Investigating The Suitability of Borrow-Pit Materials Used in the Construction of Road in Bonny

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Abstract

The primary use of soils in engineering projects such as roads, buildings, railways, dams and others structures necessitates assessing their index and mechanical properties. This study focusses on identifying the optimal materials for road construction and exploring options for managing ineffective waste generated on site. The materials are categorized based on their index and mechanical properties. Six different points of soil samples were collected at different points, ranging from 1.0 to 3.0 meters deep. The collected soils samples underwent various laboratory tests: Sieve Analysis, Compaction Test, California Bearing Ratio (CBR), and Specific Gravity (SG). Particle size distribution analysis indicated the sample's fine grading, with less than 15% passing through sieve No. 200 (0.075mm) measuring 0.04%, 0.14%, 0.31%, 0.08%, 0.01%, and 0.18%. The average Natural Moisture Content (NMC) of the six (6) sample collected was found to be 13.88%. Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of the first point were determined as 2.20g/cm^3 and 14.00%, and the remaining five (5) points were (2.20g/cm^3 and 13.50%, 2.21g/cm^3 and 12.50%, 2.08g/cm^3 and 13.00%, 2.06g/cm^3 and 12.25%, and 2.04g/cm^3/13.40%) respectively. The California Bearing Ratio (CBR) results after soaking for the six (6) samples were 25.70%, 24.50%, 22.3%, 21.7%, 20.40% and 23.40% respectively. Specific Gravity (SG) Ranged from 2.67 to 2.96kg/m^3, classified according to American Association of State Highway and Transportation Officials (AASHTO). Materials were categorized into A-1 with subgroups A-1-a and A-1-b, constituting 50% 29.1% respectively, indicating predominantly stone fragments and sand. Overall, the subgrade samples were deemed excellent too good for road construction purposes.

***Keywords**: Borrow-pit, Construction, Soil properties, Road construction and Bonny*

I. INTRODUCTION

Globally, inaccessible to infer suitable data about the index and mechanical properties of the soil and subsoil condition of the region, especially for primary prior engineering projects, antiquated and cause failures on road construction projects (Fidelis et al., 2019). That is, a failure occurring right after the project is launched or even before it is launched. It is essential for the engineers, geoscientists, and soil scientists designing road construction projects to have a good knowledge of the geotechnical, index, and mechanical parameters of the subgrade material before any construction commences (Malomo, 1977; Ola, 1978). The various properties of subgrade soil are grouped into; index properties and engineering properties (Ramamurthy and Sitharam, 2005; Osinubi et al., 2019). The mechanical properties of subgrade soils are permeability, compressibility, and shear strength while the index properties are particle size distribution, Atterberg limits, density index, and specific gravity of soil particles (Agbede, 1992; Hunt, 2007). These soil properties are mainly used in the identification and classification of soils and help the geotechnical engineer in predicting the suitability of soils as foundation and construction material (Coduto, 2007; Aroka, 2009; Ola, 1978). In this study, the borrow pit used was collected from Akiama community in Bonny Island, River State, Nigeria was investigated and used as the subgrade. These borrowed pits were originally entrenched as a source of road fill material in road construction. A borrow pit is a term used in construction for a hole, pit, or excavation that has been dug to remove gravel, clay, and sand used in a construction project such as bridges, dams, and so on (Salter, 1988; Oglesby and Hicks,1992; Ogbuagu and Okeke 2019). Investigations at borrow pit sites are mainly conducted to accurately assess the quantity, quality, and processing requirements of materials suitable for road construction. Materials that are appropriate for surfacing or blending can be extracted using earthmoving machinery. A borrow pit is also known as a sandbox, which is a large excavation created for a specific use. Almost all construction projects involve earthwork designed to determine a suitable base for engineering construction (Malomo, 1977). A key aspect is to ensure that ground conditions are sound for stable construction through grading and excavation processes. Frequently, constructions crews will dig borrow pits to gather gravel, soil, and sand for use in another location (Opeyemi et al., 2018). The digging of borrow pit falls under the engineering field of earthworks. Earthworks projects involve tasks such as moving substantial quantities of soil or rock from one location to another. Borrow pit construction may seem relatively easy to accomplish, though this type of digging requires an extensive amount of analysis before the original dig (Charkley et al., 2019). Engineers and Geoscientists need to ensure that excavating soil from borrow pit does not disturb the surrounding earth. Before the advent of geotechnical engineers and modern soil scientists, geoscientists had to estimate how much soil displacement the earth could tolerate during excavation (AASHTO, 2000; Murthy, 2007). Today, precise laboratory measurements and advanced equipment for quality control and sampling techniques are used to interpret this data. Conversely, it supports the rationale for the state's growth and development, as well as in other locations worldwide, since good road infrastructure attract global investors (Onakunle et al., 2019). Therefore, this research offers valuable geotechnical data for engineers, geoscientists, and contractors, which can be used for engineering subgrade sub base materials, while also serving as a resource new researchers.

II. MATERIALS AND METHODS

The materials used for this research work are; borrow pit sampling and distilled water. The materials were carefully transported from the borrow pit to the civil engineering laboratory where the research was carried out in stages to achieve the outline objectives of the study.

Borrow pit sampling:
The sampling method covers procedures for recovering soil samples to investigate the soil for use as a borrow pit. The test was carried out in reference to American Society for Testing and Materials (ASTM) International, which is a standard test method for analysis of Soils. The pits

were assigned: numbers, names, sites, and locations in consecutive order for filing purposes, and references of the pit.

APPARATUS: The apparatus used for the sampling include: Posthole auger with handle extensions that is capable of extending by adding sections to the handle for boring the marked point on the field into the holes to achieve the desired depth.

PR0CEDURE: The area was taken out for testing using a grid pattern with number labelling on-site and the location at about 1.0 m intervals for areas where soils vary unpredictably and 2.0 m intervals for areas where soils are reasonably uniform respectively. The hand auger is made boring by turning the auger to a desirable distance, say (1-3) m into the soil, withdrawing the auger, and removing the soil for sampling. The process was repeated for the six (6) sets of data acquired and the samples of each soil type, except topsoil, were taken. Then a map is drawn for referencing each location of the site presently being tested to landmarks with the legend indicating the name and number of the pit, district, name of the contractor, type of borrow, contract number, date sampled, names of the sampling crew, and the scale used to draw the map. Lastly, the bagged samples were returned to the laboratory for testing (ASTM D 698, 2012).

III. LABORATORY TESTS

Moisture Content (W)

The moisture content of the soil is an indicator of the amount of water present in the soil. It is the ratio of the mass of water contained in the pore spaces of soil to the solid mass of particles in that material, expressed as a percentage. A standard temperature of 110°C ±5°C is used to determine the mass of the sample.

Sample preparation for moisture content

Apparatus: The apparatus involved includes: non-corrodible container, and vented thermostatically controlled drying oven that maintains temperatures between 105°C to 115°C, a balance of sufficient sensitivity (sensitive to 0.01 g), and Container handling apparatus.

Procedure: The container was clean, dry, and weighed empty balance, tarred before it is used to measure the weight W1. The weight of the container and wetness of the soil sample of the specimen in the container was measured as W2. The container was kept in the oven for 24 hours, drying the specimen to a constant weight, maintaining the temperature between 105°C to 115°C, and recording the final constant weight W3 of the container with the dried soil sample (Head, 1994a; ASTM D 698, 2012). The moisture content of soil (W)

$$W = \frac{Mw}{Ms} \times 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots.(1)$$

Where Mw = weight of container + wet of soil W2 – weight of container + dry soil W3,

Ms = weight of container + dry soil W3 – weight of container W1.

Sieve Analysis

Sieve analysis (particle size distribution) is the determination of the size range of sand, silt, and clay present in a soil expressed as a percentage of the total dry weight.

Sample Preparation for Sieve Analysis:

Apparatus: The apparatus set up were: Drying oven maintained at 110°C ±5°C, Standard sieves, Sample splitter, Mechanical sieve shaker, and Pans.

Procedure: The procedure consists of the following: drying the soil sample in an oven for 24 hours to get rid of moisture, measuring 500 g of the dry sample, and soaking in water for 24 hours. Record the weight of the sieves and the pan that will be utilized during the analysis. Subsequently, the total percentage passing from each sieve was calculated by subtracting the cumulative percentage retained in that particular sieve and the ones above it from the totality (ASTM D422, 2007). On the other hand, the grain size distribution curve of medium-fine sand was plotted to calculate the uniformity coefficient (Cu) expresses the variety in particle sizes of soil ratio of D60 to D10. The value D60 is the grain diameter at which 60% of soil particles are finer and 40% of soil particles are coarser, while D10 is the grain diameter at which 10% of particles are finer and 90% of the particles are coarser.

$$Cu= \frac{D60}{D10} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2)$$

When Cu is greater than 4, the soil is classified as well graded; whereas when Cu is less than 4 the soil is classified as poorly graded/uniformly graded (Head, 1994b).

