Effect of Submergence on Subgrade Strength

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Abstract

Damages of roads by floods are common phenomena in Bangladesh and a huge expenditure is required almost after each flood for rehabilitation of the roads. Therefore, research aiming at finding the modes of damages to roads under flood has become necessary. Several factors may appear to be responsible for such damages, which need to be confirmed by experiments. This study aimed at determining the effects of depth of submergence and duration of submergence on the subgrade strength of soil samples collected from the Dhaka-Aricha highway which was badly damaged by the 1998 flood. CBR tests were performed with different heights of submergence after normal soaking period and also after prolonged submergence. Index and identification tests were performed for classification and for determination of the suitability of the studied soils as subgrade material. For the studied depth and duration of submergence, no significant effect of submergence on sub-grade CBR strength could be found for any of the three types of soils tested. However, it was observed that all the three types of soils tested are rated as poor materials for subgrade according to different soil classification systems.

INTRODUCTION

Floods are recurring phenomena in Bangladesh and after each occurrence, they leave behind huge scar on the national economy. However, the flood of 1998 surpassed the damage records of all the floods of the recent past in terms of devastation. Other than surpassing in the maximum flood level of all recent floods, this flood persisted for a relatively longer period compared to other floods. As a result, apart from loss of lives and properties, the country suffered immense damage to the road networks. Therefore, it was felt necessary to undertake research to identify the causes of damage, due to this flood, to a road near Dhaka with a view to minimize such damage during future floods.

SCOPE OF THE RESEARCH

When floodwater recedes, it is generally observed that ditches and holes are developed in the road pavement. Just after the flood, these are usually found to be smaller in size and depth. With continued vehicular movements, these ditches continue to increase in size and depth by loss or removal of aggregates. When the subgrade gets exposed, the extent of damage increases very fast, making the roadway completely unusable. It is assumed that submergence of the road during flood might have some link with the initiation of the damage process. There are several mechanisms, which may be responsible for the damage. Firstly, with the rise of water level to the embankment top level, the road subgrade might lose strength due to reduction in effective stress. Continued vehicular movements may result in local failure in the subgrade, which then causes secondary failure in the pavement. Secondly, it is found that even after the submergence of road surface by floodwater, vehicles (specially heavy vehicles viz. trucks and buses) continue to ply as long as the axles do not go under water. Movement of series of vehicles may impose cyclic loading on the roadway resulting in pore-pressure build up in the subgrade. In this case also, primary failure may occur in the sub-grade, which may then propagate in other areas. Thirdly, it may be possible that the pavement is damaged first due to failure of binder (as a result of loss of effective stress) resulting in loss of aggregates and finally creating holes on the roadway. Among the aforementioned failure modes, only the first one was investigated in this research program due to limited scope of the research.

TEST PROGRAM

Generally California Bearing Ratio (CBR) test is the most widely used test for evaluating the strength of sub-grade, sub-base and base course materials for use in the design of road and airfield pavements. To determine the effect of submergence on subgrade strength, it was planned to collect disturbed soil samples from Dhaka-Aricha highway embankment (which was severely damaged by the 1998 flood) and carry out CBR tests with different water height above the soil surface in the CBR mold. During the inception of this research work it was also planned that field CBR tests would be performed on selected damaged sections of the Dhaka-Aricha Highway immediately after recession of floodwater. However, by the time this research proposal was accepted and funds allocated, the road embankment became dry, repair works were done and the roadway became busy with traffic. So soil samples could not be collected from the subgrade at damaged sections of the road. Also considering the practical difficulties of carrying field-tests on such a busy and narrow highway (as part of the road way would have to be blocked), programs of field-tests had to be abandoned. Apart from CBR tests, Grain size distribution (sieve and hydrometer), Atterberg limits and Standard Proctor compaction tests were performed for classification and characterization of the soils.

