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Effects of Capillary Rise Saturation on Properties of Sub Grade Soil

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Abstract: Design of the pavement layer to be laid over the subgrade soil can start with the estimation of subgrade strength or capacity and the volume of traffic to be carried. Various pavement layers are very much dependent on the strength of subgrade soil over which they are going to be laid. The subgrade soil can be subjected to change in moisture or saturation level due to capillary rise/saturation (h_c). The hydraulic conductivity of subgrade soil can be strongly dependent on the texture (contents), grain size, densities and voids of the soil. Change in moisture level in subgrade soil causes change in subgrade properties, strength or capacity and it can be quite essential for engineers to understand the effects of capillary rise on the variation of moisture in subgrade soil and effects on the strength properties. The strength properties of subgrade soil is mostly expressed in terms of CBR (California Bearing Ratio) and understanding the dependence of the CBR strength of subgrade soil on water content (moisture variation) will contribute better towards the design and maintenance practices. The strength of subgrade soil may vary largely on the amount of saturation in it, i.e. the amount of water exposed in the subgrade soil. Hence in this research an attempt has been made are to determine or estimate hydraulic conductivity of the subgrade soil at varies densities, Saturation level due to capillary rise/height at varies degree of soaking (time of saturation) from day (0) to day (4) and study the effects of capillary saturation on the properties of subgrade soil, including CBR at different level of saturation through the purposive sampling in each five stations. It observed that for each four stations subgrade soils, the strength properties reduced, i.e. the CBR values reduced from the un soaked condition to soaked condition. For sample 1 subgrade soils, the CBR values reduced by 82% to the un soaked condition or no change in moisture and provide a subgrade soil with non-susceptible to hydraulic conductivity which can reduces flow of water through them.

Keywords: Subgrade Soil, Capillary Rise/Saturation, Hydraulic Conductivity, CBR

1. Introduction

1.1. Background

The objective of pavement design is to provide a structural and economical combination of materials to carry traffic in a given climate over the existing soil conditions for a specified time interval. Soil mechanical properties represent key factor that affect pavement structural design. As noted by [16], all pavements derive their ultimate support from the underlying subgrade: therefore, knowledge of basic soil mechanics is essential.

Soil is a gathering or deposit of earth material, derived naturally from the breakdown of rocks or decay of undergrowth that can be excavated readily with power equipment in the field or disintegrated by gentle reflex means in the laboratory. The supporting soil below pavement and its special under course is called sub grade. Without interruption soil beneath the pavement is called natural sub grade. Compacted sub grade is the soil compacted by inhibited movement of heavy compactors.

Subgrade soils have desirable properties like, strength permanency, incompressibility, stability, bearing capacity, low change in volume during moisture content variation or low shrinking and/or swelling due to moisture contents, in order to with stands stresses due to traffic loads. Moisture contents of subgrade soil can be influenced by a number of things such as: poor drainage, ground water table elevation, capillary rise/saturation, infiltration or pavement porosity (cracks in pavements).

Capillary rises or saturations in soils are the movement of pore water from lower elevation to the higher elevation through the soil particles by the hydraulic gradients acting across the pore air/pore water interface. Capillary rise / saturation are highly dependent on the hydraulic conductivity of soil, type of soil (soil constituent), density and height of capillary. [6] Proposed and empirical relationship for hydraulic conductivity for various type of soil. Saturated hydraulic conductivity for predicting the rate of capillary rise in a one dimensional column of soil was formulated [15]. The development and improvement of new or existing experimental, analytical, and numerical techniques for measuring or modeling the height, storage capacity, and rate of capillary rise and the dependence of each on the relevant soil and pore water properties has historically been an active subject of basic and applied soils. Research [9, 11, 8, 14]. Therefore, Jimma to Bedele road (study area) there are many things that cause capillary rise/saturation. For instance poor drainage, weather condition, low topography, a lot of cutting section and marshland besides them and due to infiltration (penetration) of water into asphalt layer.

Based on the desirable properties of subgrade soils, identifying the effect of capillary rise/ saturation on properties of subgrade is very essential. Effects of moisture variation on the strength properties of subgrade soil Research [1, 2]. Correlation between physical properties and CBR values of subgrade soil with and without soaking [4, 10, 12]. Effects of soaking on the top and bottom CBR value of a sub-base material [7]. Regression-based models for estimating soaking and un-soaking CBR values for fine-grained subgrade soils [13] These identifications are important while designing the subgrade foundation for highway in area which capillary rise may one of cause of failures. So, identifying of the effects capillary rise with the effects of another factor are crucial impact on the highway contraction industry in terms of design, economies, maintenance, service and other. Considering the above, it has been proposed in this thesis to study the variation in strength properties of subgrade soil at particular area or feasible station on the study area due to variation of moisture contents (capillary rise/ saturation) with respect to different density levels and conclude the general aspects of moisture conditions on determination of different strength parameters, so as to achieve the most viable and economical pavement design.

1.2. Statement of the Problem

A detailed and comprehensive geotechnical investigation is an essential requirement for the Design and construction of civil engineering projects. The proper design of civil engineering structures like foundation of buildings, retaining walls, high ways, etc. requires adequate knowledge of sub surface conditions at the sites of the proposed structures. Many damages to buildings, roads and other structures founded on soils are mainly due to the lack of proper investigation of substructure condition [5].

Investigations of the underground conditions at a site are pre-requisite to the economical design of the substructure elements. It is also necessary to obtain sufficient information for feasibility and economic studies for a proposed project [3].

In roads the effects of capillary rise saturation on the properties of subgrade soil is increasing the soil water contents or saturation of the subgrade soil, in its ultimate height of capillary through the hydraulic conductivity (rate of capillary rise) of the soil. This can change the mechanical properties of subgrade material leading to pavement weakness. Decreasing subgrade strength, stiffness and capability. This incremental in subgrade moisture contents can loses the existing subgrade strength permanency, stability, incompressibility and stiffness etc. The capillary rise/saturation can affect subgrade soil water contents (SWC) at which the maximum dry density (MDD) was attained during the compaction. So that, This change in moisture content can reduce the CBR. The reduction in subgrade bearing capacity results decreasing the strength to withstands stresses due to traffic loads, longitudinal rutting in the wheel path and associated cracking and ultimate pavement failure.

1.3. Objective

1.3.1. General Objective

To evaluate the effect of capillary rise (capillary saturation) on properties of subgrade soil

1.3.2. Specific Objectives

1) To measure the height of capillary rise saturation in subgrade soil.
2) To evaluate rate of capillary rise (hydraulic conductivity or coefficient of permeability) of a subgrade soil.
3) To evaluate the effect of capillary rise saturation on the strength of subgrade soil.

1.4. Research Questions

The research questions that this study will attempt to clarify; are as follows:

1. What is the height of capillary rise in subgrade soil?
2. How to measure the rate of capillary rise (hydraulic conductivity or coefficient of permeability) of subgrade soil?
3. What are the effects of capillary rise Saturation on the strength of subgrade soil?

1.5. Scope and Limitation of the Study

Studies on the properties of subgrade soil are very wide and vast. Because of this the properties of subgrade soil can be interpreted and described in a lot manner. This study or researching will focus on effects of capillary saturation on the properties of subgrade soil. Among the properties of subgrade soil affected by capillary saturation basically focus on the strength properties of subgrade soil. Based on the descriptive area that enhance the rise of capillary four pits of different sample are taken through purposive sampling.

The following main tests and analysis of the result are conducted in this research; index properties of subgrade soil, height of capillary rise through the soil, rate of capillary rise through the soil at different level density and the variation of moisture by capillary saturation that increase the subgrade water content and effects on the density and bearing capacity (strength) of subgrade soil. This can be described in terms of CBR and the sequences of CBR reduction are observed.

The variation of moisture or saturation in subgrade soil can be influenced by a number of things such as drainage, ground water table elevation, capillary rise/ saturation, infiltration or pavement porosity (cracks in pavement). Among these studies will be focus on the saturation due to capillary rise in a subgrade soil. The depth of ground water and its fluctuation at different season are not considered due to lack of economies and time and these tests needs deep pit by machineries and longtime observation. Only capillary rise/saturation through the soil is taken for further incremental of moisture.

1.6. Organization of the Study

The study consists of four chapters as described bellows; chapter one gives a brief introduction on subgrade soil and its desirable properties and introduction on capillary rise and cause of capillary rise in a subgrade soil. Chapter two deals with methodologies and experimental investigation and chapter three discussed about analysis of result and discussion on the investigation and at the last conclusion and recommendation of the research summarized in chapter four.

2. Methodology

2.1. Study Area

The research will be conducted in Jimma to Bedele road, which covers 138 km in Oromia region of Ethiopia, located in south west Oromia which connects Jimma town to Bedele town and un intermediate Woredas town like Yabbu, Agaro, Toba, Dembi, Yembero, Gachi, Bedele and small villages between them.

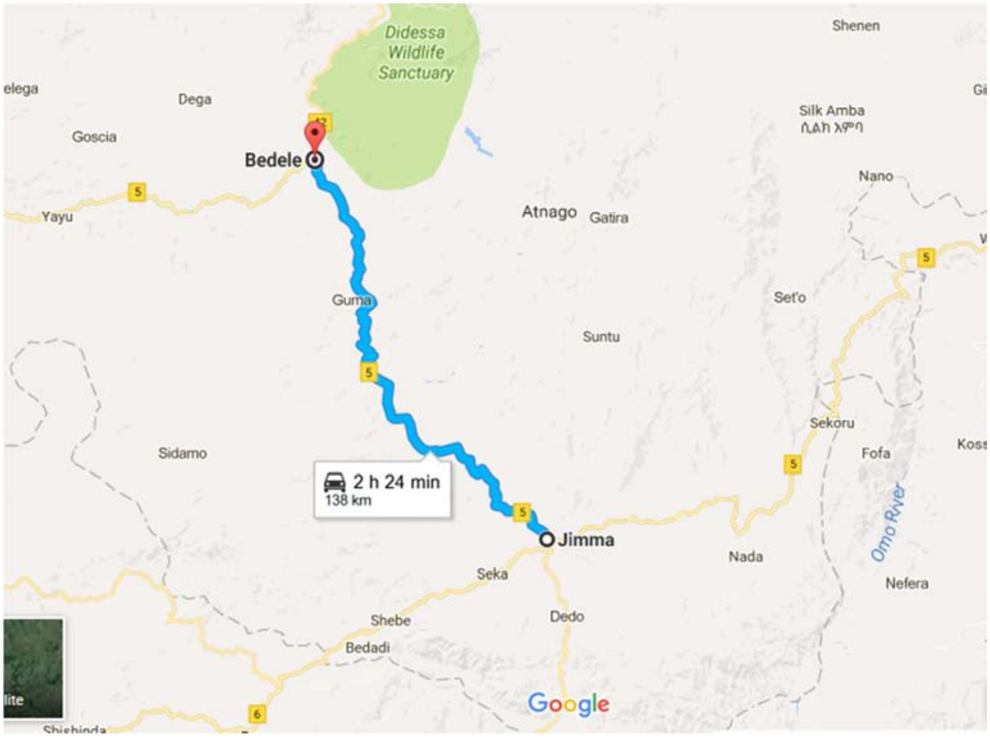

__Figure 1.__ Google map location of Jimma to Bedele roads.

2.2. Study Design

2.2.1. Soil (Test) Samples

Along the study stretch there are 4 soil samples were collected with appropriate sampling techniques for various testing condition. The soil sample places are listed below:
Soil sample 1: (Yembero), Soil sample 2: (Dembi), Soil sample 3: (Toba) and Soil sample 4: (Agaro)

