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Performance Test for Selected Total Bed Material Load Equations with High Gradient River Data

PERFORMANCE TEST FOR SELECTED TOTAL BED MATERIAL LOAD EQUATIONS WITH HIGH GRADIENT RIVER (HGR) DATA.

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ABSTRACT

A large number of total bed material load equations have been developed in the past years and worth mentioning here are Laursen (1958), Bagnold (1966), Engelund & Hansen (1967), Graf (1968), Yang for Sand (1972), Shen and Hung (1972), Acker's & White (1973), Yang for Gravel (1984) and Sinnakaudan et. al (2006) where each one has its application range and derived based on individual theoretical approaches. Most of equations developed are based on laboratory simulations and mainly focused on intermediate and low gradient rivers. There is no significance evidence available to prove the applicability of the present total bed material load equations for high gradient river conditions especially in Malaysia where the sedimentation and erosion in the upland streams are soaring. Thus, this study resulted on the development of the predicted tool, in which comprises of 9 existing total bed material load equations as mentioned above to evaluate the performance of total bed material load equations. The equations are tested upon selected 55 high gradient river data which were collected from 22 HGR(HGR) in Malaysia having diverse catchment characteristics. The accuracy of the existing equations was obtained using the discrepancy ratio, which is the ratio of calculated values to the measured values. Overall prediction indicates that Engelund & Hansen performs better compared to other equations however; the percentage prediction is still below 40 % . Thus, a site specific equation is proposed to be developed to correctly predict the sediment transport in HGR in Malaysia.

Keywords: total bed material load, high gradient river, performance test

1. INTRODUCTION

Prediction of sediment transport in rivers is being one of the most widely studied topics in river hydraulics. Good appraisals of available total bed material load equations and their performance were given by Nakato (1990), Raphelt (1990), Woo & Yoo (1993), Yu and Woo (1994), Ariffin, et al (2002), Sinnakaudan, (2003) and Sinnakdaun, et al (2006). The existing equations are mostly developed based on flume data in western countries including America and Western Europe. However not all of these equations are widely used or evaluated in other parts of the world. Several equations such as Laursen (1958), Bagnold (1966), Engelund & Hansen (1967), Graf (1968), Yang for Sand (1972), Ackers-White (1973), Yang for Gravel (1984) and Sinnakaudan et. al (2006) have been incorporated into loose boundary models such as HEC-6 (USACE, 1993) and GSTARS (Yang & Simões, 2002), SFlood (Sinnakaudan & Sulaiman, 2007) to simulate the sediment transporting capability of rivers.

The arguments on which equation to be adapted and which may yield best prediction is still heavily discussed topic among the sediment transport researchers. Employing total bed material load equations which were derived from non-native hydraulic and sediment databases often yields an undesired prediction. Furthermore, the performance of such equation also depend on the river characteristics which the equation was derived such as energy gradient, channel width, discharge, velocity, sediment particle size and etc. Thus, one should always bear in mind that the performance of existing sediment transport equations may inconsistence from region to region and from river to river and from reach to reach.

This paper reports the performance test results of the selected 9 equations namely Laursen (1958), Bagnold (1966), Engelund & Hansen (1967), Graf (1968), Yang for Sand (1972), Shen and Hung (1972), Acker's White (1973), Yang for Gravel (1984) and Sinnakaudan et. al (2006). The equations were tested with the HGR sediment and hydraulic data. However one should bear in mind that not all the equations tested here in were developed to cater the hydraulic conditions of a high gradient river. The results reported here intended to demonstrate the general performance of the selected equations when applied to a high gradient river conditions.

2. GOVERNING VARIABLES

The governing dependant and independent variables in the form of required flow and sediment input data for the selected 9 equations are listed in Table 1. It is evident that most equations assumed Volumetric Concentration(Cv) as the depended variable except for two which rely on Transport Parameter (Φ). Most equations, in general require only one representative bed material size such as d_{50} and flow characteristics such as mean flow velocity, V; mean flow depth, $y_{0;}$ and energy slope, S_o.

