Geotechnical Investigation of a Proposed Dam in Adunyin Area Ogbomosho, Southwestern Nigeria

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ABSTRACT: This paper discusses each geotechnical parameter carried out at Adunyin Area Ogbomosho, Southwestern Nigeria. This was aimed at investigating the potential or suitability of the river for dam siting. This research examined the geotechnical properties of twelve (12) soil samples (disturbed samples). The soil samples were obtained from upstream, dam axis and downstream sides of the study area, from three trial pits at depth of 3.0 meters with each sample taken at 0.5 meter interval. Geotechnical tests were carried out to determine Soil classification, Maximum Dry Density (MDD) and Optimum Moisture Content (OMC), Plasticity Index (PI), Coefficient of Permeability (CP), shear strength, and resistance to loading. Geotechnical assessment of soil samples revealed that they are generally well graded, with low to medium plasticity, the best samples for foundation have high MDD at OMC which include samples at 0.5m for pit one, 3.0m for pit two and 0.5m for pit three, the coefficient of permeability generally indicates that the samples have very low permeability, which indicates the presence of impervious soils, the shear strength shows the samples' consistency range from stiff to very stiff or hard, the resistance to loading indicates that the soils are generally good for base-sub-base.

KEYWORDS: Geotechnical , Dam , Adunyin River, Ogbomosho, Southwestern Nigeria.

INTRODUCTION

Dams are among the largest and most important in civil engineering [1]. 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. 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 [2]. Out of the various natural factors that directly influence the design of dams, none is more important than the geological, 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 [2]. It is therefore very important to intensely scrutinize any proposed dam site. However, demand for dam for the purpose of water supply especially in areas with good potential is constantly on the increase. It is therefore very important to carryout adequate pre-construction investigations.

The information provided by the study is expected to aid dam site investigation. 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 [3] to minimize the loses. Failure to do any of these may invariably result in unplanned seepage and/or total collapse of the structure [4]. [5] 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 geophysical survey is often the most cost-effective and rapid means of obtaining subsurface information especially over large study areas [6]. 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 [7].

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 [8]. Studies have shown that the engineering properties of soils improved through compaction and/or addition of other soils with better properties [9]; [10]. 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 [11] . 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.

The pre-construction investigation provides information on the subsurface lithologies and their thicknesses, identifies the competent bedrock and determines depths to its upper interface, establishes through geotechnical parameters, and examines the degree of competence of the foundation bedrock [12];[13]; and [14]. In geotechnique, subsoil competence is evaluated through series of tests which include compaction, triaxial, and consolidation tests. In geophysical prospecting, the Compression (P) and Shear (S) wave velocities in earth materials can be used to evaluate subsoil competence through the determination of the bulk modulus [15] and [16]. Compact subsoil is characterized by reduced porosity and moisture content with consequent increase in resistivity. It should therefore be possible to use resistivity measurements as indices of subsoil competence. The aim is to investigate the suitability of Adunyin River for dam siting with the objective determining the strength of the subsurface layers for the construction of the dam and evaluating the competence of the near surface formation as foundation material.

STUDY AREA

The study area is located within Ogbomoso , Southwestern Nigeria. It is located between Latitude $8^0$9’20’’ and $8^0$10’40’’N and Longitude $4^0$17’and $4^0$19’E (Figure 1) and falls within the Dahomey basin. Ogbomoso is relatively low lying and fairly undulating. General elevation varies between 338m and 390m, averaging about 364m above sea level. River Adunyin flows Southwestward with numerous rivulets. Ogbomoso exhibits the typical tropical climates of averagely high temperatures, high relative humidity and generally two rainfall maximal regimes, during the rainfall period from March to October. The mean temperatures are highest at the end of Harmattan (averaging 28^0C) i.e. from the middle of January to the onset of the rains in the middle of March. During the rainfall months, average temperatures are between 24^0C and 25^0C.; rainfall figures vary from an average of 1200mm and the onset of heavy rains to 1800mm. Geologically, the rock type at the study area is Granite gneiss (Figure 2). The study area lies within the Southwestern Nigeria which is underlain by basement complex.

The rock distribution of Ogbomoso town studied and mapped reviewed that the study area has four rock types(migmatites-gneiss-Banded gneiss complex, Granite, Quartz schist, porphyroclastic gneiss, pegmatitic veins) [17]. The rocks are generally low lying except for the porphyroclastic granite gneiss that shares the same relief with rock at Oyo town. Field observations reveal that the migmatite gneiss is the most widespread rock type within the area. It is observed to cover about half the area extent under this study. The outcrop appears a lowlying flat terrains, they occur as dark colored (mesocratic) massive rocks with streaks of felsic bands that reflect anatexis and are usually covered by a thin sheet of vegetation. The origin of the migmatitic-gneiss of the study area is yet to be reported in relation to the granite occurrence within its vicinity. Field evidences suggest that the degree of migmatization, although only vaguely, is one of metasomatic segregation.

The granite body is a low lying massive stock with gentle elevations. The granites slope presents a gentle inclination that asrent is not noticed except a roadcuts or places where exfoliation has created a steep slope. Field evidence show that this body is not homogeneous granite body but only certain portions appear granitic in texture as evident by lack of schistocity while most part show gneissose texture. Also, quartzofelsparthic veins appear to thoroughly run through this rock body in almost all directions but most prominently in the horizontal vertical directions. It is proposed that granite body is the product of a metamorphic process. The mineralogical composition is made up of quartz, feldspars (calc-alkaline feldspar) biotite and probable amphiboles.The porphyroclastic gneiss is spatially located at the northwestern end of Ogbomosho town towards Ikoyi. The rock is believed to underly the water dam at northwestern end of geological map. The porphyroclastic gneiss fills are perhaps results of doming from epirogenic movements of uplift, subsidence and faulting that so characterize the phanerozoic times [18]. Outcrop exhibit phenocrysts of alkali feldspar lath that shows rotation as a result of shearing. Other minerals observed correspond to simple mineralogy expressed by the granite gneiss and these include quartz, feldspar and biotite.

The metasediment rock unit has been classified into two groups namely; the older metasediment and the younger metasediment [18]. The classification is similar to that given to the granite intrusions of Nigeria (i.e. the older granite and the younger granite). The older metasediment were reported to occur in intercalated rock units among the migmatite-gneiss complex within the study area. Field observations show that they lack the presence of intense folding as it is the characteristics of the younger metasediment. Quartz and muscovite appear as the dominant mineral from hand specimen. The pegmatitic bodies within Ogbomoso outcrop has veins that intrude and run the granite-gneiss body in a NE-SW trend. They are tabular bodies that host microcline quartz and muscovite. The pegmatitic bodies were observed to serve as hosts to disseminated iron ore body that appear as products of magmatic segregation processes .

