GRD Journals | Global Research and Development Journal for Engineering | Recent Advances in Civil Engineering for Global Sustainability | March 2016
e-ISSN: 2455-5703

Evaluation of Sediment Transport Function using Different Fall Velocity Equations

[1]H.N. Prajapati [2]M. S. Shah [3]S. I. Waikhom [4]Dr. S. M. Yadav
[1,2]Assistant Professor [3]Associate Professor [4]Professor
[1,2,3,4]Department of Civil Engineering
[1]Pacific School of Engineering and Technology, Surat, Gujarat, India [2]GIDC Degree Engineering College, Abrama, Navsari, Gujarat, India [3]Dr. S & S. S. Ghandhy GEC Surat, Gujarat, India [4]Sardar Vallabhbhai National Institute of Technology, Surat, Gujarat, India

Abstract

Study of sediment transport in river morphological problems requires proper relation to be established for the estimation of the terminal velocity, also known as fall velocity of particles. A large number of formulas have been developed by many researchers to determine fall velocity for particles size of various ranges. Present work aims to determine the applicability of the unit stream power equation of Yang (1979) for predicting total load transport rate using different fall velocity functions of Van Rijn (1984 b), Cheng (1997), Julien (1995) and Soulsby (1997) for a range of hydraulic parameters. Flume data of Wills et al. (1972) and Stein R.A. (1965) are used to analyse the Yang's total load function. Graphical representation of 152 data points and plot of observed and predicted total load transport for the selected data sets shows the scattering of value from the line of perfect fit within small range of errors of +_100% for the data sets of Stein R.A. (1965) and Wills et al. (1972) for all the selected fall velocity functions. Applicability of Yang's total load function is also verified using different statistical parameters such as mean square error, Root mean Square Error, Inequality coefficient and Discrepancy ratio.

Keyword- Fall Velocity Approaches, Statistical Parameters, Total Load and Yang's Unit Stream Power

I. INTRODUCTION

The physical properties of a sediment particle are not an adequate measure of the behavior of the particles in motion in a fluid. Studies of the transport of sediments in streams require knowledge of the dynamic properties of the particles in a given fluid. Among the various dynamic properties of the fluid flow, the velocity of fall i.e. fall velocity of the individual particles is the most fundamental hydraulic characteristic which is required to be measured. Fall velocity is defined as a fundamental property that governs the motion of sediment particle in fluid, which is a function of its shape, size, density and viscosity of flowing fluid. Formula for the fall velocity was firstly given by Stokes in 1851. Rouse (1937) and Brown and Lawler (2003) fall velocity formula are applicable only to spherical particles. Further researchers like Rubey (1933), Ferguson and Church (2004), Yalin (1977), Julien (1995), Cheng (1997), Soulsby (1997) etc., had developed empirical or semi-empirical relations for estimating the settling velocity of sediment particles.

Many researchers such as Bagnold (1966), Toffaleti (1968), Graf (1971), Shen and Hung (1972), Engelund-Hansen (1972), Ackers and White's (1973), Yang (1973), Yang (1979), Yang (1984), Karim and Kennedy (1990), and S. K. Sinnakaudan et. al (2006) contributed in the effort of finding the suitable functions for predicting the total load sediment transport rate of alluvial river based on many concepts like energy power, unit stream power approach, regime condition etc. (Waikhom and Yadav, 2014) . Yang's unit stream power approach is well verified by many investigators. Prajapati et.al (2015), Waikhom et.al (2015a, b) also found good results for Yang's unit stream power approaches. In the present study the effect of fall velocity in Yang's 1979-unit stream power approach for predicting total load transport rate is verified using different fall velocity functions of Van Rijn (1984 b), Julien (1995), Cheng (1997) and Soulsby (1997).

