OPEN ACCESS
Saudi Journal of Civil Engineering
Abbreviated Key Title: Saudi J Civ Eng
ISSN 2523-2657 (Print) |ISSN 2523-2231 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: https://saudijournals.com/journal/sjce/home

Original Research Article

Effect of Varying Moisture Content on Shear Strength Properties of Soil

Ismail Abdullahi[1*], U. U. Imoh[1], A. C. Apata[1]

[1]Department of Civil Engineering, University of Lagos, University Road Lagos Mainland Akoka, Yaba, Lagos, Nigeria

DOI: 10.36348/sjce.2022.v06i11.001 | **Received:** 07.10.2022 | **Accepted:** 18.11.2022 | **Published:** 06.12.2022

***Corresponding author:** Ismaila Abdullahi
Department of Civil Engineering, University of Lagos, University Road Lagos Mainland Akoka, Yaba, Lagos, Nigeria

Abstract

The effect of varying moisture content on the shear strength properties of soil was conducted in this study by varying the soil natural moisture content to 2% and then 4% increment at various depth. The soil sample was cored out using drilling method at different depth below the ground surface starting from 400mm to 24.75m for point 1 and 400mm to 11.25m for point 2. Its grain distribution was found by wet sieve analysis, The natural moisture content of each soil sample was determined, other basic experiments that was carried out are specific gravity, Atterberg limit test, sieve analysis. The result from the findings showed that the soils at point 1 and 2 are composed of silt and clay and the soil at point 2 have high plasticity than the soil in point 1. Also from the findings, it was found that soil shears faster at higher moisture content and that the angle of internal friction and cohesion index are inversely related.

Keywords: Soil, Moisture content, Shear strength, Liquid limit, Plastic limit, Plasticity index.

1.0 INTRODUCTION

Soils in nature rarely exist separately as gravel, sand, silt, clay or organic matter, but are usually found as mixtures with varying proportions of these components. Grouping of soils on the bases of certain definite principles would help the engineer to rate the performance of a given soil (Onyelowe, 2013). Soil classification systems divide soils into groups and subgroups based on the common engineering properties. The most common classification systems that are used in soil classifications are the American Association of State and Transportation Officials (AASHTO) and the Unified Soil Classification System (USCS) (Onyelowe, 2013).

Shear strength is crucial for slope stability and soil erosion measurement, and shearing deformation is one of the most harmful processes for land and environment degradation *(Wei et al.*, 2019). The direct shear test is based on forcing the sample to fail along a predefined plane while being subjected to normal load. This gives a direct measure of the shear force capacity at specific conditions and enables determination of the angle of internal friction and cohesion. The shear stress in the shear box test is defined as the shear resistance developed within the sliding plane along a known section area of the sample (Dafalla, 2013). The general trends of direct shear tests on sand and clays are shown on Figures 1 and 2.

Shear strength determined by the bonding forces of soil matrix is influenced by many soil intrinsic properties, such as particle size distribution (Knapen *et al.*, 2007), bulk density (Zhang *et al.*, 2018), degree of aggregation (Wuddivira *et al.*, 2013), and organic matter (Rachman *et al.*, 2003). Apart from the effects of these intrinsic properties of soil materials, the alteration of hydrologic conditions is the most important triggers of bonding force variation, thus affecting shear strength (Horn & Albrechts, 2002). The effect of water content on shear strength, as one of the hot topics in soil mechanics and environmental engineering, has been widely studied. However, different trends about the relationship between shear strength properties and water content have been reported across locations, soils, and experiment designs e.g., Al-Shayea (2001); Hoyos *et al.*, (2014); Rahardjo *et al.*, (2012). Hence, this study is focused on classifying the soils obtained from the study area, and determining the effect of varying moisture content on soil shear strength of the soils in order to add to the existing literatures and bridge the gap in variation of the reports from previous studies.

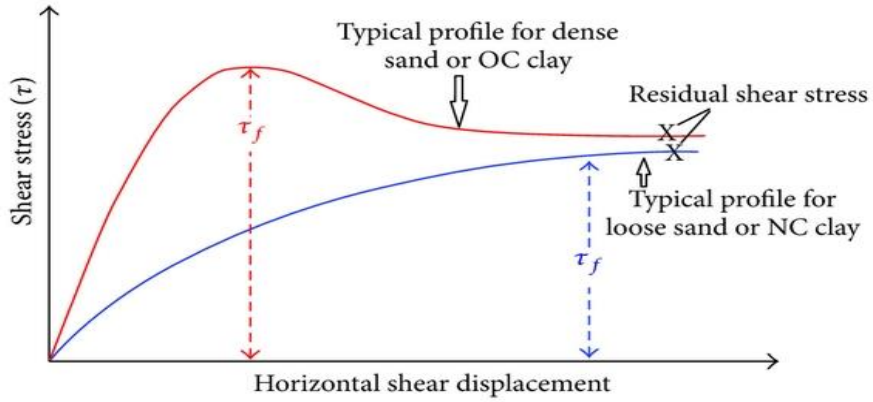

Figure 1: Typical shear stress versus horizontal shear displacement of soils (OC stands for overconsolidated and NC stands for normally consolidated)

