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Geo-Scientific Assessment of Gbugudu Dam Site Using Osin River, Kwara State, North-Central Nigeria.

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Abstract: *Gbugudu of Latitude N080° 39' 38.5'', Longitude E040° 46' 28.6'' is located in Kwara state. Acute shortage of irrigable water in the area can be addressed by impounding tributary water of Osin river in a proposed dam to be constructed in the area. 11 trial and 1 borrow pits were drilled in the area to get samples for geotechnical laboratory study. Coarse and fine-medium grained sand with clay/silt are contained in their matrix. Atterberg's limit test revealed Liquid limit of 21.0-35.1%, Plastic limit of 17.1-17.14% and Plasticity Index of 4.0-22%. In-situ permeability test ranges from 1.01 x 10^{-4}- 9.26 x 10^{-6} ms^{-1}. Compaction strength test revealed the Optimum moisture content and Maximum Dry Density ranges from 1.95-2.02 (%) and 7.80-9.20 (g/cm^3) respectively. Triaxial strength test gave a range of 5-15 KN/m^2. Conducted investigations on the soil and bedrock of the area shows it will be water tight, seepage is expected to be very minimal within the tolerant level, especially during the dry season when the water will be needed mostly, collapse not envisaged and Engineering design and construction phases will be feasible to add value to the socio-economic, agricultural and health values of the people in the area.*

Keywords: Lithological Beds, Atterbergs Limit, Plasticity Index and Permeability

INTRODUCTION

The proposed dam axis/site is located across Osin River in Gbugudu village, Moro Local Government Area, Kwara State for irrigating of farmland. The proposed dam axis is geographical located around the coordinates of latitude N080° 39' 38.5', Longitude E040° 46' 28.6'' and Latitude N080° 39' 26.9'', Longitude E04° 46' 33.3''. At the time of this investigation, the streams were moderately flowing forming trellis and dendritic drainage patterns. The study area lies within the undifferentiated basement complex of Nigeria. The study area is underlain by Precambrian basement rock which consist mainly of medium to coarse-grained granite-gneiss (with foliation), some aplitic, fine to medium-grained granite and quartz mineral content (Fig. 1). The basement complex rocks are inherently characterized by low porosity and near negligible permeability except where there is more fracture network. Crystalline igneous rocks are highly visible at the river bed at some portions of the downstream and upstream of the dam axis.

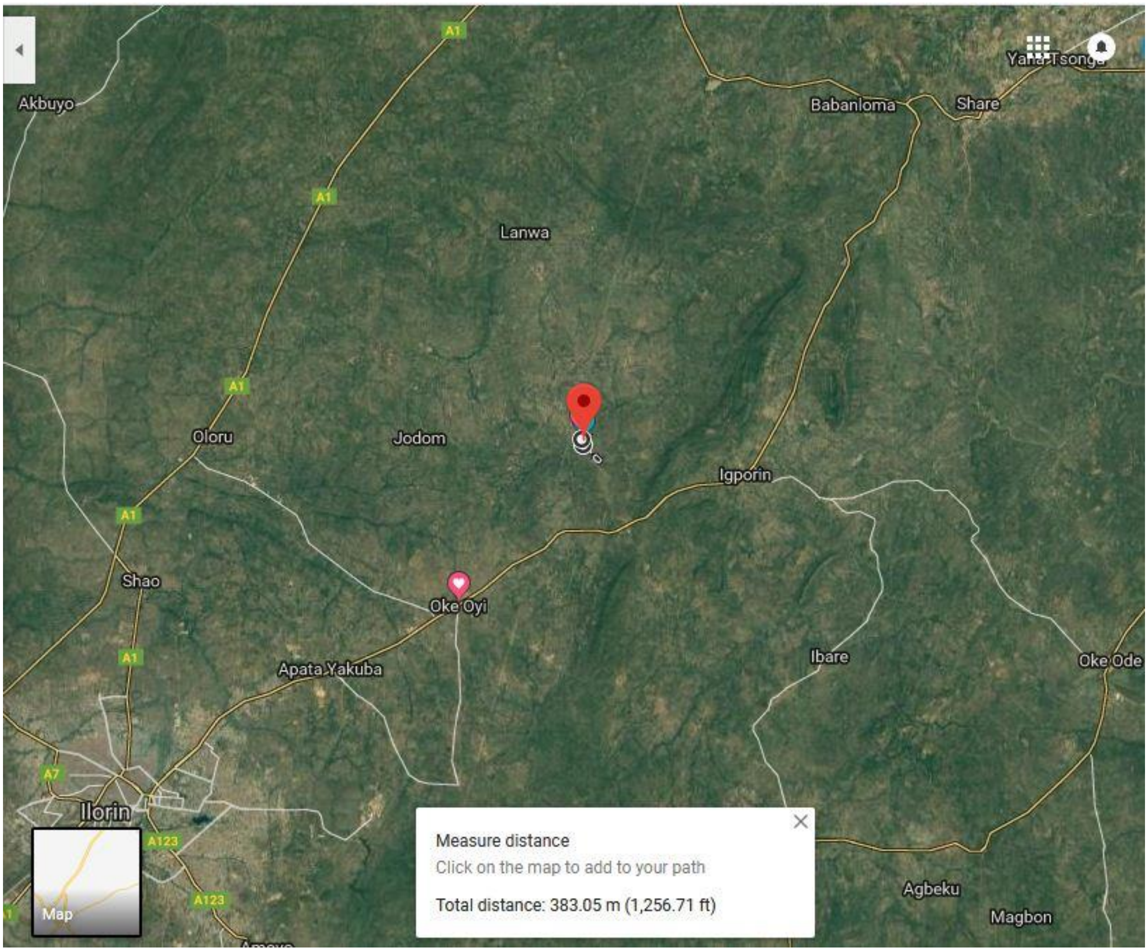


Fig. 1 Earth map of the Gbugudu study area

MATERIALS AND METHODS

The proposed dam axis was also probed with a total of seven (7) number test pits and DCP points spaced at 60m intervals. The upstream and downstream at 150 meters offset to the dam axis was also probed with a total of eight (8) number trial pit and DCP test locations. The borings were advanced to depth range of 1.5m to 2.5m. The total 16 soil samples encountered in the test pits which were carefully logged and conveyed to the laboratory for further testing (Figs. 3, Fig. 4, and Fig. 5). The Dutch formula for Dynamic Penetrometer was used for the computation of the unit cone resistance. The outcome was further used for the estimation of allowable soil bearing pressure based on penetrometer theory and application. Collected samples from the pits were subjected to laboratory studies for different geotechnical properties. 15 samples were collected from the trial pits coded as Trial Pit (TP)1-Trial Pit (TP)11, while 1 sample was collected from the borrow pit (BP) at a depth of 1.5m. Other drilled pits not represented diagrammatically include TP12-TP15, density, ignition time, burning time, water boiling tests, moisture content, volatile matter, ash content, fixed carbon content and calorific value.

