A regression model of total sediment transport based on correlation of dimensionless parameters

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Abstract - *A correct prediction of Sediment transport in open channels is a significant fluvial hydraulics challenge still. Despite many relations proposed by different researchers based on different concepts like flow regime, stream power, etc., general applicability of any relation is a distant reality. It can be understood that no universal equation can possibly be made to fit in all general situation of open channel flows. Also the limitations of actual field measurement of different essential variables and the inherent error associated with them makes the validation of proposed relation difficult. Many times the simulation of open channel flow is done in laboratory flumes to study the different aspects of sediment flow and study the existing and proposed relationship in controlled environment. In the present paper a regression relationship for prediction of total sediment transport is presented which is based on correlation of some key dimensionless parameters of sediment flow. Though extensive testing of proposed relation still needs to be done, yet preliminary testing on selected data sets show promising results. Various* ***dimensionless flow parameters like Van Rijn's, Duo's, Yang's and Yang & Lim's have been correlated with*** *Wilcock and Crowe dimensionless sediment transport parameter and correlation coefficient have been found. Based on this the best correlated pair has been used to develop the proposed model. The model is tested on independent lab and field data sets and the results obtained are good and within acceptable range.*

Key Words: Dimensionless transport parameters, Dimensionless flow parameters, correlation coefficients, regression model, total sediment transport

1. INTRODUCTION

Alluvial streams mostly come down from mountainous origin and travel down the natural land slope over a long distance to reach the mouth of oceans or seas or lakes. This passage of water through this distance entails sediment transport both from the bed material as well as surface of the catchment as surface runoff carries upper layer of soil of catchment and add it to stream flow as wash load. Depending on number of parameters like channel characteristics-cross section, roughness, etc., flow characteristics- flow discharge, mean velocity, turbulence velocity, etc, fluid characteristics- density of fluid, temperature, etc., sediment characteristics- shape, size, specific density, mean size, etc. a relation is developed considering the significant factors, a found by many researchers, which greatly affect the sediment transport in open channel.

2. TOTAL LOAD TRANSPORT

Paragraph comes content here. There are two school of thoughts when it comes to defining the total sediment transport. One side of theorists believe suspended sediment transport is an extension of bed load transport at substantial flow or it can be treated as extension of bed load transport. This approach is called macroscopic approach and it is more suitable for hydraulic field engineers who are more concerned with total sediment transport rate. The other school of thought considers the suspended and bed load transport separately. This approach is called microscopic approach. Both approaches have their takers and critiques.

Away from this discussion, some researchers have addressed the issue directly without any physical basis or explanation and used various statistical approaches to develop the total sediment transport relationship using large number of data sets.

3. METHODOLOGY

A similar approach has been tried by the authors here, and a model is developed using various flume and field data sets. The developed model is tested on other data sets to assess its predictability.

A set of dimensionless flow parameters, given by Van Rijn, Yang, Yang & Lim, Duo, Bagnold(as in equation 2-6) have been selected to test their correlation with a dimensionless sediment transport parameter qs*, given by Wilcock & Crowe as given in equation 1.

$$q_s^* = \{(\Upsilon s/\Upsilon\text{-}1)\}\, g\, q_s\}/\, u_*^3 \qquad (1)$$

where q_s is in m²/s

Dimensionless flow parameters:

φ_b (Bagnold Power Parameter), $\Phi_b = \tau_0 V$ (2)

φ_v (Van Rijn's excessive dimensionless shear stress Parameter),

$\Phi_v = (u'^2_* - u^2_{*c}) / u_*$ (3)

φ_y (Yang's Stress Parameter), $\Phi_y = VS/\omega$ (4)

φ_e (Dou's Energy Parameter), $\Phi_e = V^3/g^*R^*\omega$ (5)

φ_n (Yang and Lim Parameter),

$\Phi_n = (\Upsilon_s/\Delta\Upsilon_s)^* \tau_0{}^*(u'^2_* - u^2_{*c}) / \omega$ (6)

$$\text{Correlation Coefficient} = \frac{\Sigma(xi-xavg)(yi-yavg)}{\Sigma\sqrt{[(xi-xavg)^2(yi-yavg)^2]}} \quad (7)$$

The correlation coefficient have been found for each data set value of the selected data set using eqn. 7. The pair of parameter giving the highest correlation in maximum data sets was chosen to develop the model.

For this selected pair of sediment transport parameter and flow parameter, all the data set values were evaluated separately. Those data sets giving R^2 value greater than 0.5 were taken for developing the regression model by plotting the corresponding values of qs* and selected flow parameter for all the selected data sets. A power function curve fitting relation was used to develop the model. This proposed model is further tested on different data sets to check the validity of the model.

4. DATA COLLECTION

A set of data from the compilation of Brownlie W. R. (1981) has been taken to develop and test the model. The range of data selected and used is given in Table 1.