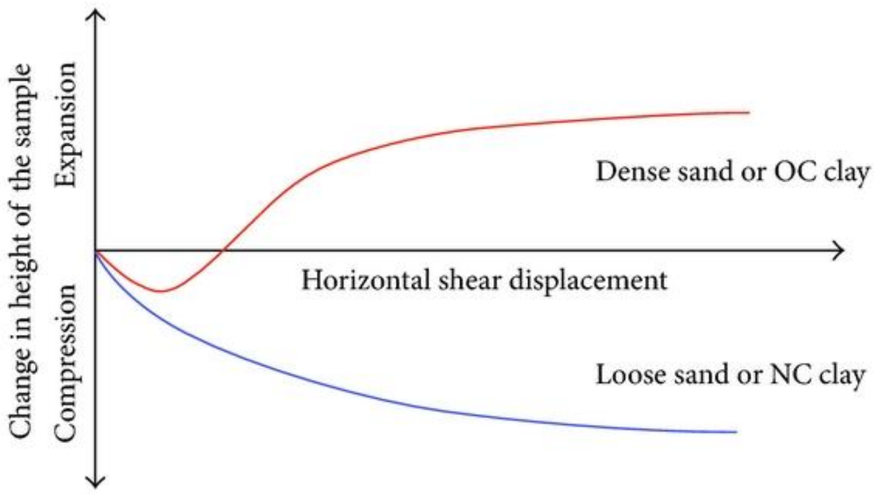

Figure 2: Typical vertical displacement versus horizontal shear displacement of soils (OC stands for overconsolidated and NC stands for normally consolidated)

2.0 MATERIALS AND METHODS

2.1 Materials

2.1.1 Soil sample

The soil sample used in this study was obtained at 20, Louis Solomon close, off Ahmadu bello way, Victoria Island, Lagos." situated at latitude $6^0$25'43.5'' N, longitude $3^0$24'28.8''E for point 1 and latitude $6^0$25'43.4'' N, longitude $03^0$24'28.6 E''for point 2.

2.2 Methods

2.2.1 Method of Obtaining Sample

The soil samples were obtained using rotary drilling method at different depth below the ground surface starting from 400mm to 24.75m for point 1 and 400mm to 11.25m for point 2 as shown in Table 1.0.

Table 1.0: Soil Moisture Content at Varying Depth

	Average moisture content	
Soil sample at various depth	**Point 1**	**Point 2**
400mm	7.55	7.53
2.25m	9.5	10.6
4.5m	-	12.8
6.75m	20.4	20.3
9.0m	-	23.11
11.25m	-	25.93
24.75m	73.5	-

The soils grain distribution was obtained by wet sieve analysis, after which the natural moisture content of each soil sample was determined in accordance with ASTM-D2216 (2019).

2.2.2 Particle Size Distribution

The particle size distribution of the soil was done in accordance with ASTM (2007) standard specifications and the soils were classified using the AASHTO Classification System.

2.2.3 Plastic Limit, Plastic Index, and Plasticity Index

The soil liquid limit (LL) and its plastic limit (PL) was determined in accordance with ASTM-D4318 (2017) , while the soil plasticity index was determined by taking the numerical difference between its liquid limit (LL) and its plastic limit (PL) as shown in equation 1.0.

PI = LL – PL ………………… (1.0)

2.2.4 Soil Shear Strength

Direct shear test method was used to determine the soil shear strength in accordance with ASTM-D3080 (2004).

3.0 RESULTS

3.1 Particle Size Distribution

The particle size distribution of the soil samples are presented in Figure 1.0 and were classified accordingly.

