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Preparation of Papers for

PREDICTABILITY OF SEDIMENT TRANSPORT USING SELECTED TRANSPORT FORMULA

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Abstract— In alluvial rivers the sediment load is transported as bed load, suspended load and wash load. The bed material of an alluvial channel moves as bed load (contact load or saltation load) at low value of average shear stress and they constitute the suspended load at the higher value of shear stress. Prediction of the suspended sediment transport rate is necessary as it is affected by hydrological as well as hydraulic characteristics of the alluvial stream. Methods are available for predicting the suspended load transport rate for uniform sediments. However, limited studies exist for non-uniform sediment transport. Microscopic approach of Swamee and Ojha (1991) which considers the non-uniformity of sediment is used in the present study to compute the suspended load transport rate. Suspended load transport formula is tested against Samaga et al flume data set (1984b) for four sediment mixtures (M-1, M-2, M-3 & M-4). The data set is peculiar as it has varying size of sediments in mixture with different mean diameter of sediments and geometric deviation for each mixture. Suspended load function is also tested using Sacramento River data measured at two USGS gauging station namely Butte city and Colusa, California. Performance of the Swamee and Ojha's suspended load function has been evaluated using statistical parameters such as Root Mean Square Error (RMSE), Discrepancy Ratio (r) and Inequality Coefficient (U). Predicted results for the suspended load transport rate are within the wide error range of -9% to +4200% for all the four mixtures and hence failed to provide satisfactory results. Predicted results for the Sacramento River data also scatters in wide range of errors (1063%) providing better results as compared to mixture M-1 of Samaga et al flume data set.

Index Terms— Grain roughness, Kramer's uniformity coefficient, non uniform sediment, samaga et al flume data, sediment transport, suspended load and statistical parameters of analysis.

1 INTRODUCTION

The collective movement of solid particles, known as sediment transport, along the natural alluvial river bed is a complex phenomenon and a large number of studies have been done to test the predictability of various sediment transport methods covering a wide range of flow conditions and sediment types [(Van denBreg, J.H. (1993), Winterwerp, J.C.(2001), Martin, Y. (2003), Pinto, L.(2006)] but the accuracy of computational sediment transport methods has remained a challenging question [ASCE (2004)].

Number of sediment transport formulas can be found in the literatures that are used to study sediment transport in alluvial channels. Transport of sediment in alluvial channels occurs mostly in the form of bed load, suspended load and wash load transport. Bed load is defined as the maximum bed load per unit width that a particular discharge can transport at a certain slope and it has been the subject of extensive research since the pioneering work of Du Boys (Garde and Ranga Raju 1985) followed by Meyer-Peter and Muller (1948), Einstein (1950), Bagnold (1966), Rijn (1984), Samaga et al (1986), Swamee and Ojha (1991), Wu et al (2000) etc while Suspended-sediment transport refers to the grains of sediment moving along a river.

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The suspended-sediment load consists largely of the finer fraction (the fine sand, silt and clay) of the sediment available to the river. As the turbulence is generated at the channel boundary and is most intense there, suspended sediment tends to have higher concentrations and involve coarser material near the boundary and both sediment size and concentration decline as we move up through the water column towards the surface of the flow. (Edward J., 2004). Suspended sediment transport is the dominant mode of transport in the lower reaches of rivers.

The suspended load also includes the wash load of the flow. Wash load differs from the rest of the suspended load in that its suspension is not dependent on the forces of turbulence associated with flow and it is not found in significant quantity (not more than 10% according to Einstein, 1950). The theoretical equation for the distribution of suspended sediment in turbulent flow has been given by H. Rouse. Further useful information on the modification of the theory can be found in, Vanoni (1984), Van Rijn (1984b), Swamee and Ojha (1991) etc.

Practically, fine particles (e.g. clay and silt) settle in a laminar flow while large particles (e.g. gravel and boulder) fall in a full turbulent flow motion. The most common approach to model the suspended sediment transport is based on the advection-diffusion theory representing the downward transport by gravity (settling) and the upward transport by turbulent processes (mixing), resulting in a Rouse-type sediment concentration profile over the water depth (Van Rijn, L.C., 2007). It has been observed in the laboratory flumes and natural rivers that the concentration of the suspended load in a vertical decreases with increases in distance from the bed.

2 DATA COLLECTION-FLUME AND FIELD DATA

In the present study, suspended load transport formula of Swamee and Ojha (1991) is tested against Samaga et al flume data set (1984b) for four sediment mixtures (M-1, M-2, M-3 & M-4) consisting varying size of sediments with different mean diameter and geometric deviation for each mixture. The data set used include hydraulic parameters such as water discharge ($0.00557 m^3/s$-$0.014638 m^3/s$), velocity (0.49m/s-0.78m/s), flume width (0.2 m), flow depth (0.06m-0.11m) and channel bedslope (0.00505-0.00693m/m). Measured suspended load lies within the range of 1.2E-05 m^2/s-5.4E-05 m^2/s.
Suspended load function is also tested using Sacramento River data measured at two USGS gauging station namely Butte city and Colusa, California. The suspended sediment grain size for the Sacramento river data ranges from the fine sand to coarse gravel with d_{50} between 0.00033 m to 0.00630 m and the geometric standard deviation 1.40 to 9.53. Suspended load transport rate lies within the range of 0.023 kg/s-18.08 kg/s while flow depth ranging between 2.01m-8.17m.