Table -1: Summary of the Data sets used

Summary of Data sets used					
Data Set	Type(data points)	Discharge Range, Q(m3/s)		Sediment range, d50 (m)	
Barton & Lin	Lab(28)	0.0254	0.259	0.00018	0.00018
Gibbs C H	Lab(9)	0.158	0.198	0.004374	0.004374
J P Soni	Lab(23)	0.001	0.009	0.00032	0.00032
William	Lab(177)	0.001	0.162	0.001349	0.001349
Mountain Creek	Field(100)	0.064	1.493	0.000899	0.000899
Trinity River	Field(4)	39.642	82.68	0.0034	0.0118
Nomicos	Lab(16)	0.005	0.016	0.000137	0.000152
AMC	Field(11)	1.217	29.42	0.000096	0.007
Rio Grande(Tof)	Field(38)	35.11	285.99	0.000207	0.000368
Willis	Lab(32)	0.016	0.048	0.00054	0.00054

5. DATA ANALYSIS AND MODEL DEVELOPMENT

From the given parameters in the data sets, the other parameter like shear stress, critical velocity, kinematic viscosity considering the effect of temperature, etc. were calculated. The mean size of sediment, d_{50} was used for the calculations. The correlation coefficients were found, as shown in Table 2 (sample and summary), and based on this R^2 values were found for different data sets, as shown in Table 3. Six lab and field data sets (341 data values) namely; Barton & Lin, J P Soni, Gibbs, Williams, Mountain Creek & Trinity River, were used for development of model.

A regression model, PM1 (eqn.8) was developed by plotting all the corresponding values of selected pair, i.e. qs* and Φ_n for all the selected data sets as shown in Fig. 1.

$$Y = 32.548\, X^{0.6148} \quad (8)$$

Where, Y represent qs* and X represent Φ_n.

Table -2: Correlation Coefficients Obtained for Data set of Barton & Lin and summary for other data sets

C.C.	φn	φb	φv	φy	φe
qs*	0.977	0.933	0.971	0.959	0.964

Summary of Correlation Coefficients	
Data Set	qs* and Φn
Barton & Lin	0.850
Gibbs C H	0.976
J P Soni	0.566
William	0.645
Mountain Creek	0.899
Trinity River	0.993

Table -3: R^2 values for different data sets

Summary of R^2 values	
Data Set	R^2 Values
Barton & Lin	0.7088
Gibbs C H	0.9693
J P Soni	0.9821
William	0.7992
Mountain Creek	0.6297
Trinity River	0.9217

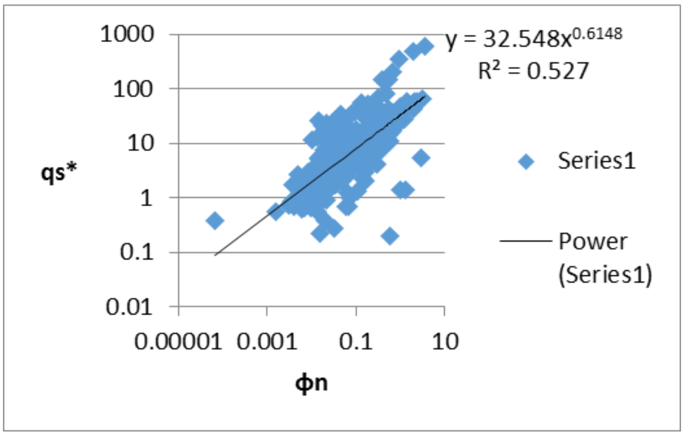

Fig 1: Plot between qs* and Φ_n for selected data sets

6. RESULT AND DISCUSSION

The developed model PM1was tested using the data sets of Nomicos, Willis, Rio Grande (Toffaletti) and AMC Simons beside the data used for developing model. The predicted sediment transport rate was analyzed using statistical parameters like mean normalized error, discrepancy ratio and score (for MNE between 0 to 2.5). The result obtained are given in Table 4.

Table -4: Statistical analysis of result using proposed model PM1

Summary of result analysis for PM1				
Data Set	MNE	DR	Score	Data
Barton & Lin	-38.844	0.612	14.286	Data sets used for model development
Gibbs C H	90.501	1.905	100.000	
J P Soni	-75.251	0.247	4.348	
William	9.906	1.099	88.701	
Mountain Creek	125.450	2.255	80.000	
Trinity River	4451.020	45.510	0.000	
Nomicos	-69.278	0.307	18.750	Independent data sets
AMC	-73.345	0.267	9.091	
Rio Grande	-59.112	0.409	28.947	
Willis	-43.430	0.566	37.500	

7. CONCLUSIONS

From the analysis result following points can be concluded:

- The dimensionless parameter considered for the development of model is very robust as it incorporate all major flow parameters like fall velocity, friction velocity, etc.
- The result predicted for Gibbs C H data set has score of 100, which is extremely good.
- The score is above 50 for the data sets of Gibbs, Williams and Mountain creek.
- MNE obtained for both lab and field data in most cases is within $\pm$ 100, which shows the prediction done using proposed model is very good and within acceptable range.
- PM1 fails to predict well in case of Trinity River by a large margin, possibly because of wide variation in input parameter values as per data set.

Overall, it can be said that the proposed model predicts total sediment transport well for most of the tested data sets and can be applied for even field data sets effectively.

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BIOGRAPHIES

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