II. METHODOLOGY

Field data of Wills et al. (1972) and Stein R. A. (1965) are used to verify the applicability of Yang's 1979-unit stream power function for total load using fall velocity functions of Van Rijn (1984b), Julien (1995), Cheng (1997) and Soulsby (1997). The various hydraulic parameters range of the selected flume data varies from 0.35 to 1.84 for mean velocity (m/s), 0.07-0.48 for discharge (m^3/s), 0.11-0.38 for flow depth, 0.00027-0.0169 bed slope. The median diameter of particle range varies from 0.0001 to 0.00039 (m). Graphs are plotted so that the scattering of the values from the line of perfect agreement can be determined. Various statistical parameters such as mean square error (MSE), Root Mean Square Error (RMSE) and discrepancy ratio (DR) are calculated to determine the applicability of Yang's total load function.

All rights reserved by www.grdjournals.com

A. Chih Ted Yang (1979) Total Load Function

Chih Ted Yang (1979) modified Yang's (1972) unit stream power function and provides the best correlation between total sediment concentration C_t and unit stream power (V_s/ω) as

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

Further from multiple regression analysis with 463 sets of laboratory data from uniform flows, the following equations were obtained for I_1 and J_1 parameters.

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

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

Where, C_t is the concentration in parts per million by weight for the particles in the sand size range with d_s as median sieve diameter of bed material.

B. Selected Fall Velocity Functions

Present research work makes the use of following settling velocity formulas to verify the predictability of Yang's 1979 total load function.

Van Rijn (1984 b) settling velocity formulae is given as

$$\omega_s = \left(10\frac{v}{D_s}\right)\{[1 + (0.01\ \Delta\ g\ D_s^3/v^2)]^{0.5} - 1\} \tag{4}$$

Cheng (1997) settling velocity is given as

$$W = v/d\ [(25 + 1.2d *^2)^{0.5} - 5]^{1.5} \tag{5}$$

Julien (1995) settling velocity is given as

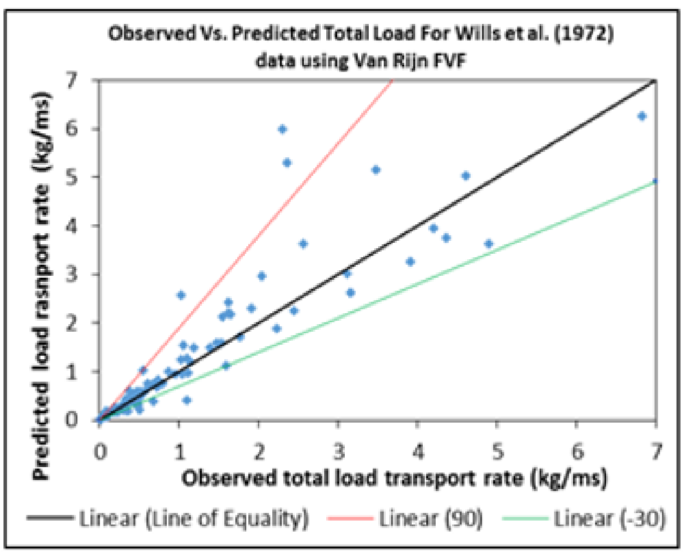
$$W = 8v/d[\left(1 + \frac{0.222\Delta g d^3}{16v^2}\right)^{0.5} - 1] \tag{6}$$

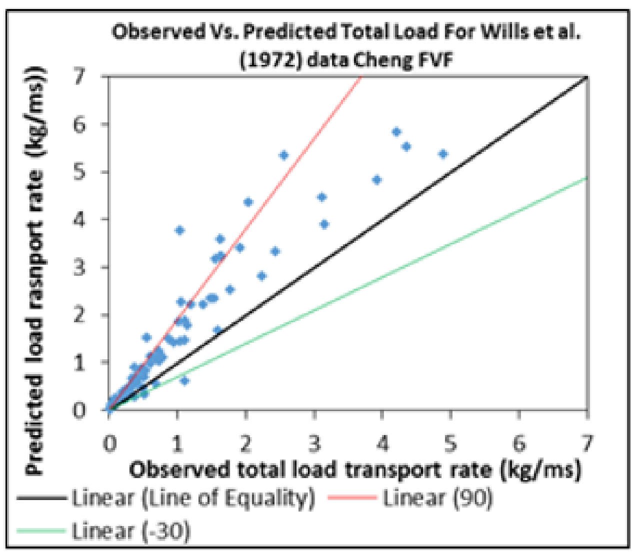
Soulsby (1997) settling velocity is given as

$$W = (10.36v/d)[\left(1 + \frac{0.156\Delta g d^3}{16v^2}\right)^{0.5} - 1] \tag{7}$$