3. DATA SOURCES

The data used in the present study are collected from 22 HGR having diverse catchment characteristics in Malaysia. The collected data were carefully studied and most reliable 55 numbers of data were used in the analysis. Table 2 shows the typical range of data used in the performance test. It is worth mentioning here that the sampling guidelines given by USGS (2005) was adopted where by the suspended load was measured using DH 48 sampler, Bedload measured using USBLH-84 sampler, velocity measured using McBirney Electromagnetic current meter. The samples taken by wading techniques and depth integrated method were employed. The typical view of the studied reach was given in Figure 1.

Table 1 Dependent and Independent Variables for Selected Equations

Sediment Concentration / Transport Formula	Selected Variables	
	Dependent Variable	Independent Variable
Engelund and Hansen (1967)	C_v	$S_s/(S_s-1), VS_O/[(S_s-1)gd_{50}]^{1/2}, \frac{y_o S_o}{(S_s-1)d_{50}}$
Ackers and White (1973)		$D_{gr}, d_{50}/y_o, \vartheta, \frac{y_o S_o}{(S_s-1)d_{50}}, V/U_*^{'}$
Yang (1972, 1984)		$w_s d_{50}/\nu, u_*/w_s, VS_o/w_s, V_c S_o/w_s$
Graf (1968)		Φ, Ψ
Shen and Hung (1972)		$(VS^{0.57}/w_s^{0.32})^{0.007}$ 501 89
Laursen (1958)		$\gamma_m, d_{50}/y_o, \tau_o/\tau_c, u_*/w_s$
Sinnakaudan et al (2006)	Φ	$\Psi, VS_o/\omega_s, D_{gr}, R/d_{50}, y_o/d_{50}$
Bagnold (1966)		$\frac{\gamma}{\gamma_s-\gamma}, \tau_b V, e_b/\tan\alpha, \frac{0.01V}{\omega_s}$

Table 2. Hydraulics and Sediment Data Range for HGR in Malaysia

River Name (No of Data)	Discharge Q, m^3/s (min-max)	Velocity V, m/s (min-max)	Width B, m	y_o, m (min-max)	S_0, m/m	d_{50}, mm (min-max)	T_b, kg/s	T_s kg/s	T_j kg/s
Ulu Paip (9)	3.75	0.10	21.30	0.88	0.014	19.30	0.0240	1.624	1.6300
	0.47	0.63		0.42		13.18	0.000	0.0075	0.0100
Air Putih (4)	0.25	0.40	6.00	0.21	0.0091	175.32	0.0043	0.0050	0.0093
	0.15	0.27		0.14		99.88	0.0004	0.0000	0.0031
Reyau (9)	1.26	0.52	8.00	0.42	0.015	149.33	0.0112	0.1400	0.1420
	0.25	0.16		0.18		70.63	0.0000	0.0030	0.0030
Telom -Jln Ipoh (3)	2.32	1.06	14.00	0.42	0.0071	67.31	0.0518	0.0000	0.0518
	1.57	0.86		0.34		50.60	0.0169	0.0000	0.0169
Telom -Jln Perlong (2)	6.67	0.69	10.00	1.16	0.0022	3.61	0.0594	0.1333	0.1928
	3.09	0.62		0.66		2.52	0.0292	0.0927	0.1218
Sedim (2)	6.7053	0.9900	12.80	0.9500	0.016	2.32	0.1720	0.0750	0.2470
	2.4738	0.6200		0.5500		2.10	0.0044	0.0000	0.0044
Sedim (Kg Sedim) (4)	4.0830	0.3700	15.00	0.4150	0.022	2.54	0.0518	0.0000	0.0518
	1.6995	0.2100		0.3380		2.05	0.0169	0.0000	0.0169
Kemia (3)	4.1439	0.3800	12.00	1.2800	0.014	60.88	0.0022	0.0080	0.0102
	1.5752	0.2170		0.7300		43.64	0.0007	0.0000	0.0007

