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Comparative Analysis of Sediment Removal Efficiency Parameters of Settling Basin

Faisal Ahmad

Abstract: ***The mechanism of flow in settling basin is so complicated that it is very difficult to establish a general regression model to accurately estimate the sediment removal efficiency. No general relationship is available which can be used for estimation of sediment removal efficiency of settling basin under flushing condition as well as without flushing condition. Even in the absence of flushing, considerable differences exist in efficiencies given by different methods. The present study aims to re-analyze the databases to develop a general regression model for the determination of sediment removal efficiency of settling basin. The equation for sediment removal efficiency of settling basin given by Ranga Raju et al. (1999) has been checked and it was observed that the Ranga Raju et al. (1999) predictor does not give the reasonable estimate of sediment removal efficiency of settling basin. Therefore, the data have been re-analyzed and a new equation is developed which is recommended in order to predict the sediment removal efficiency of settling basin. The qualitative performance of present predictor indicated that it has lowest AAD, $RMSE$, APE and highest R as compared to Ranga Raju et al. (1999) predictor.***

Keywords: ***settling basin, sediment removal efficiency, regression model, R.***

I. INTRODUCTION

For removing excess sediment entering in irrigation or power canals, taking off from an alluvial river, settling basins are commonly used. Settling basin does not require any fraction of canal discharge for sediment removal. The principle used for settling basin is simply to provide a wide and long enough section for the resulting reduced flow velocity to allow the sediment particles to settle down. The sediment removal efficiency of settling basins is defined as:

$$\eta_o = \frac{\begin{pmatrix} \text{Amount of sediment entering} \\ \text{the basin per unit time} \end{pmatrix} - \begin{pmatrix} \text{Amount of sediment leaving} \\ \text{the basin per unit time} \end{pmatrix}}{\text{Amount of sediment entering the basin per unit time}}$$

Many empirical and analytical methods for the estimation of sediment removal efficiency of settling basins have been investigated by Camp (1946), Dobbins (1944), Sumer (1977), the United States Bureau of Reclamation [(USBR), Vanoni (1975)], Garde et al. (1990), Ranga Raju et al. (1999), Singh et al. (2008). Some of these methods for the computation of sediment removal efficiency of settling basins are based on analysis of extensive amounts of laboratory data and serve as a practical tool for the design of settling basins.

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Numerical modeling that has been applied for the design or investigation of settling basins have been described by Kerssens et al. (1979), Stamou et al. (1989), Schrempf (1991), Adams and Rodi (1990), and Atkinson (1992). The design of settling basins by using numerical modeling requires the model of the flow field and turbulence involving an advection-diffusion equation. The solution for such a model under realistic boundary conditions is very complex and involves unknown coefficients. Hence, numerical models have not yet been found for general use for the design of settling basins (Schrempf 1991). Ranga Raju et al. (1999) studied the effect of flushing of a sediment-water mixture from settling basin on its sediment removal efficiency. They obtain a relationship for sediment removal efficiency of settling basins for no flushing.

Despite analyzing a wide range of laboratory data collected from literature having a wide range of hydraulic and geometrical variables, the problem of sediment removal efficiency of settling basin has remained inconclusive. It is felt to be partly because of the complexity of the phenomenon involved and partly because of the limitations of the analytical tools namely, statistical regression commonly used by most of the earlier researchers. Therefore, it is clear that regression models have not high generalization capacity to apply for the computations of sediment removal efficiency of settling basins.

No general relationship is available that can be used for estimation of sediment removal efficiency of settling basin which is valid for both with and without flushing conditions.

The present study aims to re-analyse the data bases and to develop a general regression model for the determination of sediment removal efficiency of settling basin which is valid for both with and without flushing conditions.

II. MATERIAL AND METHODS

2.1. Data collection

Data on η_o of settling basins were collected from the laboratory experiments by Singh(1987), Sujudi(1988), Saxena(1996) and Shrivastava(1997). The range of the laboratory data collected is given in Table 1. The non-dimensional parameters used in the present investigation were calculated using laboratory data from the literature.