2.2.2. Experimental Design

Effects of capillary rise/saturation on some properties of subgrade soil by experimental study or researching. This experimental study investigates index properties, height of capillary rise through subgrade soil, rate of capillary rise (hydraulic conductivity) of subgrade soil and the moisture content variation due to capillary saturation. Moisture content variation leads to incremental of subgrade water contents and effects on properties of subgrade soil. These studies will clearly interoperates the effects of moisture variation from optimum moisture on the bearing capacity of subgrade soil due to capillary saturation by testing the CBR values at different degree of saturation and percentage changed.

2.3. Study Area Population

The study area populations to be considered to complete this research are index properties of subgrade soil; which are liquid limit, plastic limit, plastic index, free swell index and specific gravity can be tested. Particle size distribution through sieve analysis (dry or wet) can be done for soil classification, so that the tested soil can be identified in percentage (empirically) to gravel, sand and silt /clay depend on their size. The grain size at which the subgrade soil can 10, 30 and 60 percent finer can investigated experimentally, Which can indicate the probable flow of water due to capillary through them. Besides the coefficient of uniformity and curvature evaluated to fix weather the soil are well-graded, gap-graded, uniformly graded and poorly graded.

The modified proctor test had been done to attain the maximum dry density with respect to optimum moisture contents. Taking this proctor result as bench mark we can directly go to CBR test for identification of the strength of subgrade soil. This can be conducting from OMC (EMC) and dry density which is un soaking condition (day 0) which is not affected by capillary saturation to different day of soaking (capillary saturation), i.e from un soaked (day 0) to soaked (day 4)

Initially experiments were conducted to find out different properties of subgrade soil such as index properties, grain size distribution, specific gravity, free swell index, rate of capillary rise (hydraulic conductivity) and height of capillary. Later on heavy compaction tests were conducted to find out the optimum moisture content & corresponding maximum dry density. Then CBR tests were made at different moisture contents including OMC and analysis made to investigate the variation of CBR with respect to different days of soaking (capillary saturation), i.e. from un soaked (day 0) to soaked (day 4). The variations were also made with regard to moisture content at different layers along with different positions (Top, Center and Bottom positions) and also the variations of moisture content with respect to different days of soaking were observed.

2.4. Sampling Frame

Soil sample from the study area or case study can be taken based on purposive sampling on the descriptive area on the existing road listed below, that can enhance our research finding, sag area or lowland area and at cuts of natural ground level, besides to sag area the probable marsh land exist along the cross section of the road without embankment provision and poor (unfunctional) drainage system exist and feasible rutting of wheel path with associated crack exist and ultimate pavement failure exists.

2.5. Sample Size and Sampling Procedures

Purposive sampling techniques are used for preparation of subgrade soil sample as described in frame sampling. Accordingly four pits of different sample that can enhance the effects of capillary saturation are taken. The bulk soil samples are taken with proper sampling techniques, equipment and methodologies.

1) The Subgrade soil samples are taken from the road 1m far from the shoulder at adequate depth to get subgrade material.
2) Sample taken can be placed inside the thick plastic bags or gauges in order to prevent moisture variation and other adverse change on soil properties.
3) From each pit at least 50kg of subgrade material are taken, which is sufficient for each variable test needed and some the materials like any rocks and other mixed materials are removed.
4) After completion of sampling they can fill the pits sample by extra filler materials and then go to experimental investigation.

2.6. Study Variables

2.6.1. Dependent Variable

Effects of capillary rise/saturation on the strength properties of subgrade soil

2.6.2. Independent Variable

1) Index properties of subgrade soils.
2) Height of capillary rise/saturation.
3) Rate of capillary rise (Hydraulic conductivity).
4) Optimum Moisture Content (OMC) and Maximum Dry Density (MDD).
5) Bearing capacity of subgrade soil through (CBR) at different level of saturation (time of soaking).

2.7. Experimental Investigations

Soils are classified with different engineering properties which affect the behavior of soil under different conditions. These properties are described briefly here.

2.7.1. Attreberg Limits

(i) Liquid Limit

The liquid limit (LL) is the water content at which a soil changes from plastic to liquid behavior. At this limit, the soil possesses a small value of shear strength, losing its ability to flow as a liquid. In other words, the liquid limit is the minimum moisture content at which the soil tends to flow as a liquid.

Prepare un air dried soil mass that pass on a sieve No. 40 (425μm Sieve) were prepared and 250g of soil passing this sieve taken per station. This quantity of soil is sufficient for both liquid and plastic limits. Mix thoroughly with distilled water to form a uniform paste and place the mixed soil in a storage dish, cover it to prevent loss of moisture, allow to stand for at least 16h and then get water content using the multipoint liquid limit methods. The liquid limit is identified in the laboratory as that water content at which the groove cut into the soil pat in standard liquid limit device requires 25 blows (drops) from a height of 1cm to close along a distance of 13mm (Casagrande method).

Plot the relation-ship between the water content, W, and the corresponding number of drops, N, of the cup on a semi-logarithmic graph with the water content as ordinate on the arithmetic scale, and the number of drops as abscissas on the logarithmic scale. Draw the best straight line through the plotted points, On the plot (known as flow curve), take the water content corresponding to the intersection of the line with the 25-drop abscissa as a liquid limit of the soil.

(ii) Plastic Limit

Plastic limit (PL) is the arbitrary limit of water content at which the soil tends to pass from the plastic state to the semi-solid state of consistency. Thus, this is the minimum water content, at which the change in shape of the soil is accompanied by visible cracks, i.e., when worked upon, the soil crumbles.

(iii) Plasticity Index

Plasticity Index (PI) is the range of water content within which the soil exhibits plastic properties, that is, it is the difference between liquid and plastic limits. If the PL is greater than the LL, report the soil as non-plastic, NP

2.7.2. Differential Free Swell

Free Swell Index is the increase in volume of a soil, without any external constraints, on submergence in water.

$$\text{Free swell index} = \frac{V_D - V_K}{V_K} x100\% \tag{1}$$

Where, V_D =volume of soil specimen read from the graduated cylinder containing distilled water.

V_K =volume of soil specimen read from the graduated cylinder containing kerosene.

2.7.3. Specific Gravity

Specific gravity of soil solids is defined as the ratio of unit weight of solids to the unit weight of water at the standard temperature (4°C). Specific gravity of soil may be defined as the ratio of the unit mass of solids (mass of solids divided by volume of solids) in the soil to the unit mass of water. In equation form,

$$G_s = \frac{M_s}{V_s \rho_w} \tag{2}$$

Where, G_s=specific gravity of soil

M_S=mass of solid, g

Vs=volume of solid, cm^3

ρ_w=unit mass of water (1g/cm^3)

The specific gravity of most natural soil falls in the general range of 2.60-2.80; the smaller the values are for coarse-grained soil. The specific gravity is essential in relation to other soil tests. It is used when calculating porosity and void ratio and is particularly important when compaction and consolidation properties are being investigated and preparing a soil sample of 20g soil passing 2mm sieve size or 100g of soil passing 4.75mm sieve size using ASTM recommendation.

2.7.4. Coefficient of Permeability (Hydraulic Conductivity)

The hydraulic conductivity (K) is a measure of the ease with which water flows through Permeable materials. It is inversely proportional to the viscosity of water which decreases with increasing temperature. The falling-head method, covered in this part, may be used to determine the permeability of both fine-grained soils (such as silts and clays) and coarse-grained soils or granular soils.

The coefficient of permeability (hydraulic conductivity) can be computed using the equation.

$$k = R_t \left(2.303 \frac{aL}{At} \log\left(\frac{h_0}{h_1} \right) \right) \tag{3}$$

Where, k=Coefficient of permeability, cm/s

a=cross-sectional area of standpipe, cm^2

L=length of the specimen, cm

A=cross-sectional area of soil specimen, cm^2

h_0=hydraulic head at beginning of test, cm

h_1=hydraulic head at end of test, cm

t=total time for water in burette to drop from h_0 to h_1, s

R_t=is the temperature correction factor for the viscosity of water

$$R_t=\eta_T/\eta_{20}°C \tag{4}$$

Where η_T=Viscosity of water at temperature T.

η_{20}°C =Viscosity of water at 20°C.

Since the hydraulic conductivity of soil depends on several factors, among that fluid viscosity, pore-size distribution, grain size distribution and viscosity are the major one, so that mostly the permeability of the soil depend on the void ratio of the soil. Based on this it can be obtained rate of capillary or coefficient of permeability of soil with different density, to achieve this it can combine different empirical formula which is;

$$\gamma_d = \frac{\gamma}{1+\omega}\ ,\ \gamma_d = \frac{G_s \gamma_w}{1+e} \text{and } \frac{k_1}{k_2} = \frac{\left(\frac{e_1^3}{1+e_1}\right)}{\left(\frac{e_2^3}{1+e_2}\right)} \tag{5}$$

Then placing the same specimen in a sink which water is about some height above the cover and soaked at least for 24hrs. The sample will be saturated until minimum amount of entrapped air, discharge in equivalent to discharge out through the soil specimen or fully saturation. Then connect the plastic tube on valves in the tops specimen (mold) at the same time closing the bottom (outlet) valves of specimen (mold) and then reading the rise water through the tube. When water in the plastic inlet tube on the top of the mold reaches equilibrium with water in the sink (allowing for capillary rise in the tube)

2.7.5. Particle Size Distribution

A soil consists of particles of various shapes, sizes and quantity. Grain-size (particle size) analysis is a method of separation of soils in to different fractions based on particle size as per test method ASTM D422. It expresses quantitatively the proportions, by mass, of varies sizes of particles present in a soil. It is shown graphically on a particle size distribution curve.