RESULTS AND DISCUSSION

Results from the 11 trial test pits (TP) and 1 borrow pit bored into Gbugudu area along the dam axis assisted the logging and collection of study samples for geotechnical analysis.

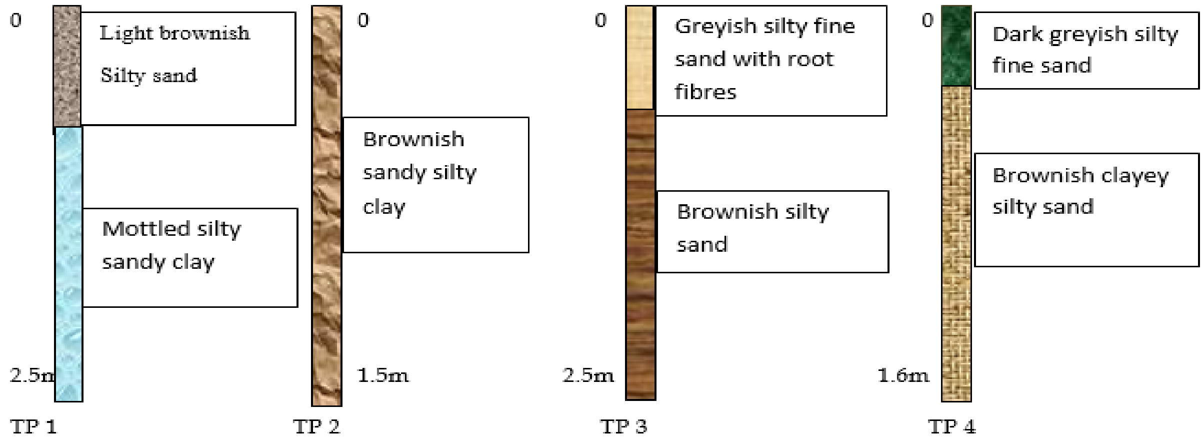


Fig. 3 Trial pits 1, 2, 3 and 4 drilled for sample collection during the investigation

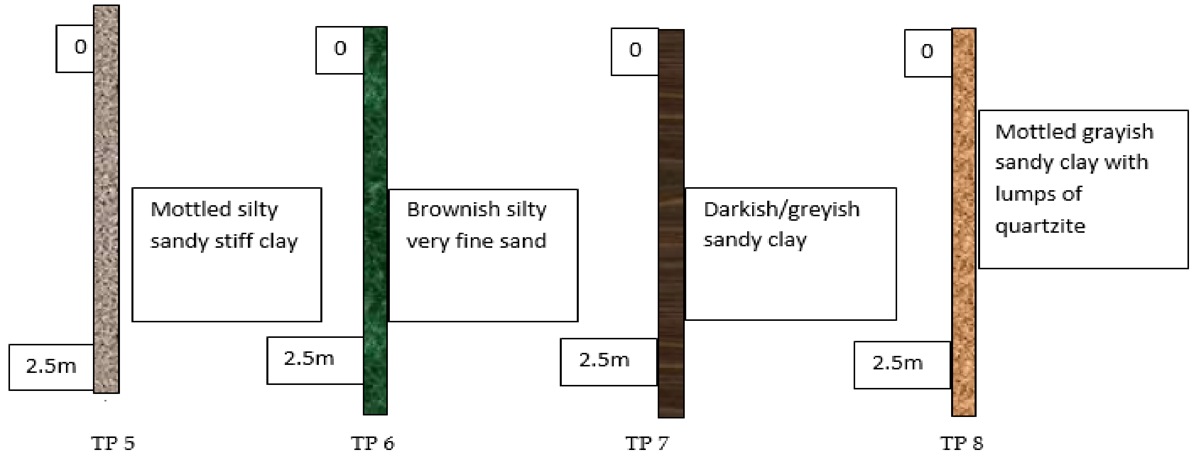


Fig. 4 Trial pits 5, 6, 7 and 8 drilled for sample collection during the investigation

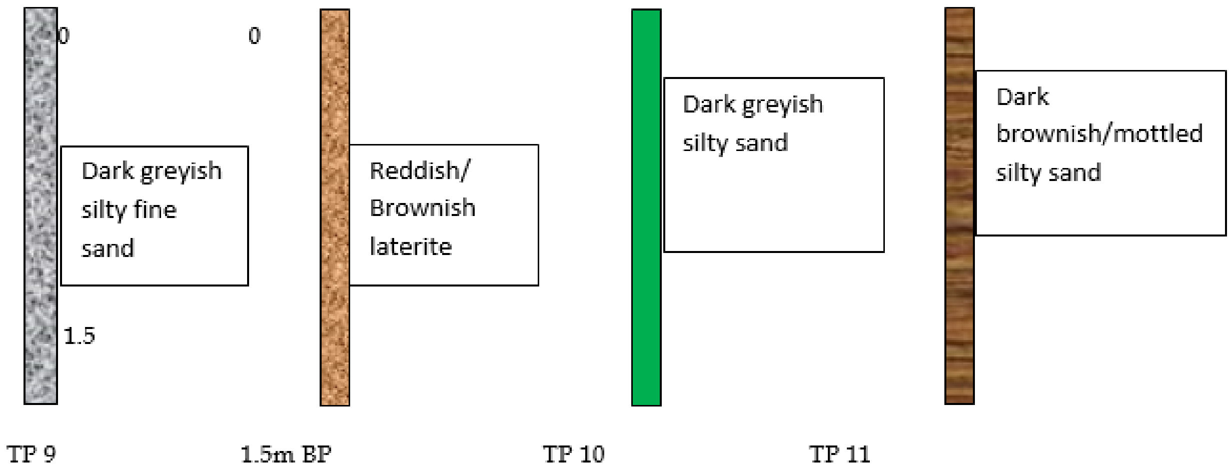


Fig. 5 Trial pits 9, 10, 11 and Borrow pit drilled for sample collection during the investigation

The essence of this is to have the best representative samples of the dam axis soil profile that can better be described for the strength and stability of the dam with very little or no leakage. The geotechnical engineering analyses of the data derived from the laboratory tests were performed in order to establish the design criteria for the dam foundation and the choice of seepage control technique for civil engineering construction work. The following tests were conducted on the collected samples for the purpose of soil classification, strength analysis and design. They include:

i. Sieve analysis
ii. Atterberg consistency limit
iii. Permeability test
iv. Compaction strength test
v. Triaxial test

All the tests were performed in accordance with BS 1377: 1990 and relevance practice in Nigeria. The summary of the laboratory test result for the material encountered along the dam axis and the construction materials were further interpreted.

A. Sieve Analysis

The Sieve analysis of the study samples was done and this has revealed a wide gradational difference across the study samples.

