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A PROPOSED DAM SITE INVESTIGATION USING INTEGRATED GEOPHYSICAL AND GEOTECHNICAL METHODS; A CASE STUDY OF LOKO AREA, NORTHEASTERN NIGERIA

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ABSTRACT

The need for dam construction in the Loko area of northeastern Nigeria becomes necessary due to consistent flooding in the area and the demand for water for agricultural and domestic purposes. It is therefore very important to carryout adequate pre-construction investigations aimed at investigating the suitability of the area for dam siting. Geophysical and geotechnical investigation was carried out along River Loko. Detailed geologic mapping carried out showed that the area is 75% covered with alluvium while basalts and fine – medium grained granites underly the smaller portion of the area. A total of 10 Vertical Electrical Soundings were carried out using Schlumberger array. Disturbed soil samples were collected at a depth interval of 0.3m, from the surface to 1.2m, from three trial pits. Results of the geophysical survey show a 3 – 4-layer model consisting of H, HA, AH-type curves, interpreted with Interpex IX1D software. Results of the particle size distribution show that most of the samples are very uniform having a coefficient of uniformity of less than 5 according to (AASHTO) classification all the soil samples collected at the three trial pits are specifically A-3 soil group, which indicates that the material are fine sands. The Atterberg limit results indicate that most of the soil samples fall within the medium plasticity index. Soils with high plasticity (22.35) and medium plasticity (9) are usually semi-impervious to impervious, hence, suitable for dam foundation. The result of the unsoaked CBR compared with the standard, according to AASHTO, indicates that all samples fall under 7-20 which shows a general rating as 'fairly soil' and can be used as 'sub-base'. Compaction results show that for Pit 1, the sample at 0.3m, with MDD 1700kg/m^3 at OMC 20.0%, is the best sample. For Pit 2, the sample at 0.9m, with MDD 2400kg/m^3 at OMC 10.0%, is the best, and for Pit 3, the sample at 0.3m, with MDD 1800kg/m^3 at OMC 11.0%, is the best. The interpretations of the undrained shear strength result indicate that all the samples have 'soft consistency' since their values range from 23.0 to 25.7 KN/m^2. Based on the availability of construction material, perennial discharge from the river in addition to suitable geology and engineering properties, the area is feasible for an earth dam construction. Deep foundation is recommended for a massive rock filled dam, and some remediation is required in the design process to reduce the threat posed by thin fractures which may possibly cause subsurface seepage.

KEYWORDS: Dam construction, Geophysical, Vertical Electrical Soundings, soil samples, rock filled

INTRODUCTION

A dam is a solid barrier constructed at a suitable location across a river with a view to impound water flowing through it. Dams are usually built using concrete or natural materials such as earth and rock. Dams are among the largest and most important structures in civil engineering. For geologic, hydrologic and topographic reasons, there are limited numbers of ideal sites for dams. They are major engineering structures that are designed and constructed with long life expectancy.

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Due to the fact that dam constructions serve tremendous purpose to the human community, the design and construction of a dam is expected to create a stable structure that will last for a very long period of time. Out of the various natural factors that directly influence the design of dams, none is more important than the geologic, not only do they control the character of the foundation but they also govern the materials available for construction. For geologic, hydrologic and topographic reasons, there are limited numbers of ideal sites for dams' placement. It is therefore very important to intensely scrutinize any proposed dam site. The demand for dam for water supply and other purposes especially in areas with good potentials is constantly on the increase. It is therefore very important to carryout adequate pre-construction investigations. Dam intended for water supplies require a low tolerance of seepage loses. Besides, the design of dam structures must be adapted to the existing dam conditions (Ajayi et al., 2005) to minimize loses. Failure to do any of these may invariably result in unplanned seepage and/or total collapse of the structure (Olorunfemi et al., 2000; Ankidawa et al., 2020). Biswas and Charttergee (1971) examined causes of dam failure worldwide and discovered that 25% of the failures were due to geotechnical problems associated with seepage, inadequate seepage cut-off, faults, settlements and landslides. A geotechnical and geophysical survey is often the most cost-effective and rapid means of obtaining subsurface information especially over large study areas (Sirles, 2006). A dam has its relevance in supply of water for municipal and industrial use, human and animal consumption, generation of electrical power and irrigation. The integrity of a dam can be undermined by the existence of geological features such as faults, fractures, fissures, jointed or shear zones. Precipitated seepage zones in the bedrock and discontinuities in the structure itself are other factors that pose threat to the integrity of a dam (Felix el al., 2013). The evaluation of dam sites among many other parameters includes stability studies, simulation of the probable maximum flood (PMF) and uplift pressures under the dam, depth to bedrock, stratigraphic continuity, structural mapping, stability studies. Studies have shown that the engineering properties of soils improved through compaction and/or addition of other soils with better properties (Ogunsanwo, 1996; Adeyemi and Salami, 2002). Movement of water through soils depends on two factors: the forces acting upon the water molecules and the ease with which they can flow through the soil. These factors vary from one soil to another, depending on the amount of organic matter of the site and arrangement of mineral particles which is by size and number of pores where water can be held (Bouwer, 1977). In soils with large, irregularly shaped sand particles, for example, large pores remain between the sand grains. Clay particles, by contrast, fit together more compactly so that the pores are smaller but numerous. An integrated geotechnical and geophysical survey is often the most cost-effective and rapid means of obtaining subsurface information especially over large study areas (Sirles, 2006). This was employed for the Loko river and was done in order to establish the depth to bed rock, depth to water table, geo-electric sections from the layered parameters, concealed basement morphology, fractures /seepage channels(s) (where they exist) in the subsurface thus, enabling the evaluation of the feasibility of the area for establishing a dam and reservoir.

