GEOTECHNICAL PROPERTIES OF MAKURDI SHALE AND EFFECTS ON FOUNDATIONS

I. O. AGBEDE[A] and P. SMART[B]
[a]*Department of Civil Engineering*
University of Agriculture, Makurdi.
[b]*Department of Civil Engineering,*
The University of Glasgow, Glasgow.

ABSTRACT

A *study was undertaken to determine the geotechnical properties of Makurdi shale. Seven disturbed soil samples were collected from two sites in Makurdi and subjected to engineering classification tests and X-ray diffraction analysis. Results of the simple index tests suggest that the soils have medium to high swelling potential while X-ray diffraction analysis showed that the soils contain a high percentage of mixed-layer illite/smectite, high percentage of kaolinite and a small percentage of illite. The mineralogical analyses explained the expansive nature of the soil and suggest the causes of cracks in buildings. Ten disturbed soil samples were collected from a third site of a proposed site for a light building and subjected to engineering classification tests. Based on the outcome of the second set of experiments, a foundation other than the conventional strip footing was proposed and constructed. The performance of the foundation was observed for 5 cycles of rainy and dry seasons and found to be very satisfactory; as very few cracks were observed compared to light buildings founded on similar sites. It can be concluded that the proposed foundation appears to be suitable for light buildings on expansive clays and is therefore recommended as a solution to the problem of foundations on such soils.*

Keywords: Engineering properties, shale, X-ray, foundation.

1.0 INTRODUCTION

Makurdi town is the headquarters of Benue State in Nigeria. The town lies between latitudes 7^0 and 8^0N as well as longitudes 8^0 and 9^0E. It has a total area of 25 km^2 and an average relief of 120m. The vegetation is mainly savannah, with maximum and minimum temperature of 35^0C and 21°C respectively. The rainfall is both convention and tropical, it has a heavy form of high intensity between 508-1016mm during rainy season and 0-254mm in the dry season.

1.1 Geology of the Study Area

Figure 1 shows the stratigraphic setting of the Makurdi formation. It has been shown that the formation comprised three zones: the lower Makurdi sandstone; the upper Makurdi sandstone and the Wadata limestone [1]. The lower Makurdi sandstone, which could be found around the Makurdi Airport consists of sandstones and mudrocks. They are micaceous throughout with mudrocks predominating. The upper Makurdi sandstone is similar to the lower sandstone but with mudrocks being relatively less common. These are found in around the North Bank of Makurdi. Sandstones and shales outcrop prominently and the sandstone units range from very fine to medium in grain size. In this zone, there are shale units of mainly fissile siltstone, usually brownish grey in colour and often abundantly micaceous.

Wadata limestone also consists of several limestone occurrences, most outcrops are shelly limestone often closely associated with mudrocks which is the most extensive member of the Makurdi formation [1]. The sandstones in this zone are generally fine to .medium grained, moderately sorted, micaceous and feldspathic. In some parts, they are calcareous, micaceous and shelly. Various types of cement like iron oxides, silica, carbonates and clay were shown to be present in the Makurdi sandstone.

1.2 Reported cases

In a general sense, shale may be defined as highly consolidated clays, silts and sands or a mixture of all three fractions of soil derived from the weathering of rocks. These fractions of soil were deposited in sea or river bed in layers and subjected to high overburden pressures which led to consolidation and diagenesis [2]. This definition is adopted in this study.

Shale is frequently encountered in road cuts and other construction sites where economic and environmental considerations often recommend its use in the construction of embankments. But a number of failures have been reported involving settlement and shear failure of compacted shale embankments [3].

A problem soil is defined as a soil which is difficult to manage in construction. Shale has been classified as a problem soil [4]. Ola [5] carried out a study on some potential foundation problems in Sokoto associated with swelling clays and clay shale, and showed that Sokoto soft clay shale had a very critical potential volume.

Williams [6] reported a case of serious crack development in a barely 3-year old, 3-storey block of flats founded on shales in South Africa. Severe distortions in certain areas of the structure and cracks in the walls resulted in the tilting away from each other of the two wings of the blocks of flats. To salvage the structure, the surrounding soil was wetted through spray irrigation, which righted the structure sufficiently to allow renovation work.

