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Failure of Building Caused By Unstable Soil, a Case Study of Atanu Village, Nigeria

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Abstract
Failure or collapse of buildings has been a major concern in Nigeria because of its incessant occurrence, causing damage to life and property. This study is to investigate the probable causes of building failure at Atanu village. Laboratory experimental procedures were used for the soil tests. The results of sieve analysis show that the percentage of soil materials passing 18mm sieve is 2.4%.This shows that a very insignificant quantity of course materials characterized the soil from the area. The results also show that the soil is poorly graded ($C_u < C_c < 3$ and $C_u \geq 6$). The Atterberg limits for all the samples show that at 25 blows, Pit 9 has Liquid Limit (LL), Plastic Limit (PL) and Plastic Index (PI) of 52, 33and 19 respectively, while Pit 15 has LL, PL and PI of 37, 23 and 14 respectively. These values correspond to A-7-6 and A-6. These are within the of range clayey soil, under AASHTO classification. Results show that the shear strength parameters depict a cohesive soil. It is also discovered that within a depth of 1m, the soil has significant quantity of clay. This clay material which has much affinity for water, cohesive in nature, has low permeability with ability to exhibit shear under loads. This could be the cause of conspicuous cracks (failures) of structures within the area.

Keywords: Building, Failure, Foundation, Soil Properties

Introduction

Majority of the houses at Atani Community in Ogbaru Local Government Area of Anambra State, Nigeria have developed very big cracks and many have actually collapsed over the years. The aim of this study is to investigate the probable cause(s) of the failure of the houses. The emphasis is on the soil investigation. Investigation of building where failure has occurred is often necessary to establish the causes of the failure and to obtain important information required for design of remedial measures. Buildings are utilized primarily for living, working and storage (Fagbenley, 2012). They must be properly planned, designed and erected to obtain safety and other conveniences. The incidence of building failure/collapse in Nigeria is reaching an epidemic proportion (Ayedun, et al, 2014).The spate of building failure or collapse has become an endemic problem that has defied all attempts at providing solution in the recent past. These incidences have resulted in the loss of lives and properties. Though building collapse is not peculiar to Nigeria, the trend in the country is becoming quite worrisome and a source of concern to stakeholders (Akinjare, 2012).

Many factors could be responsible for building failure: foundation, soil and building materials. Other causes of building failure arising from foundation problems include poor workmanship, wrong interpretation of building design, inadequate supervision, non-adherence to ethical standards, poor maintenance culture, greed, use of plan approved for bungalow or two-storey building for the construction of multi-storey buildings (www.springerlink.com*).*

Soil bears the weight of foundation and foundation bears the entire weight of building super-structure (Terzaghi and Pack, 1977). A foundation that is not properly designed or founded on suitable bearing strata will lead to a faulty structure. A foundation that is sited on a sub-soil that is not stable stands the risk of failing, as the soil mass settles under load. This failure is as a result of loading a soil mass with a super-structural load that has an overburden pressure more than the bearing capacity of the in-situ soil, in which it is founded, (Terzaghi and Pack, 1977). The simplest foundation for low-rise dwelling is a strip footing or trench filled with massive concrete. Generally, where soil strata do not have good bearing capacity due to water-logged soil, peat soil and highly compressible and cohesive soils, reinforced concrete foundation should be provided.

It is important to have an engineering/geophysical survey of the soil under a proposed structure, so that variations in the strata and soil properties can be determined. This helps the engineer and builder to ascertain the soil's bearing strata and pressure (Ambrose, 2012). It has been proven that if foundation is placed on peaty soil or clay underlain by peat, it is bound to fail due to the high compressibility of the soil under load (Young and Winterkorn, 1975). Foundation founded on expansive soil, will "heave" and cause lifting of building during periods of high moisture. Conversely, during period of reduction in the soil moisture, the soil will "shrink" resulting in settlement of the structure. Moreover, when there is unequal settlement, crack/failure could be noticed (Braja, 2010). Soil engineers identify potentially expansive soils that can cause foundation problems by measuring the percentage of clay particles in a particular sample. If over 50% of the particles in a sample are able to pass through a 75µmm sieve, then the sample is classified as either silt or clay or some combination of both (Cassagrande and Fadum, 1999).

