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SOIL EROSION EVALUATION BY USING MUSLE IN REGARDS OF EROSION SEDIMENT CONTROL PRACTICES FOR CONSTRUCTION SITE

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Abstract
Throughout construction projects, large areas of soil are exposed to the risk of water erosion due to extensive earthworks activities. Such projects pose a significant risk to the environment, which must be addressed by developers and contractors wisely. Bare slopes and drains choked with sediment can often result in a significant increase in sediment loads to receiving waters while the construction techniques used on site can cause offsite contamination. Erosion from the study area occurred from removal of vegetation covers, high rainfall intensity and the failure of the sediment basins to function effectively. The present study aims to evaluate erosion and sediment yield due to stormwater flows on a construction site located at Sungai Ara, Penang State of Malaysia. The soil loss on site was evaluated by using empirical erosion modelling namely Modified Universal Soil Loss Equation (MUSLE) by Onstad and Foster (1975). Hydraulic structure known as Sharp Crested Rectangular Weir were built on site for this measurement. Results shown that large amount of sediment has being eroded from the study area. The highest erosion rates estimated is 64 tons/ha during the storm event.

Keywords: Construction, Projects, Sediment, Environment

1. Introduction

Rapid forest conversion and construction activities have resulted in accelerated soil erosion in many parts of the world. Construction practices that fail to control pollution can cause damage to waterways and wetlands, kill fish, upset aquatic ecological systems and wildlife communities, and result in contamination of land and groundwater. Hence, soil erosion from construction sites (see Fig. 1) has long been identified as a significant source of sediment and other suspended solids in runoff. Increasingly, as humans advanced in science and technology, and preferred to live in urban habitats, they have inadvertently impacted upon the environment very significantly, often to the point of irreversible damage (Chan (2010)). Although erosion on construction sites often affects only a relatively small acreage of land in a watershed, it is a major source of sediment because the potential for erosion on highly disturbed land is commonly 100 times greater than on agricultural land (Brady and Weil (1999)).

Fig. 1 Soil erosion on a construction sites

In recent years, as much of such land has been utilized, the encroachment into steep areas has become inevitable. The risk to the environment is particularly high when construction works is done especially on hill land. Ibrahim (2002) has stated that even small changes caused by forest clearance could lead to severe damage on natural systems such as flora, fauna, climate, hydrology and soils. Although erosion is a natural process, it can pose many problems when occurrences are due to human activities. Soil erosion can affect the land and its inhabitants in both on-site and off-site effects and all of society pays for the destructive impacts. Off-site damage from sediment is the most critical problem facing from the construction sites. Erosion, which produces sediment, is accelerated when soil is disturbed, left bare, and exposed to the abrasive action of wind and water. Unless adequate measures are taken to prevent this abnormal, highly accelerated soil removal, it becomes the most visible and damaging factor in the deterioration of soil quality and the environmental quality of urban areas.

Estimation on how fast soil is being eroded must be taken into account before any implementation such as conservation or planning strategies can be implemented in any area. Soil erosion model can predict soil loss under a wide range of conditions. The Modified Universal Soil Loss Equation (MUSLE) modelling by Onstad and Foster (1975) are the modified version of The Universal Soil Loss Equation (USLE) and representing the empirical fits for erosion measurements plots to accommodate the effects of climate, soil, topography and land use. The MUSLE erosion modelling was of the following form

$$E = \{[0.646\,(EI_{30}) + 0.45\,(RO)\,Q_p^{0.333}]\,K.LS.CP\} \qquad (1)$$

where E is erosion rate in t ha^{-1}, EI_{30} is referring to rainfall erosivity factor in t.m ha^{-1}, RO is the total runoff rate per event in m^3, Q_p is the peak runoff rate per event in m^3 s^{-1} and K, LS, C, and P are respectively, the soil erodibility in t h MJ^{-1}mm^{-1}, topography, crop management and soil erosion control practice factors which is similar to the USLE model.

2. Methodology

This study site comprises of Lot 12025 located at Sungai Ara in Penang state of Malaysia, with the total development acreage of 104 acres as shown in Fig. 2. As the project site was previously a golf course, large portions of the site is covered with secondary vegetation such as trees, shrubs and golf's course grasses.