III. VERIFICATION OF YANG'S (1979) UNIT STREAM POWER FUNCTION USING SELECTED FALL VELOCITY FUNCTIONS

To verify the applicability of Yang's (1979) unit stream power function (USP), graphical comparison between the predicted total load and observed total load is carried out using different fall velocity functions as shown in Figure.1 and Figure.2.





All rights reserved by *www.grdjournals.com*

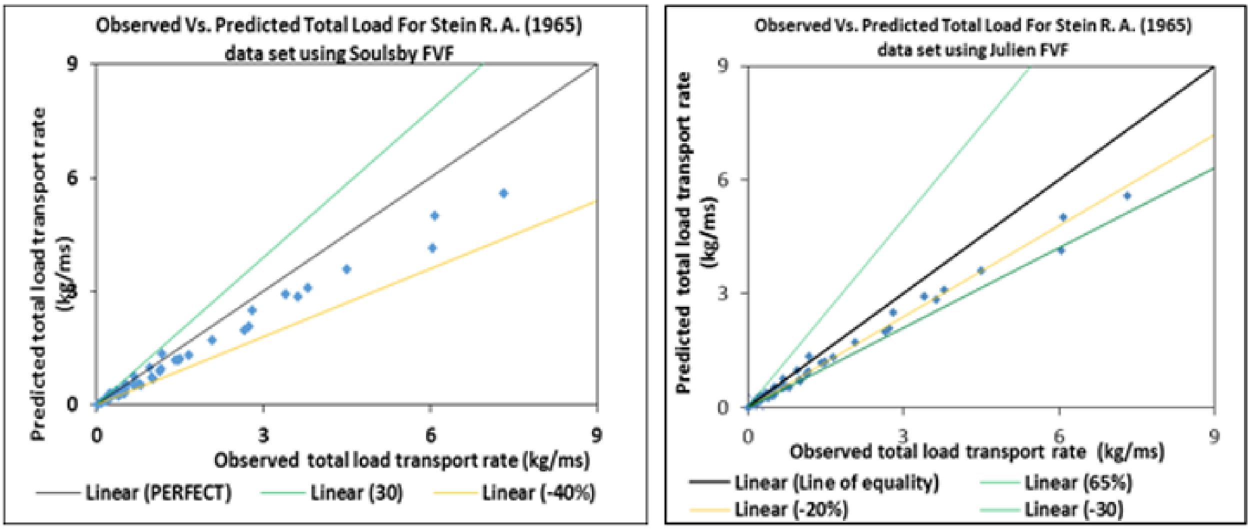


Fig. 1: Comparison between observed values and predicted results for the Yang's (1979) total load transport function using fall velocity functions of Van Rijn, Julien, Cheng and Soulsby for Wills et. al data set

From Figure 1, it can be observed that the Yang total sediment transport function over predicted as well as under predicted with an error range of -30% to +90% for the data set of Wills et al. (1972) when fall velocity function of Van Rijn (1984 b) and Soulsby (1997) and Cheng (1997) and Julien (1995) are used.

