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A STUDY ON THE EFFECT OF FLOODING DEPTHS AND DURATION ON SOIL SUBGRADE PERFORMANCE AND STABILITY

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ABSTRACT: In the event of flooding, the road infrastructure especially the subgrade will be affected in terms of its capacity to support the pavement. It is well known that subgrade deterioration will eventually cause pavement failure. However, little is known on how the subgrade reacts to different flooding conditions especially in terms of the depth and duration of the floods. The aims of this study are to evaluate the moisture content variation and strength of the subgrade using the flood simulation model. The pavement loading characteristics are referred to the Manual on Flexible Pavement Design published by the Malaysian Public Works Department (ATJ 5/85 Rev. 2013). The flood parameters used for this experimental model are based on actual data of flooding events from 1991 to 2014. It includes the parameters of flood water level, flood duration and repeated flooding. The samples were exposed to flooding for a duration of 3, 24 and 48 hours for unrepeated flooding and 2, 5, and 24 hours for repeated flooding. Flood water levels were set to 0.3 m, 0.6 m and 1 m. This study shows that there is a strong relationship between moisture content and subgrade strength. The increase in the duration of the flooding affected the performance of the subgrade due to the increasing moisture content. The study also revealed that the rate of deterioration in subgrade strength for second flooding events is 15% more than for first flooding events. The result of this experiment will be used to develop the basis for including flooding characteristics in the modified California Bearing Ratio test for soils in flood prone areas.

Keywords: Moisture content, Flooding, Road subgrade, California Bearing Ratio

1. INTRODUCTION

The economic development of a country can be assessed by the connectivity of its different regions by means of roads and railways. Thus, the construction of road infrastructure is one of the important civil engineering works undertaken for interconnecting the different places in a country [1]. For a developing country like Malaysia damage to road infrastructure due to natural disasters such as flooding commonly result in a huge expenditure for rehabilitation and road works [2]. The foundation soil supporting the pavement is called the subgrade. In the design of flexible pavements, the CBR test is the most widely performed method to estimate the strength values of the road subgrade and sub-base. These CBR values enable the design of a suitable thickness for the base and pavement layers. As the performance of a constructed road essentially depends on the various parameters e.g. subgrade material, materials used in different layers of the pavement and the traffic loading, the selection of appropriate subgrade materials with better quality is very important for getting a superior performance [3]. The destructive effect of moisture on pavement performance is an important consideration especially as the monsoon season is an annual occurrence. Furthermore, it affects the long-term performance of granular or stabilized base and sub-base, and of the sub-grade [4]. When the road is inundated for an extended time, the materials in each layer of the pavement become saturated, and then as the floodwaters drain, the subgrade soils begin to shrink and subside [2]. A study by Ismail et al. [5] on flood depths and duration found that the average flash flood occurs in less than 6 hours in most locations in Malaysia, but flash floods duration may exceed 6 hours with the flood water level above 1.0 m due to heavy rain and high tidal level. In contrast, the average monsoon flood duration is two days with an average flood water level of 1.0 m, depending on rainfall conditions. In addition, repeat flooding frequently happens within a month of the first flooding event. There are several studies by previous researchers on the effect to the soil subgrade due to the duration and flooding depth. According to Alam and Zakaria [6], the period of inundation by floodwater affects the strength of pavement layers significantly and in the case of surface layers the strength also reduces substantially. Other researchers like Fairweather and Yeaman [7] concluded that the effect of flood on the road pavement structure deterioration shows a good relationship between strain and moisture in the subgrade layer and poor relationship between surface layer strain and moisture. This manuscript presents a general overview on the following issues regarding road infrastructure especially how the subgrade will be affected in terms of its capacity to support the pavement. It is well known that subgrade deterioration will eventually cause pavement failure. However, little is known about how the subgrade reacts to the different flooding conditions, especially the depth and duration of the floods. The focus is determine the moisture content and strength of the subgrade from actual flood events using a flood simulation model. At the end, this experiment will be used to develop the basis for including flooding characteristics in the modified California Bearing Ratio Figure 1 is a typical road inundation during a monsoon flood.

