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ASSESING THE PREDICTABILITY OF TOTAL SEDIMENT TRANSPORT RATE FOR UNIT STREAM POWER APPROACH

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Abstract— Sediment transport is a significant factor in effective design of hydraulic structures and open channel water conveyance. Estimation of the amount of sediment material which a specific flow can carry is one of the major issues of sedimentation research. Unit stream power is defined as the time rate of potential energy per unit weight of water, and is found to be the dominant factor in the determination of total sediment concentration being carried by the (Yang, 1972). Yang's (1979) unit stream power approach for total load sediment transport function is applied to test the predictability of total sediment transport rate by using flume data sets of Samaga et al (1986), Willis et al (1972) and river data set of Middle Loup river of Hubbel et al (1959). The performance of the Yang's sediment transport function for different data sets has been evaluated by finding statistical parameters, such as root mean square error (RMSE), discrepancy ratio and inequality coefficient. From the evaluation, it is observed that the Yang (1979) total load function under predicts the sediment transport rate for the three mixtures M_1, M_2, M_3 and predicts well for mixture M_4 of Samaga et.al data set giving good result compared to other mixtures. For both Willis et al (1972) data set and the river data of Hubbel et al (1959) total load function of Yang (1979), both under predicts as well as over predicts sometimes.Yang total load equation gives better results for samaga et al (1986) data sets for the four mixture.

Index Terms— Fall velocity, incipient motion, sediment transport, shear velocity, total sediment load, unit stream power and Yang.C.T.

1 Introduction

The subject sediment transport and flow in alluvial stream are gaining importance with the utilization of water resources. Considerable development has taken place in the field of fluvial hydraulics which is considered as complicated branch of engineering.

Estimation of the amount of sediment material, which a specific flow can carry, is one of the major issues of sedimentation research. In alluvial river system, river banks will erode, sediment will be deposited and flood plains and side channels will undergo modification with time. Effect of sedimentation in river reduces carrying capacity which may lead to flood water damage to surrounding area.

Contributors to the development of total load sediment transport theories refers to the names of Laursen (1958), Garde and Albertson (1961), Ackers and White (1973), Engelund and Hanson (1967), Yang (1973, 1979, 1984) etc. The relationship between rate of sediment transport and rate of potential energy expenditure has been studied in detail. The concept of the rate of work done should be related to the rate of energy expenditure was used by Bagnold (1966). It was demostrated by Yang (1972) that the rate of sediment transport depends on the unit stream power more than any other hydrualic parameter. Unit stream power, defined as the time rate of potential energy expenditure per unit weight of water is shown to be the dominant factor in the determination of total sediment concentration. Yang's (1973) unit stream power equation for the computation of total sediment concentration includes the incipient motion criteria while Yang's (1979) unit stream power equation for the computation of total sediment concentration is obtained without using any criteria for incipient motion. Due to the uncertainties involved in determining the flow conditions precisely at incipient motion, the present paper will examine the possibility of developing an accurate unit stream power equation for total load or total bed material load in the sand size range without using any criteria for incipient motion.

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2 Methodology

Yang (1979) approach is used in the present analysis to predictability the total load transport rate.

2.1 Chih Ted Yang (1979)

The concept was introduced and developed by Bagnold (1966) of stream power. The unit stream power of Yang (1972) can be derived from the stream power. This slightly different theory relates the rate of potential energy dissipation of the unit weight of water. Chih Ted Yang (1979), suggest that the following relation provides the best correlation between total sediment concentration C_t and unit stream power (V_s).

$$\log C_t = I_1 + J_1 \log\left(\frac{VS}{\omega}\right) \tag{1}$$

Further from multiple regression analysis with 463 sets of laboratory data from uniform flows, the following equations were obtained for I1 and J1 parameters.

$$I_1 = 5.165 - 0.153 \log\left(\frac{\omega d_s}{v}\right) - 0.297 \log\left(\frac{u_*}{\omega}\right) \tag{2}$$

$$J1 = 1.78 - 0.36 \log\left(\frac{\omega d_s}{v}\right) - 0.48 \log\left(\frac{u_*}{\omega}\right) \tag{3}$$

Eqs. 1, 2 and 3 were proposed by Yang (1979) for the prediction of total sediment concentration C_t in parts per million by weight for the particles in the sand size range with ds = d_{50} = median sieve diameter of bed material.

2.1 Step by step computational procedure for Yang

(1979).

- Input parameter: Q, D, V, S, g, v, d_{50}.
- Output : Q_t.