Sieve analysis determine the grain size distribution curve of soil samples by passing them through a stack of sieves of decreasing mush opening sizes and by measuring the weight retained on each sieve. Soil with grain size larger than 4.75mm are taken as Gravel, those grain size between 2mm and 0.75mm as Sand and those less than 0.75mm are taken as combination of silt and clay. The data are recorded in each sieve size and computing percentage of finer. Grain size distribution curve can be obtained by plotting grain size as abscissa on logarithmic scale versus percentage fines as ordinate on arithmetic scale. The corresponding grain size 10% (D_{10}), 30% (D_{30}) and 60% (D_{60}) finer in terms of weight can be obtained. It can be obtained by using semi logarithmic interpolation between the data points of the grain size distribution curve. Coefficient of uniformity (C_u) and curvature (C_c)

$$C_u = \frac{D_{60}}{D_{10}} \quad C_c = \frac{(D_{30})^2}{D_{60} x D_{10}} \tag{6}$$

The diameter corresponding to 10% finer in the distribution curve are indicate particularly or important in regulating the flow of water through soils. The higher this value, the coarser the soil and the better the drainage characteristics.

A well graded soil has a uniformity coefficient greater than about 4 for gravels and 6 for sands. A soil that has a uniformity coefficient of less than 4 contains particles of uniform size. The minimum value of Cu is 1 and corresponds to a collection of particles of the same size.

Coefficient of curvature, also called coefficient of gradation or coefficient of concavity (C_c or sometimes C_z). The coefficient of curvature is between 1 and 3 for well-graded soils. Gap-graded soils have values outside this range.

a. Wet sieve Analysis

Wet sieve analysis is for soil containing a substantial of fine particles. For sample finer particles governing it is more convincing to do wet analysis. About 1kg of soil was taken and it was washed thoroughly with water on 75 micron sieve, soil retained on sieve was dried and weighed and used for sieve analysis. These dried soils were passed through stack of sieves like 4.75mm, 2.36mm, 1.18mm, 600µm, 300µm, 150µm, 0.75µm.

b. Dry sieve Analysis

About 2 kg of soil was taken and sieved with different sieve size and soil retained on each sieve size was recorded for the sake analysis.

2.7.6. Modified Proctor Test

Compaction means to press soil particles tightly together by expelling air from void spaces between the particles. Compaction increase soil unit weight, there by producing three important effects: (1) an increase in shear strength, (2) a decrease in future settlement, and (3) a decrease in permeability. These three changes in soil characteristics are beneficial for some types of earth construction, such as highway and other.

The Proctor compaction test is a laboratory method of experimentally determining the optimal moisture content at which a given soil type will become most dense and achieve its maximum dry density. The term Proctor is in honor of R. R. Proctor, who in 1933 showed that the dry density of a soil for a given comp active effort depends on the amount of water the soil contains during soil compaction. His original test is most commonly referred to as the standard Proctor compaction test; later on, his test was updated to create the modified Proctor compaction test.

Modified proctor compaction test follow the same procedure as the standard compaction test, but use the heavier rammer (44.5kN instead of 24.4kN) with larger height of drop (457 mm instead of 305 mm). Also compact the soil in 5layers (instead of 3) by applying 56 blows per layer (instead of 25). As per ASTM D 1558, preparing a soil sample of fraction passing 4.75mm sieve of amount at least 4.3kg for computing of moist- unit weight and moisture content in each trial.

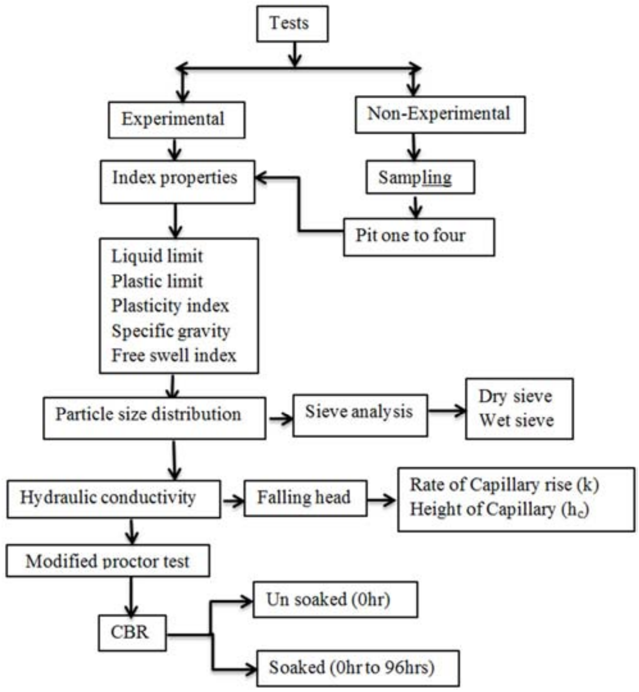

Figure 2. *Flow chart of experimental investigation.*

The moisture-unit weight relationship for the soil sample being tested can be analyzed by plotting a graph with moisture contents along the abscissa and corresponding dry unit weight along the ordinate. The moisture content and dry unit weight corresponding to the peak of the plotted curve are termed "optimum moisture content" and "maximum dry unit weight," respectively.

2.7.7. California Bearing Ratio Test

The CBR is a measure of resistance of a material to penetration of standard plunger under controlled density and moisture conditions. The test procedure should be strictly adhered if high degree of reproducibility is desired. The CBR test may be conducted in re-molded or undisturbed specimens in the laboratory. The test has been extensively investigated for field correlation of flexible pavement thickness requirement.

Briefly, the test consists of causing a cylindrical plunger of 50mm diameter to penetrate a pavement component material at 1.25mm/minute. The loads, for 2.54mm and 5.08mm are recorded. This load is expressed as a percentage of standard load value at a respective deformation level to obtain CBR value and Molding the soil sample into standard molds keeping its moisture content and dry density exactly same as its optimum moisture content and proctor density respectively. Determination of CBR strength of the respective soil samples in molds using the CBR instrument. Soil sample is tested for its CBR strength after being soaked in water for 1 day, 2 days, 3 days and 4 days. Unsoaked CBR is also determined for each sample.

Generally the experimental investigation of our study can be described in the flow chart of listed bellows.

3. Results and Discussions

3.1. Soil Sample 1

3.1.1. Index Properties

In this soil the index properties such as Liquid limit, Plastic limit, Plasticity Index, Free swell index and specific gravity value are used as an initial input for rest tests result and analysis, are presented in a table 1. follows;

Table 1. *Index properties of soil sample 1.*

Index properties	Experimental value
Liquid Limit	36.86%
Plastic Limit	18.25%
Plasticity Index	18.61%
Specific Gravity	2.65
Free Swell Index	Non expansive

The above result indicated in the table 1 shows that this soil is not further affected by shrinking and/or swelling by moisture variation based on the results of free swell index indicates non expansive and stays under plastic characteristics within the above range value shown.

3.1.2. Particle Size Distribution

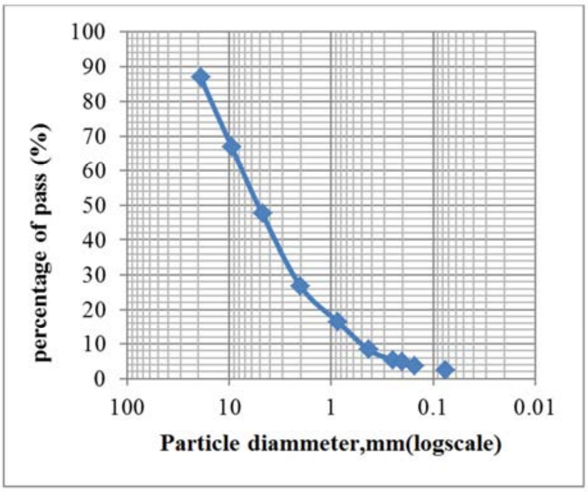

Figure 3. *Particle size distribution curve of soil sample 1.*

The sieve analysis test is done to determine the grain size distribution of the soil sample and then plotting the grain size as abscissa on logarithmic scale versus percentage of fines as ordinate on arithmetic scale.

The above figure 3. shows that soil with grain size larger or equal to 4.75mm which Gravel, takes 39.4% in a soil, soil with grain size between 2mm and 0.75mm as Sand, takes 52.6% in a soil and soil with grain size less than 0.75mm are taken as combination of silt and clays, takes 8% in a soil.

The grain size corresponding to10%, 30%, and 60% by weight finer can be obtained by using semi logarithmic interpolation between the data points of the grain size distribution curve. Therefore D_{10}, D_{30} and D_{60} values are 0.52mm, 2.43mm and 7.79mm respectively. The diameter size corresponding to 10% finer in the distribution indicate 0.52mm, this implies that there was probable flow of water through the soil.

The coefficient of uniformity ($C_u = D_{60}/D_{10}$) is 14.98 which is greater than 4 for gravel and less than 6 for sand, particle size are non- uniform and coefficient of curvature or gradation ($C_c = D_{30}^2 / D_{60} * D_{10}$) is 1.46 which is between the range of 1 and 3. This implies this subgrade soil is well graded soil.

3.1.3. Modified Proctor Compaction Test

Modified proctor compaction test has been done for this soil sample to obtain the maximum dry density and optimum moisture contents of the soil.

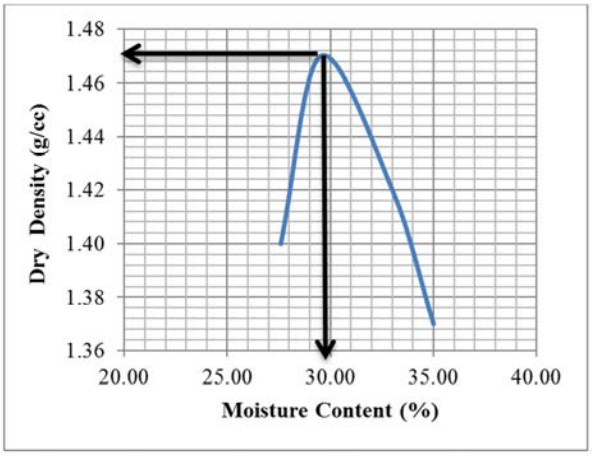

Figure 4. *Modified proctor compaction test result of soil sample 1.*

The above figure 4. shows that graph of moisture content and maximum dry density. The purpose of drawing the curve shown in the figure is to extract the Maximum (peak) Dry Density (MDD) and Optimum Moisture Content (OMC). From the above figure (OMC=29.62% and $\gamma_D = 1.47 g/cm^3$)

3.1.4. Falling Head Permeability Test

The falling-head method, covered in this part, may be used to determine the permeability of both fine-grained soils (such as silts and clays) and course- grained soils or granular soils.