THE STUDY AREA

Loko area is located in Song Local Government area of the present Adamawa State, Northeast Nigeria. The area falls within latitude 09° 43' 00''N – 9° 48' 00'' N and longitudes 12° 33' 00''E – 12° 38' 00''E (Figure 1). The area covers an aerial extent of about 83.72km^2. It is accessible through the Yola – Mubi Federal Road and is bounded to the north and northeast by Gombi and Hong Local Government Area (LGA), to the south and southeast by Girei and Fufore LGA, to the east by Maiha LGA and to the west by Shelleng LGA of Adamawa State. The main occupations of the people in the area are farming and trading. The area is characterized by two climatic seasonal patterns; the wet seasons are between the months of May to October, while the dry seasons are between the months of November-April (Adebayo, 1999). The vegetation, according to Akosim et al. (1999), is that of Northern Guinea Savannah type with average annual rainfall between 900 and 1100mm. Generally, in the months of August and September the heaviest and also the greatest number of raining days are recorded. The seasonal variation in relative humidity between January and March is very low, 20 to 30% (Adebayo, 1999). Temperatures in the study area are extreme; both the diurnal and annual ranges of temperature are wide. Temperatures during this period range from 20 to 24°C, while at night; temperatures could be as low as 10°C at higher altitudes. Months of March to June experience increasing temperatures as the rainy season set in the daily maximum temperature may exceed 46°C. The study area generally has sparse tree growth but lush grassland especially in the rainy season. The area relatively lies on a low plain with elevation that ranges from 235 to 265m, while the highest peak lies at about 280m above mean sea level. The elevation of the land surface generally increases northwards with several of the hills marked by steep straight slopes. The area is well drained by a network of streams whose courses are obviously controlled largely by geologic structures. Most streams have straight channels and flow in N-S, NW-SE or NE-SW. The major streams in the area have their origin northwards and outside the study area, where there are many hills. They then flow southwards along narrow channels. River Loko flow in a NE-SW direction and flows through the central part of the study area.

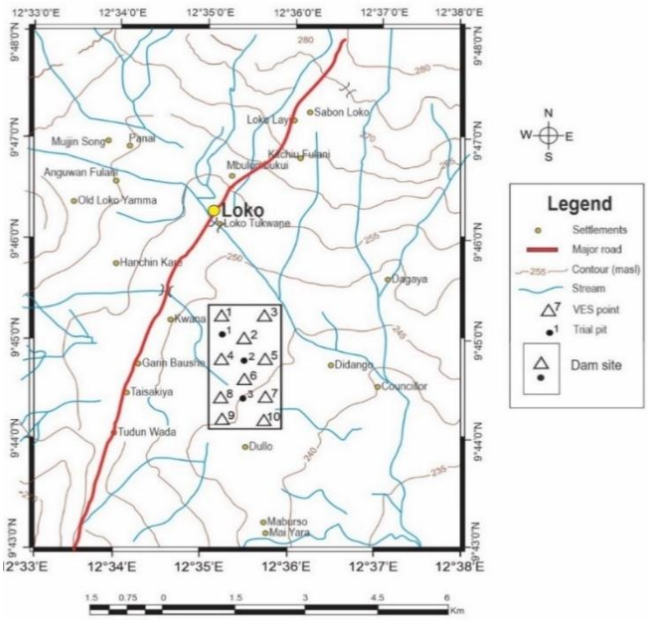


Figure 1. Topographic map of the study area showing the VES point and Trial Pit Point at the proposed dam site

MATERIALS AND METHODS

A detailed geologic mapping was carried out within the study area of Loko and environs from 23 February to 2 March, 2021, which covered an aerial extent of about 83.72km^2. Measurement and description of structures found on the in-situ exposed host rock and observations were recorded in the field book and on topographic map. During the geological mapping exercise, attention was paid to marking out the boundaries of rock types by using GPS, plotting the coordinates of the rock boundaries on the map and joining them. Ten (10) VES stations were investigated at maximum electrodes separation of AB/2 equals 160m (maximum). The ABEM (Signal Averaging System) SAS 4000 Terrameter was used for the field data collection. This instrument measures and displays the resistance of the subsurface. Metal electrodes were used to induce current into the ground and measures the potential difference, while measuring tape used to lay out electrodes, Hammer was used in driving the metal electrodes into the ground, Car battery and roll wires. Geotechnical investigation involves collection of disturbed representative samples from trial pits. The samples for geotechnical tests were collected and packaged in plastic bags and transported to the soil laboratory for analysis. The geotechnical parameters that were carried out on the samples included; grain size distribution, Atterberg limit, California bearing ratio (CBR), compaction, and shear strength. The triaxial graph (Mohr circles) is then plotted i.e. the cell pressure (KN/m^2) against the total vertical pressure (KN/m^2). The c and ø is gotten from the Mohr circles.

RESULTS AND DISCUSSION

Detailed Geologic Field Mapping

Loko area is geologically situated at the tip of the Hawal Massif of the Northeast Basement Complex. Large percentage of the area is covered by alluvial deposits followed by basalts with fine- to medium-grained granite which cover the smaller percentage of the area. The alluvial cover within the area is as a result of transported weathered material from the study area (Figure 2). Fine to medium-grained granite underlies a small portion of the area. Most of the rocks occur as boulders of different sizes ranging from 50 cm to 5m. Numerous large phenocrysts of orthoclase feldspar of different sizes, ranging from 5 mm to 3 cm, are scattered within the rock fabric and are affected by extensive spheroidal weathering. Most minerals, except biotite exhibit strain features marked by E-W and N-S trending striations in the feldspar grains. The feldspar porphyblasts, which vary from pinkish microcline to white oligoclase, are fairly aligned conformable to the N-S regional structural trend. Two types of basalts were encountered in the mapped area and covers about 20% of the study area, these are the non-vesicular and the vesicular basalt types. They occur in boulders of different sizes, ranging from 14cm to about 4m. They are fine-grained, black and contain some grains of olivine phenocrysts scattered within the matrix of the rock. The vesicular basalt ranges in size from 30cm to about 60cm. The vesicles range between 2 to 4mm in diameter and are randomly distributed within the rock. The non-vesicular basalts occur as relics of basaltic flows, represented by boulders and black soils, are found in almost all the drainage channels and low-lying plains.

Alluvial deposits covered about 75% of the study area. These alluvial deposits, which are mostly due to seasonal flooding in the study area, are mostly of fine to silty sand composition, and have been deposited over a wide area. It is also found along the narrow river channels, in few meters' deposits of medium sand. In the study area, the alluvial deposits are found along principal river channels which are broader and gently meandering with clean, coarse sandy bottoms. Exposures of the deposit also outcrop on plains in the northeastern part of the mapped area where farming activities is extensive.