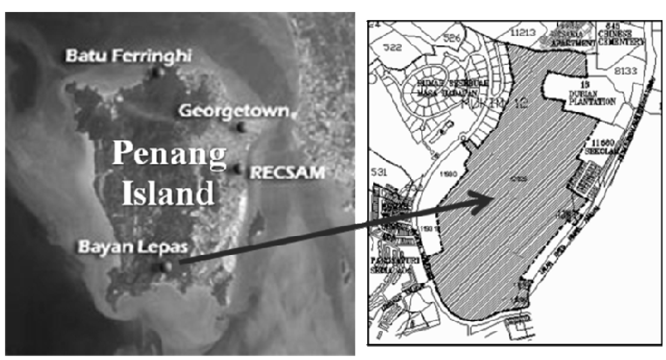

Fig. 2 Location plan and study area

Water levels were gauged during storms at Inlet and Outlet of Sediment Pond B as shown in Fig. 3 by using Rectangular Sharp Crested Weirs. Soil texture and content for this area were also determined earlier based on the Soil Investigation (SI) and Geotechnical reports prepared by the specialist consultants for the erosion calculation.

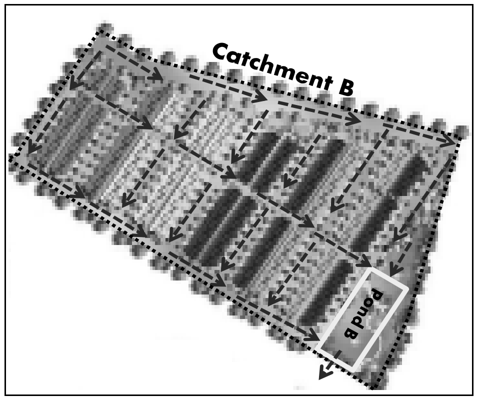

Fig. 3 Catchment B and Pond B

Storm-wise sediment yield was estimated by using MUSLE modelling given in Eq. 1. The following equation is used to calculate the Rainfall Intensity, *I* of a certain rainfall event by Onstad and Foster (1975)

$$I = \text{Amount of Rainfall/ Period of Rainfall} \quad (2)$$

Then the particular rainfall kinetic energy, E is calculated by using equation:

$$E = 210 + 89 \log_{10} I \quad (3)$$

where, I is Rainfall Intensity in cm h^{-1}. The rainfall erosivity value for rainfall event will need the maximum 30 minutes, I_{30} rainfall amount. By multiplying the product of rainfall kinetic energy and maximum 30 minutes rainfall amount of the rainfall event, the rainfall erosiveness can be finally determined from the Eq. 4

$$R = E \times I_{30} \quad (4)$$

where, E is the Rainfall kinetic energy in ton m ha^{-1} cm^{-1} and I_{30} is the 30 minutes maximum rainfall amount in cm. Values for total runoff volumes *R*O and peak runoff rates Q_p were extracted from data which were collected at the weirs during storms. These parameters were determined by the following formula based upon the discharge rates equation given for Sharp Crested Weirs with end contractions by Urban Stormwater Management Manual for Malaysia (MSMA) (2000)

$$Q = C_{SCW} (B - 0.1\, n\, H)\, H^{1.5} \quad (5)$$

where, Q is the weir discharge in m^3 s^{-1}, B is weir base width in m, H is the head above weir crest excluding velocity head in m, C_{SCW} is equal to $1.81 + 0.22 (H_1 Hc^{-1})$ (C_{SCW} will be 1.84 if the ratio $H_1 Hc^{-1}$ is less than 0.3), Hc is the height of weir to bottom of the opening and n is the number of end contractions (*n* is equal to 2 corresponds to the case of a contracted rectangular weir by Fifield (2004). These weirs were installed at Sediment Pond B prior to the main factor of site accessibilities and its location. Weir's sizing was done by referring to MSMA (2000) guidelines as shown in Fig. 4.

