International Journal of Ocean System Engineering 2(2) (2012) 71-81
http://dx.doi.org/10.5574/IJOSE.2012.2.2.071

Investigation of Dimension Changes in Under Pressure Hydraulic Sediment Flushing Cavity of Storage Dams Under Effect of Localized Vibrations in Sediment Layers

Asgar Ahadpour Dodaran[1], Sang Kil Park[1*], Asadollah Mardashti[2] and Masoud Noshadi[2]

[1]*Department of Civil Engineering, Pusan National University, Busan, Korea*
[2]*Assistant Prof, Department of Water Engineering, University of Shiraz, Shiraz, Iran*

(Manuscript Received March 22, 2012; Revised April 4, 2012; Accepted May 25, 2012)

Abstract

Several methods have been proposed to control the sedimentation process. These include catchment management, flushing, sluicing, density current venting, and dredging. Flushing is used to erode previously deposited sediments. In pressurized flushing, the sediment in the vicinity of the outlet openings is scoured and a funnel shaped crater is created. In this study, the effect of localized vibrations in the sediment layers on the dimensions of the flushing cone was investigated experimentally. For this purpose, experiments were carried out with two bottom outlet diameters, five discharge releases for each desired water depth, and one water depth above the center of the bottom outlets. The results indicate that the volume and dimensions of the flushing cone are strongly affected by localized vibrations.

Keywords: Pressure Fushing, Local Scouring, Bottom Outlet, Sediment, Localized Vibrations

1. Introduction

Sustaining the storage capacity of existing reservoirs has become an important issue rather than building new reservoirs which is difficult be cause of strict environmental regulations, high construction costs, and the lack of suitable dam sites (Shen, 1996). Several methods have been proposed to control the sedimentation process. These may include catchment management, flushing, sluicing, density current venting, and dredging. Flushing is used to erode previously deposited sediments (Brandt, 2000). One of the most effective techniques is flushing by hydraulically removing the deposited sediment by the flow. The oldest known method of flushing, practiced in Spain in the 16th century, was referred to by D'Rohan (Brown, 1943). The excess shear force of accelerated flows created by the sudden opening of the bottom outlets of dams loosens and re-suspends the sediment. The flow will then wash them from the system. If flushing takes place under pressure, it 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. Figure 1 illustrates the longitudinal view of the flushing cone in the vicinity of the bottom. This is only an option in reservoirs with a small reservoir capacity compared to the water inflow, and a large sluice capacity (Qian, 1982). Pressurized flushing has been studied extensively in the literature (White, 1984-; Shen and Lai, 1993-; Fang and Cao, 1996-; Scheuerlein, 2004-; Emamgholizadeh, 2005 and 2006). In spite of advances in the investigation of pressure flushing techniques at

*Corresponding author. Tel.: +82-51-510-2427, Fax.: +82-51-513-9596
E-mail address: sakpark@pusan.ac.kr

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

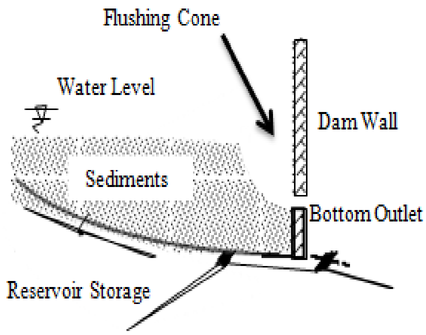


Fig. 1. Longitudinal and plan view of flushing half-cone in vicinity of bottom.

An estimation of the sediment volume removed or the volume of the flushing cone is important for designing bottom outlet gates, in which the optimum and best bottom outlet can be designed with respect to the cross section. Researches for evaluating the geometric characteristics of the scouring cone against various cross sections for the bottom outlet are necessary, in order to properly design the bottom outlet.

Moreover, the dimensions of the flushing cone are also effective in the rescue of power plant intakes. This paper deals experimentally with pressure flushing phenomena and investigates the effect of the bottom outlet cross section on the volume and dimensions of the flushing cone. The results are tabulated in terms of statistical measures and also illustrated in scatter plots.

2. Materials and Methods

2.1 Experimental arrangements

The experiments were conducted at the hydraulic laboratory of Shiraz University (Ahadpour, 2011). Experimental tests were carried out using a hexahedral shallow basin whose overall dimensions consist of a 7 meter length, 1 meter widthe and 1 meter height. Using two reticulate sheets at the reservoir's entrance, a smooth flow was created. The front wall of the model could be easily changed to accommodate different cross sections of reservoir bottom outlets. The outlets of the main reservoir include two different gate valves with diameters of 2.54 and 5.08 cm. The sediment deposits at the main reservoir consisteds of silica particles with a uniform size distribution, a median diameter of d_{50} = 1 mm, and geometric standard deviation of σ = 1.25.