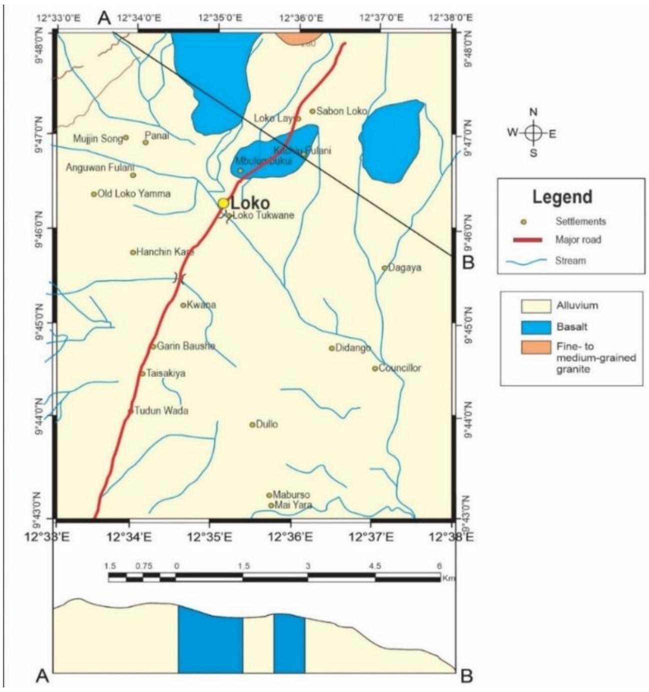
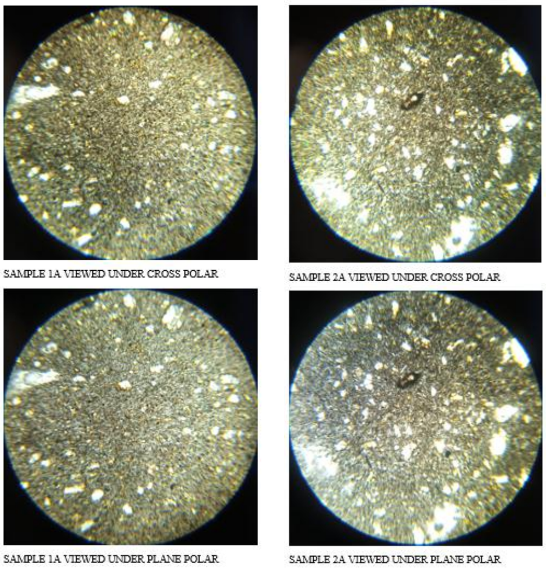


Figure 2. Geologic map of the study area with cross section

Petrographic Studies of rock samples

A total of six representative rock samples were selected and their slides prepared and observed under a polarizing microscope. The photomicrographs of the studied samples are presented in Plates 1 to 6. From the study of the rock samples under both plane polarized and cross polarized lights, the following minerals were observed: quartz, and microcline, and plagioclase in sample 4A.



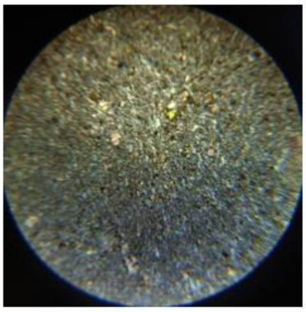
Magnification 40X Magnification 40X

Plate 1. Photomicrograph of Vesicular Basalt Plate 2. Photomicrograph of Non-vesicular Basalt


SAMPLE 2B VIEWED UNDER CROSS POLAR


SAMPLE 2B VIEWED UNDER PLANE POLAR

Magnification 40X
Plate 3. Photomicrograph of Non-vesicular Basalt


SAMPLE 3A VIEWED UNDER CROSS POLAR

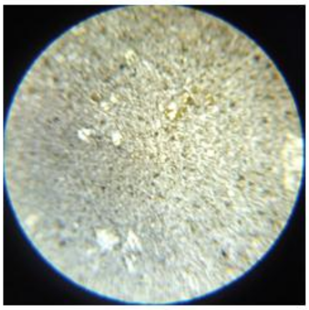

SAMPLE 3A VIEWED UNDER PLANE POLAR

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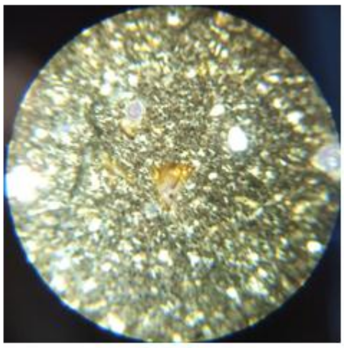
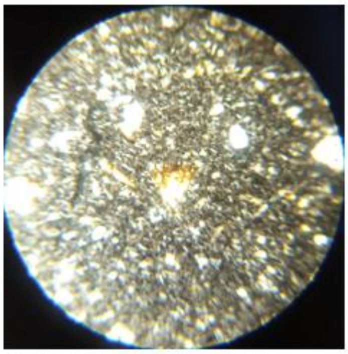
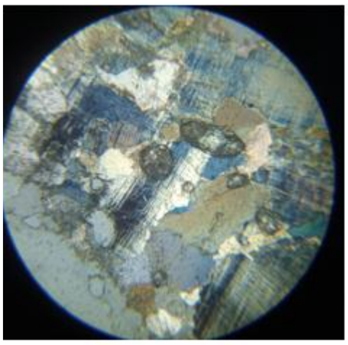
Plate 4. Photomicrograph of Non-vesicular Basalt


SAMPLE 3B VIEWED UNDER CROSS POLAR


SAMPLE 3B VIEWED UNDER PLANE POLAR

Magnification 40X
Plate 5. Photomicrograph of Vesicular Basalt


AMPLE 4A VIEWED UNDER CROSS POLAR


AMPLE 4A VIEWED UNDER PLANE POLAR

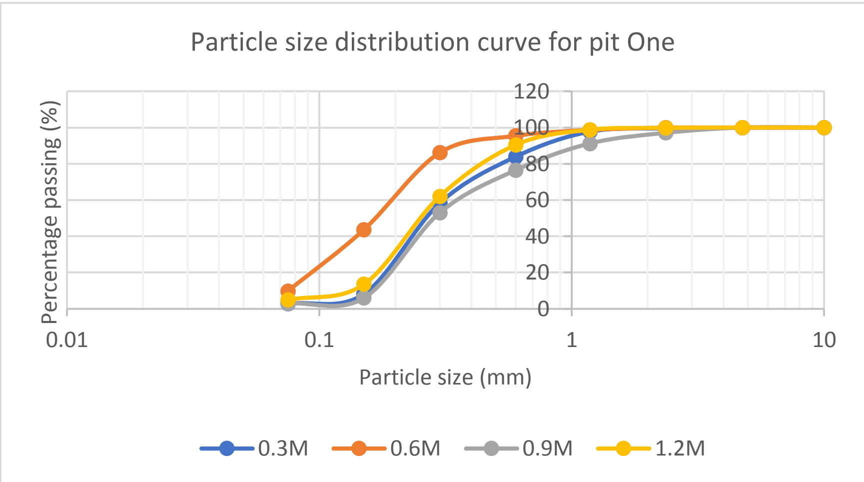
Magnification 40X
Plate 6. Photomicrograph of Fine-Medium grain Granite