Computational procedure :

The procedure for the compuatation is summarized as follows:

1. Compute the value of overall shear velocity U_* from

$$u_* = (gDS)^{0.5} \quad (4)$$

2. Calculate fall velocity of sediment particles ω using d_s=d_{50}

$$\omega = \left(\frac{10\,v}{d_s}\right)\left\{\left[1+\left(\frac{0.01\,\Delta g d_s^{\,3}}{v}\right)\right]^{0.5}-1\right\} \quad (5)$$

3. Calculate the factor I_1 from Eq., 2.

4. Calculate the factor J_1 from Eq., 3.

5. Determine the total sediment transport rate Q_t in ppm by weight from Eq., 1.

3 Data Collection

In the present study following flume and field data sets have been used for testing Yang (1979) approach.

1. Samaga et al flume data (1986).
2. Willis et al flume data (1972).
3. Middle loup river Hubbel et al (1959).

Total load transport rate using Yang (1979) relation are predicted for the four mixtures (M_1, M_2, M_3, M_4) having different arithmetic mean diameter and standard deviation as given in Samaga et al (1986) flume data set. The value of grain size d_{50} for the four sediment mixtures are M_1 = 0.350 mm, M_2 = 0.290 mm, M_3 = 0.270 mm and M_4 = 0.200 mm and for Willis et al (1972) grain size d_{50} = 0.1 mm median sieve diameter. However Yang (1979) total load function is also predicted using field data of Middle loup river Hubbel et al (1968). The computed total load transport using flume data are plotted in Fig. 1, 2, 3, 4, 5 and for field data plotted in Fig. 6. Observed and predicted values are plotted in origin to check the predictability of Yang (1979) total load function. Solid line represents the line of equality. Values above the solid line represents values are over prediction and values below the solid line represents the value are under prediction of total load.

4 Result Analysis

From the Fig. 1, it can be observed that the sediment transport rate for mixture M_1 values are below the line of equality so the observed and predicted are plotted in origin graph represent the value are underpredict. While mixture M_2 and M_3 also below the line of equality so the observed and predicted are plotted in origin graph represent the value are underpredict. For the mixture M_4 it could be concluded that the shows values are nearer the line of equality so the observed and predicted values are plotted in origin graph represent the good result for M_4 mixture. For laboratory data willis et al (1972) observed vs predicted graph shown in Fig. 5 values are above as well as below the line of equality. So, the observed and predicted values are plotted in origin graph is over predict as well as under predict and for field data Middle loup river Hubbel et al (1959) origin graph shown in Fig 6 values are above as well as below the line of equality. So the observed and predicted values are plotted in origin graph is over predict as well as under predict. Comparision between observed values and predicted values obtained for Samaga et al (1986) data set is shown in table 1, 2, 3 and 4.

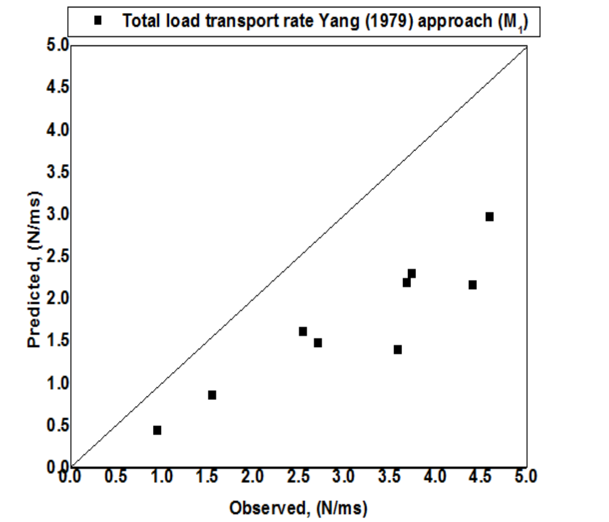


Fig.1. Observed vs predicted values for Samaga et al (1986) data set M_1 Mixture

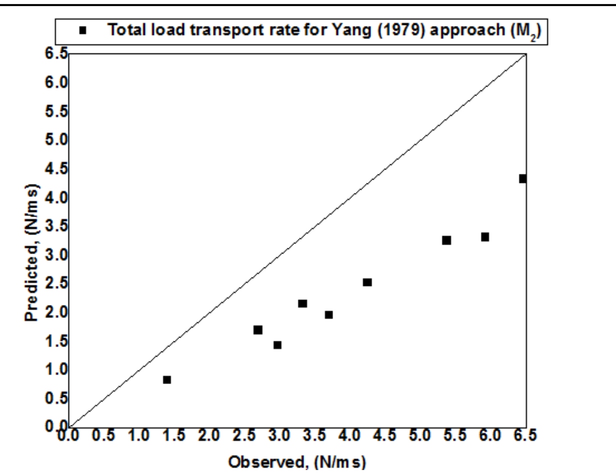
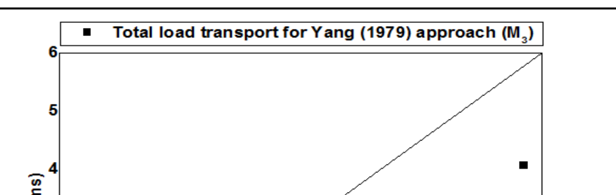


