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Experimental investigation of local half-cone scouring against dam

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ABSTRACT: 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. 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 bottom outlets cross section on the dimensions of flushing cone was investigated experimentally. For this purpose, experiments was carried out with three bottom outlet diameters, five discharges release for each desired depth of water and three water depths above the center of bottom outlets. The results indicate that the volume and dimensions 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 dam and also its dimensions of half-cone scouring.

Keywords: Pressure Fushing, Local Scouring, Bottom Outlet, Sediment, Reservoir

1 INTRODUCTION

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 (Shen, 1996). 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 (Brandt, 2000). One of the most effective techniques is flushing through which the deposited sediment is hydraulically removed 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 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 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. Figure 1 illustrates the longitudinal 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 (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 technique at reservoir storage, studies about the effect of bottom outlet diameter on flushing cone development are limited and more information about this phenomenon is needed.

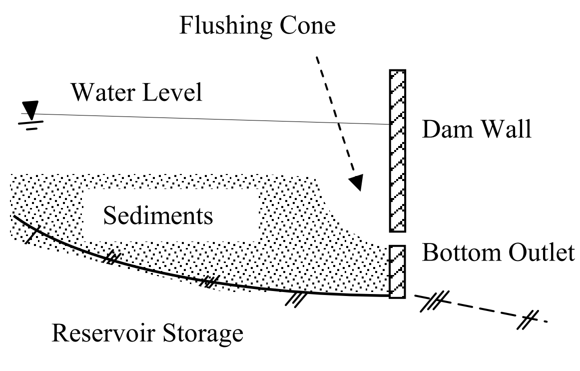

Figure 1. Longitudinal and plan view of flushing half-cone in the vicinity of bottom

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

Moreover, dimensions of flushing cone are also effective on rescue of power plant intakes. 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. The results are tabulated in terms of statistical measures and also illustrated in the scatter plots.

2 MATERIALS AND METHODS

2.1 *Experimental arrangements*

The experiments were conducted at hydraulic laboratory of Gorgan University of Agricultural Sciences and Natural Resources in Iran (Meshkati, 2010). Experiments tests carried out on hexahedral shallow basin 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 front wall of model will be easy to change to modify different cross sections of reservoir bottom outlets. The outlets of main reservoir include four different gate valves with diameter of 2.54, 3.81, 5.08 and 7.62 cm. The sediment deposits at the main reservoir was consists of silica particles with uniform size distribution, with a median diameter of d_{50}=1 mm and geometric standard deviation of σ=1.25.

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

For the downstream section it was use another stilling basin which the mixing flow of water and sediment was collect in it and through a plastic pipe in a closed circuit with the underground tank. The settling basin was 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^{o}) to measure of outflow discharge. In Figure 2 a schematic plan view of the experimental setup and the hydraulic circuits is given. T e notation of flushing half-cone under a discharge of 2 lit/s, water depth of 36 cm and 5.08 cm diameter of the outlet are illustrated in Figure 3.

