Experimental Investigation of Pressure Flushing Technique in Reservoir Storages

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Abstract: - One of the most effective techniques for removing the deposited sediments from reservoirs is pressure flushing which has less local effects. It is often used as a clearing process to remove sediments around the entrance of intakes. In this study, the effect of bottom outlets cross section on the dimensions of flushing cone was investigated experimentally. The experiment was carried out with different bottom outlet diameters, different discharges and different water depths above the bottom outlets. The results indicate that the volume and dimension of flushing cone are strongly affected by the bottom outlet diameter. Finally, by using regression analysis, a dimensionless equation was presented for calculating the volume of sediment released from a dam during the pressure flushing.

Key-Words: - Pressure Flushing, Flushing Cone, Bottom Outlet, Cross Section, Sediment, Reservoirs.

1 Introduction

The loss of storage capacity with reservoir sedimentation is one of the most serious problems of dams. Sustaining the storage capacity of existing reservoirs has become an important issue rather than building new reservoirs which is difficult due to strict environmental regulations, high costs of construction, and lack of suitable dam site [1]. Several methods have been proposed to control sedimentation process. These may include catchment's management, flushing, sluicing, density current venting and dredging. Flushing is used to erode previously deposited sediments, sluicing is used to route incoming sediments through the reservoir by drawing down the water level, and density current venting is used to route incoming sediments through the reservoir without drawing own the water level [2]. One of the most effective techniques is flushing through which the deposited sediment is hydraulically removed by the flow. Hydraulic flushing is not a new technique. The oldest known method of flushing, practiced in Spain in the 16th century, was referred to by D'Rohan [3]. The excess in shear force of accelerated flows created by sudden opening of the bottom outlets of dams loosens and re-suspends the sediment. The flow will then wash them up from the system. If flushing takes place under a pressurized condition and the water level in reservoir is kept approximately constant, this flushing is called pressure flushing and has only local effects around the outlet. In pressurized flushing, the sediment in the vicinity of the outlet openings is scoured and a funnel shaped crater is created. Fig. 1 illustrates the longitudinal and plan view of flushing cone in the vicinity of bottom. This is only an option in reservoirs with small reservoir capacity to water inflow, and large capacity of sluices [4].

Pressurized flushing has been studied extensively in the literature. White and Bettess [5] studied how far releases affect the sediment deposits. They provided a diagram indicating the interrelationship between the limit distances of scour (in static water), reservoir depth and outlet discharge. Also their results showed that by decreasing water height in the reservoir, the rate of developing of scouring cone increases toward upstream for a given discharge.
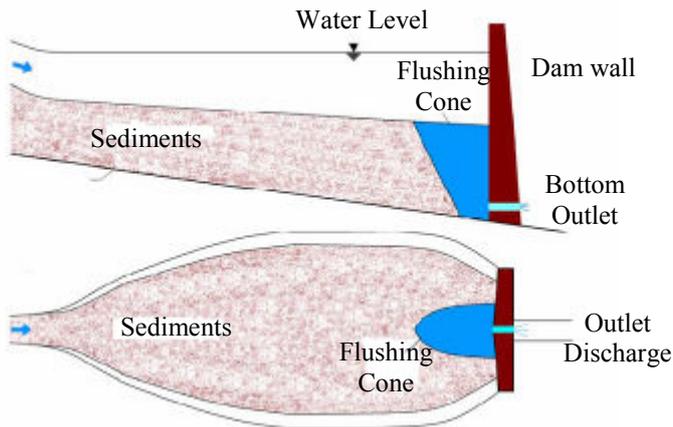
Figure 1 - longitudinal and plan view of flushing cone in the vicinity of bottom

Fang and Cao [6], using physical model, showed that large amounts of sediment are released in the beginning of flushing. Their study indicated that in equilibrium condition the clear water is released through bottom intake and funnel-shaped crater is developed with an angle of repose of the sediment. They also pointed out that although the effect of the funnel scour is restricted to the zone close to the intake, it has a very important role in preventing coarse sediment to enter power station. Fig. 2 illustrated the high concentration of sediment release from Jiroft dam (Iran), at the beginning of the pressure flushing operation [7]. For pressure flushing condition, Shen and et al. [8] presented a dimensionless regression relation for determining the maximum scouring depth of a lushing cone in non-cohesive sediment. Lai and Shen [1] investigated the flushing processes during drawdown flushing, including outflow sediment discharge, characteristics of the flushing channel and flushing effectiveness.

