GEOTECHNICAL PROPERTIES OF THE SUBSOIL FOR DESIGNING SHALLOW FOUNDATION IN SOME SELECTED PARTS OF CHANCHAGA AREA, MINNA, NIGERIA

By

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Abstract
The subsoil conditions of the study area were investigated by excavating nine trial pits from the existing ground level to 1.50 meter. Twenty seven samples were collected and analyzed. The soil is heterogeneous and two types were identified: brown, clayey, silty, gravelly sand and brown, gravelly, clayey, silty sand. The liquid limit ranges from 22.0% to 92.0%, the plastic limit varies from 7.47% to 51.10%. The plasticity index is of the order of 1.94% to 69.98%. The plasticity and shrinkage potential range from low to high. Montmorrillonite, illite, kaolinite and halloysite were identified with the latter being the most abundant. The soil cohesion (C) ranges from 9 KN/m^2 to 27.50 KN/m^2 while the angle of internal friction ( ) varies from 15^0 to 35^0. The compression index (Cc) is of the order of 0.11 to 0.74. Based on the field and laboratory results, shallow foundation (reinforced strip, pad or raft) can be adopted for lightly loaded structures. Construction techniques that should be implemented to minimize the effects of the shrinking and swelling clay are recommended.

Keywords: Geotechnical properties, Foundation design, sieve analysis, triaxial test, plastic limit, liquid limit, shrinking and swelling clay.

1.0 Introduction

Soils are formed by many processes and a wide range of materials. Transportation and deposition are irregular; end products are notoriously variable and often have geotechnical properties which may be undesirable from the point of view of a proposed structure (Clayton et al., 1995).

Shallow foundations are normally anchored on the sub-soil and serves as the receiver of transmitted building structural loads. Thorough geotechnical knowledge of the subsoil is paramount prior to construction in order to prevent post construction problems.

This work focuses on the evaluation of some relevant geotechnical characteristics of the subsoil of Chanchaga area, Minna, Northwestern Nigeria (fig. 1) with a view of utilizing the data obtained for recommending suitable, safe founding depth and shallow foundation types for the construction of new buildings.

2.0 Study Area Description

The study area is located along Minna – Paiko – Suleja road and lies between latitude 9^0 30$'$ N and 9^0 33$'$ N of the equator and longitude 6^0 34$'$ E and 6^0 37$'$ E of the Greenwich meridian (fig. 2). It is a low lying terrain and is easily accessible. The area is drained by the seasonal river Chanchaga system and associated tributaries.