The specimens of different density or voids ratio are prepared for testing the flows water through them or permeability. Accordingly the specimen data which is ready for testing are shown in the table 2. bellows:

A. Specimen data

Table 2. *Specimen data for falling head test of soil sample 1.*

Specimen Mass (M) (kg)	**0.845**
Specimen Height, L (cm)	11.5
Specimen diameter, D (cm)	10.16
volume of specimen (V) (cm^3)	931.87
Bulk density ($\gamma = M/V$)(g/cm^3)	0.91
Water Content (w) (%)	3.96
Dry density ($\gamma_{dry} = \frac{\gamma}{1+w}$) (g/cm^3)	0.87
Specific gravity of soil, G_s	2.65
Initial void ratio ($e = \frac{G_S\gamma_w}{\gamma_{dry}} - 1$) $e = \frac{G_S\gamma_w}{\gamma_{dry}} - 1$	2.04

The specimen placed in a sink which water is about 2 cm above the cover and soaked at least for 24 hours. The sample will be saturated until minimum amount of entrapped air, discharge in equivalent to discharge out (fully saturated). When water in the plastic inlet tube on the top of the mold reaches equilibrium with water in the sink (allowing for capillary rise in the tube)

Height of capillary from the mold (H_C) >=4.3cm

Height of capillary from the top of the water (H_C) >=2cm

This result can indicate that at this density there is water flow through the soil due to capillary in its height determined above. This can leads to increasing Subgrade Water Contents or Saturation which can affects mechanical properties like bearing capacity, strength permanency, stability and incompressibility of the soil.

B. Falling head test

Figure 5. *Falling head permeability (rate of capillary) test determination.*

The result of rate of capillary rise or coefficient of permeability can be determined at several densities or void ratio of the subgrade soil can be obtained. Using the same specimen data indicated before in table 2. and Cross-sectional area of stand pipe, a=1.664cm, Length of soil specimen in a permeameter (L=11.5cm) and Cross-sectional area of soil specimen (A=81.073cm2). The rate of capillary rise at initial void ratio of (e=2.04) or dry density (γ_{dry}) of 0.87 g/cm^3 indicated in above table 2 is shown in the table blows: using the equation $k = 2.303\frac{aL}{At}\log_{10}\left(\frac{h_1}{h_2}\right)$ indicated in review equation (3) and multiplying by temperature correction factor ($R_t = \frac{\mu_T}{\mu_{20}}$) in equation (4).

Table 3. *Rate of capillary rise at initial void ratio (e=2.04) of soil sample 1.*

Trial	**1**	**2**
Head, h_o (cm)	83.6	83.8
Head, h_1 (cm)	35.6	37.7
Time, t (sec)	909.6	911.4
Temperature, T (°C)	27	26
Permeability at T°C, K_T	0.000220946	0.000206903
R_t for Temperature.	0.854477489	0.872404144
Permeability at 20°C, K_{20}	0.000188794	0.000180503
Average K_{20} (cm/s)	0.000184648	

The result of rate of capillary rise gained above indicate that, in a soil there is a flow water with the above rate value within specified density or voids until to reach it height of capillary. Depend up on these values which is rate capillary at dry density of 0.87 g/cm^3 , we can determine the rate of capillary through the soil at different values of density or voids, starting from this initial value up to the Maximum Dry Density (MDD) obtained during the compaction ($1.47\ g/cm^3$) using the equation $\gamma_d = \frac{G_s\gamma_w}{1+e}$ and equation (5) in a review which relate the value of k with void ratio or density.

The rate capillary rises with respect to several densities or void ratio of the sample are shown in the table below:

Table 4. *Rate of capillary at different voids/density of soil sample 1.*

Dry density (γ_{dry})	**Void ratio (e)**	**Permeability (K)(cm/s)**
0.87	2.046	0.0001846485
1.32	1.003	0.0000674850
1.40	0.898	0.0000570470
1.43	0.858	0.0000532807
1.47	0.803	0.0000480255

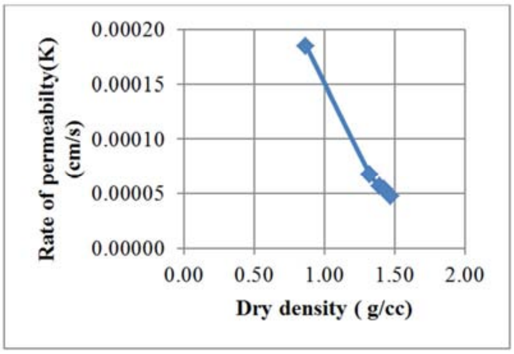

Figure 6. *Relationship between the densities and permeability of soil sample 1.*

The result shown in a graph 6 and in a table 4 indicates that the propensity of a soil to allow the flow of water through the soil. In the first two densities (1.32 to 0.87) rate flows is high due to high void spaces and saturation. And from densities (MDD to 1.40) the rates of flows is slow due to decreasing in voids but the result indicates that at MDD there is still probable flow water which can change Subgrade Water Content (SWC) or (OMC) and further incremental of saturation due to capillary. This can effect on the subgrade strength or strength permanency and other. The variation of strength due to capillary saturation has been tested by CBR at different time of soaking.

3.1.5. California Bearing Ratio Test Results

The CBR test at different level of saturation (moisture content) due to capillary including OMC and different level compaction (10, 30 and 65 blows) are investigated. The analysis are made to investigate the variation of CBR with respect to different type of soaking, which is from un soaked (day 0) to soaked (day 4) can be observed. Test conducted under OMC (29.62%) and MDD (1.47g/cc).

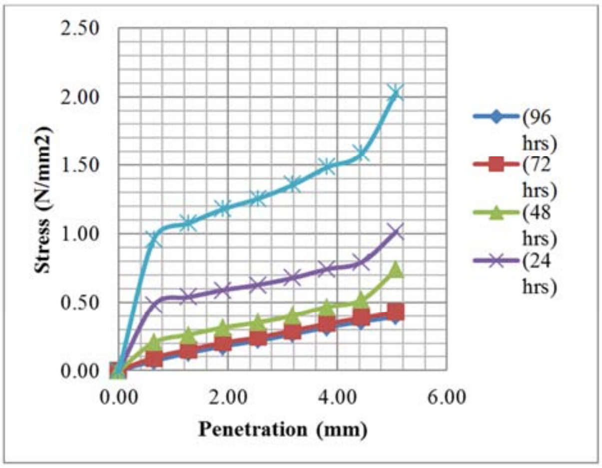

Figure 7. Stress vs penetration graph for soil sample 1 for soaked (0hr, 24hrs, 48hrs, 72hrs and 96hrs) condition.

The result shown in the above graph 7 observes that the soil can reduce the ability to withstand the stress as the saturation of the soil increasing. The CBR value or bearing capacity of subgrade soil decreasing.

3.1.6. Variation of CBR with Time of Soaking

The variation of CBR with respect to time of soaking or saturation due to capillary can be shown in the table below:

Table 5. Variation of CBR with time of soaking for soil sample 1.

Variation of CBR with time of soaking										
Time of soaking in hours										
Time	0Hr		24Hrs		48Hrs		72Hrs		96Hrs	
Pen (mm)	2.54	5.08	2.54	5.08	2.54	5.08	2.54	5.08	2.54	5.08
CBR (%)	18.21	19.65	9.1	9.83	5.1	7.16	3.49	4.1	3.16	3.82

The CBR values decreasing with time of saturation increasing but sequence of decreasing are rapid in the first three days saturation and slowly in the last one day of saturation as indicated in table 5 and figure 8. The moisture of subgrade soil increasing from OMC (at peak dry density obtained). This variation in moisture can lead subgrade soil to reduction in density, incompressibility, strength and bearing capacity.

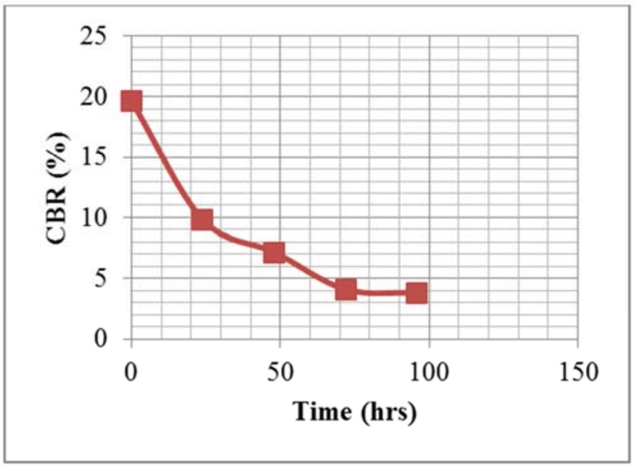

Figure 8. Variation of CBR with time of soaking for soil sample 1.

3.1.7. Moisture Variation in a Soil Sample

Take a soil sample from various part of CBR sample for determination of moisture content. The schematic diagram is given blow in a figure 9. Middle parts or around center line axis are taken, accordingly take the moisture content of a sample around the Top, Middle and Bottom are observed.

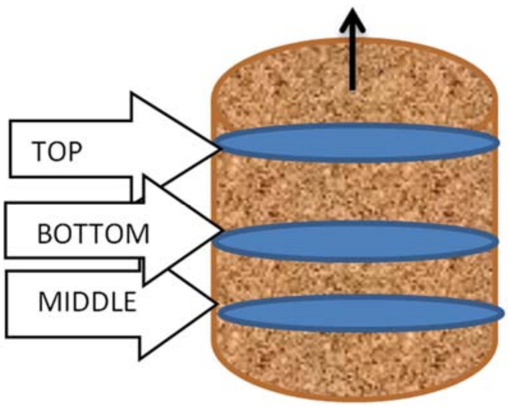

Figure 9. Schematic diagrams for moisture variation in soil sample 1.

Table 6. Moisture variation in soil sample 1 with depths and time of soaking.