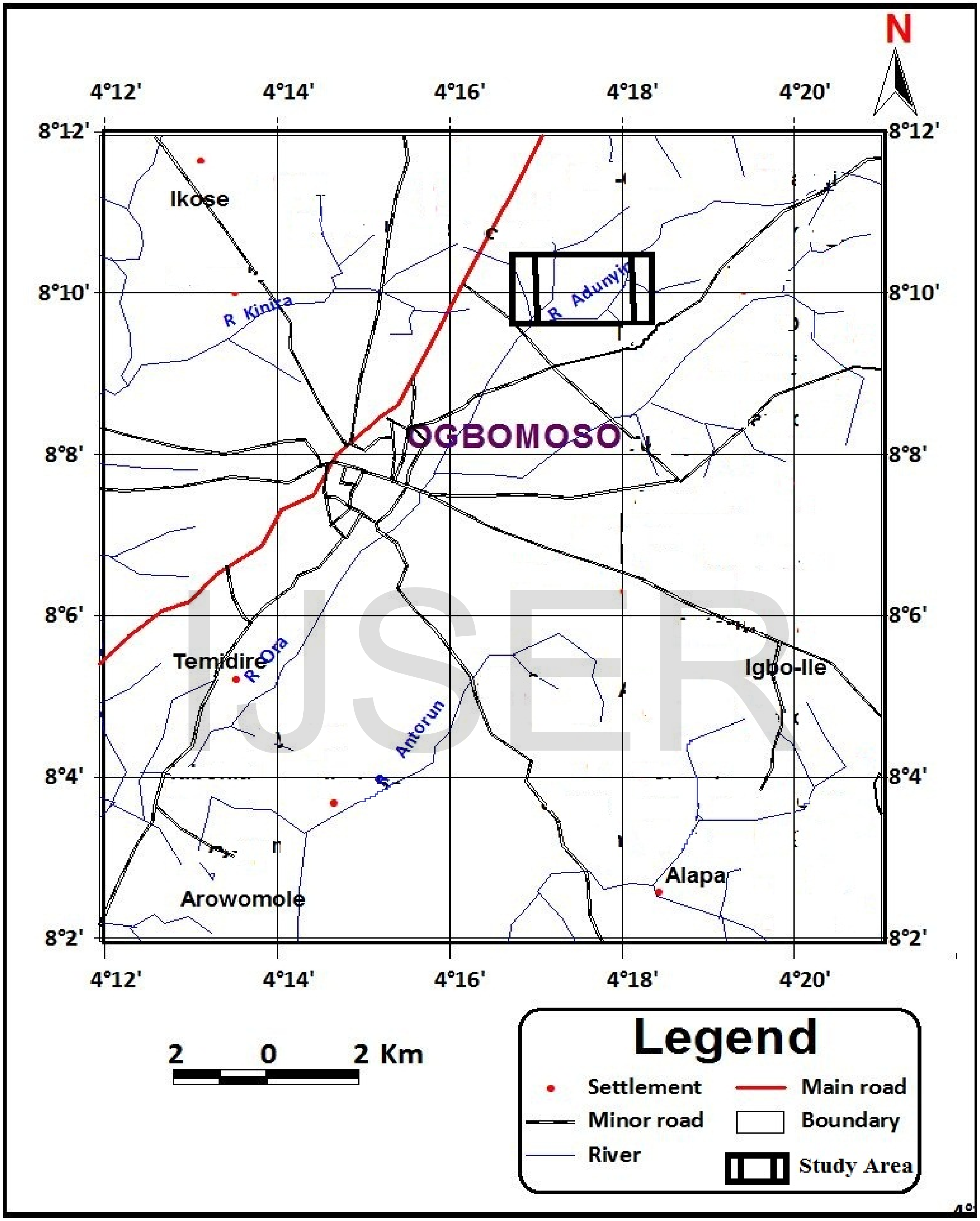

Figure 1: Accessibility and Drainage Map of Study Area

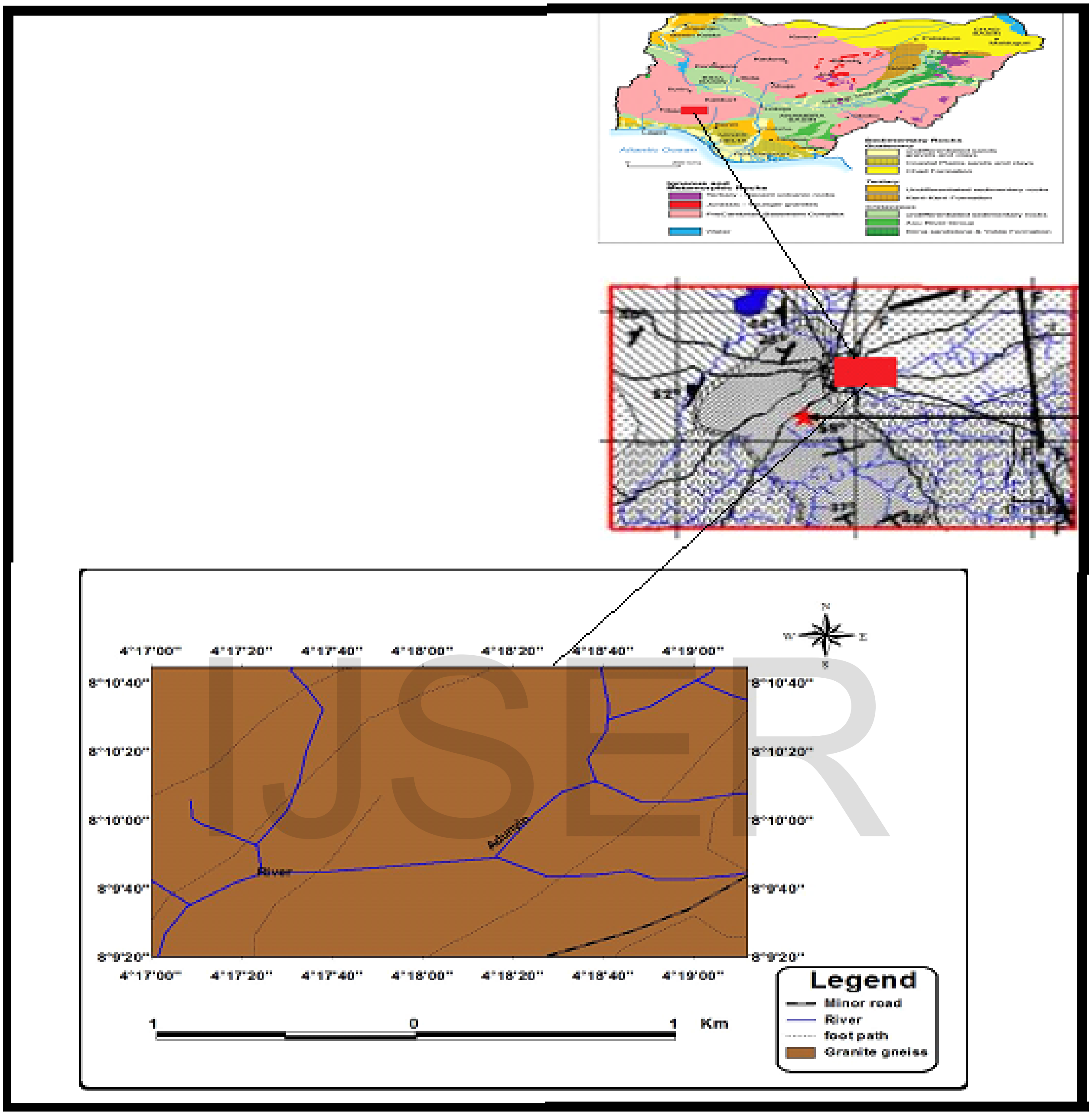

Figure 2: Geologic Map of Study Area

METHODOLOGY

The method used for the geotechnical investigation on suitability of Dam Siting across Adunyin River in Ogbomoso, includes desktop study to review previous work on the area under investigation and related studies, reconnaissance survey which was carried out in order to identify possible area for geophysical survey, which was followed by sample collections from three trial pits dogged at a depth of 3 meters and collected at 0.5 meters interval. After which the samples was prepared by air drying for weeks and finally taken to the laboratory for analysis. The geotechnical parameters carried out on the samples include; Grain size, Atterberg limit, Moisture content, Permeability, California Bearing Ratio (CBR), Compaction, and Triaxial test.Three trial pits were dug at the depth of 3m and samples were collected at 0.5m, 1.0m, 2.0m and 3.0m intervals at the study area. Four (4) samples were collected with polythene bags from each pit which makes a total of 12 samples. The 12 soil samples collected from the trial pits of the study area are air dried for weeks so as to lose its moisture content before then taken to the Laboratory for analysis. A wide variety of laboratory tests was performed on soils to measure a wide variety of soil properties. These geotechnical parameters (Laboratory Test) was carried out on the sample to evaluate how suitable they are for the proposed dam site at Adunyin River, Ogbomoso.

RESULTS AND DISCUSSION

The geotechnical tests presented and discussed here includes; classification test, atterberg limits, moisture content, permeability, California bearing ratio, compaction, triaxial/shear strength and California bearing ratio. The results for the geotechnical laboratory test for soil samples at pit one, pit two and three, are presented below.

Moisture Content

The natural moisture content of the collected samples was determined and presented in the Table .1 . The moisture-density relationship when comparing strength of the soil is based on both mechanical and strength, there should be increase moisture content with increase in the number of blows. There appear to be increase in OMC (%) as the number of blows increases. It can therefore be stated that there is little or no need to further increase the number of blows so as not to cause further damage of the soil samples. There is increase in moisture content due to increase in density; also there is increase in water content (%) due to increase in the number of blows.

Table 1: Moisture Content of the Collected Samples

Sample	Depth (m)	Moisture Content (%)
Pit 1	0.5	3.72
	1.0	3.86
	2.0	6.71
	3.0	4.92
Pit 2	0.5	6.68
	1.0	4.66
	2.0	5.84
	3.0	5.79
Pit 3	0.5	4.62
	1.0	6.96
	2.0	5.98
	3.0	7.04

Grain Size Analysis

The classification was done through the values obtained from the hydrometer and sieve analysis which is presented in the grain size distribution curves (Figure 3 – Figure 5) which spread across the chart and thereby showing a wide range of particle size. A soil is called a well-graded soil if the distribution of the grain sizes extends over a rather large range. In that case, the value of the uniformity coefficient is large (i.e.>5) as shown in the Table 2. When most of the grains in a soil mass are of approximately the same size i.e., *C*u is close to 1, the soil is called poorly graded. A soil might have a combination of two or more well-graded soil fractions, and this type of soil is referred to as a gap-graded soil scheme [19]. Table 3 shows the soils are well graded because of the value of the coefficient of uniformity is greater than 5 and also it grade from a wide extent of gravel to clay. However, the relative high uniformity coefficient which may also indicate abundance of coarse grains is because the parent the parent rock is rich in highly stable minerals such as quartz. Table 4 shows the soil is also made up of large amount of fines (i.e. clay and silt particles).

