STRUCTURE DAMAGES DUE TO INFLUENCE OF SWELLING POTENTIAL OF EXPANSIVE SOILS ON FOUNDATIONS: A CASE STUDY

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ABSTRACT

Structure damages are becoming very common at Baure, Gombe State, Nigeria, especially in case of low structures, probably due to expansive soil behaviour. This study analyzes a typical area; Baure in Gombe state, Nigeria where expansive soil was found to be the cause of structural damages. Soil samples collected at different locations below the foundation level of the affected buildings were tested according to the conventional geotechnical investigation tests, to evaluate the swelling characteristics of the expansive soil. Direct estimation of swelling potential (free swell and swell pressure) as well as index and particle size properties were used for the evaluation of swell potential and identification of the soil. Mineralogy composition of samples was determined by x-ray diffraction analysis (XRD). Quantitative analysis of XRD results revealed that the average percentages of different clay minerals in the samples are 51% montmorillinite, 32% illite, 8% offretite, 4% kaolinite, 3% microcline and 2% quartz. All the tests analysis led to the conclusion that the soil had an average to high swelling potential due to the presence of expansive-clay mineral, montmorillinite.

***Keywords**: Structure Damage, Swelling potential, Expansive soils, soils/foundation interaction*

Introduction

Expansive soils are found in many parts of the world, particularly in semiarid regions with alternating wet and dry seasons. In Nigeria, these soils occupy an area of about $10.4x10^4$ km^2 in the north eastern part (Ola, 1983).The soils in these regions experience periodic swelling and shrinkage during the alternating wet and dry seasons. Such cyclic swell-shrink movements of the ground cause considerable damage to the structures founded on them, particularly light buildings and pavements, those that cannot counteract the upward thrust posed by the soils.

Expansive soils pose a problem where rapid urbanization and development are occurring. As development extends into these areas, identification and quantification of the soil properties that define shrink-swell potential are essential to properly evaluate the stability of a soil as a foundation material. The identification of swelling potential of soils also assumes significant importance in checking the possible post-construction problems for the structure.

Various investigators (Ola, 1983, Ibrahim, 1983, Mededor andLai1985, Chen, 1975, Holtz and Gibbs, 1956, and Thomas *et al.*, 2000) recognize that shrink-swell behaviour can best be predicted by examining a combination of physical, chemical, and mineralogical soil properties. However, no one property accurately predicts shrink-swell potential. Often most expansive soils are clayey with high content of montmorillinite minerals. Studied soil properties and their proposed relations to degree of expansion are summarized in **Table 1.**

Table 1: Swelling potential prediction in soils.

Parameter	Reference	Degree of Expansion			
		Low	Medium	High	Very High
LL (%)	Chen, 1975	<30	30-40	40-60	>60
PI (%)	Chen, 1975	0-15	10-35	20-55	>55
	Holtz and Gibbs,1956	<20	12-34	23-45	>45
	Ola, 1983	<15	15-30	>30	-
Clay Content (%)	Holtz and Gibbs,1956	<17	12-27	18-37	>27
Clay Content (%)	Holtz, 1959	-	13-23	20-31	>28
Free swell (%)	Ibrahim (1983)	<50	50-80	>80	-
Swell Percent (%)	Thomas *et al.*, 2000	<3.0	3.0-6.0	6.0-9.0	>9.0
Swell Pressure(kPa)	Thomas *et al.*, 2000	<81	81-153	153-225	>225
Activity	Skempton, 1953	<0.75	0.75-1.25	>1.25	-

This paper typifies the investigation of building failures at Baure, in Gombe State, Nigeria. Most buildings in the area present foundation and wall cracks of about 1.0cm or more, displaced bricks and inward foundation deflection. On observation of the extensive cracking developed and the cracking pattern, the study was undertaken with the hypothesis that expansive soil was responsible for the problem.