Compaction

Compaction is densification of soil by direct application of mechanical load with the sole aim of reducing the air voids between the soil particles. This was carried out to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). The mechanical stress may be applied by kneading, or via dynamic or static methods (Didei and Oborie 2018). The degree of compaction is quantified by measuring the change of the soil's dry unit weight (γd), as a result of an increase in the strength of soils, and a decrease in incompressibility and permeability of soils.

Apparatus: The apparatus utilized to conduct the test include: a 10-centimeter diameter cylindrical compaction mold equipped with a base and a collar, a Proctor rammer weighing 2.5 kg or 4.5 kg depending on whether the standard of the modified test is conducted, No. 4 Sieve Steel straightedge, Moisture containers, Graduated cylinder, Mixer, Controlled oven, Metallic tray, and a scoop.

Procedure: Four soil samples were obtained and measured at about 3 kg each. 2% of water was added to the first portion and mixed thoroughly. The other was kept in separate cans to determine the weight of both wet and dry samples after 24 hours of placement in the oven to determine the moisture content. Finally, the compaction water content (W) of the soil sample was calculated using the average of the three measurements obtained from the top, middle and bottom part of the soil mass along with dry unit weight (γd) (ASTM D 1557-78):

$$\gamma d = \frac{W-Wm}{(1+w)\times V} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where W = the weight of the mold and the soil mass (kg), Wm = the weight of the mold (kg), W = the water content of the soil (%) and V = the volume of the mold (m3).

The procedure was repeated four times, for a given selected water content from lower to higher than the optimum. Hence, the calculated dry unit weights were plotted against their corresponding water contents to determine the Optimum Moisture Content (OMC) and

Maximum Dry Density (MDD) along the Zero Air Voids at a 100% saturation line. On the other hand, the Zero-Voids curve is calculated as follows:

$$\gamma d = \frac{Gs \times \gamma w}{1+W \times Gs} \quad \dots\dots\dots\dots\dots\dots (4)$$

Where GS = the specific gravity of soil particles, γw = the saturated unit weight of the soil (kN/m3) and W = the water content of the soil (%) (Head, 1994a).

Atterberg Limit

The Atterberg limits test is named after the Swedish chemist Albert Atterberg who was the first to develop a classification system to determine the different states and limits of soil consistency. The Atterberg limits test, also known as consistency, is used to determine the moisture content at which a soil changes from solid, semi-solid, plastic, and liquid states (Godwin et al., 2020). It is used to distinguish between silt and clay and determines the shrinkage limit (SL), plastic limit (PL), and liquid limit (LL) of the soil sample. The Atterberg test is performed only on soil fraction that passes through sieve No. 40 (ASTM D 4318, 2010). **Procedure:** 150 g air-dry soil samples passing sieve No. 40 were used. The Moisture was adjusted by adding 20% of water to the soil sample and mixing thoroughly. The samples were allowed to condition for at least 16 hours. For the liquid limit (LL) Test, a small portion of the soil sample was spread in the brass cup of the liquid limit device case grinder. A groove was cut to at least a 2 mm base with a grooving tool, turns the device and notes the number of blows (N) and stop when the groove in the soil closes. Finally, a sample and oven-dry were taken to find the moisture content. The tests were repeated three times and plotted the moisture content against the number of blows to determine LL, PL, and SL (ASTM D 4318, 2010).

California Bearing Ratio (CBR)

The California Bearing Ratio Test (CBR) is a penetration test developed by the California State Highway Department (U.S.A.) for evaluating the bearing capacity of subgrade soil for the design of roads and pavement. The tests are carried out on natural or compacted soils in water-soaked or unsoaked conditions and the results obtained are compared with the curves of the standard test to have an idea of the soil strength of the subgrade soil (Akaolisa et al., 2021). **Apparatus:** The apparatus involved are: mold, steel cutting collar, spacer disc, surcharge weights, dial gauges, IS sieves, penetration plunger, and loading machine.

Procedure: Soil samples were measured at about 6 kg, added water to the sample, and mixed thoroughly. Using a 2.5 kg rammer, weight of empty mold, compact the mixed sample into three (3) layers with 61 blows per layer. After compaction, the collar was removed, level the surface, and taken a sample to determine moisture content. Record the weight of mold + compacted specimen respectively. Mold was placed in the soaking tank for four days for soaked and ignored for unsoaked (Ojuri et al., 2017). Finally, the graph of piston load against penetration was plotted to determine the value of CBR, along with % CBR versus Dry Density to find CBR at the required degree of compaction (ASTM D 4318, 2010).

Specific Gravity (Sg) Test

Specific gravity is a fundamental property of soils and other construction materials. It is the ratio of material density to the density of water and is used to calculate soil density, void ratio, saturation, and other soil properties with a dimensionless unit (Akaolisa et al., 2021). It is applicable in the foundation design for structures, calculations for the stability of soil embankments, and estimations of settlement for engineer's soil fills.

Apparatus: Two density bottles of 50 ml capacity with stoppers at 27.2°C water bath, vacuum desiccator, oven, capable of maintaining a temperature of 105°C, spatula and weighing balance with an accuracy of 0.001 g.

Procedure: The density bottle along with the stopper was dried to a temperature of 105°C, cooled in the desiccator, and weighed to the nearest 0.001 g (W1). The sub-sample, which had been oven-dried, was transferred to the density bottle directly from the desiccator for cooling. The bottles and contents together with the stopper were weighed to the nearest 0.001 g (W2). The soil particles and the specific gravity are calculated as shown below:

$$\rho s = \frac{W3 - W1 \times \rho w}{(W2 - W1) - (W4 - W3} \text{ ………………….. (5)}$$

$$Gs = \frac{\rho s}{\rho w} \text{ ……………………………….. (6)}$$

Where ρw is the density of water = 997 kg/m3.

IV. RESULTS AND DISCUSSION

The results and the geotechnical investigation carried out in the laboratory on the soil sample collected from borrow pit at Coconut estate, Akiama community, Bonny are summarized and presented below:

Table 1. Summary Natural Moisture Content (NMC) of the six (6) samples

Date: 9/05/2024	NATURAL MOISTURE CONTENT						
Sample:		**PT1**		**PT 2**		**PT 3**	
Tin No.		**SP1**	**ME**	**CIO**	**3A**	**C**	**ED**
Wt of Tin	M_1	15.60	15.50	17.00	21.00	19.10	17.50
Wt of wet soil+Tin	M_2	74.30	74.50	36.40	43.90	37.30	31.60
Wt of dry soil+Tin	M_3	66.60	66.80	33.80	40.90	34.80	29.80
Wt of Moisture	$M_4 = M_2 - M_3$	7.70	7.70	2.60	3.00	2.50	1.80
Wt of dried soil	$M_5 = M_2 - M_1$	51.00	51.30	16.80	19.90	15.70	12.30
Moisture Content (%)	$(M_4 * 100)/M_5$	15.10	15.01	15.48	15.08	15.92	14.63
Mean Moisture Content (%)		**15.05**		**15.28**		**15.28**	
Date: 9/05/2024	NATURAL MOISTURE CONTENT						
Sample:		**PT4**		**PT 5**		**PT 6**	
Tin No.		**TB**	**AT**	**JIM**	**DOM**	**C**	**ED**
Wt of Tin	M_1	21.80	20.00	20.30	20.90	19.10	17.50
Wt of wet soil+Tin	M_2	40.80	35.10	39.80	39.60	36.70	31.20
Wt of dry soil+Tin	M_3	38.50	33.40	37.60	37.50	34.80	29.80
Wt of Moisture	$M_4 = M_2 - M_3$	2.30	1.70	2.20	2.10	1.90	1.40
Wt of dried soil	$M_5 = M_2 - M_1$	16.70	13.40	17.30	16.60	15.70	12.30
Moisture Content (%)	$(M_4 * 100)/M_5$	13.77	12.69	12.72	12.65	12.10	11.38
Mean Moisture Content (%)		**13.23**		**12.68**		**11.74**	