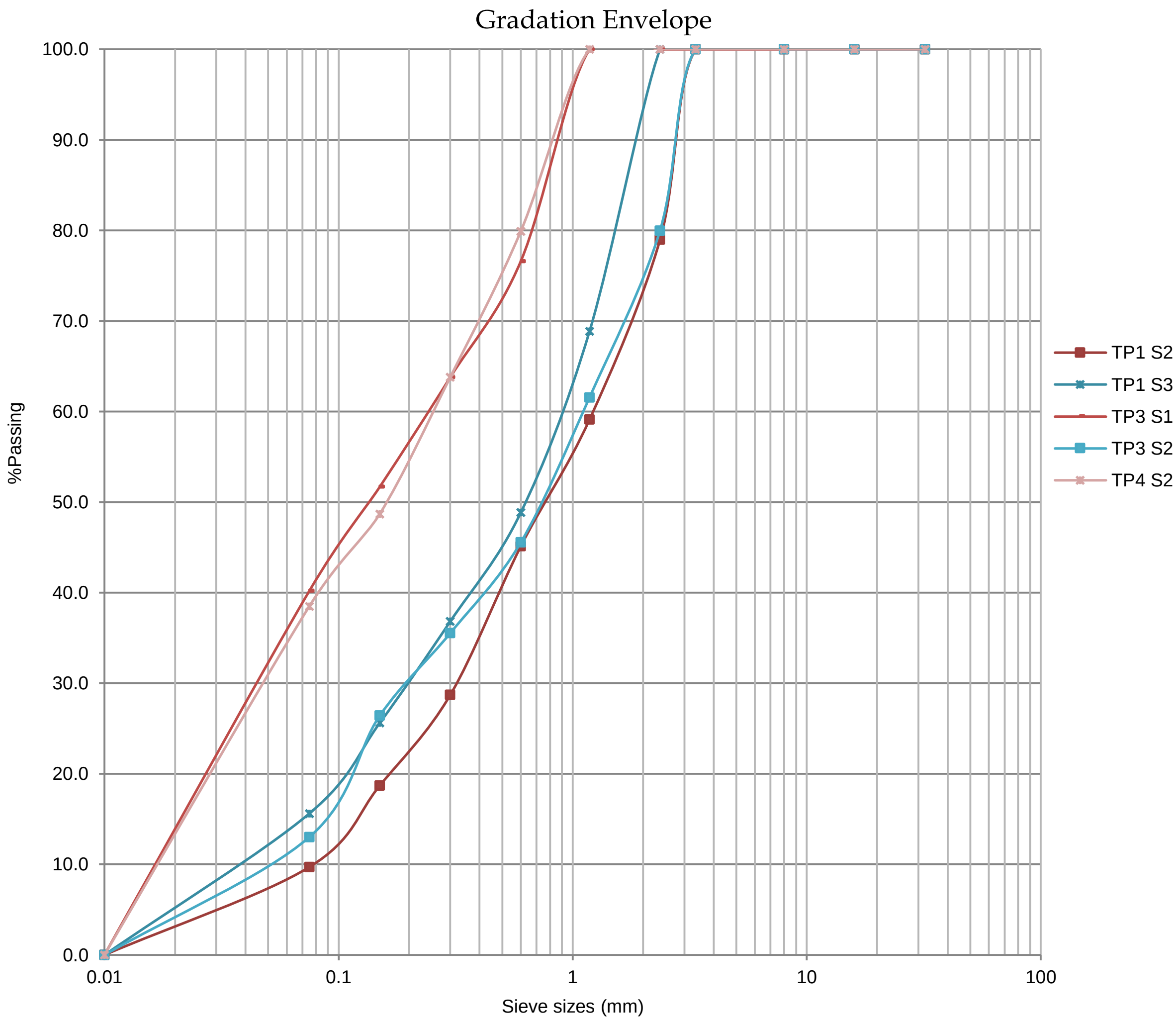


Fig. 6 Gradational curves from the Trial Pits 1, 3 and 4 of the dam axis

Studied samples from these pits revealed a larger percentage of coarse sand of about 38% in totality. TP 4 and TP 3 (S1) soil sample composition from the gradational curve lie together with almost same engineering property of very low fine material with high proportion of coarse grained sand in its matrix. The fine and medium grained sand components of the samples from these pits revealed it is moderate for the construction of a dam with no envisaged collapse. The TP 3 (S2) and TP 1 (S2 and S3) can be more compacted that the components of the samples will reveal low moisture content with high coarse grained sand that will support the bearing load capacity of the dam (Fig. 6).