COLLECTION AND IDENTIFICATION OF SOIL SAMPLES

The construction works for the lateral expansion of the Dhaka-Aricha highway between Gabtali to Savar was underway during the time of sample collection and three types of samples were collected from embankment soil near Savar Bazar. Sufficient amounts of samples of each type were collected into gunny bags and carried to BUET laboratory for investigation. One type of soil collected was grey in colour, non-plastic in nature and the grains formed little or no lump upon drying. It also contained some mica. This soil may be termed as fine sand or silt and has been designated as Soil-1 in this paper. This type of soil is usually found in char areas or on low lands and is formed of sediment deposits during flood. The other two types of soil can be classified as clay; one is the typical Dhaka clay (red) and the other is yellow clay. Upon drying these soils formed lumps having very high dry strength. The yellow and red clays have been designated as Soil-2 and Soil-3, respectively. Probably the sources of these soils were roadside borrow pits. All these soils were inorganic in nature.

APPARATUS

The standard apparatus used for CBR testing had to be modified to allow specimens to be tested with a maximum of 3 ft of water above the specimen surface. This height was selected considering weight limitations of the container to submerge the CBR mold, which is again governed by the weight capacity of the existing CBR apparatus and difficulties of placing CBR mold in a long narrow container. The lengths of shafts of the CBR apparatus and the plunger were also increased (Yasin et al., 2000).

INDEX PROPERTIES

Physical properties of the collected soils were determined for classification purpose. The results are described in the following sections.

Particle Size Distribution and Grain Characteristics

Since all the samples contained considerable amount of fines, both mechanical sieve analyses and hydrometer analyses were performed on it to determine their grain size distribution and for classification. The grain size distribution curves of these soils are shown in Fig.1. All the soils tested can be termed as uniformly graded soils. Soil-2 and Soil-3 have virtually identical particle size distribution curves, whereas Soil-1 is composed of relatively coarser particles. The grain diameters D_{10}, D_{30} and D_{60} determined from the grain size distribution curves are shown in Table 1 along with Specific Gravity and Fineness modulus values.

Table 1: Mechanical properties of the soil samples tested

Soil Type / Designation	Description	Specific Gravity	Fineness Modulus	D_{10} mm	D_{30} mm	D_{60} mm
Soil-1	Clayey silt; Grey	2.624	0.173	0.001	0.018	0.052
Soil-2	Yellow clay	2.611	0.008	----	----	0.015
Soil-3	Red clay	2.584	0.010	----	0.003	0.012

Atterberg Limits

The Atterberg limits serve as excellent basis for expressing the state of consistency of fine-grained soils. Moreover, several classification systems are based on these limits. As Soil-1 is non-plastic, Atterberg Limit tests were carried out on the other two soils i.e., Soil-2 and Soil-3. The results are summarized in Table 2. Compared to Soil-2, Soil-3 has slightly higher values of liquid limit, plastic limit, shrinkage limit, plasticity index and flow index. Fig.2 shows the 'flow curves' obtained from the liquid limit tests.

Table 2: Atterberg limits of the soil samples tested

Soil type / Designation	Description	Liquid Limit	Plastic Limit	Shrinkage Limit	Plasticity Index	Flow Index
Soil-1	Clayey silt; Grey *	-----	-----	-----	------	-----
Soil-2	Yellow clay	45.7	17.9	14.2	27.8	15.9
Soil-3	Red clay	52.5	22.0	16.5	30.5	18.2