The mineral content of shale influences its geotechnical properties. Underwood [7] stated that shale which has a clay fraction containing high percentages of illite and montmorillonite generally has lower strength, higher swelling potential and other undesirable properties than do shale with clay fractions consisting predominantly of kaolinite, chlorite or only low percentages of illite, montmorillonite, or other mixed-layer minerals. Ruwaih [8] classified the swelling soils in Saudi Arabia into four main types: montmorillonitic clay; hard gypsiferous clayey silt (shale); fissured clayey silt (shale); and calcareous clay of high salt content. The main part of the swelling in this soil was attributed to the excessive overconsolidation and the presence of traces of montmorillonite in soil; and also that part of the swelling was probably due to the hydration of the anhydrite (gypsum) content.

El-Sohby et al. [9] reported an investigation into the causes of structural damage, which occurred to many buildings founded on Mokatta shale in Egypt. The study revealed that the clay content in all the soil samples ranged from 40 to 55% and they contained more montmorillonite than kaolinite and illite, which showed a tendency to swell upon wetting

Uduji et al. [10] studied the mineralogy and geotechnical properties of soils derived from Awgu and Mamu formations in Awgu, Okigwe area of southeastern Nigeria; and identified the presence of smectite (most probably montmorillonite). The presence of this mineral, in addition to annual cycles of wet and dry seasons, were held responsible for the formation of cracks on the buildings and several potholes.

Chabrillat et al. [11] reported a high incidence of damage to roads, utilities and lightly loaded residential and commercial structures in Colorado where the claystone bedrock was identified as clay shales consisting predominantly of mixed layer illite/smectite with frequent thin bentonite beds. The soils were classified as having moderate to very high swelling potential.

The objective of this paper is therefore to study the geotechnical properties and mineralogy of Makurdi shale so as to explain the causes of cracks on buildings and suggest a possible foundation for light buildings on such shale.

2.0 MATERIALS AND METHODS

2.1 Sources of samples and sampling

Four disturbed samples were taken from depths ranging between 0.42 and 1.0m behind a classroom building at the Community Secondary School, Wadata in Makurdi as shown in Figure 2. Three disturbed samples were also taken from depths ranging between 0.5 and 1.Om at a residential building in the University of Agriculture, Makurdi as shown in Figure 3. Both buildings had suffered from severe cracking over the years. A total of ten disturbed samples were taken from the site of a proposed University Clinic while excavation for its construction had just commenced, as shown in Figure 4.

2.2 Index tests

Particle size distribution, specific gravity and Atterberg limit tests were determined in accordance with procedures in BS 1377 [12]. The free swell test was performed by slowly pouring 10 cm^3 of dry soil passing No 45 sieve (425 Dicron size) into a 100cm^3 graduated cylinder filled with water and noting the swollen volume of the soil after it came to rest at the bottom. The pH value for each soil sample was determined using as a pH meter, in a soil-water suspension of ratio 1:2.5 respectively.

2.3 X-ray diffraction analyses

X-ray diffraction analyses were made on 7 clay fraction specmens. X-ray diffraction was performed with a Phillips PW 1050/35, kW diffractometer using CoKα radiation and Fe filtration. Specimens were prepared on porous ceramic tiles using the standard routine method in Glasgow University. Specimens were examined in four different states: air-dried state, ethylene glycolated, heat treatments at 300^{0}C and 600°C. The minerals were identified by their characteristic basal spacing and also by comparing the diffraction traces to standard traces for minerals available in the Department of Geology and Applied Geology, University of Gragow. Due to the expensive nature of the X-ray diffraction tests, only soil samples from two sites could be analyzed fully. The proportions of the clays minerals present in the samples were evaluated using the method of Bullock and Loveland [13]. Expandables in the table include smectite and mixed-layer illite/smectite.

2.4 X-ray fluorescence analyses

X-ray fluorescence analyses were made on 7 clay fractions (<2mm) were obtained using sedimentation test. The concentrate was dried in the oven at 110^{O}C for 24 hours. 0.375g of oven- dry material was mixed in a platinum crucible with 2.0g of flux (SPECTROFLUX 105, containing: lithium carbonate, lithium tetraborate and lanthanum oxide). The crucible was then covered and placed in a furnace set at 1000^{O}C tor 15 minutes to free the sample of organic matter and water. Thereafter, it was removed from the furnace' and placed on a clean aluminium surface and allowed to cool. The soil-flux mixture was weighed and then melted on a blast burner. It was swirled (while holding the crucible with platinum-tipped crucible tongs) to ensure a uniform mix until the melt was at dull red heat. To form the disc the melt was carefully poured onto a platen placed on a hot plate maintained at 225^{0}C and located under a plunger assembly, then the plunger was lowered firmly onto the melt for a few seconds. The disc and the platen were then placed between two asbestos blocks and transferred unto a hot plate maintained at 200^{0}C; left to stand for 30 minutes: and then the platen and disc were allowed to cool still enclosed within the asbestos blocks. When cooled, the disc was carefully removed and labelled ready for analysis.

