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THE SEDIMENT TRANSPORT PREDICTION FOR MOUNTAIN RIVERS

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Abstract: *The phenomenon of sediment transport has been studied for the past 100 years and always given special attention by the researchers and engineers. The human activities severely affected by the sedimentation problem such as flooding, deposition, and the malfunction of hydraulic structure. Various studies had been conducted to quantify sediment transport pattern in Malaysia. However the studies which are focussed on mountain rivers are still lacking. Furthermore, there is no specific equation to predict the total bed material load transport for highland rivers in Malaysia. Thus, the present study set as a pilot project to derive such an equation. A comprehensive field sampling and laboratory analysis were carried out to obtain the sediment database. The governing parameter that has high influence on sediment transport was selected based on literature survey and field observation. These parameters were checked for its correlation with field data before developing the equation. The equation is developed by fitting the selected influential parameters into SPSS program. The Multiple Linear Regression Analyses (MLR) was employed to derive the equation. The multicolinearity effects were avoided which may reduce the efficiency of transport prediction. The performance of the existing equation was tested and validated using existing field data from rivers in Malaysia.*

Keywords: *sediment transport; mountain rivers; correlation; multiple linear regression analysis.*

INTRODUCTION

The numerical equations for sediment transport were developed and verified over a decade by past researchers. Those developed equations exhibit different efficiency due to studied parameters, theoretical backgrounds, sampling techniques and mathematical approaches (Yang, 1996). Some of those approaches were commonly applied and validated namely shear stress approach (DuBoys, 1879), discharge approach (Schoklitsch, 1934), energy slope approach (Meyer-Peter and Muller, 1948), probabilistic approach (Einstein, 1942, 1950), stochastic approach (Yang, 1972), Multiple Linear Regression (MLR) approach (Bagnold, 1966, Sinnakaudan et al., 2006) and equal mobility approach (Parker, 1990). A good appraisal for past developed sediment transport equations are cited in Einstein (1950), Einstein modified by Colby

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& Hembree (1955), Egiazaroff (1965), Laursen (1958), Colby (1964), Bagnold (1966), Engelund & Hansen (1967), Graf (1971), Toffaleti (1969), Ackers & White (1973) and Yang (1972, 1984, 1996) and Sinnakaudan et al (2006).

Most of the past sediment transport equation were developed based on the data obtained from low to medium gradient river which have typical hydraulic characteristics such as water surface slope less than 0.002m/m, sandy beds and in rivers with uniform sediment composition. The nonuniformity of bed material at the high gradient river shows distinct hydraulic differences as compared to low gradient river (Thompson, 2006). Thus, the applicability of existing equations for high gradient river sedimentation predictions is still questionable.

It is evident that since 1990s, a few attempts being made to quantify the sediment transport pattern at Malaysian river. Unfortunately, most of the research work were done at low to medium gradient rivers and mostly cited in Ariffin et al. (2002) and Sinnakaudan et al. (2006). The current development trend especially in Malaysia mountain river basin shows that excessive developments brought severe erosion and sedimentation problems while it was continuously being carried out without improper monitoring and observation (Sinnakaudan, 2006).

MALAYSIAN MOUNTAIN RIVER DATA

The sediment and hydraulic database were sampled at 22 high gradient rivers which represent different morphological characteristics for mountain drainage basin. A total number of 55 genuine sediment and hydraulic data were collected at low to medium flow condition and summarized in Table 1.

Table 1. Range of sediment data

Data groups	Analysis data	Validation data
Discharge, Q (m^3/s)	0.15-7.21	0.15-6.71
Velocity, V (m/s)	0.21-2.07	0.10-1.55
Width, B (m)	6.00-20.00	5.00-21.30
Flow Depth y_o (m)	0.15-1.28	0.13-1.41
Area, A (m^2)	0.57-10.91	0.39-11.85
Hydraulic Radius, R (m)	0.11-0.94	3.01-21.71
Slope, S_o (m/m)	0.11-0.94	0.00-0.03
Sediment Size, d_{50} (mm)	2.00-147.43	2.00-157.81
Measured Total Load, T_j (kg/s)	1.00×10^{-3} - 0.12	0.90×10^{-4} - 1.63

INFLUENTIAL PARAMETERS FOR SEDIMENT TRANSPORT

The most important part in developing the new equation is to find the influential parameter that controls the sediment transport in high gradient rivers. These parameters are used as starting point to develop the numerical equation. The significant parameters controlling the sediment transport can be grouped into 7 categories namely mobility, transport, sediment, flow resistance, conveyance shape, hiding exposure function and fractional function. The sensitivity analysis was tested to observe the trend between the sediment data and listed parameters (Figure 1). The correlation trend between dependent and independent variables were checked and verified using the Pearson correlation coefficient. The intensity of the correlation coefficient was proposed by Cohen (1988) as an indicator pattern of the sensitivity test (Table 2).