Sayap (5)	2.1500	0.4300	16.00	0.5200	0.0021	26.36	0.0043	0.0115	0.0158
	0.7811	0.3200		0.1470		11.56	0.0000	0.0000	0.0001
Abang (1)	7.208	2.0700	20.00	0.2450	0.00826	21.45	0.01454	0.0959	0.1104
Giam (1)	2.251	1.5470	9.70	0.1255	0.00276	18.54	0.00277	0.0299	0.0327
Semadang (1)	0.861	0.2233	15.00	0.3307	0.003	19.30	0.000	0.0115	0.0115
Bukit Hijau (1)	3.015	0.4250	12.40	0.4575	0.0021	30.12	0.00001	0.10050	0.1005
Tembakah (1)	0.639	0.3970	18.00	0.2100	0.0177	61.42	0.0001	0.00341	0.0035
Rasi (1)	2.352	0.2700	18.00	0.7400	0.0137	20.75	0.0021	0.0000	0.0021
Rambai (1)	0.165	0.4230	5.00	0.2000	0.0266	6.50	0.00004	0.0028	0.0028
Keruak 3B (1)	0.500	0.4167	18.00	0.1670	0.0039	38.16	0.00002	0.0172	0.01722
Lubuk Permata (1)	1.284	0.4770	17.00	0.7800	0.0054	70.28	0.00058	0.0017	0.0023
Lagus (1)	0.881	0.5867	15.00	0.1630	0.0075	78.27	0.00054	0.0038	0.0044
Loh (1)	0.264	0.1233	12.00	0.2567	0.0065	79.37	0.00004	0.0008	0.0008
Kacong (1)	0.878	0.3833	19.00	0.2623	0.0165	157.81	0.00104	0.0041	0.0051
Besut (2)	6.1594	0.6200	21.00	0.9200	0.0133	2.65	0.0149	0.1260	0.1409
	5.1801	0.5200		0.8700		2.10	0.0042	0.0826	0.0868

Figure 1. Typical View of the Sampling Reach for the Present Study

3. RESULTS AND DISCUSSION

The performances of the selected equations are tested using discrepancy ratio, r which is the ratio between the calculated total bed material load and the measured bed material load. r is expressed as

$$r = \frac{T_j\,predicted}{T_j\,measured} \tag{1}$$

The analysis was further extended by calculating the population mean or central value of the distribution and population standard deviation of the discrepancy ratio, denoted by σ, to show the variance of values from the mean discrepancy ratio values. The values of discrepancy ratios were then averaged and the test equations were recommended based on the mean of the discrepancy ratio. The closer the value to unity and smaller the standard deviation, the better suited the total sediment load equation is assumed for the current data set.

The summary of the suitability analyses for 9 selected equations is given in Table 3. Engelund & Hansen has the best performance where it shows the 40 % of the variability in the test data followed by Shen & Hung with 23.64%. The rest of the equations tested give less favorable predictions as listed in Table 3.

Table 3: Summary of Equation Performance Test with High Gradient River Data

Total Bed Material Load Equations		No of Data Fall Within D.R(0.5-2.0)	Percentage (%)
1. Laursen	1958	1	1.82
2. Bagnold	1966	1	1.82
3. Engelund & Hansen	1967	22	40.00
4. Graf	1968	3	5.45
5. Yang for Sands	1972	5	9.09
6. Shen & Hung	1972	13	23.64
7. Ackers-White	1973	0	0.00
8. Yang for Gravel	1984	3	5.45
9. Sinnakaudan et al	2006	2	3.64
No of data used Verification		55	

Figure 2 to Figure 11 shows the measured against the predicted total bed material load using the selected 9 equations. It can be seen that, almost all equations seemed to over-predict the values of TBML with some exception for Engelund & Hanson and Shen& Hung which have 22 and 13 data respectively lies within the acceptable r, 05-2.0. However, for Engelund & Hanson, data in the low flow range seemed to show a better agreement.