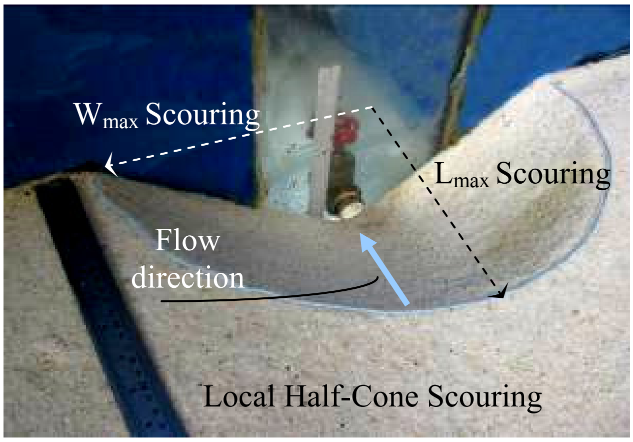

Figure 3. Local Half-cone scouring at the vicinity of bottom outlet

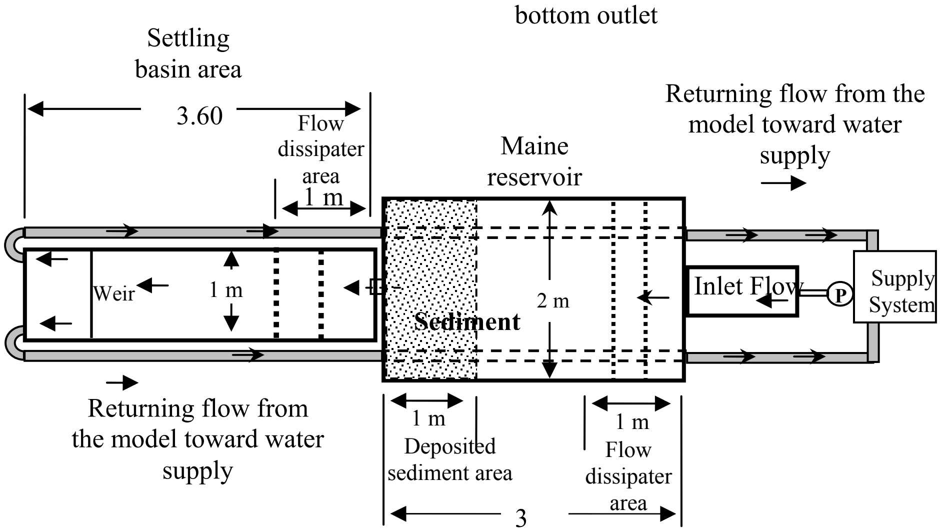

Figure 2. Schematic plan view of the experimental setup and its hydraulic circuits

(1) Dimensional Analysis

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

$$V_{Scouring} = \phi(U_{Outlet}, D_{Outlet}, H_w, H_s, B, d_{50}, \rho_s - \rho_w, \rho_w, g, \nu) \quad (1)$$

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

$$\frac{V_{Scouring}}{H_w^{\ 3}} = \varphi\left(\frac{U_{Outlet}}{\sqrt{g(G_s-1)d_{50}}}, \frac{H_s}{H_w}, \frac{D}{H_w}\right) \quad (2)$$

Where $G_s = \rho_s/\rho_w$, also using the same procedure, the width of flushing cone ($W_{Scouring}$) can be expressed as:

$$\frac{W_{Scouring}}{H} = \varphi\left(\frac{U_{Outlet}}{\sqrt{g(G_s-1)d_{50}}}, \frac{H_s}{H_w}, \frac{D}{H_w}\right) \quad (3)$$

2.2 *Experiment Designing*

As mentioned above, for considering the effect of bottom outlet cross section on dimensions of flushing cone, the experiments were conducted with three different outlet diameters (1, 2 and 3 Inch), three water depth above the center of bottom outlet i.e. 36, 66, 96 cm and at least four different discharges for each water depth. Table 1 and 2 respectively shows the range of variables conducted for measured experimental data and dimensionless parameters uses in dimensional analysis.

Table 1. Range of variables in this research

Parameters	Variations
Discharge release (Q_{Outlet})	0.15-15 Lit sec^{-}1
Depth of water (H_w)	36, 66, 96 cm
Outlet diameter (D_{Outlet})	2.54, 3.81, 5.08 and 7.62 cm
d50	1mm

Table 2. Range of dimensionless parameters

Parameters	Variations
$V_{Scouring}/H_w^3$	0.00046 -0.372
Fr*	0.16 -32.2
H_s/H_w	0.166 -0.444
D_{Outlet}/H_w	0.026-0.21

2.3 *Experimental investigation*

For running the experiments, the deposited sediment were flattened and leveled firstly to a specific level above the center of bottom outlet (16 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 (no further particle motion will be observe) 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 in which the incoming discharge was set to zero then water was carefully and slowly drained from the main reservoir. 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 Surfer8.0) software.

3 RESULTS AND DISCUSION

As mentioned before, a half-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 angle of sediment submerged repose. Figure 4 to 8 shows the variation of flushing cone dimensions (width and volume) versus the outflow discharge of bottom outlet for four bottom outlets which it was used in this research. These figures show, for constant water depth in the model, with increasing outflow discharge the dimensions of flushing cone increase, and as could be found, approximately there is same trend between all of outlets. Also, for constant outflow discharge, lower water depth in reservoir causes bigger scouring dimensions, as it could be seen in Fig 4 to 8. Therefore, for more sediment removal and for having greater dimensions of flushing cone, pressure flushing operation must perform under both possible lowest level of water and must be use in full open outlets condition. This is clear that by decreasing water surface elevation under constant discharge, vertical gradient of velocity and bed shear stress increase which lead to an increase in sediment carrying capacity in the reservoir. Also for constant water depth, with increasing the outflow discharge, water velocity and bed shear stress increases and consequently greater amount of sediment releases from dam. These results are in agreement with previous research completely. As can be understood from figures 9 to14, there is direct relation between cross section of bottom outlet and dimensions of flushing cone. In other word, for constant outflow discharge and constant water depth, with increasing the diameter (cross section) of bottom outlet, dimensions of flushing cone increases.