Table 1. Results for the natural moisture content

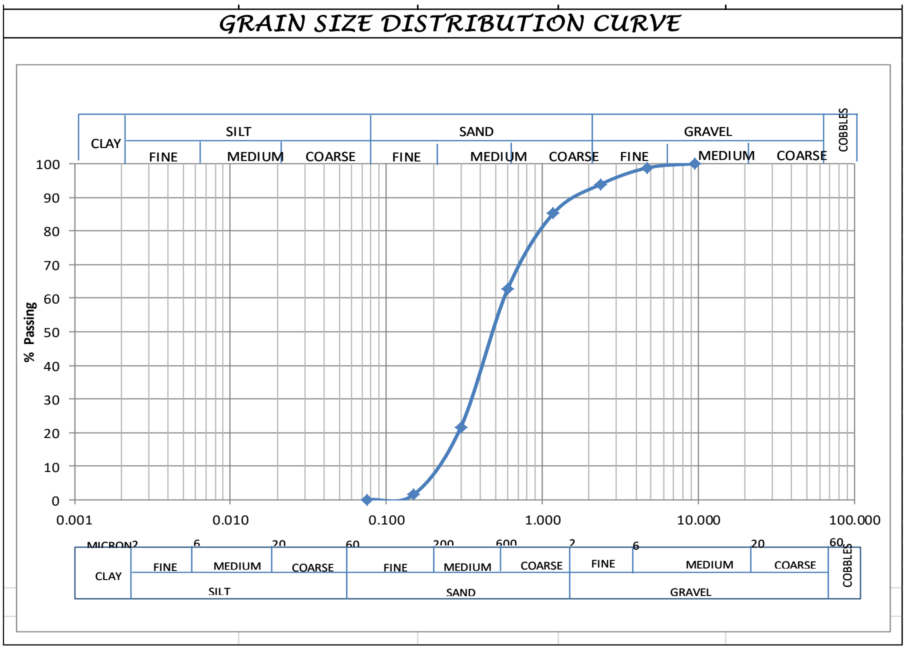
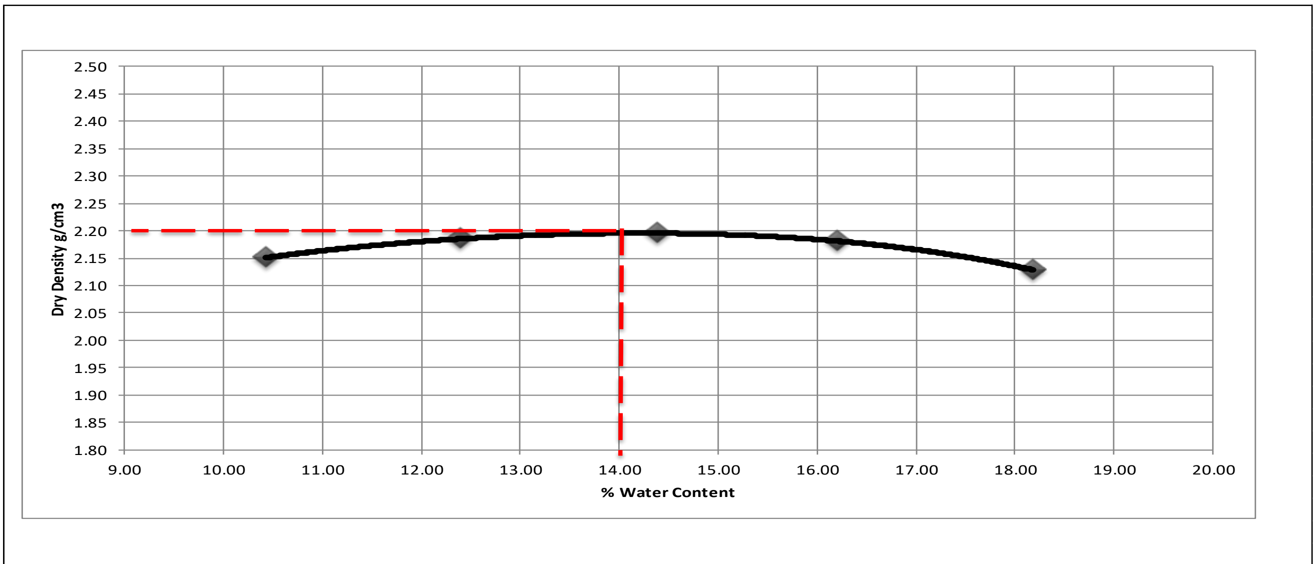


Fig. 1. A plot of the percentage passing (%) against diameter (mm)

On sieve analysis test (Point 1)



M.D.D.:	2.20	g/cm^3	**O.M.C.:**	14.00	%	

Fig. 2. A plot of dry density (mg/m^3) against water content (%) on compaction test (Point 1)

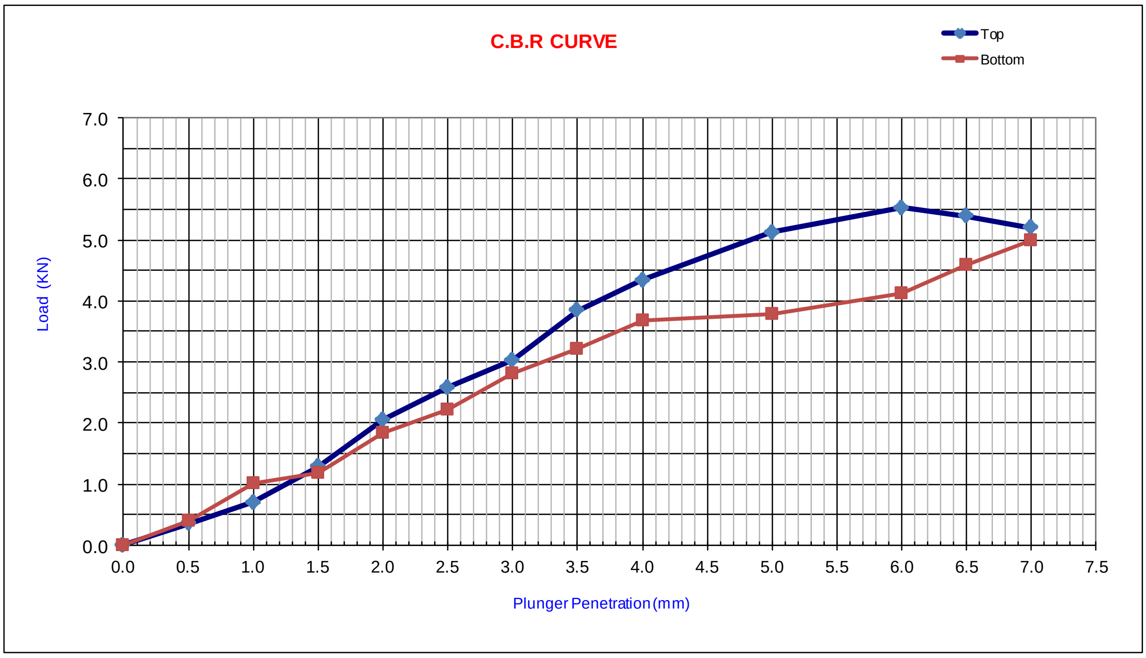


Fig. 3. A plot of load (KN) against plunger penetration (mm) on CBR test (Point 1)

