International Journal of Scientific Research in Multidisciplinary Studies
Research Paper
Vol.4, Issue.12, pp.18-35, December (2018)
E-ISSN: 2454-9312
P-ISSN: 2454-6143

Preliminary Geotechnical Characterization of Soils at the Southern Part of the Proposed Faculty of Law, Al-Hikmah University Ilorin, South-Western, Nigeria

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Available online at: www.isroset.org

Received: 19/Dec/2018, Accepted: 22/Dec/2018, Online: 31/Dec/2018

Abstract- The aim of this research work is to investigate the engineering suitability of soils for foundation purposes within the southern part of the proposed faculty of law (Atere Campus), Al-Hikmah University Ilorin, south-western Nigeria. Geotechnical investigation was carried out using analyses such as grain size distribution, Atterberg limits, specific gravity, bulk density, consolidation test and direct shear box test on nine samples which were collected from three different locations of the study area by the use of trial pits of about 1.6-1.7m depth at an interval of 0.5m. The grain size analysis shows the samples are classified as sand to gravely sand (SC/SM) based on Unified Soil Classification with 0.9% - 69.73 gravel and 30.27- 99.1% sand. The soil samples are above the activity (A) line of the plasticity chart in the zone of inorganic sand (CI). The consolidation test indicates that the soils have low settlement. The results from the direct shear box tests show that the samples have a medium angle of internal friction which ranges from 260-330 with cohesion of 20KPa-40KPa. This means that the foundation design of the area will be shallow foundation and could support moderately light to heavy structures. The soil materials can as well be used in high way construction as a sub-grade material. Also, shear strength analysis was carried out on the samples from different depth and it was discovered that the shear strength increases with depth.

Keywords: *geotechnical, soils, shear strength, foundation, trial pits,*

I. INTRODUCTION

Improper evaluation of geotechnical characteristics of soil prior to construction is often disastrous and often leads to building collapse with consequent loss of lives and properties. Geotechnical investigation is undertaken to obtain information on the physical properties of soil and rock underlying a site to design foundation for a proposed structure and for repair of distress caused by subsurface condition [1]. A geotechnical investigation will include surface and subsurface exploration in a site [2].

Geotechnical properties of soils play a significant role in engineering construction works, especially in foundations, embankments, and road and dam constructions [3]. This is because nearly all engineering projects are built on soil. Another point is that, soil properties vary significantly from one project site to another, and even at different locations within a single site.

The construction of any structure depends on the soil beneath it. In many parts of the world, the complete neglect of soil behaviours has caused appalling collapse and failure of structures such as buildings and dams. This brings about tremendous losses in production of undurable materials [4].

Because the soil behaviours and properties differ from site to site, soil evaluation is paramount. Usually, the properties are investigated and determined by field and laboratory tests. The need for adequate and reliable geotechnical characterization of sub-soil is very important. This is because the impact of the imposed load is exacerbated by the thickness and consistency of the compressible layer [5]. This in addition to other intrinsic factors contributes to the failure of civil engineering structures [6, 7]. For the purpose of generating relevant data inputs for the design and construction of foundations for proposed structures, it is imperative that site (s) be geotechnically characterized through investigation. The newly proposed faculty of law of Al-

Hikmah University is to be constructed at the study area. Hence, it is necessary to evaluate the geotechnical characteristics of the soil in order to be able to make technical recommendation on the foundation design and the suitability of the soil from the study area for use as construction material. Consequently, lives and properties will be protected. Rest of the paper is organized as follows; section I contains the introduction of the paper, section II contains related work, section III contains the methodology employed in the research, section IV describes results and discussion and section V concludes research work with future scope.

II. RELATED WORK

Some of the works that have been done in the past on geotechnical properties of soils in the area are reviewed below:
[8] investigated engineering geological and foundation characteristics of granite derived subsoils at Ibuji Town, Ondo State, Nigeria. Laboratory test results of the disturbed soil samples collected showed a natural moisture content ranging from 30.06% to 35.02%, liquid limit from 40% to 55%, linear shrinkage from 8.5% to 9.4% and specific gravity from 2.60 to 2.65. They concluded that the dominant subsoils are clay and sands with good foundation properties. [9] carried out geotechnical investigation for the design and construction of civil infrastructures in parts of Port Harcourt city of Rivers State, Nigeria. They used fourteen samples of sand and clay from different locations within the Afam Clay Member and Benin Formation were assessed. They deduced that the geotechnical behaviour of the materials within the study area shows that the cohesive materials failed some relevant material specifications for most civil infrastructures, having ultimate and safe bearing capacity averaging 410.48 KN/m^2 and 136.83 KN/m^3 respectively. Thus, they should be avoided as foundation (load bearing) materials during civil constructions, while the cohesion less soil though, of medium dense and poorly graded will serve as better load bearing materials. [1] studied the sub-soil types and profile in order to ascertain the geotechnical characteristics of the underlying soils in Akenfa in Yenagoa, Bayelsa State, Nigeria, and recommend appropriate foundation design and construction of projects in the area. They drilled three geotechnical boreholes at the site to obtain baseline data on geotechnical properties of the soil and water level monitoring. Considering the nature of the civil structures to be sited in the area, the authors concluded that the load and the moderate compressibility of the near surface silty clay and the underlying loose silty sand be supported by means of raft foundation founded within the clay layer. [10] conducted a geotechnical investigation of some selected beach sands in Lagos and got the following results: shear strength (0.18 - 3.67KN/m^2); specific gravity (2.57); bulk density (1.95g/cm^3); dry density (1.70g/cm^3); and moisture content (14.6%). They as such concluded that all the beach samples tested can only support small structures. Large scale, high-rise buildings intended for these sites would need soil improvement procedures of stabilization such as vibro-compaction and grouting.

III. METHODOLOGY

The scope of this research is based entirely on field sampling and geotechnical laboratory analyses of the soils. To achieve this goal, earth surface was exposed artificially by digging test pits manually. Nine sets of samples were collected by digging three trial pits in the study area. Three of these samples were gotten from the first pit (labelled T1) dug to about 1.6m, three from the second pit (labelled T2) dug to about 1.6m too and the rest three from the third pit (labelled T3) dug to about 1.7m. The samples were taken at an interval of 0.5m in each of the three pits so as to have representative samples of the soils therein. In order to avoid bias, the pits were dug in three different locations in the study area; one at the centre and the other two at the boarder lines. Some identification tests such as unit weight, bulk and dry density, grain size analysis, Atterberg's consistency limit, consolidation test and direct shear were conducted. The field work and sampling were done in rainy reason and the lab work started aftermath in the year 2017.

IV. RESULTS AND DISCUSSION

RESULTS

Table 1: Water Content Determination for the Samples

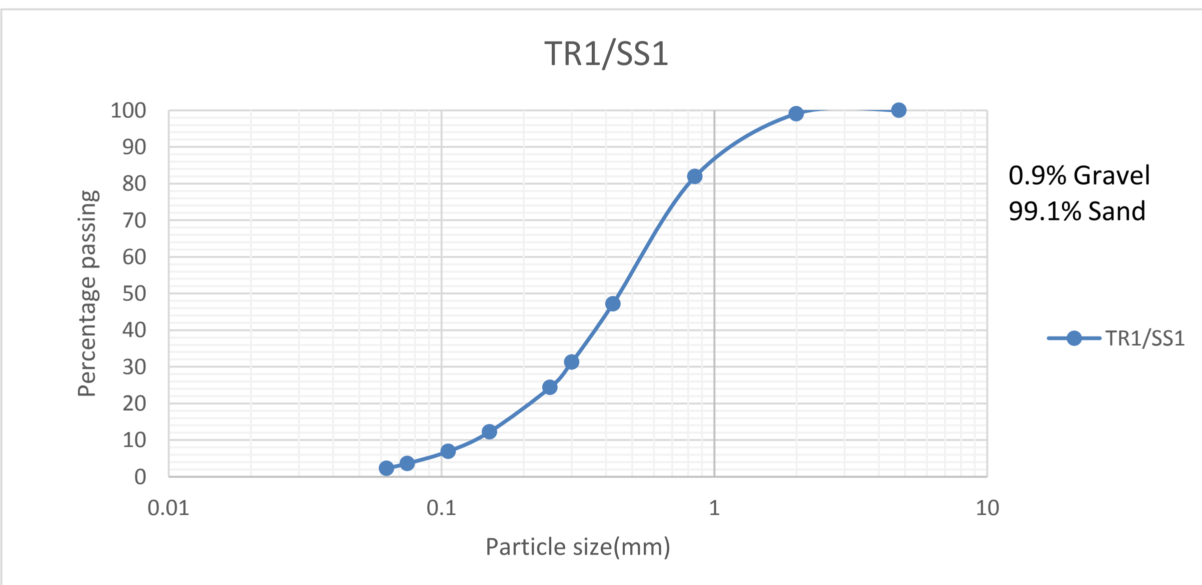
	TR1/SS1	TR1/SS2	TR3/SS1	TR2/SS1
Container no.	C_1	C_2	C	B6
Wt of can + wet soil(g)	89	87.5	103.5	76
Wt of can + dry soil (g)	87.5	86.5	101.5	74.5
Wt of can (g)	14.5	18.0	15.0	12.5
Wt of dry soil (g)	73	68.5	86.5	62.0
Wt of water (g)	1.5	1.0	2.0	1.5
Water content %	2.1	1.5	2.3	2.4