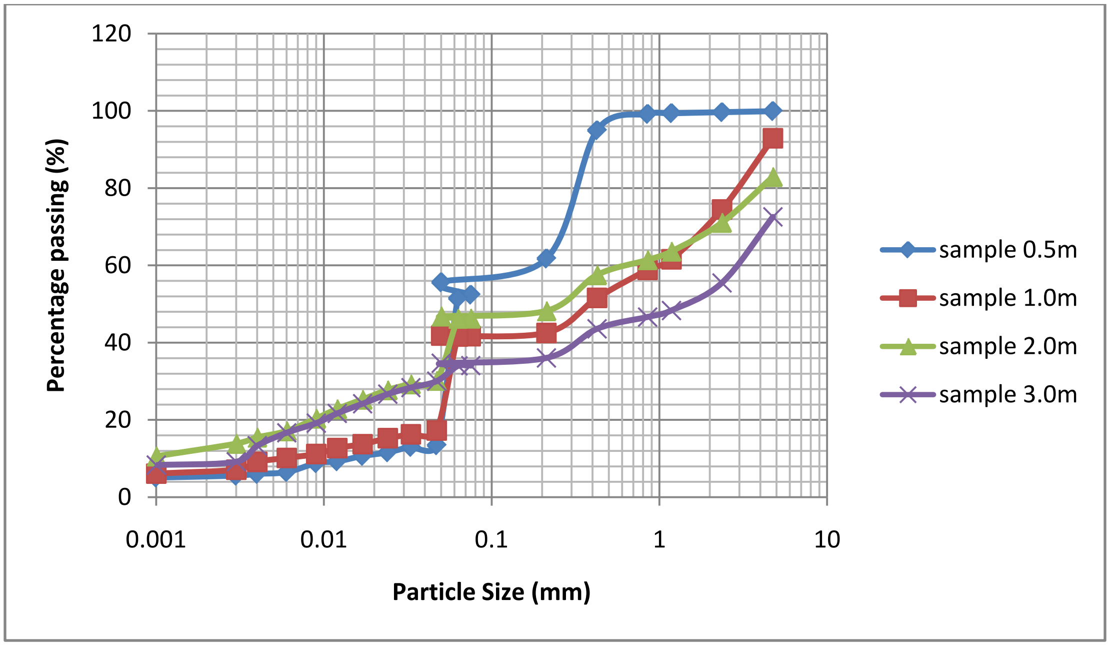

Figure 3: Particle Size Distribution Curve for Pit One

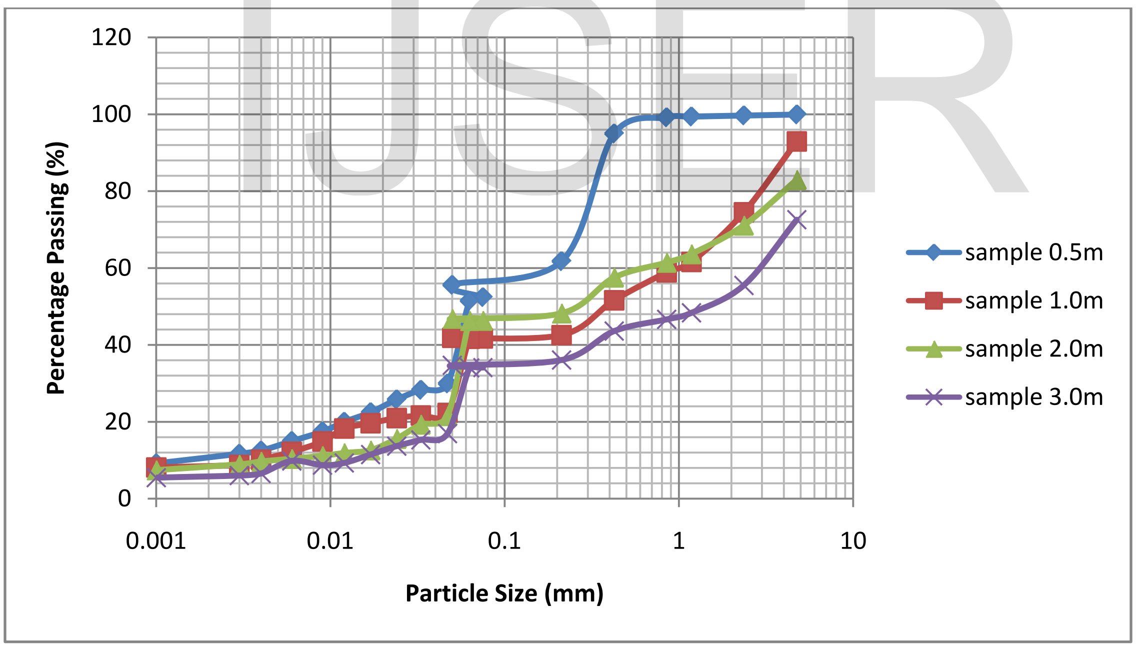

Figure 4: Particle Size Distribution Curve for Pit Two

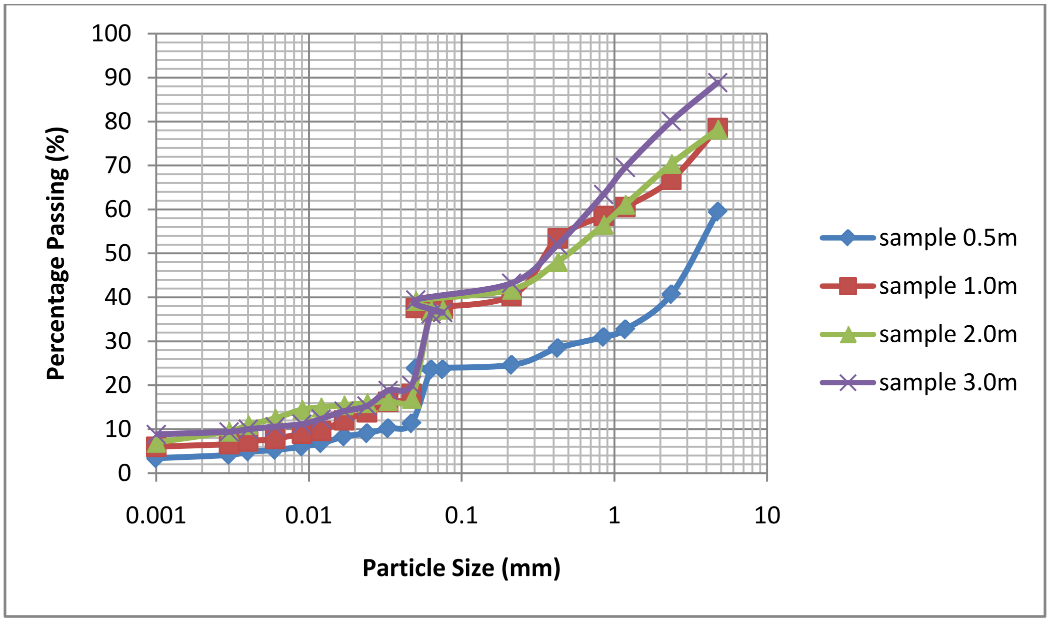

Figure 5: Particle Size Distribution Curve for Pit Three

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Table 2: Grain Size Distribution Summary

Depth (m)		Coefficient of gradation Cc	Amount of fines (%)	% Gravel fraction	% Sand fraction	% of clay fraction	% of silt fraction	**AASHTO Soil Group**	**AASHTO CLASSIFICATION**
Pit 1	0.5	0.592	28	38	36	4	21	Silty/clayey gravel and sand	A-2-4
	1.0	0.222	31	52	17	6	25	Silty/clayey gravel and sand	A-2-4
	2.0	5.00	50	13	37	12	38	Clayey soil	A-6
	3.0	4.60	51	11	40	5	44	Clayey soil	A-6
Pit 2	0.5	5.00	51	2	48	8	42	Silty soil	A-4
	1.0	90.0	41	31	29	6	34	Silty soil	A-4
	2.0	69.44	46	30	27	4	39	Silty soil	A-5
	3.0	0.100	34	48	19	5	28	Silty/clayey gravel and sand	A-2-4
Pit 3	0.5	5.07	23	62	15	3	20	Stone fragment/ gravel and sand	A-1-b
	1.0	0.0756	37	35	31	2	32	Silty soil	A-4
	2.0	1.125	37	32	32	9	33	Clayey soil	A-6
	3.0	1.333	36	24	40	7	29	Silty soil	A-4