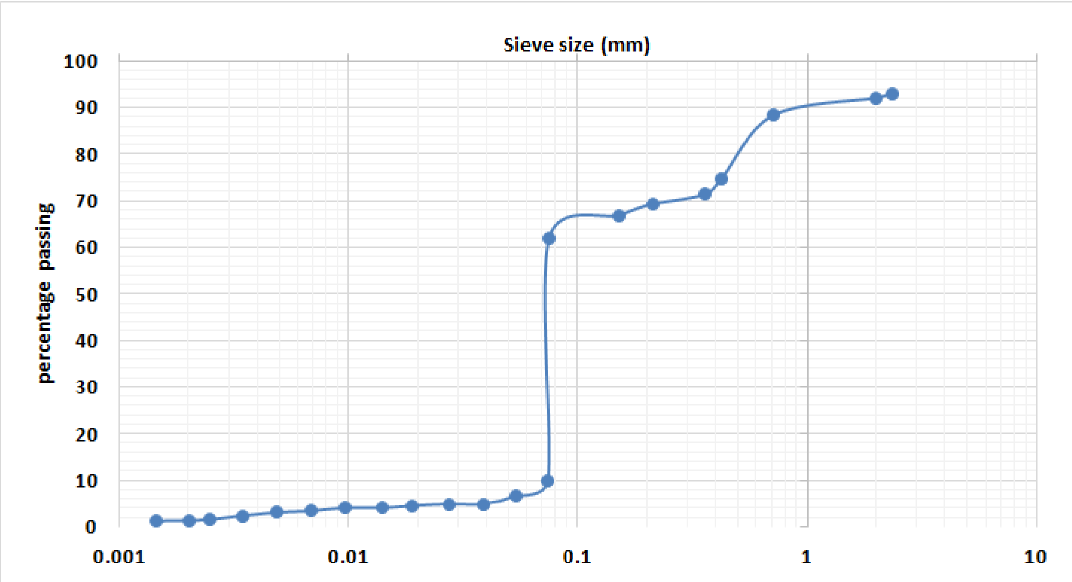

Figure 1.0: Percentage Passing Against Sieve Size

From the curves in Figure 1.0, the coefficient of uniformity (C_u) and coefficient of curvature (C_C) of the soil sample is given as;

C_c (coefficient of curvature) = $D_{30}^2 / (D_{60} * D_{10})$

C_u (coefficient of uniformity) = D_{60} / D_{10}

The calculated C_u and C_c of the soil sample was done at various depths and the result is presented in Table 2.0 and 3.0 alongside its classification and rating.

Table 2.0: Soil Classification and Rating at Various Depths for Point 1

Soil depth (m)	% Passing sieve #200	C_c	C_u	AASHTO classification	Type of material	Subgrade rate
0.4	62.10	0.87	1.00	A-6(7.2)	Clay soil	poor
2.25	57.85	8.40	15.60	A-4(3.5)	Silty soil	Fair
6.75	54.6	1.15	115.38	A-4(3.2)	Silty soil	Fair
24.75	40.65	1.13	200.00	A-7-6(3.28)	Clay soil	poor

The result from Table 2.0 shows that the C_c and C_u of the soil ranges from 0.87 – 8.40 and 1.00 – 200 respectively for point 1. Also, at 0.4m depth and 24.75m depth, the soil type way clay in poor state, while at 2.25m depth to 57.85m depth, the soil type was silty in fair state.

Table 3.0: Soil Classification and Rating at Various Depths for Point 2

Soil depth (m)	% Passing sieve #200	C_c	C_u	AASHTO classification	Type of material	Subgrade rate
0.4	61.5	1.01	1.88	A-6(8.48)	Clay soil	Poor
2.25	57.95	6.40	8.42	A-4(2.4)	Silty soil	Fair
4.5	41.55	0.68	32	A-4(0.9)	Silty soil	Fair
6.75	54.70	0.32	28	A-7-6(7.9)	Clayey soil	Poor
9.0	43.4	0.67	45	A-6(1.8)	Clayey soil	Poor
11.25	37.1	0.84	16.5	A-7-6(3.02)	Clayey soil	Poor

The result from Table 3.0 also shows that the C_c and C_u of the soil ranges from 1.01 – 6.40 and 1.88 – 16.5 respectively for point 1. Also, at 0.4m depth, 6.75m, 9.0m, and 11.25m depth, the soil type was clayey in poor state, while at 2.25m depth to 4.5m depth, the soil type was silty in fair state.

3.2 Specific Gravity

The specific gravity result of the soil at both positions of borehole did not follow a trend but has a range of 2.47 to 2.90 for both positions as shown in Figure 2 and 3.

