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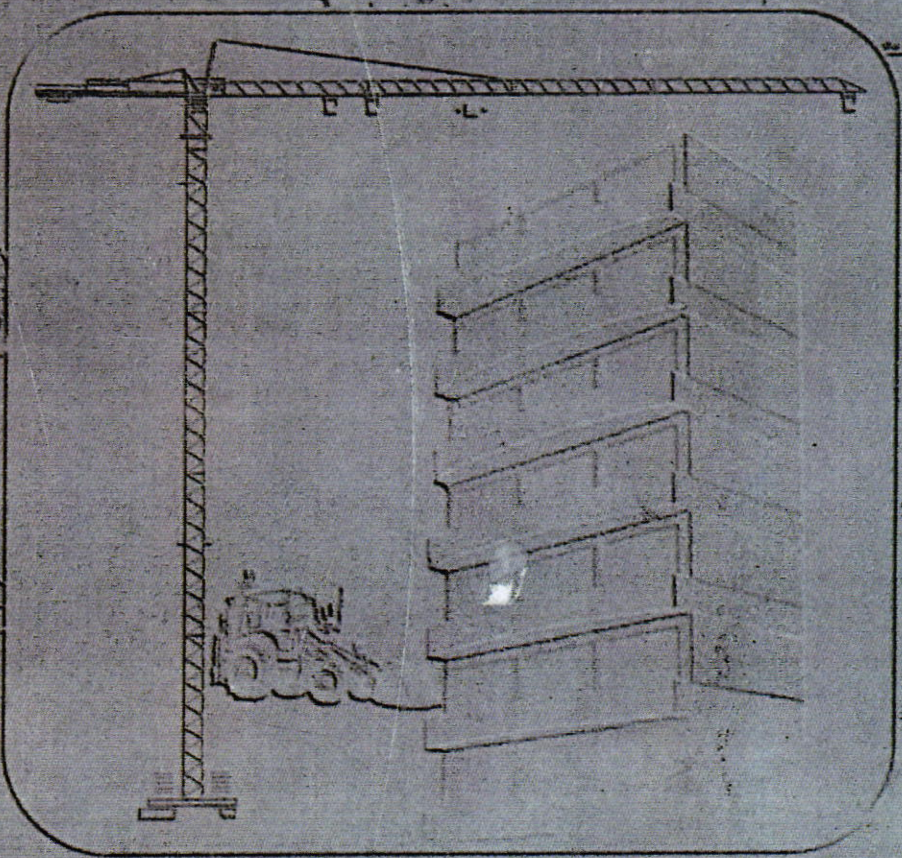

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RESULTS OF SUBSOIL INVESTIGATION ON A COLLAPSED BUILDING SITE IN LAGOS, NIGERIA

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ABSTRACT: *Geotechnical properties of the subsoil of a collapsed building site at Ebute-Metta, Lagos were evaluated by drilling a borehole from the ground level to a depth of 25.50 m. The subsoil is heterogeneous vertically. The liquid limits vary from 27.0% to 28.5%. The plastic limits are of the order of 15.0% to 21.0%. The plasticity index ranges from 6.0% to 13.5%. The shrinkage potential is low to medium. The means of the empirical compression index, moisture content and bulk density are 0.16%, 17.62% and 1.92 kg/m^3 respectively. The coefficient of volume compressibility varies from 0.104 m^2/MN to 0.156 m^2/MN. The coefficient of consolidation ranges from 2.72 m^2/yr to 58.40 m^2/yr. The existence of stiff, silty clay layer from the surface to 10.50 m depth, presence of compressible refuse materials at foundation level, unfavourable geotechnical properties and adoption of shallow foundation contributed to the collapse of the building.*
KEYWORDS Collapsed building, geotechnical properties, foundation, site, disturbed and undisturbed samples

INTRODUCTION

On July 26, 2006, a four storey residential building under occupation covering 420m^2 collapsed into a pile of rubble at No. 56 Bola Street, Ebute-Metta, Lagos (fig. 1). It was reported that forty five people died as a result of the collapse (Guardian newspaper, 2006). This particular collapse is one out of several collapsed buildings in the country with attendant loss of human lives. The most recent is another four storey building under construction in Utako district, Abuja (Daily Trust, 2008). The recurring incidences of building collapse in Nigeria and public outcry led to the formulation of the National Building code in 2006. The Federal government of Nigeria formally launched the new national building code on Friday January 26, 2007 (Abalaka, 2007). Unfortunately however, its implementation and enforcement has been slow in catching with fast pace of property developments taking place in the country (Abalaka, 2007).