* Nonplastic soil

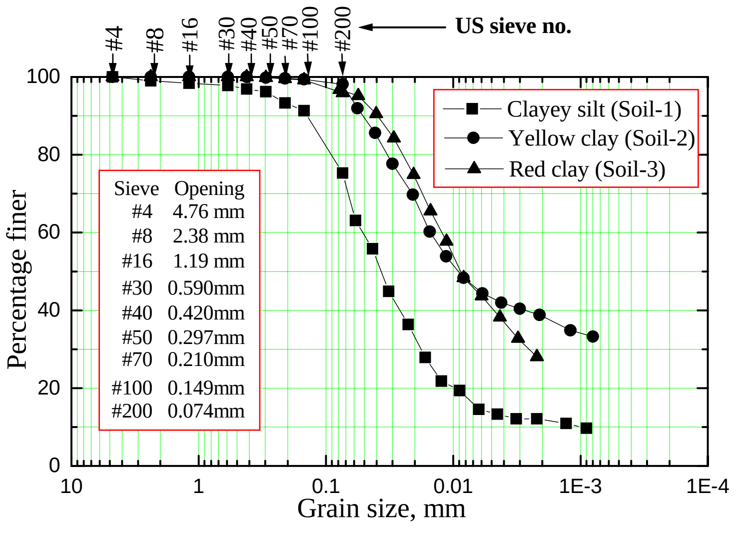

Figure 1: Grain size distribution of soils tested

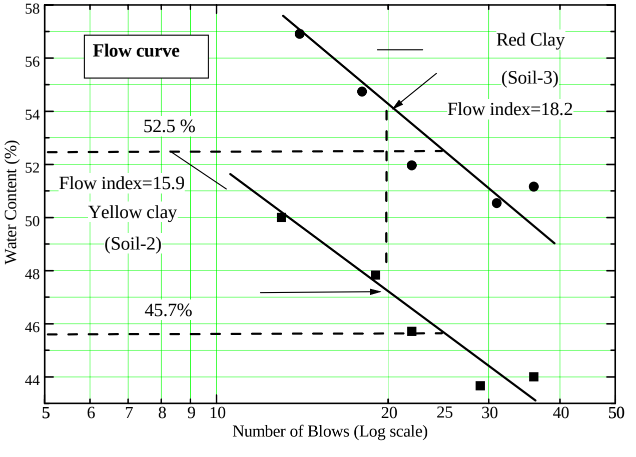

Figure 2: Flow curves for Soil-2 and Soil-3 from liquid limit tests

CLASSIFICATION OF THE SOILS TESTED

Textural Classification

In general, the texture of a soil refers to its surface appearance. However, textural classification systems are based on different size-groups of particles present in any soil. A number of textural classification systems were developed by different organizations to serve their own need. To classify a soil according to a particular textural system, the particle size distribution curve is usually plotted and the percentages by weight of the particles contained within each of the ranges of size specified in the system are calculated. Table 3 compares the amount of principal components (sand, silt, clay and gravel) in the soils studied by several classification systems (Bowels, 1984; Peck et al., 1974).

Table 3: Comparison of principal components of soils tested according to different textural classification systems

Classification system	Soil Designation	Sand (%)	Silt (%)	Clay (%)	Colloid (%)
US Bureau of soils	Soil - 1	35.7	50.5	13.8	-----
	Soil - 2	6.6	50.3	43.1	-----
	Soil - 3	4.5	55.0	40.5	-----
Unified	Soil - 1	24.7	63.6	11.7	-----
	Soil - 2	1.9	59.8	38.3	-----
	Soil - 3	4.1	95.9	----	-----
AASHTO	Soil - 1	24.7	63.6	1.7	10.0
	Soil - 2	1.9	59.8	34.5	3.8
	Soil - 3	4.1	95.9	----	-----
ASTM	Soil - 1	24.7	61.5	3.8	10.0
	Soil - 2	1.9	55.0	39.3	3.8
	Soil - 3	4.1	55.4	40.5	-----
FAA	Soil - 1	24.7	61.5	13.8	-----
	Soil - 2	1.9	55.0	43.1	-----
	Soil - 3	4.1	55.4	40.5	-----
USDA	Soil - 1	40.8	47.5	11.7	-----
	Soil - 2	10.8	50.9	38.3	-----
	Soil - 3	6.2	93.8	----	-----
MIT	Soil - 1	35.7	52.6	11.7	-----
	Soil - 2	6.6	55.1	38.3	-----
	Soil - 3	4.5	95.5	----	-----

Classification Based on Use

Airfield Classification System / Unified Classification

Casagrande originally proposed this classification system in 1948 for use in the airfield construction works undertaken by the Army Corps of Engineers during World War II. This system was revised in 1952 in co-operation with United States Bureau of Reclamation as Unified system. In 1969, the Unified system was adopted by the American Society for Testing and Materials (ASTM) as a standard method for classification of soils for engineering purposes (ASTM D-2487). Fig.3 shows the Plasticity chart used in the Unified soil classification system. The values of Plasticity Index (PI) and Liquid Limit (LL) for Soil-2 and Soil-3 are plotted in Fig.3 to assign their classification symbol. Soil-1, which has 75.3% (more than 50%) material passing No.200 sieve and which is non-plastic, can be classified as ML.

