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ROAD SUBMERGENCE DURING FLOODING AND ITS EFFECT ON SUBGRADE STRENGTH

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ABSTRACT: Deterioration of road structural integrity because of flooding may cause huge expenditure for rehabilitation and maintenance of roadway. In principle, the design of pavement structure is based on the strength of compacted soil known as the subgrade or road foundation. Therefore, subgrade is a significant part of the road structural system. When roads are inundated for a long time or repeatedly, the materials in each layer of road structure become saturated, and the original condition of subgrade soils will be compromised. This study investigated the effect on sub-grade strength and properties due to road submergence period and repeated submergence of the road structural systems. Two types of soil that are normally used as the embankment material in road construction, which can be categorized as cohesive and cohesionless materials, were used in this study. California Bearing Ratio (CBR) test and consolidation settlement test were carried out on various categories of inundation and loading conditions including repeated inundation. The findings indicated that the strength of subgrade soil further decrease when they are inundated for a longer period. Similarly, consolidation test also shows that a quick and higher settlement could occur when the soil is inundated for a longer period. These findings are useful for road design and maintenance strategies of flood affected road links.

Keywords: Flooding, Road Sub-grade, Pavement

1. INTRODUCTION

Floods have resulted in many undesirable outcomes on human and the environment. This is mainly due to their adverse impacts on humans, properties, environmental surrounding, road structures and many forth. Additionally, human activities can also contribute to the flooding event which include: (i) farming and deforestation that exposes the soil to erosion and increases surface runoff, (ii) urbanization by unplanned building construction in vulnerable areas without following the regulations of town planning, poor watershed management and failure to control the flooding promptly, and (iii) obstruction of natural flow of water through drainage modification [1]. The impact of flood disaster can be significant after the event since it may impact the whole infrastructure involved as well as can have long term effect in terms of the maintenance work. In the long run, flooding can bring the deterioration to road pavement foundation when the phenomenon keeps repeating. Continuous flood submersion of roads could bring damage on large part of the road infrastructure, thus affecting the stability of asphaltic concrete pavement layer [2].

Damages of roads structure due to flood event are commonly causing a huge expenditure for the rehabilitation and maintenance works of roads. Recently, Malaysian federal government has allocated RM42 million to repair the embankment collapsed in federal roads damaged by floods in the state of Kelantan. Previously, Bernama [3] reported that the state of Terengganu spent more than RM 74 million for flood damaged roads of only one flood event.

Similarly in town of Sibu in the state of Sarawak it was reported that the city requires RM 500 million to repair road related infrastructure damaged by flooding [4]. Malaysian federal government has also allocated RM 106 million [5] to repair federal roads damaged by flash floods in between October 2012 and January 2013 (monsoon season). Figure 1 is a typical road inundated during flash flood.

Fig.1: Typical road inundation during flash flood

Monsoon season will always come every year and it is only logical to expect the same or more amount of money will be required to reinstate the damaged roads annually. On the other hand, when the roads are inundated for a long time, the materials in each layer for road pavement become saturated, and then as floodwaters drained, the sub-grade soils began to shrink and subside. The excessive water can drain into the foundation reducing its load bearing efficiency. Thus, this situation can cause the strength of road pavement systems to be compromised.

1.1 The Sub-grade

The sub-grade is a foundation for the pavement structure to support the load from upper layer to the beneath soil. Basically, sub-grade must be stable in performance to carried load in any weather conditions. Generally in road engineering, CBR test is performed to determine the strength of sub-grade soil and these CBR values will be used to design the thickness of flexible pavement [6]. As soil is a highly variable engineering material due to its composition and the dependence of its properties on environmental conditions, it is logical to evaluate the effect of the variability associated with sub-grade strength on pavement design and performance [7], [8]. Generally, no systematic study has been performed to evaluate the effects of weak, variable sub-grade conditions on pavement design, construction, and performance prediction [9], [10]. Change of the properties of sub-grade soil is definitely affecting the performance of pavement structure.

Fairweather and Yeaman [11] recently studied the influence of flooding on road pavement deterioration and recommended further research to better predict pavement failure.

2. EXPERIMENTAL SETUP

The samples of sub-grade soil were taken from two different quarries that supply soil which is usually used as the embankment soil in road works. The soil samples were categorized as cohesive material and cohesionless material according to Standard Specification for Road Works by Public Work Department (JKR), Malaysia. The properties of soil are shown in Table 1.

