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Identification of Collapsible Soils within Maiduguri Metropolis, Borno State, North-Eastern Nigeria

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ABSTRACT

This work dwells on the identification of collapsible soils within Maiduguri Metropolis latitude 11° 41′ 30″ to 12° 00′ 00″ N and Longitude 13° 00′ 00″ to 13° 44′ E. Soil samples were collected from five designated locations (A1- A5) at 20m intervals between points and average depth of 1.2m within the study area (i.e. Dikwa, Damboa, Baga, Jos and Bama roads). The plasticity characteristics revealed that the soils are non-plastic with liquid limits of 15-20%. The percentage passing B.S No 200 sieve (0.75µm) ranging from 0.18-2.9%, thus the soil was classified as A-3 in accordance with the American Association of States Highway and Transportation officials (AASHTO) and SP according to Unified Soil Classification System (USCS). The applications of qualitative method in ascertaining collapse potential using some index properties showed that the entire area was highly collapsible, prone to collapse, some small collapse settlements. The identification of this occurrence will no doubt necessitate some proactive to structural failures.

1. INTRODUCTION

Collapsible soils are considered as one of the problematic soils found in arid and semi-arid regions of the world which covers almost 10% of the earth's surface (Evans *et al*., 2004; Nelder *et al.*, 2008). The soils are generally under unsaturated condition in the dry state, with negative pore water pressure resulting in higher effective stresses and greater shear strength. Collapsible soil can be obtained as Aeolian (such as dune sand with low silt or clay content and high void ratio) Jiangyong *et al*. (2022), residual soils and sediments due to muddy flood (Mahnam *et al.,* 2012). Loess soils have collapsibility potential and can be found in desert area in Iran, South of Kashan, Kerman province, Agh Ghala in Gorgan province, Masjid Soleiman city and Silvand in Fars province (Khosravi, 2002).These soils undergo reduction in volume, when their moisture content increases or upon application of additional loads (Coduto, 2001) exhibiting collapse mechanism. Such type of soils contain in most cases over 60% fines and have a porosity of 50 to 60%, liquid limit of about 25% and plastic limit ranging from 0 to 10% (Alain *et al.,* 2012).

Collapsible soils present significant challenges to the engineering profession during construction, service life and to a lesser degree during design stage. In addition to these problems, challenges related primarily to differential settlement and embankment failures are also encountered in road construction. It is therefore essential for the geotechnical engineers to explore sufficient knowledge on how to effectively handle all types of problematic soils, such as collapsible soils. In some parts of Maiduguri and its suburbs, there exists a deposit of light brown to yellowish brown ferruginous sand-stones popularly known as the Bama ridge soils (Kundiri *et al.*, 2016), this soil pose serious challenges in terms of low bearing capacity. Thus, these soils could be considered a threat for construction of civil engineering facilities and hence its characterization is expedient.

2. MATERIALS AND METHODS

2.1. Material Collection and Preparation of Samples

Disturbed soil samples were collected from five designated locations within the study area (i.e. Dikwa, Damboa, Baga, Jos and Bama roads) at intervals of 20m and average depths of 1.2m for each of the sampling points. Soil samples were obtained using hand Auger and preserved in plastic bags before conveying to Civil and Water Resources Engineering Laboratory of University of Maiduguri for testing**.**

2.2. Methods

Index properties tests conducted include; moisture content, specific gravity, particle size distribution and compaction in accordance with specification outlined in BS 1377 (2022). Method of evaluation of collapse potential using criteria stipulated by several researchers were adopted (Priklonski, 1952; Handy, 1957; Zur and Wiseman, 1957; Clevenger 1958; Gibbs and Bara,1962).

