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# ROAD SUBGRADE STRENGTH UNDER VARIOUS FLOODING EVENT

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## Graphical abstract

## Abstract

Flooding and water inundation could result in great damage to road pavements. In principle, the design of pavement structure is based on the strength of compacted soil known as subgrade or road foundation. Therefore, subgrade is the major significant part of road structural systems. When roads are inundated for a long time or repeatedly, the materials in each layer of road structure become saturated, and then 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 road structural systems. Two types of soil that are normally used as the embankment soils in road construction, which can be categorized as cohesive and cohesionless materials were used in this study. California Bearing Ratio (CBR) test and Oedometer consolidation test were carried out on the various categories of inundation and loading conditions including repeated inundation. The findings indicated that the strength of subgrade materials were affected differently depending of inundation period and number of repeated inundation.

*Keywords*: Flooding, subgrade, road, CBR, soil settlement

## Abstrak

Banjir boleh mengakibatkan kerosakan yang besar kepada turapan jalan raya. Pada dasarnya, rekabentuk struktur turapan jalan adalah berdasarkan kepada kekuatan tanah yang dipadatkan dan dikenali sebagai subgred atau asas jalan raya. Oleh itu, subgred merupakan lapisan struktur jalan raya yang paling penting. Apabila jalan-jalan ditenggelami air dalam masa yang lama atau berulang kali, bahan-bahan dalam setiap lapisan struktur jalan raya menjadi tepu, dan keadaan asal tanah subgred akan terjejas. Kajian ini menyiasat kesan terhadap kekuatan subgred dan sifat tanah terhadap tempoh rendaman dan rendaman berulang sistem struktur jalan raya. Dua jenis tanah yang biasanya digunakan sebagai tanah tambak di dalam pembinaan jalan, yang dikategorikan sebagai bahan padu dan jeleket telah digunakan dalam kajian ini. Ujian Nisbah Galas California (CBR) dan ujian pengukuhan Odoemeter telah dijalankan ke atas pelbagai kategori rendaman dan keadaan beban termasuk keadaan rendaman berulang. Hasil kajian menunjukkan bahawa kekuatan bahan subgred terjejas bergantung kepada tempoh rendaman dan rendaman berulang.

*Kata kunci*: Banjir, subgred, jalan, CBR, enapan tanah



## 1.0 INTRODUCTION

Flood leads to 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 Kelantan. Bernama [3] reported that Terengganu spent more than RM 74 million for flood damaged roads of only one flood event. Similarly in Sibu 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 flooding in between October 2012 and January 2013 (monsoon season). 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 damaged roads annually.

## 2.0 METHODOLOGY

The testing of soils was tested according to American Society for Testing and Materials (ASTM) and BS1377. The engineering properties and strength testing such as Sieve Analysis, Atterberg Limit, California Bearing Ratio (CBR) and Oedometer Consolidation test. The flow chart in Figure 1 has been built to summarize the steps and procedure that used to conduct laboratory experiment.

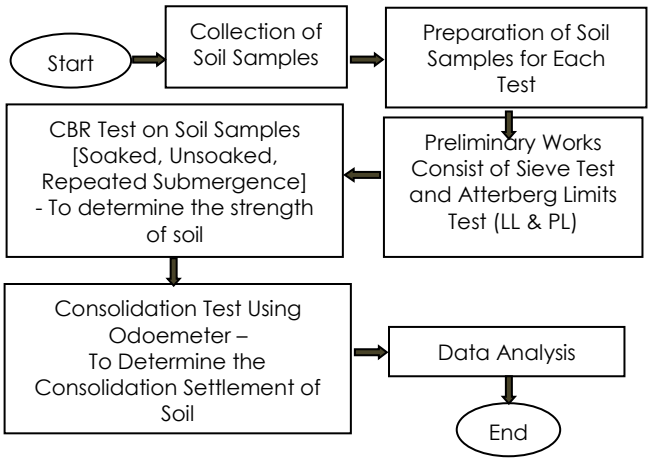


**Figure 1** Flowchart of methodology

## 3.0 EXPERIMENTAL SETUP

### 3.1 Samples of Soil

The samples of sub-grade soil were taken from two different quarries that supply soil which usually used as the embankment soil in road works. The soil samples were categorized as the 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 | 78.5 |
| | Plastic limit | 34.2 |
| | Plasticity index | 44.3 |
| Soil 2 (Silty clay and gravel) | Liquid limit | 88.8 |
| | Plastic limit | 38 |
| | Plasticity index | 50.8 |

### 3.2 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 in different days of submergence as well as the soil samples were kept submerged in water for certain period in the case of repeated flooding in order to determine the strength of subgrade soil. Finally, the Odometer consolidation tests were carried out to determine the settlement of soil.

### 3.3 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 0.01 mm.

### 3.3 Oedometer Consolidation Test

The Oedometer 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.

## 4.0 RESULTS AND DISCUSSION

### 4.1 The Effect of Unsoaked, Soaked, Repeated Submerged Condition on CBR Strength

#### *4.1.1 Soil 1*

The result of CBR strength presented in Figure 2 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.