Fig.2. Observed vs predicted values for Samaga et al (1986) data set M_2 Mixture



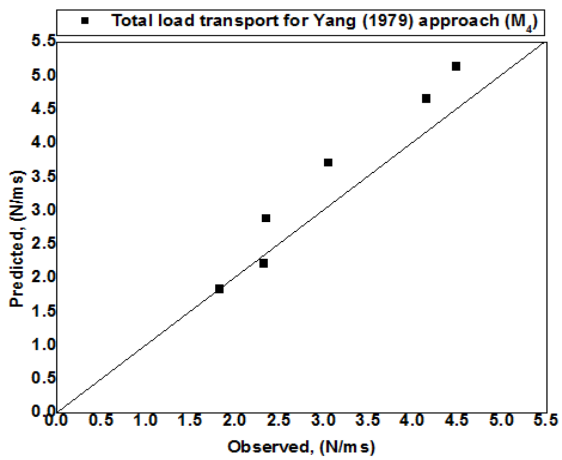


Fig. 4. Observed vs predicted values for Samaga et al (1986) data set M_4 Mixture

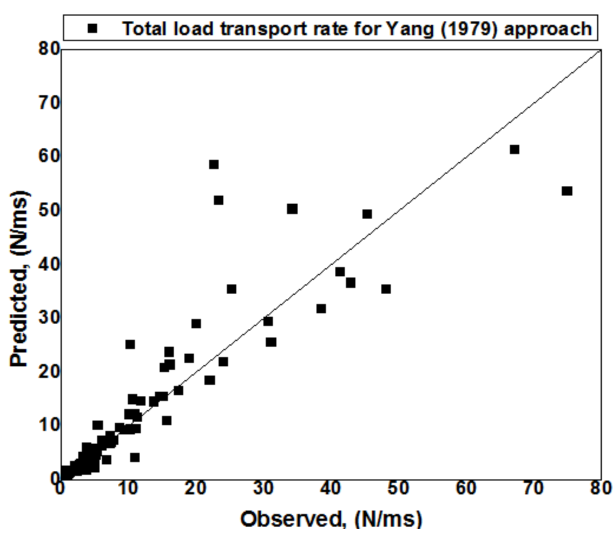


Fig. 5. Observed vs predicted values for Willis et al (1972) data set

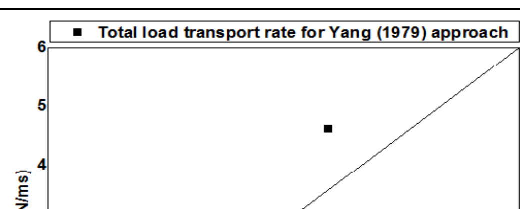


TABLE 1
COMPARISION BETWEEN PPREDICTED VALUES AND OBSERVED VALUES FOR SAMAGA ET AL, DATA SET-M_1

Yang Total load transport rate (N/ms)			
M_1 Mixture			
Sr. No	Observed Q_t (N/ms)	Predicted Q_t (N/ms)	(Observed - Predicted)*100/Predicted
1	1.545	0.866663404	-43.90528127
2	2.546	1.628463012	-36.03837345
3	3.737	2.309682088	-38.19421761
4	2.705	1.488652206	-44.96664672
5	3.68	2.196103668	-40.3232699
6	4.587	2.982457338	-34.98021936
7	0.943	0.454169146	-51.83784244
8	3.582	1.408523867	-60.67772567
9	4.399	2.169838236	-50.67428424
			-44.62198452

TABLE 2

COMPARISION BETWEEN PPREDICTED VALUES AND OBSERVED VALUES FOR SAMAGA ET AL, DATA SET-M_2

Yang Total load transport rate (N/ms)			
M_2 Mixture			
Sr. No	Observed Q_t (N/ms)	Predicted Q_t (N/ms)	(Observed - Predicted)*100/Predicted
1	1.389	0.847280884	-39.00065627
2	2.682	1.716133094	-36.0129346
3	3.689	1.973399739	-46.50583522
4	2.956	1.451595706	-50.89324403
5	4.24	2.541656644	-40.05526784
6	5.913	3.330805883	-43.66978044
7	3.32	2.174101583	-34.51501256
8	5.369	3.268806947	-39.11702465
9	6.462	4.348968642	-32.69934011
			-40.27434397