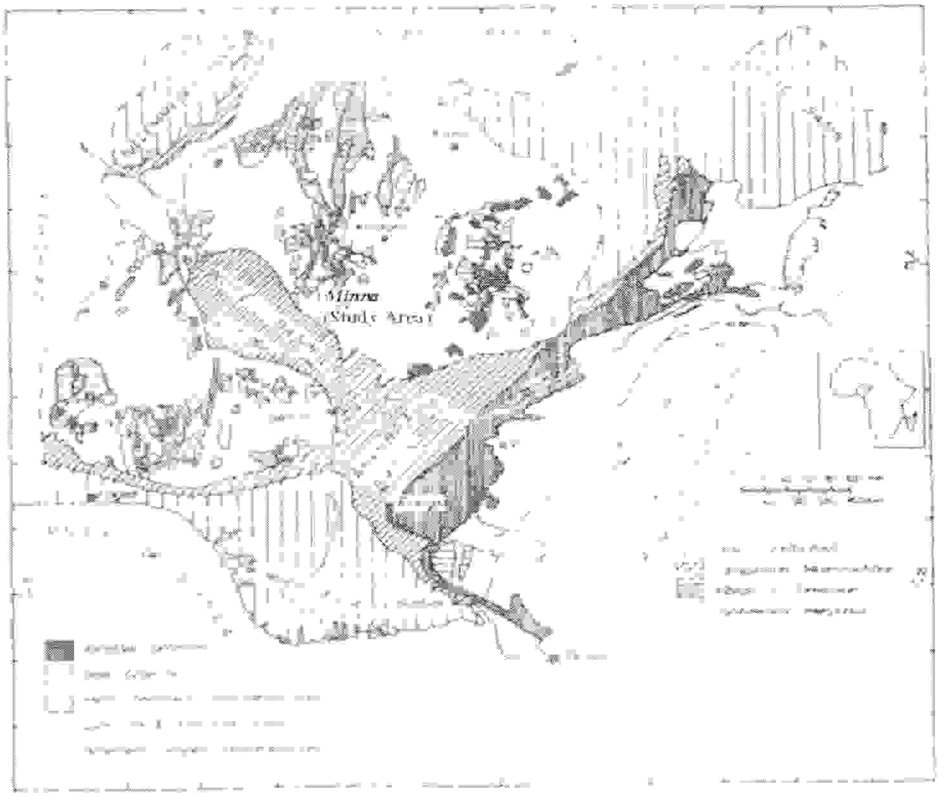


Fig. 1 Generalized Geological map of Nigeria showing the location of the study area, Minna. (*Source*: Elueze, 1995).

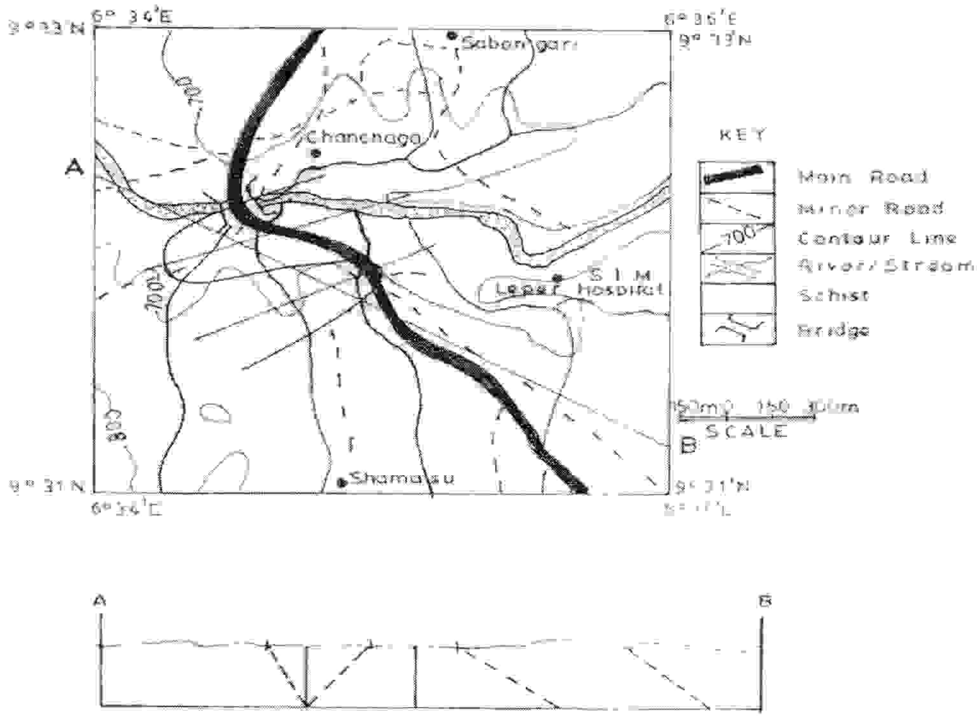


Fig. 2 Geological map of parts of Chanchaga area, Minna.

General Geology of the Area

The area investigated is a part of the north-western part of the Nigerian Basement Complex which is composed of three lithological units- migmatite gneiss complex, low grade schist belts and the older granite (Truswell and Cope, 1963, Ajibade, 1976). The Nigerian basement complex forms part of the Pan Africa mobile belt which lies between the West Africa and Congo craton.

Lithological and structural mapping revealed that the study area is underlain dominantly by schist. Outcrops of schistose rocks are not common and notable one that was identified is situated under the bridge along Minna to Chanchaga road, (fig. 2).