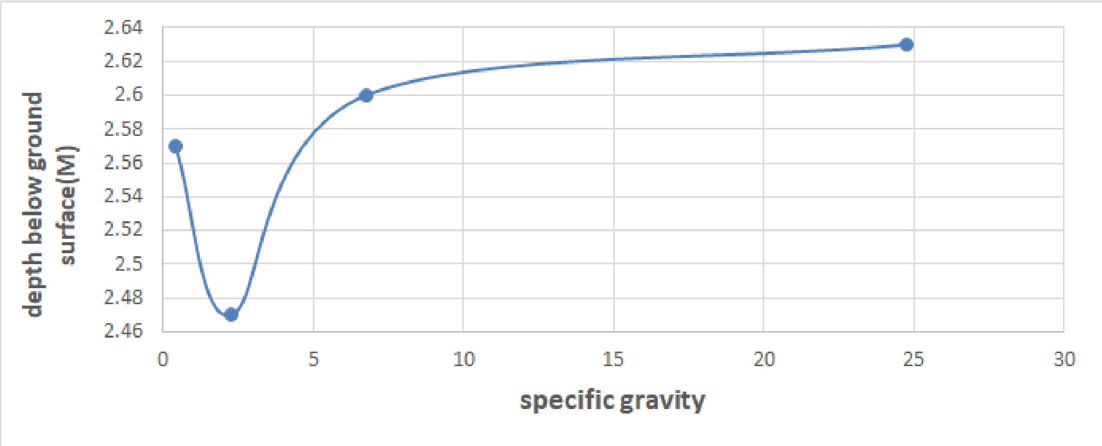

Figure 2.0: Variation of specific gravity with depth for Point 1

The result from Figure 2.0 shows that from 0.4m to 2.25m the specific gravity reduced, while from 2.25m to 24.75m the specific gravity maintained a steady increase. This is an indication that as depth increases, specific gravity might also increase.

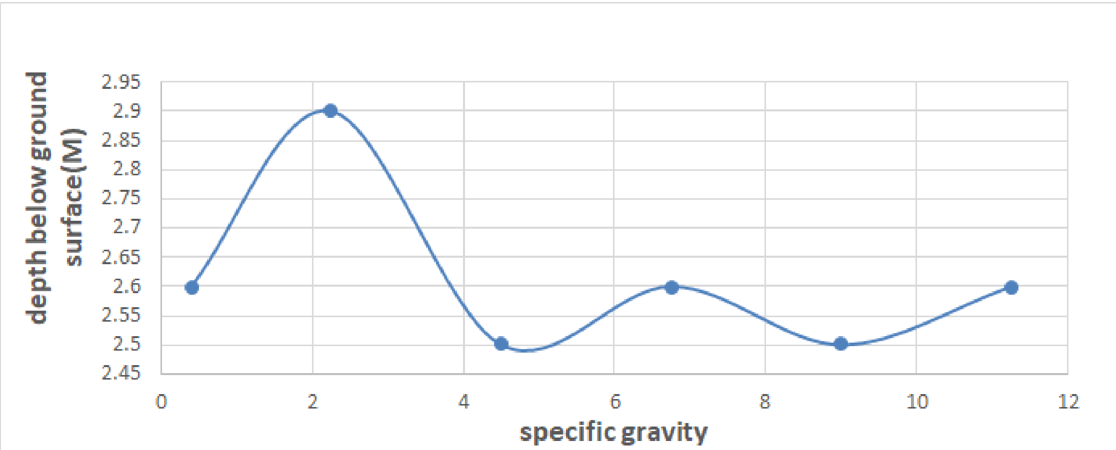

Figure 3.0: variation of specific gravity with depth for Point 2

The result from Figure 3.0 shows that from 0.4m to 2.25m the specific gravity increased, then reduced from 2.25m to 4.5m, and increased from 4.5m to 6.75m, further reduced from 6.75m to 9.0m, and increased again from 9.0m to 11.25m. The trend in specific gravity at point 2 is irregular compared to point 1.

3.3 Plasticity Index

The soil plasticity index was calculated from the liquid limit and the plastic limit and the results are presented below.