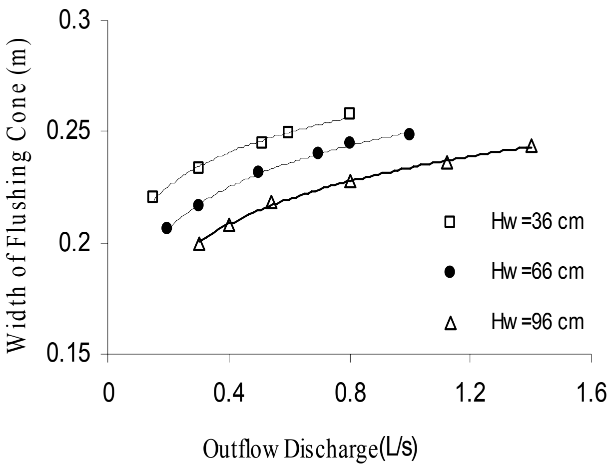

Figure 4. The variation of flushing cone width versus outflow discharge, for different water depth and the bottom outlet with 2.54 cm diameter.

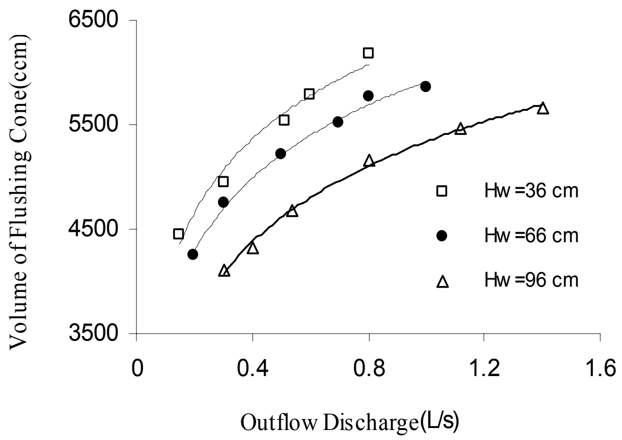

Figure 5. The variation of flushing cone volume versus outflow discharge, for different water depth and the bottom outlet with 2.54 cm diameter.

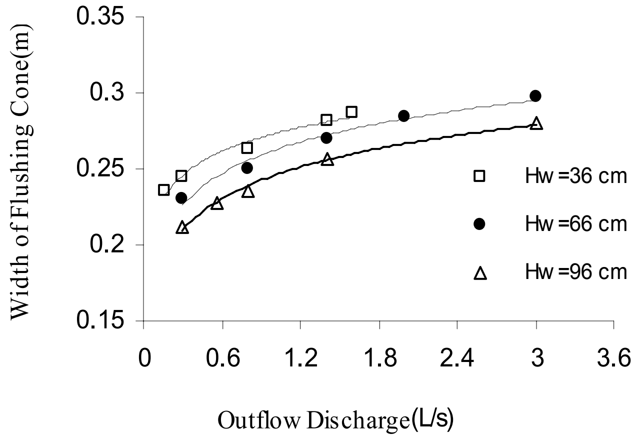

Figure 6. The variation of flushing cone width versus outflow discharge, for different water depth and the bottom outlet with 3.81 cm diameter.

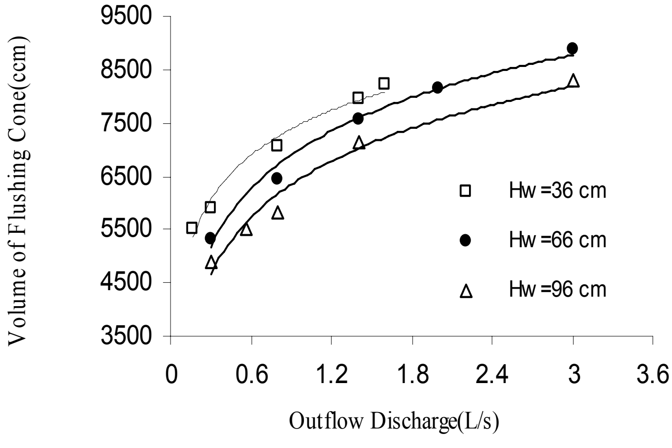

Figure 8. The variation of flushing cone volume versus outflow discharge, for different water depth and the bottom outlet with 3.81 cm diameter.