Soil-2 (yellow clay) having 98.1% (more than 50%) material passing No.200 sieve and having liquid limit of 45.7 and plasticity index 27.8 can be classified as CL. Soil-3 (red clay) having 95.9% (more than 50%) material passing No.200 sieve and having liquid limit 52.5 and plastic limit of 30.5 falls into group CH. Unified System of soil classification grades ML and CL soil as "Fair to poor" and CH soil as "Poor to very poor" (Horonjeff and Mckelvy, 1994).

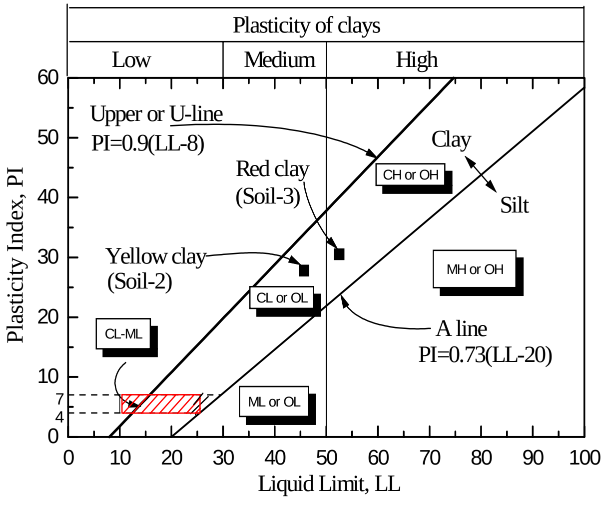

Figure 3: Plasticity chart used by UNIFIED classification system

AASHTO Classification

The AASHTO classification system was developed in 1929 by the US Bureau of Public Roads. Since then it has undergone several revisions. The classification of considered here is based on system reported by Das (1985) (Yasin et al., 2000). Soil-1 (clayey-silt) having 75.3% (more than 35%) of total sample passing No.200 sieve and being non-plastic falls into the category A-4. Soil-2 (yellow clay) having 98.1% (more than 35%) material passing No.200 sieve and having liquid limit of 45.7 and plasticity index 27.8 can be classified as A-7-6. Soil-3 (red clay) having 95.9% (more than 35%) material passing No.200 sieve and having liquid limit 52.5 and plasticity index of 30.5 also falls into group A-7-6. As rated by AASHTO classification, all of Soil-1, Soil-2 and Soil-3 fall into the category "fair to poor" as subgrade material. The data for Soil-1 and Soil-2 are plotted on a plasticity chart along with the group symbols by AASHTO in Fig.4.

To evaluate the quality of a soil as a highway subgrade material, a number called the *group index* (GI) is also used in the AASHTO classification system along with the group or subgroup designation. In general the quality of performance of a soil as a subgrade material is inversely proportional to the group index. The group index is always reported to the nearest whole number unless its calculated value is negative whereupon it is reported as zero.