3 METHODOLOGY

The required hydraulic parameters collected in the flume and field data set for computing the suspended load transport rate of the Swamee and Ojha's microscopic approach are processed through computer programs developed in the MS excel spread sheet which are based on a detailed step by step computational procedure written for the manual calculations.
The predicted suspended load transport rates are then compared with the observed values. Statistical parameters such as Root Mean square error (RMSE), discrepancy ratio and Mean normalized error were used for the comparison of performance. The accuracy order was prepared on the basis of data coverage between certain value of the discrepancy ratio, the Min. relative error and the calculated values were plotted against the observed values so that the scatter about the perfect agreement line can also be considered.

3.1 Suspended load function of Swamee and Ojha (1991) approach

Microscopic approach of Swamee and Ojha (1991) has described the non-uniformity of sediments for the suspended-load transport rates by an empirical three-parameter grain-size distribution equation for unimodal shapes. The computational procedure for the suspended load transport rate should be applied as:

1. Compute hydraulic radius related to grain roughness R' as:

$$R' = \left(V \frac{d^{1/6}}{24\,(S^{0.5})}\right)^{1.5} \tag{1}$$

Where V= velocity of flow (m/s), S= channel bed slope (m/m), d=channel flow depth (m), R'=grain roughness.

2. Compute grain shear stress T*, defined as:

$$T'_* = R'\,S/(s-1)\,d_* \tag{2}$$

Where d_* = transitional diameter.
3. Compute Kramer's coefficient as:

$$M = [0.1769\,\ln\sigma_g + 1]^{-10} \tag{3}$$

Where σ_g= standard deviation and M= Kramer's coefficient.

4. Compute suspended load transport parameter ϕ_s:

$$\emptyset_s = \{[(0.073/M)^4 + M^{3.8}][\frac{0.567}{T_*'^{M^{0.635}}}]^6 \cdot [(\frac{0.177}{M})^2 + M^{1.45}]^2 [\frac{0.538}{T_*'^{\frac{8M}{7M^{1.425}+1}}}]^3\} \tag{4}$$

5. Compute suspended load transport rate by using the parameter ϕs:

$$\emptyset_s = \frac{q_s}{d_*[(s-1)g\,d_*]^{0.5}} \tag{5}$$

Where qs = volumetric suspended load transport per unit width per unit time.

4. DATA ANALYSIS OF SWAMEE AND OJHA'S SUSPENDED LOAD FUNCTION

In order to carry out data analysis, observed (measured) values are required. Samaga et al flume data (1986 b) consisting of four sediment mixtures (M-1, M-2, M-3 and M-4) and Sacramento river data have been used to predict the Swamee and Ojha's suspended load function. Observed and predicted values are plotted graphically in origin (software) to check the predictability of Swamee and Ojha's function i.e. whether the function over predicts the value, under predicts it or lie within the line of perfect fit. A solid line represents line of equality in origin. It could be observed from fig.1, 2, 3 and 4 that the suspended load function is overpredicted for mixture M-1 and M-2 while scattering values are obtained about the line of equality for mixture M-3 with majority of data overpredicted and the majority of the values are underpredicted for mixture M-4. Majority of the Sacramento river data are found to under predict the values as shown in fig.5.

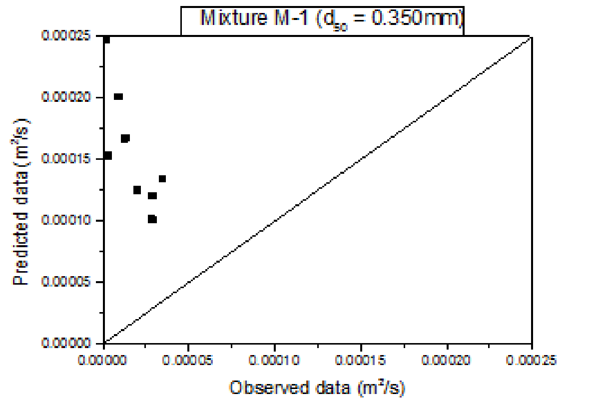

Fig.1 Graph correlating Observed & Predicted values for Samaga et al data set-M-1

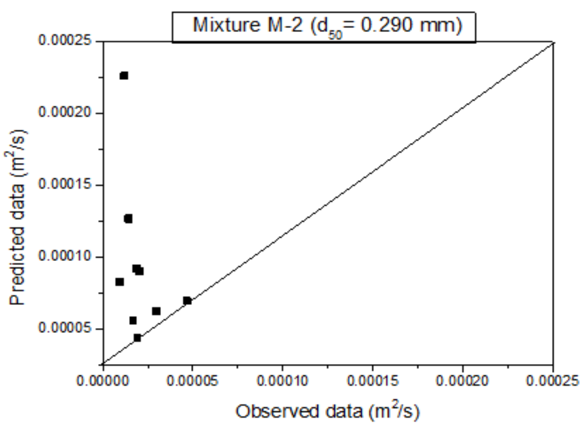

Fig.2 Graph correlating Observed & Predicted values for Samaga et al data set-M-2