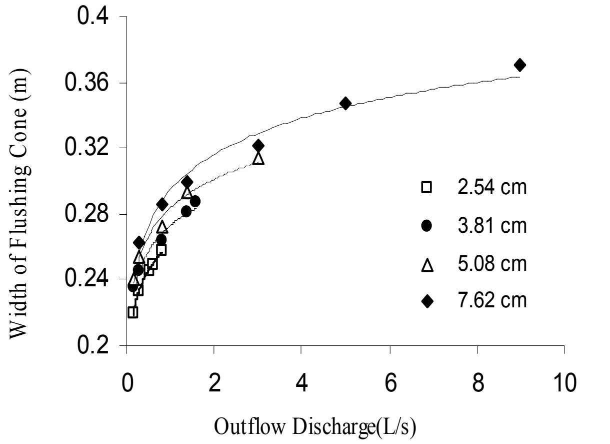

Figure 9. The variation of flushing cone width versus outflow discharge, for different outlets cross sections and 36 cm water depth.

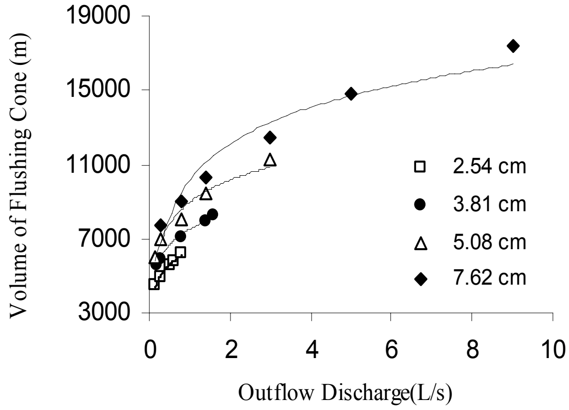

Figure 10. The variation of flushing cone volume versus outflow discharge, for different outlets cross sections and 36 cm water depth.

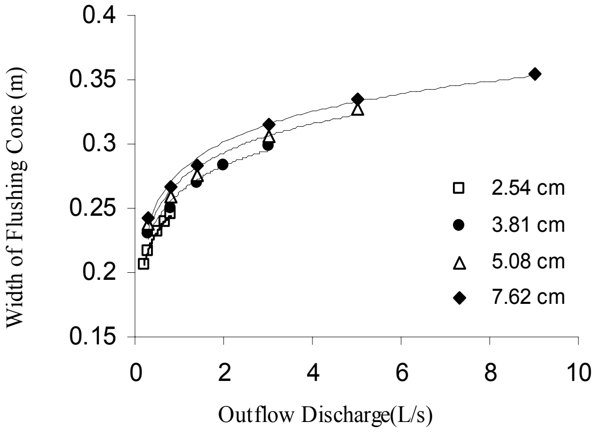

Figure 11. The variation of flushing cone width versus outflow discharge, for different outlets cross sections and 66 cm water depth.

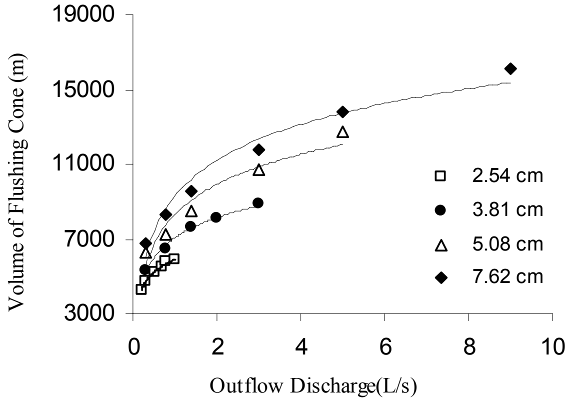

Figure 12. The variation of flushing cone volume versus outflow discharge, for different outlets cross sections and 66 cm water depth

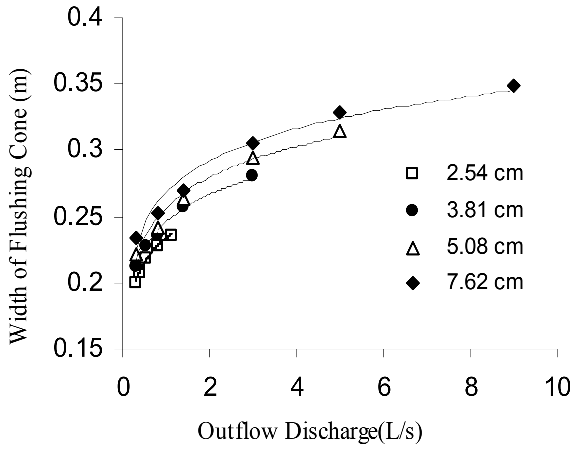

Figure 13. The variation of flushing cone width versus outflow discharge, for different outlets cross sections and 96 cm water depth.