Moisture variation in soil sample (%)						
Position	Axis	Time of soaking				
		0Hr	24Hrs	48Hrs	72Hrs	96Hrs
Top			17.4	17.52	18.01	18.61
Middle	Centre		13.46	13.8	14.92	15.5
Bottom			9.02	9.8	10.4	10.8

The moisture results indicated above in a table 6. is the variation of moisture in percent from OMC to the maximum time of soaking.

3.1.8. Variation of CBR with Respect to Moisture

The variation of CBR values with variation of moisture due to capillary saturation in a soil sample are shown in a figure below

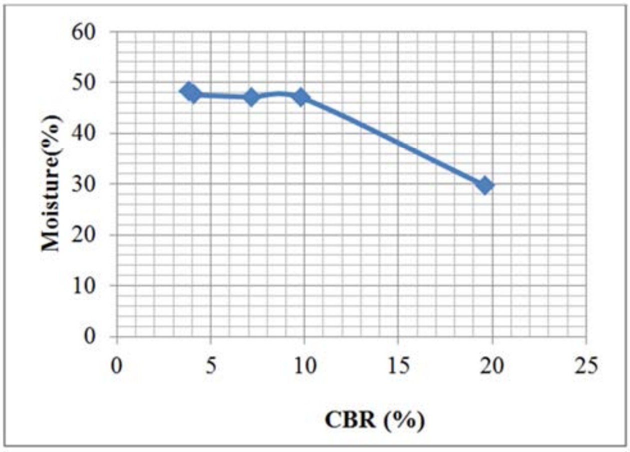

Figure 10. *Variation of CBR with moisture for soil sample1.*

The CBR values decreasing highly in the first three day of saturation due to sudden change in moisture and gradually decreasing in the last one day due to no further change in moisture content shown in table above 6.

3.2. Soil Sample 2

3.2.1. Index Properties

The soil index properties such as Liquid limit, Plastic limit, Plasticity Index, Free swell index and specific gravity value are presented as follow in a table below;

Table 7. *Index properties of soil sample 2.*

Index properties	Experimental value
Liquid Limit	49.20%
Plastic Limit	29.29%
Plasticity Index	19.91%
Specific Gravity	2.79
Free Swell Index	Non expansive

The above result indicated in the table 7. shows that this soil also is not further affected by shrinking and/or swelling by moisture variation based on the results of free swell index indicates non expansive and stays under plastic characteristics within the above range value shown.

3.2.2. Particle Size Distribution

The grain size distribution of this soil sample done by sieve analysis test and plotting the graph as shown below;

The above result shown in a figure 11 implies that in this soil sample 56% of Gravel, 42.25%of Sand and 1.75%of Silt and/or Clay are exist. The grain size corresponding to10%, 30%, and 60% by weight finer can be obtained by using semi logarithmic interpolation between the data points of the grain size distribution curve. Therefore D_{10} , D_{30} and D_{60} values are 0.83mm, 3.08mm and 7.92mm respectively. The diameter size corresponding to 10% finer in the distribution indicate 0.83mm, this implies that there was probable flow of water through the soil.

The coefficient of uniformity (C_u) are 9.54 which is greater than 4 for gravel and less than 6 for sand, particle size are non- uniform and coefficient of curvature or gradation (C_c) is 1.44 which is in the range of 1 and 3. This implies this subgrade soil is well graded soil.

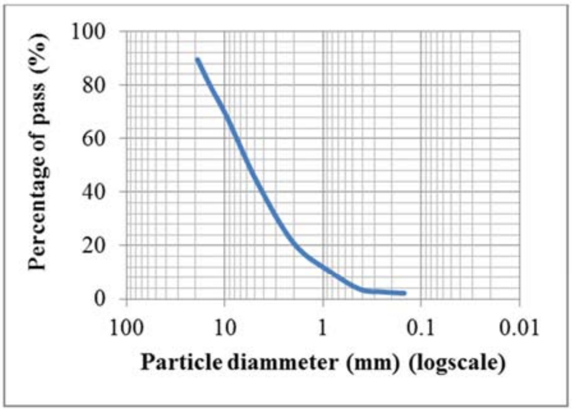

Figure 11. *Particle size distribution curve of soil sample 2.*

3.2.3. Modified Proctor Compaction Test

The results of modified proctor compaction test are represented in figure bellows:

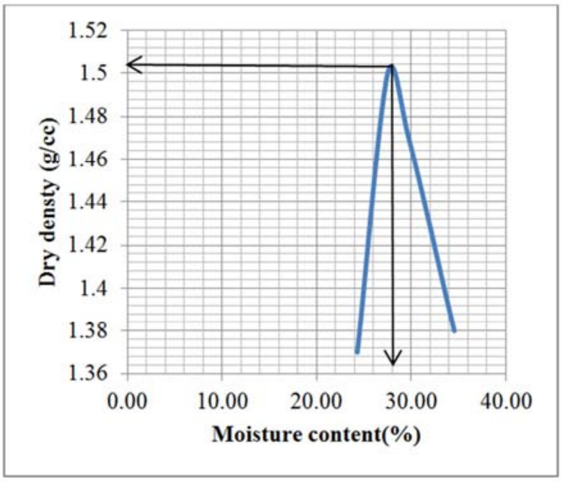

Figure 12. *Modified proctor compaction test result of soil sample 2.*

From the above figure 12, we can observes (OMC=28.00% and $\gamma_D = 1.51 g/cm^3$)

3.2.4. Falling Head Permeability Test Result

The specimens of different density or voids ratio are prepared for testing the flows water through them or permeability. Accordingly the specimen data which is ready for testing are shown in the table 8 bellows:

A. Specimen Data

The specimen placed in a sink which water is about 3 cm above the cover and soaked at least for 24 hours. The sample will be saturated until minimum amount of entrapped air, discharge in equivalent to discharge out (fully saturated).

When water in the plastic inlet tube on the top of the mold reaches equilibrium with water in the sink again it is allowing for capillary rise in the tube.

Height of capillary from the mold (H_C) >=8cm

Height of capillary from the top of the water (H_C) >=5cm.

Table 8. *Specimen data for falling head test of soil sample 2.*

Specimen Mass (M) (g)	1.08
Specimen Height, L (cm)	11.5
Specimen diameter, D (cm)	10.16
volume of specimen V (cm^3)	931.87
Bulk density, g (g/cc)	1.16
Water Content, w (%)	4.54
Dry density, (γ_d)	1.11
Specific gravity of soil, Gs	2.79
Initial void ratio, (e)	1.52

The above height of capillary is larger that of type 1 soil. This is due to grain size corresponding to 10% finer in a soil is 0.83mm which is larger than that type one as shown in particle distribution and high amount of water content exist in a soil.

B. Falling head test

The result of rate of capillary rise or coefficient of permeability can be determined at several densities or void ratio of this subgrade soil can be obtained. Using the same specimen data indicated before in table 8. The rate of capillary rise at initial void ratio of (e=1.52) or dry density (γ_{dry}) of 1.11 $^{g}/_{cm^3}$ indicated in above table 8 is shown in the table 9 blows:

Table 9. *Rate capillary rise at initial void ratio (e=1.52) of soil sample 2.*

Trial	1	2
Head, ho (cm)	85.2	88.5
Head, h1 (cm)	40.4	41.8
Time, t (sec)	420.6	420.6
Temperature, T (°C)	26.5	25
Permeability at T (°C), K_T	0.000418815	0.000421024
R_t for T	0.863356252	0.891033983
Permeability at 20°C, K_{20}	0.000361587	0.000375147
Average K_{20} (cm/s)	0.000368367	

The rate of capillary with respect to several void ratios or densities of the sample are shown in the table and figure below;

Table 10. *Rate of capillary rises at different voids /density of soil sample 2.*

Dry density (γ_D)	Void ratio (e)	Permeability (K) (cm/s)
1.11	1.514	0.0003683667
1.36	1.053	0.0002182954
1.43	0.945	0.0001855595
1.44	0.935	0.0001825375
1.51	0.755	0.0001312731

The result shown in a graph 13 and in a table 10 indicates that again there is the propensity of a soil to allow the flow of water through the soil. From densities 1.44 (g/cc) to 1.11 (g/cc) the rate flows is highly increasing due to high void spaces and saturation. And from densities (MDD to 1.44 (g/cc)) the rates of flows is slowly increasing due to decreasing in voids but the result indicates that at MDD there is still probable flow water which can change Subgrade Water Content (SWC) or (OMC) and further incremental of saturation due to capillary.

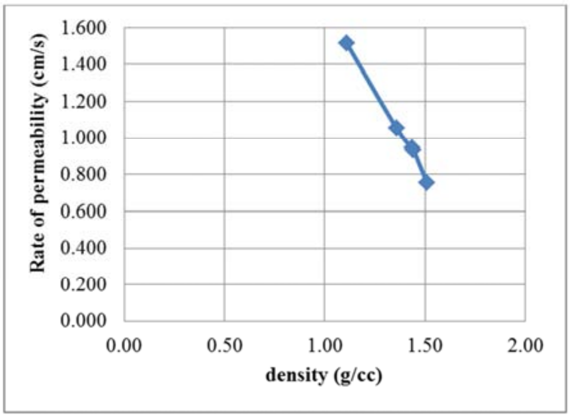

Figure 13. *Relationship between the densities and permeability of soil sample 2.*

3.2.5. California Bearing Ratio Test Results

The CBR test at different level of saturation (moisture content) due to capillary including OMC and at level compaction (56 blows) is investigated. The analysis are made to investigate the variation of CBR with respect to different type of soaking capillary saturation, which is from un soaked (day 0) to soaked (day 4) can be observed. Test conducted under OMC (28.00%) and MDD (1.51g/cc).

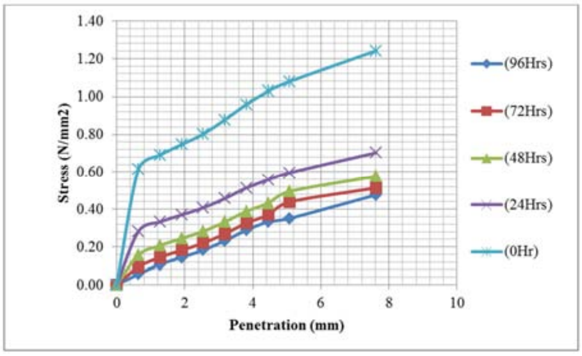

Figure 14. *Stress vs penetration graph for soil sample 2 for soaked (0hr, 24hrs, 48hrs, 72hrs and 96hrs) condition.*

The result shown in the above graph (14) observes that the soil can reducing the ability to withstands the stress as the saturation of the soil increasing. The CBR value or bearing capacity of subgrade soil decreasing.