Adjacent to the reservoir, an underground tank and pump were used to prepare and recirculate the desired inflow water discharge which we call the water supply system. The water supply system of the model was also supported by an adjusting valve, digital flow-meter, and 11 -meter flume upstream of the model. Along the basin's side walls, a movable frame was mounted to carry the measuring instruments. After each experiment, the scour cone configuration was measured using a digital point gauge device.

The downstream section used another stilling basin where the mixing flow of water and sediment was collected through a plastic pipe in a closed circuit with the underground tank. The settling basin was a rectangular flume 4 meter long, 1 meter wide, and 1 meter high. At the end of the settling reservoir there was a V-notch weir (with an angle of $90^{o\,\Theta}$) to measure the outflow discharge. Figure 2 shows a schematic plan view of the experimental setup and hydraulic circuits. The flushing half -cone under a discharge of 2 l/s, water depth of 80 cm, and outlet diameter of 5.08 cm is illustrated in Figure 3.

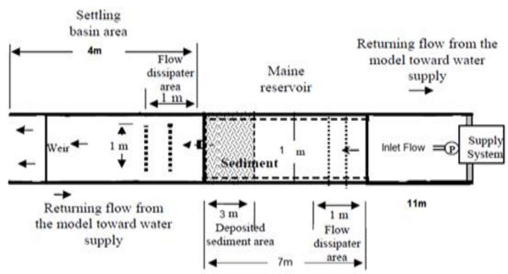


Fig. 2. Schematic plan view of experimental setup and hydraulic circuits.

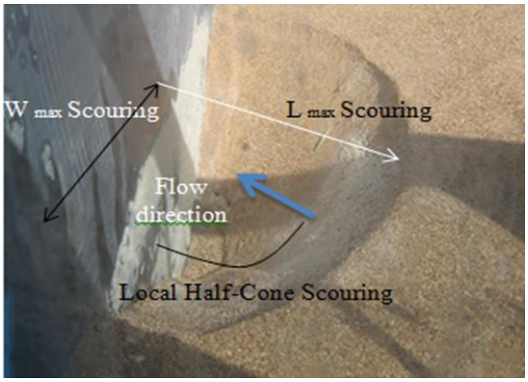


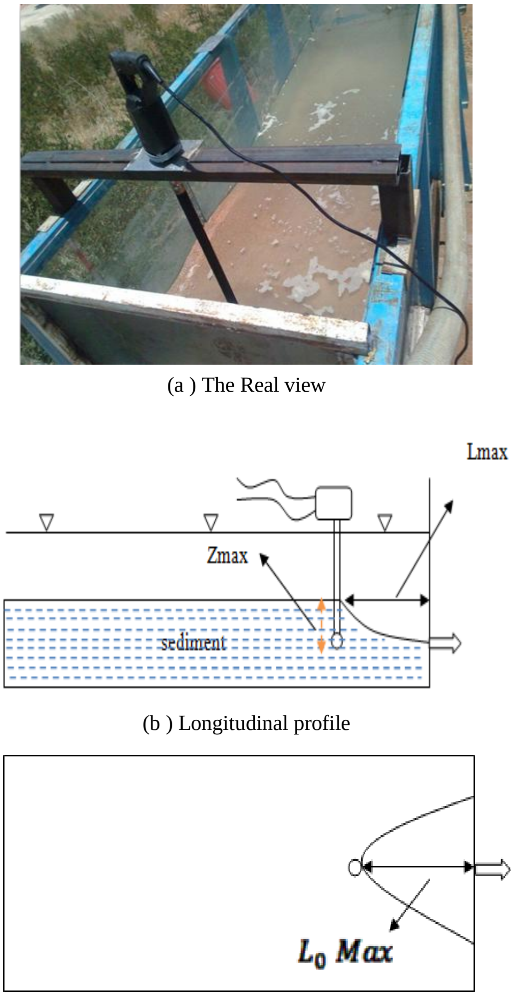
Fig. 3. Local half-cone scouring at vicinity of bottom outlet in frequency (0 HZ).

2.2 Vibrator position

This thesis deals experimentally with pressure flushing phenomena and investigates the effect of localized vibrations in the sediment layers on the volume and dimensions of the flushing cone. The experiments were conducted at the Hydraulic Laboratory of the Water Engineering Department, Shiraz University, Iran. The experiments were conducted with 2 different outlet diameters, one water depth above the center of the bottom outlet (80 cm) and at least 5 different discharges, three frequencies of vibrations, including 20, 35, and 50 Hz vibrators, and three position vibrators.

2.2.1 one vibrator position

The position, schematic view, and longitudinal profile of the vibration machine are illustrated (Frq = 20, 35, and 50 HZ) in Figure 4.