3.0 Methodology of Investigation

The subsoil conditions were investigated by excavating nine trial pits (fig. 3) from the existing ground level to 1.5 meter according to British Standard code of practice for site investigation (1981). Disturbed and undisturbed soil samples were collected from the trial pits and analyzed in civil engineering laboratory, Federal University of Technology, Minna for relevant geotechnical parameters. The laboratory tests were performed according to British Standard methods of test for soils for civil engineering purposes (British Standard Institution, BS 1377: part 1-9, 1990).

Dry sieve analysis was carried out in order to obtain the particle size distribution of the soil samples with a set of sieve sizes (5.00, 3.35, 2.00, 1.18, 0.600, 0.425, 0.300, 0.15, 0.075, 0.063) mm and mechanical sieve shaker.

Liquid limit test was performed with cone penetrometer. Plastic limit test was executed by kneading and rolling soil samples between fingers and thumb into about 6 mm diameter thread. Each thread was further rolled between fingertips on a clean flat glass paste with sufficient pressure to reduce the diameter into 3 mm. At exactly 3 mm, the soil paste starts to crumble

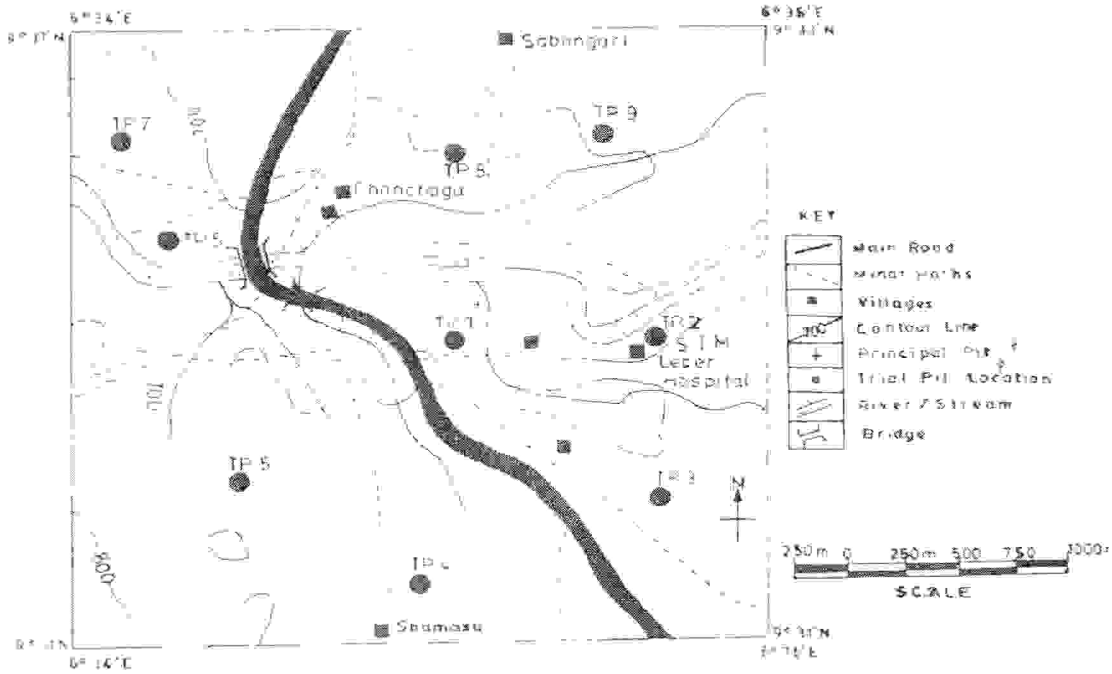


Fig.3 Map of the study area showing the sampling locations

and cannot roll further. The process was repeated until longitudinal and transverse cracks appear at a rolled diameter of 3 mm. Immediately, the moisture content of the crack thread was determined. Triaxial shear tests were performed on some chosen samples to estimate their in-situ shear strength characteristics.