Scheuerlein *et al.*[9] indicated that in the pressurized flushing the flow pattern in the vicinity of the flushing outlets is three dimensional and also due to many parameters involved in the phenomena, analytical treatment is difficult (if not impossible). They also claimed that flushing actions are restricted to very limited efficiency and for successful continuation of the flushing action drawdown of water level is required.

Experimental studies by Emamgholizadeh et al. [10] showed that, by increasing the discharge from outlet and decreasing of reservoir's water depth, the amount of flushed sediment increases. And under same conditions the flushed sediment increases when the size of the sediment changes from course to fine. In spite of advances in the investigation of

pressure flushing technique at reservoir storage shown above, studies about the effect of bottom outlet diameter on flushing cone development are limited and more information about this phenomenon is needed.

Estimation of sediment volume removed or volume of flushing cone in this technique is important for designing bottom outlet gates, in which the optimum and the best bottom outlet can be designed with respect to the cross section. Researches for understanding the geometric variations of scouring cone with the cross section change of the bottom outlet are necessary in order to make a rational design for the bottom outlet. Designing the bottom outlets must be through an optimization between some important rules (stipulations) such as: gate cost versus economical value of the increased reservoir volume after flushing. Dimensions of flushing cone are also effective on rescue of power plant intakes.

Moreover, in the planning of dam operation, it can be vital to assess how much of the sediment can be removed, and how much flushing water is required.

This paper deals experimentally with pressure flushing phenomena and investigation about the effect of bottom outlet cross section on volume and dimensions of flushing cone.

Figure 2- Pressure Flushing operation in Jiroft dam, Iran.

2 Materials and Method

2. 1 Experimental setup

The experiments were conducted at the hydraulic laboratory of Gorgan University of Agricultural Sciences and Natural Resources in Iran [11].This experimental model consists of three main parts including, water supply system, main reservoir and settling basin reservoir.

2. 1. 1 Water supply system

It consists of an underground tank and a pump to recirculate a desired steady flow. The system is also supported by an adjusting valve, a digital flow-meter, and an 11-meter flume upstream of main reservoirs.

2. 1.2 Main reservoir

Main reservoir was hexahedral shape whose overall dimensions consist of 3 meter length, 2 meter wide and 1.5 meter height. Using two reticulate sheets at the reservoir's entrance, a smooth flow is created. The outlet of main reservoir includes a gate valve of diameter of 2.54 cm. Sediment deposits at the main reservoir. The sediment consists of silica particles with uniform size distribution with a median diameter of d_s=1 mm and geometric standard deviation of σ=1.25.

2. 1.3 settling basin reservoir

During the operation of bottom outlets, the mixing flow of water and sediment was trapped in settling basin reservoir. The basin is a rectangular flume of 3.6 meter long, 1 meter wide, and 0.76 meter height. At the end of settling reservoir there was a V-notch weir (with angle of 90°) to measure of outflow discharge.

2. 2 Dimension analysis

The volume of flushing cone ($V_{Scouring}$) may be written as a function of the following variables:

$$V_{Scouring} = \phi(Q_{Outlet}, A_{Outlet}, H_w, H_s, B, d_{50}, \rho_s, \rho_w, g, \upsilon) \quad (1)$$

where, U_{Outlet} is velocity of flow at the entrance of bottom outlet, A_{outlet} is the cross section of bottom outlet, H_w is the height of water above the center of bottom outlet, H_s is the height of sediment deposited above the center of outlet, B is the width of reservoir, d_{50} is the median size of sediment particles, ρ_s is the density of sediment, ρ_w is water density, and g is the acceleration due to gravity.