Subsoil investigation is a systematic evaluation of the geotechnical characteristics (particle size, plasticity, shear strength and compressibility) of subsurface materials (for example soil) in order to obtain information required to design and construct the foundation of civil engineering facilities. Sub soil investigation is normally undertaken prior to the construction of new structures.

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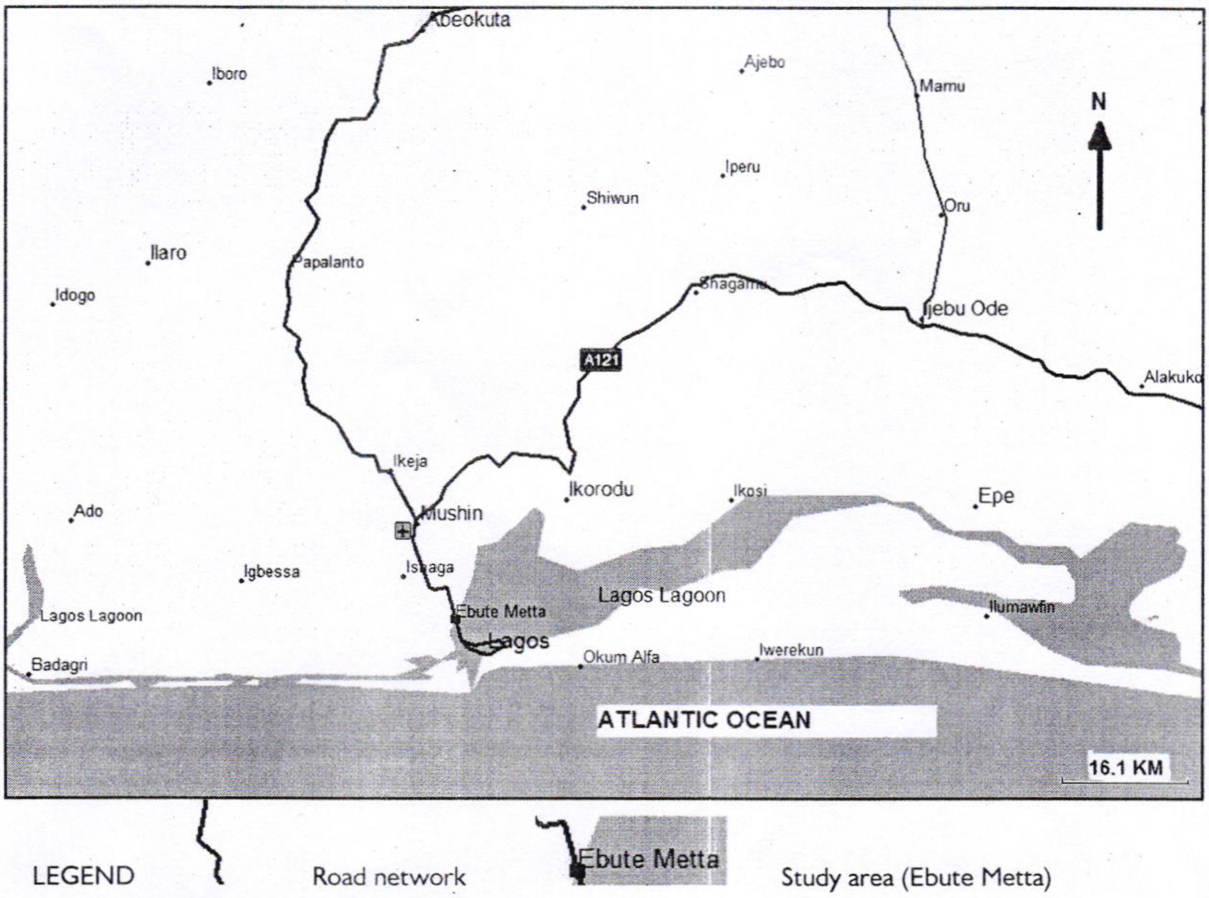

Fig. 1 Location map of the study area (Ebute Metta, Lagos)

It can also be carried out on an existing structure. A collapsed building is a house that falls down suddenly generally as a result of damage, structural weakness or lack of support.