(a) The Real view

(b) Longitudinal profile

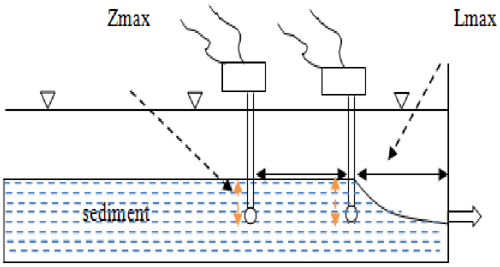
(c) Schematic plan view

Fig. 4. Real view, longitudinal profile, and schematic plan view of vibration machine position.

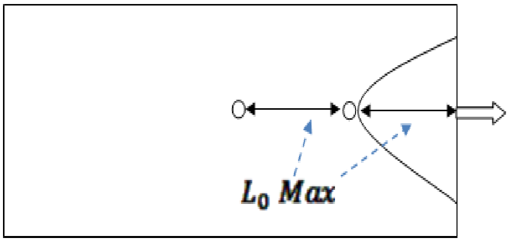
2.2.2 Two vibrator positions in one direction

The position, schematic view, and longitudinal profile of two vibration machines are illustrated (Frq = 20, 35, and 50 HZ) in Figure 5.

(a) The Real view



(b) Longitudinal profile



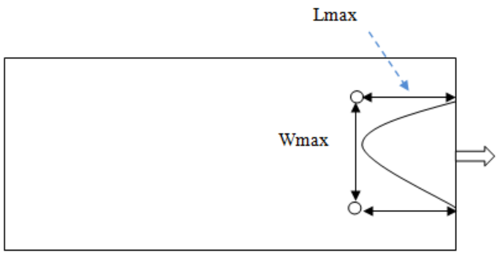
(c) Schematic plan view

Fig. 5. Real view, longitudinal profile, and schematic plan view of two vibrator positions in one direction.

2.2.3 Two vibrator positions in two directions

The positions, schematic plan, and longitudinal profile of two vibration machines are illustrated (Frq = 20, 35, and 50 HZ) in Figure 6.

(a) The Real view



(b) Schematic plan view

Fig. 6. Real view, longitudinal profile, and schematic plan view of two vibrator positions in two directions.

2.3 Dimensional Analysis

The volume of the flushing cone (V Scouring) may be written as a function of the following variables:

$$V_{Scouring} = \varphi(U_{Outlet}, D_{outlet}, H_w, H_s, B, d_{50}, \rho_s, \rho_w, g, \upsilon, Frq, Lvib) \qquad (1)$$

where, U_{Outlet}= velocity of flow at the entrance of the bottom outlet, D_{outlet} = the cross section of the bottom outlet, H_w = the height of the water above the center of the bottom outlet, H_s= the height of the sediment deposited above the center of the outlet, B= the width of the reservoir, d_{50}= the median size of the sediment particles, ρ_s= the density of the sediment, ρ_w= water density, g= the acceleration due to gravity, υ = the kinematic viscosity, Frq= the frequency of the vibration, and Lvib= the position vibration. By using Buckingham's theorem, and choosing the ρ_w, H_w , and U_{Outlet} as repeating variables, the following functional relationship describes the dimensionless flushing volume:

Table 1. Range of variables in this research and parameter variations

Parameters	Variations
Discharge release	0.15— 6.11 l/s
Depth of water	80 cm
Outlet diameter	2.54 and 5.08 cm
d 50	1mm
Frequency	20 , 35, and 50 HZ

$$\pi_1 = \frac{V_{Scouri}}{H_s^{\,3}} \;, \pi_2 = \frac{A_{Outlet}}{H_w^{\,2}} \;, \quad \pi_3 = \frac{H_S}{H_w}$$

$$\pi_4 = \frac{B}{H_w} \qquad \pi_5 = \frac{d_{50}}{H_w} \qquad \pi_6 = \frac{\rho_s}{\rho_w}$$

$$\pi_7 = \frac{gH_w}{U^2{}_{Outle}} \qquad \pi_8 = \frac{H_w \times U_{Outlet}}{\upsilon}$$

$$\pi_9 = \frac{L_{vib}}{H_w} \quad , \quad \pi_{10} = \frac{H_w \times Frq}{U_{outlet}}$$

$$\frac{V_{Scouring}}{H_s^{\,3}} = \varphi\left(\frac{A_{Outlet}}{H_w^{\,2}}, \frac{H_s}{H_w}, \frac{U_{Outlet}}{\sqrt{g \times H_w}}, \frac{H_w \times Frq}{U_{outlet}}, \frac{L_{vib}}{H_w}\right)$$