Table 3: Coefficient of Uniformity Chart (after [20])

Coefficient of Uniformity (C_u)	Description
1	Perfectly (very poorly graded material)
<5	Very Uniform
>5	Very well Graded

Table 4: Showing the Effective Size, Uniformity Coefficient

Location	Depth (m)	D_{60}	D_{30}	Effective size D_e or D_{10}	Uniformity Coefficient D_{60}/D_{10}	Interpretation
	0.5	1.90	0.150	0.020	95	Well graded
Pit one	1.0	3.00	0.063	0.006	500	Well graded
	2.0	0.400	0.045	0.001	400	Well graded
	3.0	0.180	0.048	0.003	60	Well graded
	0.5	0.200	0.045	0.002	100	Well graded
Pit two	1.0	1.00	0.600	0.004	250	Well graded
	2.0	0.600	0.500	0.006	100	Well graded
	3.0	3.35	0.063	0.012	279	Well graded
	0.5	4.75	0.850	0.03	158	Well graded
Pit three	1.0	1.18	0.050	0.028	42	Well graded
	2.0	1.18	0.052	0.002	590	Well graded
	3.0	0.600	0.057	0.004	150	Well graded

The variation in the percentage of clay and silt can be due to difference in the degree of weathering, and the nature of the parent rock. According to [21] classification the soil samples at 0.5m and 1.0m, the soil is specifically A-2-4, which indicates that the significant material is silty or clayed gravel and sand. At 2.0m and 3.0m, the soil is specifically A-6, which depicts that clay soil is the significant material. At 0.5m and 1.0m, the soil is specifically A-4, which means that the usual significant material is silty soil. At 2.0m, the soil is specifically A-5, the usual material silty soil. At 3.0m, the soil is specifically A-2-4, which indicates silty or clayey gravel and sand. At 0.5m, the soil is specifically A-1-6, usual significant material indicate stone fragment, gravel and sand. At 1.0m and 3.0, the soil is specifically A-4, usual significant material is silty soil. At 2.0m, the soil is A-6, with usual significant material as clayey soil.

Atterberg Liquid

It shows the relationship between liquid and plastic limit alongside plastic index. In the cassagrande chart classification of the samples, it indicates that most of the soil samples fall within the medium plasticity. Soils with high plasticity and medium plasticity are usually semi-impervious to impervious [22], hence, will be suitable for damming. Those with medium plasticity have a higher compressibility than those with high plasticity. As represented in the Table 5, the liquid limits for all the samples at pit one, two, and three fall below 50%, hence, the Unified Soil Classification shows that pit one samples at

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depth 1.0m, 2.0m, and 3.0m are CL, while the sample at 0.5m corresponds to OL. For pit two, samples at 0.5m, 1.0m, and 2.0m, corresponds to OL (organic soil), while the sample at 3.0m is ML (inorganic soil with slight plasticity), for pit three, samples at 0.5m, 2.0m, and 3.0m are CL (inorganic soils with medium plasticity), while that of 1.0m is OL. The plasticity indices of all the samples range from 5-20 presented in Table 6, which indicates the state of plasticity of the soil samples range from 'Low to Medium' according to [23] in Table 7.

Table 5: The Unified Soil Classification System (Bowles, 1977)

Major Division		Group Symbol	Typical Name
Fine grained soil, more than half of material smaller than No. 200	Silts and clays liquid limit<50%	ML	Inorganic silts and very fine sands, rock flour, silt or clay fine sands or clayey silts with slight plasticity
		CL	Inorganic clays of very low to medium plasticity, gravelly clays, sandy clays, silt clays, lean clays
		OL	Organic silts and organic silty clays of low plasticity
	Silts and clays liquid limit>50%	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
		CH	Inorganic clays or high plasticity fate clay
		OH	Organic clays of medium to high plasticity, organic silt
	Highly organic soils	Pt	Peat and other highly organic soils

Table 6: The Plastic Indices of the Samples and their State of Plasticity

Sample @ Depth (m)		Plastic Index (%)	State of plasticity
	0.5	9.77	Low
Pit 1	1.0	9.76	Low
	2.0	16.37	Medium
	3.0	16.54	Medium
	0.5	9.99	Low
Pit 2	1.0	9.91	Low
	2.0	9.98	Low
	3.0	9.91	Low
	0.5	6.40	Low
Pit 3	1.0	10.09	Medium
	2.0	13.08	Medium
	3.0	10.70	Medium

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Table 7: Plastic Indices and Corresponding State of Plasticity [23]

S/N	Plastic Index (%)	State of Plasticity
1	0	Non-plastic
2	1-5	Slight
3	5-10	Low
4	10-20	Medium
5	20-40	High
6	>40	Very High

Cassagrande Chart Classification

The cassagrande 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 with the graphs of the soil samples represented in Figure 6- 8. This chart can be used to determine if a soil has a high plasticity, medium plasticity or low plasticity. Cassagrande classification of all the soil samples with pit one at 1.0m, 2.0m, and 3.0m as 'Inorganic Medium Plasticity' while at 0.5m is 'Organic Medium Plasticity', for pit two, samples at 0.5m, 1.0m and 2.0m are 'Organic Medium Plasticity' soils, with the sample at 3.0m being an 'Inorganic Low Plasticity' soil, for pit three, the samples at 0.5m, 2.0m, and 3.0m are 'Inorganic Medium Plasticity' soils, while the sample at 1.0m showing 'Organic Medium Plasticity'. Soils with high plasticity and medium plasticity are usually semi-impervious to impervious [22]. 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 have high plasticity, low shear strength and therefore no 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.