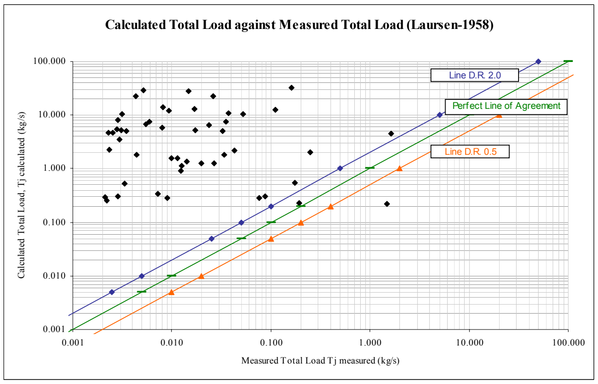

Figure 2: Comparison of measured and predicted sediment discharges using Laursen (1958) Equation

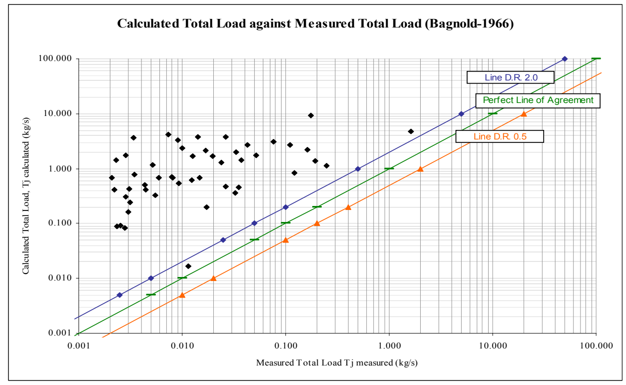

Figure 3: Comparison of measured and predicted sediment discharges using Bagnold (1966) Equation

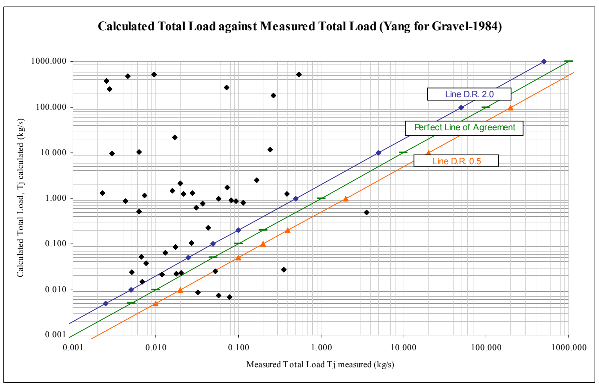

Figure 4: Comparison of measured and predicted sediment discharges using Yang (1984) Equation

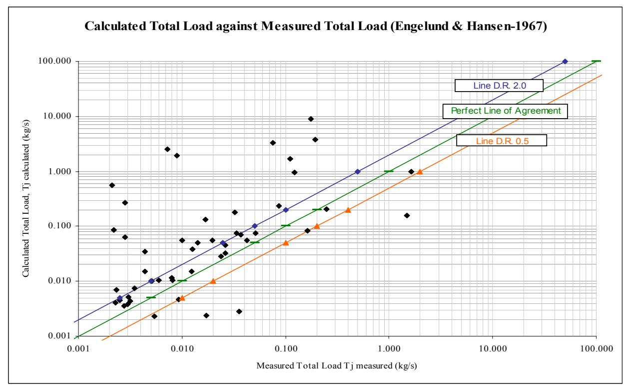

Figure 5: Comparison of measured and predicted sediment discharges using Engelund & Hansen (1967) Equation

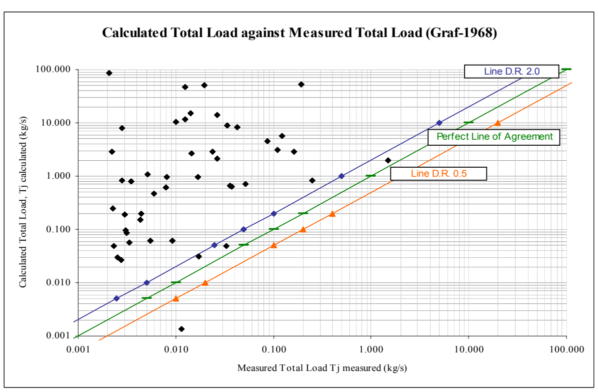

Figure 6: Comparison of measured and predicted sediment discharges using Graf (1968) Equation