The discs were analyzed using a Philips PW 1450/20 automatic X-ray fluorescence spectrometer equipped with a 60-positon sample changer and on-line "Super Brain' microcomputer for data processing. The major elements (SiO_2, T_iO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, and P_2O_5) were analyzed from the fused glass discs using influence factor-, to correct for the remaining absorption-enhancement effect.

3.0 RESULTS AND DISCUSSION

3.1 Index tests results

Table 1 summarizes the result of simple index test on Makurdi soils. All the points plotted within the A-line and the U-line of the Casagrande plasticity chart, and are within a broad parallel band with a few of them closer to the U-line than the A-line Makurdi soil sample plot within the with the same band as Igumale soils [4] and can be classified as inorganic clays of medium to high plasticity.

According to the methods of vander Merwe [15] Makurdi soils have, on the average, have high swelling potential. Using the criteria presented by BRE [16], the soils have, on the average, high shrinkage potential. When the Atterberg limits were tested according to the classification of Ajayi [17] they can be classified as having high to very high plasticity. Using the classification of Ola [18] the soils can be referred to as having high to very high swelling potential, which could result in structural damage by differential heave of the foundation subsoils.

The free swell values for Makurdi roils are between 23 and 73%; which suggests that Makurdi soils have some capacity to swell and will probably cause problem for foundation and road construction purposes [19]. The pH of Makurdi soils ranged from 5.4 to 6.8, which suggests that Makurdi soils can be described as moderately to weakly acid [20].

3.2 X-ray diffraction test results

Table 3 summarizes X-ray diffraction analyses data on clay fraction of Makurdi soils. The X-rray diffraction patterns obtained for the clay fraction of Makurdi soils in its air-dried state, displayed a moderately intense, broad reflection at 10.92-14.46Ȧ, characteristic of illite/smectite mixed-layer clay [21] strong sharp reflections at 7.09-7.19Ȧ and 3.56-3.59Ȧ (characteristic of kaolinite), and a weak reflection at 3.35Ȧ (characteristic of quartz). The first and second basal reflections, shifted to about 11.80-16.55Ȧ and 7.09-7.19Ȧ respectively after ethylene glycol treatment, which suggests that the mixed layer clay mineral is expansive. After the samples were heated to 300°C for one hour and tested, they shifted to 9.97-12.83Ȧ and 7.09-7.19Ȧ respectively. When samples were heated to 600°C for one hour and tested, the reflection patterns collapsed to 9.93- 10.03A. The diffraction traces showed that the main minerals in the clay fraction are mixed-layer illite/smectite, kaolinite and quartz. Only traces of illite could be observed.

Table 4 summarizes the results of the semi- quantitative analyses of the clay minerals. The table showed that the clay fractions contained a high percentage of mixed-layer illite/smectite, high percentage of kaolinite and a small percentage of illite.

3.3 X-ray fluorescence test results

Table 5 summarizes the chemical compositions of the clay fraction of some Makurdi soil samples obtained from the X-ray fluorescence analysis. The test results showed that the soil consists mainly of silica, SiO_2, alumina, $A1_2O_3$ and iron oxide, Fe_2O_3. The total iron has been expressed in the form of ferric oxide (Fe_2O_3). The loss of ignition was not carried out due to the non- availability of sufficient samples.

3.4 Proposed foundation

Figure 5a shows the initial design of a concrete strip footing on which the clinic was to rest. The foundation was modified to suit the ground conditions as shown in Figure 5b. Instead of the1.0m deep footing, the foundation excavation was extended to a depth of 1.3m. This additional 30cm was backfilled with sand, which acted as a cushion. Since the settlement of sandy soil would be essentially immediate or elastic, the sand was provided to avoid large-scale or differential settlement and to protect the foundation against the heaving of the clay underneath. On top of the bed of sand, a 50mm concrete blinding was provided to receive a ground beam of 225 x 225mm, which tied all the columns together and thus minimized differential settlement. The 150mm hollow blockwall was later filled with concrete. The wall was backfilled with sand to avoid direct contact of the soil with the expansive soil. In addition, the courtyard and the perimeter of the building were paved with concrete to ensure that water was prevented from infiltrating the foundation.

