefficient is calculated subsequently.

Governing Parameters

Important dimensionless terms which should be used for experimental studies to define the discharge coefficient and critical submergence of vertical intake are:

$\frac{S_C}{d}$: Relative Submergence

$C_D=\frac{4Q}{\pi d^2\sqrt{2g\frac{S_C}{d}}}$: Discharge Coefficient

$Fr=\frac{4Q}{\pi d^2\sqrt{gd^5}}$: Froude number

$Re=\frac{Q}{\upsilon d}$: Reynolds number

$We=\frac{\rho v^2 d}{\sigma}$: Weber number

Where S_C is critical submergence, d is pipe intake diameter, Q is discharge, g is gravitational acceleration, υ is kinematic viscosity, ρ is density, σ is surface tension and v is the flow velocity in the pipe. According to the recommended Weber number and Reynolds number ranges that is mentioned in table 1, the effect of surface tension and viscosity could be neglected.

Table 1. Renge of Weber Number and Reynolds Number for neglecting the effect of surface tension and viscosity.

Researcher	We	Re
Daggett and Keulegan (1974)	$We\le 120$	$Q/(vD)\ge 3\times 10^3$
Anwar et al. (1978)	$We\le 120$	$Q/(vS)\ge 3\times 10^4$
Jain et al. (1978)	$We\le 120$	$\frac{\sqrt{gD^3}}{v}\ge 5\times 10^4$
Padmanabhan and Hecker (1984)	$We\le 600$	$vD\ge 7.7\times 10^4$
Odgaard (1986)	$We\le 720$	$vD\ge 1.1\times 10^5$

MATERIALS AND METHODS

In this research, four different mouth shapes of vertical intake for 24 discharge rates in a cylindrical tank were tested and corresponding critical submergences were recorded subsequently. The experiments were conducted at the hydraulic laboratory at Tabriz University, in Iran. Experiments were carried out in a tank that is made of 2 parts. First part is a cube 1.0 meter length and 1.0 meter height and the second part is a semi-cylindrical tank, 1.0 meter in diameter and 1.0 meter in height. Figure 2 shows the schematic of the tank. The circulated water was pumped from a large sump and a triangular weir was used to measure actual discharge of vertical intake (at end of experimental model). Flow enters the first part of tank horizontally and uniformly through a sand screen diffuser. The sand screen was set in the tank to make flow further smooth by using a 0.1 meter thick rock crib, which consisted of rocks coarser 0.01 meter sieve.

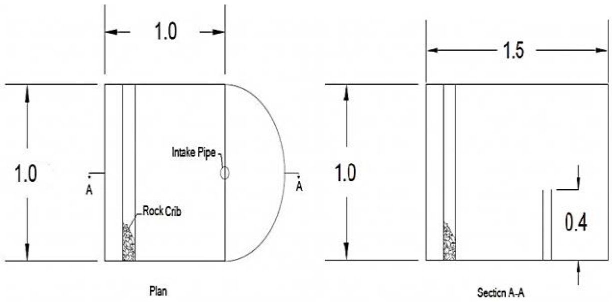

Figure 2. Schematic of tank used in the present work.

The flow discharges through a vertical pipe intake, 0.4 meter in height and 0.0704 meter diameter at the centre of second part of the tank. Figure 3 shows the experimental setup.

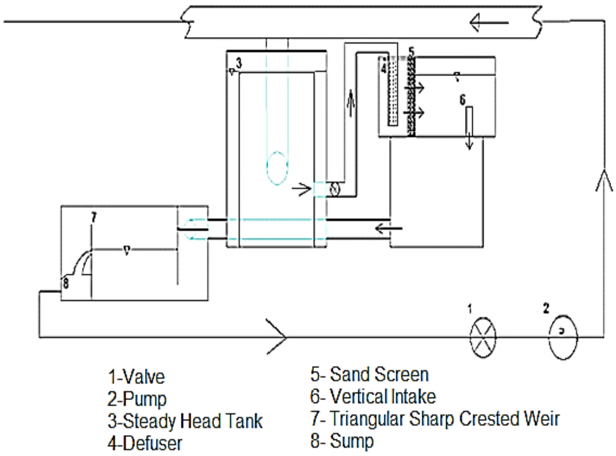

Figure 3. Schematic of experimental setup.

Two ultrasonic point gage level meters was used to measure depth of flow on the upper level of intake mouth and behind of triangular weir.

The test variables were discharge and the radius of curvature of intake mouth. The height of mouth shapes number 2 to 4 was 0.5d and the outer radius of them was 2d and the radiuses of curvature were 2d, 1.5 d and d. Figure 4 shows the schematic of four mouth shapes of intakes used in present work. Figure 5 shows bell-mouth vertical intake used in present work.