RESULTS

Field Observations

A typical soil profile of a trial pit is shown in figs 4. The soil profile of the trial pits reveals that the soil in the study area is generally made up of brown, clayey, silty, gravelly sand.

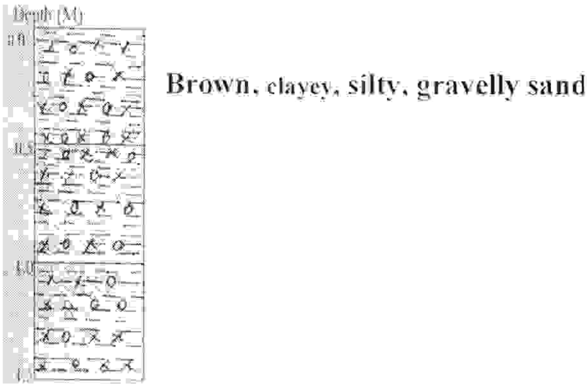


Fig. 4 Soil profile of trial pit 1.

Laboratory Results

Sieve Analysis

The results of the sieve analysis are summarized in table 1.

A typical particle size distribution curve is illustrated in fig. 4. Two types of curves were identified. Majority of the soil samples have the ratio of sand > gravel > clay + silt (Brown, clayey, silty, gravelly fine to coarse sand). This group of soil is classified as Sp according to British classification scheme Curtin et. al., (1997).

The other soil samples have the proportion of sand > clay + silt > gravel (Brown, gravelly, clayey, silty fine to coarse sand) as reflected in trial pit 3 collected at 1 meter, trial pit 4 retrieved at 1 meter and trial pit 7 collected at 0.50 meter. This group of soil is classified as Spc according to British classification scheme Curtin et. al., (1997).

Atterberg Limits

The results of the Atterberg limits are presented in table 2.

The mean values of the liquid limit, plastic limit and plasticity index are 45.43%, 21.85% and 23.57% respectively. The liquid limit ranges from 22.0% - 92.0%, the plastic limit is of the order of 7.47% - 51.10% while the plasticity index varies from 1.94% - 68.98%.

Generally, the plasticity ranges from low to high. The plasticity is in the following order of decreasing intensity, intermediate plasticity > high plasticity > low plasticity. However the sample retrieved from trial pit 2 at 1.50 meter indicate very high plasticity.

A plot of PI (plasticity index) against LL (Liquid limit) is presented in fig. 6 to show the types of clay minerals. Table 3 summarizes the clay minerals inferred from the plotting. The clay mineral distribution and summary are contained in Tables 3 & 4 respectively. It was observed that the percentage of montmorrillonite > illite > Kaolinite > Halloysite. Figs. 7 & 8 illustrate the bar-chart and pie-chart of the inferred clay minerals respectively. Clay minerals are formed from the weathering of rock forming minerals. Feldspars weather to form clay. Orthoclase feldspar reacts in the presence of water to give illite and plagioclase feldspar reacts in a similar manner to give montmorrilonite which is a shrinking and swelling or expansive clay. If excess water is present, both reactions will eventually produce kaolinite which is the final product (Gribble, 1991).

Table 5 was used to ascertain the shrinkage potential and it ranges from low to high (table 2).