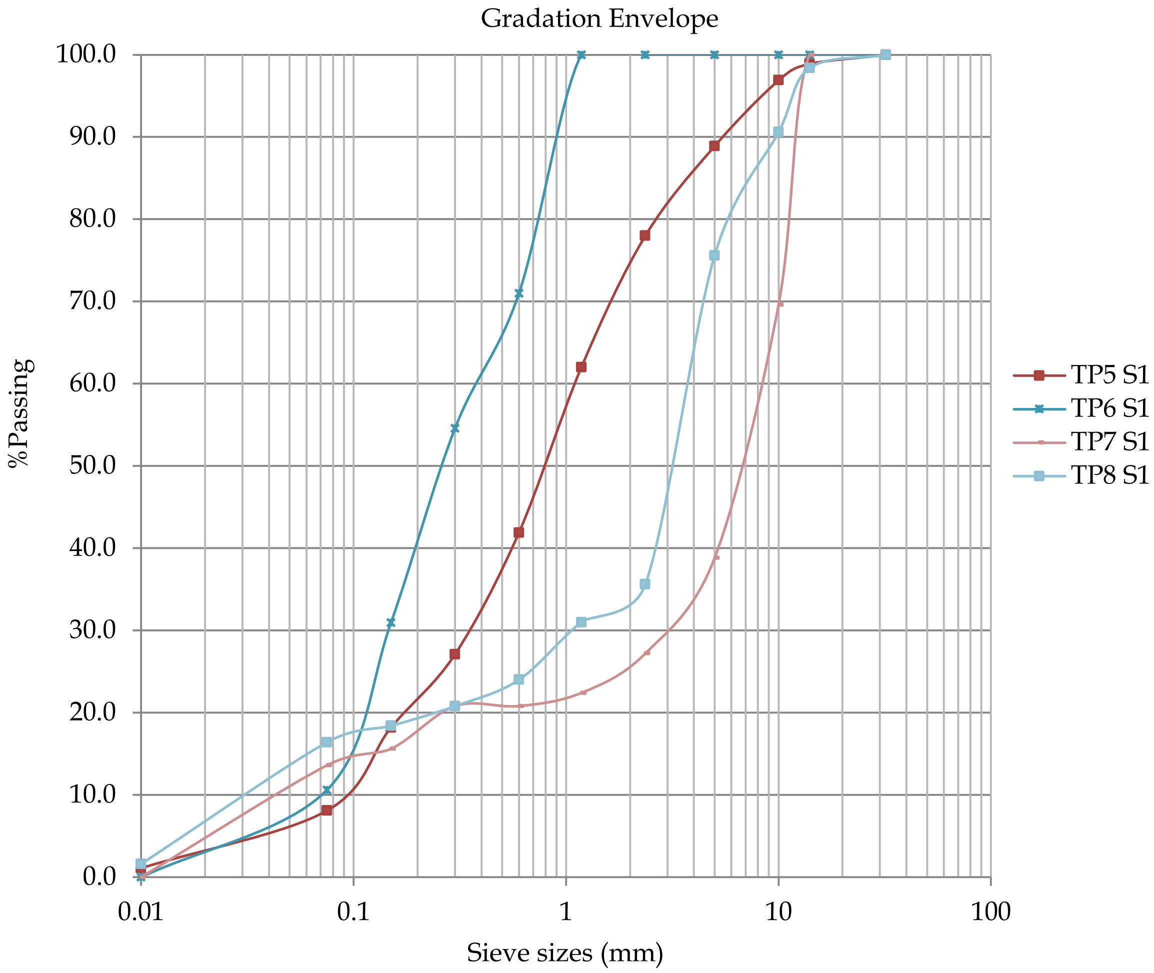


Fig. 7 Gradational curves from the Trial Pits 5, 6, 7 and 8 of the dam axis

Studied samples from pits 5, 6, 7 and 8 revealed a well graded coarse to fine grained sand and little amount of clay/silt in the matrix. The interlocking property of the grains due the sub-angularity of the grains will make them suitable for dam construction because they have revealed a higher shear strength. Collected samples (S1) from these pits revealed soil sample composition from the gradational curve that lie in a graded manner with almost same engineering property of coarse-fine sand material and low proportion of fine silt in its matrix. The coarse and fine grained sand components of the samples from these pits revealed it is good for the construction of a dam with no envisaged collapse or leakage.

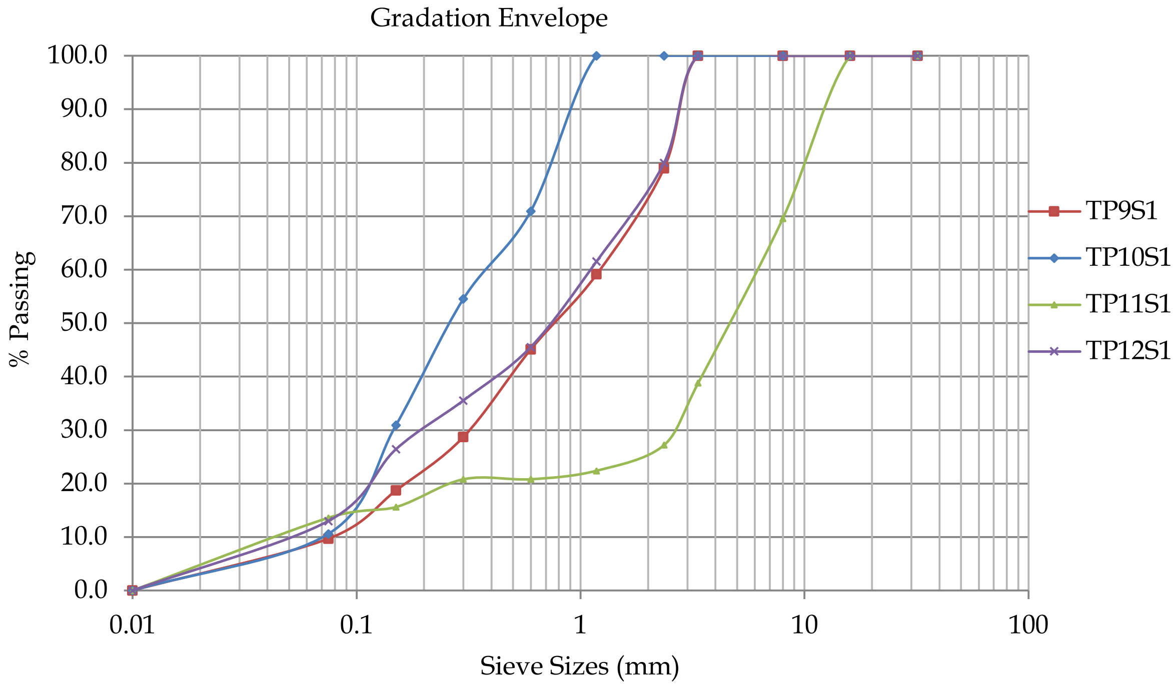


Fig. 8 Gradational curves of Trial Pits 9, 10, 11 and 12 of the dam axis

The collected samples (S1) from the Trial pits were compared with TP 9 and TP 10 displaying a better tie of gradational trend of interwoven curve and a D10 and D60 of 0.076 mm and 1.25mm. TP 10 and TP 11 samples are well graded with the components of the sample having a high proportion of silty/clay material with other components of sand and gravel. More excavation of the well graded silt/clay material and replacement with either the uniformly graded sand or gap graded gravel will be needed to allow a proper stability of the dam on this foundation. More importantly, the infiltration of groundwater or even rain water percolation into the thick clayey sandy gravel will render it unsafe to hold the foundational dam load to serve as a reservoir if not properly excavated.