Building collapse can be attributed to a number of factors namely; under-design, poor quality of construction materials, unsuitable subsoil, use of wrong or untested construction techniques and methods and the use of quacks. Building collapse could also be caused by natural factors such as, erosion, landslide, earthquake, volcanic eruption, flooding, tsunami, subsidence, faults, folding, poor drainage system, unfavourable soil geochemistry and groundwater conditions.

This work focused on evaluating the geotechnical properties of the subsoil of a collapsed building site in Ebute-Metta, Lagos. The aim was to determine if the subsoil characteristics contributed to the collapse of the building and recommend necessary procedures to prevent recurrence for any building that may be constructed on the same site in the future.

STUDY AREA DESCRIPTION

The study area is located in Ebute-Metta, Lagos state within the mainland part of Lagos metropolis (fig. 1). The collapsed building was situated at No 71a Ibadan Street, Ebute-Metta. It is located precisely at latitude 6°29.212'N and longitude 3°23.165'E with an elevation of 11m above sea level and an area extent of 12m by 35m ($420m^2$). The area investigated is accessible through Murtala Muhammed way, Yaba, Oyingbo and 3rd Mainland Bridge.

Regional Geology of the Area

The study area is situated within Dahomey Basin which is an extensive sedimentary basin on the continental margin of the Gulf of Guinea (Fig.2). It runs parallel to the coastal margins of Ghana, Togo, Benin Republic and Southwestern Nigeria. The Dahomey Basin is separated from the Niger Delta basin by the Benin hinge line and the Okitipupa ridge (Adegoke, 1969, Bankole et al., 2006). The basin is a marginal pull-part (Klemme, 1975) or marginal sag basin (Kingston et al., 1983) which developed in the Mesozoic era when the African and South American plates separated and the continental margin was founded (Burke et al., 1971, Whiteman, 1982). The Benin hinge line is a part of the chain oceanic fractures while the Okitipupa ridge is a submarine basement ridge (Adegoke, 1969).

The stratigraphy of Dahomey basin is summarized in Table 1 (modified after Jones and Hockey, 1964; Adegoke and Omatsola, 1981).