2.2. Dimensional Analysis

Referring to Fig. 1, the efficiency of sediment removal of settling basin, η_o can be expressed as

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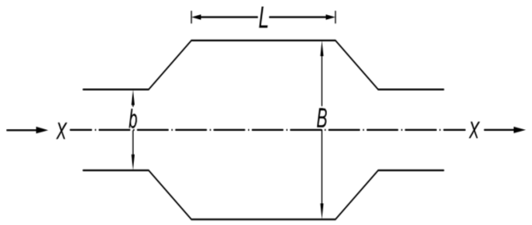
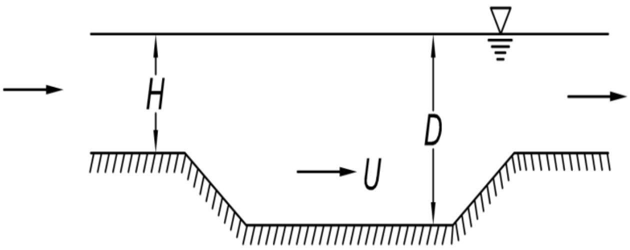


(a) PLAN



(b) ELEVATION AT X-X

Fig. 1 Definition sketch of settling basin

$$\eta_o = f\ (U, D, \omega, g, L, b, H, n\ , B, d)\ (1)$$

Where ω is fall velocity of the particle, g is acceleration due to gravity, n is Manning's coefficient and d sediment size. The other rnotations are as defined in the sketch. Using principles of dimensional analysis, one can reduce equation (1) to

$$\eta_o = f_4\left(\frac{\omega}{U}, Fr, \frac{L}{H}, \frac{B}{b}, \frac{Un}{D^{2/3}}, \frac{d}{D}\right) \qquad (2)$$

Here $Fr = U/\sqrt{gD}$

III. ANALYSIS OF DATA

A new relationship is derived for determination of sediment removal efficiency of the settling basin.

3.1 Verification of existing relationship

All the available data have been first used to verify existing model by Ranga Raju et al. (1999) for estimation of η_o. This equation is listed in Table-1. The comparison between observed values of sediment removal efficiency, η_o and those computed by the Ranga Raju et al. (1999) model and qualitative performance of the Ranga Raju et al. (1999) model is presented in Table-1. Also Fig. 1 (a) shows a comparison between removal efficiency of the settling basin computed by the Ranga Raju et al. (1999) model and the observed values of removal efficiency. A close study of these figures reveals that existing model (Ranga Raju et al. (1999) model) has not been able to predict the values of sediment removal efficiency,η_o satisfactorily for the data used in present study.

3.2. Proposed regression model

On the basis of functional relationship derived in (2),η_o can be expressed in the following form:

$$\eta_o = f((\omega/U), (Fr), (L/H), (B/b), (Un/D^{2/3}), (d/D)) \qquad (3)$$

Or

$$\eta_o = K_1(\omega/U)^{n_1}(Fr)^{n_2}(L/H)^{n_3}(B/b)^{n_4}(Un/D^{2/3})^{n_5}(d/D)^{n_6} \qquad \textbf{(4)}$$

whereK_1 is a constantandn_1, n_2, n_3, $n_{4,}n_5$ and n_6 are exponents.The values of constant K_1 and exponents of equation (4) may be estimated using the available experimental data. After removing the outliers, the data were used in the estimation of exponents and constant K_1. The number of rows with outliers with greater than three times standard deviations was obtained by Matlab tool box. The range of data used in the study is shown in Table 4.2. Matlab toolbox for non-linear regression was used to obtain the values of constant K_1 and exponents n_1, n_2, n_3, n_4, n_5 and n_6 for the prediction of sediment removal efficiency η_o for the settling basin using 80% of the available data which was selected randomly and contains minimum and maximum values. Finally, the following equation for the estimation of sediment removal efficiency of the settling basin was obtained.

$$\eta_o = 226.225\left[\frac{\omega}{U}\right]^{1.550}[Fr]^{2.118}\left[\frac{L}{H}\right]^{0.058}\left[\frac{B}{b}\right]^{0.079}\left[\frac{Un}{D^{2/3}}\right]^{-0.257}\left[\frac{d}{D}\right]^{-1.508} \qquad (5)$$

The validation of the above equation was done using the remaining 20% of the data which were not used in the derivation. Ranga Raju et al. (1999) model was also tested for the training, validation and all data sets along with the present predictor and the results are shown in Table-1.