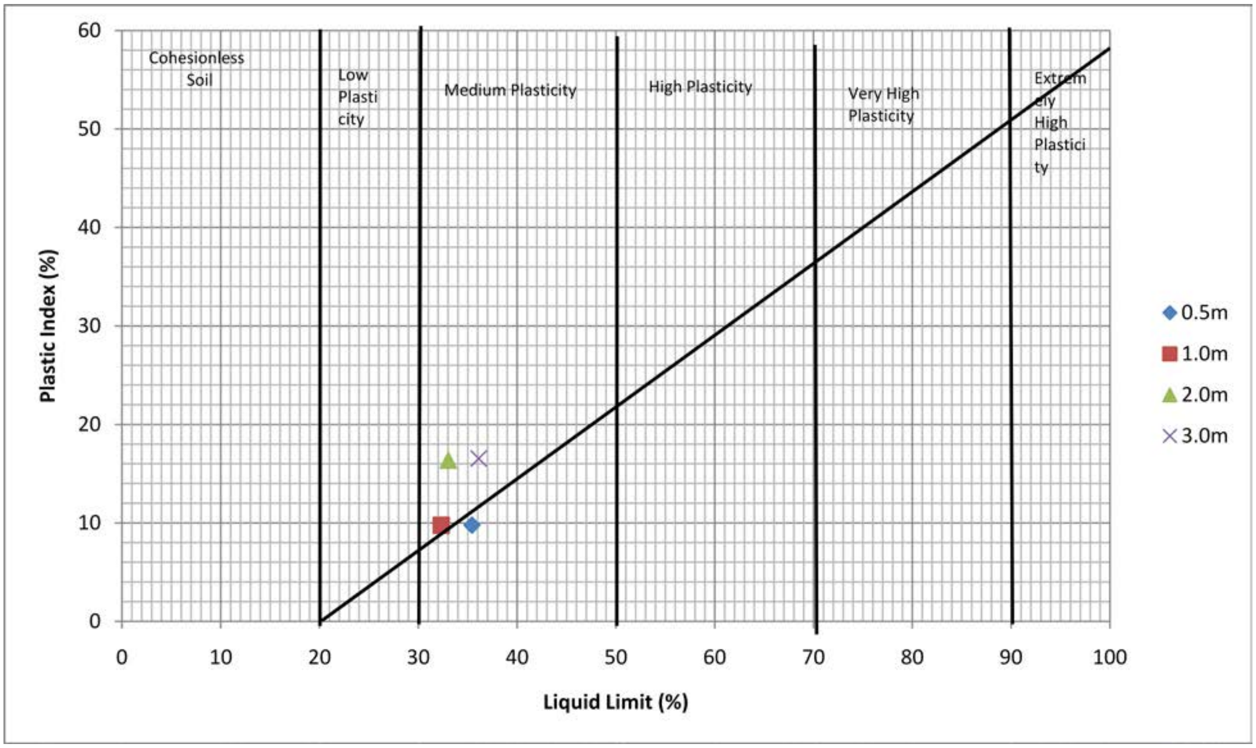

Figure 6: Cassagrande Chart for Pit One

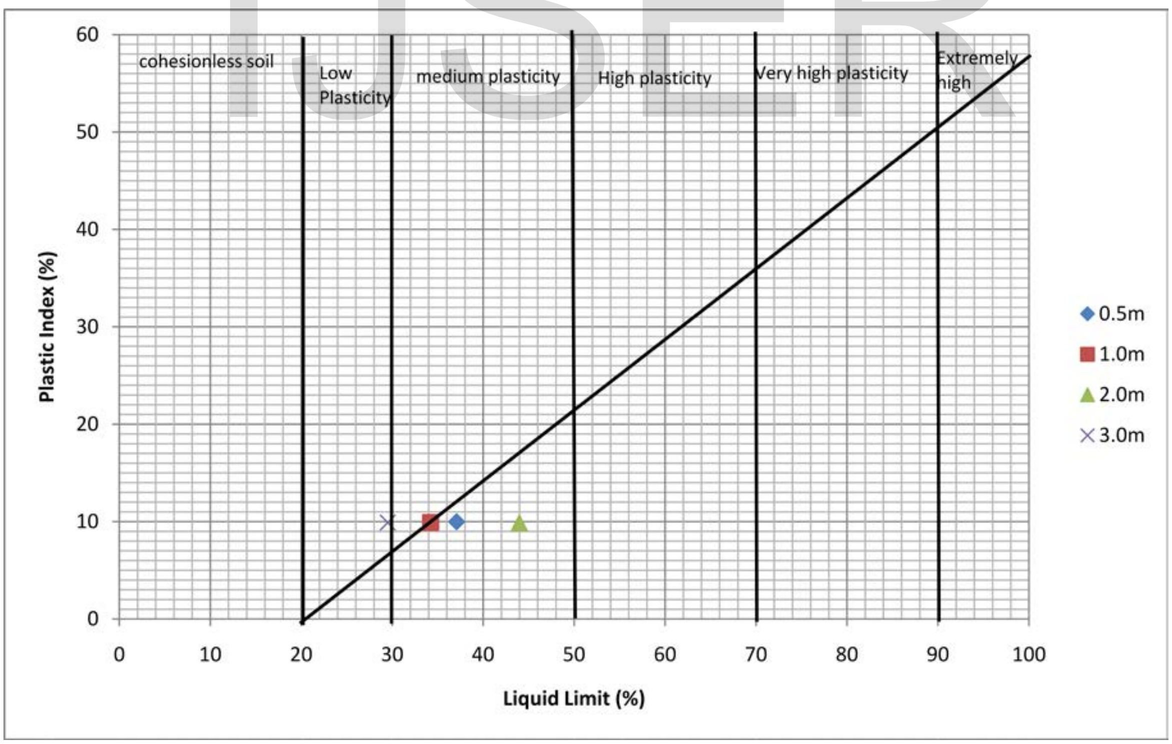

Figure 7: Cassagrande Chart for Pit Two

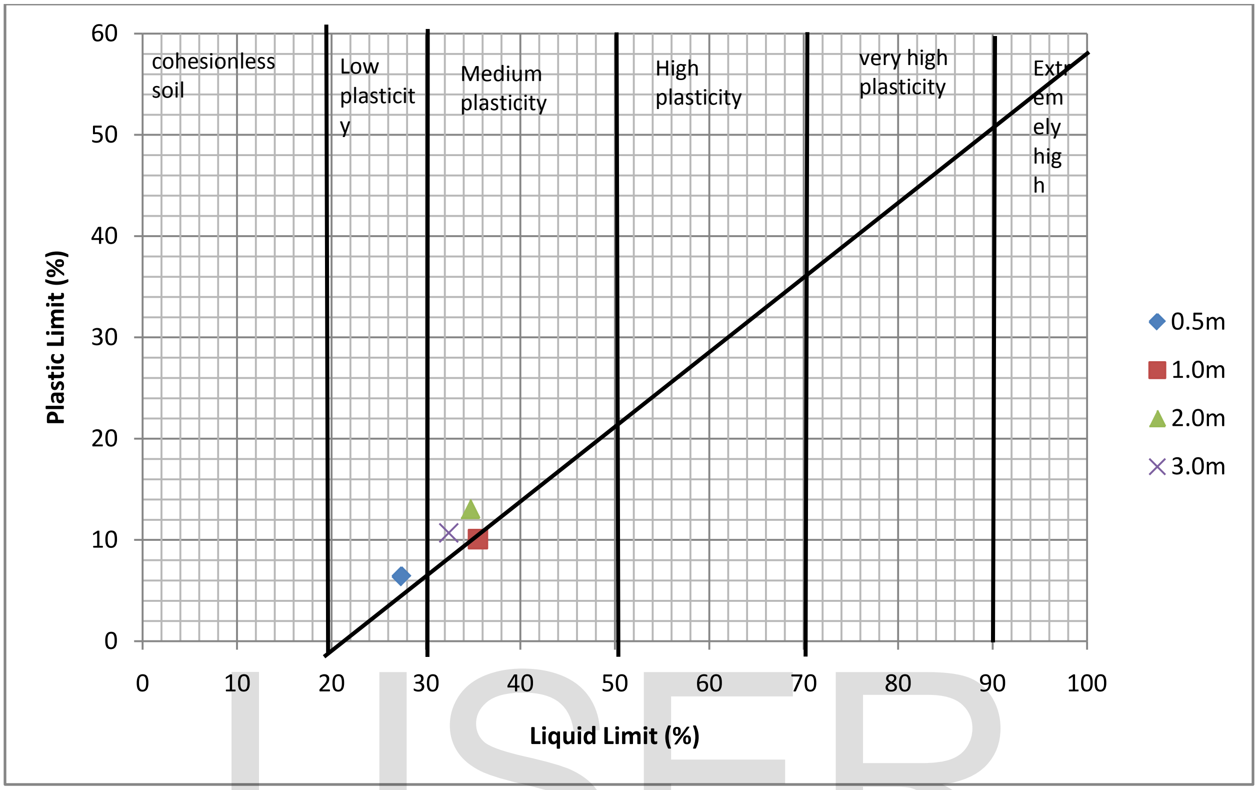

Figure 8: Cassagrande Chart for Pit Three.

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Activity of the Soil Samples

Activity is the measure of water- holding capacity of clayey soils. The changes in the value of a clayey soil during swelling or shrinkage depend upon the activity. The soils containing the clay mineral montmorillonite has very high activity (A>4). The soil containing the mineral kaolinite are least active (A<1) whereas the soils containing the mineral illite are moderately active (A=1-2), the standard of the influence of activity on soil samples [24] is presented in Table 8 . The activity of the soil samples shows the presence of clay minerals such as Illite, Smectite, and montmorillonite (only found in pit three at 1.0m) in the soil samples. It also shows that samples are 'active to very active' soil type.

Table 8: Influence of Activity of Soil Samples (after [24])

Activity		Clay type/mineral
0.25-0.5	Inactive	Illite, kaolinite, halloysite
0.5-1.0	Normal	
1.0-2.0	Active	Smectite, illite, allophone, altapulgite
2.0-3.0	Very Active	Smectite

Permeability

Permeability is the ease with which water can flow through a soil easily. In an impervious soil, the permeability is very low and water cannot flow through it. A completely impervious soil does not permit the water to flow through it. However, such completely impervious soils do not exist in nature, as all the soils are pervious to some degree [25]. According to [26], the soils having the coefficient of permeability greater than 10^{-3} mm/sec are classified as pervious and those with a value less than 10^{-5} mm/sec are impervious. The soils with the coefficient of permeability between 10^{-5} to 10^{-3} mm/sec are designated as semi -impervious. The values of permeability coefficients range from 1.32×10^{-6}cm/sec to 5.59×10^{-6}cm/sec. Compared to the standard of permeability of [27] (Table 9) , the samples for Pit 1, 2 and 3 falls under 'Very Low Permeability', which classifies the samples as impervious soils (silt and clay), with very low transmitting capacity, and these low values are not good for subgrade soils because they can retain water which will weaken the soils/pavement but will is an important parameter for the suitability of dam siting. Also compared to [28] represented in Table 10, all samples in Pit 1, 2 and 3 shows a 'Very slow Class'. Generally, all the samples in pit 1, 2, and 3 are 'silty clay to clay' soil type which shows a 'Very Poor' drainage property according to [26] (Table 11).

Table 9: Degree of Permeability after [27]

Degree of Permeability	K(cm/s)
High	Over 10^{-1}
Medium	10^{-1}- 10^{-3}
Low	10^{-3}- 10^{-5}
Very Low	10^{-5}-10^{-7}
Practically Impermeable	Less than 10^{-7}

Table 10: Standard for Permeability after [28].