Table 2: Bulk Density Determination

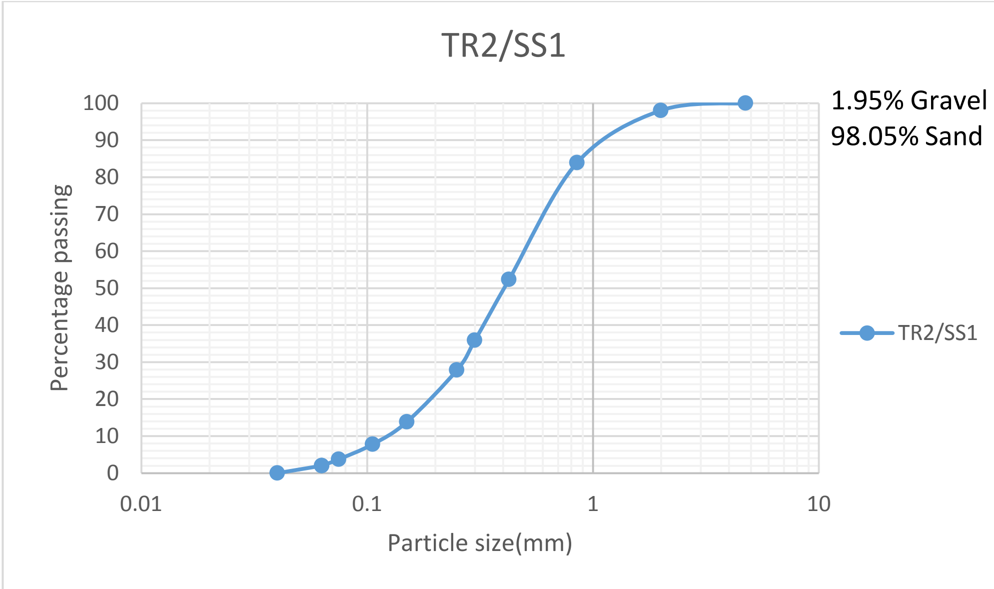
	TR1/SS2	TR1/SS3	TR2/SS1
Wt of mould (g)	183.0	283.63	283.63
Wt of mould + wet soil (g)	538.5	446.0	473
Wt of wet soil (g)	355.5	162.37	189.37
Volume of mould (cm³)	251.4	139.95	139.95
Bulk density (g/cm³)	**1.41**	**1.16**	**1.35**
Unit weight (kN/m^2)	**13.83**	**11.38**	**13.23**
Wt of mould + dry soil (g)	742	438	469
Wt of mould (g)	400	283.63	283.63
Wt of dry soil (g)	342	154.37	185.37
Volume of mould (cm³)	251.4	139.95	139.95
Dry density (g/cm³)	**1.36**	**1.10**	**1.32**
Dry unit weight (kN/m^2)	**13.33**	**10.79**	**12.95**

Grain Size Analysis

Figure 1 and figure 2 show the particle size distribution curve for the soil samples TR1/SS1 and TR2/SS1. All other results and curves are in the appendix



Figures 1: Particle Size Distribution Curve for the Soil Samples TR1/SS1



Figures 2: Particle Size Distribution Curve for the Soil Samples TR2/SS1

Table 3: Summary of grain size analysis

Sample	Gravel (%)	Sand (%)	D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	Coefficient of Uniformity, C_u	Coefficient of Curvature, C_c	USCS
TR1/SS1	0.90	99.10	0.15	0.30	0.55	3.67	1.09	GP
TR1/SS2	1.04	98.96	0.15	0.31	0.56	3.73	1.14	GP
TR1/SS3	2.29	97.71	0.18	0.38	0.70	3.89	1.15	GP
TR2/SS1	1.95	98.05	0.12	0.28	0.50	4.17	1.31	GW
TR2/SS2	1.91	98.09	0.14	0.29	0.52	3.71	1.16	GP
TR2/SS3	46.78	53.22	0.40	0.80	2.60	6.50	0.62	GW
TR3/SS1	69.73	30.27	0.55	2.00	5.20	9.45	1.40	GW
TR3/SS2	63.89	36.11	0.45	1.50	5.00	11.11	1.00	GW
TR3/SS3	40.32	59.68	0.20	0.60	2.00	10.00	0.90	GW

Atterberg Limit Tests Results

The results for the Atterberg limit tests of soil sample TR1/SS1 are presented in Figure 3 and 4 while those of the other samples in the appendix.

Table 4: Liquid Limit Determination

Can no	A_1	A_2	A_3	A_4
Wt. of wet soil + can	30	31.5	22	17.3
Wt. of dry soil + can	28	29	20	14.5
Wt. of can	14.0	16.5	11.0	3.5
Wt. of dry soil	14.0	12.5	9.0	11.0
Wt. of moisture	2.0	2.5	2.0	2.8
water content %	14.3	20.0	22.2	25.5
No. of blows	35	27	21	11

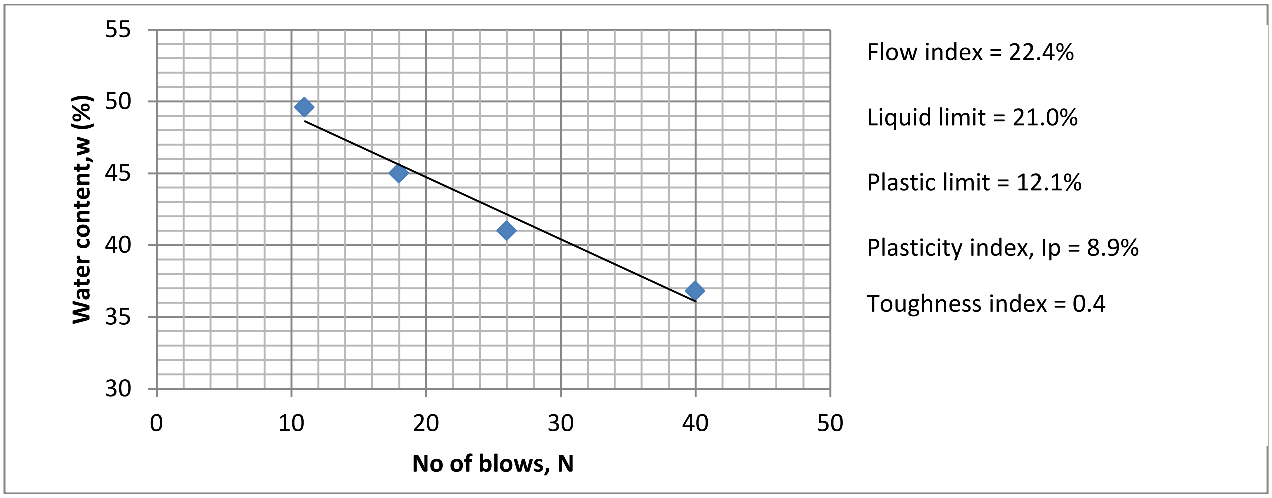


Figure 3: Consistency graph for sample TR1/SS1

Table 6: Plastic Limit Determination

Can no	A_5	A_6	A_7
Wt. of wet soil + can	21.5	29.7	29.0
Wt. of dry soil + can	20.5	28.5	27.5
Wt. of can	11.5	19.0	15.0
Wt. of dry soil	9.0	9.5	12.5
Wt. of moisture	1.0	1.2	1.5
water content %	11.1	13.3	12.0

