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ESTABLISHMENT OF JET INDEX J_i FOR SOIL ERODIBILITY COEFFICIENTS USING JET EROSION DEVICE (JEd)

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ABSTRACT: Soil erodibility has been identified as one of the major factors that govern threshold of resistance to erosion. Accurate measurement of soil erodibility in the field is indeed important for the determination of critical shear stresses. Critical shear stress is the stress that initiates particle movement that promotes shifting of the bankline. An attempt to establish soil erodibility parameters was successfully carried out using a newly fabricated Jet Erosion Device (JEd) based on soil properties. Soil erodibility coefficients are introduced to represent the erodibility of the soils under study. Statistical test is used to confirm the validity and accuracy of the proposed technique. Field data measurements were carried out on 3 rivers. Empirical models were developed using data from Selangor River and validated using data from Bernam and Lui rivers and other secondary river data. Analyses have shown high correlations and the parameters were further examined and analysed for the development of a predictive relationship for J_i. The most accurate model was selected based on the adjusted R^2, standard error of the estimate and discrepancy ratio to illustrate its significance. Selection of the predictive variables was based on their ability to explain the variation of J_i. The models established could significantly reduce the cost, time and usage of water supply for field data collection using JEd.

Keywords: Jet Index, Soil Erodibility Coefficients, Jet Erosion Device (JEd), Statistical Analysis

1. INTRODUCTION

Increased in river bank erosion and lateral migration rates are conceivably due to the increasing of hydraulic shear or increasing of bank erodibility [1]. The evaluation of critical shear stress and erodibility is of main importance for modelling river bank erosion problems.

Most relationship for soil erodibility is shown either through equations or lists of parameters. The variables reviewed indicated that the most repetitively mentioned variables for soil erodibility are critical shear stress, bulk density, shear strength and particle size distribution (percentages of clay, silt and sand). The three latter values can be obtained directly through laboratory experiments. Critical shear stress, τ_c determination requires indirect measurement and calculations. Besides the mentioned variables, erodibility coefficient, K or kd is also used as a representation of soil erodibility which consists of various different variables. However, it is found that established relation of erodibility coefficient, k_d are mostly for surface erosion. (e.g. [2]). Most fluvial erosion studies were focused on critical shear stress relationship to soil properties. Some researchers had linked τ_c to k_d (e.g. [3]-[6]). Soil properties such as water content and densities tests were also identified in the determination of erodibility [7].

There are a number of measurement techniques to identify the soil erodibility. One of the methods which can be employed both in the laboratory and in the field is the Jet Erosion Test (JET). This study particularly utilized the newly developed equipment fabricated from the aforementioned JET namely Jet Erosion Device (JEd) as shown in Fig. 1 which was introduced briefly by [8] and explained comprehensively by [9] on the method procedures, calibration and verification of the fabricated equipment and appropriate analysis chosen. This paper involves the relationship of soil erodibility parameters established from the Jet Erosion Device (JEd) to the soil properties obtained through the laboratory and in situ tests. Statistical regression analysis were performed on these parameters against the erodibility coefficients to assess whether basic soil properties results could be used to represent the erodibility of a particular river as an extension of the JEd results.

2. STUDY AREA

Three different rivers located in the state of Selangor, Malaysia were chosen for this study. Each river was reported to experienced series of flood events that causes riverbank erosion and bank failures. JEd tests were conducted on different points of locations and soil samples were taken at each point.

Fig. 1. JEd test at field location

2.1 JEd Testing and Soil Properties

Riverbanks at each site of Selangor River, Bernam River and Lui River were tested in situ using the Jet Erosion Device (JEd) to obtain the soil erodibility parameters of Jet Index (J_i) and erodibility coefficient (k_d). Undisturbed or disturbed soil samples at each location were either tested in situ or were collected and tested in the laboratory to obtain the soil properties values. Disturbed soil samples were extracted from each location of selected sites using a hand auger at locations where Jet Erosion Device (JEd) tests were conducted (Fig. 2). In total, 30 samples were collected from each site and taken to the laboratory for further testing prior to the required basic soil parameters.

Fig. 2. Post JEd test soil condition

The soil samples laboratory analysis using ASTM standards were conducted to identify the basic soil properties such as the moisture content (WC(%)), classification of soil type (%Sand, %Silt, %Clay), Atterberg limits consisting of plastic limit (PL), liquid limit (LL) and plasticity index (PI), specific gravity (SG), bulk density (ρ_b) and dry densities (ρ_d). In situ tests for the undrained soil shear strength (S_u) were also conducted at each test points using a pocket penetrometer.