Figs. 1 (a) and 1 (b) shows the comparison between the computed sediment removal efficiency η_o using the existing as well as present relationship and observed values for all data sets. The quantitative comparisons in terms of the performance parameters such as coefficient of correlation between computed values from the present model and desired output(R), mean absolute percentage error($MAPE$), root mean square error($RMSE$), and average absolute deviation(AAD), is shown in Table-1 for present equation along with the relations available in literature.

The Table-1 shows that the value of R is maximum 0.90 while $MAPE$,AAD, and $RMSE$ values are as low as 200.477, 24.52 and 0.14 respectively for the present model. This indicates the satisfactory estimation of the sediment removal efficiency of settling basin. The values of η_o computed by equation (5) are plotted in Figs. 1 (b) against their corresponding observed values. Also equation (5) is much better than those available in the literature (refer Table -1). However, the equation (5) should only be used for the range of data presented in Table-2.

Values of $\eta_o$computed by equation (5) and those of existing model are plotted in Fig. 1 (c) against their corresponding observed values. It can be seen from this figure that equation (5) computes η_o values with a maximum of ±40% error for approximately all the data. This accuracy is considered satisfactory considering that laboratory data for basins with varying geometric configurations were used. The accuracy of equation (5) is also much better than that of existing relationships for η_o as shown in

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Table-1. However, it should be noted that Equation (5) should only be used for the range of data presented in Tables-2.

IV. CONCLUSIONS

The following conclusions are drawn from present study:

(i) The equation for sediment removal efficiency of settling basin given by Ranga Raju et al. has been checked for its accuracy using a wide range of data available in the literature. The results of equation thus obtained are summarized in Table-1. It is observed that the Ranga Raju et al. predictor does not give a reasonable estimate of sediment removal efficiency of settling basin. Therefore, the data have been re-analyzed for the purpose of developing a generalized fit of the statistical non-linear regression equation for sediment removal efficiency which yielded the equation (5) which is recommended in order to predict the sediment remove inefficiency of settling basin.

(ii) The qualitative performance of present predictor indicated that it has lowest $AAD, RMSE, APE$ and highest R as compared to Ranga Raju et al. predictor.

