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JET EROSION DEVICE (JED) – MEASUREMENT OF SOIL ERODIBILITY COEFFICIENTS

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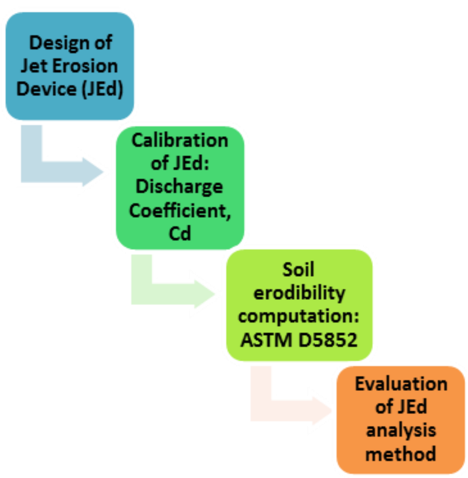
Graphical abstract



Abstract

Erosion from riverbank is most properly represented by the erodibility factor. One of the methods that can be used for in situ soil erodibility testing is the submerged jet test called Jet Erosion Test (JET). In this study, a newly modified version of the JET device namely Jet Erosion Device (JEd) is fabricated, with improved features and design that facilitates testing in the field and the laboratory. Analysis and calibration of the JEd tests were conducted to check on the reliability and performance of the Jet Erosion Device (JEd). Some preliminary results were shown to give some insights on the capabilities of the JEd. An evaluation of the erosion performance index i.e. jet index was performed to characterize the erosion resistance. The estimation of erodibility coefficients were made using the results of jet index obtained.

Keywords: Soil erodibility, Jet Erosion Device (JEd), jet index, erodibility coefficients

1.0 INTRODUCTION

Streambank erosion or retreat is considered as one of the primary processes for a combination of subaerial processes and erosion, fluvial erosion, and bank failure [1]. Erosion from riverbank is most properly represented by the erodibility factor. Erodibility is the extent of erosion of a media (soil) that determines the amount that is erodible. Thus erodibility of a soil that made up the riverbank determines the rate of erosion and erosion profile. Erodibility is a function of three major factors consisting of physical, geochemical and biological properties. Physical properties that affect erodibility are average particle/aggregate size, particle size distribution (i.e. clay, mud and sand contents), bulk density, water content and temperature [2]. Most fluvial erosion studies focused on critical shear stress, τ_c or erodibility coefficient, k_d relationship to soil properties. The critical shear stress is defined as the stress at which soil detachment begins or the condition that initiates soil detachment. In situ tests are required to incorporate natural field conditions and the influence of soil structure and variability on streambank erosion [3]. An *in situ* soil erodibility testing called the submerged jet test (Jet Erosion Test (JET)) was introduced [4-6]. This jet test estimates the critical shear stress needed to initiate erosion and can be performed *in situ* on exposed, horizontal or inclined [7] soil surfaces, or in the laboratory using tube samples or remolded samples in compaction molds [8]. Although JET is widely used for cohesive soils, study by Coffman [9] confirmed that JET can also be used for non-cohesive soil. Therefore it is applicable to a wide range of soils. However, the only disadvantage of this method is that it is difficult to set up and use due to the large size of the apparatus. Hanson [10] constructed a miniature version of the original JET called 'mini' JET to overcome the disadvantage of the original JET. The 'mini' JET is smaller and lighter than the original submerged jet hence makes it easier to use in the field and requires a smaller water supply. However, the equipment is not easily purchased and is not accessible in the market. Hence, the device requires fabrication of the existing devices. This paper introduces a newly modified fabricated Jet Erosion Device (JEd) which includes the calibration processes in order to determine if the Jet Erosion Device (JEd) measures equivalent values in comparison to the original JET and the "mini" JET devices. An evaluation analysis is also performed to check on the suitability and the reliability of the method.

2.0 JET EROSION DEVICE (JED)

2.1 Introduction of Jet Erosion Device (JEd) - Apparatus and Methodological Approach

The Jet Erosion Device (JEd) consists of Perspex submergence tank (200 mm diameter, 250 mm height), stainless steel depth or point gauge that also acts as the inlet for the water jet, aluminium foundation ring and PVC outlets as shown in Figure 1. The pressure gauge is not attached to the main frame of the submergence tank but mounted to a standing pole as opposed to the original and 'mini' JET which the pressure gauge is attached to the submergence tank. The purpose is to have flexibility in terms of controlling the valves attached to the pressure gauge. This will aid the data collection in the field where very steep and narrow river banks or river beds that are too far and low from the banks may be considered. This pressure gauge is connected to a submerged pump or a tank with pump for water supply. The inlet hose will be connected to the top of the point gauge.