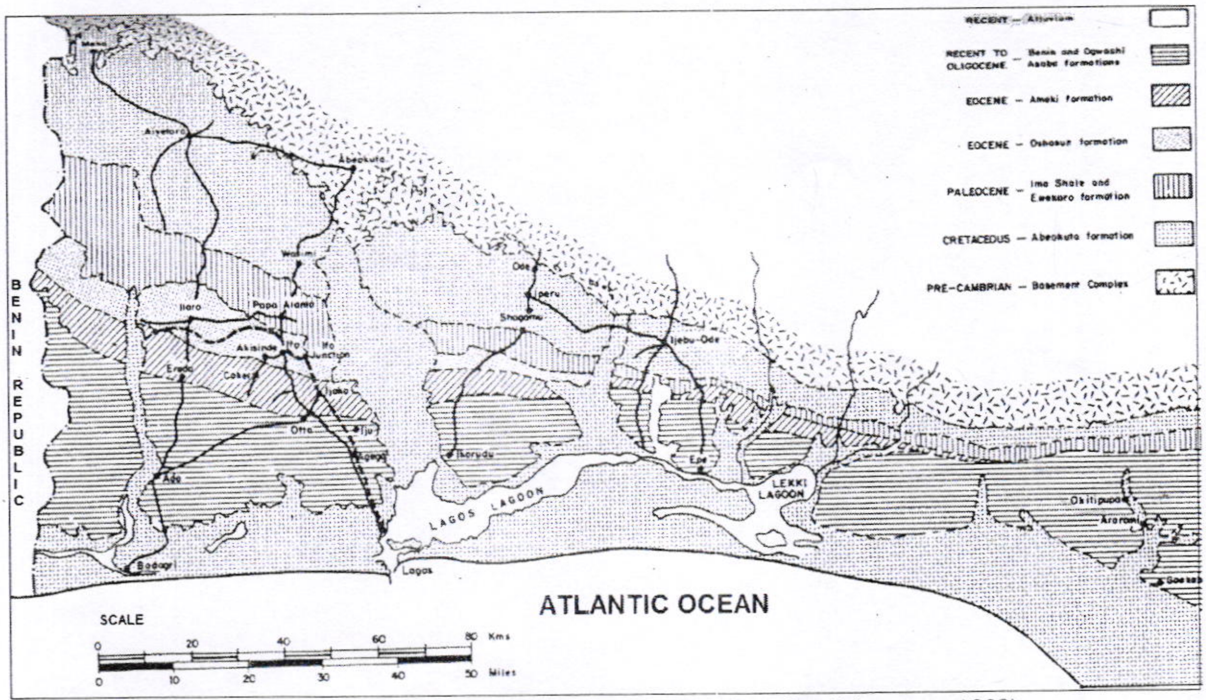

Fig. 2. Geological map of Dahomey Basin (Modified after Whiteman, 1982)

Table 1: Stratigraphic sequence of Dahomey Basin

Age	Jones and Hockey (1964)	Adegoke and Omatsola (1981)
Recent	Alluvial, Lithoral, Lagoonal Deposit.	
Miocene – Oligocene	Coastal Plain Sand	Coastal Plain Sand
Upper Eocene – Oligocene	Ilaro Formation	Ilaro Formation
Lower Eocene - Middle Eocene	Oshosun Formation	Oshosun Formation
Lower Eocene - Upper Paleocene	Akinbo Formation	Akinbo Formation
Paleocene	Ewekoro Formation	Ewekoro Formation
Maastrichtian	Araromi Formation	Araromi Formation
Turonian	Afowo Formation	Afowo Formation
Neocomian – Albian	Ise Formation	Ise Formation
Precambrian	Basement Complex	Basement Complex

METHODOLOGY OF INVESTIGATION

The soil strata were investigated by using a percussion drilling rig with shell and auger tool to bore to 25.50 m below existing ground level according to British standard code of practice for site investigation BS 5930 (1981). Standard penetration tests were carried out in situ on the non cohesive strata to determine penetration resistance in the silty/sandy material. Disturbed and undisturbed soil samples were collected from the boreholes and taken to the laboratory for relevant geotechnical analysis according to British Standard methods of test for soils for civil engineering purposes (British Standard Institution, BS 1377, 1990). The essence of undertaking the tests is to ascertain if the geotechnical properties of the soil contributed to the collapse of the building. Dry sieve analysis was carried out in order to obtain the particle size distribution of the soil samples and was performed with a set of sieve sizes: (19.00 mm, 9.50 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 μm, 425 μm, 300 μm, 150 μm, 75 μm) and mechanical sieve shaker. Liquid limit was carried out with a liquid limit device (Casagrande cup). 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 plastic with sufficient pressure to reduce the diameter into 3 mm. At exactly 3 mm, the paste starts to crumble and cannot roll further. The process was repeated until longitudinal and transverse cracks appear at a rolled diameter of 3 mm. When this process occurs an average moisture content of the cracked threads was then determined. Consolidation tests were performed on some selected undisturbed samples using the Oedometer to determine the compressibility parameters of the materials.

Results of Boring Operation

The records of standard penetration test (SPT), disturbed and undisturbed samples collected during boring are contained in table 2. The summary of the subsoil conditions from the borehole is presented in table 3. Table 4 was used to infer the consistency of granular and cohesive soils with the use of their standard penetration test N values. The granular soil varies from medium dense to dense. The cohesive soil is generally stiff. Table 5 was utilized in inferring the relationship between 'N' values and sand properties.

Table 2: Sample number, Depth and SPT "N" values of the different soils Encountered during boring.

Sample number		Depth (m)	SPT "N" Count
Disturbed	Undisturbed		
1		0.15	
2		0.75	
	3	1.50	23
4		2.25	
	5	3.00	28
6		3.75	
	7	4.50	36
8		5.25	
	9	6.00	29
10		6.75	
	11	7.50	30
12		8.25	
	13	9.00	31
14		9.75	
	15	10.50	40
16		11.25	
	17	12.00	26
18		12.75	
	19	13.50	32
20		14.25	
	21	15.00	34
22		15.75	
	23	16.50	36
24		17.25	
	25	18.00	37
26		18.75	
	27	19.50	36
28		20.00	
	29	21.00	
30		21.75	
	31	22.50	
32		23.25	
	33	24.00	
34		24.75	
	35	25.50	