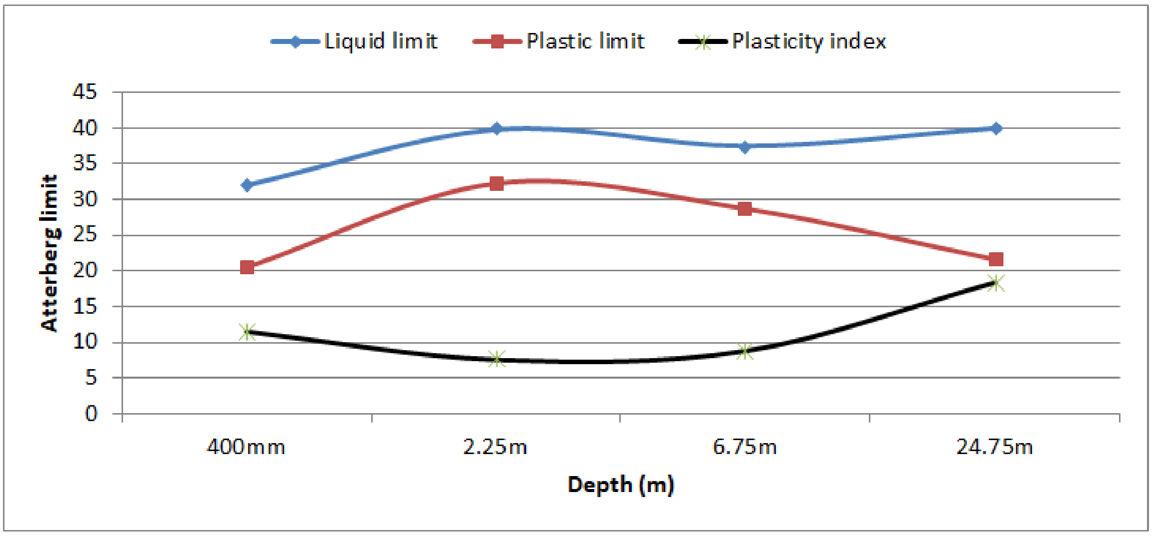

Figure 4.0: Atterberg limit of soil at Point 1

The result from figure 4.0 shows the liquid limit (LL), plastic limit (PL), and plasticity index (PI) of the soil at various depths. However, the result showed that the PI is inverse of the LL and PL and it ranges from 11.5 – 18.4 with a trend that reduced from 0.4m to 2.25m then further increase from 2.25m to 24.75m. The outcome of this findings showed that the PI of the soil exhibits medium plasticity (i.e. between 10 - 20) which is an indication that the soil is partly silty and clayey as confirmed in Table 2.0. Hence, the soil is composed of silt and clay in nature.

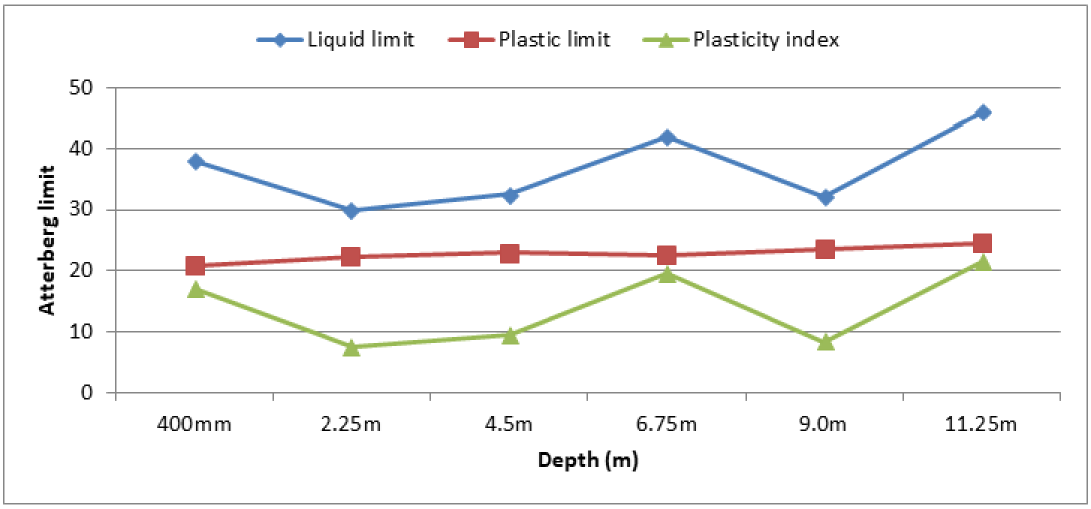

Figure 5.0: Atterberg limit of soil at Point2

The result from Table 5.0 shows that the soil atterberg limit at point 2 exhibits an irregular pattern and ranges from 17.1 – 21.5 which implies that the that the PI of the soil at point 2 exhibits medium - high plasticity (i.e. between 10 – 20; 20 - 40) which is an indication that the soil in point 2 is highly plastic and can hold large amount of water in it compared to soil sample at point 1. Also the outcome of the findings showed that the soil at point 2 is partly composed of silt and clay as confirmed from the result in Table 3.0.

3.4 Shear Strength

The figures below show the angle of internal friction and cohesion index results for points 1 and 2 at various depths. The result also shows the angle of internal friction and cohesion index values of the at its natural moisture content, at 2% and 4% increment.