It is known that no one soil property or expansive soil test can precisely predict shrink-swell potential. However, a set of properties and tests can determine shrink-swell behaviour. With these premises in mind, the main objective of this study was to establish the causes of building failures at Baure in the North Eastern part of Nigeria.

Materials and Methods

Representative disturbed samples were collected at a depth between 0.5-1.0 m below the foundation level of the affected buildings. The samples were sealed in plastic bags and put in sacks to avoid loss of moisture during transportation. They were air-dried before pulverising to obtain particles passing British standard sieve No 4 (4.75mm aperture).

Laboratory analyses included particle-size distribution, liquid limit (LL), plastic limit (PL), clay content, natural moisture content, dry unit weight, free swell, swell pressure, and clay mineralogy. Particle size distribution, LL, PL, clay content, natural moisture content, and dry unit weight tests were accomplished according to the standards of the American Society for Testing and Materials, while the free swell and swell pressure tests were accomplished according to British standards. Mineral composition was determined by x-ray diffraction (XRD). After conducting the tests, the diffraction pattern for each sample was matched with the standard patterns.

Results and Discussion

The results of index property parameters in **Table 2.** Shows that the natural moisture content ranges between 12.80 % and 24.40%, specific gravity from 2.63 to 2.86, and the dry density from1.53 mg/m^3 to 1.72mg/m^3. Results of Atterberg limits indicate that liquid limits ranges from 46.8% to 70.8%, plastic limit from 16% to 36.8% and plasticity index from 29.3% to 43.6%. For all the samples collected, similar values have been reported by other researchers for expansive soils. A comparison between Atterberg's limits (**Table1**) and the studied soil sample shows that this soil can be classified as highly expandable.

Table 2: Index property parameters

Sample No	w (%)	G_s	ρb (mg/m^3)	ρd (mg/m^3)	LL (%)	PL (%)	PI (%)
1	18.90	2.65	2.03	1.71	58.7	22.1	36.6
2	21.20	2.75	2.06	1.70	69.0	36.8	32.2
3	12.80	2.63	1.82	1.61	70.8	32.2	38.6
4	18.10	2.70	1.95	1.65	64.5	32.2	32.3
5	15.90	2.73	1.88	1.62	62.1	26.2	35.9
6	19.20	2.68	1.88	1.58	69.6	31.9	37.7
7	14.30	2.67	1.75	1.53	68.6	28.6	40.0
8	15.20	2.59	1.85	1.61	66.8	23.2	43.6
9	23.30	2.81	2.01	1.63	68.6	30.5	38.1
10	17.80	2.70	1.86	1.72	61.7	29.6	32.1
11	22.10	2.86	2.07	1.70	55.5	16.0	39.5
12	20.90	2.76	2.03	1.68	46.8	17.5	29.3
13	14.20	2.72	1.80	1.58	66.8	29.1	37.7
14	17.80	2.73	1.88	1.60	61.0	25.7	35.3
15	13.80	2.71	1.82	1.60	67.7	28.7	39.0
16	14.91	2.68	1.93	1.68	66.4	30.5	35.9
17	24.40	2.67	2.00	1.61	61.1	25.7	35.4
18	16.50	2.69	1.97	1.69	50.0	16.4	33.6
19	19.80	2.71	2.02	1.69	58.9	20.5	38.4
20	16.70	2.74	1.91	1.64	66.5	27.7	38.8

Key: w: Natural moisture content **G_s:** Specific gravity **ρb:** Bulk density **ρd:** Dry density **LL:** Liquid limit **PL:** Plastic limit **PI:** Plasticity index

The particle size analysis indicates that 92% of the soil passed through a No 200 B.S sieve and the clay fractions ranges from 51.3% to 58.7%. The composition of the clay were; sand (5.0 - 12.9) %, silt (10.7-25.6) %, and clay (51.3 – 58.7) %. According to the Unified Soil Classification System (USCS) the studied soil is classified as an inorganic fat clay (CH) and/or elastic silt (MH) with high plasticity, which is an indication of its expansive nature, since most expansive soils are often clayey. All the samples tested can be classified as highly expansive. The soil belongs to the A-7-6 subgroup of AASHTO Classification.