Analysis of VES Data

Three curve types were identified within the study area and the number of layers varies between three layers and four layers; with four layered type curves being predominant. Table 1 shows the summary of the interpretation of VES 1 to VES 10 curves in terms of the apparent resistivity and the thickness of each soil layer. The VES are typical of the basement terrain being H, HA, AH-type curves. In general, the subsurface of the dam axis consists of the following three layers: VES 5, VES 6, VES 7 and VES 8. The 1st layer which extends from the surface down to a depth of 8m significantly composes of top soil and alluvium of sandy-clay and fine- to medium grained sands with apparent resistivity values ranging from 18.20 to 22.00 Ωm. The 2nd layer which extends from the depth of about 8m to 80m with apparent resistivity values ranging from 8.70 to 13.40 Ωm, suggesting that these layers are composed of weathered basalt/basement. The 3rd layer which extends from depth of about 80m to infinity with apparent resistivity values ranging from 20.50 to 25.70 Ωm and suggests that these layers are composed of fresh basement. The subsurface of the dam axis with four layers consist of VES 1, VES 2, VES 3, VES 4, VES 9 and VES 10. The 1st layer which extends from the surface down to a depth of 8m significantly composes of alluvium (fine sands and sandy-clay) with apparent resistivity values ranges from 7.77 to 15.00 Ωm. The 2nd layer which extends from the depth of about 8m to 50m with apparent resistivity values ranging from 7.33 to 31.50 Ωm, suggesting that these layers are composed of weathered basaltic rocks. The 3rd layer which extends from the depth of about 50 to 100m suggest that these layers are composed of weathered/fractured basement rocks. The 4th layer extends from the depth of 100m to infinity with apparent resistivity values ranging from 19.00 to 37.4 Ωm, suggesting that these layers are composed of fresh basement.

Table 1. Summary of computer software output of VES data from the ten (10) points

VES	LAYER THICKNESS (M)			LAYER RESISTIVITY (ΩM)				CURVE TYPE	FITTING ERROR	INFERED LITHOLOGY
	h_1	h_2	h_3	ρ_1	ρ_2	ρ_3	ρ_4			
1	3	47	50	15	31.5	22.7	31.6	AH	0.86	Alluvium, Weathered basalt, Fractured basement, Fresh basement
2	6.5	23.5	35	8.37	16.6	27.6	37.4	HA	0.87	Alluvium, Weathered basalt, Weathered basement, Fresh basement
3	8	12	80	7.77	12.1	18.6	26	HA	0.82	Alluvium, Weathered basalt, Weathered basement Fresh basement
4	1.5	23.5	75	13.4	7.33	12.3	19	HA	0.93	Alluvium, Weathered basalt, Weathered basement, Fresh basement
5	8	72	-	18.8	13.4	23.2	-	H	0.71	Alluvium, Weathered basalt, Fresh basement
6	6.5	73.5	-	21.9	12.8	24.1	-	H	0.84	Alluvium, Weathered basement, Fresh basement
7	6.5	70	-	18.2	12.1	25.7	-	H	0.82	Alluvium, Weathered basement, Fresh basement
8	1.5	7.2	-	22	8.7	20.5	-	H	0.89	Alluvium, Weathered basement, Fresh basement
9	2.5	5.5	92	14.1	21.2	25.4	32.8	AH	0.74	Alluvium, Weathered basalt, Fractured basement, Fresh basement
10	2	38	60	14.1	8.38	14.7	24.8	H	0.88	Alluvium, Weathered basalt, Weathered basement Fresh basement



Subsurface resistivity is related to the physical property of interest such as lithology, porosity, water content, etc., therefore, electrical resistivity measurements determine subsurface resistivity distributions thereby differentiating layers based on resistivity values as studied by Ako (1996); Amos et al. (2012). Zohdy (1989) indicated that sounding curves obtained over a horizontally stratified medium could be presented as a descriptive profile displaying variation of apparent resistivity with depth. The profile is a scale drawing of the successive layer resistivities and thicknesses. Thus, a geoelectric section is a profile displaying variation of apparent resistivity with depth. The geoelectric section of the study area is presented in Figure 3.

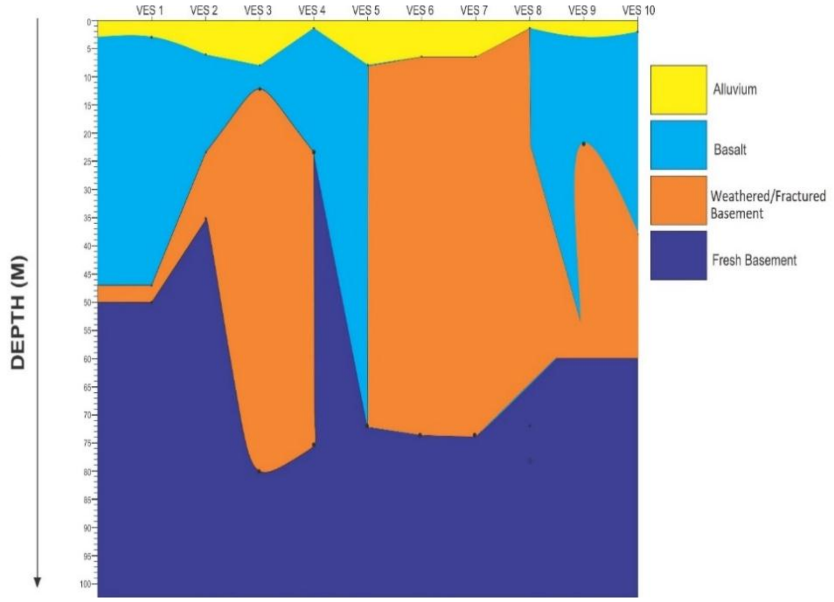


Figure 3. Geoelectric section of the study area

Particle Size Distribution

The classification was done through the values obtained from the sieve analysis which is presented in the grain size distribution curves (Figures 4 to 6) and indicated well graded sand (SW) group. A soil is called a well-graded soil if the distribution of the grain sizes extends over a rather large range in the chart (Adewoye and Esho, 2017; Ankidawa et al., 2020). Table 2 shows that the soils at TP 1 are very uniform because of the coefficient of uniformity is less than 5. Soils from TP 2 at 0.3 and 0.6m are also very uniform while at 0.9 and 1.2m are well graded soils because of the value of the coefficient of uniformity is greater than 5. Soils from TP 3 at 0.3 and 1.2 are very uniform while at 0.6 and 0.9m are very well graded. According to the American Association for State Highway Transportation Officials' (AASHTO) classification, all the soil samples collected at the three trial pits are specifically A-3, which indicates that the significant material are fine sands (Table 3). The variation in the percentage of fines, sand and gravel can be due to difference in the degree of weathering, and the nature of the parent rock.