Some of these physical properties influence the cohesive soils erosion [10]. Some riverbank erosion studies incorporate soil properties characteristics to enhance the analysis results such as the effect of seepage behavior due to water fluctuations on riverbank stability [11]. There are substantial differences between the effects of soil parameters towards erodibility of cohesive and noncohesive soils [12] where the erodibility of cohesive soils are influenced by grain size distribution, bulk density, clay type and clay content, organic matter content, and pore and water chemistry [11]. Reference [13] stated that the soil properties shown to be most important in noncohesive soils erosion, which is controlled primarily by gravitational forces, grain size distribution, grain shape, and particle density. The selection of variables for the soil properties to be tested is based upon the works of previous researches on channel erosion such as [14], [15], [10], [16], [17], [18] and [12]. More recent relationship established are from [19], [20] and [21].

3. DATA ANALYSIS

3.1 Jet Erosion Device (JEd) Test Analysis

Data from the JEd tests were evaluated to determine soil erodibility coefficients, k_d, following the procedures of [22] and [23]. Initially jet indices were obtained from the plotted graph of D_s/t versus $U_o\ (t)^{-0.931}$ where D_s is the maximum depth of scour for each time interval (cm) and U_o is the velocity of the jet at the nozzle (m/s) and t is time in seconds. The erodibility equation $k_d=0.003e^{385J_i}$ introduced by [24] where k_d is the erodibility coefficient (cm3/N-s) and J_i is the jet index were used to assess the category of the JEd results. The physical soil properties results were also compared. The results indicated the categories of resistance to erosion from moderate resistance to high resistance based on the Jet Index values. Selangor River and Bernam River seem to have a mixture of moderate and high resistance categories while Lui River was dominated by the high resistance category.

Graphs in Fig. 3(a) and 3(b) depicts the boxplots of Jet Index, J_i and erodibility coefficient, k_d data range for all three rivers. The vast difference in k_d variability between Bernam River, Selangor River and Lui River can be observed in both figures. The jet index and erodibility coefficient values of Bernam River are wider in range as compared to Selangor River and Lui River. This most probably caused by the variability of the soil condition of the locations selected in performing the JEd tests. The large variability of both values measured in the field suggest that changes in streambank surface soils due to subaerial processes play a significant role in determining the minimum shear stress required to initiate sediment movement for cohesive soils. The variability of these results could be caused by variety of variables such as the presence of gravel or roots at the JEd site, differences in moisture content, or soil heterogeneity. Subaerial processes and soil heterogeneity are the most possible variability occurrence mentioned by previous studies ([4] and [19]).

3.2 Statistical Analysis of Overall Data Set

The field data were analyzed using statistical analysis to observe the correlation between parameters by using the Pearson's correlation coefficient calculation which include Pearson's r for the entire data set of erodibility coefficient, k_d with the corresponding p-value. For clarity, only those coefficients greater than 0.3 with p-values less than 0.05 are considered. Results from this analysis indicated k_d was negatively correlated to percentage of water content (%WC; r = -0.336, p = 0.045), void ratio (e; r = -0.442, p = 0.007) and porosity (n; r = -0.46, p = 0.005). Soil k_d is positively related to the bulk density (ρ_b; r = 0.516, p = 0.001) and dry density (ρ_d; r = 0.452 , p = 0.006).

Having over 50% of the variance in each erosion parameter, bulk density appeared to have the greatest influence and positively related to k_d. This finding endorses the observations made during jet erosion test field data collection that density of soils influences the scour depths of each tests. It was found that little scour occurred on high density soils during jet tests [19]. However, the Pearson correlation indicated the other significant soil parameters were strongly correlated to soil water content though the contradicting results do not affect the development of the erodibility parameters relationship to soil properties. Attempts were made to establish the relationship of J_i to the observed soil properties as published in the past ([12], [25] and [21]).

3.3 Model Regression and Validation

The statistical analysis was utilized to assess the goodness fit and the goodness prediction of a regression model in order to choose the best model. In the linear multiple regression models considered for J_i, the predictors selected are soil water content (%), bulk density (Mg/m^3), dry density (Mg/m^3), void ratio, particle size distribution (% clay, silt and sand), plasticity index (PI) and activity which is the PI divided by the clay percentage of the soil. The selection of these variables is based on the reported Pearson correlation analysis.