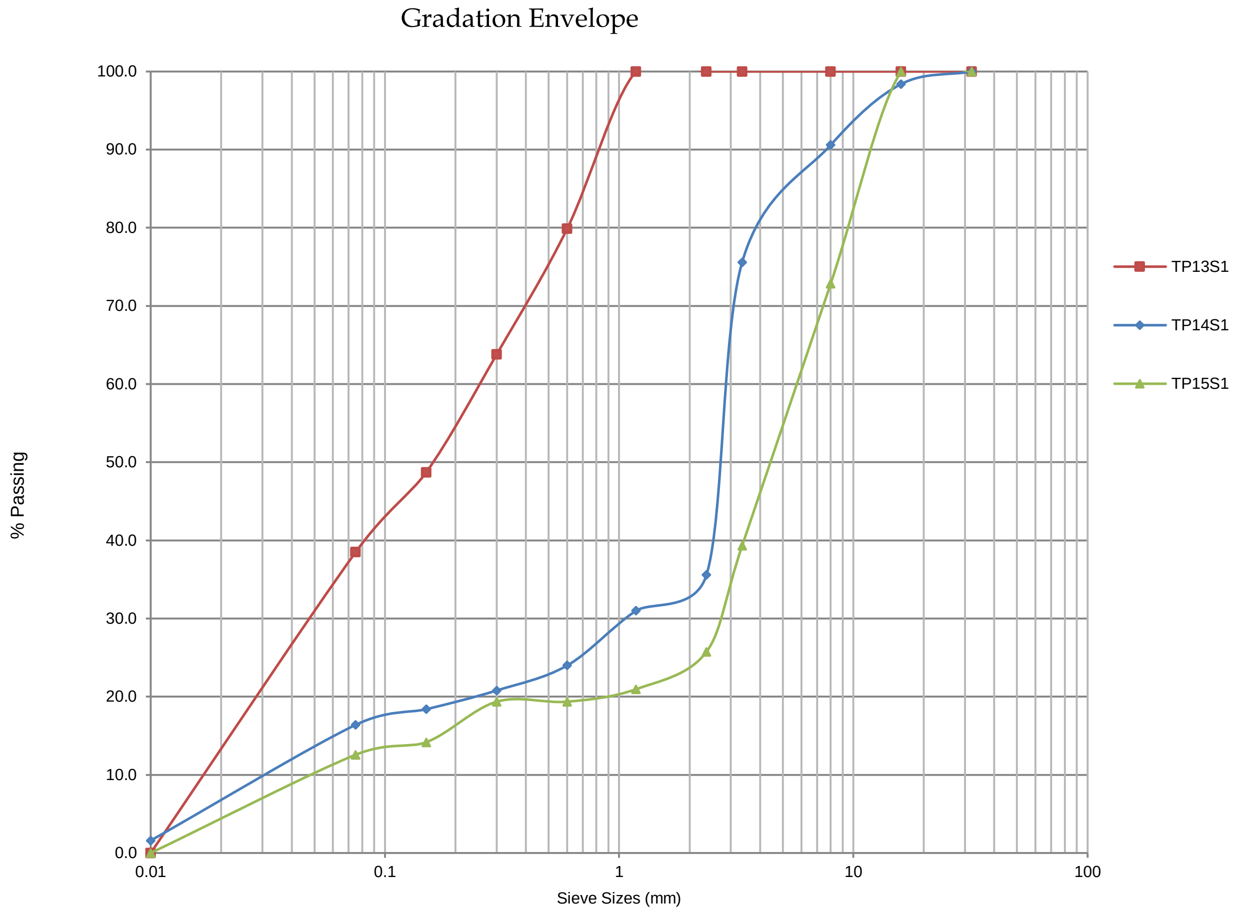
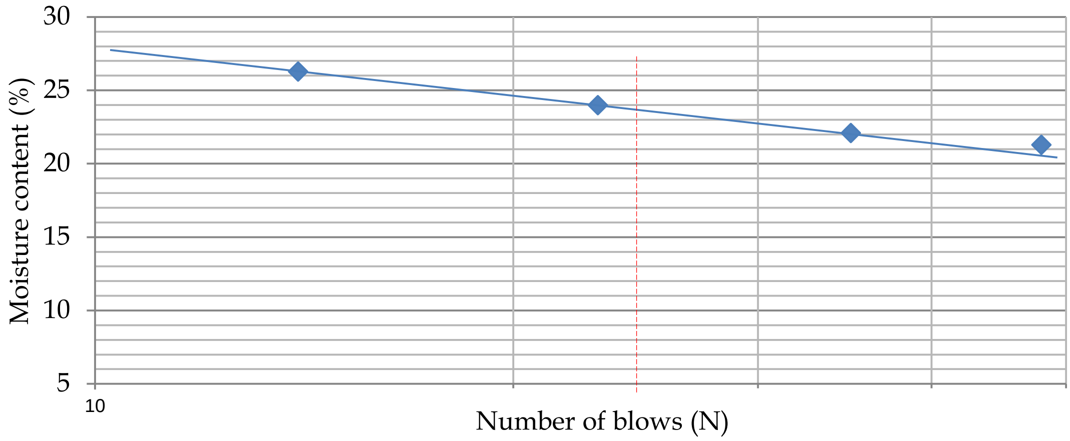


Fig. 9 Gradational curves of Trial Pit 13, 14 and 15 of the dam axis

TP 13, 14 and 15 S1 samples display a high proportion of gap graded gravel and well graded silt with no sign of uniformly graded sand from the pits sample. The D10 values of TP 13, 14 and 15 was measured as 0.07, 0.03 and 0.045mm respectively. The corresponding D60 of the pit samples was measured to be 0.24mm, 2.93mm and 5.97mm. The uniformity coefficient was calculated to be 3.428, 97.666 and 132.666 respectively.

B. Atterberg Consistent Limit

Atterberg's test was carried out on some of the study pit samples with high clay/silt content in their matrix. As such, TP1 (S2), TP1 (S3), TP3 (S1) and TP3 (S2) were subjected to Atterberg's consistency limit test to determine their moisture content. The liquid limit, plastic limit and plasticity index were determined for the samples to know if they will need be excavated and replaced with a suitable geologic material that will be crucial for the dam construction load. TP1 (S2) sample recorded a liquid limit value of 23.8%, plastic limit of 17.1% and Plasticity index of 6.7% (Table 1). TP1 (S3) sample recorded a liquid limit value of 23%, plastic limit of 17.14% and Plasticity index of 5.86%. TP3 (S1) recorded a liquid limit value of 22%, plastic limit of 0% and Plasticity index of 22%. TP3 (S2) recorded a liquid limit value of 35.1%, plastic limit of 0% and Plasticity index of 35.1% (Table 1).



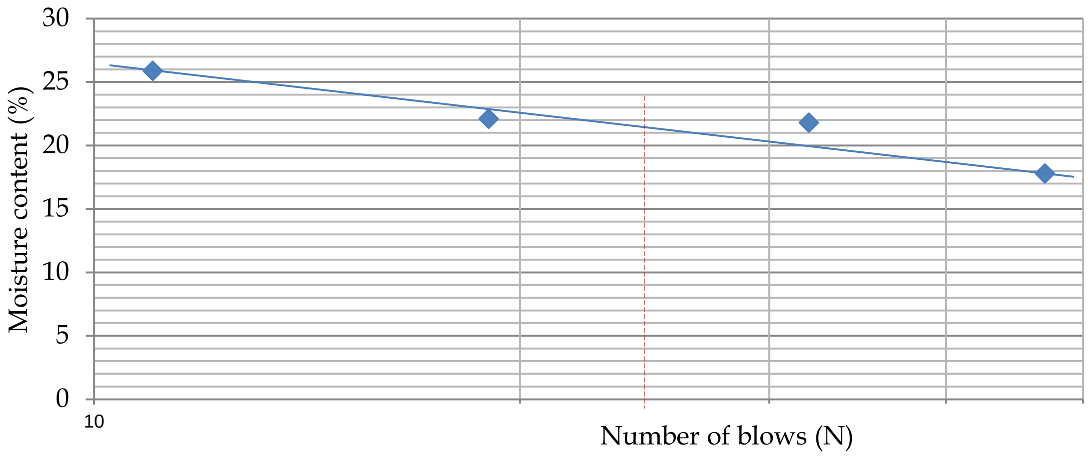
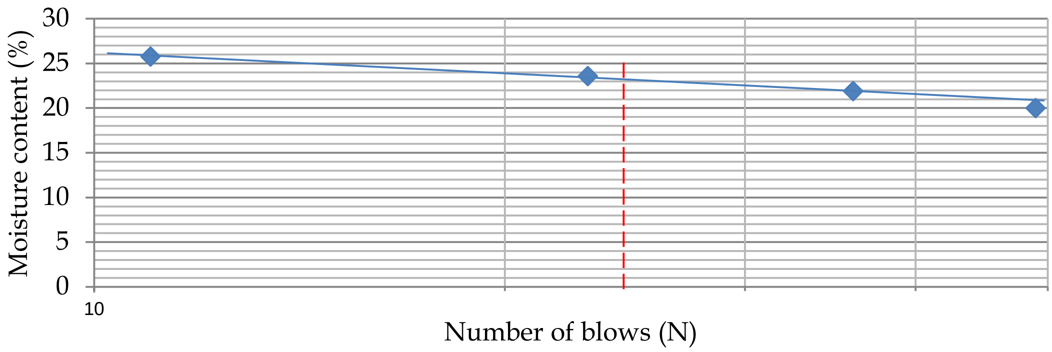