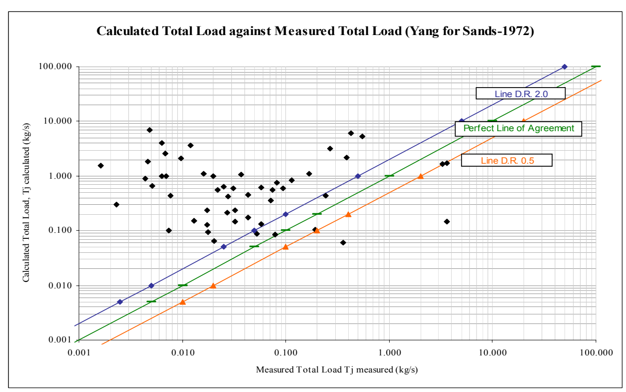

Figure 7: Comparison of measured and predicted sediment discharges using Yang (1972) Equation

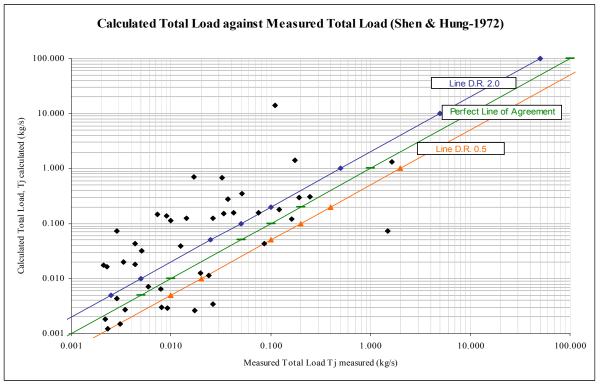

Figure 8: Comparison of measured and predicted sediment discharges using Shen & Hung (1972) Equation

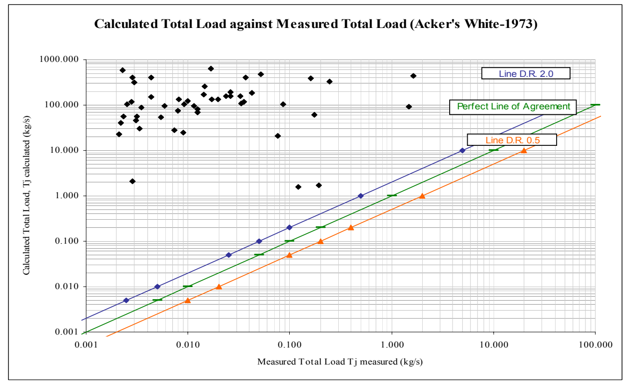

Figure 9: Comparison of measured and predicted sediment discharges using Ackers & White (1973) Equation

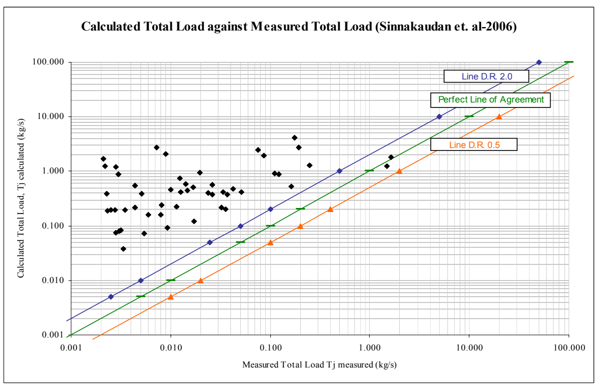

Figure 10: Comparison of measured and predicted sediment discharges using Sinnakaudan et al. (2006) Equation