Table 1: Summary of results obtained from sieve analysis

Trial pit No.	Depth (m)	% of Gravel	% of Sand	% of Silt + Clay	Coefficient of uniformity, C_u	Coefficient of curvature, C_c
1	0.5	14	81	5	9.4	2.94
	1.0	9	89	2	4.0	1.07
	1.5	15	81	4	6.50	1.14
2	0.5	16.45	78	5.55	7.41	0.67
	1.0	26	70	4	8.57	1.15
	1.5	23.33	71.67	5	10	1.11
3	0.5	9	87	4	5.95	0.81
	1.0	5.56	88	6.54	10	0.60
	1.5	14.65	82	3.35	7.30	0.75
4	0.5	8	85	7	7.25	0.80
	1.0	5.66	88	6	8	1.04
	1.5	44	53	3	7.54	1.08
5	0.5	10.99	87.47	1.54	5.14	1.15
	1.0	26	71	3	8.59	0.95
	1.5	24.93	71.57	3.5	6.56	1.00
6	0.5	31.56	64.44	3	8.2	1.49
	1.0	27	68	5	10.25	1.15
	1.5	4.5	95	0.5	2.80	1.00
7	0.5	3.87	84	12.13	10	0.63
	1.0	20.17	71	8.83	18.13	0.88
	1.5	40	57	3	1.18	1.04
8	0.5	11.74	83	5.26	10.58	0.55
	1.0	22.65	73	4.35	10	0.90
	1.5	19.91	80	0.09	5	0.90
9	0.5	6.37	89.51	4.12	6.40	0.90
	1.0	8.90	86.54	4.52	4	0.70
	1.5	11.76	78	4.24	6.78	2.19
Range		3.87 - 31.56	53 - 89.51	0.09 - 12.13	1.18 - 18.13	0.55 - 2.94
Mean		17.07	78.27	4.23	7.36	0.98

The more expansive clay a soil contains, the higher its swell potential and the more water it can absorb. As a result, these materials increase in volume when they get wet and shrink when dry. The effects of allowing soils with a high shrinking and swelling potential to become either too wet or too dry can be severe when they are supporting buildings and other man made structures. Damage to a structure is possible when as little as 3% volume expansion takes place. Failure results when the volume changes are unevenly distributed beneath the foundation (Jones, 2002).

Triaxial Test

The result of quick undrained triaxial compression test is contained in table 2. The cohesion (c) ranges from $9KN/m^2$ to $27.50KN/m^2$ while the angle of internal friction (Ø) varies from 15^0 to 35^0.

Consolidation Test

The compression index (Cc) was computed from the empirical formula 0.009 (LL - 10) and was found to be of the order of 0.11 to 0.74 with a mean value of 0.32 (table 2).

Table 2: Summary of results obtained from Atterberg limit test, triaxial test and empirical compression index, Cc.

Triaxial Pit No.	Depth range (m)	Atterberg Limit			Shrinkage Potential	Cc = 0.009 (LL - 10)	Triaxial Test	
		LL (%)	PL (%)	PI (%)			C (KN/m^2)	
1	0.5	52.00	50.06	1.94	Low	0.38		
	1.0	45.00	20.33	24.67	Medium	0.32	9	20^0
	1.5	25.00	9.11	15.89	Low	0.14		
2	0.5	62.00	26.33	35.67	Medium	0.47		
	1.0	52.00	28.14	23.86	Medium	0.38		
	1.5	92.00	22.02	69.98	High	0.74	15	35^0
3	0.5	70.00	40.13	29.87	Medium	0.54		
	1.0	50.00	18.62	31.38	Medium	0.36	26.5	12^0
	1.5	37.00	9.34	27.66	Medium	0.24		
4	0.5	39.00	20.33	18.67	Medium	0.26		
	1.0	31.00	12.53	18.47	Medium	0.19		
	1.5	30.00	20.00	10.00	Low	0.18	36	20^0
5	0.5	45.00	14.15	30.85	Medium	0.32		
	1.0	40.00	15.23	24.77	Medium	0.27	16	20^0
	1.5	48.00	8.03	39.97	Medium	0.34		
6	0.5	32.00	7.47	24.53	Medium	0.20		
	1.0	57.00	51.10	5.90	Low	0.42	12	15^0
	1.5	45.00	25.17	19.83	Medium	0.32		
7	0.5	37.50	16.17	21.33	Medium	0.25		
	1.0	31.00	22.47	8.53	Low	0.19	27.50	
	1.5	52.00	22.99	29.01	Medium	0.38		
8	0.5	40.00	10.92	29.08	Medium	0.27		
	1.0	43.00	19.17	23.83	Medium	0.30		
	1.5	57.00	30.87	26.13	Medium	0.42		
9	0.5	45.00	24.21	20.79	Medium	0.32		
	1.0	22.00	15.71	6.29	Low	0.11		
	1.5	47.00	29.43	17.57	Low	0.33		
Range		22.00 - 92.00	7.47 - 51.10	1.94 - 69.98	Low - High	0.11 - 0.74	9 - 27.50	15 - 35
Average		45.43	21.85	23.57		0.32	20.29	20.33

Table 3: Summaries the inferred clay minerals from the results of Atterberg Limits.