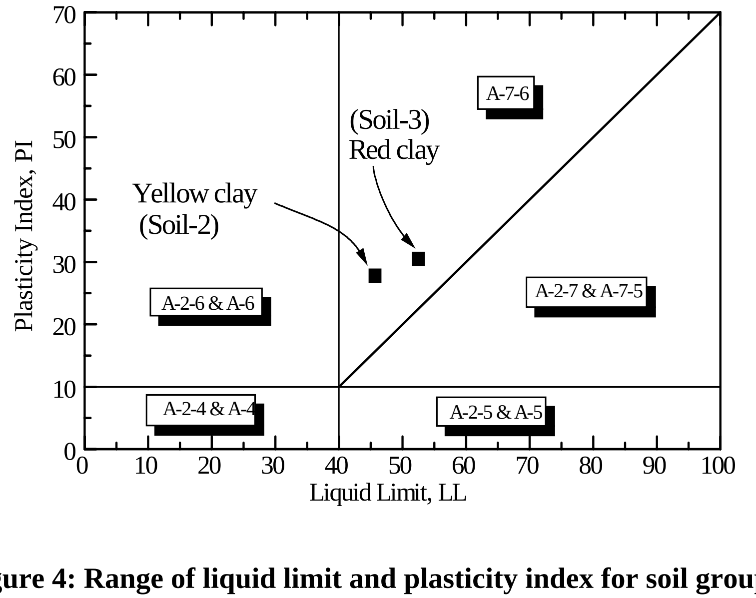

Figure 4: Range of liquid limit and plasticity index for soil groups by AASHTO

The group index is appended to the group and subgroup classification in parenthesis e.g., A-2-6(3). The group index is calculated as follows:

$$GI=(F-35)[0.2+0.005(LL-40)]+0.01(F-15)(PI-10)$$

where, F = Percent passing No. 200 sieve
LL = Liquid limit
PI = Plasticity index

This classification rates a soil as follows: (1) Poorer for use in road construction as one moves from left to right in the AASHTO classification chart (Das, 1985) i.e., A-6 soil is less suitable than A-5 soil, (2) Poorer for road construction as the group index increases for a particular subgroup, i.e., an A-6(3) is less satisfactory than A-6(1).

For Soil-1, GI=0, for Soil-2, GI= 29 and for Soil-3, GI=33. The values of GI for Soil-2 and Soil-3 are quite high indicating their unsuitability for subgrade construction. Since GI for Soil-1 is zero it may be considered as a relatively better material than the other two soils, but not a good quality material for subgrade, as indicated by the group designation.

COMPACTION AND CBR TEST

Compaction Characteristics

To determine the compaction characteristics, Standard Proctor compaction tests (ASTM D698; Test methods for moisture-density relations of soil and soil aggregate mixture using 5.5-lb rammer and 12 in drop) were carried out on the collected samples. Fig.8 compares the dry density versus water content curves from these tests. The Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) values are presented in Table 4. As seen from Fig.5, all the three soils show quite different compaction characteristics. Among the three types of soils tested, Soil-2 has the highest MDD (108.3 pcf) with OMC of 17.7% and Soil-3 has the lowest MDD (102.6 pcf) with OMC of 21.3%. Soil-2 has an MDD of 106.8 pcf at an OMC of 16.8%. The zero air void curves in Fig.5 are plotted using the relationship

$$\gamma_d = \frac{G\gamma_w}{1+(Gw/S)}$$

to show the theoretical limits of density of these soils at different water contents. Here, G denotes specific gravity of soil particles, γ_w denotes wet unit weight at a moisture content of w and degree of saturation S. Specific Gravity values used for the computation of γ_d are given in Table 1.

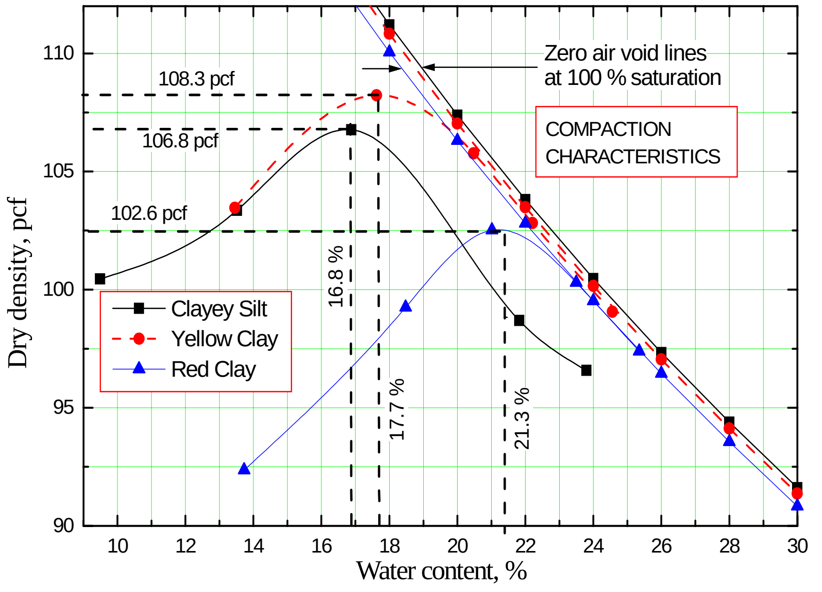

Figure 5: Dry density versus water content curves from standard Proctor Compaction Test