3. RESULTS AND DISCUSSION

Index properties results showed low values of specific gravity (Gs) between 2.5-2.9. The soils are non-plastic with liquid limits between 15-20%, and the percentage passing B.S No 200 sieve (0.75µm) between 0.18-2.9%. The soils are classified as A-3 in accordance with American Association of States Highway and Transportation officials AASHTO (1986) and poorly graded sand (SP) according to Unified Soil Classification System (USCS) ASTM D2487 (2006). The compaction characteristics showed that Optimum Moisture Content (OMC) of the soils ranged from 13.5 - 16% with maximum dry densities (MDD) ranging from 1.57-1.94g/cm^3. Table 1 presents the index properties of the soil.

Table 1: Index properties of soils

Location	Sampling point	LL (%)	PL (%)	OMC (%)	MDD (g/cm^3)	Gs	Soil classification	
							AASHTO	USCS
Dikwa Road	A1T1	20.00	NP	15.0	1.84	2.7	A-3(0)	SP
	A1T2	19.00	NP	11.0	1.57	2.5	A-3(0)	SP
Damboa Road	A2T1	18.00	NP	13.5	1.88	2.8	A-3(0)	SP
	A2T2	15.00	NP	5.50	1.81	2.6	A-3(0)	SP
Baga Road	A3T1	20.00	NP	10.0	1.94	2.9	A-3(0)	SP
	A3T2	18.50	NP	10.0	1.85	2.7	A-3(0)	SP
Jos Road	A4T1	16.00	NP	13.0	1.91	2.6	A-3(0)	SP
	A4T2	16.90	NP	16.0	1.84	2.6	A-3(0)	SP
Bama Road	A5T1	17.00	NP	15.0	1.87	2.6	A-3(0)	SP
	A5T2	19.50	NP	13.0	1.94	2.6	A-3(0)	SP

The particle size distribution plots of soils from the study area are shown in Figure 1. The trend of particle size curve showed that sampling point A4T1 of Jos road had the highest percentage passing with up to 99% while Bama road at sampling point A5T2 had the lowest percentage finer of 79%.

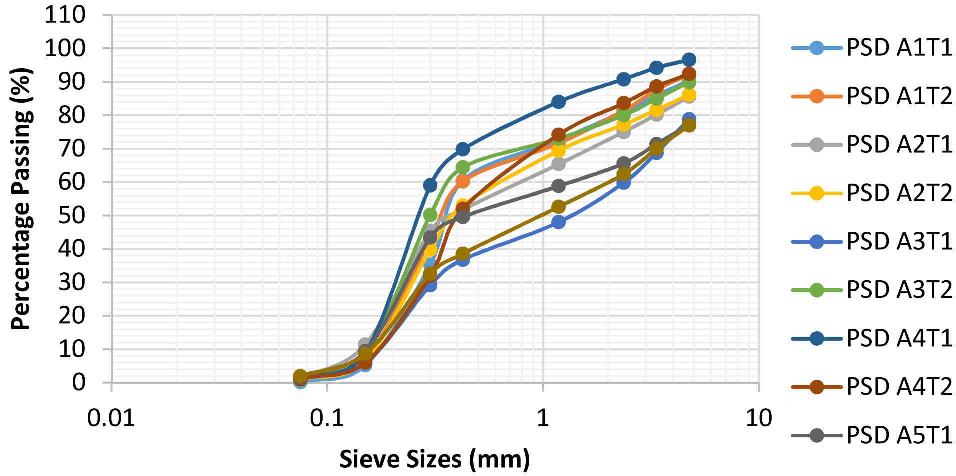

Figure 1: Particle size distribution plots of soils from the study area

3.2. Qualitative Method of Evaluating Collapsible Soils

3.2.1 Priklonski, (1952) criteria

Table 2 showed the results obtained from the study area based on Priklonski (1952) criteria. The result was obtained based on moisture content and Atterberg limits relationship $K_D = (W_n - PL)/PI$ where K_D is the liquidity index, W_n is the natural moisture content, PL is plastic limit and PI is the plasticity index. The results revealed that five sampling points were observed to be highly collapsible (HCS), four non-collapsible (NCS) with one swelling soil (SS). This might be as a result of non-plastic nature of the soil which is in agreement with the works of Delage (2005); Wail (2012) as well as Mahnam *et. al* (2019).