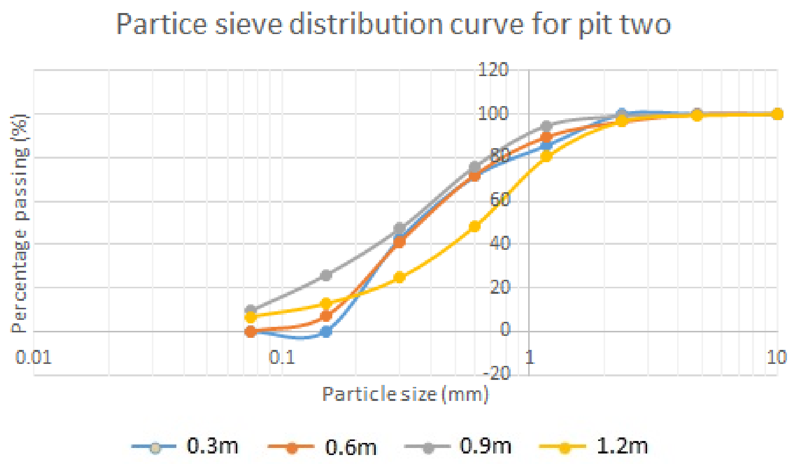


Figure 4. Particle size distribution curve for TP 1

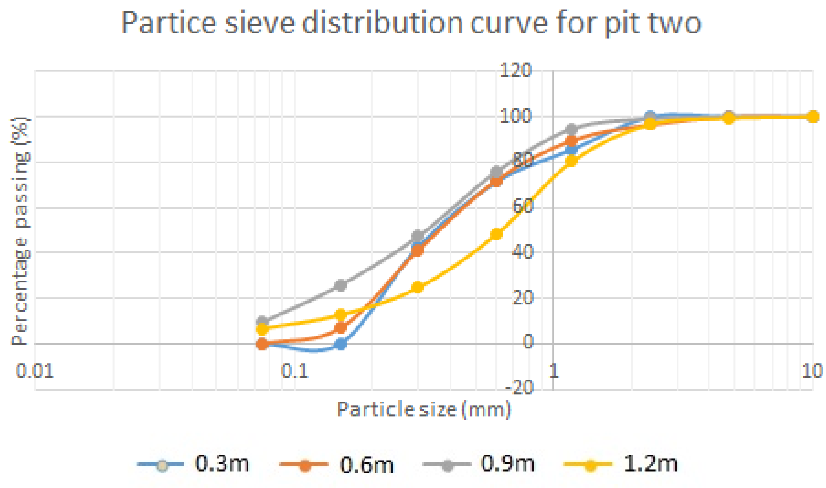


Figure 5. Particle size distribution curve for TP 2

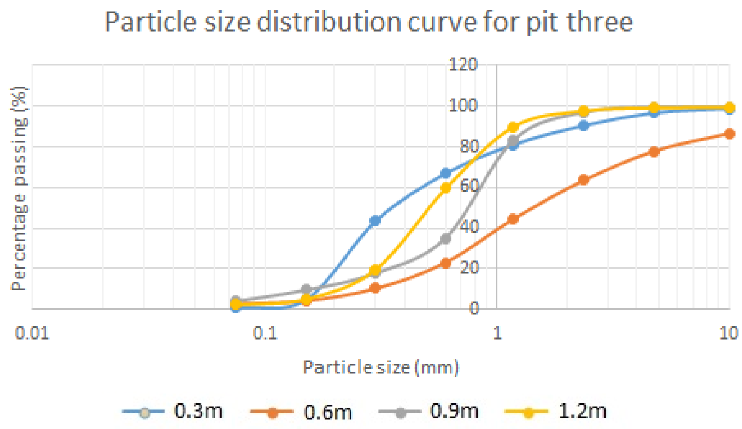


Figure 6. Particle size distribution curve for TP 3

Table 2. Showing the Effective size and Uniformity Coefficient

Trial Pit	Sample at depth (m)	D_{60}	D_{30}	Effective Size D_e or D_{10}	Uniformity Coefficient D_{60}/D_{10}	Interpretation
1	0.3	0.3	0.23	0.17	1.76	Very Uniform Sand
	0.6	0.17	0.12	0.076	2.24	Very Uniform Sand
	0.9	0.37	0.22	0.16	2.31	Very Uniform Sand
	1.2	0.29	0.18	0.14	2.07	Very Uniform Sand
2	0.3	0.5	0.23	0.18	2.7	Very Uniform Sand
	0.6	0.42	0.26	0.17	2.47	Very Uniform Sand
	0.9	0.45	0.18	0.072	6.25	Very Well Graded Sand
	1.2	0.8	0.38	0.11	7.27	Very Well Graded Sand
3	0.3	0.48	0.23	0.16	3	Very Uniform Sand
	0.6	1.9	0.73	0.27	7.04	Very Well Graded Sand
	0.9	1	0.5	0.16	6.25	Very Well Graded Sand
	1.2	0.6	0.4	0.2	3	Very Uniform Sand

Table 3. Grain size distribution summary

Trial Pit	Sample at depth (m)	Coefficient of gradation Cc	% fines (%)	% Sand	% Gravel	AASHTO Soil Group	AASHTO Classification
1	0.3	1.04	3	97	0	Fine Sand	A-3
	0.6	1.54	9	91	0	Fine Sand	A-3
	0.9	0.81	3	97	0	Fine Sand	A-3
	1.2	0.78	5	95	0	Fine Sand	A-3
2	0.3	0.58	0.7	99.3	0	Fine Sand	A-3
	0.6	0.94	0	100	0	Fine Sand	A-3
	0.9	1	9	91	0	Fine Sand	A-3
	1.2	1.75	7	92	1	Fine Sand	A-3
3	0.3	0.71	0.8	95.2	4	Fine Sand	A-3
	0.6	1.04	2	76	22	Fine Sand	A-3
	0.9	1.56	4	95	1	Fine Sand	A-3
	1.2	1.33	2	97	1	Fine Sand	A-3