Permeability (cm/s)	Class
<4.2×10^{-5}	Very slow
4.2×10^{-5}- 1.4×10^{-4}	Slow
1.4×10^{-4}- 4.2×10^{-4}	Moderately slow
4.2×10^{-4}- 1.4×10^{-3}	Moderate
1.4×10^{-3}- 4.2×10^{-3}	Moderately rapid
4.2×10^{-3}- 1.4×10^{-2}	Rapid
>1.4×10^{-2}	Very rapid

Table 11: Typical value of the Coefficient of Permeability [26]

Soil Type	Coefficient of Permeability (mm/sec)	Drainage Property
Clean gravel	10+1 to 10+2	Very good
Coarse and medium sand	10-2 to 10+1	Good
Fine sands, loose silt	10-4 to 10-2	Fair
Dense silt, clayey silt	10-5 to 10-4	Poor
Silty clay, clay	10-8 to 10-5	Very poor

California Bearing Ratio

Testing the sample after compaction at Optimum Moisture Content (OMC) is CBR test. The value of the test at the bottom will be higher than the top due to the compaction rate. The test was conducted on a disturbed sample. The result of the unsoaked CBR compared with the standard according to [21] (Table 12) indicates that all samples in pit 2 fall under 20-50 which shows a general rating as 'good soil' and can be used as 'base- sub-base'. For pit one, samples at 0.5m to 1.0m indicates general rating as 'Excellent soil' and can be used as 'base', while the samples at 2.0m and 3.0m indicates general rating as 'good soil' and can be used as 'base- sub-base'. For pit three. Samples at 0.5m and 3.0m are 'Excellent soil' and can be used as 'base' while samples at 1.0m and 2.0m are 'good soils' and can be used as 'base- sub-base'. The CBR number was obtained as the ratio of the unit load required to effect a certain depth of penetration into the compacted sample specimen of soil and some water content to the standard unit load required. In the presence of water there is swelling in some of the samples which indicates the presence of impervious soil (clayey soil). The result of the final moisture content and the swelling are represented in the Table 13.

Table 12: Typical Rating According to [21].

CBR Number	General Rating	Uses
0-3	Very Poor	Sub-grade
3-7	Poor to Fair	Sub-grade
7-20	Fair	Sub-base
20-50	Good	Base- Sub-base
>50	Excellent	Base

Table 13: Final Moisture Content and Swelling for Pit One, Pit Two and Pit Three

	0.5m	1.0m	2.0m	3.0m
Final Moisture Content %	11.18-11.84	11.88-15.66	17.32-15.20	15.61-14.78
Swelling (mm)	0-1.5	0-2	2-2	1.5-1.5

Compaction

When a sample is compacted at two different levels, the level that gives the higher Maximum Dry Density at lower Optimum Moisture Content is better. When two samples are compacted at a level, the sample with higher Maximum Dry Density at lower Optimum Content is best for foundation. The samples were compacted at the same level, for Pit one the sample at 0.5m with MDD 1920kg/m^3 at OMC 10.2% is the best sample, for Pit two the sample at 3.0m with MDD 1850.10kg/m^3 at OMC 12.5% is best, and for Pit three the sample at 0.5m with MDD 1890.2kg/m^3 at OMC 11.2%. The graphs are represented in Figure 9-11,since the whole samples has been described as well graded in the earlier test, the compaction interpretation will be based on granular material with soil, fine sands and sands, sandy silts and silts, and silty clays Table 14. With visual description as granular material with soil, all the samples with the maximum MDD 1.92g/cm^3 to 1.81 g/cm^3 as the least fall under the standard of 1.76-2.16 g/cm^3, with maximum OMC of 15.20 to 10.20% fall under the standard 9-18%, hence, are fair to excellent as anticipated embankment performance. For fine sands and sands all the samples are fair to good as anticipated embankment performance. For sandy silts and silts and silts, they are poor to good as anticipated embankment performance. For silty-clays, all the samples are poor to good for anticipated embankment performance.