Table 3: Summary of subsoil condition from the borehole

Layer (m)	Layer Thickness (m)	Range of SPT blow N value	Unified soil Classification Scheme (USCS)	Soil Description
0 to 10.50	10.50	23 to 49	CL	Reddish brown, lateritic stiff silty CLAY.
10.50 to 12.00	1.50	26.49	SC	Brown, gravelly, clayed dense SAND
12.00 to 15.00	3.00	26 to 34	SC/SM	Yellowish brown, gravelly, silty, clayey, medium dense SAND
15.00 to 25.50	9.50	34 to 37	SM	Yellowish brown, silty, gravelly, dense SAND

Table 4: Consistency of granular and cohesive soils in terms of 'N' values.

Soil type	Consistency	'N' Value
Granular soils	Very loose	0-4
	Loose	4-10
	Medium dense	10-30
	Dense	30-50
	Very dense	>50
Cohesive soils	Very soft	0-4
	Soft	4-6
	Medium	6-15
	Stiff	16-25
	Hard	>25

(Source: Curtin, et al., 1997)

Table 5: Relationship between 'N' values and sand properties.

	Very loose	Loose	Medium dense	Dense	Very dense
SPT N value (blow/0.3m)	<4	4-10	10-30	30-50	>50
CPT cone resistance (N/mm^2)	<5	5-10	10-15	15-20	>20
Equiv. relative density (%)	<15	15-35	35-65	65-85	85-100
Dry unit weight (kg/m^3)	<14	1.4-1.6	1.6-1.8	1.8-2.0	>2.0
Friction angle (degrees)	<30	30-32	32-35	35-38	>38
Cyclic stress ratio causing liquefaction	<0.04	0.04-0.10	0.10-0.35	>0.35	-

(Source: Curtin et al., 1997)

LABORATORY RESULTS

Sieve analysis

The results of sieve analysis are summarized in table 6. A typical particle size distribution curve obtained from the area investigated is illustrated in fig 3. Two groups of soils were identified from all the particle size distribution curves. The first type is sand > clay > silt > gravel. The second type is sand > gravel > silt > clay. Table 7 summarizes the drainage characteristics of the different soil particle sizes.