This foundation was observed for five cycles of wetting and drying with excellent performance.

Cracking was observed to be minimal except in the open corridors in the courtyard where the lintels were not run continuously for the entire length of the wall. The other lintels over the windows and the doors were made continuous throughout the length and breadth of the building. Compared to similar structures in the neighbourhood, the performance of this foundation can be said to be excellent.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The main conclusions reached in this study are as follows:

1. Engineering classification showed that the soils have medium to very high swelling and shrinkage potential. This was supported by the free swell.
2. X-ray diffraction analysis showed that the soils contained a high percentage of mixed- layer illite/smectite, high percentage of kaolinite, a small percentage of illite and nonclay minerals.
3. The mineralogical analyses explained the highly expansive nature of the soil.
4. The proposed foundation stood the test of five cycles of wetting and drying and could therefore be recommended as a possible foundation for light buildings on Makurdi shale.

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Table 1: Results of index tests on Makurdi soil samples

Sample No	Depth (m)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	LL (%)	PL (%)	PI (%)	LS (%)	A	Spec. Gravity (G_s)
S1PS	0.5	68	12	12	8	33	17	16	16	2.0	-
S2PS	0.76	23	10	27	40	45	14	31	13	0.78	2.62
S3PS	1.0	34	7	40	19	67	19	48	18	2.52	2.62
S1CS	0.42	24	31	29	16	47	19	28	16	1.75	2.64
S2CS	0.5	71	11	9	9	51	24	27	18	3.00	2.63
S3CS	0.7	18	22	29	31	61	21	40	19	1.29	2.62
S4CS	1.0	2	25	24	49	52	21	31	15	0.63	-
S1	1.0	0	22	20	58	59	21	38	7	0.65	2.85
S2	1.0	0	8	14	78	65	21	44	9	0.56	2.91
S3	1.0	0	58	18	24	52	17	35	9	1.45	2.74
S4	1.0	0	10	14	76	51	18	33	6	0.43	2.69
S5	1.0	0	22	20	58	59	26	33	6	0.57	2.85
S6	1.0	0	74	16	10	53	24	29	9	2.90	2.67
S7	1.0	0	22	20	58	49	23	26	5	0.44	2.69
S8	1.0	0	56	18	26	54	19	35	5	1.34	2.74
S9	1.0	0	30	18	52	61	20	41	9	0.78	2.90
S10	1.0	0	8	14	78	61	19	42	6	0.53	2.85

Table 2: Free swell and pH values of Makurdi soil samples

Sample	Depth (m)	Free swell (%)	pH value
S1CS	0.42	48	5.6
S2CS	0.5	50	5.7
S3CS	0.7	60	5.8
S4CS	l.0	60	5.4
S1PS	0.5	35	6.8
S2PS	0.76	23	6.1

S3PS	1.0	65	5.6

Table 3: X-ray diffraction analysis data for Makurdi soil samples.