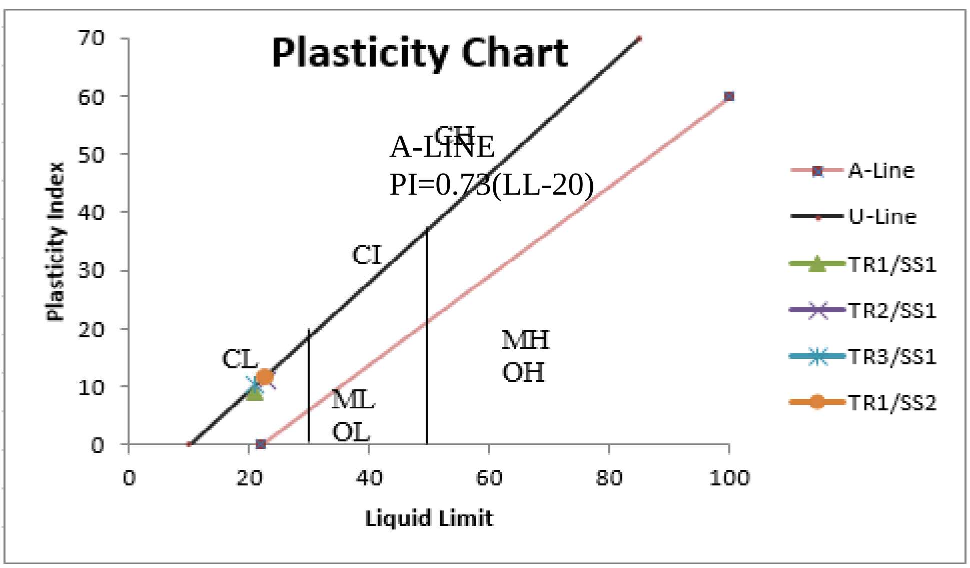


Figure 4: Plot of samples from study area on plasticity chart

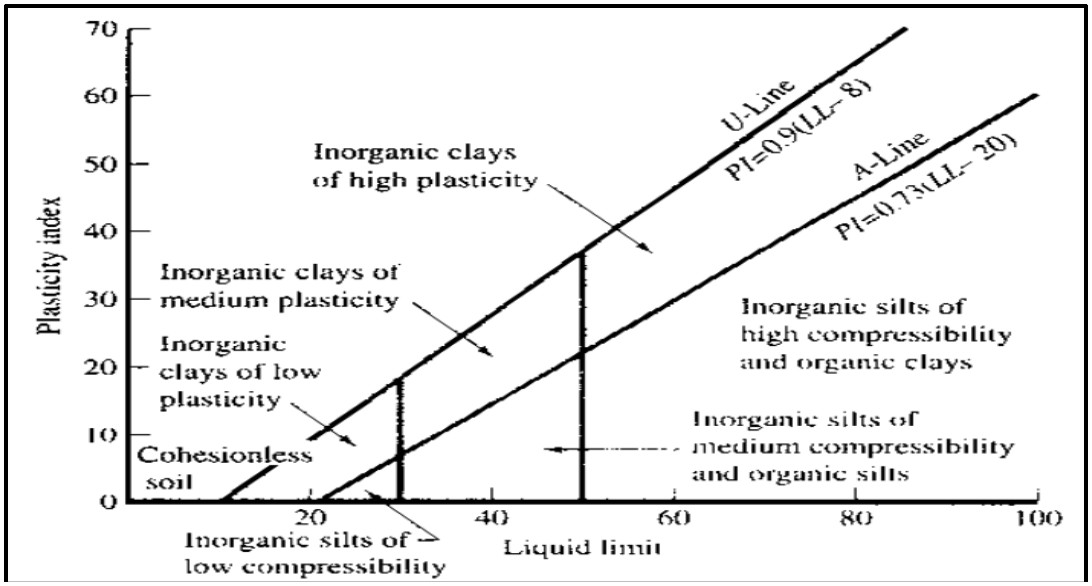


Figure 5: Standard Plot of Plasticity Index against Liquid Limit (AASHTO SOIL classification system)

Table 7: Summary of Atterberg Limit Tests

Symbol	LL (%)	PL (%)	IP (%)	Plot on the plasticity Chart
TR1/SS1	21.0	12.1	8.9	Below CL
TR1/SS2	23.0	11.5	11.5	Below CL
TR2/SS1	23.0	12.1	10.9	Below CL
TR3/SS1	21.0	10.7	10.3	Below CL

Consolidation Test

Table 8: Consolidation Test

VOID RATIO: 1.007 CHANGE IN VOID RATIO: 0.122 SAMPLE THICKNESS: 16.5cm.
AV: 2.5X 10^{-2}KN/m^2 MV: 1.2X10^{-2}KN/m^2 S: 12mm/m

Vertical Load (Kg)	Vertical load ==Wg(kg)x g / 1000 (2)	Stress(KN/$m^{2)}$= Vertical load / Area of machine (3)	Dial Gauge Reading At 24hrs. ×0.01=	Change in Thickness after Consolidation (mm) (5)= (4)x0.0042	Thickness of soil after Consolidation (mm) (6)= 20-(5)
5.00	0.0049	11.10	38.5	0.385	19.62
10.00	0.098	22.20	67	0.67	18.95
15.00	0.147	33.30	85	0.85	18.10

The thickness of the sample after consolidation is 16.50mm

The Value of the Void Ratio, E at the End of Each Consolidation Test

Pressure (KN/m^2)	H (mm)	Dh (20-Final thickness)	De	E
0.0	20.00	1.9	0.21	1.37
11.10	19.19	1.05	0.12	1.16
22.20	17.93	0.38	0.04	1.04
33.30	16.50	0.00	0.00	1.00

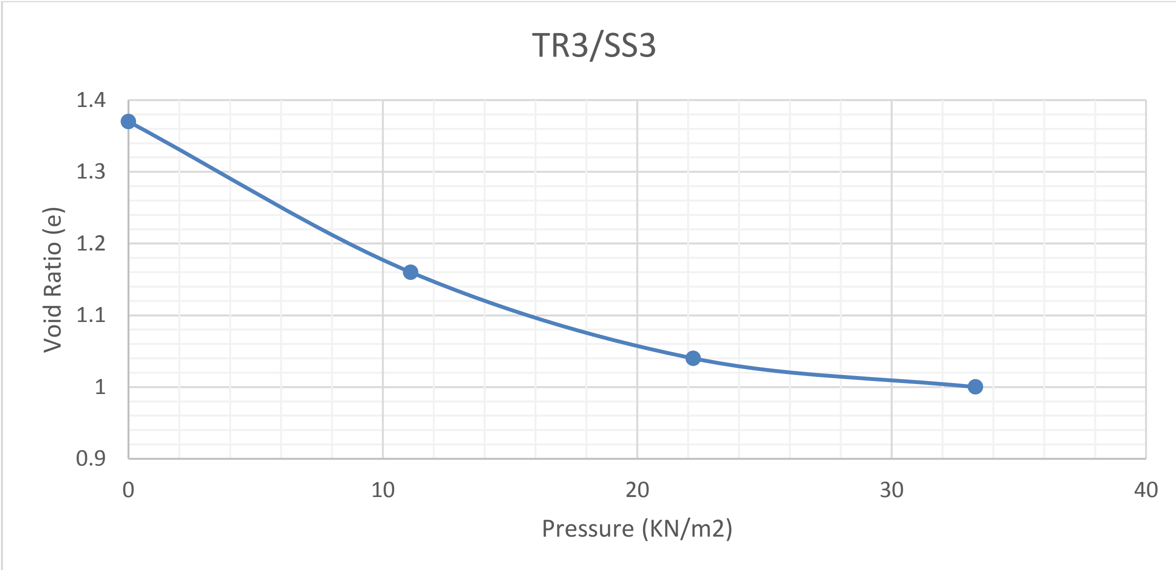


Figure 6: Graph of void ratio against pressure for sample TR3/SS3

Table 9: Summary of results for consolidation (Oedometer) Tests

Sample Label	Mv (m^2/KN)	Av(m^2/KN)	S(mm)
TR2/SS3	1.2 X 10^{-2}	2.5 X 10^{-2}	0.41
TR3/SS1	2.3 X 10^{-2}	2.0 X 10^{-1}	0.24
TR3/SS3	2.2 X 10^{-2}	1.0 X 10^{-1}	0.11

Direct Shear Data

Table 10 shows the results obtained in the direct shear test for standard and modified Proctor tests for sample TR2/SS3.

Table 10: Normal Stress and Shear Stress for TR2/SS3

LOAD (KG)	NORMAL STRESS (kN/m^2)	LOAD DIAL READING	SHEAR STRESS (kN/m^2)
5	188.0	297	142.97
10	324.3	423	203.63
15	460.5	634	305.20
20	596.8	788	379.33

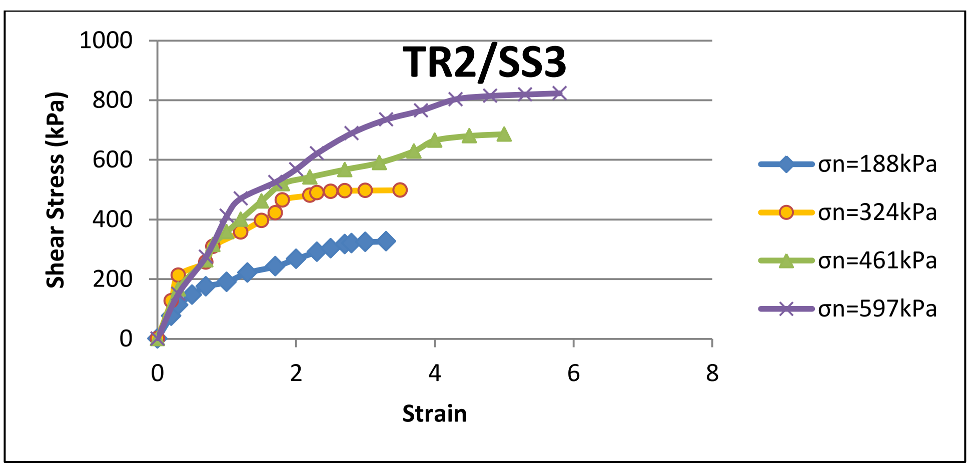


Figure 7: Plots of Shear Stress (kPa) against Strain (%)