Shrinkage Limit (SL) is the maximum moisture content at which further loss of moisture does not cause a decrease in volume of the soil. In other words, at this water content, shrinkage ceases. The difference between the plastic limit and the liquid limit is a measure of the plasticity index of the sample. Clay which has a plasticity index greater than 50 is considered to be highly plastic clay and often called "fat clay". The America Society of Testing Material (ASTM, D 4829), has published a test method, and an expansion index to quantify the results. The expansion range and potential expansion are as follows:

0 – 20: Very low
21 – 50: Low
51 – 90: Medium
91 – 130: High
>130: Very high

Plasticity Index (I_P) is the range of water content over which the soil remains in plastic state. It is equal to the difference between the liquid limit (LL) and plastic limit (PL) as represented in equation (1).

$$I_p = LL - PL \quad (1)$$

Materials and Methods

The soil samples used for the tests in this study were disturbed samples collected from Atani community in Ogbaru Local Government Area of Anambra state, Nigeria. This community is located about 4km from the popular Ugah Junction en-route Onitsha via Asaba, while descending River Niger Bridge. Four locations were chosen within the area where there were buildings with noticeable cracks and collapse, suspected to be as a result of foundation problem. The locations were at 150m apart. In each location, five pits (0.9-1.0m depth) where dug at different directions, 30m apart. Some of the tests were conducted at the soil laboratory of Civil Engineering Department, Nnamdi Azikiwe University Awka, while some were done at the soil laboratory of University of Agriculture Makurdi.

The following tests were conducted on the soil samples based on British Standards: Soil Grading (BS 1377-2, 1990), Moisture content (BS 812-109, 1990), Compaction (BS 1377-4, 1990), Atterberg limits (BS 1377-2, 1990) and Tri-axial test (BS 1377-7, 1990).

Sieve Analysis

Coefficient of uniformity (C_u) and Coefficient of consistency (C_c) of soil are given by equations 2 and 3 respectively;

$$C_u = \frac{D_{60}}{D_{10}} \quad (2)$$

$$C_c \quad \frac{(D_{30})^2}{D_{60} x D_{10}} \quad (3)$$

D refers to the effective diameter of soil sample.

Moisture Content

Moisture Content (W) is given by,

$$W = \left(\frac{W_w}{W_s}\right) x100 \quad (4)$$

W_w is the weight of water present in the soil mass and W_s is weight of dry soil mass.

Compaction Test

Dry density (D_d) of soil is given by

$$D_d = \frac{M}{V\,(1+w)} \quad (5)$$

M is total mass of soil, V is volume of soil, and w is water content of the soil

The bulk density D_b in g/m^3 of each compacted specimen is calculated from

$$D_b = \frac{m_2 - m_1}{1000} \quad (6)$$

m_1 is mass of mould and base in gramme (g)
m_2 is mass of mould, base and soil in gramme, (g)

Trial-axial Test

The condition of the failure of the sample was gotten by drawing a strength line as tangent to the Mohr circles.

The shear strength (t) is given by,

$$t = c^! + \varphi \tan\emptyset \quad (7)$$

$c^!$ is cohesion, $\emptyset$ is angle of shearing resistance and φ (σ - u), is defined as the effective stress. σ is the total stress applied normal to the shear plane, and u is the pore water pressure acting on the same plane.

Results and Discussion

Figure 1 shows a typical sieve analysis curve for the soil samples. The results show that the highest percentage of materials retained in 18mm sieve (gravel) is 2.4 %. This shows near absence of course materials in the sample. However, 58.0 % of the materials passed 75µmm sieve. This depicts a soil with an appreciable quantity of fine particles, since it is only silt and clay constituents that can pass through this sieve size. Furthermore, using the Unified Soil Classification System (USCS), grading system, if 1< C_c<3 and $C_u \geq 4$, the soil is well – graded gravel (G), and if 1< C_c< 3 and $C_u \geq 6$, it is a poorly – graded fine materials. However, the results show a C_u and C_c that tend to infinity (∞). Hence, the soil in this area can be classified as poorly graded (clayey- silt). Also, this conforms to AASHTO classification of A-7-6 and A-7-5.