Each test included feeding the test tank by using pump, with 12 minute delay time the experiment is started and liquid is drained from test tank and the flow rate and reservoir submergence was controlled by a gate valve that is connected to the lowest level of vertical intake. The free surface of liquid in the tank is recorded by an ultrasonic point gage level meter. After air entered the vertical intake, the submergence in the tank is recorded and drained flow is measured by triangular weir and then the experiment is finished.

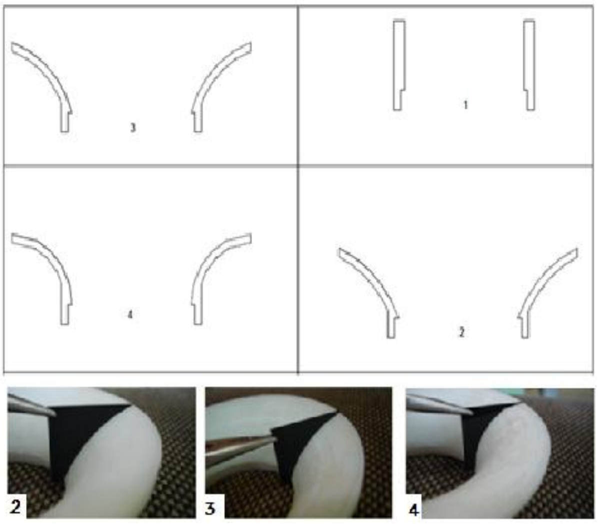

Figure 4. Schematic of 4 mouth shapes of intake used in present work.

Figure 5. Bell-mouth vertical intake used in present work.

RESULTS AND DISCUSSION

In the experimental model, the geometry is fixed, and the Reynolds number and Weber number are large enough so their effects on the experimental results are ignored. The critical submergences in different discharge rates were measured. Hence the most significant variables involved in this situation, as discussed previously are Froude number, critical submergence and the radius of curvature. For a comparison of bell-mouth intakes with together and with a reference, first experiments were carried out on a simple intake mouth named intake mouth number 1. The intake mouth number 1 results are showed in figure 6.

As can be seen in figures 6 to 9, the submergence ratio changes, against the Froude number is uptrend. And with increasing submergence ratio, the discharge coefficient is increasing too as it is shown in Figure 10.

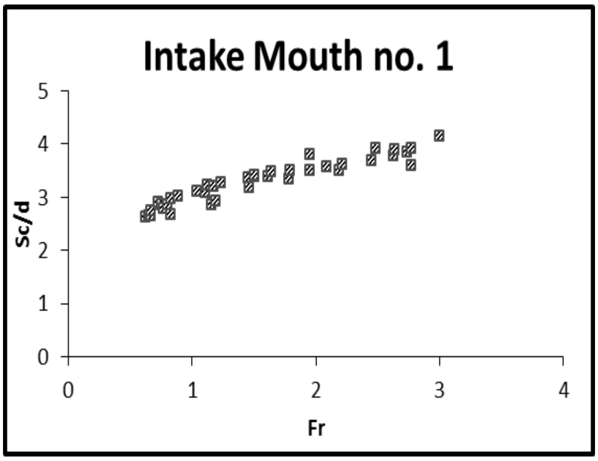

Figure 6. The Experimental results of the critical submergence at various Froude numbers. (Intake mouth No.1)

By experimental findings, critical submergence for simple vertical intake is formulated as:

$$\frac{S_C}{d} = 3Fr^{0.248}$$

Then, three different radiuses of curvature equal to d, 1.5d and 2d named intake mouth no.2, 3 and 4 were installed on vertical intake and the relevant results are showed in figures 7 to 9.

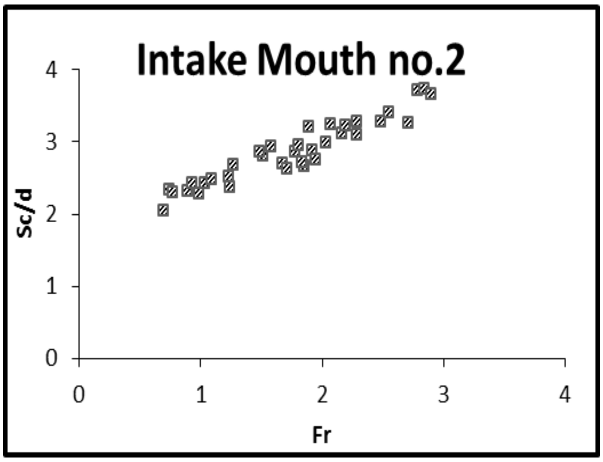

Figure 7. The Experimental results of the critical submergence at various Froude numbers. (Intake mouth No.2)