Table 2. Correlation Coefficients (Cohen (1988).

Correlation	**Negative**	**Positive**
Small	−0.29 to −0.10	0.10 to 0.29
Medium	−0.49 to −0.30	0.30 to 0.49
Large	−1.00 to −0.50	0.50 to 1.00

The coefficient, r, is given as

$$r = \frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)}{\left[\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2 \sum_{i=1}^{n}\left(y_i - \bar{y}\right)\right]^{1/2}} \tag{1}$$

The value of the correlation coefficient, r lies between -1 to 1. The correlation is perfect if the r = 1 or r = -1. If $1 \le r \le -1$ and $r \neq 0$, there exist linear relationship between two variables. Cohen [21] suggest the high correlation coefficient value as $\pm 0.5 \le r \le \pm 1.0$. The highly correlated parameters are shown as

$$\Phi = f\left(\begin{array}{l} \dfrac{VS_o}{\omega_s}, y_o / d_{50}, R / d_{50}, \dfrac{\omega_s d_{50}}{\nu}, \\ \Psi, \dfrac{u_*}{\omega_s}, D_{gr}, \dfrac{V}{\sqrt{g d_{50}(S_s - 1)}}, \\ \Omega, F^*, \xi_i, \dfrac{d_{50}}{B} \end{array}\right) \tag{2}$$

Those highly correlated parameters (eqn.2) are selected for later equation development.

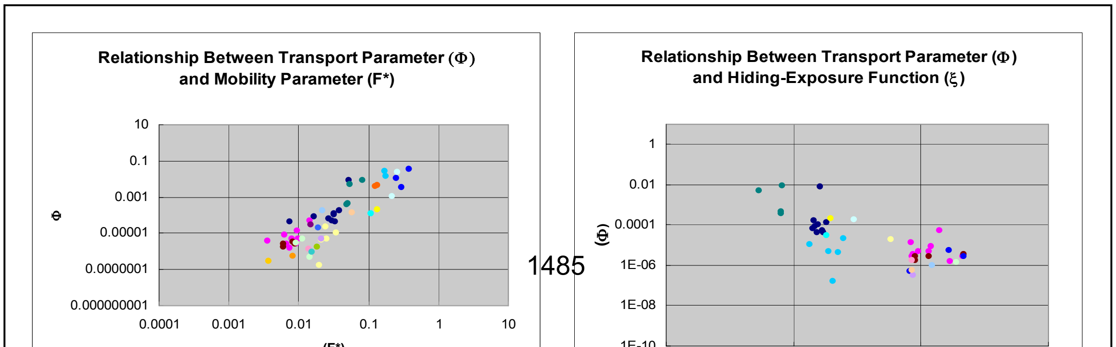

Figure 1. Scatter plot between dependent and independent variables

TOTAL BED MATERIAL LOAD EQUATION

The Multiple Linear Regression Analysis (MLR) method was employed to find the relationship between the dependent and independent variables. The transport parameter (Φ) by Einstein (1942) was depicted as the dependent variables while the mobility, sediment, conveyance shape, flow resistance and hiding-exposure factor as independent variable. The regression equation emulated the power concept where the relationship between the dependent variable (Φ) and the independent variable (X) can be written in the form of equation 7.

$$\Phi = \beta_o X^{\beta 1} \tag{3}$$

Equation 3 can be further expressed in the form of

$$\log\Phi = \log\beta_o + \beta_1 \log X \tag{4}$$

The $\log\beta_o$ marked as constant and β_1 as regression coefficient. If more than one independent is tested, the equation 8 becomes

$$\log\Phi = \log\beta_o + \beta_1 \log X_1 + \beta_2 \log X_2 + \ldots\ldots\ \beta_n \log X_n \tag{5}$$

A total number of 900 possible combinations was tested and the best combinantion was selected based on four selection criteria.. The first criterion is based on the coefficient of determination or *R* square values. R_p^2 denotes the coefficient of determination for regression model with p-1 independent variables and an intercept term (p) which is less than or equal to the number of variables plus 1. The analysis adds variables to the model up to the point where any additional variable is not useful because it results in a small increase in R_p^2. The second criterion is to consider the mean square error MSE (p) for a p variable(s) equation. The model with minimum MSE (p) is chosen. The third criterion is Mallow's C_p statistics. Mallow's C_p is used in multiple linear regression analysis as the criterion for choosing the best subset of predictor effects when a best subset regression analysis is being performed. This measure of the quality of fit for a model tends to be less dependent (than the *R* square) on the number of effects in the model, and hence it tends to find the best subset that includes only the important predictors of the respective dependent variable. The best model is the one where the Cp value is approximately equal to p ($Cp \approx p$). The fourth criterion is based on the modifications of R_p^2 that account for the number of variables in the model. While the addition of predictor variables will always cause the coefficient of determination to rise, the adjusted coefficient of determination may fall if the added predictor variables have little explanatory power and are statistically insignificant (Hair et al. 1995). The best regression is as depicted in equation (6) is selected based on the possible combinations of parameters with the value of R^2 equal to 0.7, adjusted R^2 equal to 0.678, C_p statistic equal to 4.39 and MSE equal to 0.409.