By using Buckingham theorem, and choosing the ρ_w, H_w, and U_{Outlet} as repeating variables, the following dimensionless parameters were obtained:

$$\pi_1 = \frac{V_{Scouring}}{H_w^3}, \quad \pi_2 = \frac{A_{Outlet}}{H_w^2}, \quad \pi_3 = \frac{H_S}{H_w}, \quad \pi_4 = \frac{B}{H_w}, \quad \pi_5 = \frac{d_{50}}{H_w},$$

$$\pi_6 = \frac{\rho_s}{\rho_w}, \quad \pi_7 = \frac{gH_w}{U^2_{Outlet}}, \quad \pi_8 = \frac{\upsilon}{H_w U_{Outlet}}$$

where the parameters H_s, B, d_{50}, ρ_s, ρ_w and g are constant. Hence, the aforementioned dimensionless

parameters can be summarized to four parameters. Consequently, the following functional relationship describes dimensionless flushing volume:

$$\frac{V_{Scouring}}{H_w^3} = \varphi(\frac{A_{Outlet}}{H_w^2}, \frac{H_s}{H_w}, \overbrace{\frac{U_{Outlet}}{\sqrt{g \times H_w}}}^{Fr_{outlet}}) \quad (2)$$

Using the same procedure, the dimension of flushing cone such as length ($L_{Scouring}$) and width ($W_{Scouring}$) of flushing cone can be expressed as:

$$\frac{L_{Scouring}}{H_w} = \varphi(\frac{A_{Outlet}}{H_w^2}, \frac{H_s}{H_w}, Fr_{Outlet}) \quad (3)$$

$$\frac{W_{Scouring}}{H_w} = \varphi(\frac{A_{Outlet}}{H_w^2}, \frac{H_s}{H_w}, Fr_{Outlet}) \quad (4)$$

The notation of flushing cone dimensions at the vicinity of bottom outlet and also a three-dimensional view of the flushing cone after the experiment with a discharge of 2 lit/s, water depth of 36 cm above the center of the outlet and 5.08 cm diameter of the outlet are illustrated in Fig. 3 and Fig. 4 respectively.

2. 3 Experiment Designing

For considering the effect of bottom outlet cross section on dimensions of flushing cone, the experiments were conducted with 3 different outlet diameters (1, 2 and 3 Inch), three water depth above the center of bottom outlet i.e. 36, 66, 96 cm and six different discharges. Table 1 and 2 shows the range of variables conducted in this study for measured experimental data and non-dimensional parameters for dimensional analysis.

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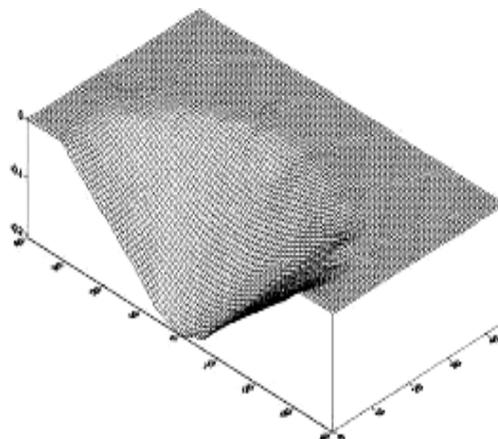
Figure 4 A three-dimensional view of the flushing cone, for discharge of 2 lit/s, water depth of 36 cm and 5.08 cm diameter of the outlet.
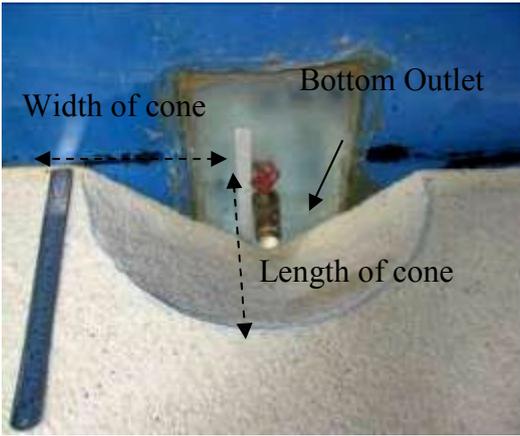
Figure 5 Flushing cone at the vicinity of bottom outlet