Fig.1 Typical road inundation during monsoon flood. (Source: Department of Irrigation and Drainage Malaysia)

2. EXPERIMENTAL SET UP

An experimental program was planned to study the effect of flood events on subgrade soil performance on a reduced scale in the laboratory. The first phase was specimen and test preparations and the second phase was the preparation of an experimental model section. The proposed test is called a Flood Simulation Model (FSM). The samples of sub-grade soil were taken from quarries that supply soil which is usually used as the embankment soil in road works. The soil samples were approved according to the Standard Specification for Road Works - Section 2: Earthworks by the Public Work Department (PWD), Malaysia. The properties of the soil samples are shown in Table 1 and the physical and mechanical properties of the soil samples were determined according to the Unified Soil Classification System (ASTM D2487). The tested soils were found and can be classified in the group of “Well-graded sand’’.

2.1 Specimen and Test Preparation

Initially, experiments such as the Atterberg limit, sieve analysis and index properties were conducted to determine the properties of the soil. Soil with a total mass of 4956g with an optimum moisture content at 12% was compressed in the mould using Static Compression with Tamping [8] for unflooded and unrepeated flood sample. For repeated flood events a soil sample with total mass of 5067 g with adjustment optimum moisture content at 14.5% was used. 80 specimens were prepared in total, and the specimens were intended for control, unrepeated flood and repeated flood.

Table 1 Basic Properties of soil Sample

Soil properties	Value
Specific Gravity	2.65
Moisture content	12%
Adjustment moisture content	14.5 %
Maximum dry density	1.92
Ph value	5.04
Organic Content	1.69%
Liquid limit	45%
Plastic limit	Non-Plastic
Plasticity index	Non-Plastic
Grading	SW

2.2 Flood Simulation Model (FSM)

The flood parameters used in this experimental model were based on actual data of flooding events from 1991 to 2014. The data on flood statistics were obtained from an annual flood report issued by for the Department of Irrigation and Drainage Malaysia. Only complete information was considered in the study. It includes the parameters of flood water level; flood duration and repeated flooding were identified based on the high frequency of flood cases. The samples were exposed to flooding for a duration of 3, 24 and 48 hours for unrepeated flooding and 2, 5, and 24 hours for repeated flooding. Table 2 which shows the flooding characteristics of the flood simulation model. The percentages of adjustment moisture content were determine based on the duration estimated within a day-10 using an outdoor moisture content test (Fig.6). The purpose of the outdoor moisture content test is to determine the reduction of moisture content after the soil sample was submerged. In this test, the soil sample is submerged for 24 hours and then placed in an outdoor area for an estimated reduction of the moisture content in one month (Fig.2).

Table 2 Flooding characteristics of FSM

Types of flooding	Duration flooding (Hours)	Water level (Meter)	Duration repeated flooding (Days)
Unrepeated flooding	3,24 and 48	0.3,0.6, and 1.0	_
First repeated flooding	2,5 and 24	0.3,0.6, and 1.0	10 days
Second repeated flooding	2,5 and 24	0.3,0.6, and 1.0	10 days

(a) (b)

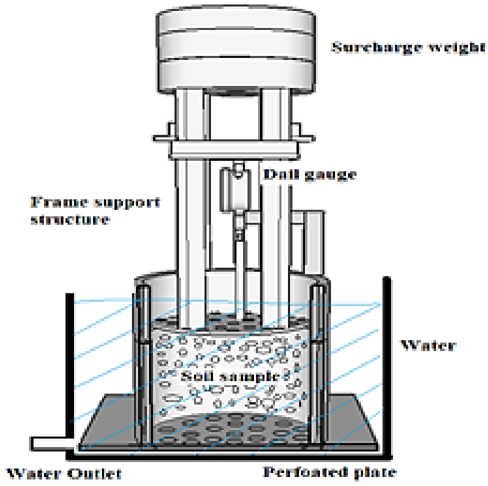
Fig.2 (a) Specimen under water to simulate flood and (b) placed in outdoor area

To clarify the methodology of the research, this study focuses only on one type of conventional flexible pavement: granular base. Table 3 shows the loading characteristics of the flood simulation model for the purpose of calculating the loading characteristics to simulate the load of the pavement structure on the subgrade layer to represent the actual flooding event. These calculations have been designed based on typical conditions for roads and highways in Malaysia as referred to the Manual for Flexible Pavement Design published by the Malaysian Public Works Department. Pavement structure has slightly different characteristics due to unknown variables and several factors such as environmental and weather conditions. The design of actual pavement structures depends on the types of local material and the design approval from local authorities.[9]. Figure 3 shows the layout of the apparatus for FSM. All specimens will be tested referring to a modified soaking procedure from Malaysian Standard MS 1056: 2005 (Confirmed:2013), Soils for Civil Engineering purposes, Part 4. After that, the California Bearing Ratio (CBR) test was carried out to determine the strength of the subgrade soil [8].