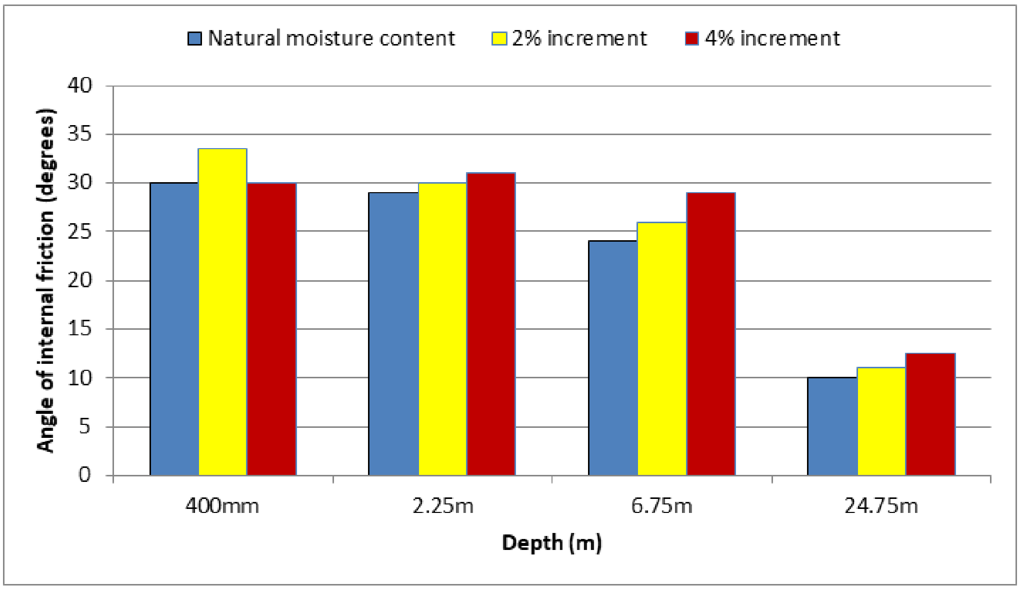

Figure 6.0: Soil angle of internal friction for point 1

The result from Figure 6.0 shows that at point 1, the angle of internal friction increases as moisture content increases from 2 – 4% at various depths below the ground surface i.e. 0.4m, 2.25m, 6.75m, and 24.75m. However, the maximum angle of internal friction at 0.4m depth occurred at 2% moisture increment, while the maximum angle of internal friction at 2.25m, 6.75m, and 24.75m depth occurred at 4% moisture increment followed by 2% moisture increment. The outcome of these findings suggests that the angle of internal friction reduces as the soil depth increases, and as moisture content increases, the soil angle of internal friction also increases.

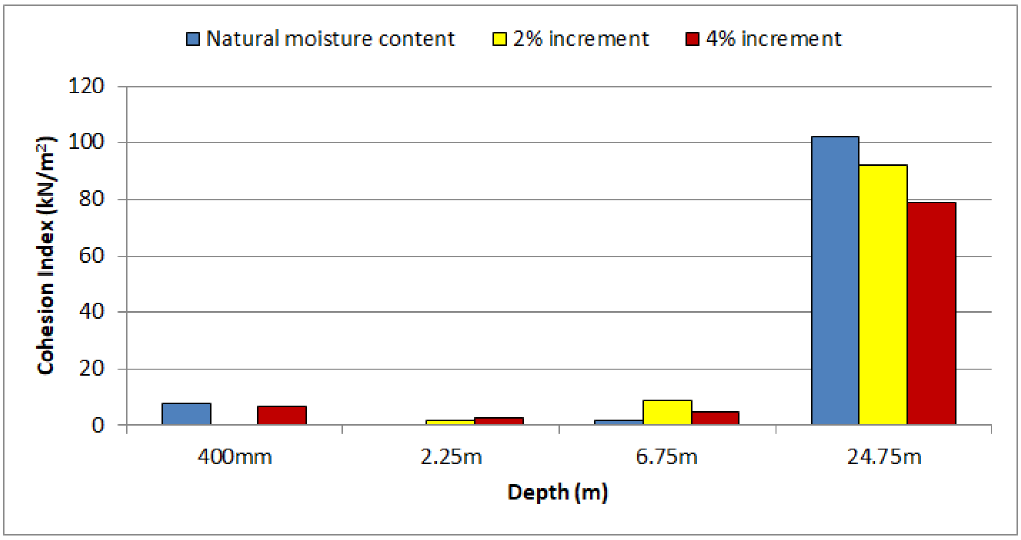

Figure 7.0: Soil Cohesion index for point 1

The result from Figure 7.0 gave an irregular pattern for the soils cohesion index. The natural moisture content of the soil had the maximum cohesion index at 0.4m and 24.75m depth, while 2% moisture increment had the maximum cohesion index at 2.25m depth, and 4% moisture increment had the maximum cohesion index at 6.75m depth. Also, at 0.4m – 6.75m depth, the soil cohesion index was below $10kN/m^2$. However, at 24.75n depth, the soil cohesion index was between 80 – $100kN/m^2$ which exhibited a decreasing trend as moisture content increases.