Table 1 Range of variables in this research

Parameters	Variations
Discharge release (Q_{Outlet})	0.15-14 Litr sec⁻1
Depth of water (H_w)	36, 66, 96
Bottom outlet (A_{Outlet})	1, 2 and 3 Inch

Table 2 Range of non-dimensional parameters in this research

Parameters	Variations
$V_{Scouring}/H_w^3$	3.74 E⁻⁵-0.0018
Fr	0.007-0.865
H_s/H_w	0.166-0.444
A_{Outlet}/H_w^2	0.0003-0.0368

2. 4 Experimental Procedure

For running the experiment, the deposited sediment were flattened and leveled firstly to a specific level above the bottom outlet (30 cm), and the model was slowly filled with water until the water surface elevation reached to a desired level. Then, the bottom outlet was manually opened until the outflow discharge, become equal to the inflow discharge. Consequently, the sediment was released from main reservoir. At the beginning of the experiment when the downstream outlet opened, sediment was discharged with high concentration, but the concentration of sediment flushing decrease with time. Experiments were continued until the flushing cone reached to an equilibrium condition in which the sediment concentration was negligible at the end of the experiment. The time required for the formation of the flushing cone depends on hydraulic conditions. The development of flushing cone was

very fast, and the process finished in less than one minute to ten minutes in the experimental model. In this study, the time for running the experiment was set to 45 minute. At the end of each experiment, the flushing outlet was closed and water was carefully and slowly drained from the main reservoir and the measurement of bed configuration was done in a grid system around the bottom outlet. After the run of each experiment, the bed level of scouring was measured using digital point gages, and the volume of flushing cone was calculated by Surfer 0.8 software.

3 Results and Discussion

As previously mentioned, a funnel shape of scouring is created at the vicinity of outlet gates in the pressure flushing operation. The maximum scour depth of this cone is found very close to the dam wall. Surface development of scouring cone is same in both width and length, but the plan shape of the flushing cone over the deposited sediment is close to half a circumference. The cone slopes of both longitudinal and side are approximately equal, and also these are similar to the repose angle of the submerged sediment.

Fig. 5 shows the variation of Q_{Outlet} against $V_{Scouring}$ for each bottom outlets when depth of water above the center of outlet is 36 cm. It can be found that in a specific discharge by increasing of outlet cross section, the scour volume increases. Fig. 6 and 7 also present the variation of Q_{Outlet} against $V_{Scouring}$ for 66 and 96 cm depth of water, respectively. The figures show the same trend for volume release of sediment with outlet discharge. The comparison of results shows that the effect of bottom outlet diameter on scouring volume is much higher at the greater value of water depth.

According to the dimensional analysis and functional relationship given by equations 5 to 7, following equations are obtained for volume, width and length of flushing cone, respectively by using regression analysis:

$$\frac{V_{Scouring}}{H^3_w} = 0.042(Fr)^{0.149}(\frac{H_s}{H_w})^{3.082}(\frac{A_{Outlet}}{H^2_w})^{0.174} \quad (5)$$

$$\frac{W_{Scouring}}{H_w} = 0.031(Fr)^{0.104}(\frac{H_s}{H_w})^{0.733}(\frac{A_{Outlet}}{H^2_w})^{0.146} \quad (6)$$