Where $Fr_{Outlet} = \dfrac{U_{Outlet}}{\sqrt{g \times H_w}}$

$$\frac{V_{Scouring}}{H_s^{\,3}} = \varphi\left(\frac{A_{Outlet}}{H_w^{\,2}}, \frac{H_s}{H_w}, Fr_{Outlet}, \frac{H_w \times Frq}{U_{outlet}}, \frac{L_{vib}}{H_w}\right) \tag{2}$$

2.4 Experiment Design

As mentioned above, the experiments were conducted at the Hydraulic Laboratory of the Water Engineering Department, Shiraz University, Iran. The experiments were conducted with 2 different outlet diameters, one water depth above the center of the bottom outlet (80 cm), and at least 5 different discharges and three frequency vibrations, including 20, 35, and 50 Hz vibrators, along with three position vibrators. Tables 1 and 2 respectively show the range of variables used for measuring the experimental data and the dimensionless parameters used in the dimensional analysis.

Table 2. Range-s of dimensionless parameters.

Parameters	Variations
$\frac{V_{scouring}}{H_s{}^3}$	0.00046— 0.372
Fr*	0.16 — 2.86
H_s/H_w	0.5
D_{outlet}/H_w	0.026 — 0.21

2.5 Experimental Investigation

To conduct the experiments, the deposited sediment was first flattened and leveled to a specific level above the center of the bottom outlet (15 cm),. Next, the model was slowly filled with water until the water surface elevation reached the 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 the main reservoir. At the beginning of the experiment when the downstream outlet opened, sediment was discharged with a high concentration, but the concentration of sediment flushing decreased with time. The experiments were continued until the flushing cone reached an equilibrium (no further particle motion was observed) condition, in which the sediment concentration was negligible at the end of the experiment. The time required for the formation of the flushing cone depended on the hydraulic conditions.

The development of the 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 at 45 minutes. At the end of each experiment, the flushing outlet was closed and the incoming discharge was set to zero. Then, the water was carefully and slowly drained from the main reservoir. After the run of each experiment, the bed level of scouring was measured using a laser, as seen in Figure 7, and the volume of the flushing cone was calculated using Surfer 8.0 software.

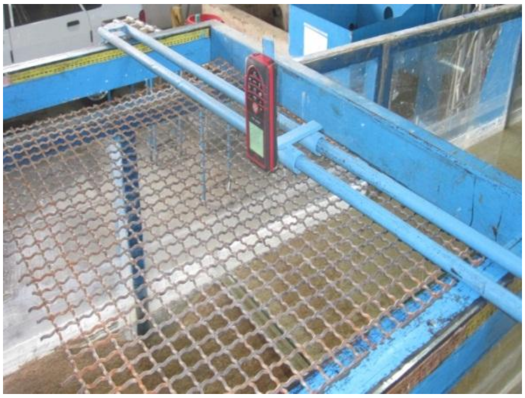


Fig. 7. Laser.

3. Results and Discussion

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

The results show that the position of the vibrator with respect to the dam axis and the vibration frequency were the main parameters affecting the flushing cone dimensions. In addition, with an increase in the vibration frequency, the dimensions of the flushing cone (volume, length, and width) increased. Based upon the experimental data, dimensionless equations for predicting the flushing cone parameters were formulated. These equations have high correlation coefficients and present a good estimation. The initial researches showed that the appropriate frequency and appropriate position vibrator will be the best option to rescue power plant intakes. However, this investigation on the efficiency of an under -pressure flushing operation indicated that two vibrators located at the maximum flushing length and width in the case without a vibrator produce the greatest sediment removal volume and represent the optimum vibrator configuration.