$$(\eta_o)_{\text{predicted}} = 1.962(\eta_o)_{\text{observed}} - 0.1656$$

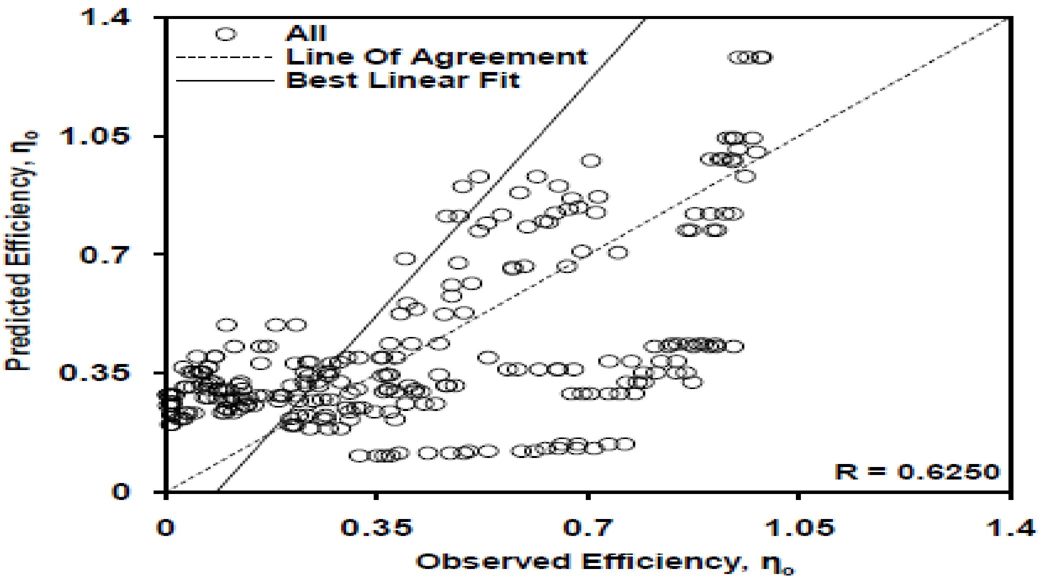

Fig. 1 (a) Comparison between Observed and Predicted Values of ηo for Ranga Raju et al. (1999) Model

$$(\eta_o)_{\text{predicted}} = 0.7874(\eta_o)_{\text{observed}} + 0.1056$$

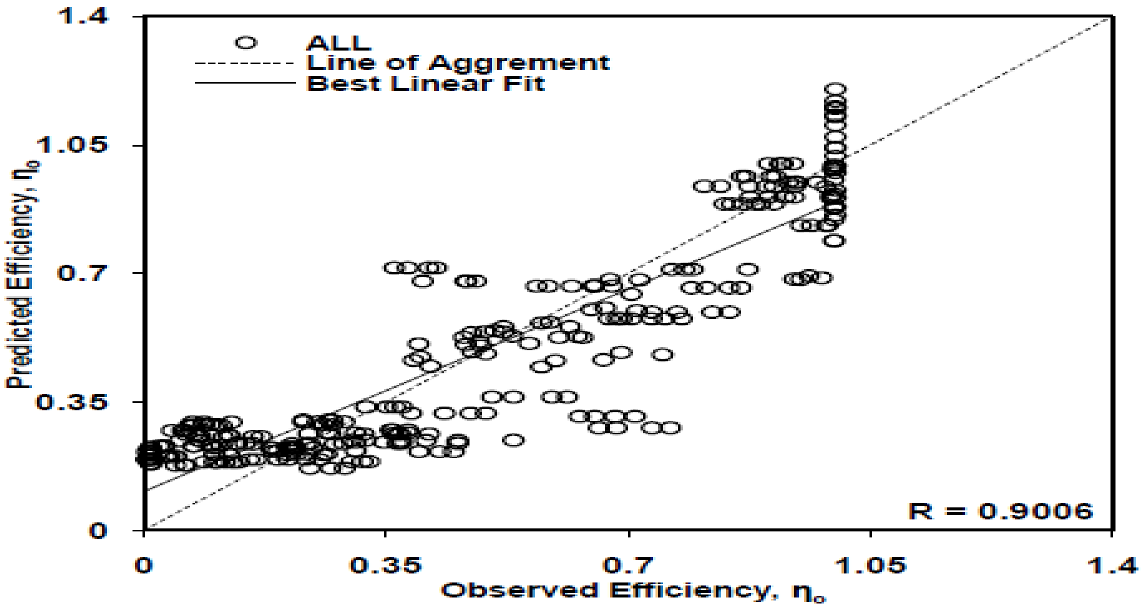

Fig. 1(b) Comparison between Observed and Predicted Values of ηo for Present Regression Model