Table 2: Evaluation of collapsibility potential using Priklonski, (1952) criteria

Location	Sampling point	W_n (%)	PL (%)	PI (%)	Collapsibility coefficient formula	Collapsibility coefficient range	Collapse intensity
Dikwa Road	A1T1	4.40	NP	20.00	$K_D(W_n - PL)/PI$	0.22	HCS
	A1T2	13.90	NP	19.00		0.73	NCS
Damboa Road	A2T1	18.30	NP	18.00	If K_D < 0: highly collapsible soils	1.02	SS
	A2T2	5.20	NP	15.00		0.35	HCS
Baga Road	A3T1	10.80	NP	20.00	If K_D> 0.5: non collapsible soils	0.54	NCS
	A3T2	10.00	NP	18.50		0.54	NCS
Jos Road	A4T1	1.70	NP	16.00		0.11	HCS
	A4T2	7.70	NP	16.90	If K_D >1.0: Swelling soils	0.46	HCS
Bama Road	A5T1	9.60	NP	17.00		0.56	NCS
	A5T2	8.40	NP	19.50		0.43	HCS

HSC: Highly collapsible soil, NSC: Non-collapsible soil and SS: Swelling soil

3.2.2. Handy, (1957) criteria

Table 3 shows the results obtained from the study area based on Handy (1957) criteria. This criterion used the percentage clay content of a soil or the ratio of liquid limit to saturation moisture content in determination of soil collapsibility. The results depicted that the entire study area was highly collapsible.

Such a scenario occurred as a result of the low clay content which is dominant in the soils of the test area. Similar findings were reported earlier by Delage (2005) and Wail (2012).

Table 3: Evaluation of collapsibility potential using Handy, (1957) criteria

Location	Sampling point	Clay contents (%)	Collapsibility coefficient range	Collapse intensity
Dikwa Road	A1T1	0.4		HCS
	A1T2	0.6	Clay content < 16%; Highly collapsible	HCS
Damboa Road	A2T1	0.2		HCS
	A2T2	0.6	24% > clay content > 16%; Probability to collapse	HCS
Baga Road	A3T1	0.2		HCS
	A3T2	0.6		HCS
Jos Road	A4T1	0.8	32 > clay content > 25%; probability of collapse of less than 50%	HCS
	A4T2	0.4		HCS
Bama Road	A5T1	0.8	Clay content > 32%; Non collapsible	HCS
	A5T2	1.0		HCS

3.2.3. Zur and Wiseman, (1957) criteria

Table 4 present the result obtained based on dry density and liquid limit of the soil. Zur and Wiseman (1973), used the dry density versus liquid limit as a collapse criteria. The results revealed that the entire study area was prone to collapse. This might be as a result of high void ratio of the soil which is in agreement with Wail (2012).

Table 4: Evaluation of collapsibility potential using Zur and Wiseman, 1957 criteria

Location	Sampling Point	D_o	D_{LL}	Collapsibility coefficient formula	Collapsibility coefficient range	Collapse intensity
Dikwa Road	A1T1	1.84	20.00		0.09	PC
	A1T2	1.57	19.00		0.08	PC
Damboa Road	A2T1	1.88	18.00	D_0/D_{LL}	0.10	PC
	A2T2	1.81	15.00		0.12	PC
Baga Road	A3T1	1.94	20.00	If, $D_0/D_{LL} < 1.1$; soil prone to collapse	0.10	PC
	A3T2	1.85	18.50		0.10	PC
Jos Road	A4T1	1.91	16.00	If, $D_0/D_{LL} < 1.3$; soil prone to swell	0.12	PC
	A4T2	1.84	16.90		0.11	PC
Bama Road	A5T1	1.87	17.00		0.11	PC
	A5T2	1.94	19.50		0.09	PC

PC: Prone to collapse

3.2.4. Clevenger, (1958) criteria

Table 5 showed the results obtained from the study area. Clevenger suggested a criterion for collapsibility of soils based on its maximum dry density. The results revealed that the entire study area showed small collapse settlement as a result of low dry densities. Similar findings were achieved by Rafie *et. al* (2008), Wail (2012) and Mahnam *et. al* (2019).