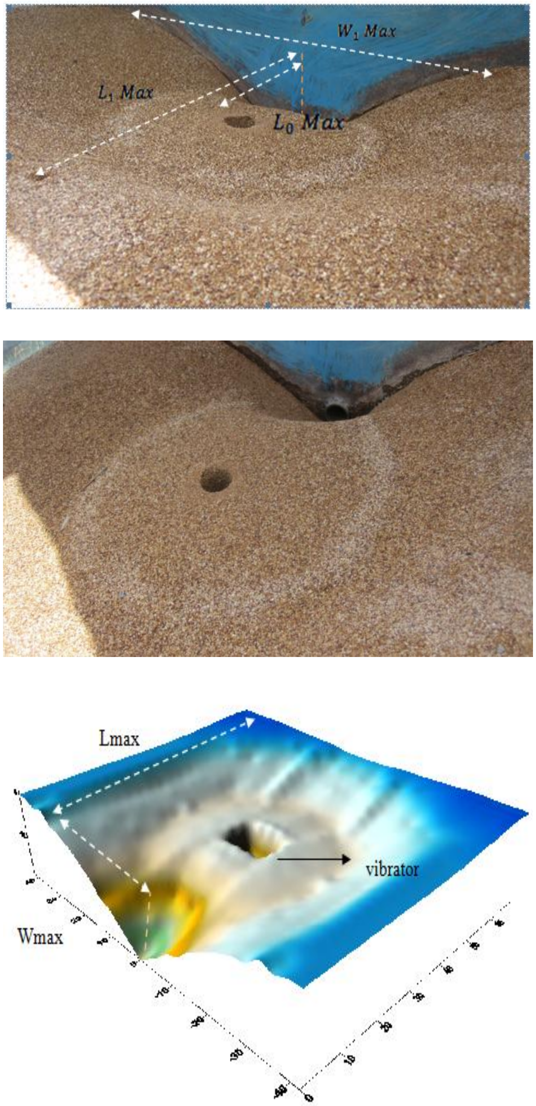


Fig. 8. Vicinity of bottom outlet in frequency(50 HZ); 3Dimensional, Volume: 15695 cm^3, Q= 3 l/s, Hw=80cm R=2 inch.

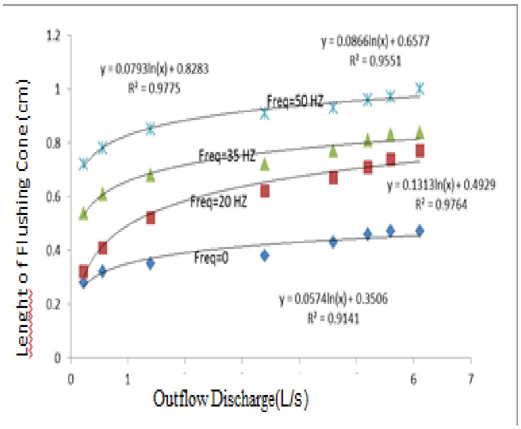


Fig. 9. Variation in flushing cone length versus outflow discharge, for fixed water depth(80 cm) and bottom outlet with 5.08 –cm diameter.(Frq=0, 20, 35, and 50 HZ) for one vibrator.

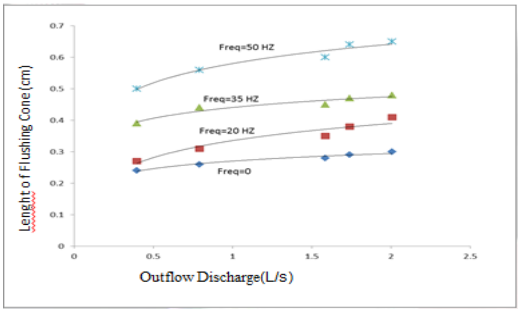


Fig. 10. Variation in flushing cone length versus outflow discharge, for fixed water depth(80 cm) and bottom outlet with 2.54 -cm diameter.(Frq=0, 20, 35, and 50 HZ) for one vibrator.

Table 3. Ranges of variables in this research: discharge versus length(Freq=50 HZ).

Q(l/s)	% length vs Freq=0
0.230—— 0.396	111.864—— 113.32
0.560—— 0.792	106.383—— 112.65
1.400—— 1.584	108.696 —— 114.56
3.4 —— 1.74	126.279 —— 116.4
4.6 —— 2.03	139.474 —— 122.18
5.2	142.857
5.6	143.750
6.11	157.143

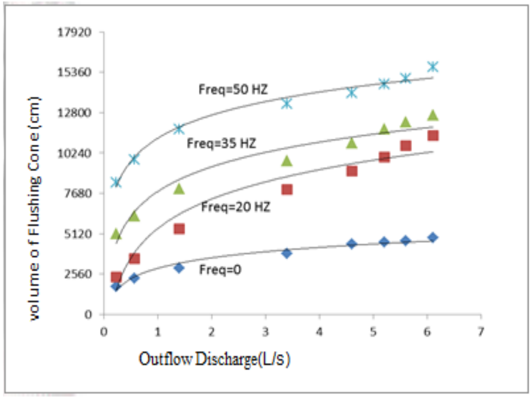


Fig. 11. Variation in flushing cone volume versus outflow discharge, for fixed water depth(80 cm) and bottom outlet with 5.08 -cm diameter.(Frq=0, 20, 35, and 50 HZ) for one vibrator.

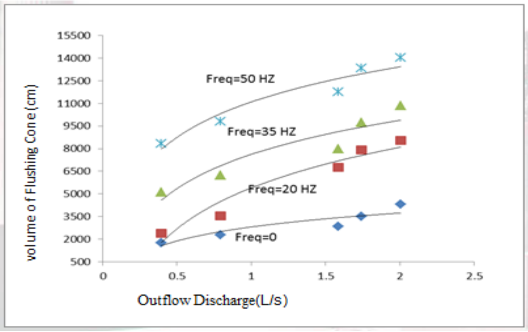


Fig. 12. Variation in flushing cone length versus outflow discharge, for fixed water depth(80 cm) and bottom outlet with 2.54 -cm diameter.(Frq=0, 20, 35, and 50 HZ) for one vibrator.