Table 4: Compaction characteristics of soil

Soil type / Description	Maximum Dry Density γ_d (MDD), pcf	Optimum Moisture Content (OMC), (%)
Clayey silt; Grey	106.8	16.8
Yellow clay	108.3	17.7
Red clay	102.6	21.3

CBR TEST

California Bearing Ratio (CBR) tests were performed on all the three types of soils according to ASTM D1883-87. Tests were performed on soaked specimens without submergence and also with submergence of 3 ft of water. Specimens were prepared at optimum moisture content (Table 4) and with Standard Proctor compacting energy (ASTM D698) i.e., 5.5 lbs hammer, height of fall 12 in, number of layers 3 and 25 blows per layer. An automatic compactor was used for preparation of CBR molds. During soaking, a surcharge of 10 lbs was applied to the specimens. The tests performed can be classified into three groups. In the first group, after a soaking period of 96 hours the specimens were drained for 15 minutes and then the CBR test was performed without any submergence. There are three tests in this group – one for each type of soil. In the second group, after a soaking period of 96 hours the specimens were placed in an empty cylindrical container placed on the base of the CBR apparatus. Then water was gently poured into the container until water level rose to 3ft above the soil surface in the mold. Then CBR test was carried out with submergence of 3ft of water. Three tests were conducted – one from each type of soil. Only one test was done for the third group, in which the specimen was soaked for 15 days and then tested with 3 ft of submergence. For all the samples, soaking was done with 6" of water above the specimen surface. Fig.6 compares the load penetration curves obtained in 'group one' and 'group two' tests on each types of soil. The CBR values corresponding to 0.1 inch and 0.2 inch penetration are compared in Table 5. No significant difference in the load – penetration response or CBR values could be observed between 'group one' and 'group two' tests.

These tests showed that there should not be any detrimental change in the subgrade strength due to submergence of a road by 3ft of water. Also the single test performed to see the effect of prolonged submergence did not reveal any change in the CBR characteristics of Soil-2 (Fig.7). Therefore, it can be concluded that the damage of the road in this case was not initiated in the sub-grade by reduction of effective stress due to submergence. However, other mechanisms such as hydrodynamic load and pore pressure build up due to passage of heavy vehicles during submergence might have played a key role in the failure of the road sub-grade and the pavement material. Although, initially it was planned to perform CBR tests with depths of submergence of 1 ft and 2 ft of water, these were later aborted due to time limitations.

Table 5: Comparison of CBR values

Soil type	CBR values at penetrations of	Without submergence	With 3 ft submergence	Tested after 15 days of submergence with 3 ft of water
Soil - 1	0.1 inch	5.6	6.1	--
	0.2 inch	7.2	7.8	--
Soil - 2	0.1 inch	4.4	4.1	3.7
	0.2 inch	4.3	4.0	3.8
Soil - 3	0.1 inch	4.7	5.1	--
	0.2 inch	4.6	4.6	--