$$\frac{L_{Scouring}}{H_w} = 0.031(Fr)^{0.104}(\frac{H_s}{H_w})^{0.733}(\frac{A_{Outlet}}{H^2_w})^{0.146} \quad (7)$$
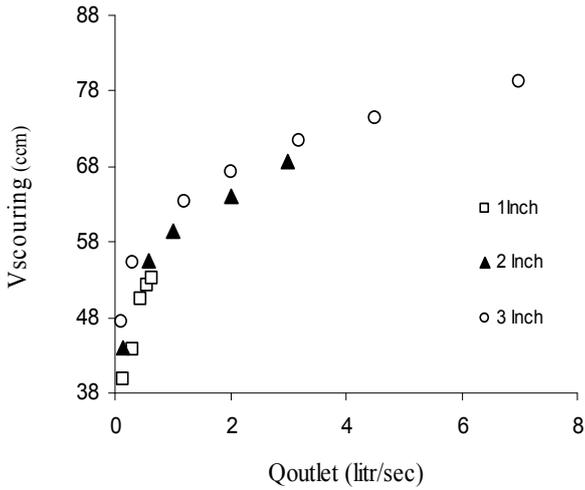
Figure 5 The variation of Q_{Outlet} against $V_{Scouring}$ for H_w=0.36m.
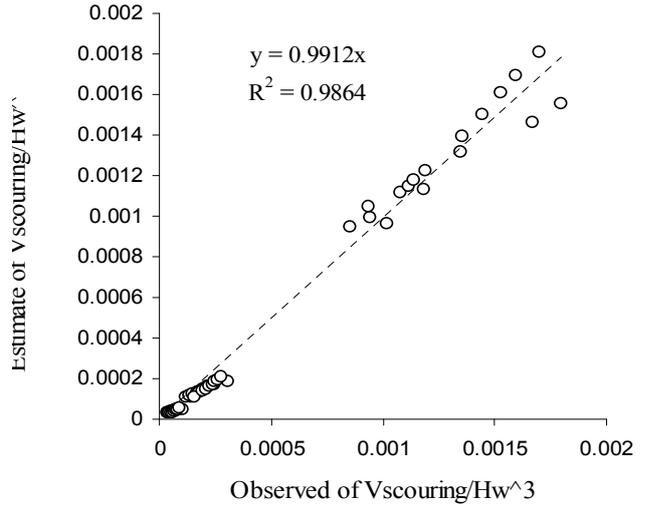
Fig 8 Comparisons between measured and computed relative flushing volume cone.
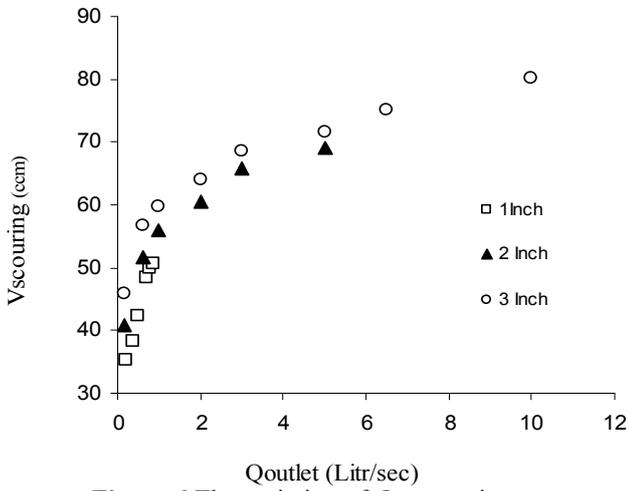
Figure 6 The variation of Q_{Outlet} against $V_{Scouring}$ for H_w=0.66m
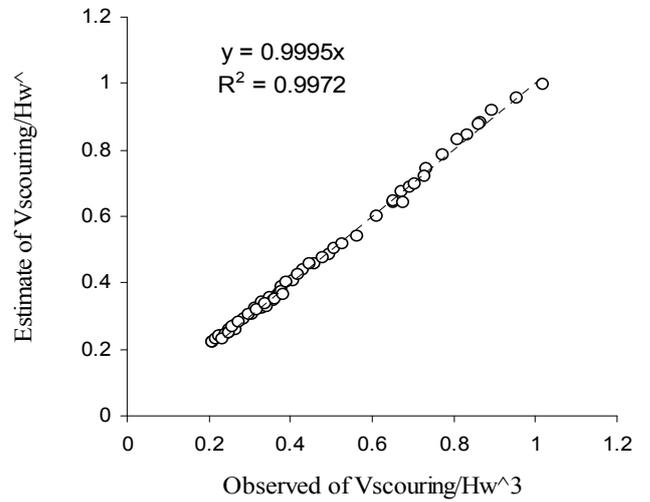
Figure 9 Comparisons between measured and computed relative flushing width cone.
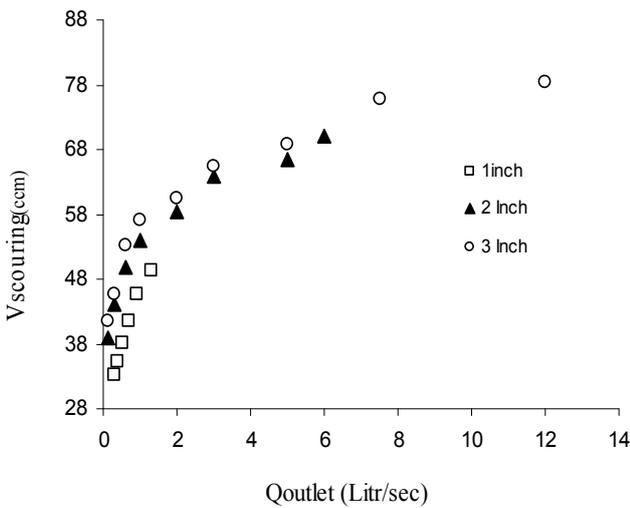
Figure 7 The variation of Q_{Outlet} against $V_{Scouring}$ for H_w=0.96m
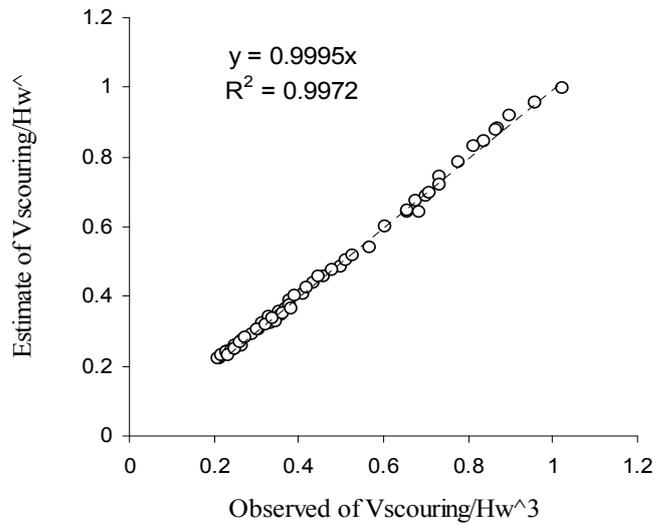
Figure 10 Comparisons between measured and computed relative flushing length cone.

Fig. 8 to 10 shows the comparison between the calculated flushing cone parameters using above equations and observed values.

For the verification of results, the statistical parameters such as root mean square error (RMSE) ,mean absolute percentage error (MAPE) and R-squared value were calculated for the above equations and presented in Table 3.

Table 3 Statistical verification for presented equations

Number of Equation	RMSE	MAPE	R^2
Eq.5	0.00007	0.005	0.98
Eq.6	0.0001	0.009	0.99
Eq.7	0.0001	0.009	0.99

4 Conclusion

This study shows that A_{Outlet} is the main parameters in correlating the flushing cone dimensions. The results indicate that with increase of diameter of bottom outlet, the new hydraulically condition established on flushing mechanism. And this mechanism is common between all of scouring dimensions.

Based upon experimental data, under clear water flow, dimensionless equations for prediction of flushing cone parameters are presented. The present equations have high correlation coefficient and in spite of their correlation there applicability should be tested using other experimental and field data. Further experiments are necessary by using different size, shape and graduation of bed material, under different hydraulic conditions to conform the results obtained from this study.

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