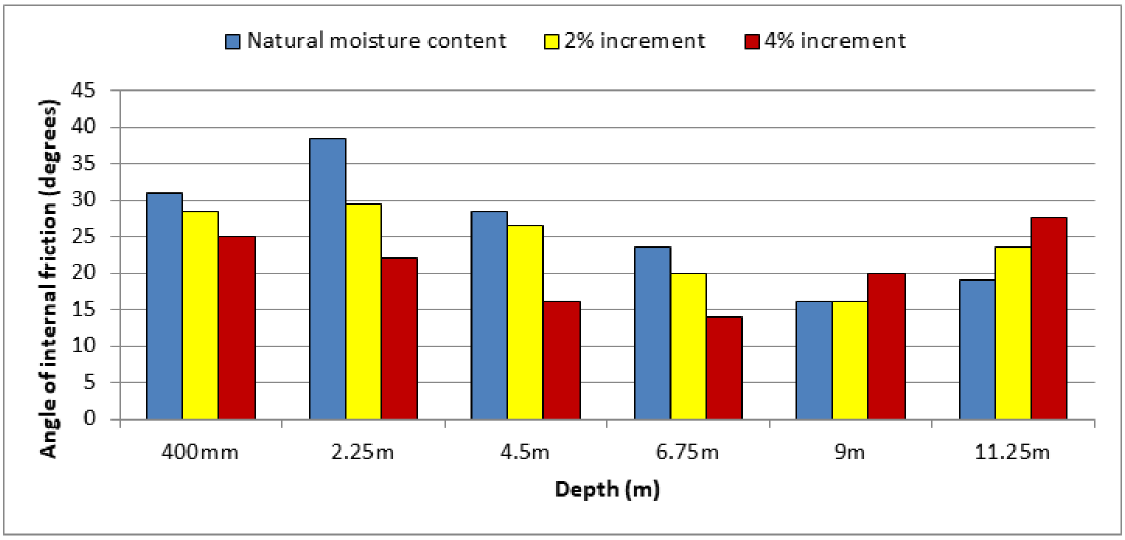

Figure 8.0: Soil angle of internal friction for point 2

The result from Figure 8.0 shows that the soil angle of internal friction reduces as moisture content increases all depths except for 9m soil depth. However, the maximum angle of internal friction at 0.4m, 2.25m, 4.5m, and 6.75m soil depth occurred within the soils natural moisture, while the maximum angle of internal friction at 9m and 11.25m depth occurred with 4% moisture content increment.