Sample	Untreated		Ethylene Glycol		Heated to 300 °C		Heated to 600 °C		Mineral Identified
	°2θ	d(Å)	°2θ	d(Å)	°2θ	d(Å)	°2θ	d(Å)	
S1PS	9.00 14.30 20.70 29.00 31.10	11.41 7.19 4.98 3.58 3.34	8.70 14.30	11.80 7.19	10.24 14.30	10.03 7.19	10.24	10.03	Illite/Smectite Kaolinite Quartz Kaolinite Quartz
S2PS	9.40 14.30 20.70 29.00 31.10	10.92 7.19 4.98 3.58 3.34	7.50 14.30	13.69 7.19	10.24 14.30	10.03 7.19	10.24	10.03	Illite/Smectite Kaolinite Quartz Kaolinite Quartz
S3PS	7.10 14.30 20.70 29.00 31.10	14.46 7.19 4.98 3.58 3.34	7.60 14.30	13.51 7.19	10.30 14.30	9.97 7.19	10.34	9.93	Illite/Smectite Kaolinite Quartz Kaolinite Quartz
S1CS	8.40 14.30 24.30 29.10 31.10	12.22 7.19 4.25 3.56 3.34	7.40 14.40	13.87 7.14	10.30 14.40	9.97 7.14	10.30	9.97	Illite/Smectite Kaolinite Quartz Kaolinite Quartz
S2CS	8.50 14.40 24.30 29.10 31.10	12.08 7.14 4.25 3.56 3.34	6.40 14.50	16.04 7.09	8.00 14.50	12.83 7.09	10.50	9.78	Illite/Smectite Kaolinite Quartz Kaolinite Quartz
S3CS	7.10 14.30 20.60 28.90 31.10	14.46 7.19 5.01 3.59 3.34	6.60 14.40	15.55 7.14	10.10 14.40	10.17 7.14	10.40	9.87	Illite/Smectite Kaolinite Quartz Kaolinite Quartz
S4CS	7.10 14.30 20.60 29.00 31.10	14.46 7.19 5.01 3.58 3.34	6.20 14.30	16.55 7.19	9.80 14.30	10.48 7.19	10.40	9.87	Illite/Smectite Kaolinite Quartz Kaolinite Quartz

Table 4: Mineralogical composition of Makurdi soils (< 2μm)

Sample	Depth(m)	Kaolinite(%)	Illite(%)	Expandables
S1CS	0.42	56.1	8.9	34.9
S2CS	0.5	56.0	7.0	37.0
S3CS	0.7	52.2	4.3	43.4
S1PS	0.5	48.1	18.0	33.9
S2PS	0.76	47.0	9.9	43.0
S3PS	l.0	47.1	15.2 ,	37.8

Table 5: Chemical composition of clay fraction (<2μ*m)* of Makurdi soil samples

Sample	$SiO\text{-}_2$	AI_20_3	$Fe_2O^1_3$	TiO_2	MnO	M_gO	CaO	Na_2O	K_2O	P_2O_5	Total
S1PS	49.59	26.50	8.52	1.90	0.07	0.80	0.33	2.31	2.04	0.67	92.73
S2PS	49.02	25.24	8.37	1.98	0.03	1.16	0.26	2.57	1.85	0.50	90.98
S3PS	47.55	25.02	9.12	1.87	0.04	1.71	0.36	2.59	1.96	0.38	90.60
S1CS	47.32	27.97	9.21	1.90	0.08	1.22	0.36	2.75	1.21	0.91	92.93
S2CS	43.69	27.46	10.30	1.33	0.07	1.22	0.77	2.67	1.25	0.30	89.06
S3CS	49.53	29.08	*9.12*	1.24	0.03	1.38	0.79	3.04	1.38	0.26	95.85
S4CS	47.39	24.89	10.04	1.22	0.02	1.29	0.93	2.42	1.29	0.14	88.69