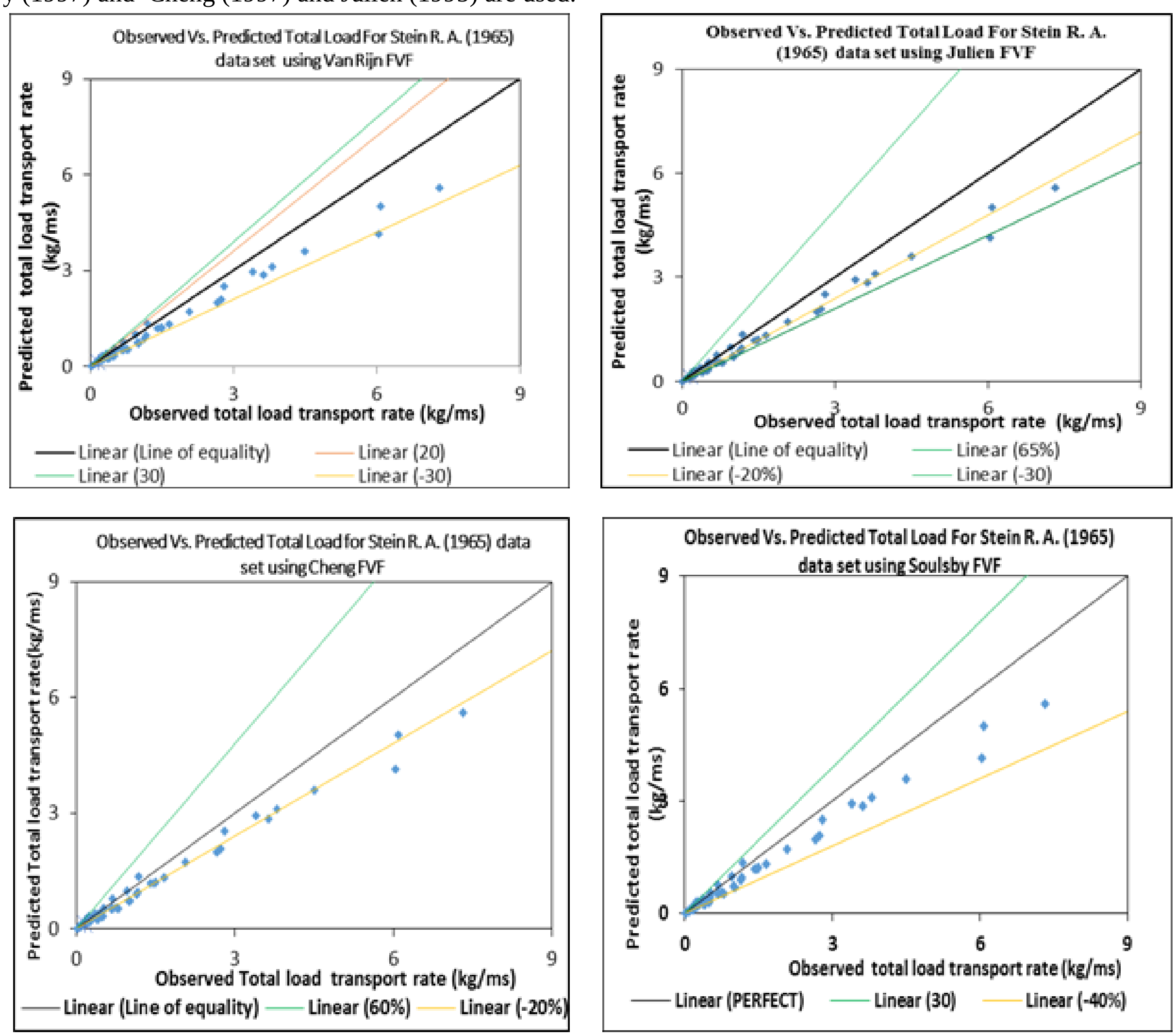


Fig. 2: Comparison between observed values and predicted results for the Yang's (1979) total load transport function using fall velocity functions of Van Rijn, Julien, Cheng and Soulsby for Stein R.A. data set

All rights reserved by *www.grdjournals.com*

From Figure 2.it is observed that total load transport predicted using Yang,s USP approach , scatters over small range of errors from the line of perfect fit i.e. from -30% to +90% for flume data of Stein R. A.(1965) when the fall velocity functions of Van Rijn (1984 b), Julien (1995), Cheng (1997) and Soulsby (1997) are used.