Table 3 Loading characteristics of FSM

Level	Pavement structure (kg)	Flood water level (kg)	Total weight (kg)
0.3 m	17.6 kg	5.4 kg	23 kg
0.6 m	17.6 kg	10.8 kg	28.4 kg
1m	17.6 kg	18 kg	35.6 kg

In this study, regression models were established to show the relationship between dependent variables and independent variables. Correlation equations are developed by performing single linear and multi linear regression analysis using Microsoft Excel tool pack analysis. Firstly, simple linear regression analysis (SLRA) was carried out by considering the moisture content as the independent variable (IV) and CBR values as dependent variables (DV). Secondly, a multiple linear regression analysis (MLRA), was determined by considering first and second repeated events as independent variables (IV) and CBR values as dependent variables (DV). The scatter diagrams are presented in Figures 5 and 9.



(a)

(b)

Fig. 3. Set up of the flood simulation model configuration: (a) diagram model (b) photograph

3. RESULT AND DISCUSSION

3.1 Unrepeated Flood

The results of CBR strength and moisture content values presented in Figure 4 illustrate the comparison between unflooded and flooded conditions. The soil samples were flooded for 3, 24 and 48 hours for unrepeated floods. From the combo chart, the vertical left and right axes represent the CBR value and moisture content (MC). It shows the CBR value for unflooded condition is relatively higher than the CBR value for flooded condition due to the saturated duration for flooded soil. Obviously, the presence of water when the soil was flooded for 3, 24 and 48 hours contributes to the decreasing of soil strength and performance. The soil had been losing strength starting in the 2-hour flood when it is compared to the unflooded condition. In addition, in the 48 hours of flooded condition at flood level 1.0 m, the value of CBR was reduced from 20% to 18%.

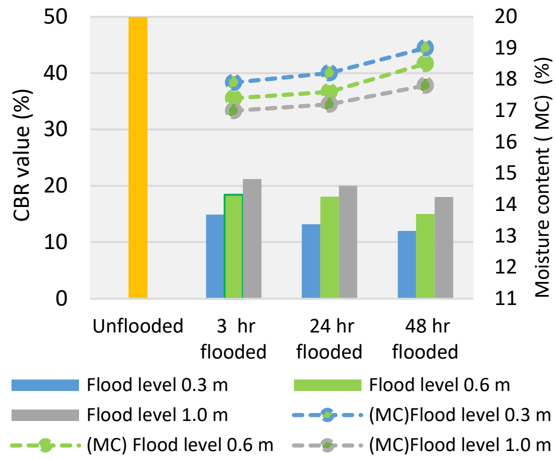


Fig.4 Comparison of CBR value and water content of unrepeated flood samples.

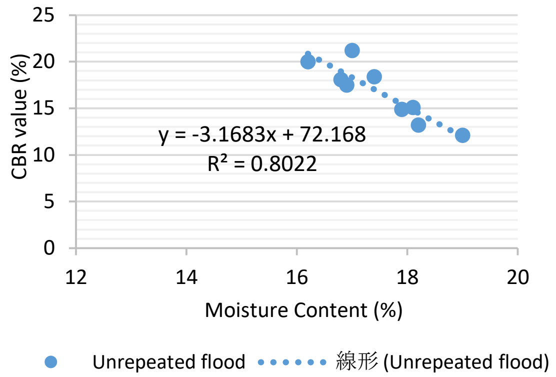


Fig.5 Relation between moisture with CBR value of unrepeated flood

Figure 5 presents the model developed for CBR values where the coefficient of correlation R^2 was found to be 0.82. Thus, moisture content has a high influence on the CBR value and the linear regression equation for unrepeated flood is CBR value (inundation) = -3.1683(MC) + 72.168