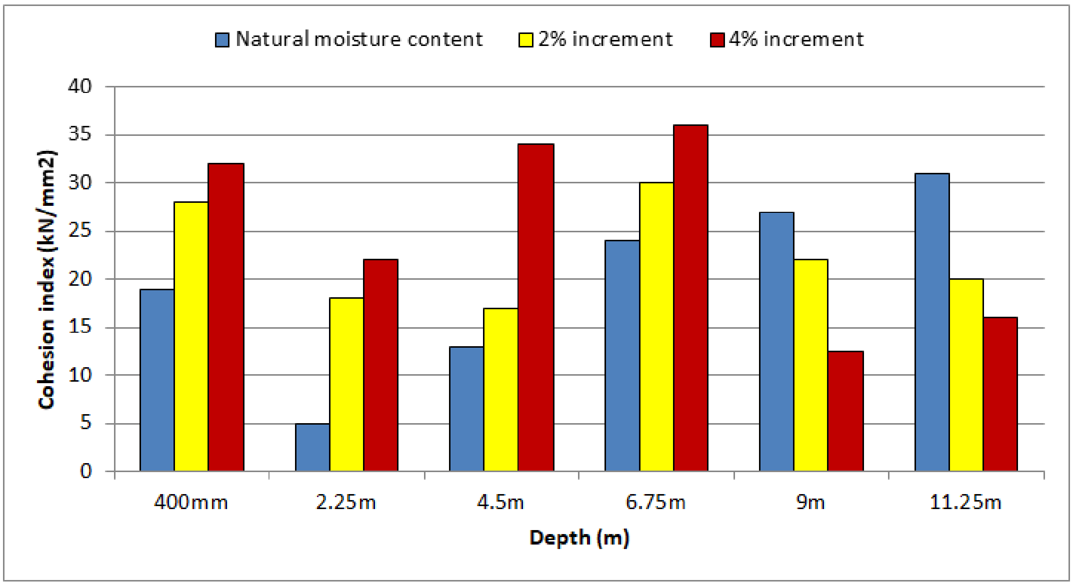

Figure 9.0: Soil Cohesion index for point 2

The result from Figure 9.0 shows that soil cohesion index increases as moisture content increases at depths 0.4m, 2.25m, 4.5m, and 6.5m, while soil cohesion index decreases as moisture content increases at depths 9m and 11.25m. Also from Figure 7.0, at depths 0.4m, 2.25m, 4.5m, and 6.5m, the maximum cohesion index is achieved at 4% moisture increment, while at 9m and 11.25m, the maximum cohesion index is achieved at the soil natural moisture content. The outcome of this finding is an indication that for this particular soil, the optimum cohesion index occurs at 6.75m and declines below 6.75m.

4.0 CONCLUSION

The study was conducted to determine the effect of varying moisture content on shear strength properties of soil. The soil classification and rating system shows that the soil is composed of clayey and silty soil of poor and good subgrade rating respectively, while the soils specific gravity ranges from 2.47 to 2.90, and the soil plasticity index at point 2 is higher than that of point 1 which is an indication that it can hold more water without losing its plasticity. Also from the findings, the angle of internal friction reduces as the soil depth increases, and as moisture content increases, the soil angle of internal friction increases at point 1 with the maximum value achieved at 4% moisture content increment, while the soil cohesion index exhibited an irregular pattern at point 1. At point 2, the soil angle of internal friction reduces as moisture content increases at depths 0.4m – 6.75m with the soil natural moisture content attaining the maximum value, but increases as moisture content increases at depth 9 - 11.25m with 4% moisture content attaining the maximum value, while the soil cohesion index increases as moisture content increases from 0.4m – 6.75m with 4% moisture content attaining the maximum value, and reduces as moisture content increased at depths 9 – 11.25m with the soil natural moisture content attaining the maximum value.

REFERENCE

- Al-Shayea, N. A. (2001). The combined effect of clay and moisture content on the behavior of remolded unsaturated soils. *Engineering geology*, *62*(4), 319-342.
- ASTM-D2216. (2019). Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass. *ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA, 19428-2959 USA*.
- ASTM-D3080. (2004). Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions. *ASTM International [ASTM]*.
- ASTM-D4318. (2017). Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils *ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA, 19428-2959 USA*.
- ASTM, D. (2007). Standard test method for particle-size analysis of soils.
- Dafalla, M. A. (2013). Effects of clay and moisture content on direct shear tests for clay-sand mixtures. *Advances in Materials Science and Engineering*, *2013*.
- Horn, R., & Albrechts, C. (2002). Stress strain effects in structured unsaturated soils on coupled mechanical and hydraulic processes. 2002 ASAE Annual Meeting,
- Hoyos, L. R., Velosa, C. L., & Puppala, A. J. (2014). Residual shear strength of unsaturated soils via suction-controlled ring shear testing. *Engineering geology*, *172*, 1-11.
- Knapen, A., Poesen, J., Govers, G., Gyssels, G., & Nachtergaele, J. (2007). Resistance of soils to concentrated flow erosion: A review. *Earth-Science Reviews*, *80*(1-2), 75-109.
- Onyelowe, K. C. (2013). Effect of water content on the shear strength of amaoba lateritic soil. *Int J Res Civil Eng Architect Design*, *1*, 1-10.
- Rachman, A., Anderson, S., Gantzer, C., & Thompson, A. (2003). Influence of long-term cropping systems on soil physical properties related to soil erodibility. *Soil Science Society of America Journal*, *67*(2), 637-644.
- Rahardjo, H., Satyanaga, A., Leong, E. C., Ng, Y. S., & Pang, H. T. C. (2012). Variability of residual soil properties. *Engineering geology*, *141*, 124-140.
- Wei, Y., Wu, X., Xia, J., Miller, G. A., Cai, C., Guo, Z., & Hassanikhah, A. (2019). The effect of water content on the shear strength characteristics of granitic soils in South China. *Soil and Tillage Research*, *187*, 50-59.
- Wuddivira, M. N., Stone, R. J., & Ekwue, E. I. (2013). Influence of cohesive and disruptive forces on strength and erodibility of tropical soils. *Soil and Tillage Research*, *133*, 40-48.
- Zhang, C., Wang, X., Zou, X., Tian, J., Liu, B., Li, J., Kang, L., Chen, H., & Wu, Y. (2018). Estimation of surface shear strength of undisturbed soils in the eastern part of northern China's wind erosion area. *Soil and Tillage Research*, *178*, 1-10.