This Jet Erosion Device (JEd) applies the impact of jet experiment equipment commonly found in any fluid mechanics laboratory. The size is also similar with the equipment. Apart from that, a pressure gauge is used instead of a head tank that was used in the original JET. This is to actually accommodate the field application. The materials used for the Jet Erosion Device (JEd) are also different where the submergence tank is made of Perspex and not steel or acrylic material used in the previous studies whereas the foundation ring is made of aluminium instead of steel to reduce the cost of the equipment.

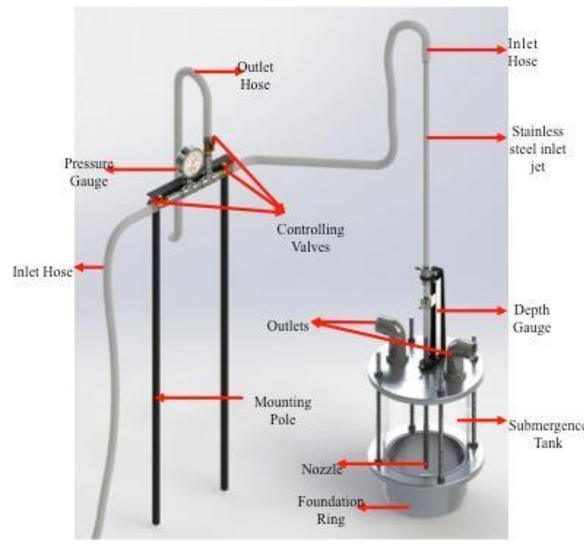


Figure 1 Diagram of Jet Erosion Device (JEd) Assembly

Another different feature of the Jet Erosion Device (JEd) is that there are three different sizes of nozzles (3 mm, 4 mm and 6 mm) attached to the tip of the point gauge that can be replaced which acts as water jet (Figure 2). The nozzle is also adjustable with the adjustable point gauge to accommodate the different ratios of nozzle height, J_i to nozzle diameter, d_o, (J_i/d_o). Other than that, the depth gauge itself serves as the water jet where the inlet hose is positioned at the top of the point gauge.

Figure 2 Nozzles of three different sizes (3 mm, 4 mm and 6 mm)

The methodology test set-up requires a setting for J_i/d_o for the newly Jet Erosion Device (JEd) of this study and the 'mini' JET developed by [11] must be set equivalent in order to maintain consistent methodology (value of the ratio of the 'mini' JET is 10.2). While the unit of k_d must be in cm^3/Ns to be consistent with previous researches [11, 12].

Field and laboratory setting procedures for the JEd are quite similar. These settings are in-line with the methodological procedures of previous researches (e.g. [11]; [12]). The soil specimen prepared in the laboratory or the field soil material of interest will be placed in the center of the submergence tank directly below the jet nozzle. Initially, water source will be opened but the valve connecting to the nozzle will be closed to prevent water from entering the jet nozzle and the submergence tank. The pressure gauge in unit bar will be set by adjusting the valve at the desired constant head and hoses will be connected to the JEd device. At time zero, the depth gauge will be used to determine the height of jet nozzle and the soil specimen surface. Then the jet valve will be opened to fill the submergence tank with water until the nozzle is fully submerged. At this point, a rotating plate is used to hold the water from impinging directly on the soil specimen surface. When the nozzle is fully submerged, the rotating plate is moved in order for the water jet to start impinging the soil surface to start the test and record the time. The readings of the scour bed will be taken using the depth gauge at different time intervals. 1st reading will be acquired after 30 seconds while subsequent readings will be acquired each 5 to 10 minutes for the clayey sand soil with a maximum test period of 120 minutes and each 1 to 5 minutes for the silty sand soil with a maximum test period of 60 minutes [11].

2.2 Calibration of Jet Erosion Device (JEd)

Calibration and maintenance of the Jet Erosion Device (JEd) is required to continue producing consistent data. As highlighted by Al-Madhhachi [11], there are two procedures for this purpose consisting of determination of coefficient of discharge, C_d and checking on the jet device performance. Both are carried out in the laboratory with soil sample preparation based on the ASTM Standard D698A.