Table 1 Properties of Soil

Soil	Properties	Values
Soil 1 (Well-graded sand with clay and gravel)	Liquid limit Plastic limit Plasticity index	78.5 34.2 44.3
Soil 2 (Silty clay and gravel)	Liquid limit Plastic limit Plasticity index	88.8 38 50.8

2.1 Sample Preparation

Initially, the experiments such as grain size distribution and index properties were conducted to find out the different properties of soil. After that, the CBR test was performed on unsoaked and soaked specimens with different days of submergence. Additional set of specimens were kept submerged repeatedly under water for certain period to simulate repeated flooding. Finally, the Odometer consolidation apparatus were used to determine the progressive settlement of soil specimens.

2.2 CBR Test

CBR test was carried out according to the BS1377. 4300g of soil was compressed in the mould and assign to unsoaked, soaked and repeated submerged condition. The unsoaked soil sample is tested immediately after the soil being compressed into mould, while soaked soil sample is tested for its strength after being soaked for 1, 3 and 7 days. Furthermore, to simulate the effect of repeated inundation the samples were kept in water for 1 hour on Day 1, Day 3 and Day 7. The penetration was measured using a dial gage which has accuracy 0.01mm.

2.3 Oedometer Consolidation Test

The Odoemeter test was carried out according to the ASTM D2435. In this research, the Oedometer was modified by using data logger for data recording. The standard Oedometer test is carried out on a cylindrical specimen of saturated soil with the dimension of 75 mm diameter and 20 mm thick. The soil sample is enclosed in a metal ring and is placed on a porous stone. The soil samples were prepared for 1-day submerged and 3-days submerged before tested. The test involves applying increments of 1kg, 2kg, 4kg, 8kg, 16kg and 32kg of vertical static load to the sample and recording the corresponding settlement. The time intervals were 6s, 15s, 30s, 60s, 120s, 240s, 480s, 900s, 1800s, 3600s, 7200s, 14400, 28800s and 86400s.

3. RESULTS AND DISCUSSION

The mechanical and physical properties for the two types of the tested soils were determined and the particle size distribution for the tested soils, according to American Association of State Highway and Transportation Officials (AASHTO), is shown in Fig. 2 indicating that the percentage passing no. 200 sieve for Soil 1 and Soil 2 are 0.6%

and 1% respectively. Based on the AASHTO soil classification system, both soils belongs to soil group which usual types of significant constituent materials are silty or clayey gravel and sand. Moreover, according to the Unified Soil Classification System (ASTM D2487), the tested soils were found and can be classified in group name of “well-graded sand with clay and gravel” for the Soil 1, whereas for the Soil 2 is “poorly graded silty clay and gravel”.

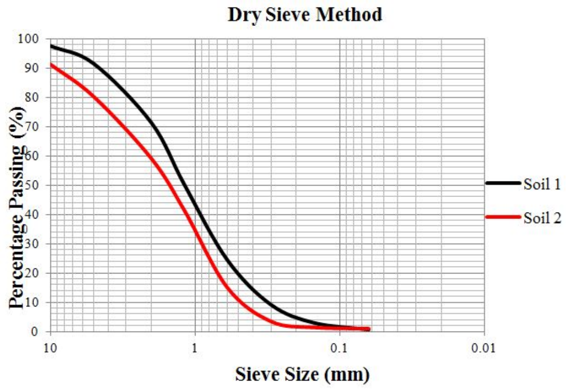

Fig. 2 Particle Size Distribution Curve

3.1 CBR Performance

Soil 1

The result of CBR strength presented in Fig. 3 illustrated the comparison of soil strength for unsoaked and soaked condition. The soil samples were inundated for 1, 3 and 7 days for soaked condition. From the bar chart, it shows the CBR value for unsoaked condition relatively higher than CBR value for soaked condition due to the saturated period for soaked soil samples. It shows that the CBR value for unsoaked condition was 35.7% and on submerging the soil samples for 1, 3 and 7 days, the CBR values were 15%, 12.2% and 8.6% respectively. Generally, the soil strength has been reduced by 76% from the condition of unsoaked sample to the 7-day soaking sample. Obviously, the presence of water when the soil had been soaked for 1, 3 and 7 days contributes to the decreasing of soil strength. Soil had been loss strength starting on 1-day soaking when it compared to the unsoaked condition. Soil sample in unsoaked condition show its capability to sustain the higher load since it is evident that there have no subsequent loss of strength. The unsoaked sample basically showed better performance on their strength and the CBR strength probably can be increased with well compacted on soil tested.