Trial Pit No.	Depth (m)	Inferred Clay Mineral
1	0.5	Halloysite
	1.0	Illite
	1.5	Montmorillonite
2	0.5	Illite
	1.0	Illite
	1.5	Montmorillonite
3	0.5	Kaolinite
	1.0	Montmorillonite
	1.5	Montmorillonite
4	0.5	Illite
	1.0	Montmorillonite
	1.5	Illite
5	0.5	Montmorillonite
	1.0	Montmorillonite
	1.5	Montmorillonite
6	0.5	Montmorillonite
	1.0	Halloysite
	1.5	Illite
7	0.5	Montmorillonite
	1.0	Illite
	1.5	Illite
8	0.5	Montmorillonite
	1.0	Montmorillonite
	1.5	Kaolinite
9	0.5	Illite
	1.0	Illite
	1.5	Kaolinite

Table 4: Statistical summary of clay mineral distribution

S/No.	Inferred clay mineral	Frequency	Percentage (%)	Angle (^{0})
1	Montmorillonite	12	44.44	160
2	Illite	10	37.04	133.33
3	Kaolinite	3	11.11	40
4	Halloysite	2	7.41	26.67
	Total	27	100.00	360

Table 5: Clay shrinkage potential

Plasticity Index (%)	Clay fraction (%)	Shrinkage potential
Greater than 35	Greater than 95	Very high
22 - 48	60 - 96	High
12 - 32	30 - 60	Medium
Less than 18	Less than 30	Low

Source of table 5: Curtin et. al. (1997).