TABLE 3

COMPARISION BETWEEN PREDICTED VALUES AND OBSERVED VALUES FOR SAMAGA ET AL, DATA SET-M_3

Yang Total load transport rate (N/ms)			
M_3 Mixture			
Sr. No	Observed Q_t (N/ms)	Predicted Q_t (N/ms)	(Observed - Predicted)*100/Predicted
1	5.51	3.1367993	-43.07079344
2	5.765	4.0844178	-29.15146979
3	3.61	2.2516402	-37.62769518
4	2.718	1.2372069	-54.48098051
5	3.512	1.9038214	-45.79096361
6	3.852	3.0936835	-19.68630587
7	3.001	1.6758522	-44.15687548
8	1.897	1.0947261	-42.29171736
9	4.918	3.471243	-29.41758746
			-38.40826541

TABLE 4

COMPARISION BETWEEN PPREDICTED VALUES AND OBSERVED VALUES FOR SAMAGA ET AL, DATA SET-M_4

Yang Total load transport rate (N/ms)			
M_4 Mixture			
Sr. No	Observed Q_t (N/ms)	Predicted Q_t (N/ms)	(Observed - Predicted)*100/Predicted
1	2.34	2.8956627	23.74627103
2	4.476	5.1463373	14.9762585
3	2.315	2.2236182	-3.947378787
4	4.143	4.6685543	12.68535621
5	1.82	1.8449986	1.373546746
6	3.043	3.7184669	22.19740124
			11.83857582

5 STASTICAL PARAMETER TO CHECK THE PREDICTABILITY OF YANG (1979)

Various stastical parameters such as Root Mean Square Error (RMSE), Discrepancy Ratio (r) and Inequality Coefficient (U) are calculated to analyse the predicted results of the Yang's (1979) macroscopic approach by using Samaga et al (1986) flume data for the four sediment mixture (M_1, M_2, M_3, M_4), flume data of Willis et al (1972) and field data of Middle loup river Hubbel et al (1968). Summary of calculated statistical parameters for total load transport rate are shown in table 5, 6 and & respectively.

TABLE 5

SUMMARY OF STATISTICAL PARAMETER OBTAINED USING YANG'S 1979 TOTAL LOAD FUNCTION FOR SAMAGA ET AL.(1986)

Statistical Parameters					
Sr. No.	Type of mixture	RMSE	Discrepancy ratio, r	Inequality coefficient	Avg. % error(MNE)
1	M-1	1.47299	0.55378	0.284841	-44.6220
2	M-2	1.70534	0.59725	0.246796	-40.2743
3	M-3	1.49623	0.61591	0.223736	-38.4082
4	M-4	0.499925	1.11838	0.073485	11.8386

TABLE 6

SUMMARY OF STATISTICAL PARAMETER OBTAINED USING 1979 TOTAL LOAD FUNCTION FOR WILLIS ET AL.(1972)

Statistical Parameter				
Sr. No.	RMSE	Discrepancy ratio, r	Inequality coefficient	Avg. % error(MNE)
1	6.4142	0.1757	1.210027	21.0027

TABLE 7

SUMMARY OF STATISTICAL PARAMETER OBTAINED USING YANG'S 1979 TOTAL LOAD FUNCTION FOR MIDDLE LOUP RIVER HUBBEL ET AL.(1959)

Statistical Parameter				
Sr. No.	RMSE	Discrepancy ratio, r	Inequality coefficient	Avg. % error(MNE)
1	1.80401	0.623242	0.388431	-37.6758

6 CONCLUSION

Analysis of predicted results and observed values for the Yang's total load function can be summarized with the following findings:

- It was observed that the predicted results of total load transport rate for M_1, M_2 and M_3 mixture is good giving nearly equal values in Yang (1979) approach of Samaga et al (1986) data
- It was also observed that Yang's approach under predicts total load transport rate for all the three mixture M_1, M_2 and M_3 of Samaga et al (1986) data.
- It was also observed that the value of Yang (1979) approach for total load transport for M_4 mixture provide good results as compared to the mixtures M_1, M_2 and M_3.
- Yang (1979) total load function over predict as well as undepredict for Willis et al (1972) flume data set and Middle loup river Hubbel et al (1970) field data set.

NOTATIONS

TABLE

NOTATION

A	=	Area (m2)
Q	=	Discharge (m3/s)
W	=	Width of flume (m)
d	=	Diameter of particles (mm)
D	=	Water depth (m)
R	=	Hydraulic radius
S	=	Slope (m/m)
U	=	Average velocity (m/s)
U*	=	Shear velocity
τ	=	Bed shear stress
V	=	Average water velocity (m/s)
Vcr	=	Critical average water velocity
ω	=	Fall velocity
g	=	Acceleration due to gravity
v	=	Kinematic viscosity
Ct	=	Total Concentration in parts per million by weight

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