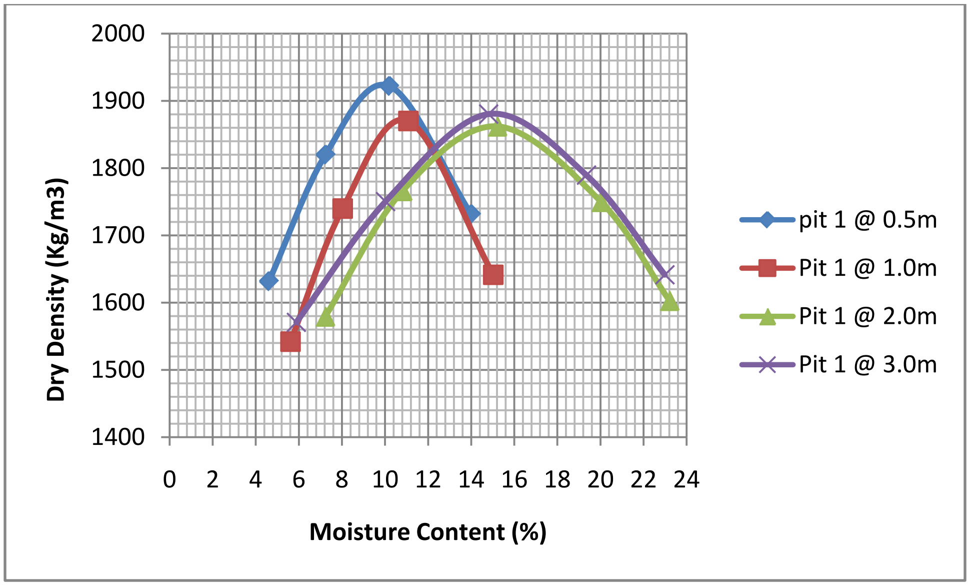

Figure 9: Graphical Representation of Compaction for Pit One

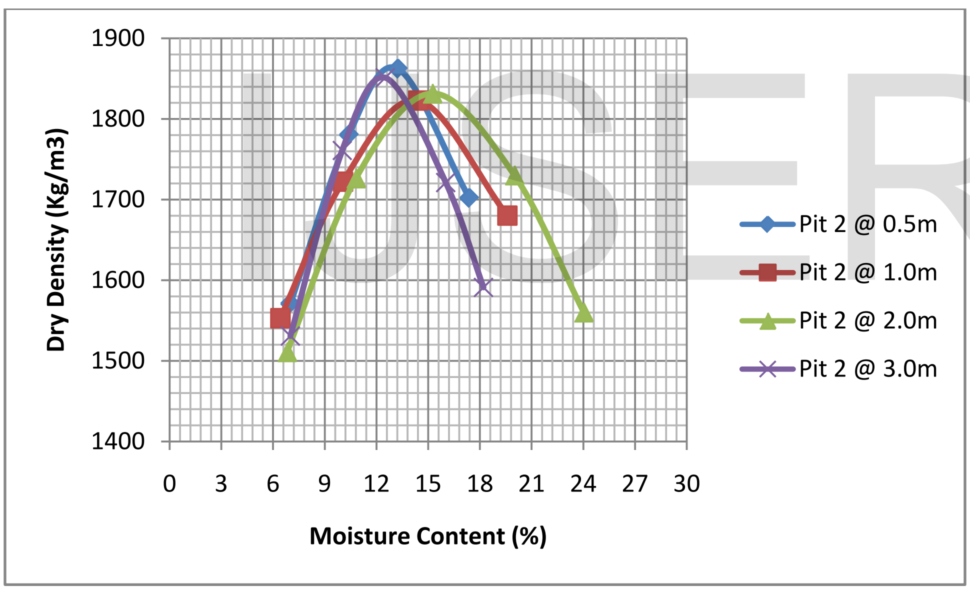

Figure 10: Graphical Representation of Compaction for Pit Two

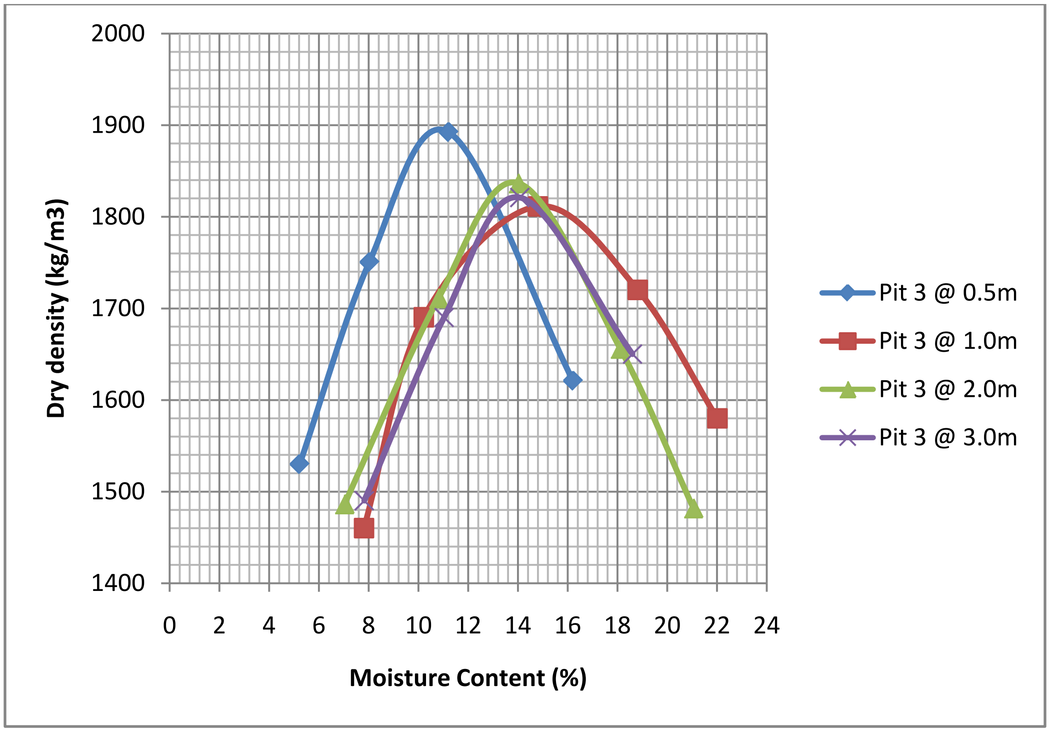

Figure 11: Graphical Representation of Compaction for Pit Three

Table 14: Compaction Characteristics and Ratings of Unified Soil Classification Classes for Soil Construction [29]

Visual description	Maximum Dry Density Range (g/cm^3)	Optimum Moisture Range (%)	Anticipated Embankment performance	Value as Sub-grade Material	Value as Base Course
Granular materials	2.00-2.27	7-15	Good to excellent	Excellent	Good
Granular material with soil	1.76-2.16	9-18	Fair to excellent	Good	Fair to poor
Fine sands and sands	1.76-1.84	9-15	Fair to good	Good to fair	Poor
Sandy silts and silts	1.52-2.08	10-20	Poor to good	Fair to poor	Not suitable
Elastic silts and clay	1.36-1.60	30-35	Unsatisfactory	Poor	Not suitable
Silty-clays	1.52-1.92	10-30	Poor to good	Fair to poor	Not suitable
Elastic silty clay	1.36-1.60	30-35	Unsatisfactory	Poor to very poor	Not suitable
Clays	90-115	15-30	Poor to fair	Very poor	Not suitable

Triaxial test/Shear Strength Determination

The interpretations of the undrained shear strength result indicates that all the samples in pit one, pit two, and pit three have 'very stiff or hard consistency' since there values are greater than 150 (KN/m^2) except for the sample at pit three (2 meters) which shows strength of 136 (KN/m^2) indicating a 'stiff consistency'. Generally, the samples of pit one at depth of 0.5m, 1.0 and 2.0m shows that the grain sizes are coarser and the grain shapes are more angular due to higher angle of internal friction when compared to the other samples. Also, the varying angle of internal friction can help conclude that all the samples are characterized by approximately different grain sizes which indicate that it is well graded.

The shear stress parameters, cohesion (c) and angle of internal friction (ø) were obtained for all the samples. The interpretation of the angle of internal friction (ø) as compared to the data by [31], 1978) (Table 15) shows that all the samples from the three pits are 'very loose' soil type since the angle of internal friction for the samples fall below 29/30. 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 is accompanied by a decrease in the volume of the specimen. 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 cohesion (c) and angle of friction (ø) is gotten from the Mohr circles. The triaxial graphs are shown in Figure 12-14.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, [32] and later modified by [33] in Table 16.

Table 15: Undrained Strength Classification (Reproduced from CP 2004: 1972 by Permission of the British Standards Institution)

Consistency	Undrained Strength (KN/m2)
Very stiff or Hard	>150
Stiff	100-150
Firm to Stiff	75-100
Firm	50-75
Soft to Firm	40-50
Soft	20-40
Very Soft	<20

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Table 16: Soil Test Parameter (Data from [31])

	Friction Angle ø		
Soil Type	Mayerhof (1974)	Peck, Hanson & Thornburn (1974)	Mayerhof (1974)
Very Loose	<30	<29	<30
Loose	30-35	29-30	30-35
Medium	35-38	30-36	35-40
Dense	38-41	36-41	40-45
Very Dense	41-44	>41	>45