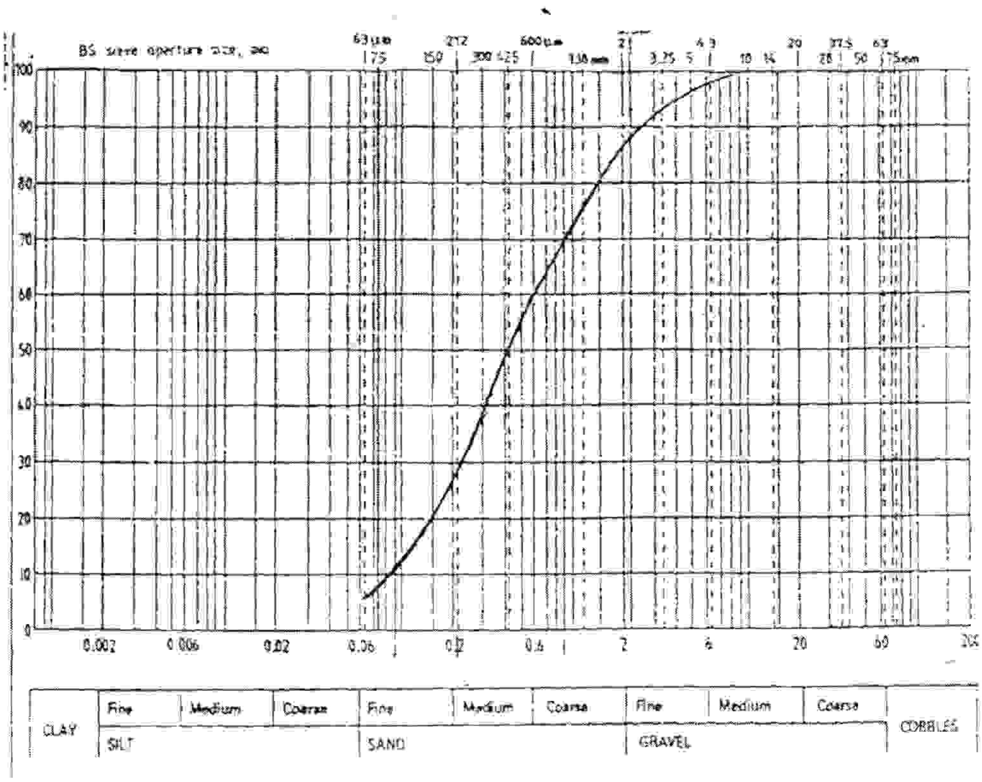


Fig. 5. A typical particle distribution curve from the study area

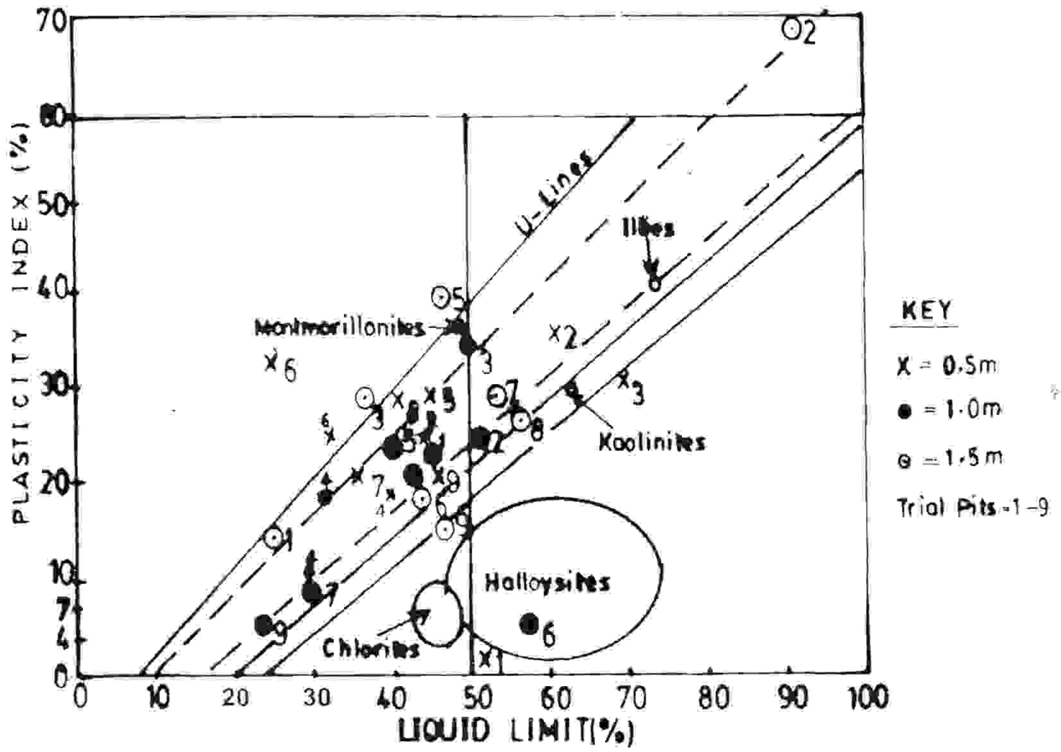
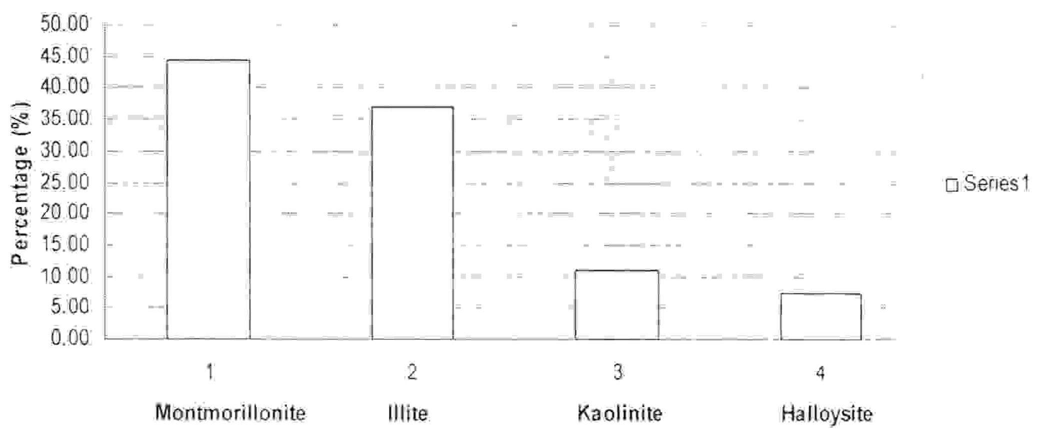