3.2.6. Variation of CBR with Time of Soaking

The variation of CBR with respect to time of soaking or saturation due to capillary can be shown in the table below:

Table 11. *Variation of CBR with time of soaking for soil sample 2.*

Variation of CBR with time of soaking										
Time of soaking in hours										
Time	0Hr		24Hrs		48Hrs		72Hrs		96Hrs	
Pen (mm)	2.54	5.08	2.54	5.08	2.54	5.08	2.54	5.08	2.54	5.08
CBR (%)	11.65	10.43	5.92	5.76	4.1	4.79	3.19	4.25	2.64	3.4

The CBR values decreasing with time of saturation increasing but sequence of decreasing are rapid in the first days (24hrs) saturation and slowly in the last three days (48, 72 and 96hrs) of saturation as indicated in table 11 and figure 15. The moisture of subgrade soil increasing from OMC (at peak dry density obtained).

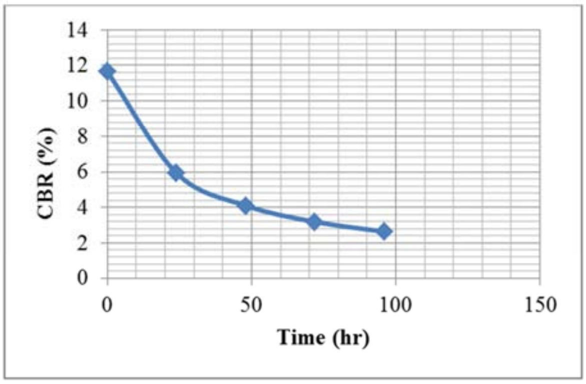

Figure 15. *Variation of CBR with time of soaking for soil sample 2.*

3.2.7. Moisture Variation in a Soil Sample

Moisture content variation in a soil sample with depths (top, middle and bottom) through the center axis shown previously in schematic diagrams and time of soaking (capillary saturation) are observed as shown in a table 12 bellows:

Table 12. *Moisture variation in type-2 soil sample 2 with depths and time of soaking.*

Moisture variation in soil sample (%)						
Position	Axis	Time of soaking				
		0Hr	24Hrs	48Hrs	72Hrs	96Hrs
Top			11.5	12.52	13.6	13.85
Middle	Centre		11	11.3	11.9	12.4
Bottom			9.02	9.6	10.4	10.7

3.2.8. Variation of CBR with Respect to Moisture

The variation of CBR values with variation of moisture due to capillary saturation in a soil sample are shown in a figure below:

The CBR values decreasing highly in the first day of saturation due to sudden change in moisture and gradually decreasing in the last three days due to no further change in moisture content shown in table above 12.

3.3. Soil Sample-3

3.3.1. Index Properties

The index properties such as Liquid limit, Plastic limit, Plasticity Index, Free swell index and specific gravity value are presented as follows;

Table 13. *Index properties of soil sample 3.*

Index properties	Experimental value
Liquid Limit	52.37%
Plastic Limit	34.19%
Plasticity Index	18.18%
Specific Gravity	2.73
Free Swell Index	Non expansive

3.3.2. Particle Size Distribution

The grain size distribution of this soil sample done by sieve analysis test and plotting the graph as shown below;

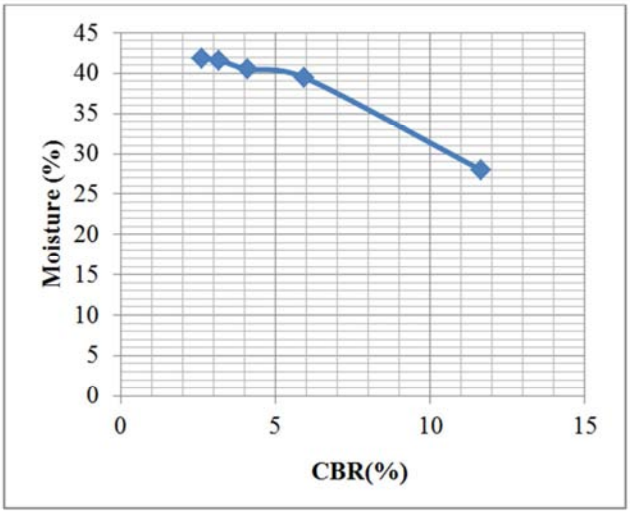

Figure 16. *Variation of CBR with moisture for soil sample 2.*

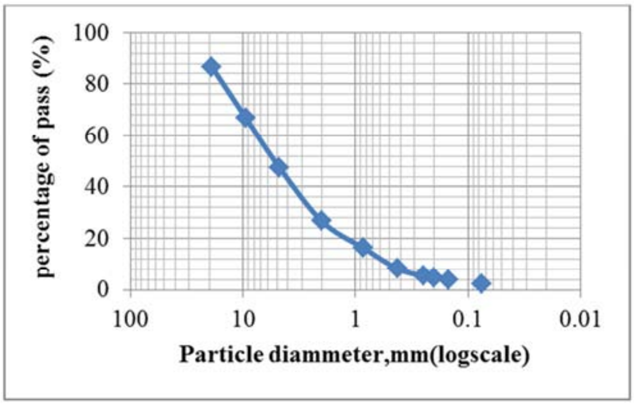

Figure 17. *Particle size distribution curve of soil sample 3.*

This implies that in this soil sample 39.4% of Gravel, 52.6%of Sand and 8% of Silt and/or Clay are exist and D_{10} , D_{30} and D_{60} values are 0.518mm, 2.431mm and 7.795mm respectively. The diameter size corresponding to 10% finer in the distribution indicate 0.518mm, this implies that there was probable flow of water through the soil.

The coefficient of uniformity (C_u) are 15.05 which is greater than 4 for gravel and less than 6 for sand, particle size are non- uniform and coefficient of curvature or gradation (C_c) is 1.46 which is between the range of 1 and 3. This implies this subgrade soil is well graded soil.

3.3.3. Modified Proctor Compaction Test

The results of modified proctor compaction test are represented in figure bellows;

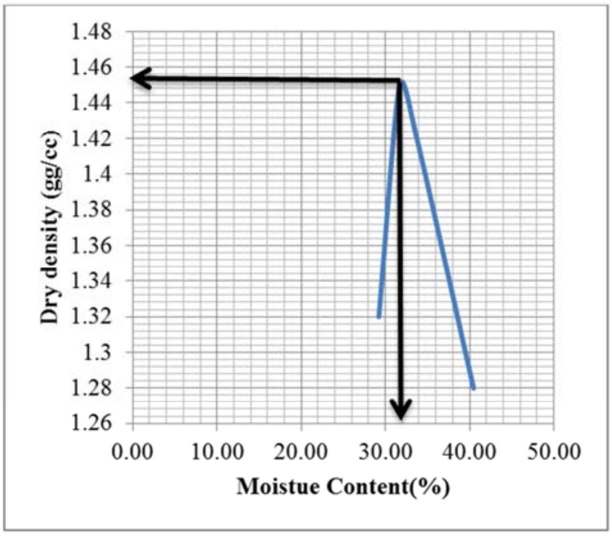

Figure 18. *Modified proctor compaction test result of soil sample 3.*

From the above figure 18, we can observes (OMC=32.00% and $\gamma_D = 1.45 g/cm^3$).

3.3.4. Falling Head Permeability Test Result

The specimens of different density or voids ratio are prepared for testing the flows water through them or permeability. Accordingly the specimen data which is ready for testing are shown in the table 14 bellows:

A. Specimen Data

Table 14. *Specimen data for falling head test of soil sample 3.*

Specimen Mass (M) (kg)	1.015
Specimen Height, L (cm)	11.5
Specimen diameter, D (cm)	10.16
volume of specimen, V (cm^3)	931.87
Bulk density, (γ) (g/cc)	1.09
Water Content, w (%)	2.86
Dry density, (γ_{dry})	1.06
Specific gravity of soil, G_s	2.73
Initial void ratio,(e)	1.58

The specimen placed in a sink which water is about 3 cm above the cover and soaked at least for 24 hours. The sample will be saturated until minimum amount of entrapped air, discharge in equivalent to discharge out (fully saturated).

When water in the plastic inlet tube on the top of the mold reaches equilibrium with water in the sink again it is allowing for capillary rise in the tube.

Height of capillary from the mold (H_C) >=6.5cm

Height of capillary from the top of the water (H_C) >=3cm

B. Falling head test

The result of rate of capillary rise or coefficient of permeability can be determined at several densities or void ratio of this subgrade soil can be obtained. Using the same specimen data indicated before in table 14. The rate of capillary rise at initial void ratio of (e=1.58) or dry density (γ_{dry}) of 1.06 g/cm^3 indicated in above table 14 is shown in the table 15 blows:

The rate of capillary rises or coefficient of permeability with respect to several void ratios or densities of the sample are shown in the table and figure below;

Table 15. *Rate of capillary rise at initial void ratio (e=1.58) of soil sample 3.*

Trial	1	2
Head, h_o (cm)	82.2	84.7
Head, h_1 (cm)	41.8	42.3
Time, t (sec)	520	627
Temperature, T (°C)	25	25
Permeability at T°C, K_T	0.000220946	0.000179849
R_t for T	0.891033983	0.891033983
Permeability at 20°C, K_{20}	0.000196871	0.000160252
Average K_{20} (cm/s)	0.000178561	

Table 16. *Rate of capillary rise at different voids/ density of soil sample 3.*

Dry density (g/cc)	Void ratio (e)	Permeability (K) (cm/s)
1.06	1.58	0.000178561
1.31	1.09	0.000105604
1.38	0.98	0.000090125
1.42	0.92	0.000082019
1.45	0.88	0.000076685

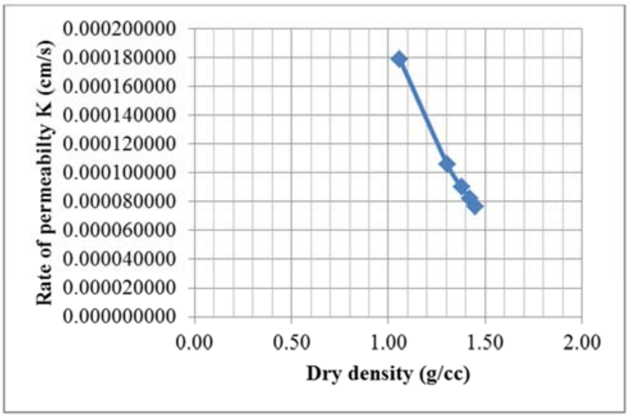

Figure 19. *Relationship between the densities and permeability of soil sample 3.*

The result shown in a graph 19 and in a table 16 indicates that again there is the propensity of a soil to allow the flow of water through the soil. From densities 1.38 (g/cc) to 1.06 (g/cc) the rate flows is highly increasing due to high void spaces and saturation. And from densities (MDD to 1.38 (g/cc)) the rates of flows is slowly increasing due to decreasing in voids but the result indicates that at MDD there is still probable flow water which can change Subgrade Water Content (SWC) or (OMC) and further incremental of saturation due to capillary.