[1]Total Fe as Fe_2O_3

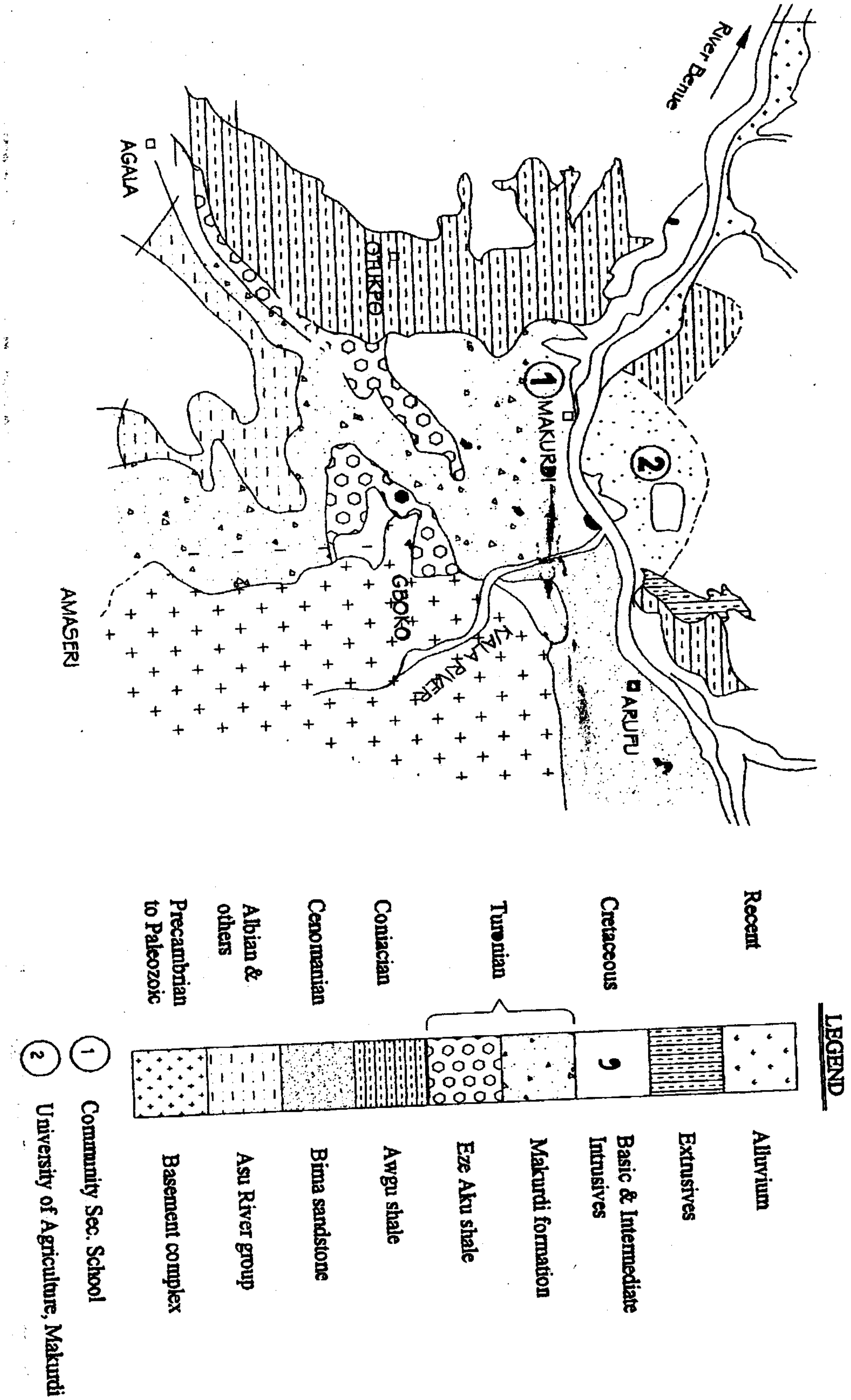

Fig. 1: Stratigraphic setting of the Makurdi formation After Nwajide [1]

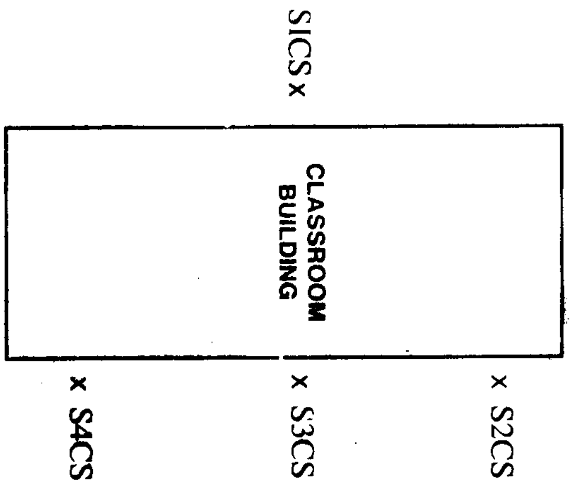

Fig. 2: Sampling layout at Community Secondary School, **Wadata - Makurdi.**

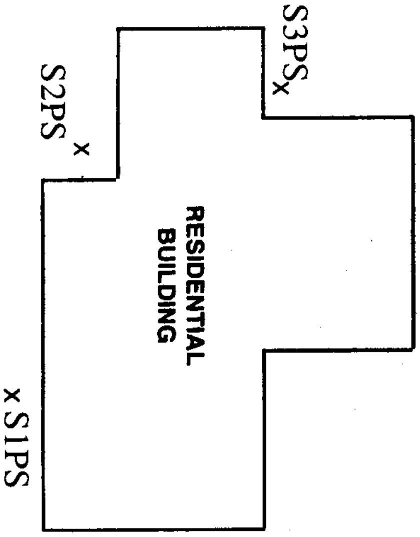

Fig. 3: Sampling layout at residental building of the university of Agriculture, Makurdi.