Table 4. Ranges of variables in this research: discharge versus volume(Freq=50 HZ).

Q(l/s)	% volume vs Freq=0
0.230 —— 0.396	195.054 —— 203.12
0.560 —— 0.792	185.940 —— 208.34
1.400 —— 1.584	198.015 —— 212.41
3.4 —— 1.74	224.511 —— 215.198
4.6 —— 2.03	279.567 —— 234.12
5.2	311.717
5.6	328.104
6.11	371.706

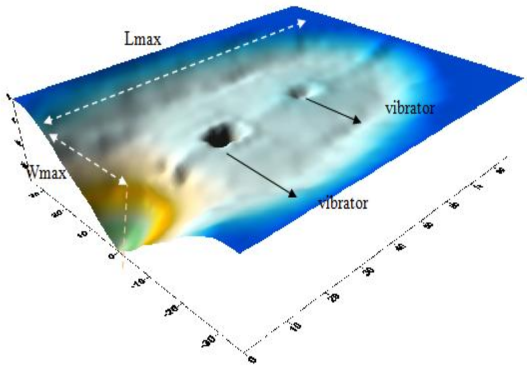


Fig. 13. Vicinity of bottom outlet in frequency(50 HZ), 3-Dimensional, Volume: 52621 cm^3, Q= 3 L/S , Hw=80cm R=2 inch.

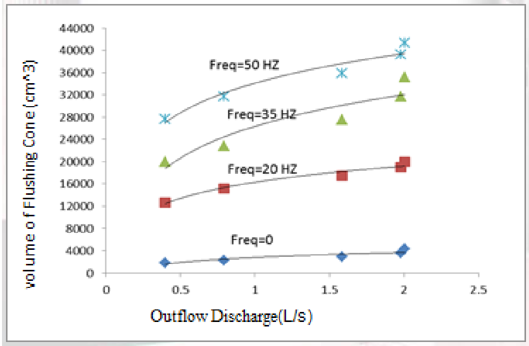


Fig. 14. Variation in flushing cone length versus outflow discharge, for fixed water depth(80cm) and bottom outlet with 2.54 -cm diameter.(Frq=0, 20, 35, and 50 HZ) for two vibrators in one direction.

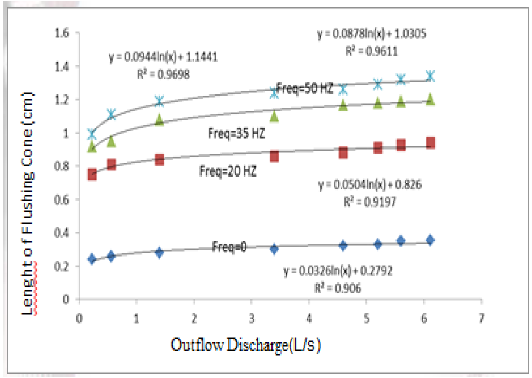


Fig. .15. Variation in flushing cone length versus outflow discharge, for fixed water depth(80cm) and bottom outlet with 5.08 -cm diameter.(Frq=0, 20, 35, and 50 HZ) for two vibrators in one direction.

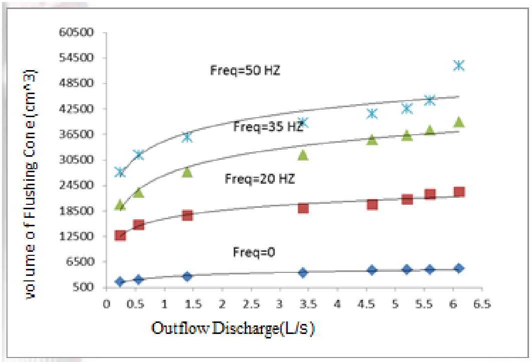


Fig. 16. Variation in flushing cone volume versus outflow discharge, for fixed water depth(80cm) and bottom outlet with 5.08 -cm diameter.(Frq=0, 20, 35, and 50 HZ) for two vibrators in one direction.

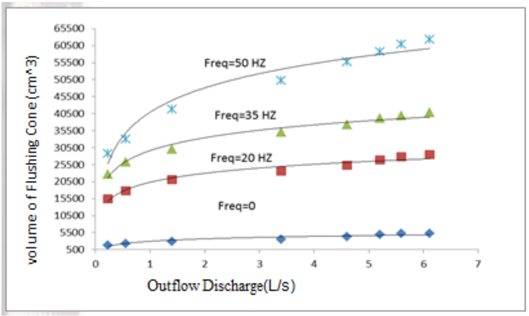


Fig. 17. Variation in flushing cone volume versus outflow discharge, for fixed water depth(80cm) and bottom outlet with 2.54 -cm diameter.(Frq=0, 20, 35, and 50 HZ) for two vibrators in one direction.