3.2 Repeated Flood

The outdoor moisture content test is a process by which soils decrease the moisture content in the specified volume. In this test, the focus is on observing the reduced effect water content from the outdoor condition for the soil sample. Figure 6 shows the result of the outdoor moisture content test for one month and the figures are given as percentages of the moisture content. It can be seen that the percentage of moisture content slightly increased to 20.2 % after a 24 hour soaking. Otherwise, there was a minimal decrease in the percentage of moisture content in the day-1 to day-30 tested samples and the average percentage reduction in water content is 0.4 % per day. However, this is dependent on the weather factor and the outdoor environment. The typical weather condition in Malaysia is uniform temperature and high humidity which is the one major factor contributing to the fluctuation in the rate of the soil moisture content. In a general overview, it shows that the moisture content will return to its original rate of 12% on day-16. Therefore, it can be concluded that the repeated flood after day-16 can be categorised as unrepeated flood. The moisture in the soil will return to its original value.

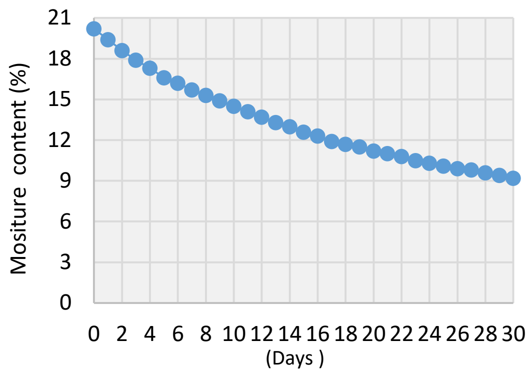


Fig.6 Percentages moisture content of outdoor test

The result of CBR strength and moisture content presented in Figure 7 illustrates the comparison between unflooded and flooded condition. From the combo chart, the vertical left and right axes represent the CBR value and moisture content (MC). The soil samples were flooded for 2, 5 and 24 hours for the first repeated flooding condition. It shows that the CBR value for unflooded condition was 41% and in the first repeated flood for 2 hours at flood water levels 0.3 m, 0.6 m and 1.0 m, the CBR values were 15.4%, 17% and 18% respectively. In addition, at 5 hours on flood water levels 0.3 m, 0.6 m and 1.0 m, the CBR values were 16%, 17% and 19% respectively. The unflooded samples mostly showed better performance in their strength and the CBR strength probably can be increased with suitable compaction of the soil tested. However, for 24 hours flooding at flood levels 0.3 m, 0.6 m and 1.0 m the CBR values were 17.9%, 16.5% and 22% respectively. The average CBR strength was reduced in 2 hours flooding to 24% and subsequently the CBR value also reduced in the 5 to 24-hour floods compared to the unflooded sample. The CBR strength increased by 2.9% after flooding for 2 hours at flood level 1.0 m. The moisture content values in the combo chart show the fluctuation pattern of the result.

In contrast, the combo chart in Figure 8 shows the second repeated flood condition is seen differently compared to the unflooded and flooded conditions. From the combo chart, the vertical left and right axes represent the CBR value and moisture content (MC).

The soil samples were similar with the first repeated flood in which the soil samples were flooded for 2, 5 and 24 hours. It shows that the CBR value for unflooded condition was 41% and in the first repeated flood for 2 hours at flood water levels of 0.3 m, 0.6 m and 1.0 m, the CBR values were 11.9%, 12.6% and 14% respectively.

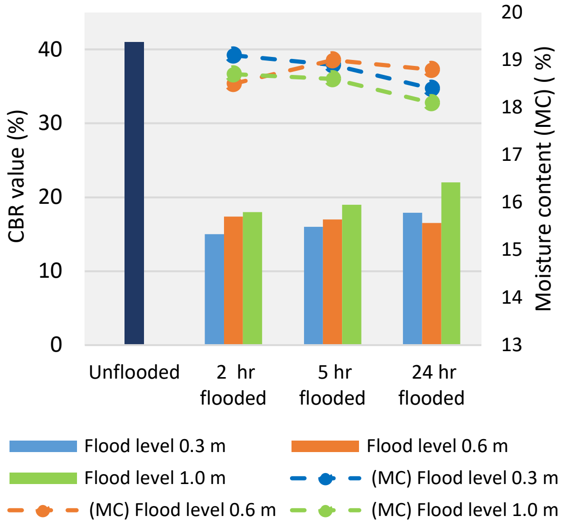


Fig.7 Comparison of CBR value and water content of first repeated flood samples.