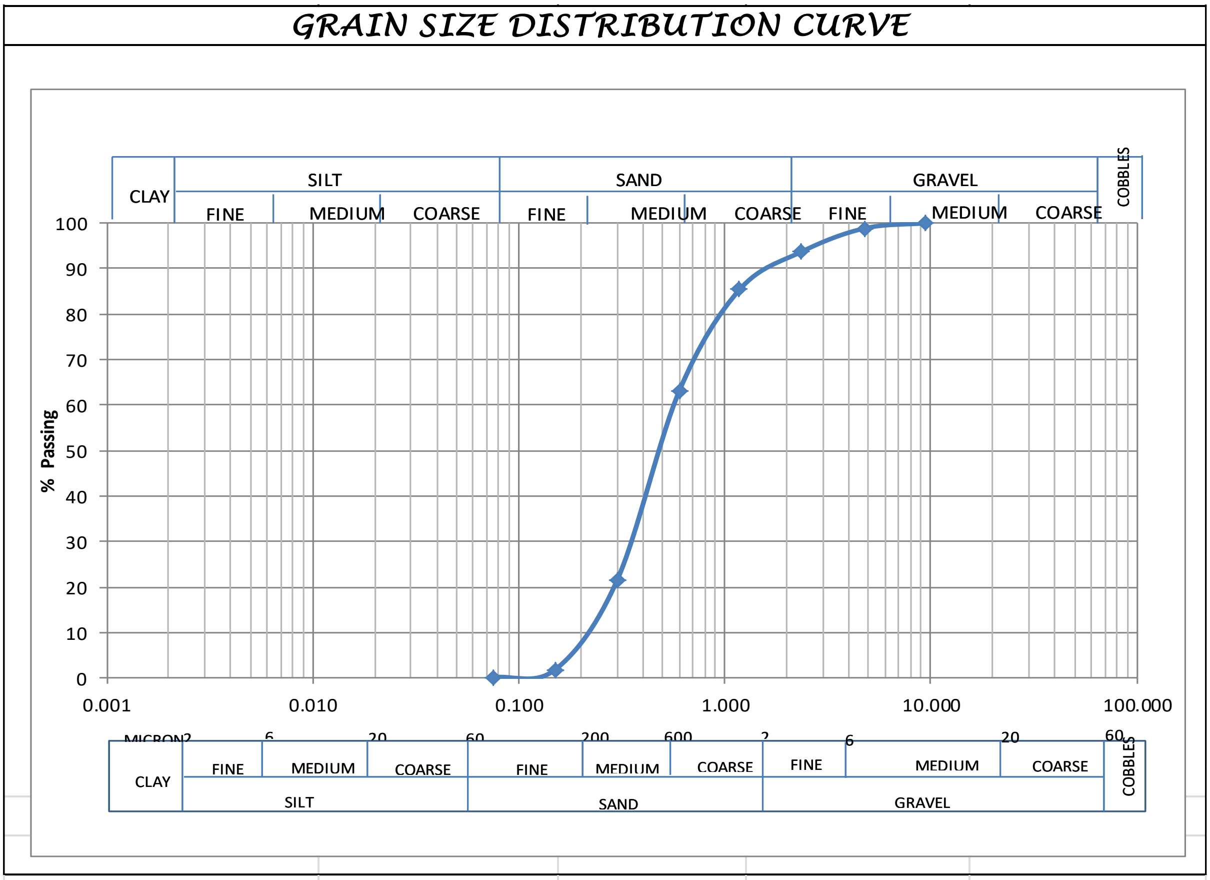
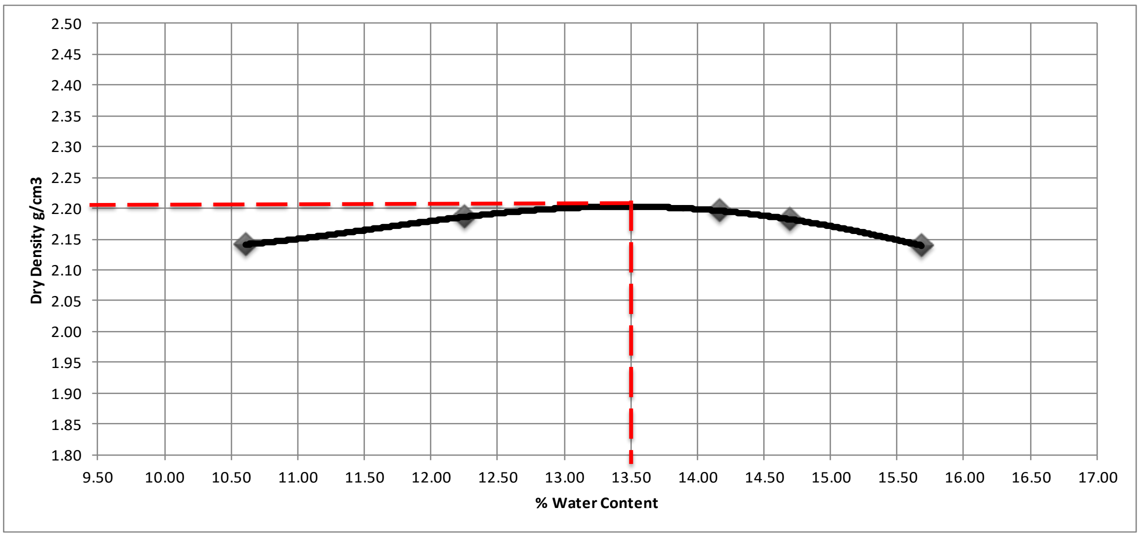


Fig. 4. A plot of the percentage passing (%) against diameter (mm)

On sieve analysis test (Point 2)



M.D.D.:	**2.20**	g/cm³	**O.M.C.:**	**13.50**	%	

Fig. 5. A plot of dry density (mg/m^3) against water content (%) on compaction test (Point 2)

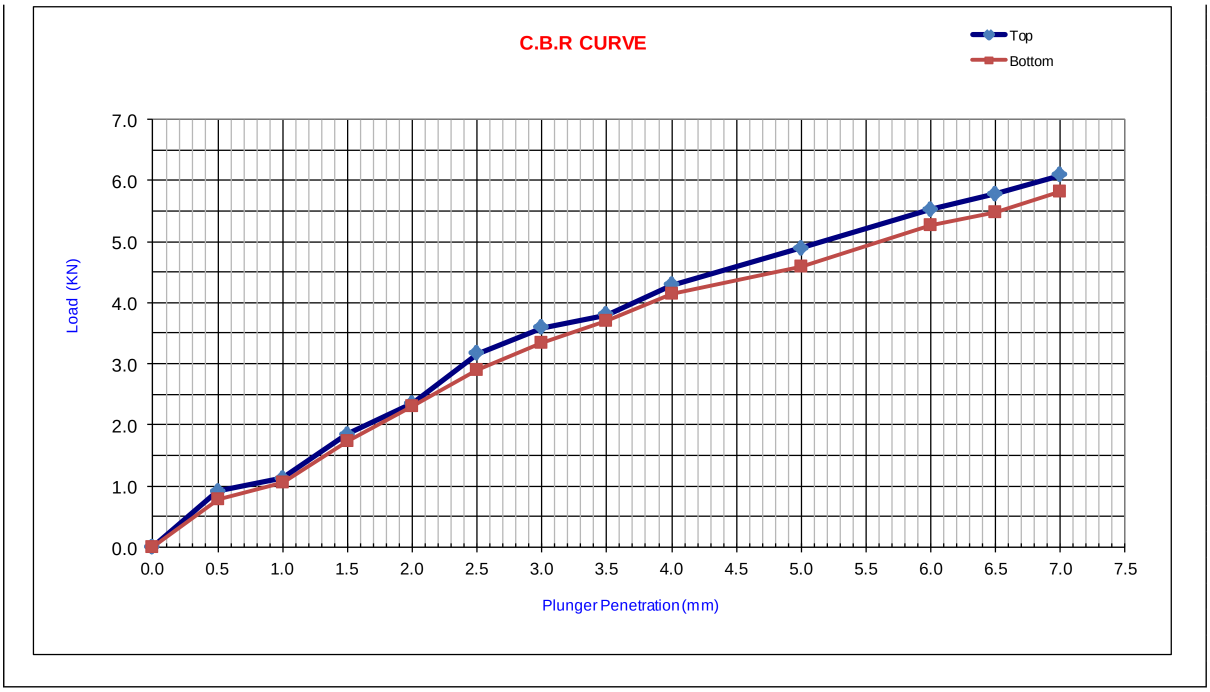


Fig. 6. A plot of load (KN) against plunger penetration (mm) on CBR test (SOAKED-24HRS Point 2)