The results of Atterberg limits are shown in Table 2 for all the samples. The results show that at 25 blows, PIT 9 has LL, PL and PI of 52, 33 and 19 respectively, while PIT 15 has LL, PL and PI of 37, 23 and 14 respectively. These values correspond to A-7-6 and A-6. These values are within the range of clayey soil, under AASHTO classification. This entails that the soil at Atani village is largely clay in composition. Clay is known to be unstable and troublesome (Terzaghi and Pack, 1977). The quick– undrained Tri-axial Test results, conducted on the disturbed samples from these locations, are shown in Table 2. The shear strength parameters depict a cohesive soil. It can be noted that cohesionless soils have cohesion (c^l) equal to zero.Also from Table 2, the least cohesion was 13.0 KN/m^2 for PIT 1, and the highest cohesion was 59.0 KN/m^2 for PIT 11. The results show that the soil is soft to medium clay. The more the clay content in a soil, the less is the angle of internal friction. The results of moisture content of the soil from PIT 1 are shown in Table 1. The average moisture content for the soil and all the soil samples from all the Pits are 48.7 and 42.2 respectively, Table 2 shows the results of compaction of the soil. The maximum bulk density (D_b) and dry (D_d) density are 1.74 and 1.43 Kg/m^3 respectively. Tables 4 and 5 explain the values of cohesion and AASHTO with USCS as shown in Table 2 respectively.

Conclusion

Failure of building structures is a regular phenomenon in Nigeria. Atanu village in South-East Nigeria is a good example. This research is directed towards finding the probable cause of frequent building failure at Atanu community. Site reconnaissance and the laboratory tests for grading, Atterberg Limits, Compaction and Shearing Stress of the soil samples from the area were conducted. It was found that within 1m depth, the soil has significant quantity of clay. This clay material which has much affinity for water and cohesive in nature, has low permeability with ability to exhibit shears under loads (Yong, and Winterkorn, 1975). This could be the cause of conspicuous cracks, sometimes total collapse of structures within the area,

Recommendations

Based on the outcome of this study, I would recommend the followings:

1. Proper soil investigations should be conducted before erecting building structures.
2. Raft foundation should be considered for the buildings to be erected.
3. Soil stabilization could also be considered in the area.

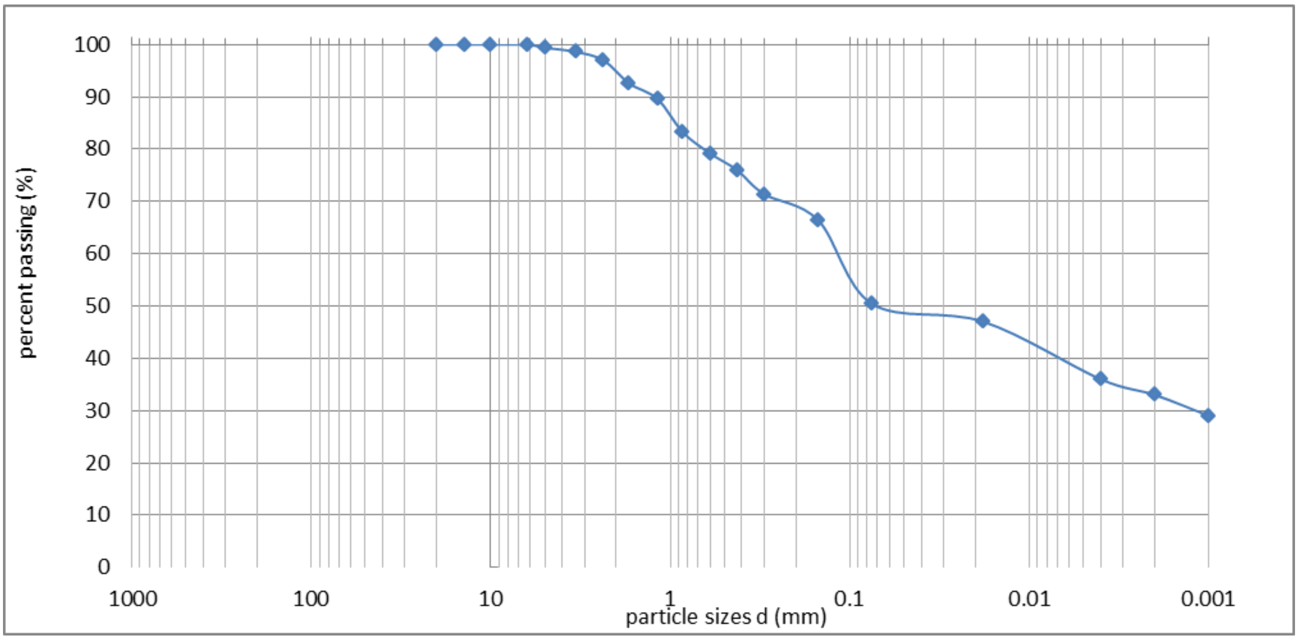

Fig. 1: Grading curve for Pit No. 3 soil (Typical of all the grading curves)

Table 1: Results of the soil's moisture content (Pit 2)