3.2.5. Gibbs and Bara (1962) criteria

Table 6 present the result obtained from the study area. This criterion used the natural dry density together with the liquid limit for estimating the susceptibility of soil to collapse as; $\gamma_d < 162.3/(1+0.026W_L)$ Ibs /ft^3 or $e_0 > 2.6W_L/100$ where, γ_d is the natural dry density and W_L is the liquid limit. The results entails that the entire soils were collapsible. Such scenario was achieved by Wail (2012) and Mahnam *et. al* (2019).

Table 5: Evaluation of collapsibility potential using Clevenger (1958), criteria

Location	Sampling point	Max dry density(g/cm^3)	Collapsibility coefficient formula	Collapsibility coefficient range	Collapse intensity
Dikwa Road	A1T1	1.84	If $\gamma_d$max < 1.28 g/cm^3: Significant Settlement and $\gamma_d$max >1.44 g/cm^3: Small Collapse	>1.44 g/cm^3	Slightly collapse
	A1T2	1.57		>1.44 g/cm^3	Slightly collapse
Damboa Road	A2T1	1.88		>1.44 g/cm^3	Slightly collapse
	A2T2	1.81		>1.44 g/cm^3	Slightly collapse
Baga Road	A3T1	1.94		>1.44 g/cm^3	Slightly collapse
	A3T2	1.85		>1.44 g/cm^3	Slightly collapse
Jos Road	A4T1	1.91		>1.44 g/cm^3	Slightly Collapse
	A4T2	1.84		>1.44 g/cm^3	Slightly Collapse
Bama Road	A5T1	1.87		>1.44 g/cm^3	Slightly Collapse
	A5T2	1.94		>1.44 g/cm^3	Slightly Collapse

Table 6: Evaluation of collapsibility potential using Gibbs and Bara (1962) criteria

Location	Sampling point	Dry density (g/cm^3)	W_L (%)	Collapsibility coefficient formula	Collapsibility coefficient range	Collapse intensity
Dikwa Road	A1T1	1.84	20.00	γ_d< 162.3/ (1+0.026W_L)	106.8	CS
	A1T2	1.57	19.00		108.6	CS
Damboa Road	A2T1	1.88	18.00		110.6	CS
	A2T2	1.81	15.00		116.8	CS
Baga Road	A3T1	1.94	20.00		106.8	CS
	A3T2	1.85	18.50		109.6	CS
Jos Road	A4T1	1.91	16.00		114.6	CS
	A4T2	1.84	16.90		112.7	CS
Bama Road	A5T1	1.87	17.00		112.6	CS
	A5T2	1.94	19.50		107.7	CS

CS: Collapsible soil

4. CONCLUSION

In this research, the application of qualitative method in ascertaining collapse potential using some index properties of the soils based on moisture content and Atterberg limits relationship showed that that six sampling points were observed to be highly collapsible (HCS), three non-collapsible (NCS) with one swelling soil (SS), while criteria based on percentage clay content, dry density versus liquid limit, maximum dry density and natural dry density together with the liquid limit showed that the entire area were highly collapse, prone to collapse, some small collapse settlements. The identification of this occurrence will no doubt necessitate more proactive measures to reduce structural damage to infrastructure (buildings, pavement, dams etc) built over them; resulting from differential settlement, ground fissuring due to their low bond strength, high void ratio which makes the soil structure liable to volume changes under small structural load once they are saturated or via shock wave.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

AASHTO (1986). Standard Specification for Transportation, Material and Methods of Sampling and Testing. 14th ed. Washington D.C. *Amsterdam Association of States Highway and Transportation Officials.*

Alain, E. H., Pao-Tsung, H., Racheal, B. and Maria,C.S. (2012). Identification and behavior of Collapsible Soils. *Joint Transportation Research Program Technical Report FHWA/IN/JTRP.*

ASTM D 2487 (2006). Standard practice for classification of soils for engineering purposes (unified soil classification system), *American Society for Testing and Materials*. Philadelphia.