However, the CBR value for soaked condition decreased with the strength accordingly due to the number of inundation days for each soaked soil samples. It was found that further increase in the number of days of soaking decreases the CBR value gradually and it is also observed that the loss of CBR value between conditions of 1 day until 7 days soaking. Significant loss of strength was observed caused by inundation and subgrade soil becomes saturated within the soaking period. From the results, it is concluded that the value of CBR for the given soil sample decreases rapidly from unsoaked condition to 1 day of soaking. Additionally, it is also observed that the variation between 1-day and 7-day soaking values are quite different. Soil had been loss more strength on 7-day soaking compared to 3-day soaking since the percentage of CBR value decrease from 12.2% to 18.6% respectively. The volume of soil has been changed effect from the soaking condition, thus the strength of soil become less due to number of inundation days.

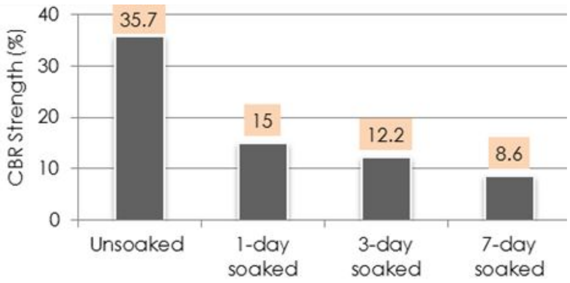

Fig. 3 Comparison of CBR values of inundated samples (Soil 1)

Meanwhile, the bar chart in the Fig. 4, for the repeated submerged condition has shown different result of unsoaked and soaked condition. The soil samples were submerged for 1 hour only on day-1, day-3 and day-7. It shows that the CBR value for unsoaked condition was 35.7% and on repeated submerging for 1 hour on day-1, day-3 and day-7, the CBR values were 25%, 15.9% and 18.5% respectively. Basically, the result shows that unsoaked condition still have the higher CBR strength value when it compared to the repeated submerged condition of soil samples. In the repeated submerged case, the CBR strength was reduced on day-1 after submerged for 1 hour and subsequently the CBR value also reduced on day-3 compared to the unsoaked sample. However, on the day-7, the soil sample was gaining its strength again when inundated for 1 hour after on the day 3. The CBR strength was increased by 16% after submerged for 1 hour on day-7.

Soil sample in unsoaked condition show its capability to sustain the higher load since it is evident that there were no subsequent loss of strength. Moreover, the CBR values for repeated submerged condition is higher than soaked condition since the soil was only inundated for short period when it compared to the soaked condition which the soil has been inundated for a longer period. CBR values were strongly affected by the long-term inundation compared to the case of repeated submerged condition. Since the soil 1 was categorized as well-graded sand with clay and gravel, the possibility of soil to gain the strength on day-7 after submerged on 1 hour is easier because of the soil particle and lower pore water pressure itself.

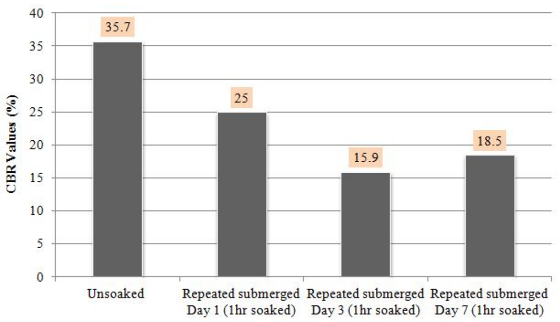

Fig. 4: Comparison of CBR of repeated submergence samples (Soil 1)

Soil 2

Figure 5 presented the result of CBR value for the second soil samples which comparing between unsoaked and soaked condition of soil samples. The test and soil conditions were conducted similar with the first soil samples. From the bar chart, it shows the CBR value for unsoaked condition relatively higher than CBR value for soaked condition due to the saturated period for soaked soil samples. It shows that the CBR value for unsoaked condition was 22.9% and on submerging the soil samples for 1, 3 and 7 days, the CBR values were 10.7%, 6.84% and 3.42% respectively. Generally, the CBR value for both conditions on second soil quite different from soil 1 since the soil 2 was categorized as silty clay and gravel. CBR strength has been reduced by 85% from the condition of unsoaked sample to the 7-day soaking sample. Basically, the second soil sample in unsoaked condition shows its capability to sustain the higher load similar with the first soil samples since it is evident that there has no subsequent loss of strength. However, the CBR strength of soil samples for soaked condition was decreased due to submerging time.