Atterberg Limits Analysis

The Atterberg or consistency limits tests determine the moisture content at which the soil will flow under its own weight. It defines the boundaries of several state of consistency of plastic soil. It is used to determine the plasticity of soil. Atterberg limits tests were used in determining the following parameters: liquid limit, and plastic limit. Table 4 presents the results obtained from the laboratory. Atterberg limit shows the relationship between liquid and plastic limit. In the Casagrande plasticity chart of the samples, it is indicated that most of the soil samples fall within the medium plasticity. Soils with high plasticity and medium plasticity are usually semi-impervious to impervious (Daniel, 1993), hence, would be suitable for damming. Those with medium plasticity have a higher compressibility than those with high plasticity. According to Bouwer (1977), the liquid limits for fines fraction of the samples from the three trial pits fall below 50%, hence, the Unified Soil Classification (USCS) shows that TP 1 samples at depths 0.6m, 0.9m and 1.2m are CL (inorganic soils with medium plasticity), while the sample at 0.3m corresponds to OL (organic soil with medium plasticity). For TP 2, samples at 0.3m, 0.6m and 0.9m, corresponds to CL, while the sample at 1.2m is ML (inorganic soil with slight plasticity).For TP 3 pit , the samples at 0.3m, 0.9m, and 1.2m are CL, while that of 0.6m is OL. The plasticity indices of all the samples range from 8.00 - 22.35 indicating low to medium plasticity (Burmister, 1997).

Table 4: Result of Atterberg Limits Tests

Trial Pit	Sample at depth (m)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index	Linear Shrinkage Limit (mm)
1	0.3	32.00	24.00	8.00	9.65
	0.6	30.00	20.30	9.70	10.35
	0.9	30.00	16.00	14.00	11.05
	1.2	43.00	20.65	22.35	10.35
2	0.3	39.00	20.30	18.70	6.80
	0.6	35.00	19.00	16.00	16.43
	0.9	34.00	18.40	15.60	9.65
	1.2	29.00	14.60	15.00	9.30
3	0.3	30.00	20.30	9.70	6.07
	0.6	36.00	25.40	10.60	9.64
	0.9	34.00	23.00	11.00	2.86
	1.2	34.00	19.03	14.97	4.65

Casagrande Plasticity Chart Classification

The Casagrande chart classifies soils according to their plasticity characteristics. The plasticity index is plotted against the liquid limit and A-line is drawn which separate inorganic soils from organic soils. The graphs of the tested soil samples are represented in Figures 7 to 9. The plastcicity chart can be used to determine if a soil has a high plasticity, medium plasticity or low plasticity. The Casagrande classification of all the soil samples at TP 1 as 'inorganic medium plasticity', for TP 2, samples at 0.3m, 0.6m and 0.9m are classified as 'inorganic medium plasticity' while sample at 1.2m is 'inorganic low plasticity' soils, for TP 3, all the soil samples are 'inorganic medium plasticity'. Soils with high plasticity and medium plasticity are usually semi-impervious to impervious (Daniel, 1993). The general classification of the soil samples show they range between low-medium plasticity. Those with medium plasticity however have a higher compressibility than those with high plasticity. Also, low plasticity soils have fair shear strength while the highly plastic soils have poor shear strength. Thus, organic soil has high plasticity, low shear strength and therefore not suitable for sub-base material. The shear strength determines the workability of the soil as the smaller the shear strength, the poorer the workability of the soil; although some factors have to be considered.