3.3.5. California Bearing Ratio Test Results

The CBR test at different level saturation (moisture content) including OMC and at level compaction (56 blows) are investigated and the analysis are made to investigate the variation of CBR with respect to different type of soaking (capillary saturation) which is from un soaked (day 0) to soaked (day4) can be observed. Test conducted under OMC (32.00%) and MDD (1.45g/cc).

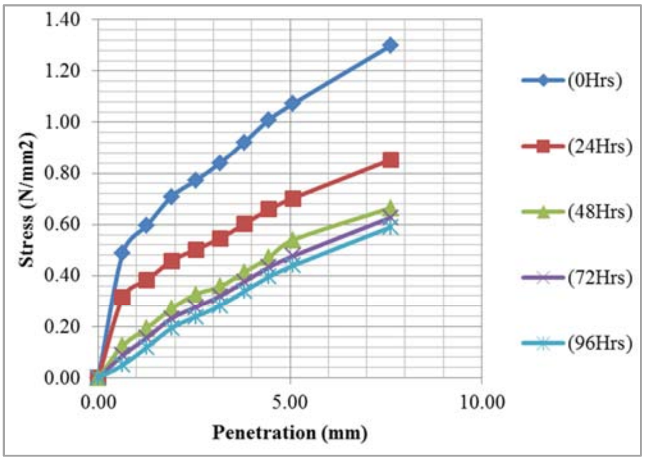

Figure 20. *Stress vs penetration graph for soil sample 3 for soaked (0hr, 24hrs, 48hrs, 72hrs and 96hrs) condition.*

3.3.6. Variation of CBR with Time of Soaking

The variation of CBR with respect to time of soaking or saturation due to capillary can be shown in the table below:

Table 17. *Variation of CBR with time of soaking for soil sample 3.*

Variation of CBR with time of soaking										
Time of soaking in hours										
Time	0Hr		24Hrs		48Hrs		72Hrs		96Hrs	
Pen (mm)	2.54	5.08	2.54	5.08	2.54	5.08	2.54	5.08	2.54	5.08
CBR (%)	11.2	10.37	7.28	6.79	4.73	5.22	4.01	4.61	3.46	4.25

The CBR values decreasing with time of saturation increasing but sequence of decreasing are rapidly in the first two days (24hrs and 48hrs) and slowly decreasing in the last two days (72hrs and 96hrs).

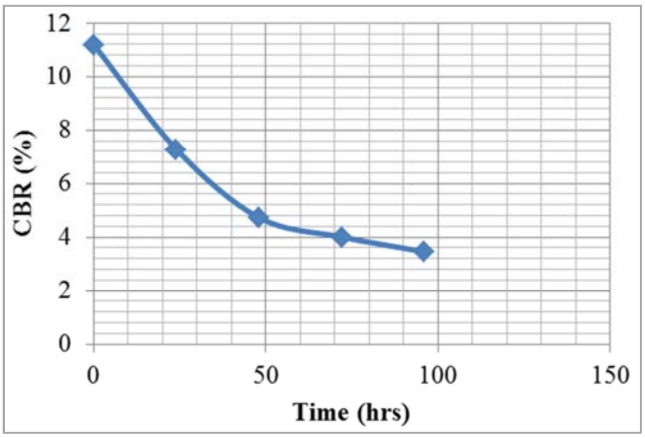

Figure 21. *Variation of CBR with time of soaking for soil sample 3.*

3.3.7. Moisture Variation in a Soil Sample

Moisture content variation in a soil sample with depths (top, middle and bottom) through the center axis shown previously in schematic diagrams and time of soaking (capillary saturation) are observed as shown bellows:

3.3.8. Variation of CBR with Respect to Moisture

The variation of CBR values with variation of moisture due to capillary saturation in a soil sample are shown in a figure below:

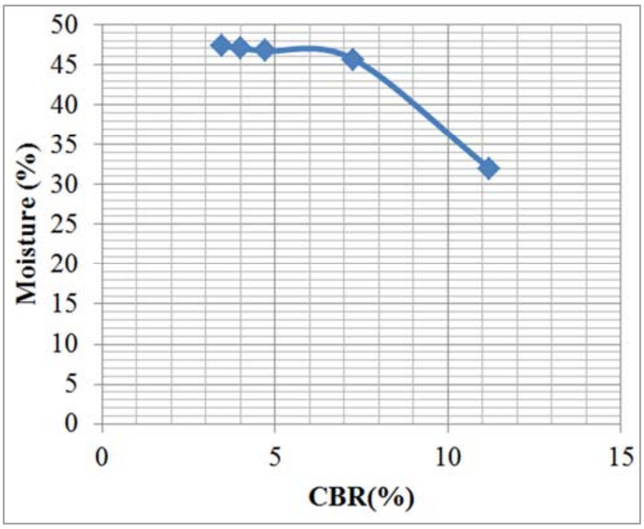

Figure 22. *Variation of CBR with moisture for soil sample 3.*

Table 18. *Moisture variation in soil sample 3 with depths and time of soaking.*

Moisture variation in soil sample (%)						
Position	Axis	Time of soaking				
		0Hr	24Hrs	48Hrs	72Hrs	96Hrs
Top			13.65	14.7	15.01	15.36
Middle	Centre		13.46	14.32	14.92	15.1
Bottom			13.42	14.01	14.4	14.7

The CBR values decreasing highly in the first two day of saturation due to sudden change in moisture and gradually decreasing in the last two days due to no further change in moisture content shown in table above 18.

3.4. Soil Sample 4

3.4.1. Index Properties

The index properties such as Liquid limit, Plastic limit, Plasticity Index, Free swell index and specific gravity value are presented as follows;

Table 19. *Index properties of soil Sample 4.*

Index properties	Experimental value
Liquid Limit	44.25%
Plastic Limit	31.57%
Plasticity Index	12.68%
Specific Gravity	2.77
Free Swell Index	Non expansive

3.4.2. Particle Size Distribution

The grain size distribution of this soil sample done by sieve analysis test and plotting the graph as shown below;

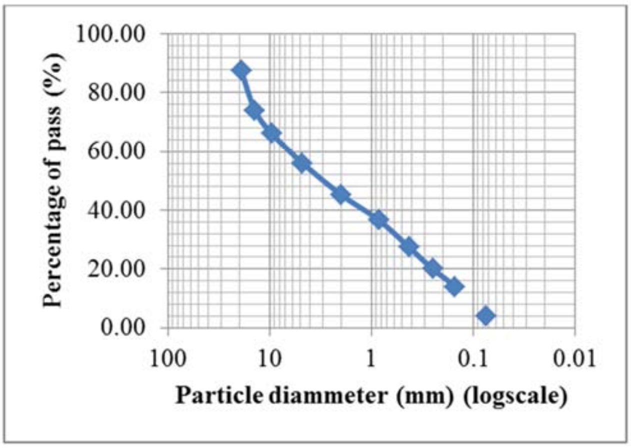

Figure 23. *Particle size distribution curve of soil Sample 4.*

The above result shown in figure 23 implies that in this soil sample 44.00% of Gravel, 52.00%of Sand and 4.00%of Silt and/or Clay are exist and D_{10}, D_{30} and D_{60} values are 0.12mm, 0.55mm and 6.65mm respectively. The diameter size corresponding to 10% finer in the distribution indicate 0.12mm, this implies that there was probable flow of water through the soil.

The coefficient of uniformity (C_u) are 55.42 which is greater than 4 for gravel and less than 6 for sand, particle size are non- uniform and coefficient of curvature or gradation (C_c) is 0.38 which is out of the range between 1 and 3. This implies that this subgrade soil is Gap- graded soil.

3.4.3. Modified Proctor Compaction Test

The results of modified proctor compaction test are represented in figure bellows;

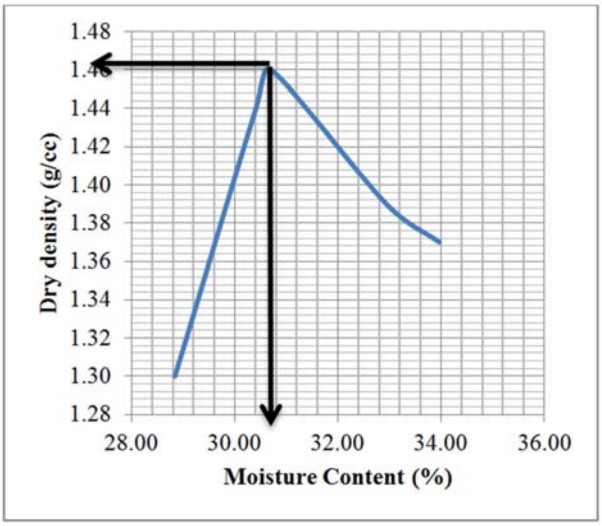

Figure 24. *Modified proctor compaction test result of soil Sample 4.*

From the above figure 24 we can observe that (OMC=30.70% and γ_D = 1.462g/cm^3)

3.4.4. Falling Head Permeability Test Result

The specimens of different density or voids ratio are prepared for testing the flows water through them or permeability. Accordingly the specimen data which is ready for testing are shown in the table 20 bellows:

A. Specimen Data

Table 20. *Specimen data for falling head test of soil Sample 4.*

Specimen Mass (M) (kg)	**0.95**
Specimen Height, L (cm)	11.5
Specimen diameter, D (cm)	10.16
volume of specimen, V (cm^3)	931.87
Bulk density, γ (g/cc)	1.02
Water Content, w (%)	6.36
Dry density,(γ_d)(g/cc)	0.96
Specific gravity of soil, G_s	2.77
Initial void ratio, (e)	1.89

The specimen placed in a sink which water is about 3 cm above the cover and soaked at least for 24 hours. The sample will be saturated until minimum amount of entrapped air, discharge in equivalent to discharge out (fully saturated).