The discharge coefficient, C_d for the orifice of the original JET is from 0.95 to 1.00 while for the orifice of the "mini" JET is from 0.70 to 0.75 [11]. C_d is the slope of the plotted measured discharge ($Q_{measured} = C_d A_{or}\sqrt{2gh}$) against $A_{or}\sqrt{2gh}$ where A_{or} is the orifice area for JET devices $\left(\frac{\pi}{4}d_o^2\right)$. The value of C_d will be determined using the above analysis as well as to carry out curve-fit correlations where the solution is iterative in nature. The cohesive soil sample near the optimum water content in a standard mould was prepared according to the ASTM Standard D698A as discussed in the preceding section. The laboratory procedure followed the procedures of Jet Erosion Device (JEd) mentioned previously. Figure 3 displays the experimental layout and the compacted soil sample. An experiment was conducted to obtain the measured flowrate taken from the outlet of the JEd at different pressure heads. A graph of measured discharge, $Q_{measured}$ against $A(2gh)^{0.5}$ was plotted and the discharge coefficient of the nozzle based on the slope of the graph is identified as 0.75. In this case, the coefficient of discharge of JEd is identical to the 'mini' JET. Hence, further analysis on erodibility determination can be made based on the above findings.

2.3 Soil Erodibility Computation: Jet Index Method (ASTM – D5852)

The Jet Index Method, which covers the estimation of erodibility of a soil, was developed by Hanson [4] and consists of jet scour depth per unit time and velocity-time functions. The test method can run on both undisturbed field site samples and on compacted samples in the laboratory. The Jet Index Method is issued under the ASTM standard of D 5852 and its main focuses are to quantify the soil erosion resistance and to provide a common description of soil properties in developing performance and prediction relationships [13]. Many investigators have used this method in deriving the erodibility parameter for soil with various different applications (e.g. [14-15]; [9]; [16-17]).

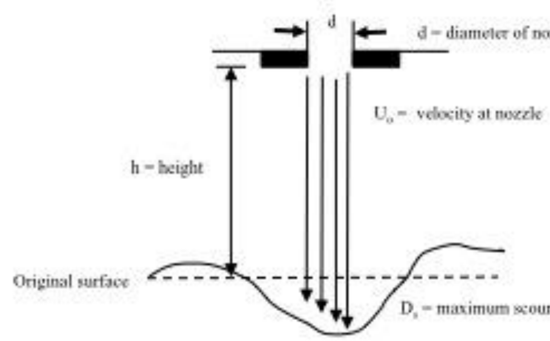


Figure 4 A simplified schematic of a submerged jet (After Allen *et al*., 1999)

This index was developed based on the original JET apparatus. Therefore the characteristics of the apparatus and the working procedures are similar to what have been discussed in the previous sections. The analysis for this Jet Index Method is simple and straightforward where the jet index is defined as the slope of the least squares fit line describing the scour depth per unit time versus the velocity-time function as described in the ASTM standard.

(a) (b) (c)

Figure 3 (a) the compacted soil sample, (b) the soil sample placed in the foundation ring, and (c) the layout setting of the jet device in the laboratory

The principal factors influencing jet scour are the nozzle height above the original surface of the soil sample, the nozzle diameter, and the velocity of the jet as shown in Figure 4. The velocity of the jet at the nozzle is $U_o = C_d\sqrt{2gh}$ where C_d is the nozzle coefficient. For the case of the Jet Erosion Device (JEd), the discharge coefficient for the nozzle is taken as 0.75 as analysed in the previous sections. The maximum depth of scour, D_s for each time interval was also computed. An example of the jet index was determined by plotting D_s/t versus U_o $(t)^{-0.931}$ with t in seconds [6]. The slope of the line through zero and the single resulting point results in an estimation of the jet index (Figure 5). In this figure, the jet index, which is the slope of the line, is indicated as 0.0093. The typical values of the jet index, J_i based on Hanson [6] are within the range of 0 to 0.03. He estimated that the value of 0.001, 0.01, and 0.02 indicating high resistance, moderate resistance and low resistance to erosion, respectively. Hence, the plotted graph is indicating that the soil sample is high resistance. The jet index is an erosion performance index and further analysis to produce an erodibility coefficient employs the following equation from Hanson [4]:

$$k_d = 0.003e^{385J_i} \quad (1)$$

where k_d is the erodibility coefficient (cm^3/N-s) and J_i is the jet index. This equation applies when the critical tractive stress, τ_c is assumed to be small relative to the effective stress, which is effectively zero. Although the computation of the soil erodibility values is straightforward, unfortunately, this method only gives the value of erodibility coefficient, k_d. The critical shear stress value will have to be established using different approaches.