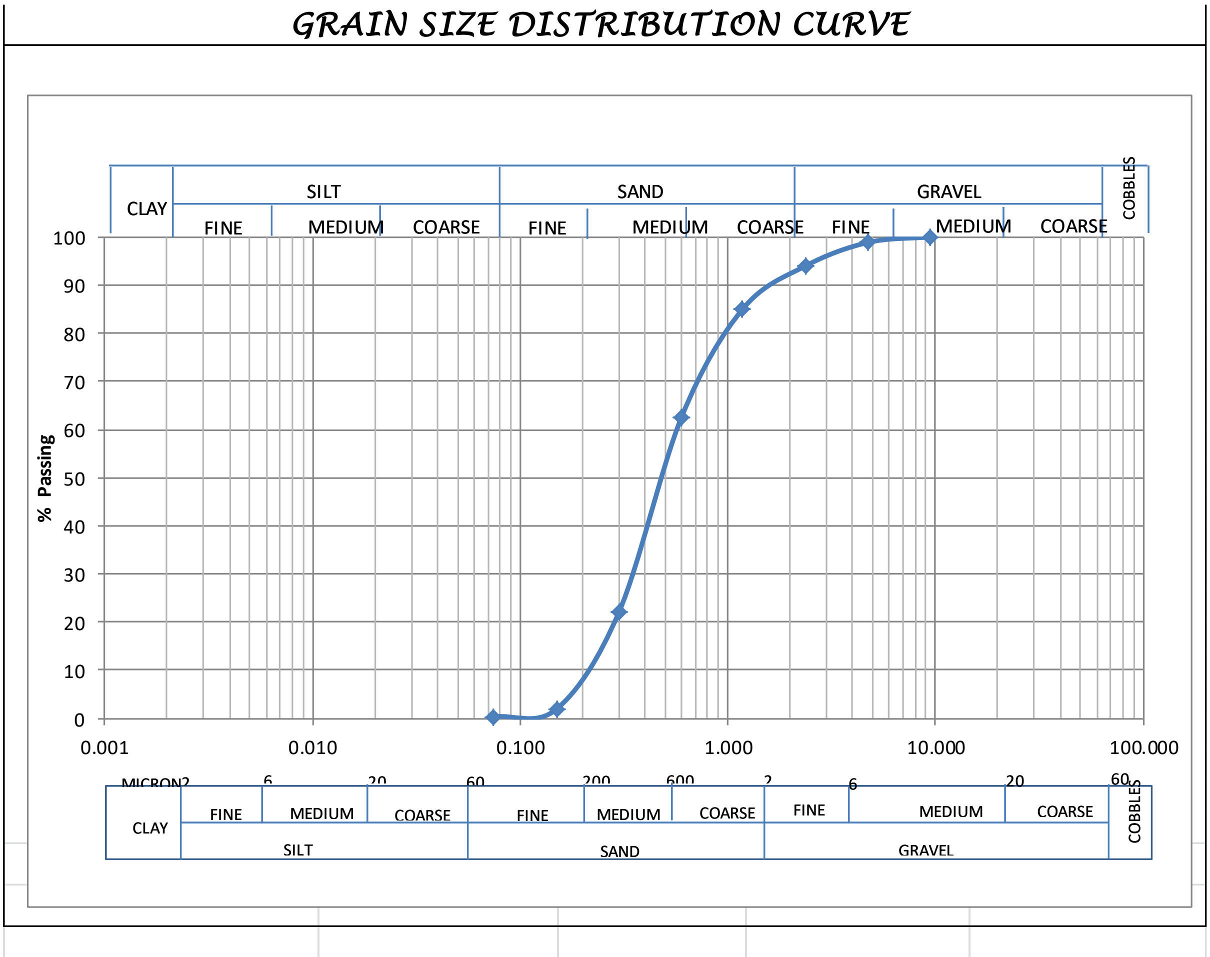
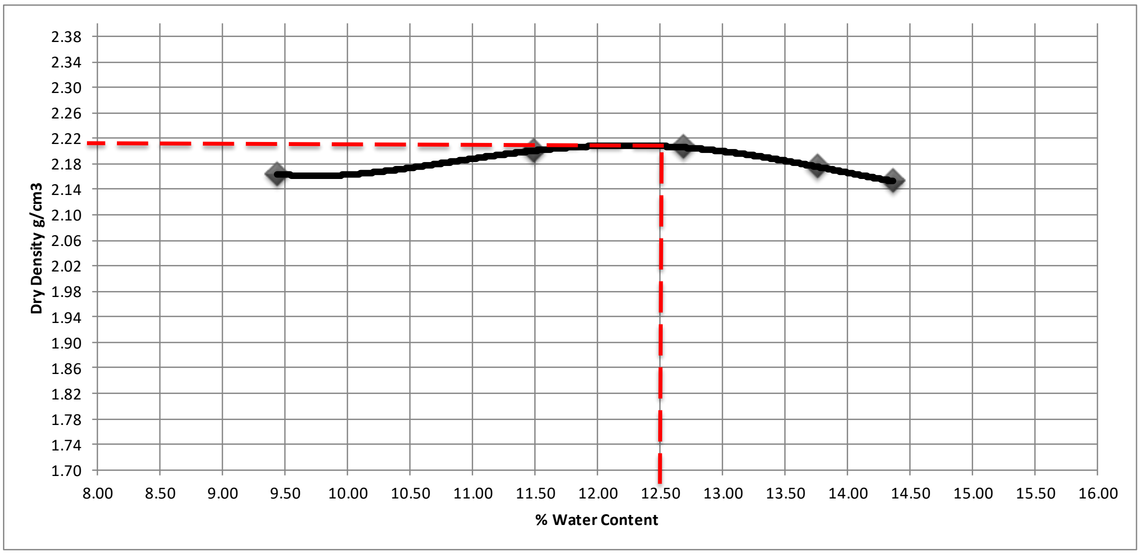


Fig. 7. A plot of the percentage passing (%) against diameter (mm)

On sieve analysis test (Point 3)



M.D.D.:	2.21	g/cm^3	**O.M.C.:**	12.50	%	

Fig. 8. A plot of dry density (mg/m^3) against water content (%) on compaction test (Point 3)

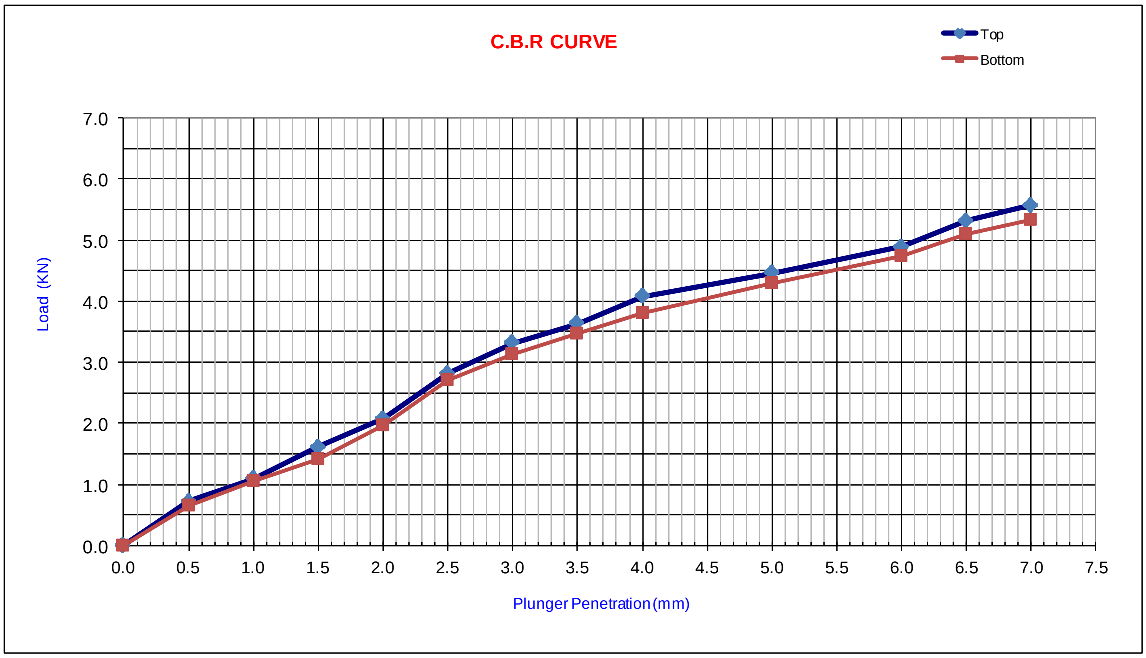


Fig. 9. A plot of load (KN) against plunger penetration (mm) on CBR test (Point 3)

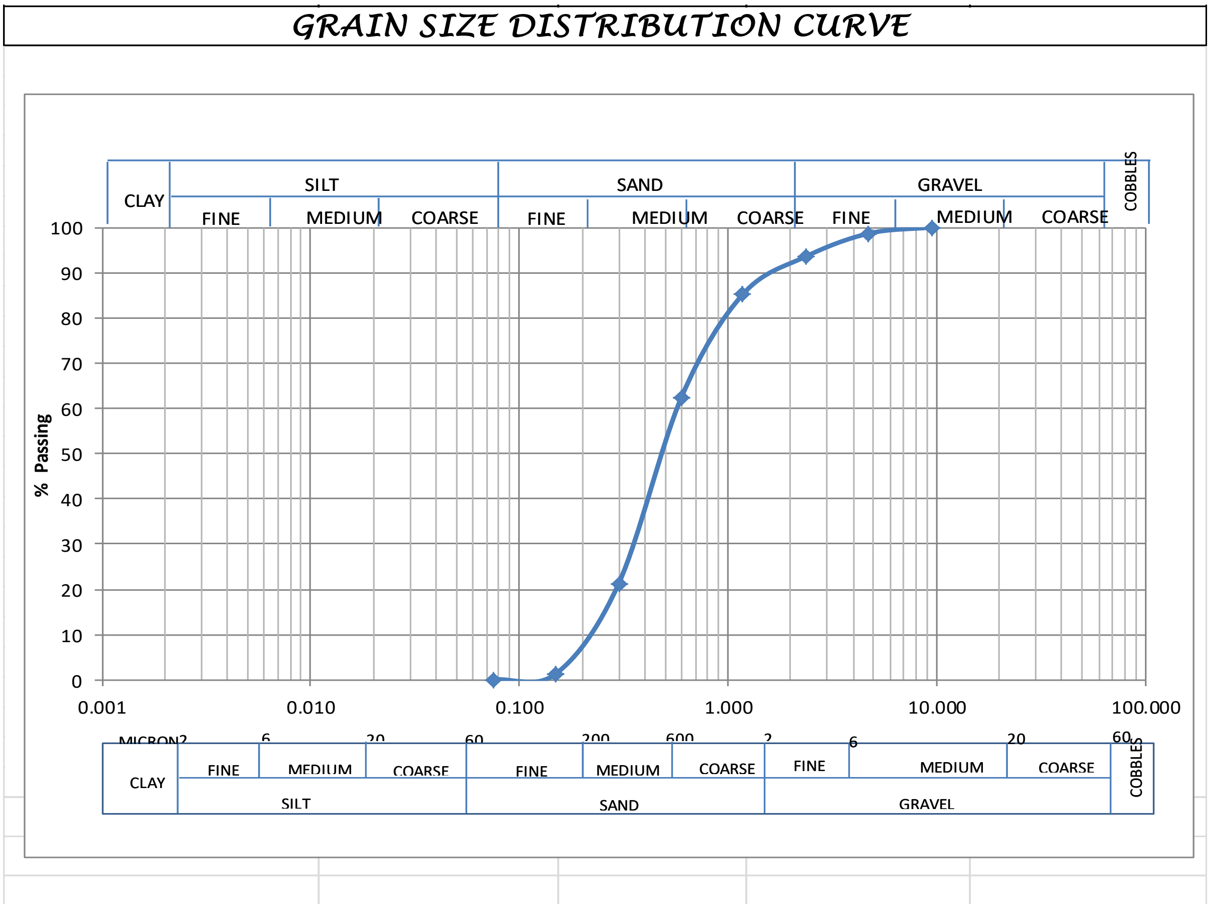
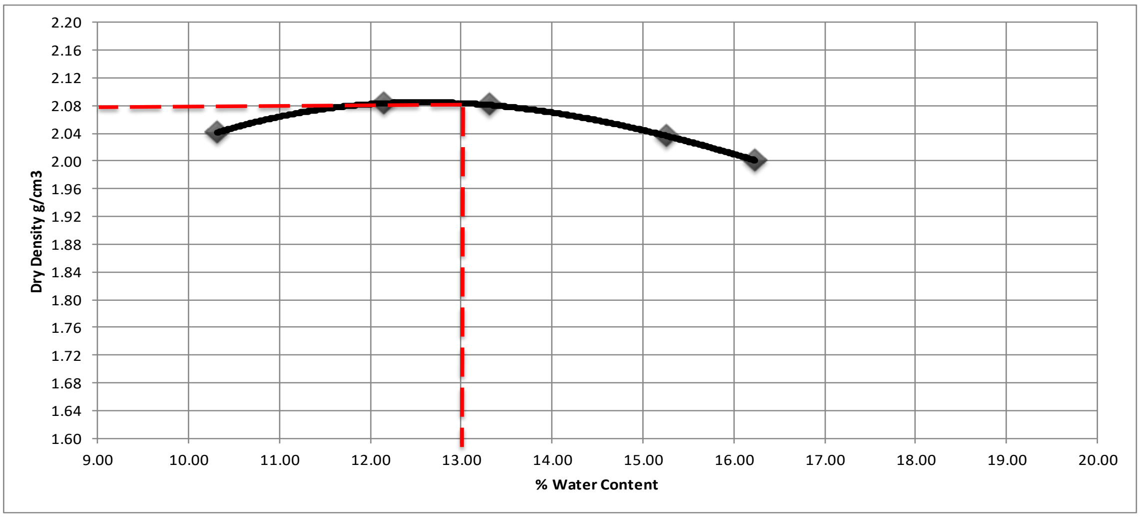