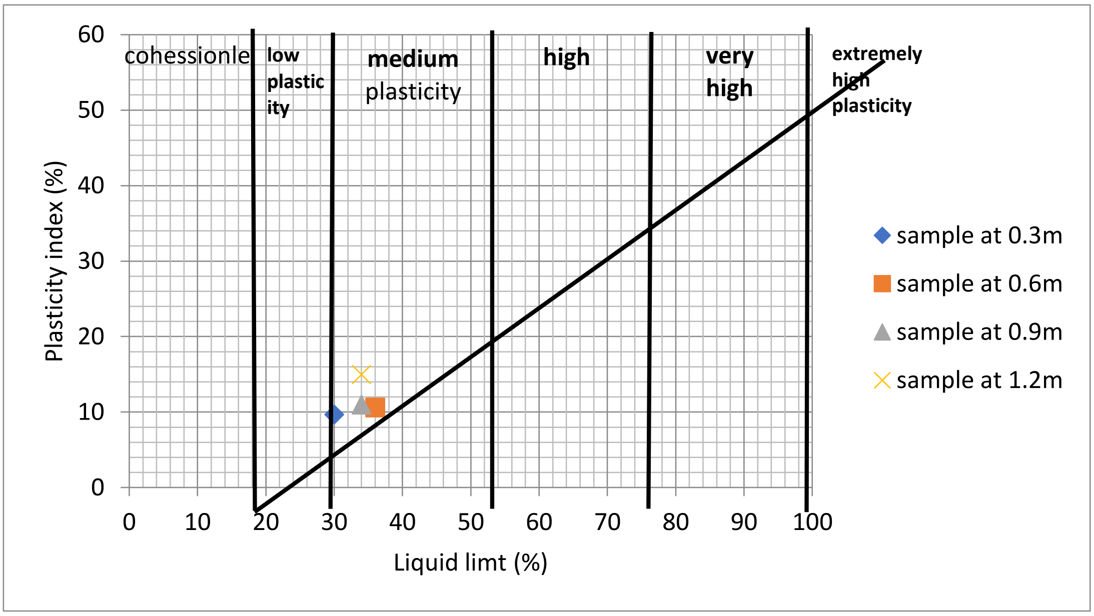


Figure 7. Casagrande Chart for TP 1

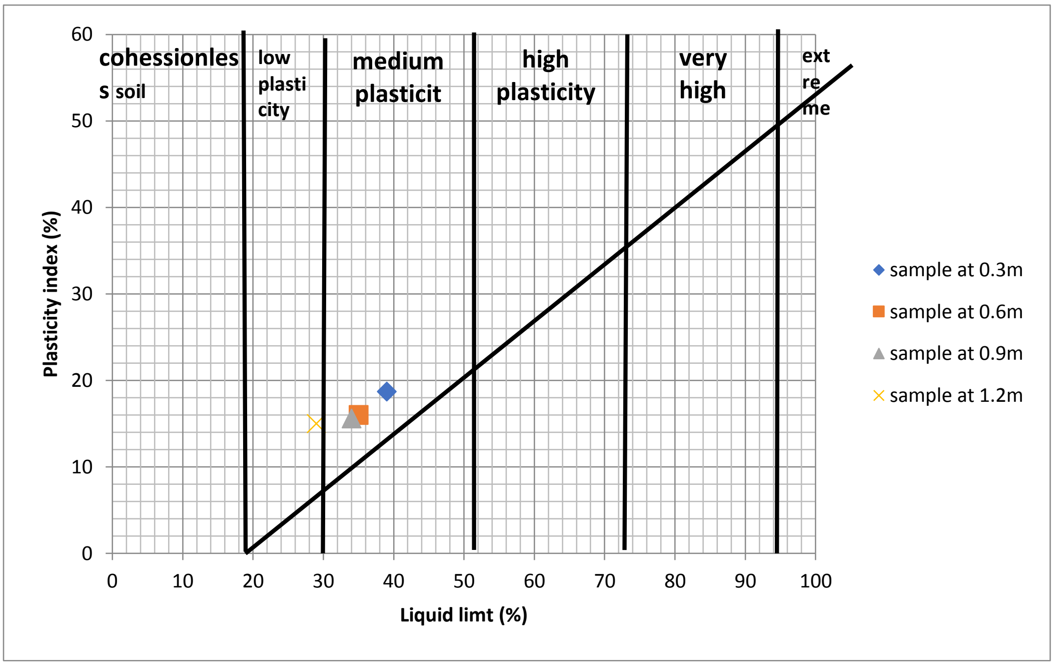


Figure 8. Casagrande Chart for TP 2

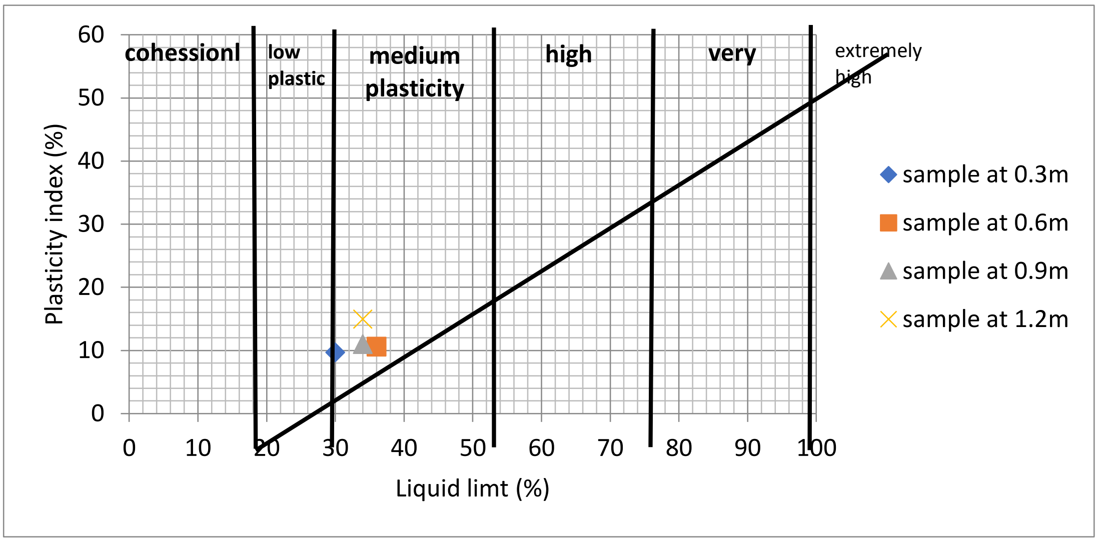


Figure 9. Casagrande Chart for TP 3

Compaction

When a sample is compacted at two different levels, the level that gives the higher maximum dry density (MDD) at lower optimum moisture content (OMC) is better. When two samples are compacted at a level, the sample with higher MDD at lower OMC is better as foundation material. In this study, the samples were compacted at the same level For TP 1, the sample at 0.3m, with MDD of 1700kg/m^3 at OMC of 20.0%, is the best sample. For TP 2, the sample at 0.9m, with MDD 2400kg/m^3 at OMC 10.0%, is the best, and for TP 3, the sample at 0.3m, with MDD 1800kg/m^3 at OMC 11.0%, is the best. The graphs are represented in Figures 10 to 12, Since the whole samples have been described as well graded sands and very uniform in their composition by the earlier grain side distribution test, the compaction interpretation will be based on granular material with soil, fine sands and sands, sandy silts and silts, and silty clays (ASTM, 1992) with visual description as granular materials. TP 2, with sample at 0.9m having 2.4g/cm^3 MDD with 10.0% OMC, fall under the standard of 2.00-2.27g/cm^3 with OMC range of 7-15%, is good to excellent as anticipated embankment performance, excellent for sub-grade material and good as base course. Granular materials with the maximum MDD 1.9g/cm^3 to 1.8g/cm^3 has the least fall under the standard of 1.76-2.16 g/cm^3, with maximum OMC of 8.0% to 11.0% fall under the standard 9-18%, hence, are fair to excellent as anticipated embankment performance. For sandy silts and silts, all the samples are poor to good as anticipated embankment performance. For silty-clays, all the samples are poor to good for anticipated embankment performance.