Fig. 10 Atterberg's limit graphs of moisture content against number of blows for TP1 (S2) and TP1 (S3) Samples

Table -1 Atterberg's limit of selected pit samples along Gbugudu dam axis

S/N	Pit and Sample I.D	Plastic Limit (%)	Liquid Limit (%)	Plasticity Index (%)
1	TP 1(S2)	17.1	23.6	6.5
2	TP 1(S3)	17.14	21.4	4.96
3	TP 3(S1)	0	23.1	23.1
4	TP 3(S2)	0	30.8	30.8



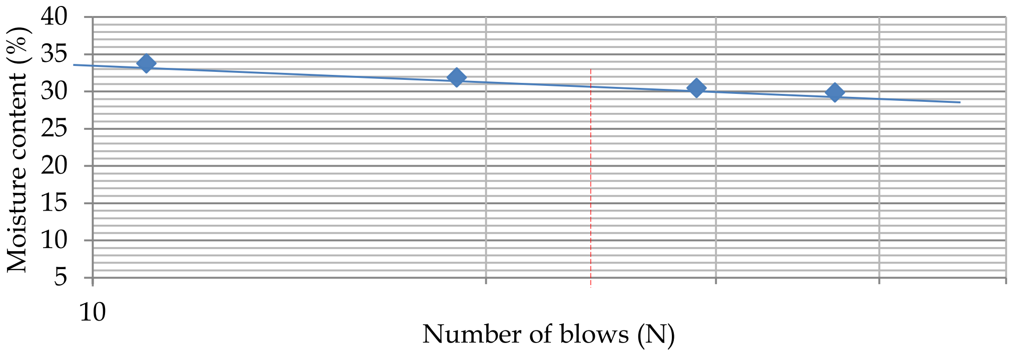


Fig. 11 Atterberg's limit graph of moisture content against number of blows of TP3 (S2) and TP 3 (S3) Samples

C. Permeability Test

Because permeability controls the strength and deformation of soils, it directly affects the quantity of water that will flow towards the point of excavation where design of the cutoffs beneath the dam for a permeable foundation will be needed. As such, an in-situ permeability test was conducted with varying time intervals with their recorded values (Table 2). The test has revealed a value that ranges from 1.01 x 10^{-4} to 9.26 x 10^{-6} m/s, thus the ability of the sand medium to allow percolated underground water and infiltrated rain water to pass through, which is low and expected to be insignificant to support the water tight condition need of the Gbugudu dam.

Table -2 Table of in-situ permeability test result of proposed Gbugudu dam axis

Test sample/location	Time taken (s)	Permeability (m/s)
TP1	180	1.23 x 10^{-5}
TP2	393	5.65 x 10^{-6}
TP3	240	9.26 x 10^{-6}
TP4	135	1.65 x 10^{-5}
TP5	205	2.44 x 10^{-4}
TP6	22	2.27 x 10^{-3}
TP7	142	1.08 x 10^{-5}
TP8	-	-
TP9	-	-
TP10	-	-
TP11	220	1.01x10^{-4}

D. Compaction Strength Test

Compaction strength test was conducted on the study samples of TP1 (S2), TP1 (S3), TP3 (S1), TP3 (S2), TP 4 (S2) and TP 5 (S1) with a value that ranges from about 3-14% moisture content. The curves were plotted for each sample as dry density (g/cm³) against moisture content (%) of each sample. Inverted V curves were generated for all studied samples which was further interpreted as cohesive soils with fines in all study samples (Figs. 12-14).

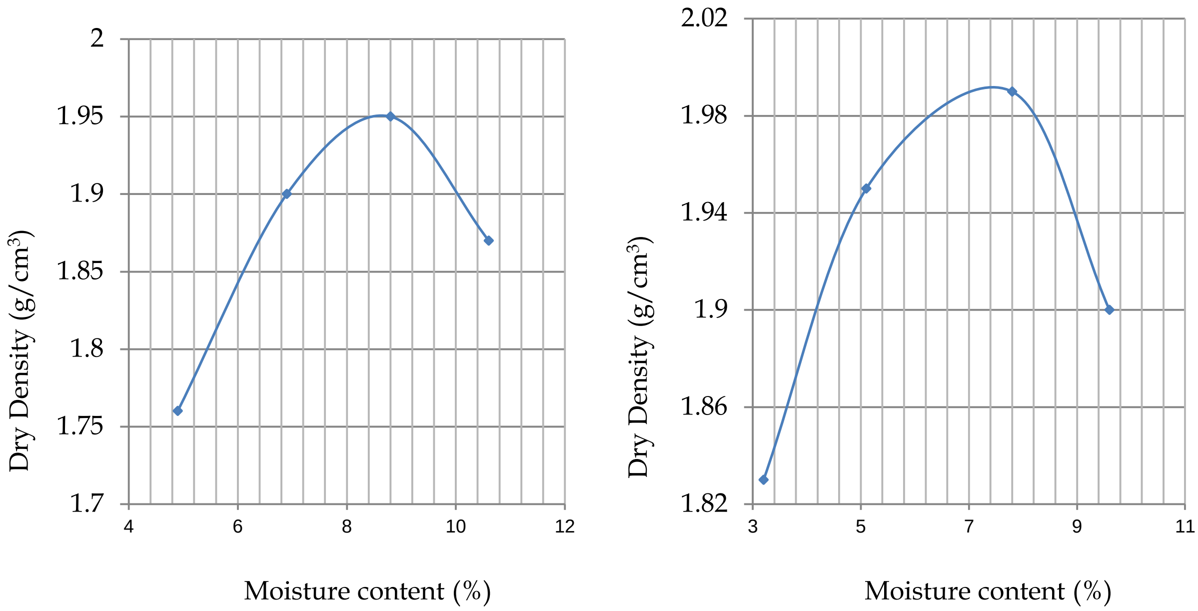


Fig. 12 Compaction curve of TP1 S2 and S3 samples of Gbugudu study area.