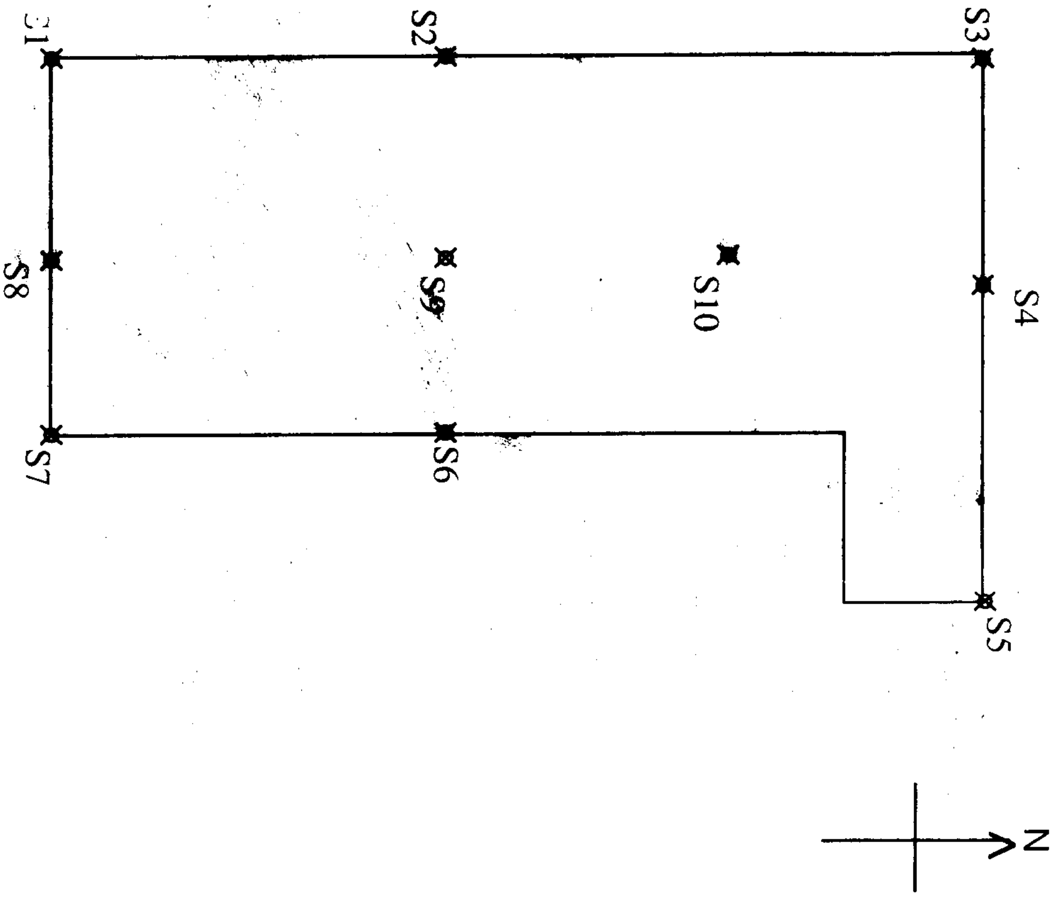

Fig. 4: Sampling layout at the University of Agriculture Clinic, **Makurdi.**

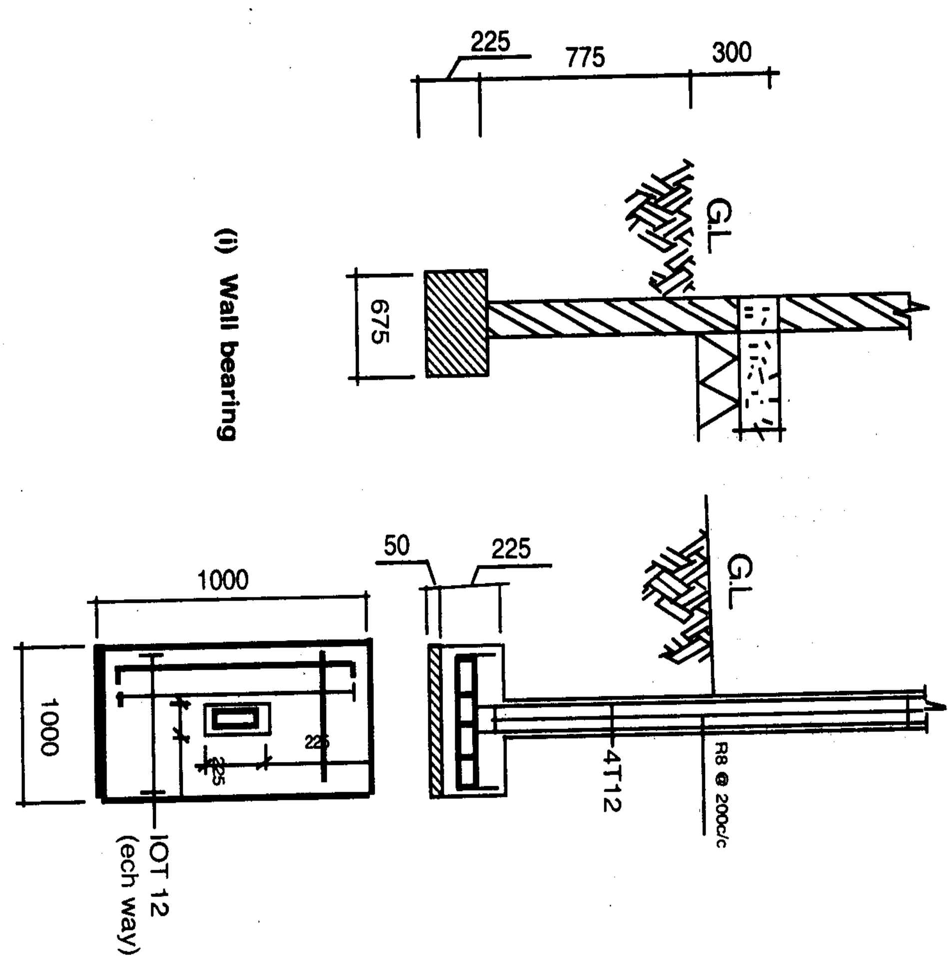