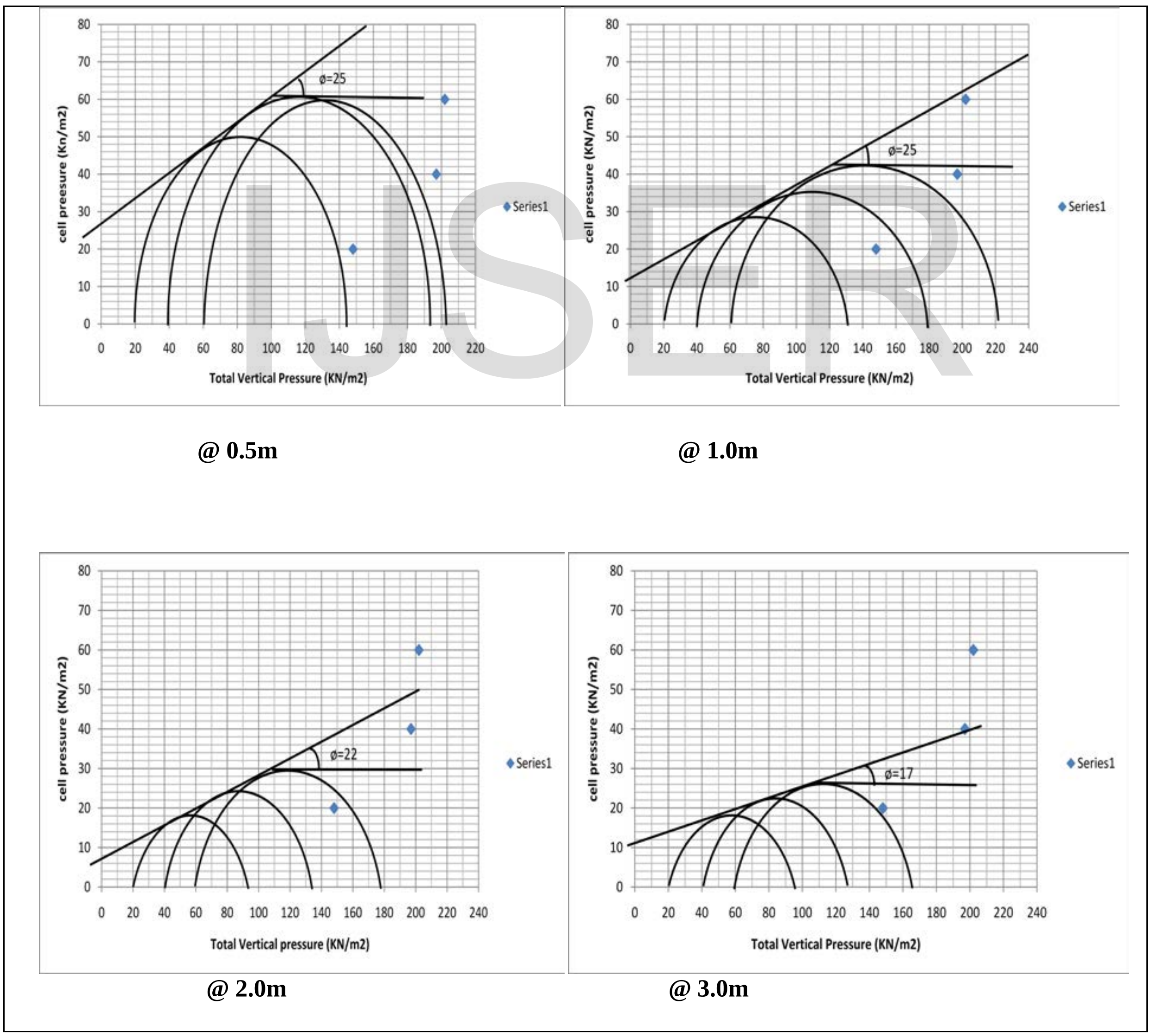

Figure 12: Graphical Representation of Triaxial Test for Pit One

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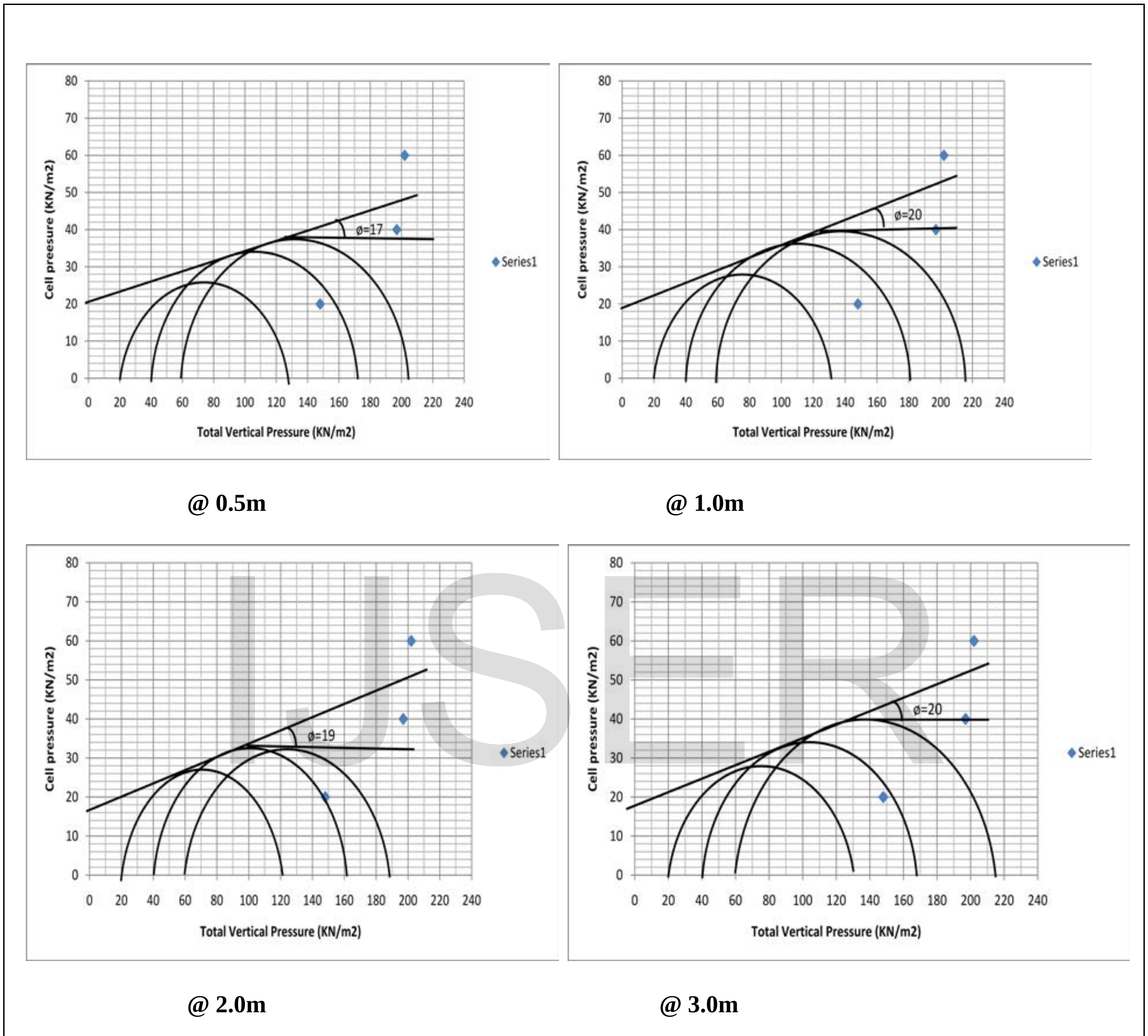

Figure 13: Graphical Representation of Triaxial Test for Pit Two

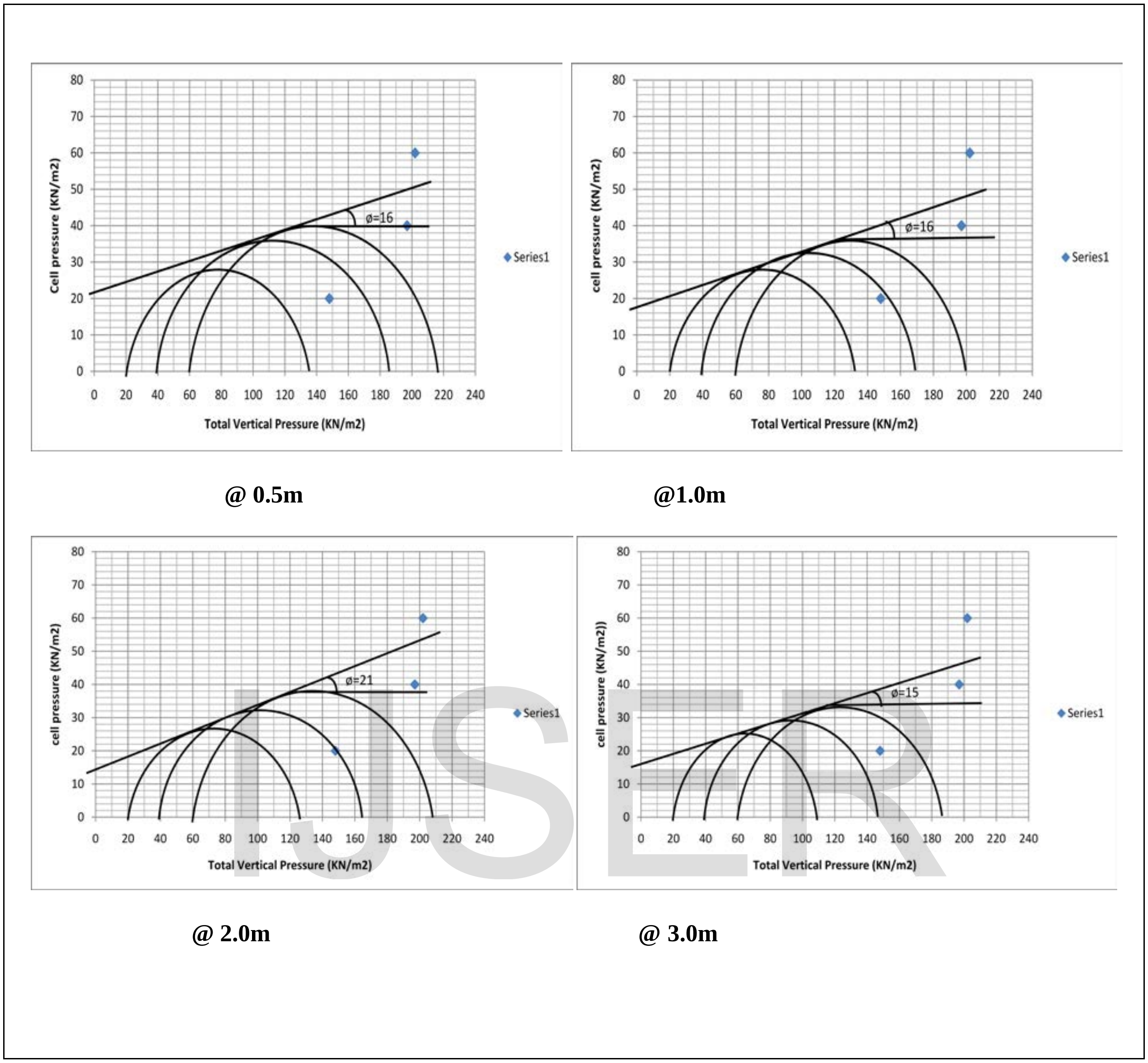

Figure 14: Graphical Representation of Triaxial Test for Pit Three

CONCLUSION

The different geotechnical analyses carried out on the samples (disturbed) from the site along Adunyin River, Ogbomoso, Southwestern Nigeria, is to determine the competence of the soil for dam siting. The Grain size result shows the presence of A-6 soil group with indicates the presence of clayey soils, while the atterberg result shows the state of plasticity of the soils range from 'Low-Medium' which also corresponds to the cassagrande classification which shows that most of the soils are Inorganic soils with Low to Medium plasticity. The permeability test results shows that the soil samples have very low permeability with very slow class which classifies the samples as impervious soils, which is an important parameter for the suitability of dam siting. The shear strength of the soils shows consistency of the samples as 'stiff to very stiff or hard' and corresponds to the CBR result that generally describes the soil samples as being 'Good to Excellent' and can be used as 'base-sub-base'. The result of the geotechnical investigation carried out at downstream, dam axis and upstream portion of the site reveals that the site soil materials may be suitable for dam siting. It is recommended the type of dam that will be most suitable for the site is an earth dam due and that in-situ field tests used to provide field measurements of soil properties should be carried out on the site at more appreciable depth, as this will enhance better study of the competence of the subsurface layers for dam siting.

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