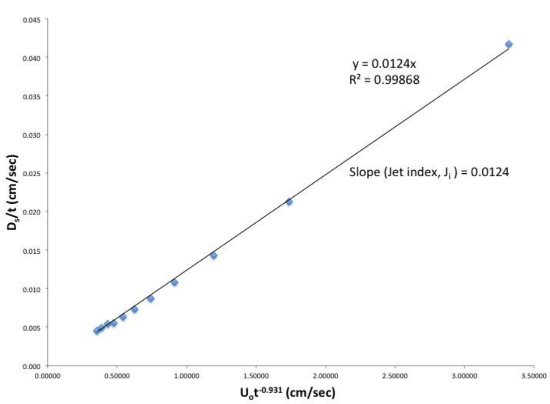


Figure 5 D_s/t versus U_o $(t)^{-0.931}$

2.4 Evaluation of Jet Erosion Device (JEd) Analysis Methods

A preliminary trial run was conducted to test the functionality of the Jet Erosion Device (JEd) (Figure 6(a)). The tests were carried out at Sungai Bernam, Hulu Selangor. Scour depth data were collected at 5 minutes interval under a constant head pressure. 8 sets of data were analyzed to obtain the soil erodibility parameters. Figure 6(b) shows the soil scouring caused by the water jet from the JEd at a riverbank in Sungai Bernam. Disturbed soil samples were also collected for further analysis.

According to the ASTM Standard method explained in the previous section, an evaluation of the analysis method was made to evaluate the reliability and feasibility of the newly developed Jet Erosion Device (JEd) for the soil erodibility computation. Table 1 is the data of erodibility coefficient values for the ASTM Standard method. Each data is accompanied by the erosion resistance categories based on [6].

(a) (b)

Figure 6 (a) JEd test layout at a riverbank and (b) Soil scouring by JEd

The ASTM method showed a lower range of jet index and erodibility coefficient values ranging between 0.0060 to 0.0134 and 0.0079 to 0.1465 cm^3/N-s, respectively. The category of soil resistance falls under moderate resistance to high resistance categories. Theoretically, cohesive soils are less susceptible to erosion hence they are more resistance towards erosion. Non-cohesive soils however are prone to erosion and the resistance towards erosion are very low. From the field observation, most of the soils for the riverbanks in Sungai Bernam are under cohesive soil. Therefore, it can be concluded that reliable results for the Jet Erosion Device (JEd) can be obtained using the Jet Index Method. Further analysis on the soil properties will be conducted to find the correlation and relationship between soil erodibility and soil properties. Although it is reported that there are no precision and bias of the test method has been determined, precautions and care need to be taken in performing procedures to obtain important statistical evaluation [13].

3.0 CONCLUSIONS

The newly modified Jet Erosion Device (JEd) in this study is an alteration of the original JET. The most significant changes are the size of the device, the replacement of the orifice with changeable and adjustable height nozzle and the position of controlling valve for ease in field data collection. A calibration procedure was carried out to determine the coefficient of discharge for the nozzle using laboratory set up and compacted soil sample. The Jet Index method adopted from the ASTM Standard (D5852) is considered to be reliable in estimating riverbank soil erodibility although the method of analysis is straightforward. This study will greatly contribute to the erosion prediction study of the rivers in Malaysia hence provide sufficient data on soil erodibility for future studies.

Table 1 Erodibility coefficient data for JEd analysis (ASTM Standard D5852)

No	Test Location Description	Left or Right Bank	Label	Ji	K_d	Category
1	Sg. Bernam – Bend	Right	B-1AR(1)	0.010	0.141	Moderate resistance
2	Sg. Bernam – Bend	Right	B-1AR(2)	0.012	0.304	Moderate resistance
3	Sg. Bernam – Bend	Right	B-1AR(3)	0.006	0.030	High resistance
4	Sg. Bernam – Straight	Right	B-1BR(1)	0.013	0.447	Moderate resistance
5	Sg. Bernam – Straight	Right	B-1BR(2)	0.010	0.141	Moderate resistance
6	Sg. Bernam – Straight	Right	B-1BR(3)	0.011	0.207	Moderate resistance
7	Sg. Bernam – Sg. Inki Confluence	Right	B-1CR(1)	0.009	0.096	High resistance
8	Sg. Bernam – Sg. Inki Confluence	Right	B-1CR(2)	0.008	0.065	High resistance

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