Table-3 Geotechnical properties of TP 1 S2 and TP 1 S3.

TP 1 S2. MDD = 1.95, OMC = 8.80.				
Dry Density (g/cm³)	1.76	1.90	1.95	1.87
Moisture Content (%)	4.93	6.81	8.80	10.60
TP 1 S3. MDD = 2.00, OMC = 7.8				
Dry Density (g/cm³)	1.83	1.96	2.00	1.90
Moisture Content (%)	3.21	5.11	7.80	9.6

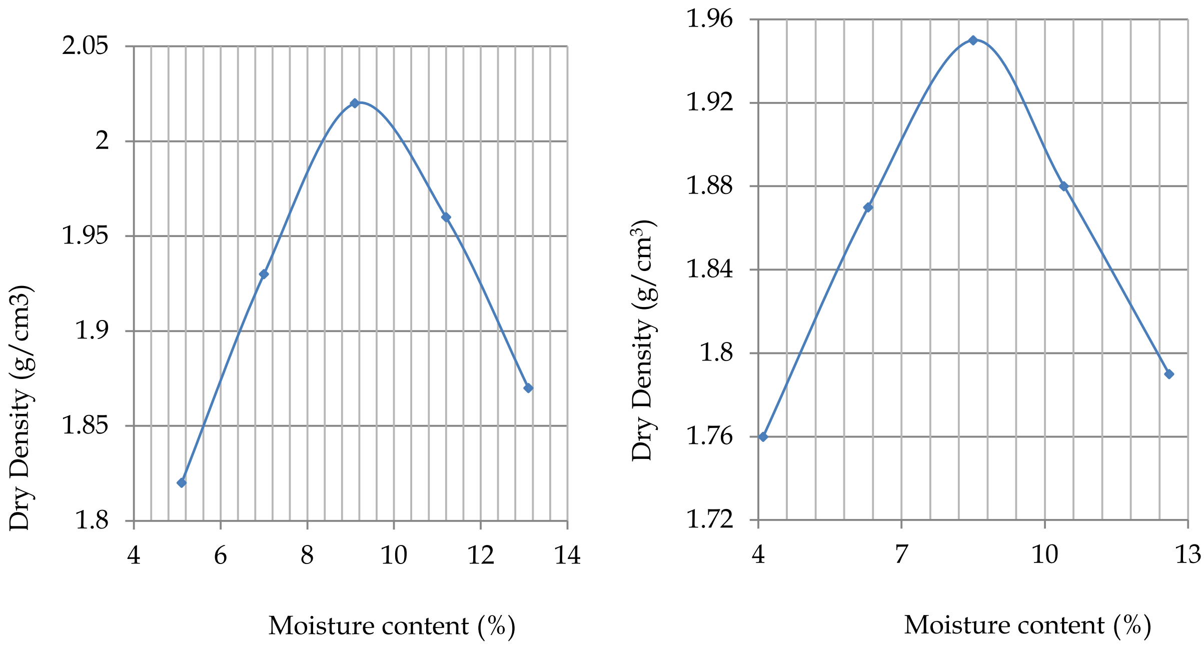


Fig. 13 Compaction curve of TP3 S1 and S2 samples of Gbugudu study area.

Table -4 Geotechnical properties of TP 3 S1 and TP 3 S2.

TP 3 S1. MDD = 1.95, OMC = 8.80.					
Dry Density (g/cm³)	1.82	1.93	2.02	1.96	1.87
Moisture Content (%)	4.87	6.99	9.20	11.20	13.10
TP 3 S2. MDD = 1.99, OMC = 7.80					
Dry Density (g/cm³)	1.76	1.87	1.94	1.88	1.79
Moisture Content (%)	4.07	5.59	8.50	10.90	12.33

The compaction geotechnical strength test conducted on the study samples has revealed that, as water was gradually added to the dry samples, the particles became closer with void reducing across the samples and this reflected in the dry density mass that increased before slightly dropping. As the moisture content also increases, the soil particles developed larger water film around the particles as protective layer, as such, water seepages, which is almost totally inevitable in the proposed dam construction from the groundwater and rainwater infiltration will have less effects on the dam foundation property to conserve water. The test has thus revealed very cohesive soil property with fines in the voids that constitute the matrix of the studied samples. The maximum dry density of all study samples were equally obtained at the optimum water content to reveal its property of highly cohesive nature which is desirably good in dam construction. In essence, the tested soil samples for the construction of a dam/weir in Gbugudu area will be supportive with very little issue of liquefaction and seepage expected in the soil profile of the area.

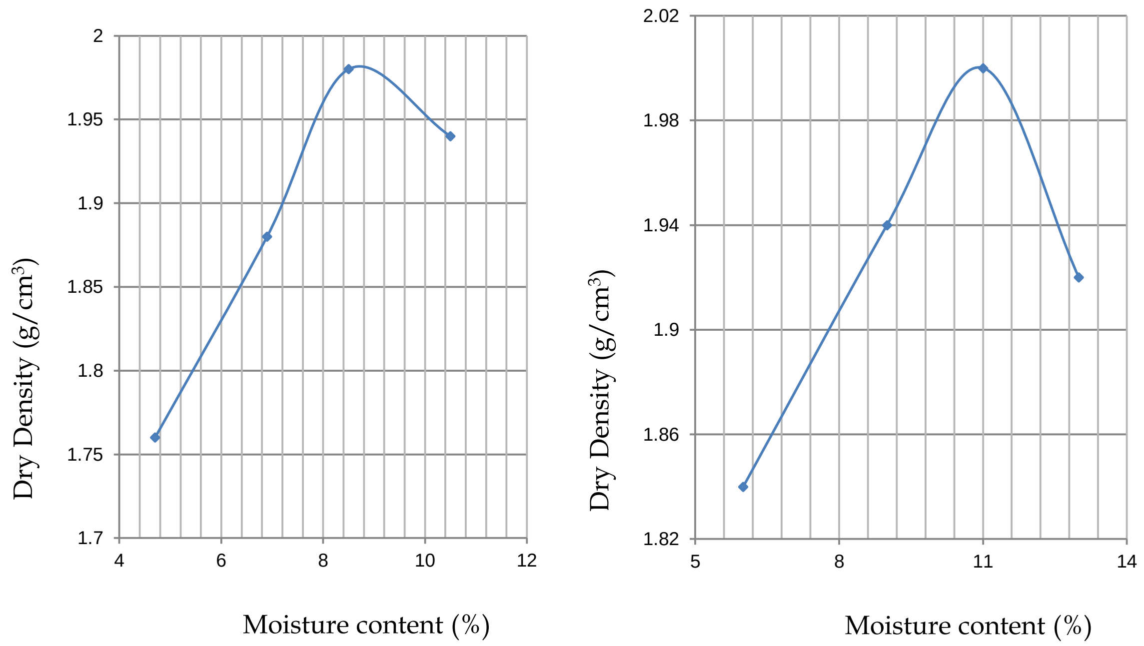


Fig.-14 Compaction curve of TP4 S2 and TP 5 S1 samples of Gbugudu study area

Table-5 Geotechnical properties of TP4 S2 and TP 5 S1

TP4 S2 MDD = 2.02, OMC = 9.20.				
Dry Density (g/cm^3)	1.76	1.90	1.95	1.87
Moisture Content (%)	4.90	6.83	8.80	10.6
TP 5 S1 MDD = 1.99, OMC = 7.80				
Dry Density (g/cm^3)	1.83	1.96	1.99	1.90
Moisture Content (%)	3.16	5.18	7.80	9.60