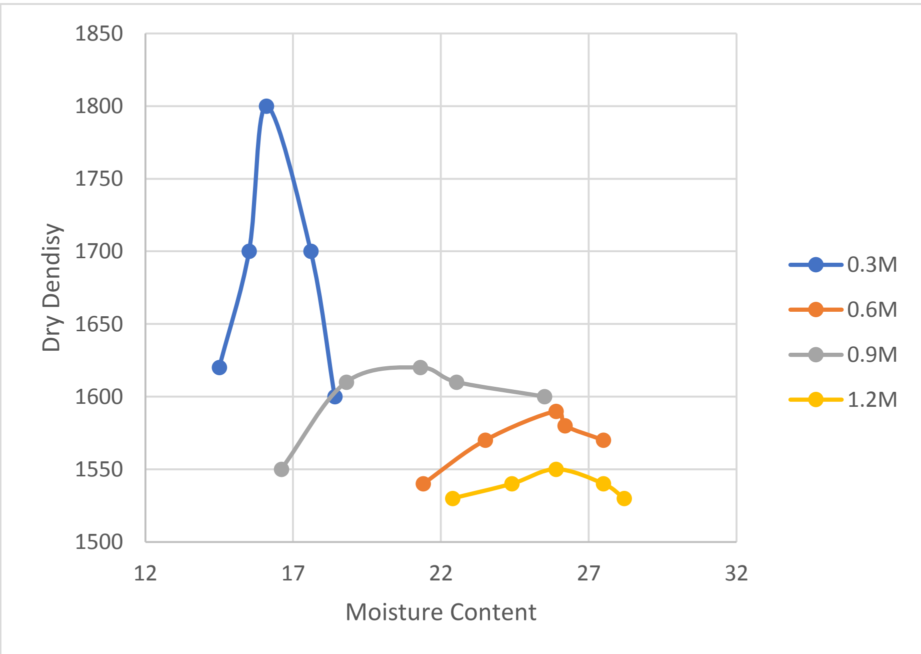


Figure 10. Graphical Representation of Compaction for TP 1

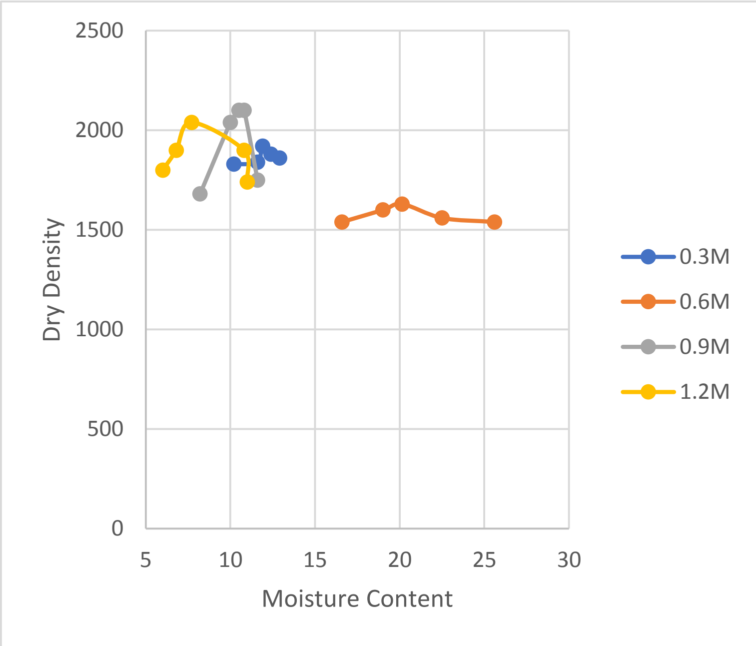


Figure 11. Graphical Representation of Compaction for TP 2

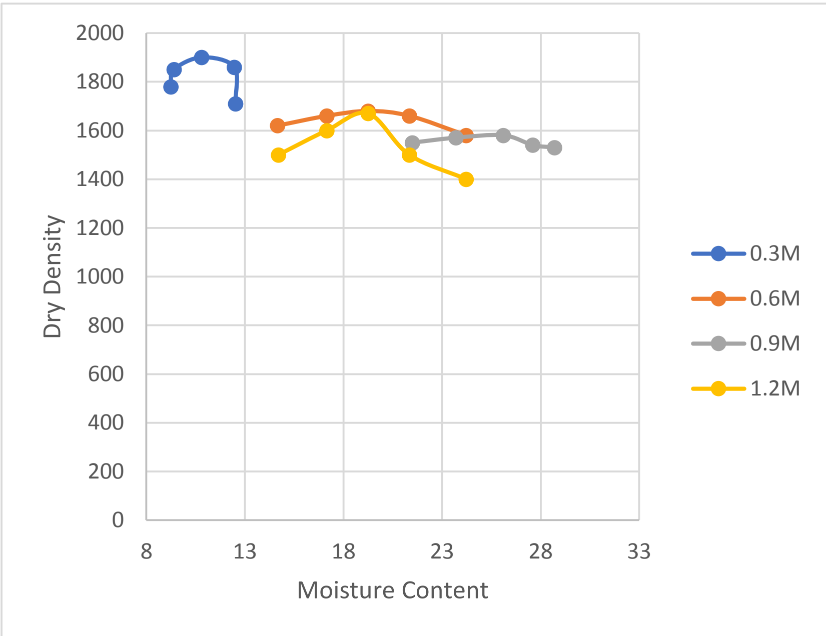


Figure 12. Graphical Representation of Compaction for TP 3

Triaxial Test/Shear Strength Determination

The interpretations of the undrained shear strength result indicate that all the samples from all the three trial pits have 'soft consistency' since their values are between 23.0 - 25.7 KN/m^2 (Adewoye and Esho, 2017). Generally, the samples from TP 2 at depths 0.6m, 0.9 and 1.2m show grain sizes that are coarser and the grain shapes that are more angular due to higher angle of internal friction when compared to the other samples. Also, the varying angle of internal friction can assist in concluding that the samples from TP 2 and TP 3 are characterized by approximately
different grain sizes which indicates that it is well graded except for TP 1 that has have? a uniform angle of internal friction. The shear strength parameters, cohesion (c) and angle of internal friction (ø) were obtained for all the samples. The interpretation of ø as compared to the data by Terzaghi (1943) and Schmertmann et al. (1978). According to Terzaghi (1943), all the samples from the three trial pits are 'very loose' soil type since their ø all fall below 30°. In case of loose sand, there is no initial particle interlocking to be overcome and the shear stress increases gradually to an ultimate value there being no peak value. The increase in shear stress strength is accompanied by a decrease in the volume of the specimen. The shear strength of a soil is dependent on the angle of internal friction, thus, the higher the angle of internal friction the higher the shear strength property of the soil. Some factors affect the shear strength properties of a soil, these includes; Grain size, shape, and degree of compaction, (Mayerhof, 1974**)** and later modified by (Schmertmann et al., 1978).

CONCLUSIONS

Geologic field mapping revealed that 75% of the study area is covered by alluvial deposits, basalts and fine to medium grain granites. Results of the petrographic analysis reveals that the granites have mineralogical composition of quartz, plagioclase, microcline and opaque mineral while the basalts are consisting of quartz, pyroxene, olivine, iron oxide and opaque mineral. Results from the 10 VES points show a 3 – 4-layer earth model comprising of top soil, alluvium, weathered basalt, weathered basement and fresh basement as indicated in the rock resistivity values. The grain size distribution test results show the presence of A-3 soil group which indicates the presence of fine sands, while the Atterberg result shows the state of plasticity of the soils range from 'low-medium' which also corresponds to the Casagrande classification which shows that most of the soils are inorganic soils with low to medium plasticity. The shear strength of the soils shows consistency of the samples as 'soft consistency' and corresponds to the CBR result that generally describes the soil samples as being fairly good and can be used for dam foundation. The results of the geophysical and geotechnical investigation carried out along the proposed river Loko dam site showed that the area is underlain by thin superficial (overburden) material of fine sands (alluvium) and thin fractures were detected within the proposed dam site which could cause subsurface seepage channels. Base on the engineering geological investigation together with classification the area is feasible for an earth dam and construction materials can be found within a reasonable distance from the site, such as sand, gravel and clay.

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