Table3: Particle Size Property Parameters

Sample No	Gravel fraction (%) (60-2mm)	sand fraction (%) (2-0.06mm)	silt fraction (%) (0.06-0.002)	clay fraction (%) (0.002-0.001)	colloidal fraction (<0.001mm)	Activity number AC
1	0.2	5.2	22.3	56.7	15.6	0.65
2	3.3	8.0	22.2	52.9	13.6	0.61
3	0.3	11.2	16.2	51.3	21.0	0.75
4	0.2	8.7	22.5	52.3	16.3	0.62
5	0.1	10.3	16.5	55.3	17.8	0.65
6	0.0	7.7	23.5	52.3	16.5	0.72
7	0.5	9.7	11.6	54.4	23.8	0.74
8	0.0	6.7	15.1	55.8	22.4	0.78
9	3.2	5.8	25.6	56.2	9.2	0.68
10	0.0	7.2	21.8	52.8	18.2	0.61
11	1.2	11.9	20.8	55.3	10.8	0.71
12	1.7	9.7	22.2	52.4	14.0	0.56
13	1.5	5.0	11.6	58.7	23.2	0.64
14	0.3	7.8	23.7	52.5	15.7	0.67
15	0.6	10.0	14.8	52.9	21.7	0.74
16	0.0	12.9	10.7	56.2	20.2	0.64
17	0.8	10.6	21.3	54.2	13.1	0.65
18	0.0	9.1	18.7	56.3	15.9	0.60
19	0.4	10.2	14.5	58.4	15.5	0.66
20	0.4	11.0	20.3	53.0	15.3	0.73

Direct estimation of the swelling potential (Free swell and swell pressure) of expansive soils in the laboratory is important for the prediction of swell heave. The results of free swell characteristics of the investigated soil ranges between 87% and111%.The free swell rises with clay fraction, plasticity index and liquid limit. From standards, soils with free swell values less than 50% are not likely to show expansive properties. Free swell values above 50% can cause considerable damage to lightly loaded structures. It can therefore be inferred that the soil has expansive characteristics with negative influence on the foundations of the structures.

A swell pressure value of 81.94kN/m^2 was observed at S_1 and S_2 **(Fig1),** which is classified as moderate swelling potential. Moreover the swell pressure decreases to 62.96kN/m^2 at S_5. This decrease was probably caused by the increase in dry unit weight and depth, an indication of soil resistance to swelling with increasing depth.

Fig.1 Swell pressure curves

Mineral composition of samples was determined by X-Ray diffraction analysis (XRD). A result of X-ray diffraction test shows the presence of kaolinite, quartz, microcline, offretite, bentonite (a mineral from the montmorillinite group) and illite in all samples. A typical result of XRD test is shown in **fig.2.**