$$\Phi = 2.138 \times 10^{-11} \frac{\omega_s d_{50}}{v}^{1.117} \Omega^{0.603} \xi_i^{-0.336} \tag{6}$$

The analysis was further extended by calculating the population means 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 functions were recommended based on the mean of the discrepancy ratio (Raphelt, 1990). 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. Since the transport parameter, $\Phi = \frac{C_v VR}{\sqrt{g(S_s - 1)d_{50}^3}}$, consist of volumetric concentration, C_v, then the equation 6 can be expressed as:

$$C_V = 2.138 \times 10^{-11} \times \left[\frac{\frac{\omega_s d_{50}}{v}^{1.117} \times \Omega^{0.603} \times \xi_i^{-0.336}}{VR} \right] \times \left[g\left(S_s - 1\right) d_{50}^3 \right]^{1/2} \tag{7}$$

The newly developed equation (7) was validated with the existing data from Malaysian high gradient rivers. The discrepancy ratio test; which is a ratio of predicted total bed material load over measured total bed material load with an acceptable range of 0.5–2.0, is checked. An approximate 54.5% of the tested data lay within the acceptable range of 0.5-2.0. As comparison, Figure 2 shows the comparison between measured sediment load and calculated sediment load.

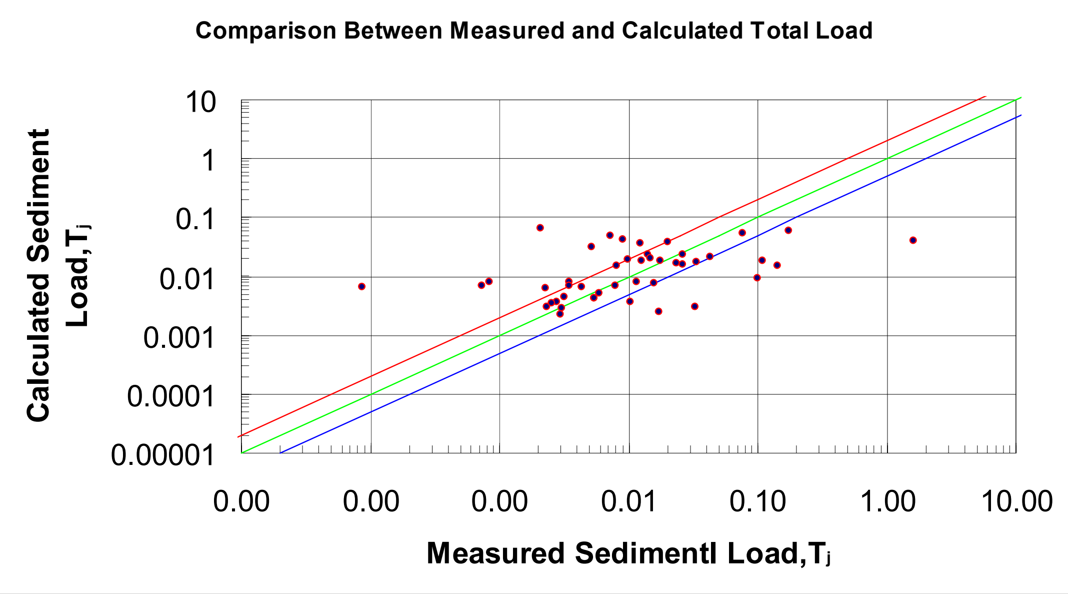

Figure 2. Comparison between measured sediment load and calculated sediment load using equation 7

CONCLUSION

The newly developed equation is suitable to be applied for coarser bed river with d_{50} ranges from 2.00 mm to 147.43 mm and the results are very much influenced by the hiding and exposure effect. It is evident that the smaller grains sheltered within a mixture of sizes tend to be harder to move than the smaller grains in uniform size bed. Thus, to cater closely this phenomenon, the present equation incorporates the hiding exposure function which is obviously affecting the sediment transport prediction at the high gradient rivers. However, the physical characterization of the microform such as particle clusters, emerged or submerged conditions of the bed materials and their effect to the bed material transport and flow structure were not being the main focus of the present study and can be a good subject matter for further analysis. One should take note that the predictive power of the present equation is up to 54.5 %. This equation can be further improved by fitting the high flow data which is not considered during the course of this study.

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