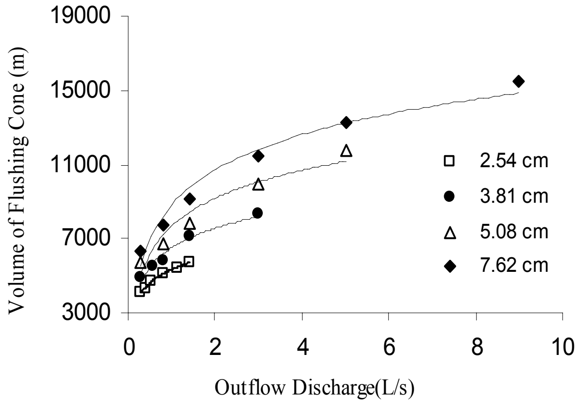

Figure 14. The variation of flushing cone volume versus outflow discharge, for different outlets cross sections and 96 cm water depth.

The comparison of the prediction accuracy using multiple linear regression analysis on training data set and testing data set, by using the statistical parameters such as root mean square error (RMSE) and R-squared value were calculated(Table 3).

Table 3. Statistical verification for presented equations

Performance index	$V_{Scouring}$		$W_{Scouring}$	
	Training	Testing	Training	Testing
R^2	0.997	0.997	0.997	0.999
MAE	0.0023	0.0037	7.9E-05	6.2E-05
RMSE	1.6E-05	5.E-05	9.E-09	8.E-09

A close fit was obtained during the training, testing and especially in validation, and the results show that the errors in predicting the flushing cone volume and flushing cone width are much low.

4 CONCOLUSION

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. The results indicate that with increasing the diameter (cross section) of bottom outlet, dimensions of flushing cone increases, and the new hydraulically condition established on flushing mechanism. And this mechanism is common between all of scouring dimensions. So that, for bigger bottom outlet, there is greater diameter influence and they can make stronger orifice flow, consequently they can erode the sediment particle form farther distance from outlet.

Based upon experimental data, under clear water flow, dimensionless equations for prediction of flushing cone characteristics 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.

The bigger bottom outlets have greater diameter influence, so they can make stronger orifice flow, consequently they can erode the sediment particle form farther distance from outlet. In addition to, in the bigger outlets there is more space on dam wall for releasing, also outflow streamlines or on the other means sediments have fewer compress to each other and as result, less friction force make against erosion force during flushing operation. The multiple linear regression were developed using the non-dimensional of experimental data, according to the dimensional analysis and functional relationship given by equations 2 and 3, following equations are obtained for volume and width of flushing cone, respectively:

$$\frac{V_{Scouring}}{H_w^{\ 3}} = 4.6\left(\frac{U_{Outlet}}{\sqrt{g(G_s-1)d_{50}}}\right)^{0.21}\left(\frac{H_s}{H_w}\right)^{2.2}\left(\frac{D}{H_w}\right)^{0.89} \quad (4)$$

$$\frac{W_{Scouring}}{H_w} = 0.02\left(\frac{U_{Outlet}}{\sqrt{g(G_s-1)d_{50}}}\right)^{0.1}\left(\frac{H_s}{H_w}\right)^{0.75}\left(\frac{D}{H_w}\right)^{0.34} \quad (5)$$

The experimental data related to this research consisting of 65 data series are divided into two parts randomly: a training set consisting 50 series and a testing set consisting of 15 data series, for assess the performance of proposed regression model. Figure 15 depict the results with the performance indices between estimated and observed experimental data for the testing data sets.

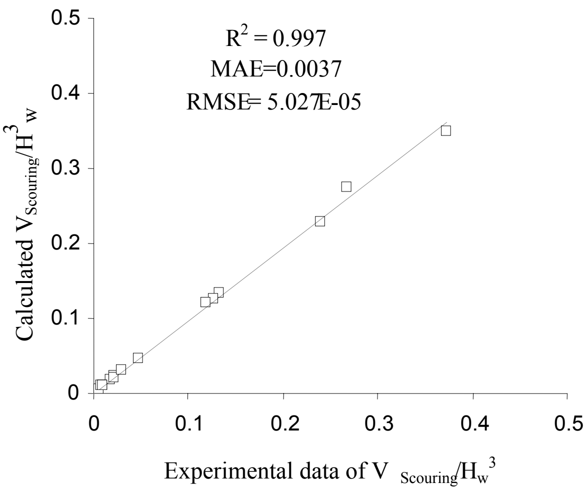

Figure 15. Plot of observed and estimate of dimensionless flushing cone volume for testing data set using regressive model.

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