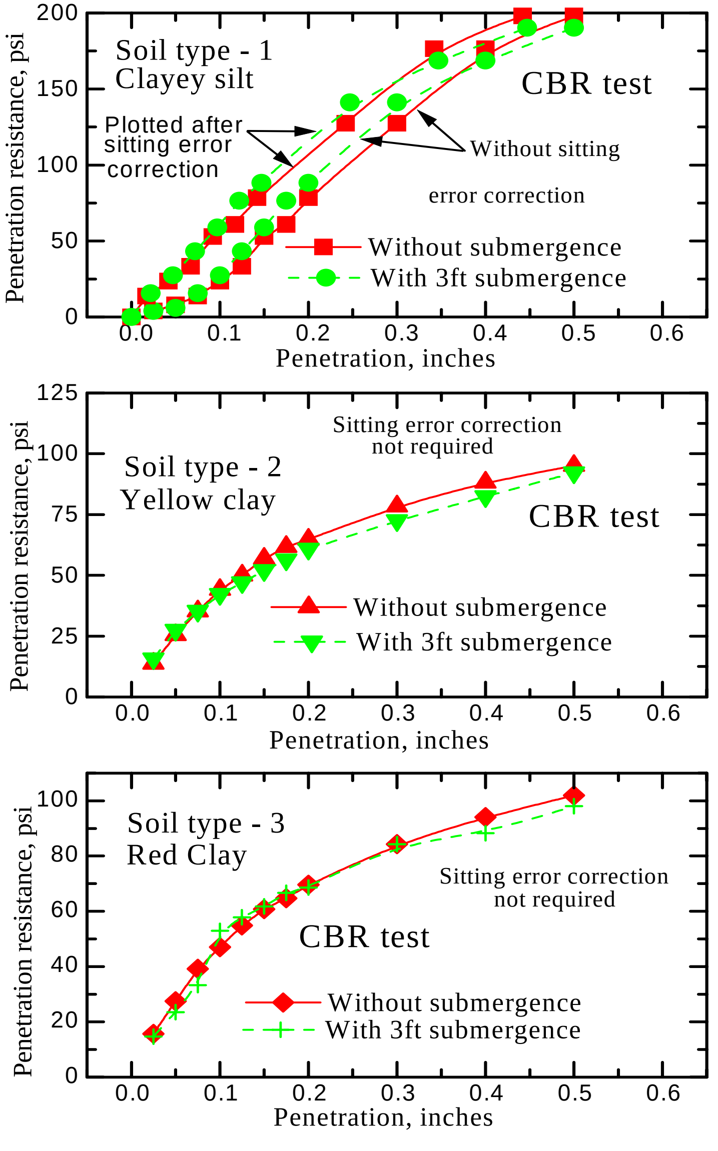

Figure 6: Comparison of penetration resistance among samples without submergence and with 3 ft of submergence

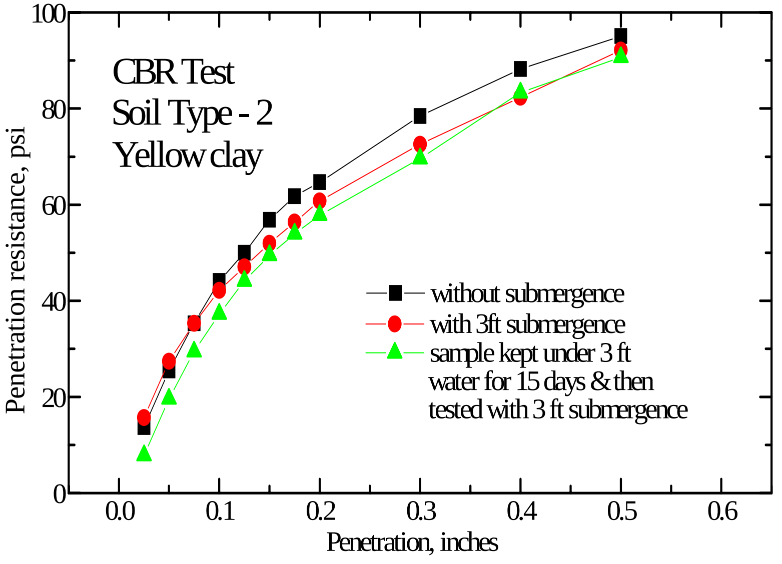

Figure 7: Comparison of penetration resistance among samples with different conditions of submergence

CONCLUSIONS

This research work was aimed at investigating whether the depth of submergence and duration of submergence during flood affects the sub-grade strength causing damage to a roadway. For the studied depth and duration of submergence, no effect of submergence on sub-grade CBR strength could be found for any of the three types of soils tested. However, this study points out that future research should be directed to other possible failure mechanisms such as failure caused by pore pressure build up in the sub-grade due to dynamic loading from the vehicles and change of properties of the pavement material itself due to submergence. Also it needs to be assessed whether subgrade soil stabilisation (during initial construction) will reduce the long-term cost (i.e., maintenance) of a roadway when poor quality soils are to be used in the subgrade.

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