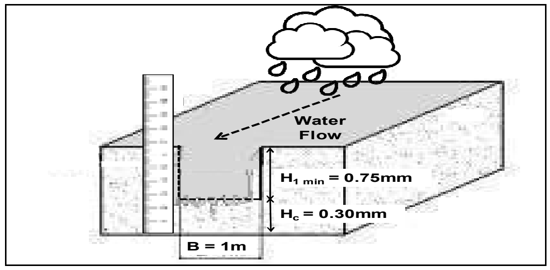

Fig. 4 Weir's sizing

Fig. 5 shows the weirs which were constructed at the study area. These weirs were installed with a gentle pressing by using the backhoe. On site available crushed boulders and stones were also collected and placed on both sides of the weirs in order to prevent the weirs to be washed away during heavy rain. A 'timber ruler' was hammered at one side of these weirs head for water level readings during storms and marked as H_1 (from June 2008 until December 2008).

Fig. 5 Weirs at the study area

Then Q for each measured water level is calculated by using Eq. 1. The value for *R*O and Q_P can be obtained from the runoff hydrograph generated from water level measurement at these weirs. The area under the Inflow hydrograph is the runoff volume while the highest point of the hydrograph will be the peak rate of discharge.

For other parameters, K is a measure of the intrinsic susceptibility of a given soil to detachment and transport by rainfall and runoff on the basis of five soil parameters namely percent silt, percent sand, organic matter content (OM), soil structure (S) and permeability (P). K can be defined by using Eq. 6 as follows;

$$K = (2.1 \times 10^{-6})(12 - OM) M^{1.14} + 0.0325(S - 2) + 0.025(P - 3) \quad (6)$$

K value results will be converted to SI Units by multiplying K in Imperial Units with 0.132 ton/ ha/ (MJ mm ha^{-1} h^{-1}). M is equal to (% silt + % fine sand)(100 - % clay). The Soil Series for this area is *'Renggam Bukit Temiang'*, hence the Organic Matter (OM) value is equal to 1.18 by referring to Erosion and Sediment Control Plan (ESCP) map by DID Malaysia while the S code is 4 and P is equal to 2. LS factor by Roslan (2009) is;

$$LS = (\lambda / 22.13)^{m} \, (0.065 + 0.046 \, S + 0.0065 \, S^{2}) \quad (7)$$

where; λ is slope length in m and S is the slope in percent. For C and P factor for construction sites is referred to Fifield (2004) which is 1.

3. Results And Discussions

The Q value for Inlet and Outlet at Pond B is determined by using Eq. 5 for every three minutes interval of storms follow by the plotting of graphs Q versus time. Area in between Inflow and Outflow of the graph is known as the required reserved volume for Pond B at those particular storms. By using the hourly rainfall data provided by Malaysian Meteorological Department (MMD) for the year 2008 and Eq. 2, 3, and 4 by Onstad and Foster (1975), EI_{30} is then calculated. The K factor was calculated to be 0.03 while the LS factor for Catchment B is equal to 3.81.

C and P factors are equal to 1 for this area. By using this information, soil loss estimation is depicted in Table 1. It is shown that the erosion quantity ranges from 32 t/ha to 64 t/ha during storms on the study area.

Table 1 Soil loss rates estimation at Pond B

Storm Event	Catchment Area (ha)	Soil Loss (t/ha)
22.06.2008	9.27	32.68
10.07.2008	9.27	63.55
18.08.2008	9.27	56.77
30.09.2008	9.27	39.80
04.10.2008	9.27	51.22
25.11.2008	9.27	34.21
14.12.2008	9.27	36.43

From the analysis, it was observed that rates of erosion may be high after an intensive rainfall at Catchment area B. Higher EI_{30} value will increase the amount of soil loss at a particular event. By referring to the classification of soil erosion rate provided by Department of Agricultural Malaysia, erosion rates for this study area in majority risk as above average category.

4. Conclusion

The construction activities in our county commonly involve extensive earthworks, with significant potential for erosion and subsequent sedimentation of waterways. These impacts can be minimised by appropriate project planning and design, and the implementation of effective site controls. From this research, the application of the MUSLE model was examined for use on a storm-by-storm basis at a construction site in Sungai Ara Penang state of Malaysia. The results verified the ability of this model for sediment yield prediction for assessing impact of erosion associated with this land-use by using gauging weirs. Hence, the amount of soil exposed for erosion during construction can be minimized by requiring proper construction phasing, planning and also sequencing.

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