Fig. 10. A plot of the percentage passing (%) against diameter (mm)

On sieve analysis test (Point 4)



M.D.D.:	2.08	g/cm^3	O.M.C.:	13.00	%	

Fig. 11. A plot of dry density (mg/m^3) against water content (%) on compaction test (Point 4)

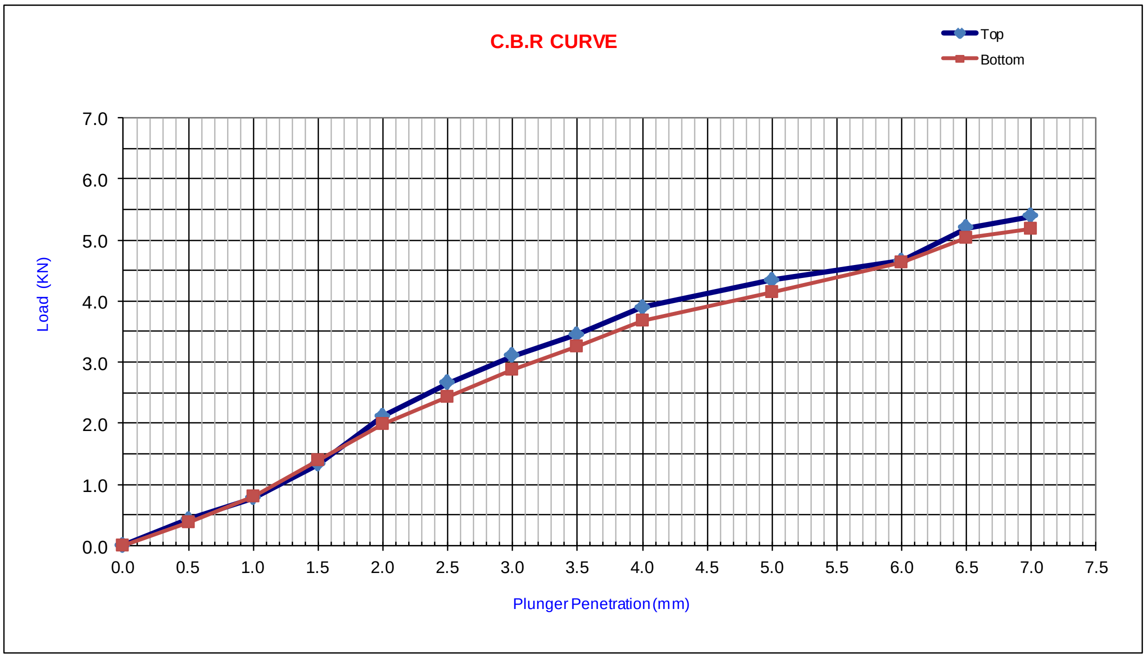


Fig. 12. A plot of load (KN) against plunger penetration (mm) on CBR test (SOAKED-24HRS Point 4)

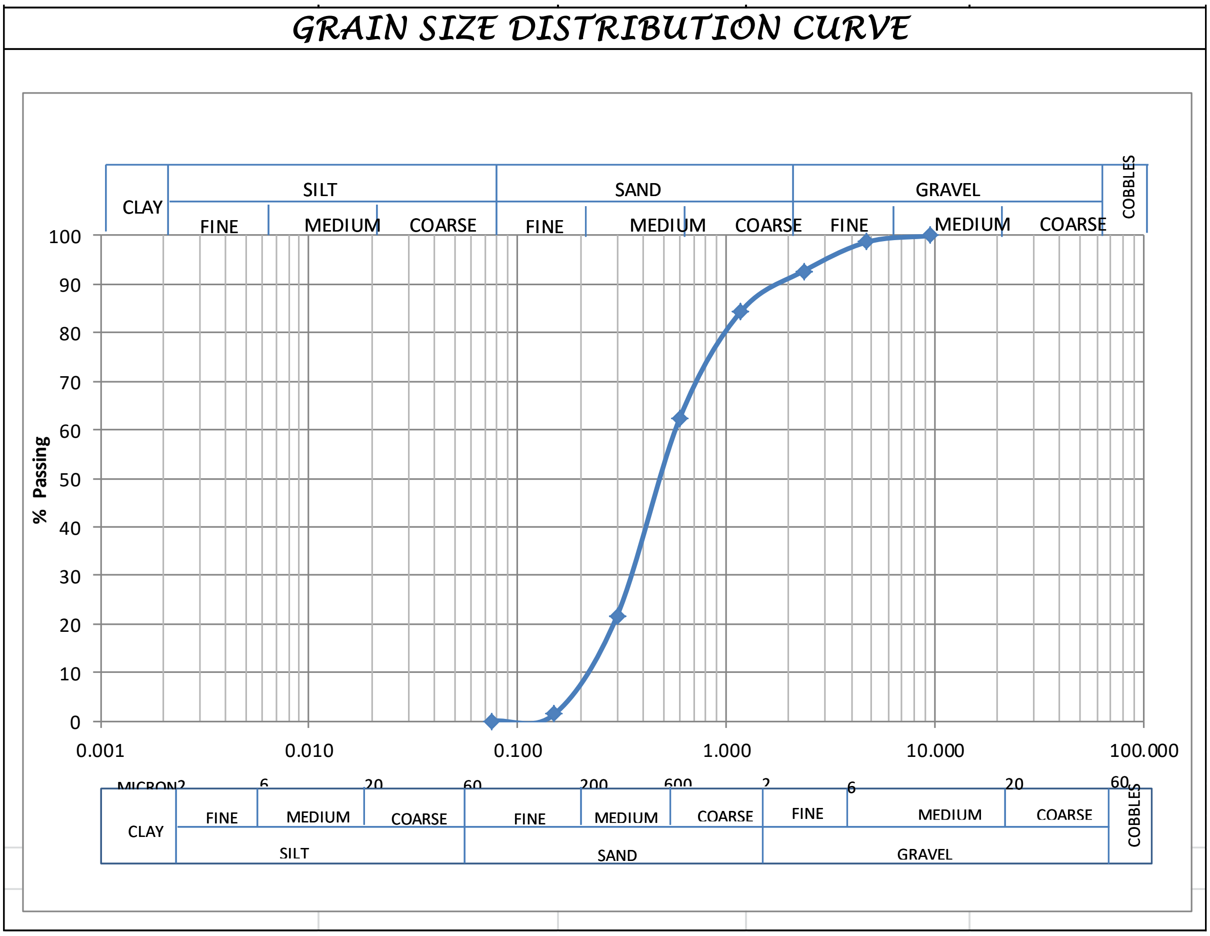
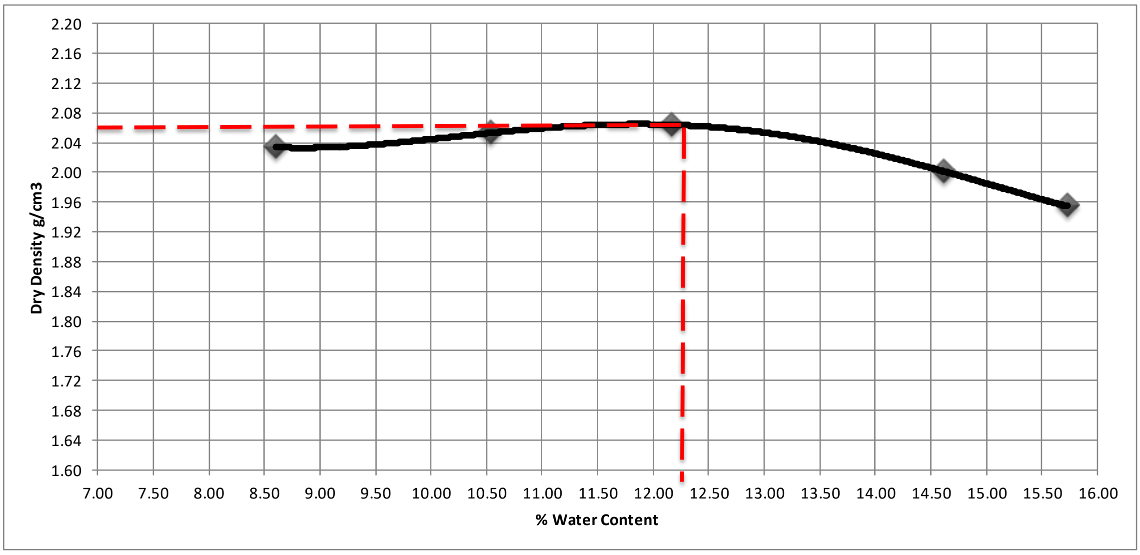