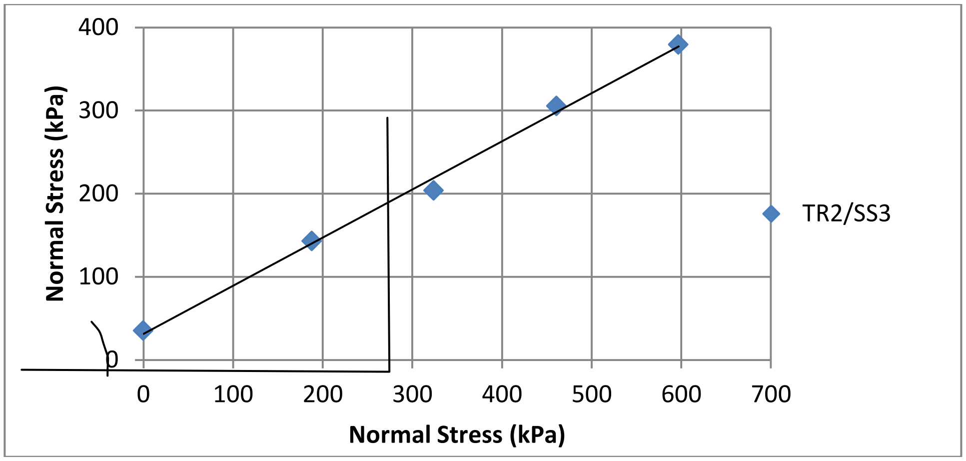


Figure 8: Plot of shear stress (kPa) against normal stress (kPa)

Table 11: Shear strength for the samples

Norma stress (kPa)	Shear strength for TR1/SS1	Shear strength for TR3/SS2	Shear strength for TR1/SS3	Shear strength for TR3/SS3	Shear strength for TR3/SS2
188	55.0	111.7	140.5	162.1	152.5
324	218.6	178.0	225.4	250.4	237.4
461	294.5	144.8	311.1	339.4	323.1
597	370.0	311.2	396.0	427.7	408.0

DISCUSSION

Grain Size Analysis

The graphical representation of the results of grain size analysis of soil samples gave an indication of the presence of gravel and sand. These samples are classified as clayey sand to silty sand (SC/SM) based on Unified Soil Classification. The percentage of sand predominates in most of the samples. Samples TR2/SS3 and TR3/SS1-SS3 have considerable percentage of gravel.

On the engineering use chart, the samples occur as mainly GP and GW which show that the soil samples are clean gravels and sands with little or no fines. They have good to fair shear strength and low compressibility when compacted and saturated, and have good workability as construction material which can resist erosion. The samples according to the results suggest that they can be used in dam constructions, canal sections, railways and foundations.

Atterberg Limit Test

The results of Atterberg consistency limits carried out on the samples indicated liquid limits ranging from 21% to 23%, flow index of 7.4 to 22.8 and toughness index of 0.4 to 1.6.

According to [11], samples TR1/SS1, TR3/SS1, TR2/SS1, and TR1/SS2 are dominantly of low plasticity (plasticity index of 8.9 to 11.5). According to the USCS classification chart, the samples are below CL zone (low plasticity). Plot on the plasticity chart also confirmed that the samples are composed of inorganic clays of low plasticity (Figure 4).

Consolidation test

The rate of consolidation, Cv, generally decreases with increase in the liquid limit of soil. The range of variation of Cv for a given liquid limit of soil is rather wide. The above results indicated very low consolidation parameters for the studied soil samples. The primary consolidation settlement S, for TR3/SS3 is 0.11mm which indicates that the soil has low compressibility and settlement and so for the other soil samples.

Shear box test

Shear box results obtained for the samples gave angle of internal friction of 26^0 to 33^0, cohesion of 20kPa to 40kPa for the compacted soil specimens. For soil sample TR1/SS1, the angle of internal friction is 29^0 with cohesion of 39kPa. Comparing this with the Unified Soil Classification, the soil samples can be classified as dense silt of non-plastic in nature. TR3/SS3, TR2/SS3 and TR3/SS2 have angle of internal friction of 32^0, 33^0 and 31^0 respectively indicating loose sand of angular grains. TR1/SS3 could be classified as clayey sand with phi value of 26^0 while TR1/SS1 as silty sand with phi value of 29^0.

The results from the ultimate bearing capacity showed that for the trial pit 1, the ultimate bearing capacity increases. This might be as a result of the increase in moisture content and so trial pit 1 is recommended because of relatively high shear strength gotten. Likewise trial pit 3 which shows similar result as the ultimate bearing capacity increases with depth. Thus, for superstructure, further geotechnical studies should be conducted and proper on site investigation like Cone Penetration Test, Plate loading test etc.

V. CONCLUSION AND FUTURE SCOPE

The grain size analysis showed that the samples are classified as sand to gravely sand (SC/SM) based on the Unified soil classification with 0.9% - 69.73 gravel and 30.27- 99.1% sand. The soil samples are above the activity A-line in the zone of inorganic sand (CI). The results from the direct shear box tests showed that the samples have a medium angle of internal friction which ranges from 26^0 - 33^0 with cohesion of 20KPa - 40KPa. This means that the foundation design of the area will be shallow foundation and could support moderately light to heavy structures. Also, ultimate bearing capacity analysis was carried out on the samples from different depth and it was discovered that the bearing capacity increases with depth. The shear strength of the soils is in the range of $55kN/m^2$ to $162.1kN/m^2$ with normal stress of 188kN/m2 and can be as high as $311.2kN/m^2$ to $427.7kN/m^2$ with normal stress of $597kN/m^2$.

The soil materials in the area will be a good material in high way construction as a sub-grade material. In view of high bearing capacity values and settlements, the area is recommended for structure with shallow foundations. For superstructure, further geotechnical studies should be conducted and proper on site investigation like Cone Penetration Test, Plate loading test etc should be employed.

REFERENCES

[1]. **H.O. Nwankwoala, A.N. Amadi, F.A. Ushie, T. Warmate, C. J. Eze:** Determination of subsurface geotechnical properties for foundation design and construction in Akenfa Community, Bayelsa State, Nigeria. American Journal of Civil Engineering and Architecture, Vol. 2, No. 4, pp. 130-135, 2014

[2]. **A.N. Amadi, P.I. Olasehinde, I.A. Okunlola, N.O. Okoye, S. Waziri:** A multidisciplinary approach to subsurface characterization in northwest of Minna, Niger State, Nigeria. Bayero Journal of Physics and Mathematical Sciences, Vol. 3, No. 1, pp. 74-83. 2010

[3]. **O.A. Omotoso, O.J. Ojo, E.T. Adetolaju:** Engineering properties of lateritic soils around Dall Quarry in Sango Area, Ilorin, Nigeria. Earth Science Research, Vol. 1, No.2, pp. 71-81. 2012

[4]. **W.N. Legget and O.A. Hotheway:** Assessment of some geoenvironmental problems associated with road construction in the eastern Niger Delta. African Journal of Environmental Pollution and Health, Vol. 8, No. 1, pp. 1-7. 1988

[5]. **S.A. Oke and A.N. Amadi:** An assessment of the geotechnical properties of the subsoil of parts of Federal University of Technology, Minna, Gidan Kwano Campus, for foundation design and construction. Journal of Science, Education and Technology, Vol. 1, No. 2, pp. 87-102. 2008

[6]. **P.O. Youdeowei, and H.O. Nwankwoala**: Suitability of Soils as Bearing Media at a Freshwater Swamp Terrain in the Niger Delta. Journal of Geology and Mining Research, Vol. 5, No. 3, pp. 58-64. 2013

[7]. **A.N. Amadi, C.J. Eze, C.O. Igwe, I.A. Okunlola, N.O. Okoye:** Architect's and geologist's view on the causes of building failures in Nigeria. Modern Applied Science, Vol.6, No. 6, pp. 31-38. 2012

[8]. **O. G. Jegede, and B. M. Olaleye:** Engineering geological and foundation characteristics of granite derived subsoils at Ibuji Area, south western Nigeria. The International Journal of Engineering and Science, Vol. 2 No. 5, pp. 15-17. 2013

[9]. **K.C. Ezenwaka, A. Ugboaja, C.V. Ahaneku, T.A. Ede:** Geotechnical investigation for design and construction of civil infrastructures in parts of Port Harcourt, Rivers State, southern Nigeria. The International Journal of Engineering and Science, Vol. 3, No.8, pp. 74-82. 2014

[10]. **D.A. Alao, A.O. Adeoye, O.O. Abioye**: Geotechnical properties of some selected beach sands in Lagos, southwestern Nigeria. Geosciences Review. Vol. 4, No.3, pp. 51-53. 2014

[11]. **A.W. Cassagrande:** Research on the Atterberg Limits of Soils. Road Research Laboratory. Vol. 13. No. 8. Pp. 121 – 136. 1932