The unsoaked sample basically showed better performance on their strength and the CBR strength probably can be increased with better compaction before the soil will be tested. Meanwhile, soil that soaked for 7 days show the deterioration of its strength performance compared to the 1 and 3 days of soaking condition. Significant loss of strength was observed caused by inundation and subgrade soil becomes saturated within the soaking period. From the results, it is concluded that the value of CBR for the given soil sample decreases rapidly from unsoaked condition to 1 day of soaking. Soil had been loss more strength on 7-day soaking compared to 3-day soaking.

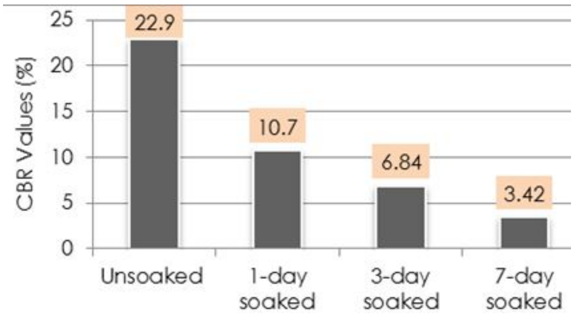

Fig. 5: Comparison of CBR values of inundated samples (soil 2)

On the other hand, the bar chart in the Fig. 6 shows the repeated submerged condition seen differently compared to the unsoaked and soaked condition. The soil samples were submerged similar with soil 1 condition which is the soil samples were submerged for 1 hour only for 1, 3 and 7 days. It shows that the CBR value for unsoaked condition was 22.9% and on repeated submerging for 1 hour on day-1, day-3 and day-7, the CBR values were 13.5%, 8.05% and 5.25% respectively. Basically, the result shows that unsoaked condition still have the higher CBR strength value when it compared to the repeated submerged condition of soil samples. In the repeated submerged case, the CBR strength was reduced on day-1 after submerged for 1 hour and subsequently the CBR value also reduced on day-3 and day-7 compared to the unsoaked sample. The reduction of strength was 61.1% from day-1 submerged for 1 hour to day-7 submerged for 1 hour. This condition occurs probably due to clay condition which its properties consist of small particle size which tends to be very dense. The density of clay that thicker and heavier than other soil types will takes longer time to clay particles absorb this water, and further slowing the flow of water through the soil.

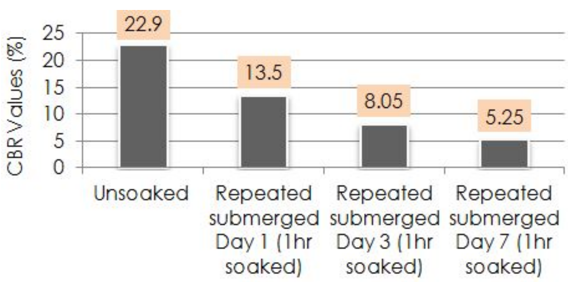

Fig. 6 Comparison of CBR values of repeated submergence samples (Soil 2)

3.2 Consolidation Performance

Consolidation is a process by which soils decrease in volume. In this study, the focus is to observe the settlement effect from various loading capacity. Figure 7 and Figure 8 show the graph of settlement against time for soil condition of 1-day (24 hours) submerged and 3-days (72 hours) submerged respectively. For 1 day submerged condition, as shown in Fig. 7, the settlement increases due to the increment of loading. Generally, the load of 1kg, 2kg and 4 kg obtain quick initial settlement at 60s before the soil reached at the optimum settlement. In addition, the load for 8kg, 16kg and 32kg take longer time to reach the constant settlement. The average time to soil reached the constant settlement was about 2 hours. The higher settlement takes places when 32kg load was applied and reach the constant settlement at 1.52mm.