Test No	1	2
Can No	84	70
Wt of Can (m_4) (g)	17.1	16.9
Wt of Can + wt sample (m_1) (g)	45.8	56.1
Wt of Can + dry sample (m_2) (g)	37.6	38.0
Wt of dry sample (m_3) (g)	20.5	21.1
Wt of moisture (m_1- m_2) (g)	8.2	12.1
Moisture content (%)	40.0	57.3
Average Moisture Content (%)	48.7	

Table 2: Results of compaction of the soil (pit 2)

Percentage of water added	**15**	**18**	**21**	**24**	**27**
Test No.	1	2	3	4	5
Container No.	02	101	63	77	55
Weight of Container + Wet soil (Kg)	60.2	52.3	66.2	98.9	78.6
Weight of Container + Dry soil (Kg)	54.6	46.7	57.3	83.2	65.3
Weight of Container (Kg)	16.1	15.8	16.0	17.3	16.8
Weight of Moisture (Kg)	30.5	30.9	41.3	65.9	48.5
Weight of Dry Soil (Kg)	5.6	5.6	8.9	15.7	13.3
Moisture Content (%)	14.5	18.1	21.5	23.8	27.4
Weight of Mould + Wet soil (Kg)	5036	5178	5273	5244	5218
Weight of Wet soil (w) (Kg)	1500	1642	1737	1708	1682
Bulk Density (Kg/m^3)	1.50	1.64	1.74	1.71	1.68
Dry Density (Kg/m^3)	1.31	1.39	1.43	1.38	1.32

Table 3: Results of the soil properties

PT NO.	**C_u**	**C_c**	**D_{60}**	**D_{10}**	**D_{30}**	**LL (%)**	**PL (%)**	**PI (%)**	**AASHTO Classification**	**c^{I}(KN/m^2)**	**φ°**
1.	∞	∞	0.115	0	0.0012	41	23	18	A – 7 – 6	13	17
2.	∞	∞	0.149	0	0.0025	45	27	18	A – 7 – 6	15	18
3.	∞	∞	0.149	0	0.0016	43	24	19	A – 7 – 6	29	16
4.	∞	∞	0.149	0	0.0019	53	36	17	A – 7 – 6	17	28
5.	∞	∞	0.151	0	0.0010	42	26	16	A – 7 – 5	22	17
6.	∞	∞	0.139	0	0.0010	41	27	14	A – 7 – 5	20	11
7.	∞	∞	0.113	0	0.0010	50	37	13	A – 7 – 6	25	7
8.	∞	∞	0.112	0	0.0011	51	35	16	A – 7 – 6	18	12
9.	∞	∞	0.112	0	0.0010	52	33	19	A – 7 – 6	34	10
10.	∞	∞	0.090	0	0	48	29	19	A – 7 – 6	29	14
11.	∞	∞	0.100	0	0	48	31	17	A – 7 – 6	59	7
12.	∞	∞	0.111	0	0.0012	46	26	20	A – 7 –6	17	12
13.	∞	∞	0.129	0	0.0030	45	32	13	A – 7 – 5	20	11
14.	∞	∞	0.121	0	0.0040	39	26	13	A – 7 – 5	27	16
15.	∞	∞	0.122	0	0.0029	37	23	14	A – 7 – 5	16	15
16.	∞	∞	0.140	0	0	46	28	18	A – 7 – 6	14	16
17.	∞	∞	0.200	0	0.001	43	24	19	A – 7 – 6	24	17
18.	∞	∞	0.151	0	0	46	23	23	A – 7 – 6	28	18
19.	∞	∞	0.153	0	0.0035	42	27	15	A – 7 – 6	31	19
20.	∞	∞	0.113	0	0.0013	46	23	23	A – 7 – 6	25	20

Table 4: Description of C_u values for Clayey Soil (BS 1377. 1990)

S/N	**Soil**	**Cohesive (KN/m^2**
1	Very soft clay	< 12
2	Soft to medium clay	12-25
3	Stiff clay	50-100
4	Very stiff	100-200
5	Hard	> 200

Table 5: Equivalence of AASHTO and USCS (BS 1377. 1990)

AASHTO System	**USCS (Most Probable)**
A-1-a	GW, GP
A-1-b	SW, SM, GM, SP
A-2-4	GW, SM
A-2-5	GM, SM
A-2-6	GC, SC
A-2-7	GM, GC, SM, SC
A-3	SP
A-4	ML, OL, MH, OH
A-5	MH, OH, ML, OH
A-6	CL
A-7-5	OH, MH, CL, OL
A-7-6	CH, CL, OH

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