AUTHOR'S PROFILE

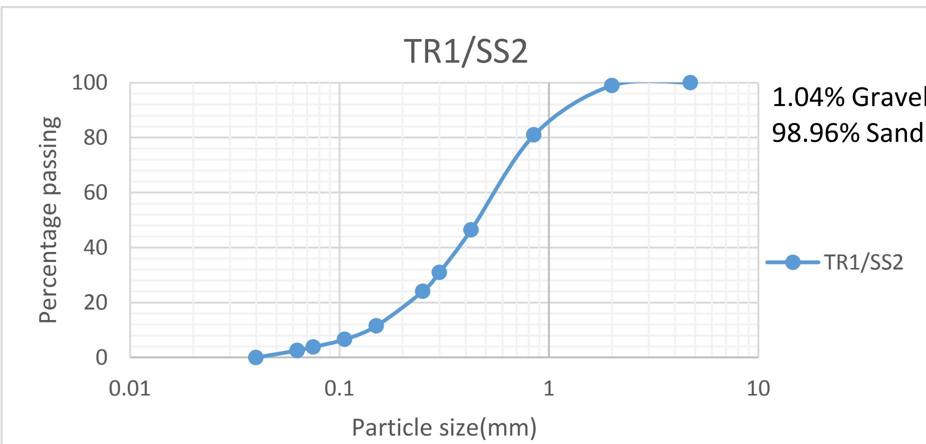
M. Abdullahi bagged BSc. in Geology from Al-Hikmah University, Ilorin in 2015. He is currently working as Graduate Assistant in the Department of Geological Sciences, Federal University Gusau. He is a member of the Nigerian Mining and Geosciences Society (NMGS) and American Association of Petroleum Geologists (AAPG) since 2014. His main research area of interest is Engineering Geology, particularly in the area of soil mechanics.

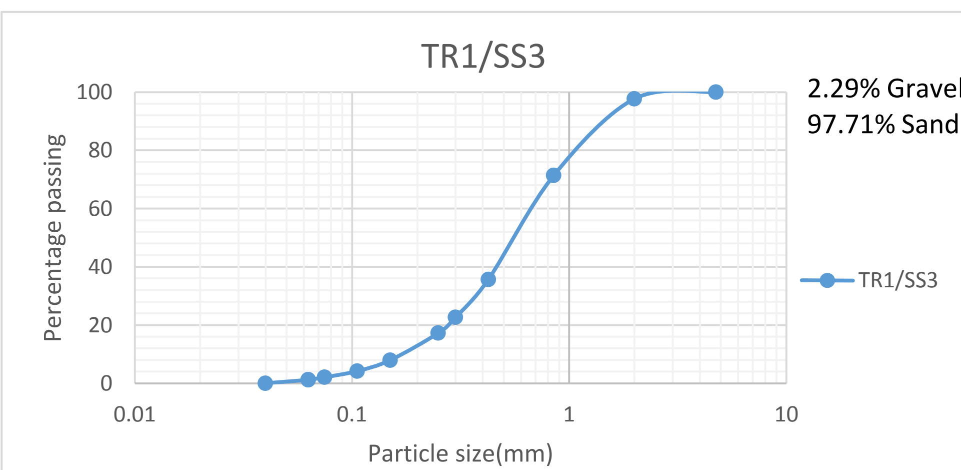
AUTHOR'S PROFILE 2
A.Y. Ojulari, is a Lecturer II in the Department of Chemical and Geological Sciences, College of Natural Sciences, Al-hikmah University, Ilorin, Nigeria. He holds a Masters (M.Sc.) degree in Engineering Geology and Hydrogeology. His research focuses on Engineering Geology, particularly in the area of soil mechanics including geophysical, geological, petrologic, and even geochemical studies towards solving geological and environmental problems especially foundation and road construction problems. He currently is pursuing a Ph.D. in the area of Engineering Geology.

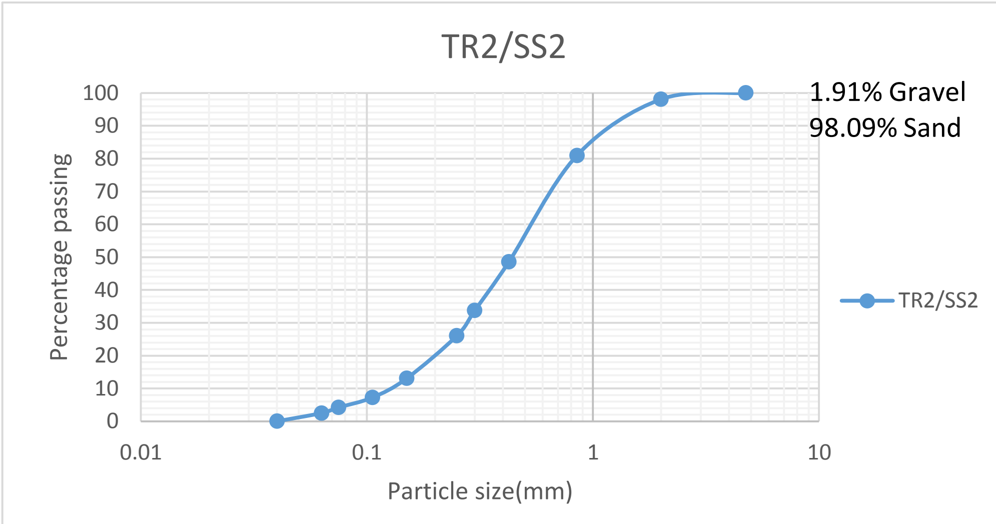
AUTHOR'S PROFILE 3
N.Y. Abdullahi obtained a Bachelors Degree in Geology from the department of Geology, Ahmadu Bello University Zaria, Nigeria. He currently works as a Graduate Assistant in the Department of Geological Sciences, Federal University Gusau. He is a registered member of the Nigerian Mining and Geosciences Society. His research interest focuses on the engineering geological assessment of collapsed structures and the tectonic evolution of the basement complex of Nigeria.