It follows that, for 5 hours at flood water levels of 0.3 m, 0.6 m and 1.0 m the CBR values were 12.3%, 13% and 14.3% respectively. However, for 24 hours at flood levels 0.3 m, 0.6 m and 1.0 m the CBR values were 14.3%, 15.4% and 17% respectively. In the second repeated flood case, the moisture content increased in the 5 hour flood at flood levels 0.3 m and 0.6 m, to 20.7% and 20% respectively. This condition may be due to the subgrade of the soil becoming saturated because of the number of floods and the loads used during the FSM in the soil sample affecting the absorption of moisture content.

From Figure 9 it is observed that there is a multi linear relationship between the moisture content and CBR value in repeated flood events. In general, as moisture content increases the subgrade strength decreases, indicating a linear relationship exists between these two parameters. From linear regression the coefficient of correlation R^2 for these two parameters in first and second repeated floods were found to be 0.80 and 0.79 respectively.

5. CONCLUSIONS

This study was carried out to evaluate the moisture content variation and strength of the subgrade using the FSM. It can be concluded that:

i) Based on experimental results and linear regression this study shows that there is a good relationship between moisture content and subgrade strength.

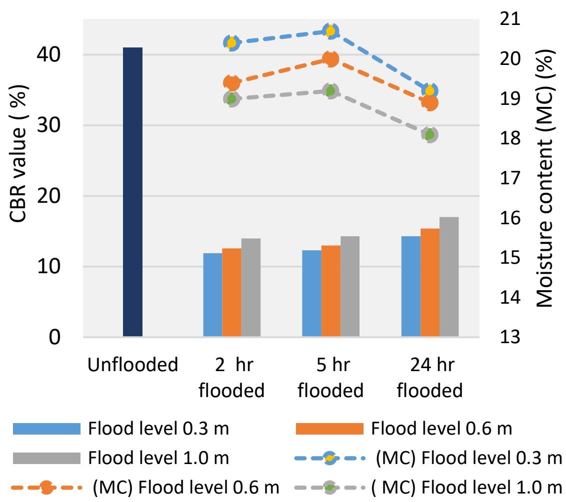


Fig.8 Comparison of CBR value and water content of second repeated flood samples.

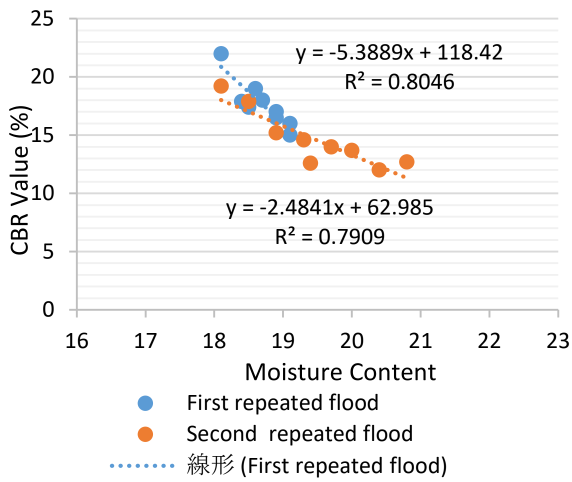


Fig.9 Relation of CBR value and water content of repeated flood.

A linear relationship exists between moisture content and subgrade strength with a coefficient of correlation on unrepeated flood, first and second flood events, $R^2 = 0.80$, 0.80 and 0.79 respectively. It illustrates that the increase in the duration of the flooding affects the performance of the subgrade due to the increasing moisture content.

ii) The study also revealed that the rate of deterioration in subgrade strength for the second flood is 15% more than for the first repeated flood.

For future works, this study will continue to investigate the effect of the period for inundated roads and recurring inundation and how these could affect the whole road structural systems in different localities and sub-grade properties.

6. ACKNOWLEDGEMENTS

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