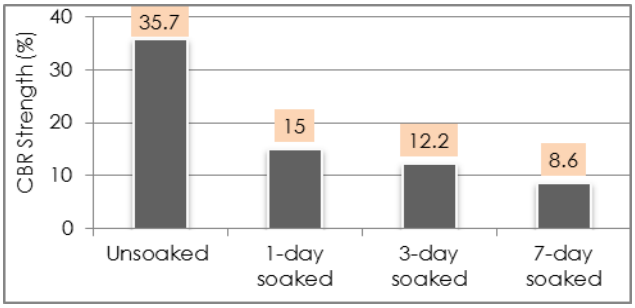


**Figure 2** Comparison of CBR values between unsoaked sample and soaked samples

Meanwhile, the bar chart in the Figure 3, 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.

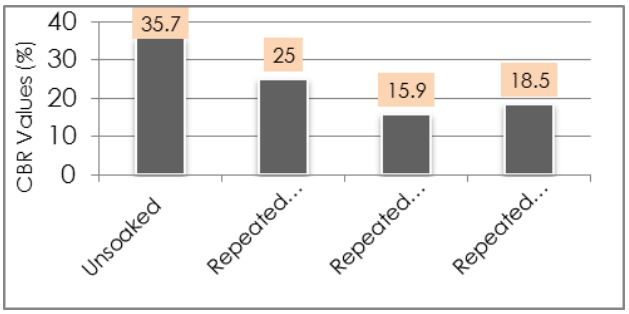


**Figure 3** Comparison of CBR values between unsoaked sample and repeated submerged samples

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.

### 4.1.2 Soil 2

Figure 4 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.

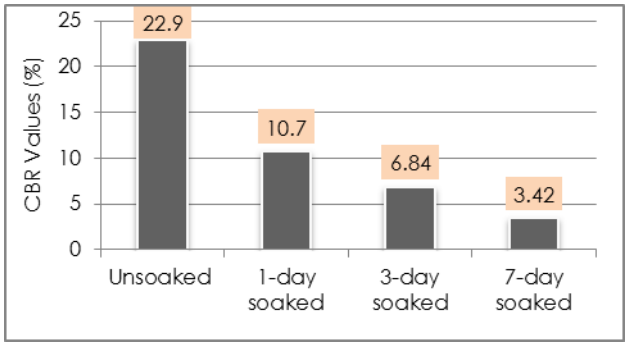


**Figure 4** Comparison of CBR values between unsoaked sample and soaked samples

On the other hand, the bar chart in the Figure 5 show 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.

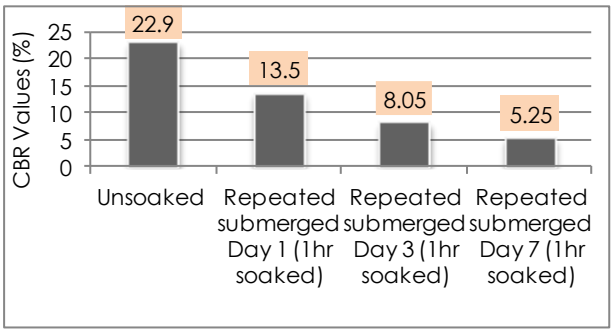


**Figure 5** Comparison of CBR values between unsoaked sample and repeated submerged samples

## 4.2 Odoemeter Consolidation Test

Consolidation is a process by which soils decrease in volume. Figure 6 and Figure 7 show the graph of settlement against time for soil condition of 1-day submerged and 3-days submerged respectively. The consolidation settlement which known as the primary consolidation occur when the expulsion of water from soils accompanied by increase in effective stress and strength. For 1 day submerged condition as shown in Figure 6, it shows that the settlement increase 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. This is because the soil that had been tested was disturbed soil sample, thus the properties not similar

with the original clayey soil. The higher settlement takes places when 32 kg load was applied and reach the constant settlement at 1.52 mm.

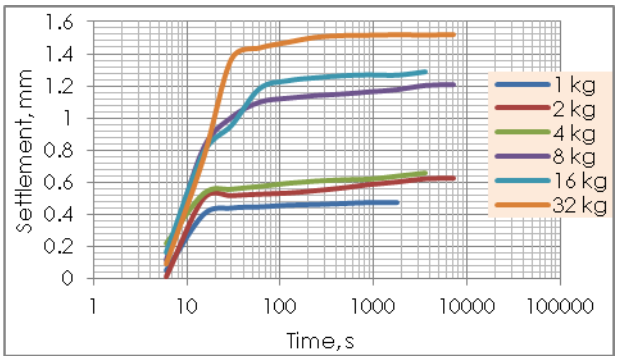


**Figure 6** Graph of settlement against time for 1-day submerged sample

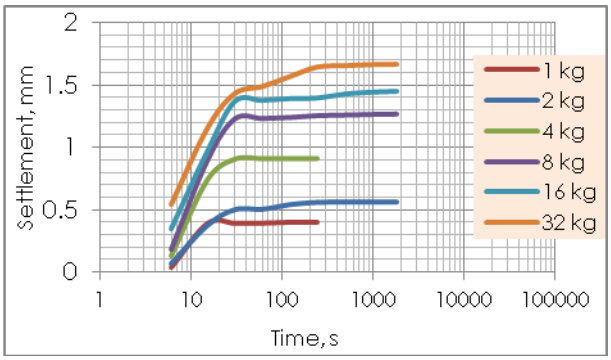


**Figure 7** Graph of settlement against time for 3-days submerged sample

Figure 7 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.

## 5.0 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 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 were inundated for a longer period. Similarly, Odoemeter consolidation test also prove that 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.

## Acknowledgement

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