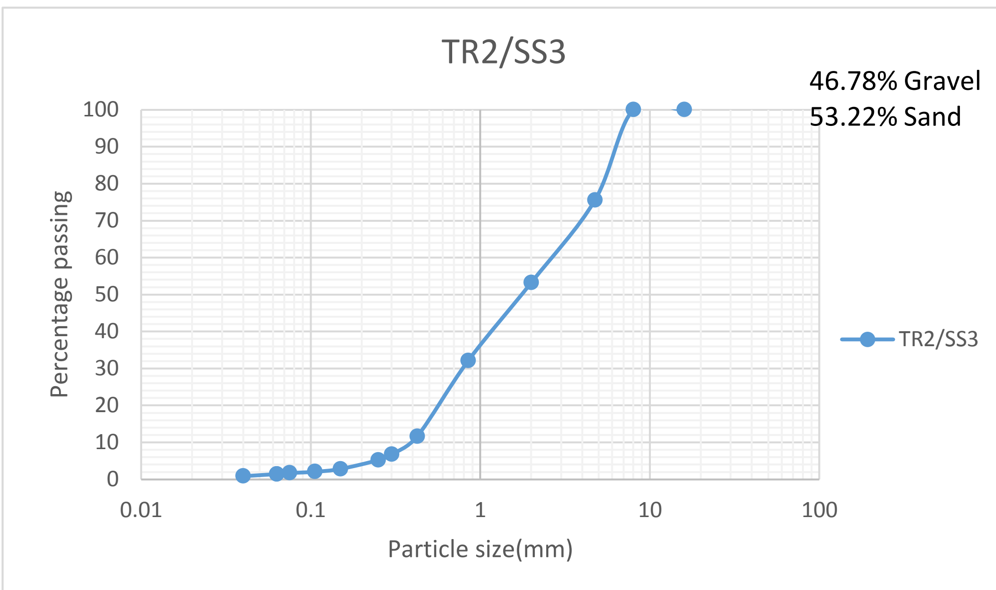
APPENDICES

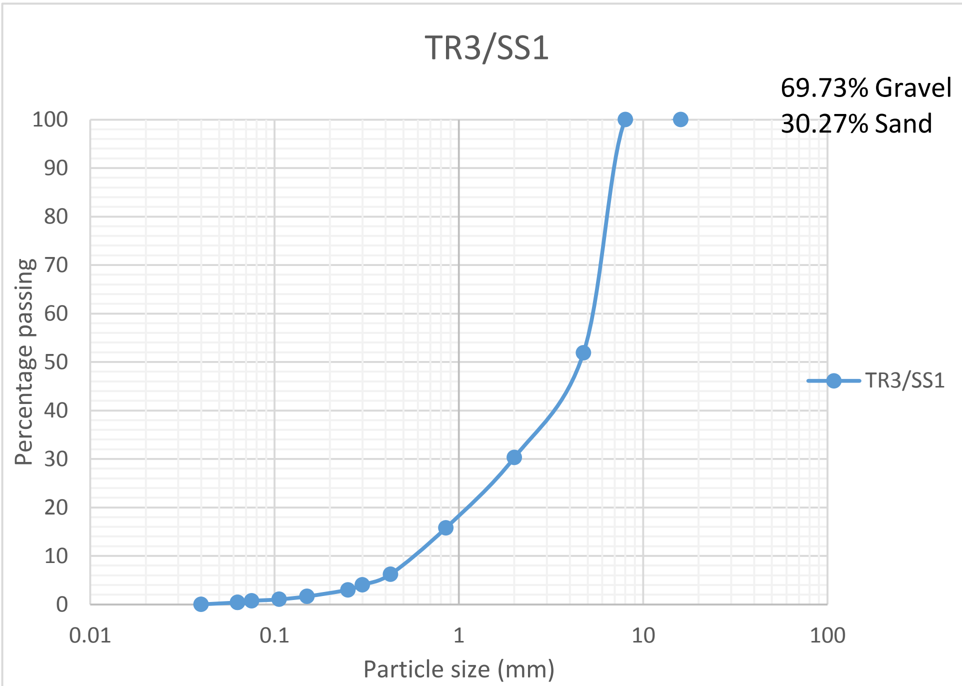
PARTICLE SIZE DISTRIBUTION CURVE

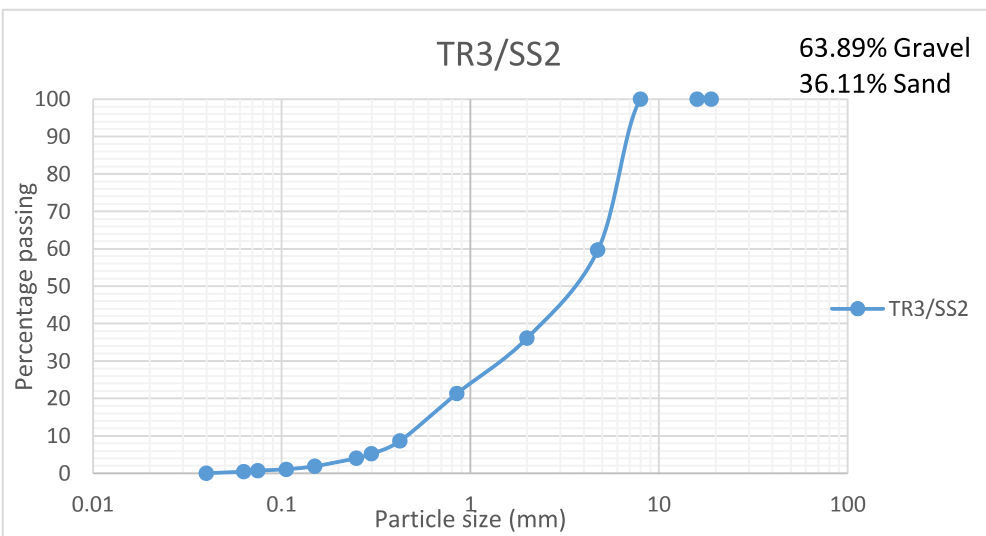




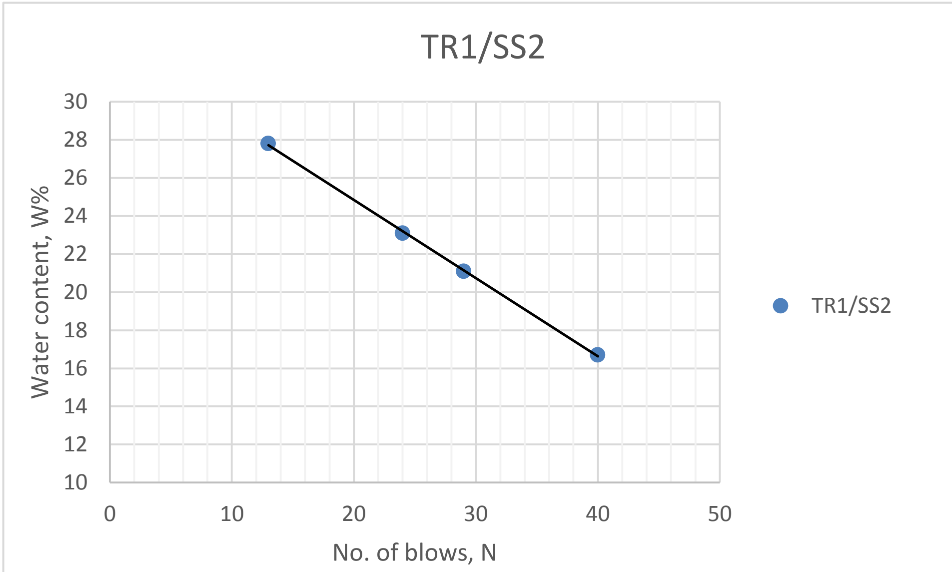

TR2/SS2
1.91% Gravel
98.09% Sand
Percentage passing
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
Particle size(mm)
TR2/SS2


TR2/SS3
46.78% Gravel
53.22% Sand
Percentage passing
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
100
Particle size(mm)
TR2/SS3

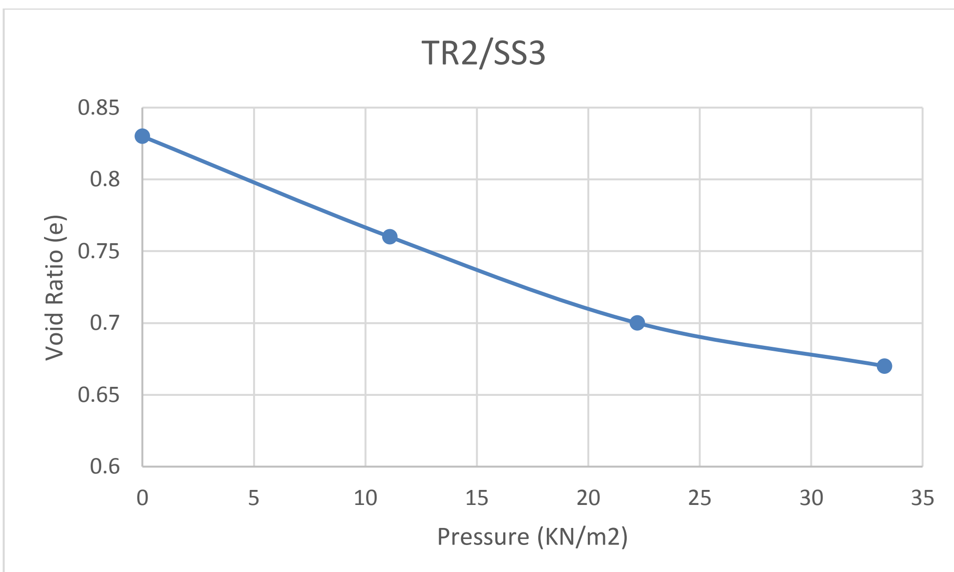

TR3/SS1
69.73% Gravel
30.27% Sand
100
90
80
70
60
50
40
30
20
10
0
Percentage passing
0.01
0.1
1
10
100
Particle size (mm)
TR3/SS1

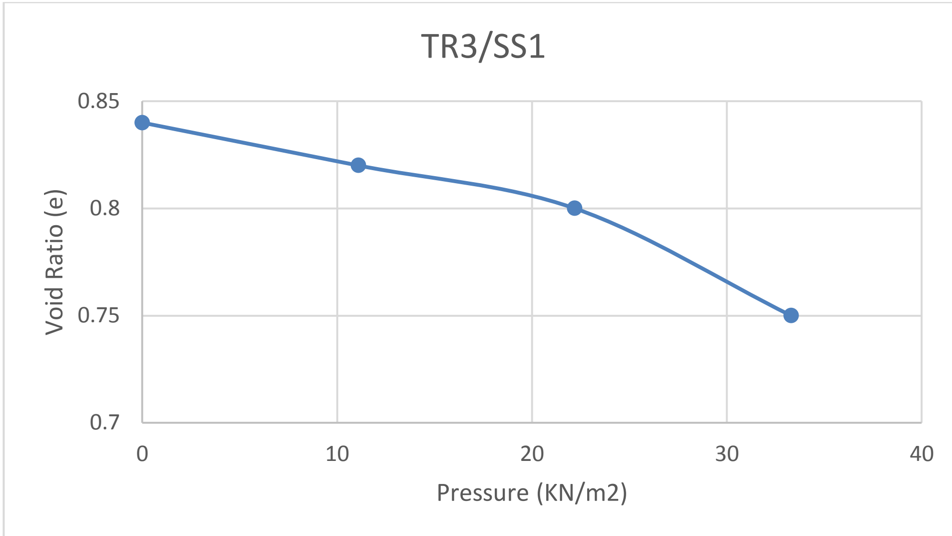

TR3/SS2
63.89% Gravel
36.11% Sand
100
90
80
70
60
50
40
30
20
10
0
Percentage passing
0.01
0.1
1
10
100
Particle size (mm)
TR3/SS2