The Selangor River data were regressed using simple linear regression backward method. The models developed with the coefficient of determination, R^2, significance of F value and p-value are summarized in Table 1. The coefficients produced from the analysis were then verified using a total of 45 combined data sets obtained from Jet Erosion Device (JEd) field measurement for Lui River and Bernam River with additional secondary data from [12] to vary the data hence giving a more reliable relationship. Based on this step, the accuracy of the equation is measured using discrepancy ratio (DR) distribution of 0.5 – 2.0 limit. The developed models showed the DR value ranging from 67.4% to 72.1% for the combined data sets for the accuracy evaluation of the equations. The equations and details statistical outputs for the models are shown in Table 2.

Out of the all eight models, Model 2, Model 4 and Model 7 gave highest DR values of 72.1%. However, the lowest significance of p-value is shown for Model 7 which is 0.06. The rule of thumb of statistical evaluation specified that p-value greater than 0.05 will give a poor fit for the linear curve. Therefore, Model 7 is considered the best-fit linear equation model for this relationship although its p-value slightly higher than 0.05 and low R^2. However, other models could also be considered due to DR values higher than 50% and depending on the availability of soil properties information provided for each specific site locations. Graphs of the predicted erodibility coefficient to observed erodibility coefficient for each linear equation are given in Fig. 4. The plotted graphs show that the range of observed and predicted data falls within the DR distribution limits.

4. CONCLUSION

Erodibility parameters using Jet Erosion Device (JEd) can be measured directly through a designated analysis of ASTM-D5852 standard or by [22] and [26]. However, the method requires the availability of the specialized equipment and also the results are site specific. Therefore, an attempt was made to allow for results of in situ and laboratory testing of soil materials to be used to quantify the erodibility parameters. The establishment of this relationship would significantly limits the cost and time spent for field data collection studies. Additionally, it would also allow for the extension of the erodibility parameters throughout the upstream to downstream of a studied river assuming that the site geology and measurable soil material consists of homogeneous properties.

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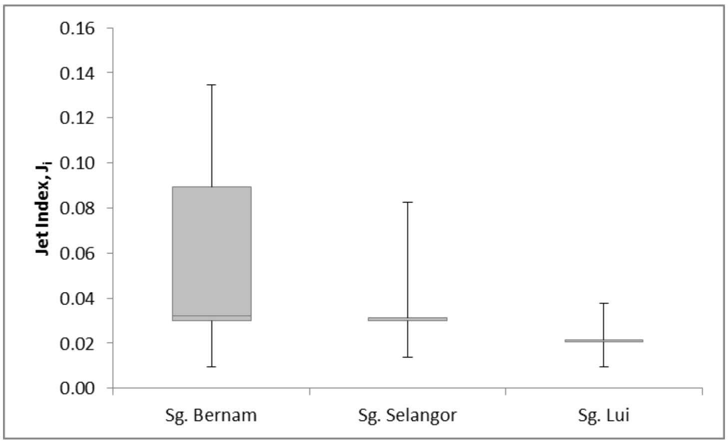
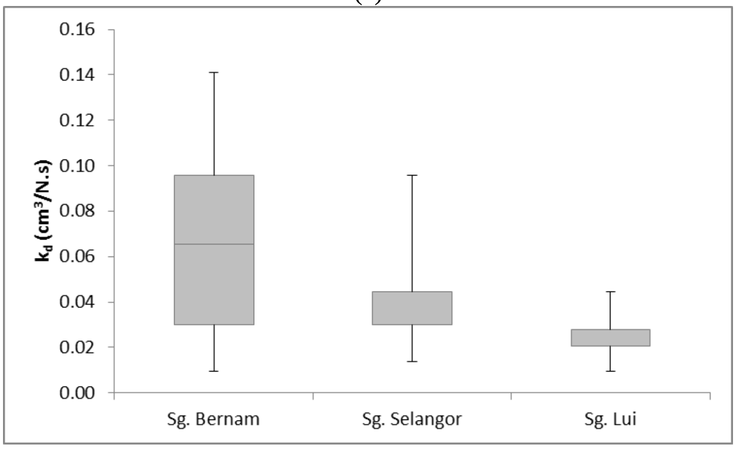


(a)



(b)