Fig.. 5a: Initial foundation for wall and column

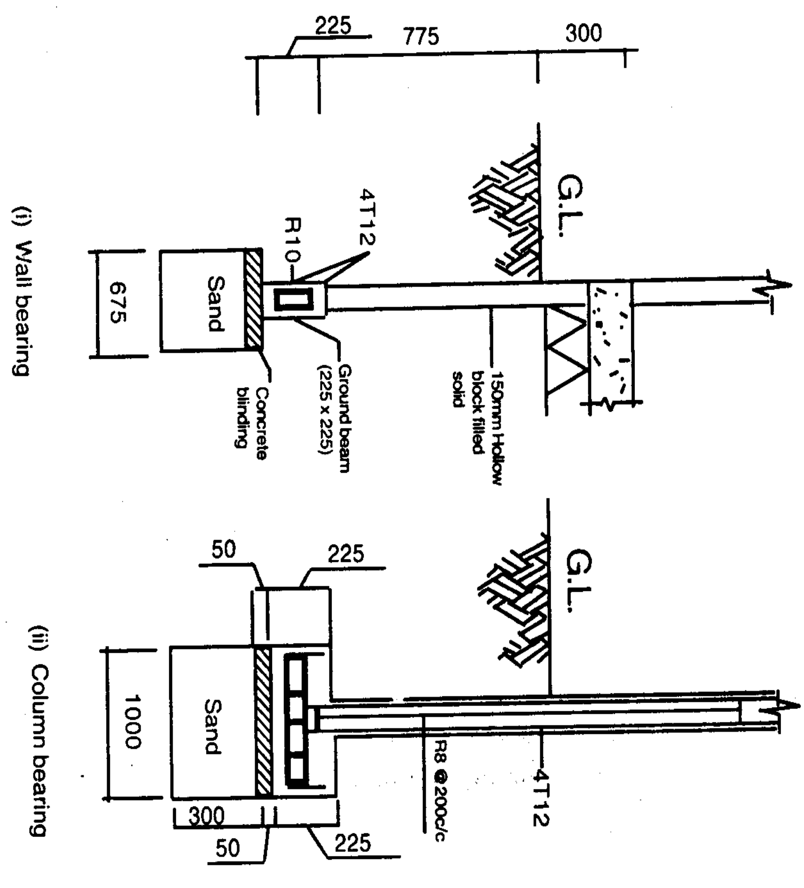

Fig.5b: Modified foundation for wall and column.