Fig. 13. A plot of the percentage passing (%) against diameter (mm)

On sieve analysis test (Point 5)



M.D.D.:	2.06	g/cm^3	O.M.C.:	12.25	%	

Fig. 14. A plot of dry density (mg/m^3) against water content (%) on compaction test (Point 5)

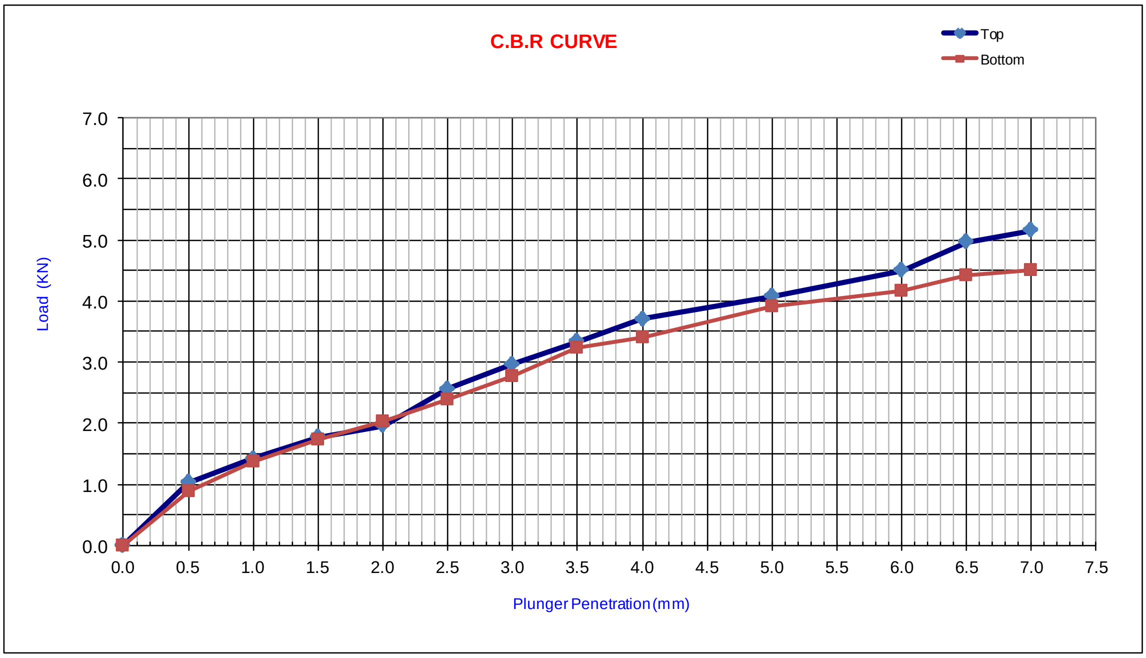


Fig. 15. A plot of load (KN) against plunger penetration (mm) on CBR test

(SOAKED-24HRS Point 5)

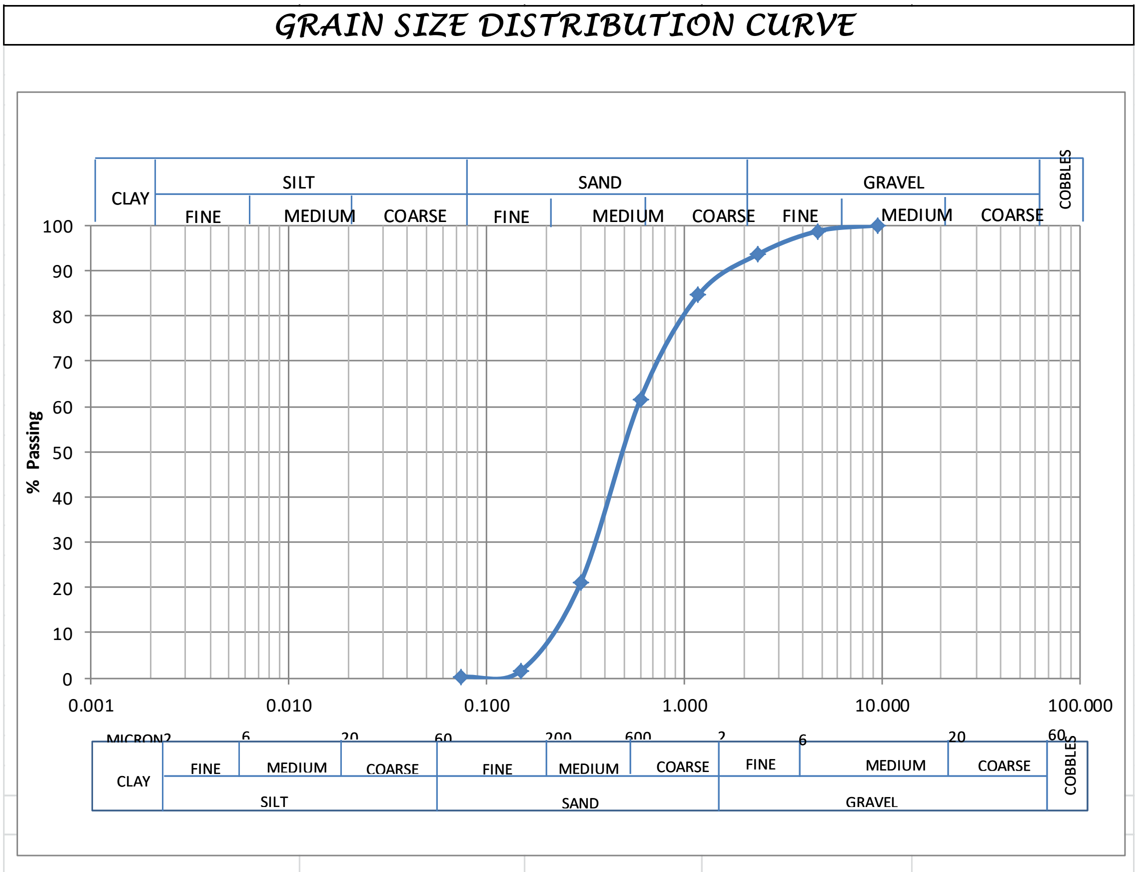
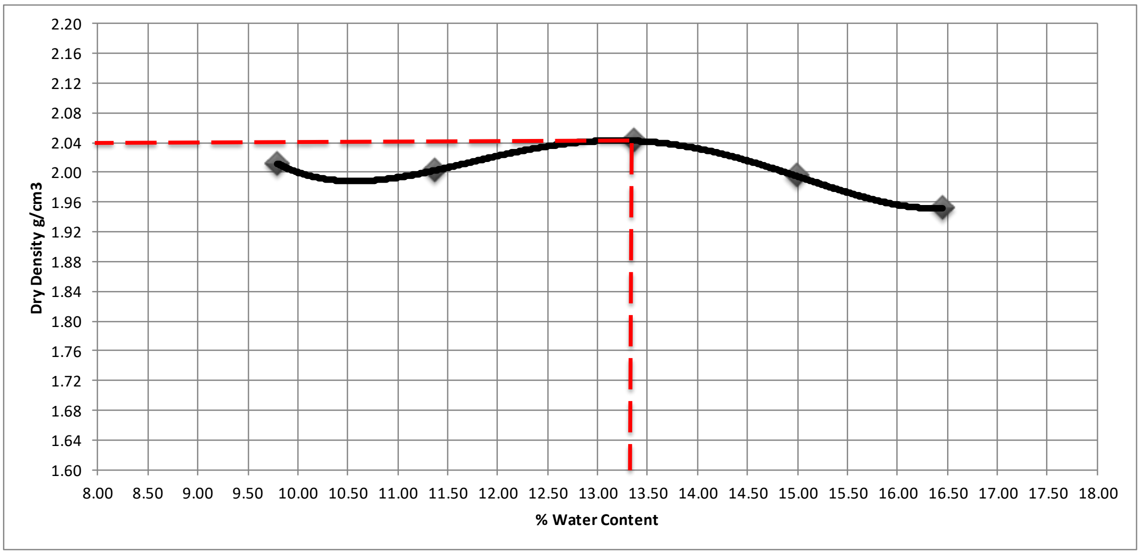