Fig. 6. Plot of Plasticity Index versus Liquid Limit for Chanchaga soil. (Modified after Holtz and Kovacs (1981) to show types of clay minerals.

Fig. 7 Bar-chart of percentage of inferred clay minerals.



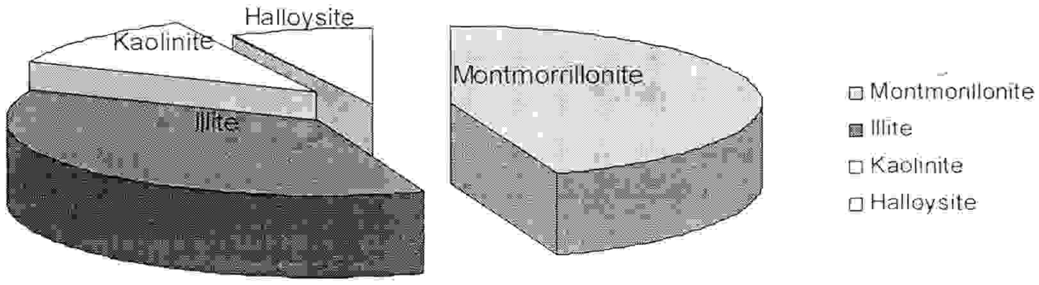


Fig. 8. Pie-chart of inferred clay minerals

Foundation Recommendation

The foundation analysis is based on the results obtained from the field investigation and laboratory tests using the regulations stipulated by British standard code of practice for foundation (1986).

Shallow (spread) Foundation

Shallow foundation can be considered for lightly loaded structures for example, bungalows. Generally, reinforced strip, pad or raft foundation can be adopted. Foundation can be placed between 1.0 m and 1.5 m below the existing ground level in study area within the brown, gravelly, clayey, silty, fine to medium sand.

As a guide in design, for foundation not exceeding 1.0 m in diameter (strip and pad), an allowable bearing pressure of 125 KN/m^2 should be utilized in foundation design with total settlement not exceeding 25mm and negligible differential settlement (Tomlinson, 1999). For foundation width greater than 1.0 m or of about 4.0 m, an allowable bearing pressure of 100 KN/m^2 should be adopted. The total settlement expected will not exceed 25 mm (Curtin, et al., 1997). The percentage of clay + silt in the soil samples analyzed ranges from 0.09 % to 12.13 %. The percentage of clay minerals identified as montmorillonite (expansive clay) was 44.44 %.

In order to prevent the adverse effect of shrinking and swelling clay which eventually will result to foundation failure which can manifest as cracks on the building walls and corners: 1. It is recommended that excavation volume (length, width and depth) should exceed 0.25 meters of the foundation area.

2. The soil removed during excavation should not be used for back filling. Fine to medium grained sand mixed with cement should be utilized. This will reduce water infiltration into the ground around the foundation. 3. Adoption of a pad foundation will make the structure to be flexible and reduce the soil swelling potential ((Jones, 2002).

Conclusion

The knowledge of the geotechnical characteristics of Chanchaga area, Minna as obtained from geological field work, excavation of trial pit and laboratory analysis of recovered soil samples have provided valuable data that can be used for designing and constructing shallow foundation of future civil engineering structures. It has also reveal the presence of montmorillonite and need to take precautionary measure during foundation construction in order to minimize its adverse effects.

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