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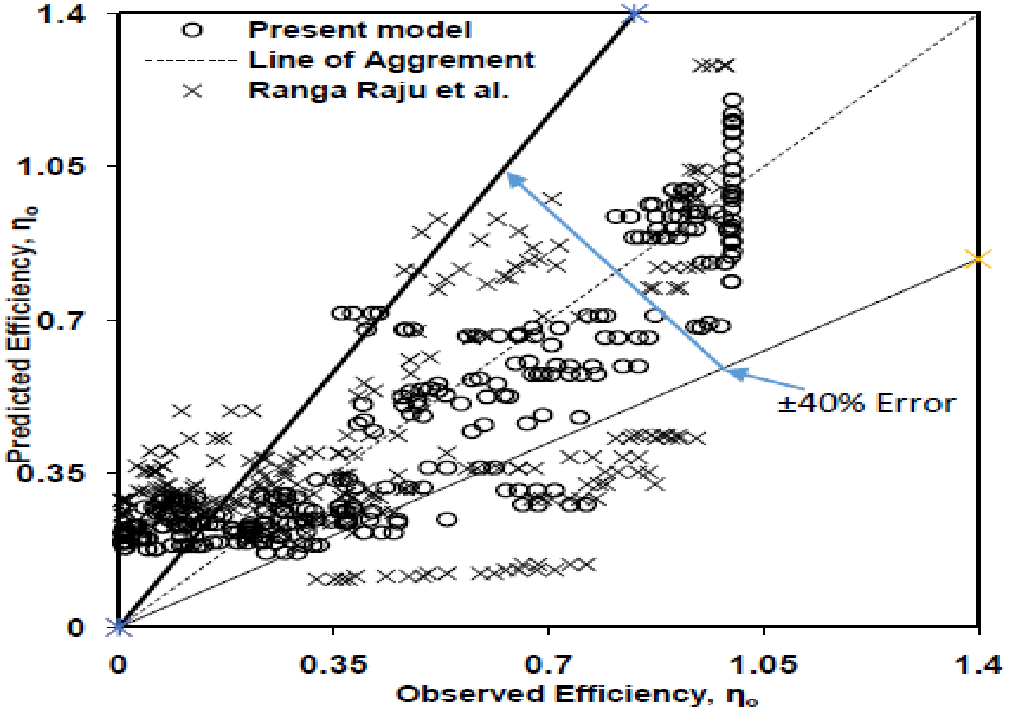

Fig. 1 (c) Comparison between observed and predictive values of ηo forexisting and proposed regression model

TABLE-1: Performance Parameters of Existing and Proposed Models

S.No.	SOURCE	MODELS	PERFORMANCE PARAMETERS								DATA SET
			R	*APE*	*MAPE*	*AAD*	*RMSE*	*STDV*	*E*	*SI*	
1	Ranga Raju et al. (1999)	$\eta_o = 11.7\left[\frac{\omega}{U}\right]^{0.81}\left[\frac{LB}{bh}\right]^{0.23}\left[\frac{D^{1/6}}{n\sqrt{g}}\right]^{0.98}$	0.6250	-270.9852	300.0589	99.8532	0.9350	785.0238	-6.6812	1.9650	All
2	Present Regression model	$\eta_o = 226.225\left[\frac{\omega}{U}\right]^{1.550}[Fr]^{2.118}\left[\frac{L}{H}\right]^{0.058}\left[\frac{B}{b}\right]^{0.079}\left[\frac{Un}{D^{2/3}}\right]^{-0.257}\left[\frac{d}{D}\right]^{-1.508}$	0.9006	-180.9664	200.4773	24.5299	0.1469	593.8966	0.8102	0.3088	All

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TABLE-2: Range of Data Collected From Literature

S. No.	INVESTIGATORS	PARAMETERS													
		U (m/s)	D (m)	ω (m/s)	g (m/s^2)	L (m)	b (m)	H (m)	n	B (m)	d_{50} (mm)	η_o (%)	S	u_* (m/s)	Q_f (%)
1	Shrivastava (1997)	0.298 -0.396	0.14 -0.248	0.034 -0.057	9.81	2.4	0.19	0.116 - 0.188	0.028	0.3	0.252- 0.387	56.71-94.13	.0021-.004	0.042-0.059	0.0-8.0
2	Saxena (1996)	0.3-0.585	0.15-0.246	0.007-0.105	9.81	2.4	0.19	0.105-0.165	0.019	0.3	0.09 -0.707	32.16-98.85	.0021-.0074	0.024-0.3	0.0-13.0
3	Sujudi (1988)	0.119-0.234	0.114-0.207	0.006-0.009	9.81	0.5-5	0.107-0.3	0.078-0.144	0.016	0.75	0.082-0.106	0.5-53.5	.0012-.0028	0.008-0.13	0.0
4	Singh (1987)	0.108-0.207	0.196-0.405	0.016-0.105	9.81	1-6	0.3	0.104-0.224	0.015	0.75	0.147-0.707	39-100	.002-.0025	0.007-0.013	0.0

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