E. Triaxial Strength Test

Triaxial strength test of selected representative samples were done using the Mohr circle for better interpretation of the failure plane to determine the feasibility of constructing a suitable dam/weir for irrigation purpose. The samples (TP1 S2, TP1 S3 and TP2 S1) of the drilled pits were subjected to appropriate confining overburden pressure using the triaxial cell. The hydraulic pressure was kept constant for the 3 cycles of each test and the deviator stress increased until coulomb's failure occurred for the samples. When the soil samples finally failed, the shear stress on the failure plane that defines the shear strength of the soil was measured against the normal stress for each investigated sample (Figs. 15 and 16) and was found to vary from 5-15KN/m^2.

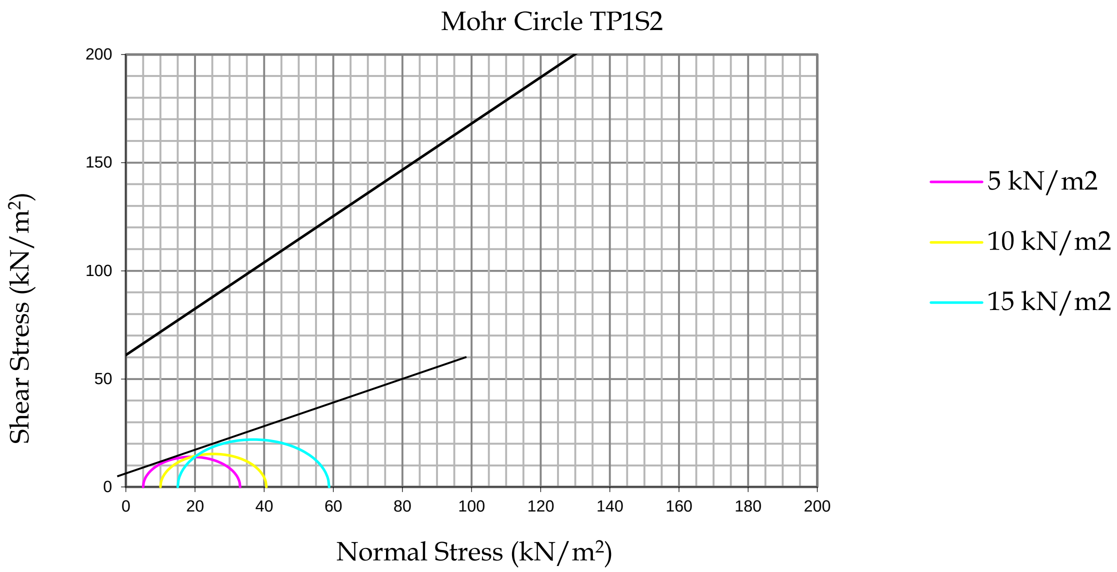


Fig. 15 TP1 S2 Mohr's circle curve of shear stress against Normal stress.

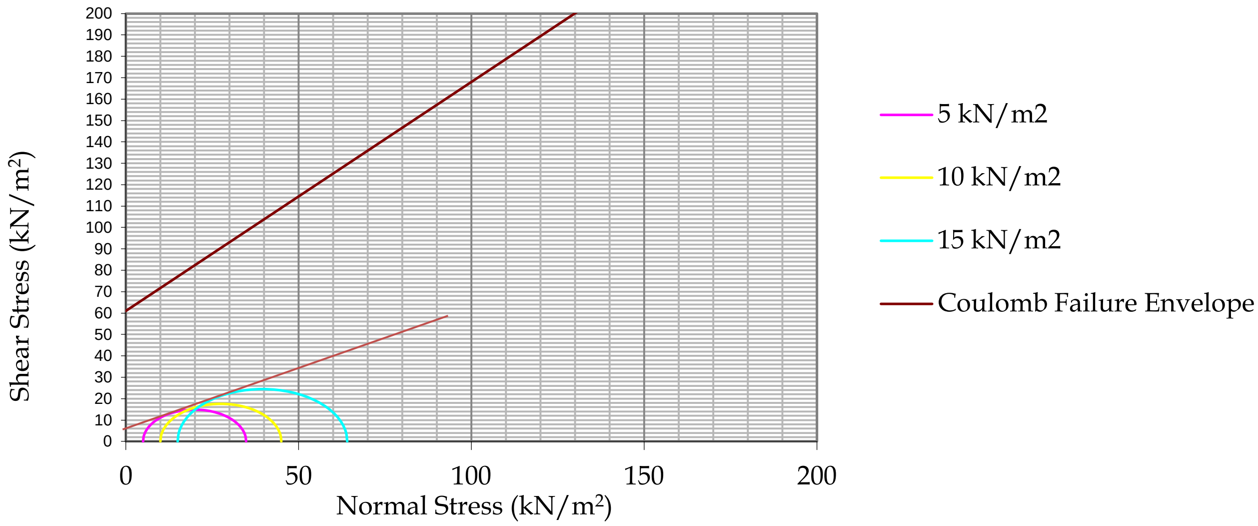


Fig. 16: TP1 S2 Mohr's circle curve of Shear stress against Normal stress.

CONCLUSION

Coarse and fine-medium grained sand with silty clay are contained in the matrix with varieties of sandy silty clay desirable for construction of dams. Atterberg's limit of Liquid limit of 21.0-35.1%, Plastic limit of 17.1-17.14% and Plasticity Index of 4.0-22% point towards a stable earth dam for the area. In-situ permeability test that ranges from 1.01 x 10^{-4} to 9.26 x 10^{-6} ms^{-1} will allow minimum infiltration of water into the subsurface. Compaction strength test revealed the Optimum moisture content and Maximum Dry Density that ranges from 1.95-2.02 (%) and 7.80-9.20 (g/cm^3) respectively will support the durability of the dam.

RECOMMENDATIONS

Introduction of any viable geophysical technique to comb the area for fractural network will assist the evaluation of water retention capacity of the proposed dam for suitable seepage control mechanism that will be used in the area.

ACKNOWLEDGEMENT

Special thanks to the staffs of Lower Niger River Basin Development Authority, especially the PID ie Planning, Investigation and Design Department for allowing the valuable time spent on this research outside work schedules.

CONFLICT OF INTEREST

The research work was carried out by me and there is no conflict of interest associated with it.

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