BS 1377-2:(2022). Methods of test for soils for civil engineering purposes - Classification tests and determination of geotechnical properties. British Standard Institution, UK.

Clevenger, W. A. (1958). Experiences with loess as foundation Material. *Transaction of American Society of Civil Engineers*, 123, pp.151–169.

Coduto, D. P. (2001). Foundation Design Principles and Practices (2nd ed).

Delage, P., Cui1, Y.J. & Antoine, P. (2005). Geotechnical problems related with loess deposits in Northern France. *Proceedings of International Conference on Problematic Soils*, 25-27 May 2005, Eastern Mediterranean University, Famagusta, N. Cyprus

Evans, R. D., Jefferson, I., Northmore, K. J.,Synac, O. and Serridge, C. J. (2004). Geophysical investigation and in-situ treatment of collapsible soils. In G. E. for T. Projects (ed.), *Proceedings of Geo-Trans,* pp.1848–1857. Geotechnical Special publication, n 126 II.

Gibbs, H.J. and Bara, J. P. (1962). Prediction Surface Subsidence from Basic Soil Tests*, Report No. EM-658, Bureau of Reclamation.*

Handy, R. L. (1973). Collapsible loess in Lowa. *Soil Science Society of America*, pp. 281–284.

Jiangyong Wang, Guizai Gao, Dongmei Jie, Qi Fang, Hainan Wang, Honghao Niu, Meng Meng, Guihua Zhang, Ying Liu, Lina Song, Linlin Liu. (2022). Aeolian soils on the eastern side of the Horqin Sandy Land, China: A provenance and sedimentary environment reconstruction perspective,CATENA, Volume 210,105945, ISSN 0341-8162. Available electronically at https://doi.org/10.1016/j.catena.2021.105945

Khosravi, F. (2002). Soils and collapsibility potential on different areas in Iran. *Third international conference in Geotechnical Engineering and soil Mechanics,* Tehran, Iran. (In persian).

Kundiri, A. M., Muhammad, A.S. and Muhammad, I. S. (2016). An Investigation of Geotechnical Properties of Bama Ridge Soil as a suitable sub Grade Material in Road Construction. *Faculty of Engineering Seminar Series*, 7, pp. 31–35.

Mahnam, R.H., Micheal, Y. and Rouzbeh, D. (2022). Evaluation of Collapsibility Potential in Soil Layers Based on Practical Methods (Case study: Hir City-Ardabil Province). *Advance Researches in Civil Engineering,* 1(2) , pp. 42-49.

Nelder, L. M., Lan, S., Northmore, K. N., Jefferson, I. and David, C.E (2008). On-site Characterization of Loessic Brick earth Deposits at Ospringe, Kent, UK. *Proceedings of the Institution of Civil Engineers, Geotechnical Engineering*, 16 (1), pp. 3–17.

Priklonski, V. A. (1952). Prediction of metastable soil collapse. *Publication of the 121st International Association of Hydrological Sciences.*

Rafie, B.M.A., Moayed, R.Z. and Esmaeli, M. (2008). Evaluation of Soil Collapsibility Potential: A Case Study of Seamnan Railway Station. *Electronic Journal Of Geotechnical Engineering*, 13, pp. 1-7.

Wail,O. M. H. (2012). An Experimental Study on Collapsible Soils in Ondurman. *A thesis submitted in partial fulmfillment for the degree of Master of Science in Building Technology.*

Zur, A. and Wiseman, G. (1973). A study of collapse phenomena of an undisturbed loess. *Proceedings of the 17th International Conference on Soil Mechanics and Foundation Engineering*, 22, pp. 265–269.