Fig. 16. A plot of the percentage passing (%) against diameter (mm)

On sieve analysis test (Point 6)



M.D.D.:	2.04	g/cm^3	**O.M.C.:**	13.40	%	

Fig. 17. A plot of dry density (mg/m^3) against water content (%) on compaction test (Point 6)

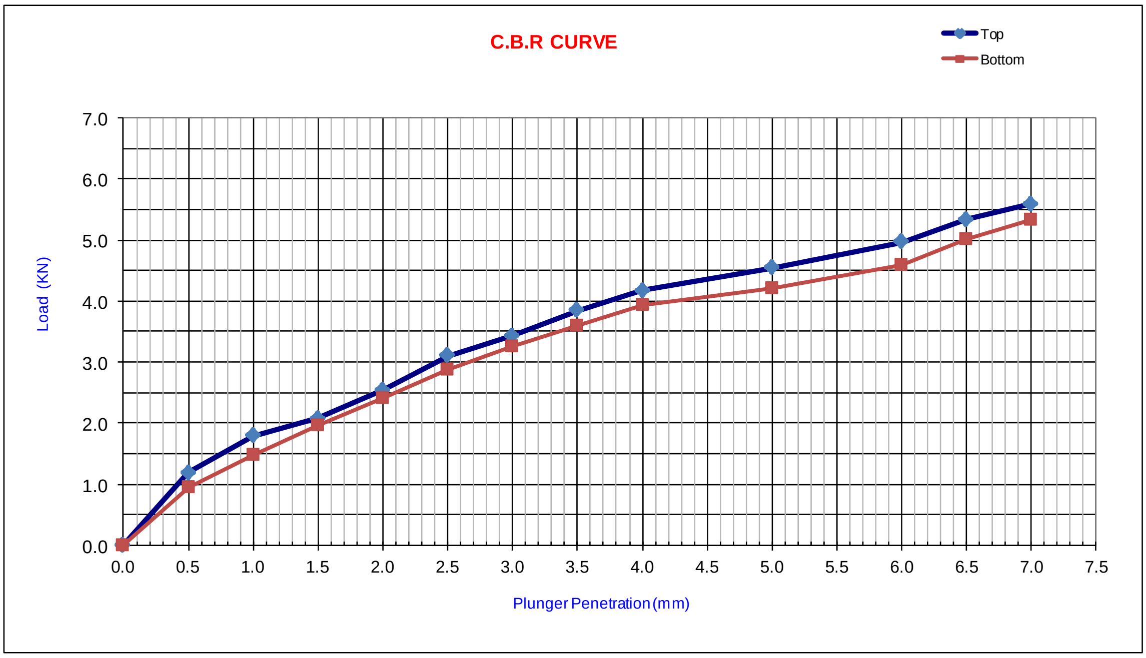


Fig. 18. A plot of load (KN) against plunger penetration (mm) on CBR test

(SOAKED-24 HRS Point 6)

V. RESULTS DISCUSSION

The result obtained from the geotechnical analysis test was classified based on the AASHTO standard and compared quantitatively by specifications to establish if the material is the same quality throughout and evaluate scattering results errors. The test carried out with the sample used in this research was calculated and presented in the chart above. To align with the F.M.W & H specification requirements for LL and PI of not more than 35% and 12%, determined by the American Society for Testing Materials Method (ASTM D422, 2007). The subgrade is suitable to be used in road construction since LL and PI values do not exceed the standard limit of 35% and 12% respectively. However, based on (AASHTO, 2000) and (USCS, 2006) comparison, samples classified as sandy silt, a non-plastic material. This gives an intimation of the prospects to productively restrain dilapidation waged being foot covering during dumpster diving (EPA, 2014). On the other hand, soils with regards to high-rise clarity indulge breathe prone to bulk shrinking (Rowe et al., 1995). Conforming to (Guney et al., 2014), for soil to be potent sheathing substantial, fragment dimensions are requisite to mollify at the minimum of (15-20)% clayed-sized materials with plasticity of greater than 10%. The density of the soil particles was found to range from (2.32 to 2.61) kg/m3 with an average value of 2.40 kg/m3 across the soil layer of the borrow pit. This exhibits a continuous periodic displacement of particle soil density concerning several blows. Moreover, the comparison of GS with soil density was done to ascertain its data sets from findings, It also shows that the subgrade sample of the borrow pit is primarily of good material, according to the specification of specific gravity ranging from 2.67 to 2.96. From the results presented in the graph above, the result revealed a CBR value of sample one to six after soaked as 25.7%, 24.4%, 22.3%, 21.7%, 20.4%, and 23.4% respectively. Based on (ASTM D422, 2007) specification requirements, the minimum strength for subgrade should not be less than 10% after at least 48 hours of soaking and not less than 80% un-soaked. Therefore, the above CBR soaked value obtained is good for road construction as required in the specification. However, Figure 3, 6, 9, 12, 15, and 18 shows linear variations of the load (kg) against penetration (mm). This implies an increase in penetration, increasing the load-bearing capacity of the road and its strength. In mechanical properties, the Natural Moisture Content (NMC) of earth materials from the borrowed pit ranges (from 11.74 to 15.28) % with an average of 13.88%. The low value obtained in some areas revealed that NMC loses moisture readily in its natural state. The MDD and OMC values of (2.20, 2.20, 2.21, 2.08, 2.06, and 2.04) kg/m3 and (14.00, 13.50, 12.50, 13.00, 12.25, and 13.40) % respectively were depicted as illustrated in Figure 2, 5, 8, 11, 14, and 17 with a vertical comparison between dry density water content as shown above. This variation in MDD and OMC values of the sample revealed that the subgrade samples are better classified due to their conformity to absorb less water increase on drying which promotes robust construction works. The sieve analysis in figure 1, 4, 7, 10, 13, and 16 shows the range and distribution of various sizes of particles. In line with the Federal Ministry of Work and Housing (F.M.W&H) specification requirement for subgrade samples. The percentage base on the limit of ≤35% for subgrade was 29.1% passing sieve No. 200. This required no need for advanced tests on samples, revealing good subgrade samples. The plot of a percent (%) passing sieve analysis in Figure 1, 4, 7, 10, 13, and 16, shows that the soil is well-graded. That is, from fine, medium to coarse particle size. Therefore, the uniform coefficient (Cu) and coefficient of curvature (CC) assessments of the soil particles range from 8 to 6, and 1. Under the Unified Soil Classification System (USCS, 2006), Cu greater than 4 to 6 classifies the soil as well graded, whereas, Cu less than 4 classifies it as poorly graded soil. Moreso, for the soil to be well graded, the value of CC must range between 1 and 3. Hence, the samples were classified as well-graded. On the other hand, employing the (AASHTO, 2000) system of soil classification, the inorganic soil sample acquired was grouped into A-1, Subgroups into A-1-a, and A-1- b constituting 50% and 29.1% significant material, rating the subgrade sample as excellent to good material suitable for construction works.

VI. CONCLUSION

The choice of suitable borrow pits used as subgrade material is crucial in road design and construction. This study specifically assessed the suitability of soils from Akiama community in Bonny Island, River State, Nigeria. as subgrade materials for road construction at Bonny Island. Comparison with standard samples indicated that these soils can effectively serve as graded subgrade material due to their favourable index and mechanical properties. According to AASHTO and USCS classifications, the subgrade was rated as excellent to good for construction purposes. The implications of this research are significant, demonstrating the feasibility of using borrow pits for road subgrade material. However, it is recommended that thorough laboratory testing be conducted on borrow pit material prior to their use in construction to ensure strength and stability. Geologists, Geotechnical engineers and contractors in the field should utilize this laboratory data to ensure durable road construction that adheres to engineering standards.

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