Table 5. Ranges of variables in this research: discharge versus volume(Freq=50HZ).

Q(l/s)	% volume vs Freq=0
0.230 ___ 0.396	749.614 ___ 756.23
0.560 ___ 0.792	787.771 ___ 795.65
1.400 ___ 1.584	868.267 ___ 856.94
3.4 ___ 1.74	954.182 ___ 883.61
4.6 ___ 2.03	1015.672 ___ 931.78
5.2	1155.224
5.6	1280.563
6.11	1460.093

Table 6. Ranges of variables in this research: discharge versus Length(Freq=50HZ).

Q(l/s)	%Length vs Freq=0
0.230 ___ 0.396	173.898 ___ 176.76
0.560 ___ 0.792	180.851 ___ 182.41
1.400 ___ 1.584	186.435 ___ 188.26
3.4 ___ 1.74	193.023 ___ 190.21
4.6 ___ 2.03	226.316 ___ 195.46
5.2	240.000
5.6	246.875
6.11	253.571

Fig. 18. Vicinity of bottom outlet in frequency(50HZ) 3-Dimensional, Volume: 62605 cm^3, Q= 3 L/S, Hw=80cm R=2 inch.

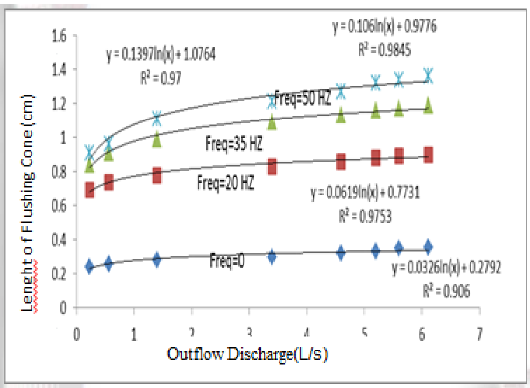


Fig. 19. Variation in flushing cone length versus outflow discharge, for fixed water depth(80cm) and bottom outlet with 5.08 -cm diameter.(Frq=0, 20, 35, and 50 HZ) for two vibrators in two directions.

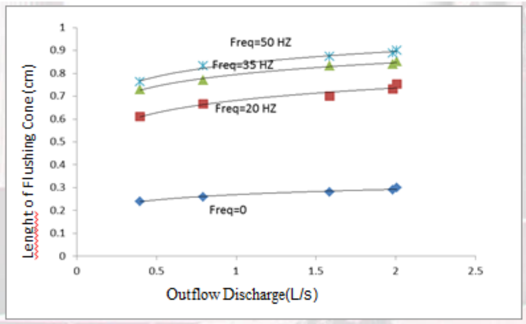


Fig. 20. Variation in flushing cone length versus outflow discharge, for fixed water depth(80cm) and bottom outlet with 2.54 -cm diameter.(Frq=0, 20, 35, and 50 HZ) for two vibrators in two directions.

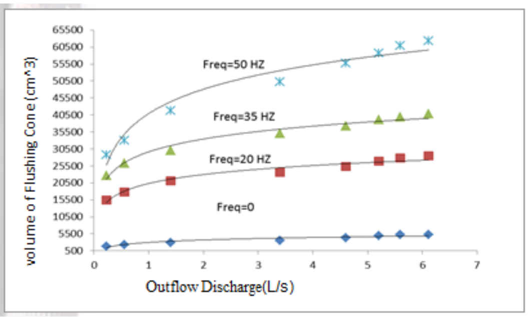


Fig. 21. Variation in flushing cone volume versus outflow discharge, for fixed water depth(80cm) and bottom outlet with 5.08 -cm diameter.(Frq=0, 20, 35, and 50 HZ) for two vibrators in two directions.

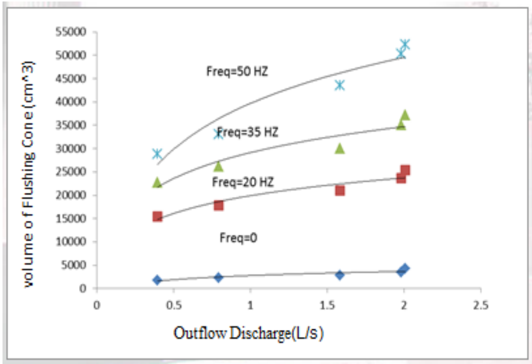


Fig. 22. Variation in flushing cone volume versus outflow discharge, for fixed water depth(80cm) and bottom outlet with 2.54 -cm diameter.(Frq=0, 20, 35, and 50 HZ) for two vibrators in two directions.