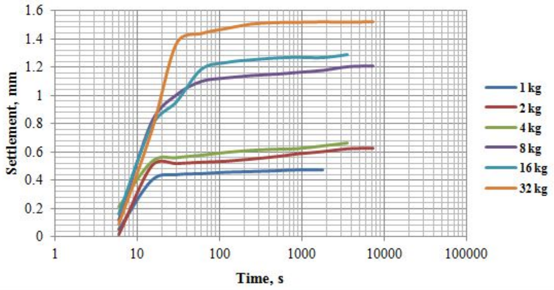

Fig. 7 Graph of settlement against time for 1-day (24 hours) submerged sample

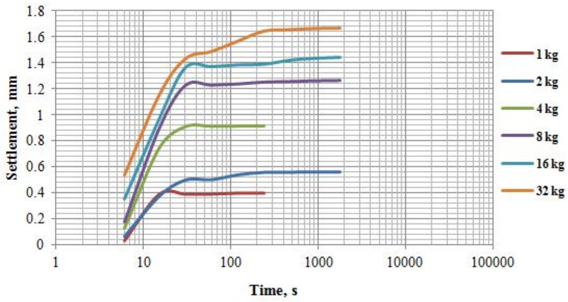

Fig. 8 Graph of settlement against time for 3-days (72 hours) submerged sample

Figure 8 shows the settlement of soil against time for the 3-days submerged condition. The pattern line of graph can be seen quite different when compared to soil samples of 1-day submerged condition since the initial settlement occurs for each load is higher than 1-day submerged condition. This is because the longer period of inundation cause the quick and higher initial settlement. The higher settlement takes places when 32kg load was applied and reach the constant settlement at 1.70mm which higher than the 1-day submerged condition but the consolidation occur in a relatively short time to reach the constant settlement.

The test provides a reasonable estimate of the amount of settlement on soil samples However, the rate of settlement is often underestimated, that is, the total settlement is reached in a shorter time than that predicted from the test data. This is largely due to the size of sample which does not represent soil fabric and its profound effect on exact conditions. Besides the natural condition of the sample, sampling disturbance will have a more pronounced effect on the results of the test done on small samples. Furthermore, the boundary effect from the ring enhances the friction of the sample. The friction reduces the stress acted on the soil during loading and reduces swelling during unloading.

4. CONCLUSION

Experimental study has been carried out to determine the strength of soil samples when tested in different inundation conditions. The CBR strength for both soils samples indicated the decreases of its strength due to higher increment number of inundation days. It can be concluded that the strength of soil further decrease when they are inundated for a longer period. Similarly, consolidation test also shows that a quick and higher settlement could occur when the soil is inundated for a longer period. A more extensive testing will provide the basis for the inclusion of inundation effect in the road design procedures.

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6. REFERENCES

[1] Adedeji, A. A. and Salami A. W., (2008): Environmental hazard: Flooding and Its Effects on Residential Buildings in Ilorin, Nigeria. http://www.scribd.com/doc/9268022/ . Date Accessed Jan 29 2015.

[2] Bowoputro, H. et al. (2009): Temperature Influence and Lapindo Mud Submersion towards the Stability Value of Asphaltic Concrete Mix, Rekayasa Sipil Journal, Volume 3, No.3 1978 – 5658.

[3] Bernama (2009): RM 21 Juta Untuk Baiki Jalan Rosak Akibat Banjir. Bernama.Com. December 22, 2009.

[4] mySarawak (2009): RM 500 juta bina infrastruktur rosak akibat banjir di Sibu. mySarawak, February 8 , 2009

[5] The Star (2013): RM 106 Juta Diperuntuk Untuk Baik Pulih Jalan Persekutuan Rosak Akibat Banjir. The Star, Jauary 11, 2013.

[6] Naagesh, S., Sathyamurthy, R., Sudhanva, S. (2013): Laboratory Studies On Strength and

Bearing Capacity Of GSB-Soil Sub-Grade Composites.

[7] Deshpande, V. P., Damnjanovic, I., and Gardoni, P. (2008): *Modeling The Effects of Rehabilitation Actions on The Reliability of Flexible Pavements*, Proc., Transportation Research Record 87th Annual Meeting, Transportation Research Board, Washington, D.C.

[8] Tarefder, R. A., Saha, N., Hall, J. W., and Ng, P. T. T. (2008): *Evaluating weak subgrade for pavement design and performance prediction: A case study of US 550*, Journal of GeoEngineering, 3(1), 13–24.

[9] Khogeli, W. E. I. and Mohamed, E. H. H. (2004): *Novel Approach for Characterization Of Unbound Materials.* Journal of the Transportation Research Board, No. 1874, Washington, D.C., 38-46.

[10] Theyse, H. L., Hoover, T. P., Harvey, J. T., Monismith, C. L. and Coetzee, N. F. (2006): *A Mechanistic-Empirical Subgrade Design Model Based On Heavy Vehicle Simulator Test Results*, Geotechnical Special Publication No. 154, Pavement Mechanics and Performance, B., Huang, R., Meier, J., Prozzi, E., Tutumluer, Geo Institute, ASCE, 195-202

[11] Fairweather, H. and Yeaman, J. (2014). “A study of the parameters affecting the performance of roads under extreme rainfall event”. Int. J. of GEOMATE, Sept., 2014, Vol. 7, No. 1 (Sl. No. 13), pp.955-960

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