ATTERBERG LIMIT

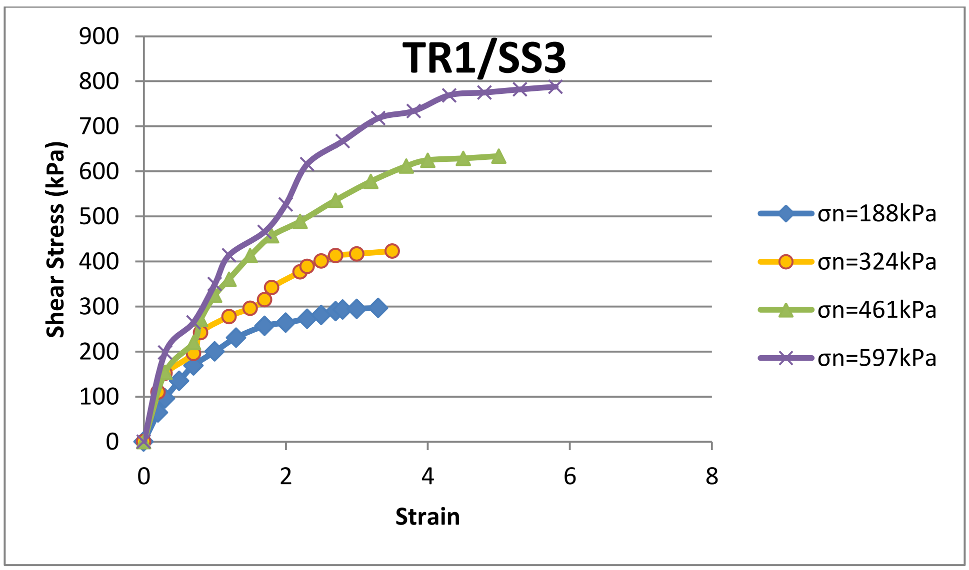


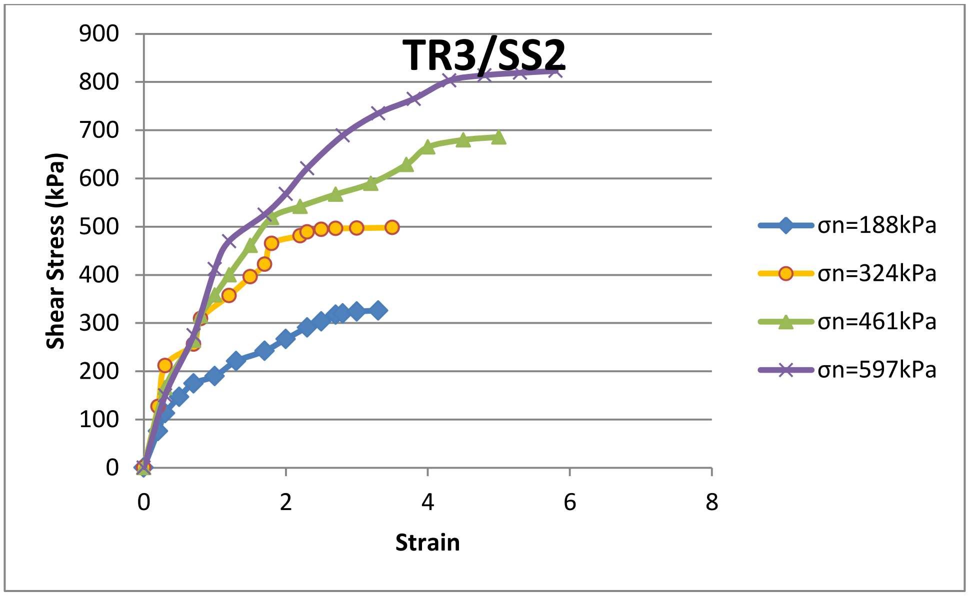
CONSOLIDATION

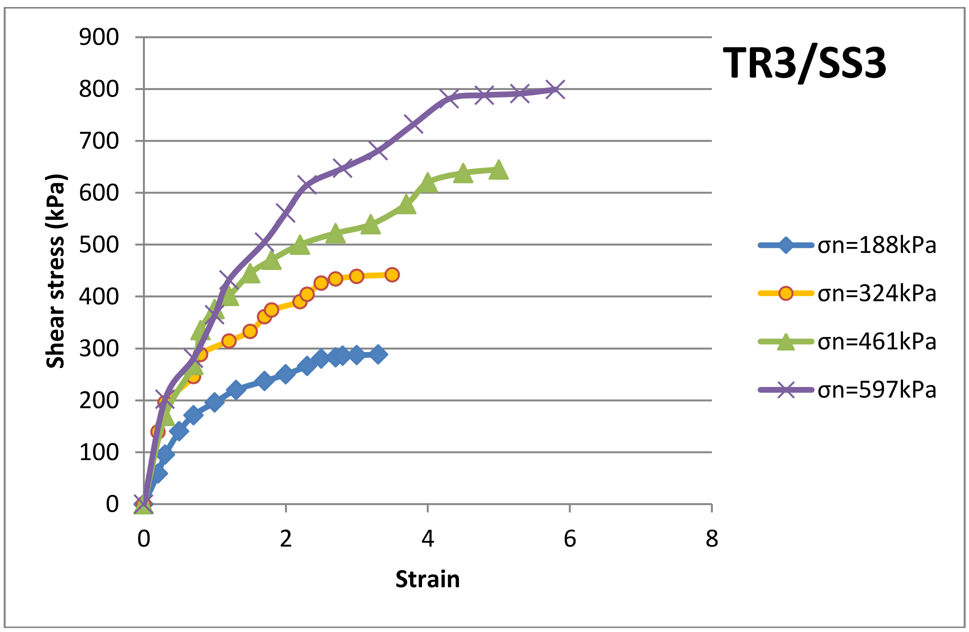


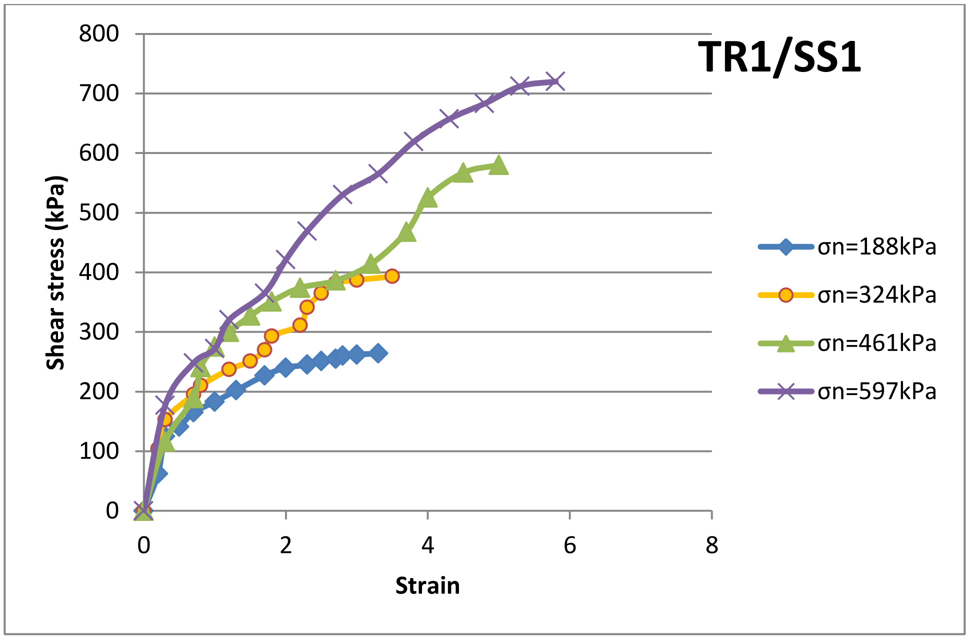


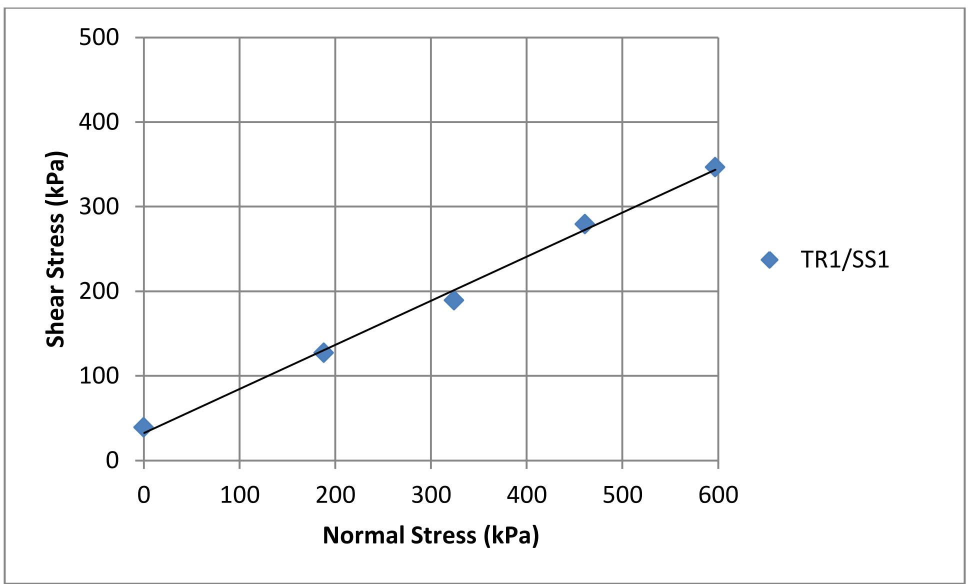
DIRECT SHEAR STRESS CURVE

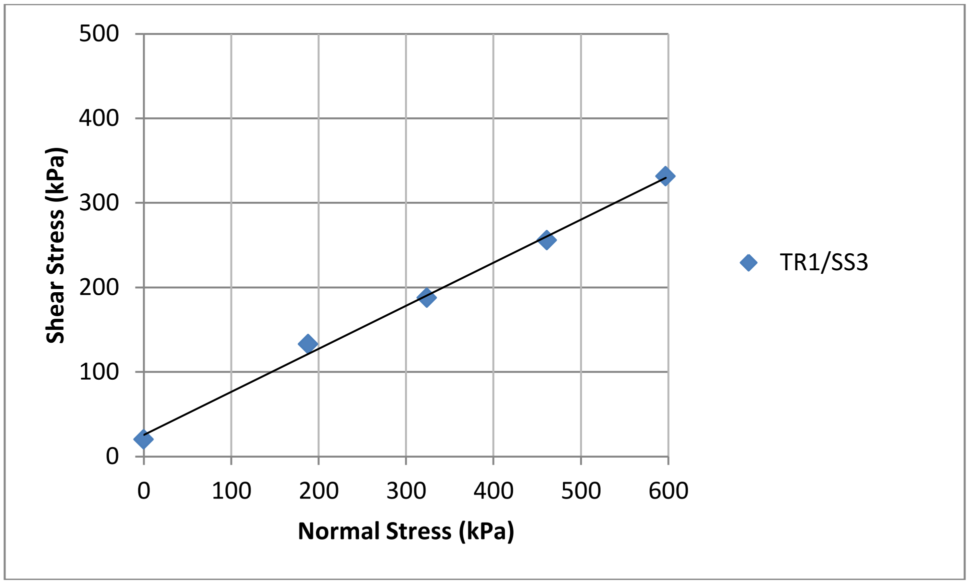


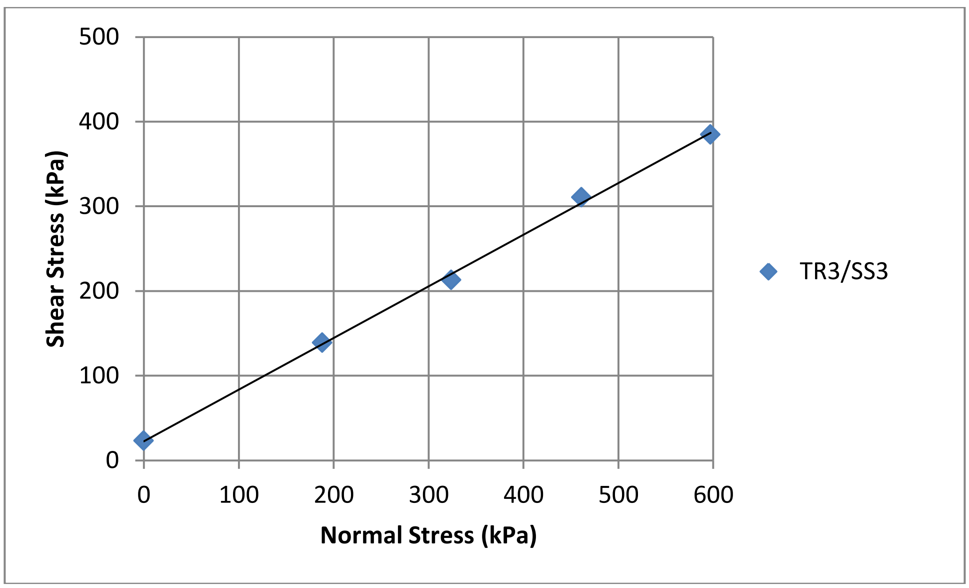

TR3/SS2
Shear Stress (kPa)
900
800
700
600
500
400
300
200
100
0
0
2
4
6
8
Strain
σn=188kPa
σn=324kPa
σn=461kPa
σn=597kPa

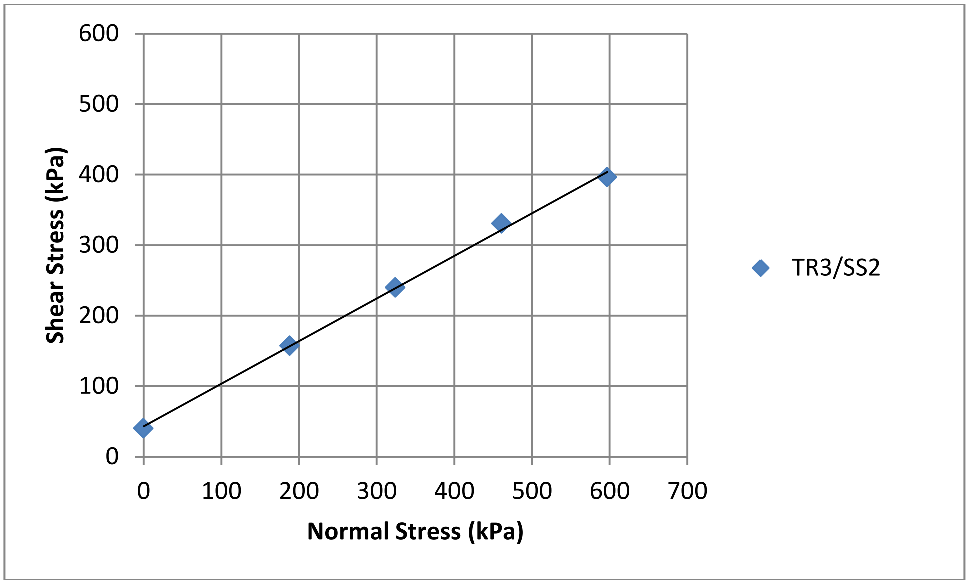

TR3/SS3
Shear stress (kPa)
900
800
700
600
500
400
300
200
100
0
0
2
4
6
8
Strain
σn=188kPa
σn=324kPa
σn=461kPa
σn=597kPa