When water in the plastic inlet tube on the top of the mold reaches equilibrium with water in the sink (allowing for capillary rise in the tube)

Height of capillary from the mold (H_C) >=6.5cm

Height of capillary from the top of the water (H_C) >=3.5cm

B. Falling head test

The result of rate of capillary rise or coefficient of permeability can be determined at several densities or void ratio of this subgrade soil can be obtained. Using the same specimen data indicated before in table 20. The rate of capillary rise at initial void ratio of (e=1.89) or dry density (γ_{dry}) of 0.96 g/cm^3 indicated in above table 20 is shown in the table 21 blows:

Table 21. *Rate of capillary rise at initial void ratio of soil Sample 4.*

Trial	**1**	**2**
Head, h_o (cm)	83.4	83.4
Head, h_1 (cm)	45.2	47.4
Time, t (s)	1200	1320
Temperature, T (°C)	23.5	23
Permeability at T°C, K_T	0.000220946	0.000146357
R_t for T	0.9204248	0.930640247
Permeability at 20°C, K_{20}	0.000203364	0.000136205
Average K_{20} (cm/s)	0.000169785	

The rate of capillary rise or coefficient of permeability with respect to several void ratios or densities of the sample are shown in the table and figure below;

Table 22. *Rate of capillary rise at different voids/density of soil Sample 4.*

Dry density (g/cc)	**Void ratio (e)**	**Permeability (K)(cm/s)**
0.960	1.89	0.000169785
1.316	1.07	0.000076729
1.389	0.97	0.000065370
1.396	0.96	0.000064321
1.462	0.87	0.000055516

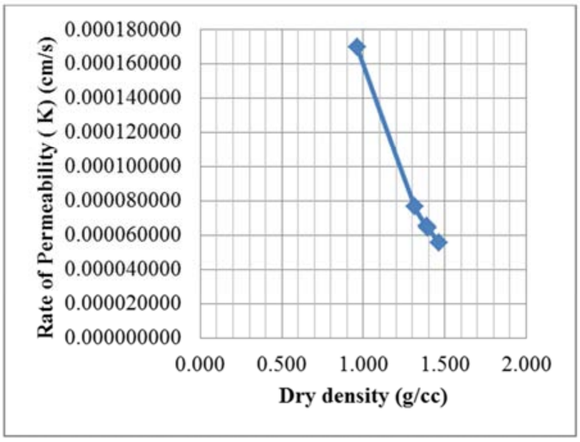

Figure 25. *Relationship between the densities &permeability of soil Sample 4.*

The result shown in a graph 25 and in a table 22 indicates that again there is the propensity of a soil to allow the flow of water through the soil. From densities 1.389 (g/cc) to 0.96 (g/cc) the rate flows is highly increasing due to high void spaces and saturation. And from densities (MDD to 1.389 (g/cc)) the rates of flows is slowly increasing due to decreasing in voids but the result indicates that at MDD there is still probable flow water which can change Subgrade Water Content (SWC) or (OMC) and further incremental of saturation due to capillary.

3.4.5. California Bearing Ratio Test Results

The CBR test at different moisture content including OMC and at different level compaction (10, 30 and 65 blows) are investigated and the analysis are made to investigate the variation of CBR with respect to different type of soaking (capillary saturation), i.e from un soaked (day 0) to soaked (day4) can be observed. Test conducted under OMC (30.7%) and MDD (1.462g/cc).

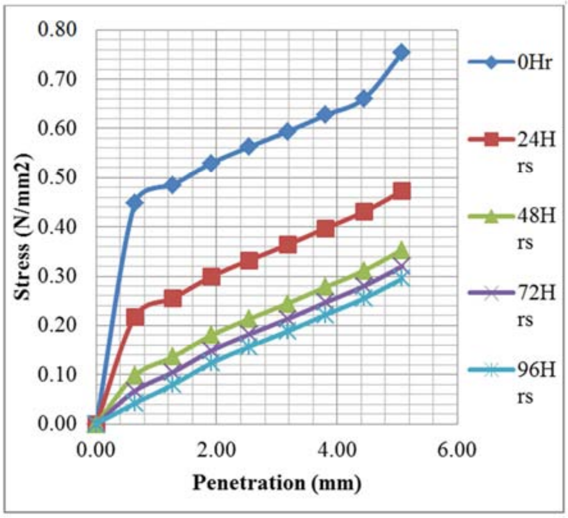

Figure 26. *Stress vs penetration graph for soil Sample 4 for soaked (0hr, 24hrs, 48hrs, 72hrs and 96hrs) condition.*

3.4.6. Variation of CBR with Time of Soaking

The variation of CBR with respect to time of soaking or saturation due to capillary can be shown in the table below:

Table 23. *Variation of CBR with time of soaking for soil Sample 4.*

Variation of CBR with time of soaking										
Time of soaking in hours										
Time	**0Hr**		**24Hrs**		**48Hrs**		**72Hrs**		**96Hrs**	
Pen (mm)	2.54	5.08	2.54	5.08	2.54	5.08	2.54	5.08	2.54	5.08
CBR (%)	8.16	7.28	4.82	4.57	3.1	3.42	2.64	3.09	2.28	2.85

The CBR values decreasing with time of saturation increasing but sequence of decreasing are rapidly in the first two days (24hrs and 48hrs) and slowly decreasing in the last two days (72hrs and 96hrs).

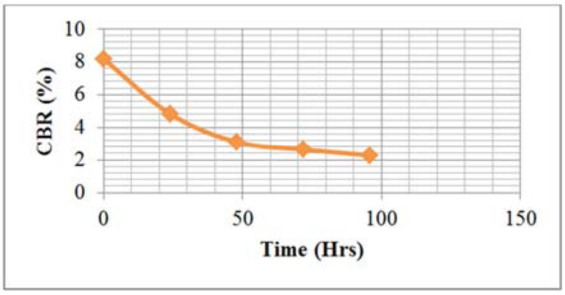

Figure 27. *Variation of CBR with time of soaking for soil Sample 4.*

3.4.7. Moisture Variation in a Soil Sample

Moisture content variation in a soil sample with depths (top, middle and bottom) through the center axis shown previously in schematic diagrams and time of soaking (capillary saturation) are observed as shown bellows:

Table 24. *Moisture variation in soil Sample 4 with depths and time of soaking.*

Moisture variation in soil sample (%)						
Position	**Axis**	**Time of soaking**				
		0Hr	**24Hrs**	**48hrs**	**72Hrs**	**96Hrs**
Top			15.83	17.02	20.8	21.75
Middle	Centre		13.46	13.8	14.92	15.5
Bottom			10.92	11.45	12.3	13.3

3.4.8. Variation of CBR with Respect to Moisture

The variation of CBR values with variation of moisture due to capillary saturation in a soil sample are shown in a figure below:

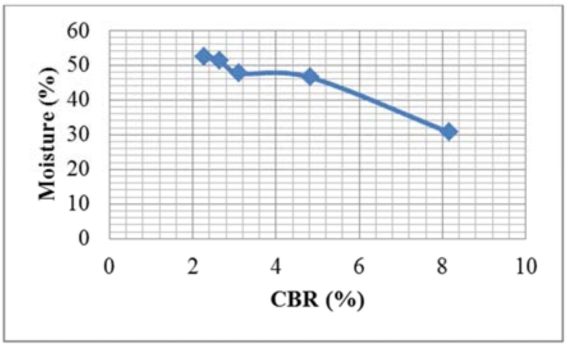

Figure 28. *Variation of CBR with moisture for soil Sample 4.*

The CBR values decreasing highly in the first two day of saturation due to sudden change in moisture and gradually decreasing in the last two days due to no further change in moisture content shown in table above 24.

4. Conclusion and Recommendation

4.1. Conclusion

An attempt has been made in this study were to explore effect of capillary rise/saturation on the subgrade properties of soil, namely the capillary rise/height through the subgrade soil, the hydraulic conductivity of subgrade soil with varies densities or voids and the strength properties of subgrade soil in terms of the most widely parameter for pavement design as CBR, i.e. with varies soaking on the strength properties of subgrade soil are considered. For all four types of subgrade soil at different station, the effects of capillary rise/saturation have been considered in this research. From the result and discussion presented earlier the following conclusions are drawn:

1) It is observed that, for each Soil Sample the subgrade soil are conductive to water flow in its height of capillary rise/saturation which are greater than or equal to 4.3cm, 8cm, 6.5cm and 6.5cm respectively.
2) Rate of capillary rise or hydraulic conductivity of subgrade soil with any densities exists at each soil sample. The rate of conductivity rapidly increasing from 90% of MDD to the initial dry density taken and conductive slowly from 95% of dry density to the MDD.
3) It also observed that CBR values decrease with time of soaking or capillary saturation in each soil sample, the rate of reduction of CBR values can be varies for each soil. For first soil Sample the CBR values rapidly decrease in the first two days and slowly decrease in the last two days of saturation (soaking). While CBR values reduced by 5.76 times (82%) to the un soaked condition. For second soil sample the CBR values rapidly in the first day and slowly decrease in the last three days, while CBR values reduces by 4.41 times (77.30%) to the un soaked condition. For the third soil sample the CBR values decreases in the first two days and slowly decrease in the last two days, while CBR values reduces by 3.24 times (69.11%) to the un soaked condition. For fourth soil sample the CBR values rapidly decrease in the first day and slowly decrease in the last three days, while CBR values reduces by 3.57 times (72.1%) to the un soaked condition. It can also observe that the variation of moisture content in a soil sample with capillary saturation or time of soaking. The rate of variation is high in the first two days and minimum changing in the last two days.

Generally capillary rise saturation changes the Subgrade Moisture Content (SWC) or Optimum Moisture Content (OMC) and reduces the ability to the soil to withstand stress or reduce subgrade strength.

4.2. Recommendation

1) For Ethiopian Road Authority (ERA), it is better in the future construction or during maintenance of this road and others to provide a subgrade soil with non-susceptible to hydraulic conductivity, at least in the height of capillary rise / saturation in the areas of sensitive. Provide the subgrade soil with a minimum diameter of grain size with corresponding to 10% finer (weight) in the distribution to overcome flow of water through them that can cause adverse effects on the strength properties of subgrade soil.
2) During the construction or maintenance of this road or any others our hosting university can be gave a better consultation on the selection of proper material of subgrade soil that can reduces the flows of water through them and placing it at appropriate station with adequate depths in the road cross section and deals with further investigation or researches on the effects of capillary saturation on the strength properties of subgrade soil.
3) Further study should be carried out on the other factors that cause variation of moisture or saturation in a subgrade soil.
4) Further study should be carried out on the depth of ground water and its fluctuation at different season.

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