Table 7. Ranges of variables in this research: discharge versus volume(Freq=50HZ).

Q(l/s)		%Volume vs Freq=0	
0.230	0.396	1051.27	1062.98
0.560	0.792	1081.869	1087.08
1.400	1.584	1178.537	1197.20
3.4	1.74	1287.699	1221.72
4.6	2.03	1331.397	1253.64
5.2		1363.025	
5.6		1340.795	
6.11		1526.97	

Table 8. Ranges of variables in this research discharge versus length (Freq=50HZ)

Q(l/s)		% Length vs Freq=0	
0.230	0.396	188.136	183.12
0.560	0.792	185.106	188.03
1.400	1.584	186.957	191.28
3.4	1.74	195.349	189.54
4.6	2.03	218.421	195.04
5.2		217.143	
5.6		200.000	
6.11		225.000	

4. Conclusion

This study showed that A_{Outlet} and vibration frequncy are the main parameters in correlating the flushing cone dimensions. The results indicated that with increases in the diameter of the bottom outlet and vibration frequency, a new hydraulic condition is established for the flushing mechanism. This mechanism is common between all of the scouring dimensions. Thus, for a bigger bottom outlet and greater frequency, there is a greater diameter influence and a stronger orifice flow results. Consequently, sediment particles can be eroded at a greater distance from the outlet.

The initial researches showed that the appropriate frequency and appropriate position vibrator will be the best option to rescue power plant intakes. However, this investigation on the efficiency of underpressure flushing operations indicated that two vibrators located at the maximum flushing length and width in a case without a vibrator removes the greatest volume of sediment and represent the optimum vibrator positions.

Based upon the experimental data, under clear water flow, dimensionless equations for predicting the flushing cone characteristics were presented. The presented equations have high correlation coefficients. In spite of their correlation, there applicability should be tested using other experimental and field data. Further experiments should be conducted using different sizes, shapes and graduations of bed materials, under different hydraulic conditions, to confirm the results obtained from this study.

Larger bottom outlets have a greater influence. Thus, they produce a stronger orifice flow and can erode sediment particles farther away from the outlet. In addition, with larger outlets, there is more space on the dam wall for releasing, outflow streamlines and sediments are less compressed. As a result, there is less friction force against the erosion force during a flushing operation.

References

[1] Brandt, S. A.(2000). “A review of reservoir desolation”, International Journal of Sediment Research. Vol. 15, No. 2. pp. 321-342.

[2] Brown, C.B.(1943), “The Control of Reservoir Silting”, United States Department of Agriculture, Miscellaneous Publication No. 521, Washington, D.C. p. 166.

[3] Emamgholizadeh, S., Bina, M., Fathimoghadam, M. and Ghomeyshi, M.(2006). “Investigation and Evaluation of the Pressure Flushing through Storage Reservoir”, ARPN Journal of Engineering and Applied Sciences. Vol. 1, No. 4.

[4] Fang, D. and Cao, S.(1996). “An experimental study on scour funnel in front of a sediment flushing outlet of a reservoir”, Proceedings of the 6th Federal Interagency Sedimentation Conference, Las Vegas, March 10-14 1996, pp. I.78-I.84.

[5] Meshkati Shahmirzadi, M. E(2010). “Experimental investigation of pressure flushing operation in reservoir storage”, MSc thesis, Gorgan University of Agriculture Sciences and Natural R sources, Iran.

[6] Qian, N.(1982). “Reservoir sedimentation and slope stability; technical and environmental effects”, Fourteenth International Congress on Large Dams, Transactions, Rio de Janeiro, Brazil, 3-7 May, Vol. III. pp. 639-690.

[7] Scheuerlein, H., Tritthart, M. and Nunez Gonzalez, F.(2004). “Numerical and physical modeling concerning the removal of sediment deposits from reservoirs”, Conference proceeding of Hydraulic of Dams and River Structures, Tehran, Iran.

[8] Shen, H.W., Lai, J.S. and Zhao, D.(1993). “Hydraulic desiltation for noncohesive sediment”, Proceeding of the 1993 Annual ASCE Hydraulic Engineering Conference, San Francisco, H.W Shen, S.T. Su, and F. Wen, eds, pp. 119-124.

[9] Shen, H.W. and Lai, J. S.(1996). “Sustain reservoir useful life by flushing sediment”, International Journal of Sediment Research. Vol. 11(3): 10-17.

[10]White, W.R. and Bettess, R., *The feasibility of flushing sediments through reservoirs*, Challenges in African Hydrology and Water Resources, Proceeding of Harare Symposium, July, D.E. Walling, S.S.D. Foster, P. Wurzel, eds, IAHS Publication No, 1984.