IV. STATISTICAL PARAMETERS CALCULATION

To evaluate the performance of the Yang's 1979-unit stream power equation for total load, statistical parameters calculation such as Mean Square Error (MSE), Root Mean Square Error (RMSE), percentage error and Discrepancy ratio (D.R) are calculated. Comparative values of each of the statistical parameters used for the analysis of the Yang's function for the data set of Wills et al. (1972) and Stein R.A. (1965) are shown in each of the Table 1, 2, 3nd 4 respectively.

Sr No.	*Data Set*	*Comparatively Discrepancy Ratio (D.R)*			
		Van Rijn (1984 b)	*Cheng (1997)*	*Julien (1995)*	*Soulsby (1997)*
1	*Willis*	*1.18*	*1.77*	*0.01257*	*1.17*
2	*Stein*	*0.86*	*1.13*	*0.85509*	*0.84*

Table 1: Comparative summary of the Discrepancy Ratio for the data set of Wills et al. and Stein R.A.

Sr No.	*Data Set*	*Comparatively Mean Percentage Error (MPE) (%)*			
		Van Rijn (1984 b)	*Cheng (1997)*	*Julien (1995)*	*Soulsby (1997)*
1	*Willis*	*18.43*	*77.34*	*-98.74330*	*16.56*
2	*Stein*	*-14.49*	*13.43*	*17.73448*	*-16.41*

Table 2: Comparative summary of the Percentage Error for the data set of Wills et al. and Stein R.A.

Sr No.	*Data Set*	*Comparatively Root Mean Square Error (RMSE) (%)*			
		Van Rijn (1984 b)	*Cheng (1997)*	*Julien (1995)*	*Soulsby (1997)*
1	*Willis*	*0.65*	*1.27*	*1.78*	*0.64*
2	*Stein*	*0.49*	*0.25*	*0.31*	*0.52*

Table 3: Comparative summary of the Mean Normalized Error (MPE) for the data set of Wills et al. and Stein R. A.

Sr No.	*Data Set*	*Comparatively Inequality Coefficient (U)*			
		Van Rijn (1984 b)	*Cheng (1997)*	*Julien (1995)*	*Soulsby (1997)*
1	*Willis*	*0.18*	*0.28*	*0.97*	*0.17*
2	*Stein*	*0.11*	*0.05*	*0.06*	*0.22*

Table 4: Comparative summary of Inequality coefficient (U) for the data set of Wills et al. and Stein R. A.

V. CONCLUSION

Present study concludes the following findings:

- Yang's (1979) total load function predicts well for Wills et al. data set when the fall velocity value computed using Van Rijn and Soulsby is used giving an average error of 18.43% and 16.56% respectively.
- Predicted values of the total load transport for the data set of Stein R.A. data set using the computed fall velocity value of Van Rijn and Soulsby fall velocity functions lies within small error range of -14.41 and -16.41 respectively.
- Total load predicted using flume data of Wills et al. scatters over wide range of error for the fall velocity function of Cheng (1997) and Julien (1995) as compared to the fall velocity functions of Van Rijn (1984 b) and Soulsby (1997)
- Little variation in result is observed when total load transport is predicted using the selected four fall velocity function for Stein R.A data set.
- Yang's (1979) total load function performed better for Stein R.A data set as compared to Wills et al. data set with minimum discrepancy of near equal to 1.

REFERENCES

[1] Graf W.H. (1971), Hydraulics of sediment transport, McGraw Hill, N.Y.
[2] Karim, M.F., and J.F. Kennedy (1990). Means of Coupled Velocity and Sediment-Discharge Relationships for Rivers, Journal of Hydraulic Engineering, ASCE, vol.116, no. 8, pp 973-996.
[3] Laursen, E.M. (1958). The total sediment load of streams. Journal of Hydraulic Division, ASCE 84(HY1): 1-36.
[4] Toffaleti, F.B. (1968). "A procedure for computation of the total river sand discharge and detailed distribution, bed to surface", Technical Report No.5, US Army Corps of Engineers, Vicksburg, Miss.
[5] Shen, H.W., and C.S. Hung (1972). "An Engineering Approach to Total Bed-Material Load byRegression Analysis," Proceedings of the Sedimentation Symposium, ch. 14, pp. 14-1 through 14-1 7. |