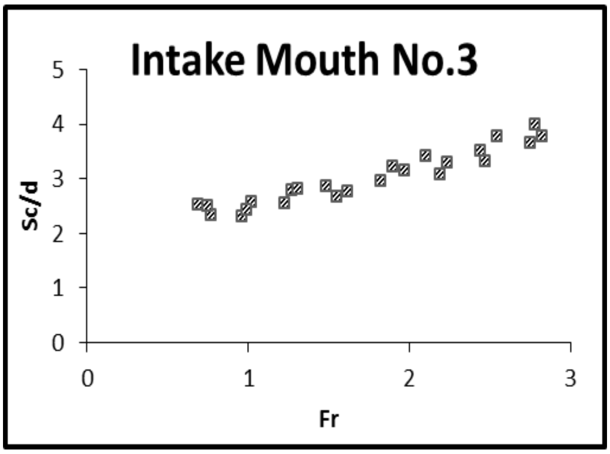

Figure 8. The Experimental results of the critical submergence at various Froude numbers. (Intake mouth No.3)

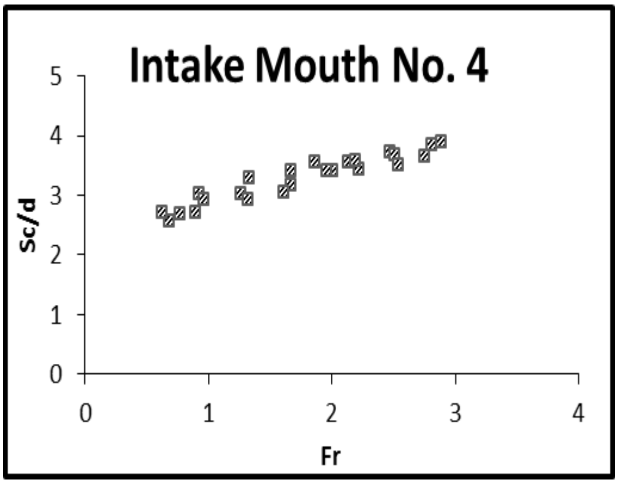

Figure 9. The Experimental results of the critical submergence at various Froude numbers. (Intake mouth No.4)

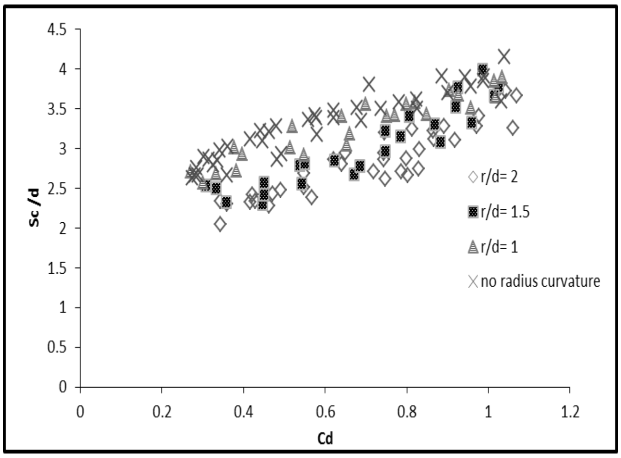

Figure 10. Variation of discharge coefficient against the critical submergence ratio.

As is showed in figure 10, in the constant discharge coefficient, with increasing radius of curvature of intake mouth, the critical submergence rate is decreasing. Existence of bell-mouth drain port instead of simple shape of intake makes the flow with lower critical submergence to reach the higher discharge coefficient. According to the results, it can be mentioned that with increasing discharge of intake, effect of curvature of intake mouth to reduce critical submergence of intake will be less. Figure 10 is showing that a clear different between the critical submergence of the intake mouth with curvature radius profile and simple intake mouth. This fact shows that intake mouth with curvature, which is named bell-mouth intake, effectively prevents vortex formation and can cross flow with high efficiency.

CONCLUSION

Bell-mouth intake is one of the drain ports is used when high discharge efficiency is needed. The main problem they are forced with all of intakes is development strong vortex in their mouth. In this study, the critical submergence of bell-mouth vertical intakes was investigated in a reservoir tank. Developed equation can be used to predict critical submergence ratio for simple vertical intake while knowing hydraulic conditions. The results showed that with using bell-mouth intakes, critical submergence occurs in higher discharge rate also the maximum discharge coefficient with a radius of curvature of 2d of intake mouth was created. It should be mentioned that the proposed conclusion is made with the present experimental setup and many more experimental models is needed in order to achieve a generalized sequel.

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