Fig. 3. Boxplot of Jet Index, Ji (a) and soil erodibility, kd (b) measurements for Bernam River, Selangor River and Lui River

Table 1 Model equations and verification statistical output details

No.	Model	R^2	F	p-value	Discrepancy Ratio, DR
1	$J_i = 0.02 + 0.0004w\% - 0.022\rho_b + 0.022\rho_d - 0.015e + 1.44\times10^{-5}\%clay - 4.01\times10^{-5}\%silt - 8\times10^{-5}\%sand - 0.0001PI + 0.0015Act$	0.418	0.879	0.57	67.4
2	$J_i = 0.021 + 0.0004w\% - 0.021\rho_b + 0.02\rho_d - 0.015e - 5.06\times10^{-5}\%silt - 8.60\times10^{-5}\%sand - 9.17\times10^{-5}PI + 0.0013Act$	0.418	1.076	0.44	72.1
3	$J_i = 0.0087 + 0.0002w\% + 0.028\rho_b - 0.0092e - 4.56\times10^{-5}\%silt - 8.11\times10^{-5}\%sand - 6.59\times10^{-5}PI + 0.0013Act$	0.408	1.279	0.33	69.8
4	$J_i = 0.014 + 0.0002w\% - 0.106e - 4.60\times10^{-5}\%silt - 8.01\times10^{-5}\%sand - 6.21\times10^{-5}PI + 0.0012Act$	0.407	1.599	0.22	67.4
5	$J_i = 0.013 + 0.0002w\% - 0.012e - 3.96\times10^{-5}\%silt - 5.62\times10^{-5}\%sand + 0.0007Act$	0.392	1.933	0.15	72.1
6	$J_i = 0.012 + 0.0002w\% - 0.011e - 2.2\times10^{-5}\%silt - 3.45\times10^{-5}\%sand$	0.377	2.418	0.09	67.4
7	$J_i = 0.011 + 0.0002w\% - 0.011e - 2.47\times10^{-5}\%sand$	0.351	3.061	0.06	72.1
8	$J_i = 0.08 + 0.0002w\% - 0.009e$	0.300	3.856	0.04	67.4

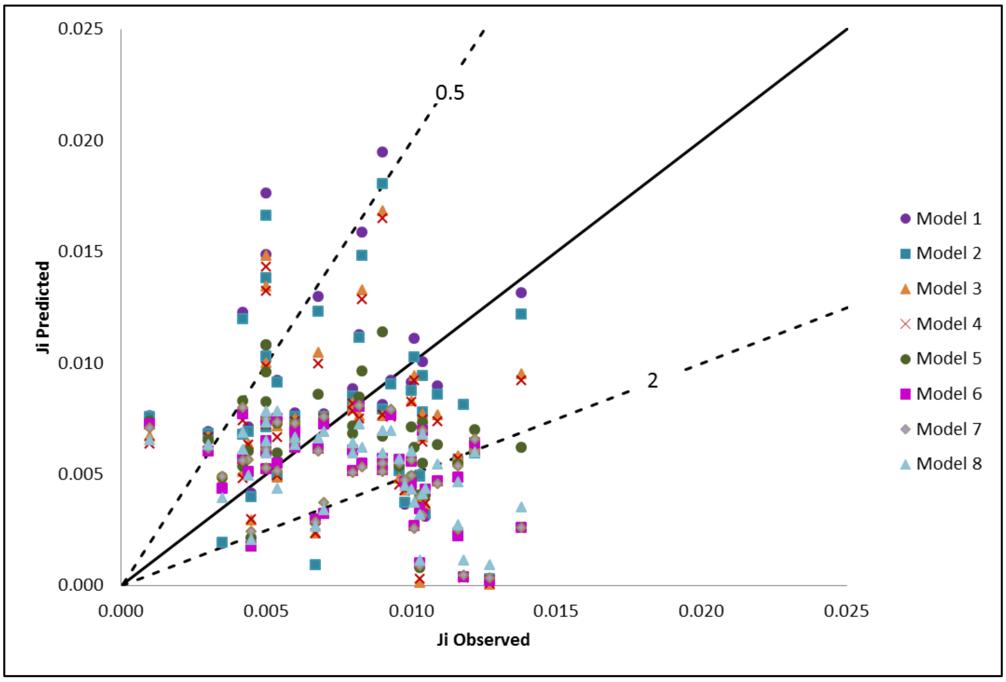


Fig. 4. Predicted J_i versus Observed J_i

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