[6] K. Sinnakaudan, A. Ab Ghani, M. S. S.Ahmad and N. A. Zakaria, (2006), Multiple Linear Regression Model for Total Bed Material Load Prediction, Journal of Hydraulic Engineering, Vol. 132, No. 5, ASCE, ISSN 0733-9429/2006/5-521–528.
[7] Brown, P. P., and Lawler, D. F. 2003, "Sphere drag and settling velocity revisited". J. Environ. Eng., Celik, I., and Rodi, W. (1991). "Suspended Sediment Transport Capacity for open Channel Flow." J. H.E ASCE, Vol. 117.
[8] Cheng, N. S. 1997, "Simplified settling velocity formula for sediment particle". J. H. Eng., ASCE, 123(8), Dietrich, W.E. 1982. Settling velocity of natural particles. Water Resource. Res., 18(6), 1615–1626.
[9] Ferguson, R.I. and Church, M., 2004, "A simple universal equation for grain settling velocity Journal of Sedimentary Geology", 74, 933937.
[10] Garde, R. J., and Ranga Raju, K. G., "Mechanics of Sediment Transportation and Alluvial Streams Problems," Wiley Eastern Ltd., 1977, p. 171.
[11] Hilay Prajapati, Mrs. S. I. Waikhom,Dr. S. M. Yadav (2015), "Assessing the predictability of Total sediment Transport rate for Unit Stream Power Approach" International Journal of Advance Engineering and Research Development Special issue PP. NCRRETCE25.
[12] Julien, P. Y., "Erosion and sedimentation", Cambridge University Press, 1995.
[13] Rijn, L. C Van," Sediment Transport, Part II: Suspended Load Transport," J. H.E., ASCE, 1984b, Vol. 110,
[14] Rouse H. "Modern Conceptions of mechanics of fluid turbulence" Trans. ASCE, 1937, Vol. 102, pp.463-543.
[15] Rubey, W., "Settling velocities of gravel, sand andsilt particles". Am. J. Sci., 1933, 225, 325–338.
[16] Samaga, R. B., RangaRaju, G. K. and Garde, J. R., "Suspended Load Transport of Sediment Mixtures," J. Hydr. Engrg., ASCE, 1986b, Vol. 112, No. 11, pp. 1019-1035.
[17] Soulsby, R. L., Dynamics of marine sands,Thomas Telford, London, 1997.
[18] Toffaletti, F.B., "A procedure for computation of the total river sand discharge and detailed distribution, bed to surface", Technical Report No.5, US Army Corps of Engineers, Vicksburg, Miss, 1968.
[19] S. I. Waikhom., Hilay Prajapati,, S. M. Yadav, "Evaluation of unit stream power approach for predicting total load transport rate," Proceedings of 20th International Conference on Hydraulics, Water Resources and River Engineering, IIT Roorkee, 2015.
[20] S. I. Waikhom. , S. M. Yadav., Hilay Prajapati, "Predictability of Yang (1984) for sand-gravel bed material," International Journal of Engineering Research and General Science, 2015,Volume 3, Issue 4, PP 2015 954-958.
[21] Yang, C.T., "The movement of sediment in rivers". In: Geophysical Survey Vol. 3: Holland, pp. 39--68. Julien, P. Y. (1995), "Erosion and sedimentation", Cambridge University Press, 1977.
[22] Yang, C.T., "Unit stream power and sediment transport". J. Hydraul. Div., A.S.C.E., Proc. Pap. 9295, 98(HY10): 1805--1826.US Geological Survey Water Supply Paper 1357, 1979.
[23] Yang C.T., "Unit Stream Power Equation for Gravel", Journal of Hydraulic Engineering, ASCE, 1984, Vol. 1 10, no. 12, pp. 1783-1 797.

All rights reserved by *www.grdjournals.com*