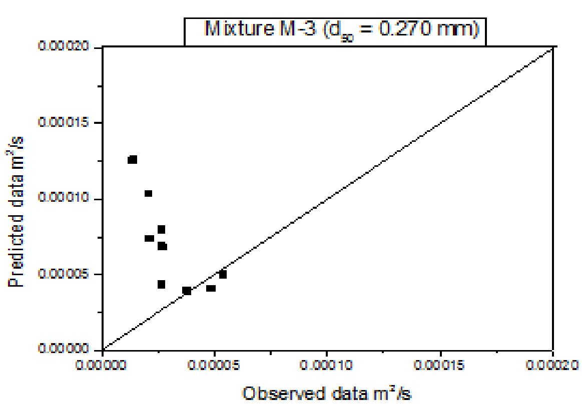

Fig.3 Graph correlating Observed & Predicted values for Samaga et al data set-M-3

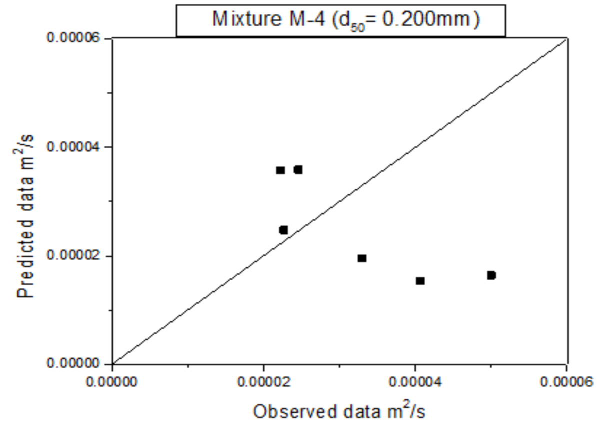

Fig. 4 Graph correlating Observed & Predicted values for Samaga et al data set-M-4

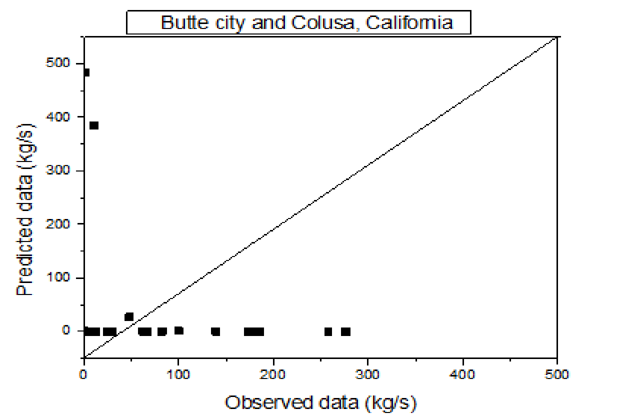

Fig.5 Graph correlating Observed & Predicted values for Sacramento river data set measured at two USGS gauging station, Butte city and Colusa, California.

4.1 Statistical parameters

Measure of the deviation between the trend of predicted results and observed values can be determined with the help of RMSE while the discrepancy ratio represents the divergence or disagreement of the predicted results from the line of perfect fit. Table 1 below represents the summary of statistical parameters used to check the predictability of Swamee and Ojha's suspended load function for the Samaga et al (1986b) flume data set and Sacramento river data set.

TABLE 1

SUMMARY OF STATISTICAL PARAMETERS FOR THE SAMAGA ET AL (1986B) FLUME DATA AND SACRAMENTO RIVER DATA SET.

Sr.No.	Data set	Type of mixture	RMSE	Discripancy ratio (r)	Inequality coefficient (U)	Avg. % error(MNE)
1	Samaga et al flume data (1986 b)	M-1	0.00022763	42.9950522	0.8807693	4199.505223
		M-2	0.0000931	6.21274136	0.7111687	521.2741361
		M-3	3.3637E-09	3.07083072	0.5075044	207.0830719
		M-4	1.94E-05	0.90930977	0.3246428	-9.06902335
2	Sacramento river data		1.67E+02	11.6381	0.70096	1063.81

5 CONCLUSION

Following findings can be summarized from the analysis of predicted and observed suspended load transport rate:

- It was observed that the discrepancy ratio value was found to nearly equal to one for mixture M-4 as compared to mixture M-1, M-2 and M-3 of Samaga et al (1984 b) data set.
- The results for the Swamee and Ojha's suspended load transport rate are overpredicted for the majority of data used.
- It was noticed that the Swamee and Ojha's suspended load function provide results with a wide error range of -9% to +4200% for all the four mixtures of Samaga et al (1986) data set.
- It was also observed that the Swamee and Ojha's suspended load transport rate provide better results as compared to mixture M-1 of Samaga et al data set.

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