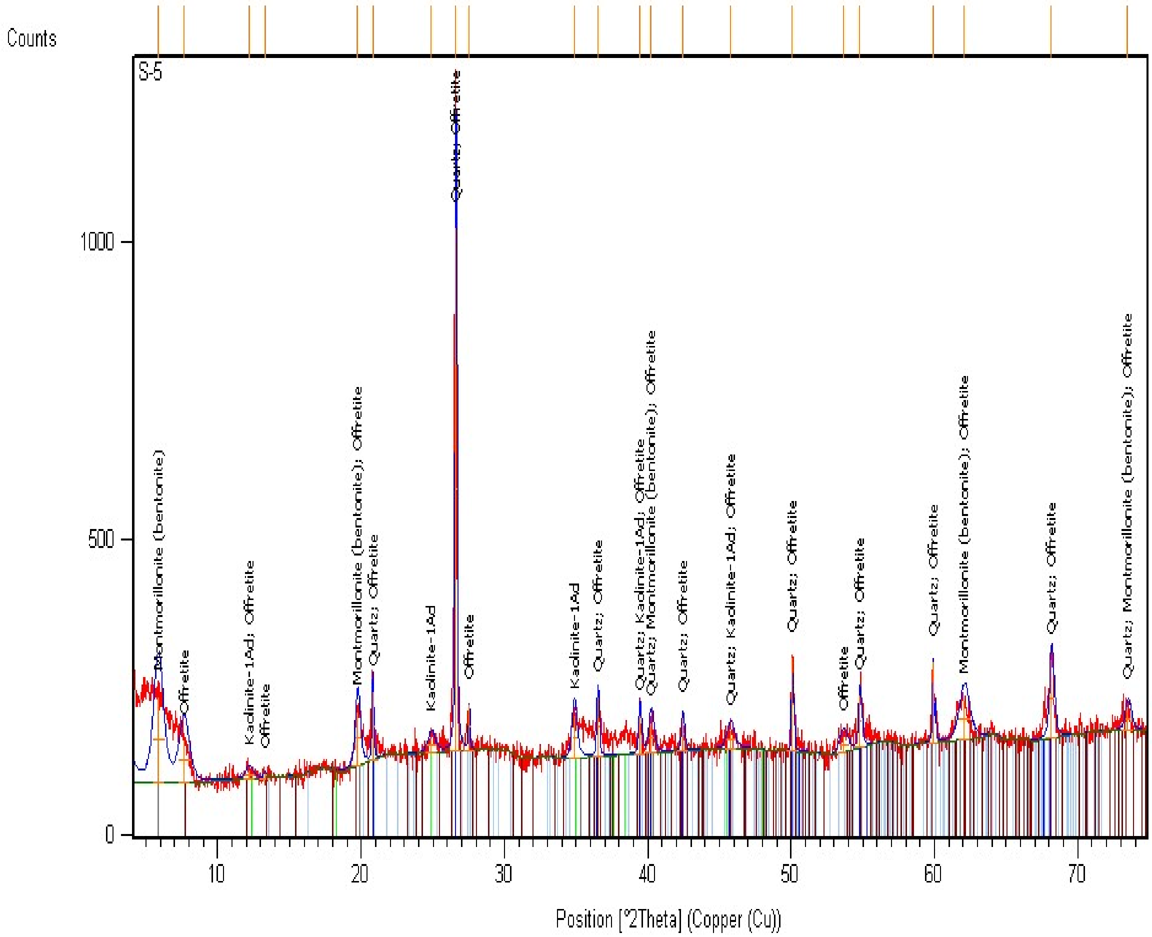

Fig. 2 X-ray diffraction result of natural sample showing Kaolinite, Montmorillinite (bentonite) and offretite minerals.

Kaolinite, offretite and quartz having a stable structure (due to the strong bonds) reacts with water to a minimum extent, by contrast with montmorillonite (bentonite) and microcline which are regarded as very hydrophilic due to their mobile structure, making them highly expansive. Illite in turn is a mineral that reacts with water to a limited extent. Quantitative analysis of XRD results revealed that the average percentages of different clay minerals in the samples are 51% montmorillonite, 32% illite, 8% offretite, 4% kaolinite, 3% microcline and 2% quartz.

Conclusion

Analyses of soil characteristics based on direct estimation of swelling potential (free swell and swell pressure) as well as index and particle size parameters showed that the soil is highly expansive. Furthermore, mineral composition of samples revealed a high content of expansive clay minerals such as Bentonite and montmorillinite. Moreover, minerals such as illite, offretite kaolinite and microcline, which react with water to a limited extent, were found. Based on the results of this investigation, it can be concluded that the cause of damage to structures at the study area is essentially due to high swelling and shrinking characteristics of expansive soil in the foundation media.

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