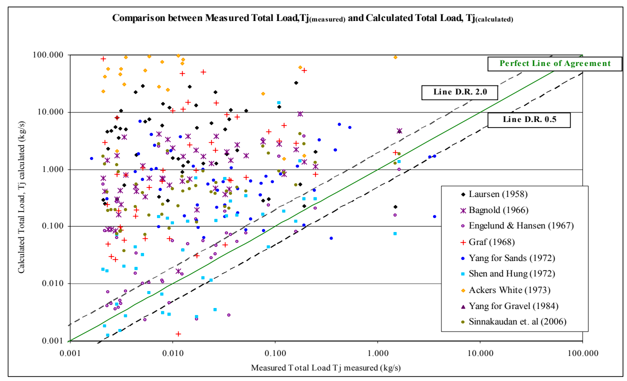

Figure 11: Summary of performance test for selected 9 equations

4. CONCLUSION

The TBML equation performance test reported herein suggest that some careful technical consideration are needed before any of the existing sediment transport formulas can be applied to field design activities. The equations tested in this study were yielded from sound theoretical background and reliable source of data. However, the results of present study indicates that prediction of total bed material is cannot be done by using any typical equation and basically there is no universal sediment transport equation which has "general applicability" is available. It's not the main aim of the present paper to rank the performance of the equation tested but it is merely to stress that there is limitation in predicting TBML in HGRs and not any TBML equation can be simply applied in HGR conditions. It might not be feasible for the field engineer to study the theoretical background of the selected formula but it is strongly suggested that one should be always look in to the applicable range of the equation and some validation with field data is a must. Most of the equation available developed for sand bedded rivers to medium gravels. However, when someone ventured into HGR conditions, he/she will have non uniform bed materials from fine sand to large boulders which are above the range of mean bed material size capacity of most of the equation tested here in.

Another problem may arise in equation validation is that there is no standard guideline on field data measurements practiced by the researchers. The equation which was listed here may have been developed based on a set of field data which was derived on sampling equipment which is unknown to the most of the engineering community. For example, Bedload samples are actively measured using 3 different samplers namely Helley-Smith, US-BLH84, Sediment Trap and might have different estimation when applied to same river reach. Beside that, there is a trend whereby the equations are derived based on the laboratory data. The equation derived based on the data obtained under the control environment may not be able to yield good prediction when applied to real world conditions. Thus, the uncertainties of using right sampling probes with site specific river morphological conditions are needed to be further studied.

It is hoped that this paper would promote more rigorous work on techniques on field data measurements, finding right sampling equipments and revisit of existing theories to cater High Gradient River conditions. It is also hoped that hydraulic and sediment transport engineers to evaluate few equations based on specific site conditions before making the final selection. The future direction of the present research is aimed to come out with the site specific equation for Malaysian HGR conditions to correctly predict the sediment transport in Malaysia.

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REFERENCES

Ackers, P. and White, W.R. (1973), "Sediment Transport: New Approach and Analysis." *J. Hydraul. Eng.* 99(HY11), 2041-2060.

Bagnold, R.A. (2006), "An Approach to the Sediment Transport Problem from General Physics", *U.S. Geological Survey Professional Paper*, 422-1, 37.

Engelund, F. and Hansen, E. (1972), *A monograph on Sediment Transport in Alluvial Stream,* Teknisk Forlag, Copenhagen.

Graf, W.H. (1971), *Hydraulics of Sediment Transport.* McGraw-Hill, New York.

Laursen, E.M (1958), "The Total Sediment Load of Streams"**,** *Journal of the Hydraulics Division 8*, 1530-1 – 1530-36.

USGS- United State Geological Survey, (2005), Sediment Data Collection Technique*,USGS Training Course –SW1091TC,* Vancouver, USA.

Shen, H.W. and C.S. Hung. (1972), "An Engineering Approach to Total Bed Material Load By Regression Analysis." *Proc. Of the Sedimentation Symposium,* chap.14, 1-17.

Sinnakaudan,S., A.Ab Ghani, M.S.S. Ahmad. and N.A. Zakaria. (2006). "Multiple Linear Regression Model for Total Bed Material Load Prediction." *J. Hydraul. Eng.,* 132(5) 521-528.

Sinnakaudan,S., Sulaiman, M.S. (2007). Development of Total Bed Material Load Equation for High Gradient Rivers in Malaysia, *In Proceeding of the 10th International Symposium on River Sedimentation*, pp. 297-304, Moscow State University, Moscow.

Yang, C.T. (1972). "Unit Stream Power and Sediment Transport." *J. Hydraul. Eng.,* 98(HY10), 1805-1826.

Yang, C.T. (1984). "Unit Stream Power Equations for Gravel." *J. Hydraul. Eng.,* 110(HY12), 1783-1797.