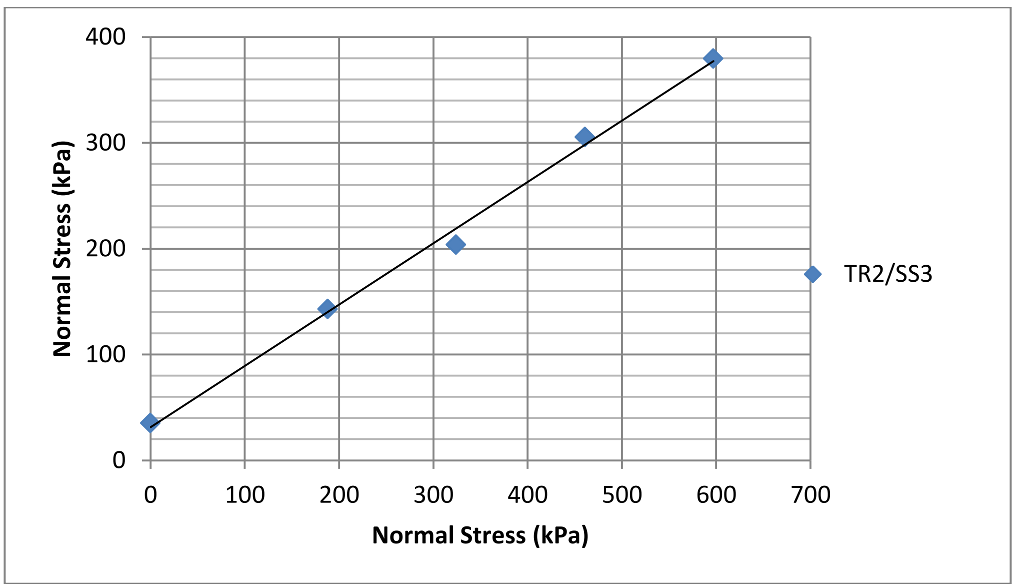

TR1/SS1
Shear stress (kPa)
800
700
600
500
400
300
200
100
0
0
2
4
6
8
Strain
σn=188kPa
σn=324kPa
σn=461kPa
σn=597kPa


Shear Stress (kPa)
500
400
300
200
100
0
0
100
200
300
400
500
600
Normal Stress (kPa)
TR1/SS1


500
400
300
200
100
0
0
100
200
300
400
500
600
Shear Stress (kPa)
Normal Stress (kPa)
TR1/SS3


500
400
300
200
100
0
0
100
200
300
400
500
600
Shear Stress (kPa)
Normal Stress (kPa)
TR3/SS3


600
500
400
300
200
100
0
Shear Stress (kPa)
0
100
200
300
400
500
600
700
Normal Stress (kPa)
TR3/SS2


400
300
200
100
0
Normal Stress (kPa)
0
100
200
300
400
500
600
700
Normal Stress (kPa)
TR2/SS3