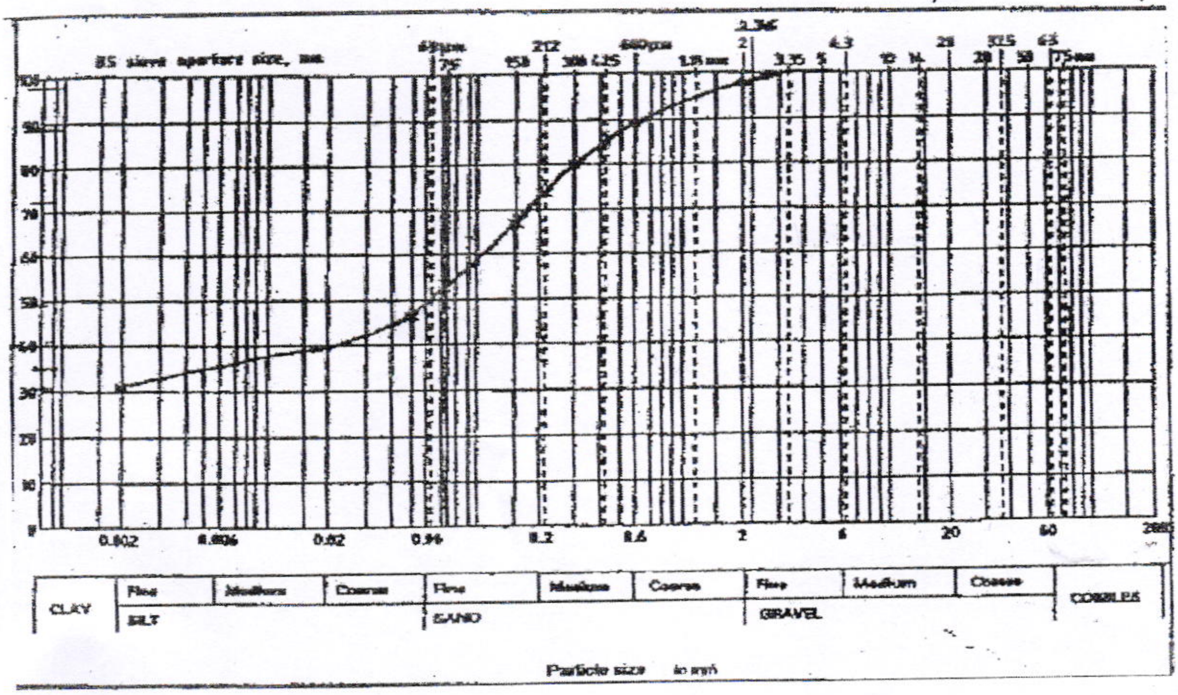

Fig.3. Particle size distribution curve of the study location

Table 6: Summary of Result obtained from sieve analysis.

Sample Number	Depth (m)	% of clay Clay	% of silt Fine	Medium	Coarse	% of sand Fine	Medium	coarse	% of gravel Fine	Medium	Coarse
15	10.50	32	3	5	8	24	16	10	2	0	0
			total = 16			total = 50			total = 2		
17	12.00	20	3	5	8	23	26	11	4	0	0
			total = 16			total = 60			total = 4		
21	15.00	0	0	0	10	24	42	6	7	9	2
			total = 10			total = 72			total = 18		
Range		0 - 32	0 - 3	0 - 5	8 - 10	23 - 24	16 - 42	6 - 11	2 - 7	0 - 9	0 - 2

Table 7. Soil Description and particle sizes. (Source: Weltman and Head, 1983).

Grain size (mm)	200	60	20	6	2	0.6	0.2	0.06	0.02	0.006	0.002	
Basic Soil Type	Boulder	Cobble	Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine	CLAY
			GRAVEL			SAND			SILT			
	VERY COARSE SOIL				COARSE SOIL					FINE SOIL		
Drainage Property	High Permeability generally k > 10^{-5}m/s (fine sand) Maximum can approach 1 m/s								Low permeability Poor drainage 10^{-8}m/s<k<10^{-5}m/s			Practically Impervious K<10^{-8} m/s

Atterberg limit

The results of the Atterberg limits are presented in Table 8. The mean values of the liquid limit, plastic limit, and plasticity index are 27.8%, 18.00% and 9.75%, respectively. The liquid limit ranges from 27.00% to 28.50%, the plastic limit from 15.00% to 21.00% while the plasticity index ranges from 6.00% to 13. 50%. The plasticity is generally low (<35%). However the samples retrieved below 14.0m were non-plastic. A plot of plasticity index (PI) against liquid limit (LL) is shown in fig 4. Table 9 was used to ascertain the shrinkage potential which ranges from low to medium. The effect of allowing soils with high shrinking and swelling potential to become either too wet or too dry can be catastrophic especially when they are supporting buildings and other man-made structures.

Table 8: Atterberg Limits, empirical compression index, moisture content, bulk density, coefficient of compressibility and consolidation test results.

Sample No.	Depth (m)	Atterberg Limit			Shrinkage Potential	Empirical Compression Index Cc=0.009(LL-10) (%)	Moisture Content (%)	Bulk Density kg/m³	Oedometer Consolidation		
		LL (%)	PL (%)	PI (%)					Coefficient of volume Compressibility, M_v (m^2/MN)	Stress Range (KN/m²)	Coefficient of Consolidation, C_v (m^2/yr)
3	1.50	28.5	15.0	13.5	medium	0.17	14.38	1.70			
4	2.25										
7	4.50						16.40				
9	6.00						18.20				
11	7.50	27.0	21.0	6.0	Low	0.15	21.50	2.14	0.140	0-28	38.30
									0.156	28-56	58.40
									0.104	56-112	2.72
									0.125	112-224	11.84
									0.108	224-336.5	3.25
20	14.25	Non plastic									
Range		27.0 - 28.5	15.0 - 21.0	6.0 - 13.5	Low - Medium	0.15 - 0.17	14.38 - 21.50	1.7 - 2.14	0.104 - 0.156	0.0 - 336.5	2.72 - 58.40
Mean		27.8	18.0	9.75		0.16	17.62	1.92	0.1266		22.90

Table 9: Clay Shrinkage Potential

Plasticity index (%)	Clay fraction (%)	shrinkage potential
Greater than 95	greater than 95	very high
22-48	60-96	High
12-32	30-60	Medium
less than 18	less than 30	Low

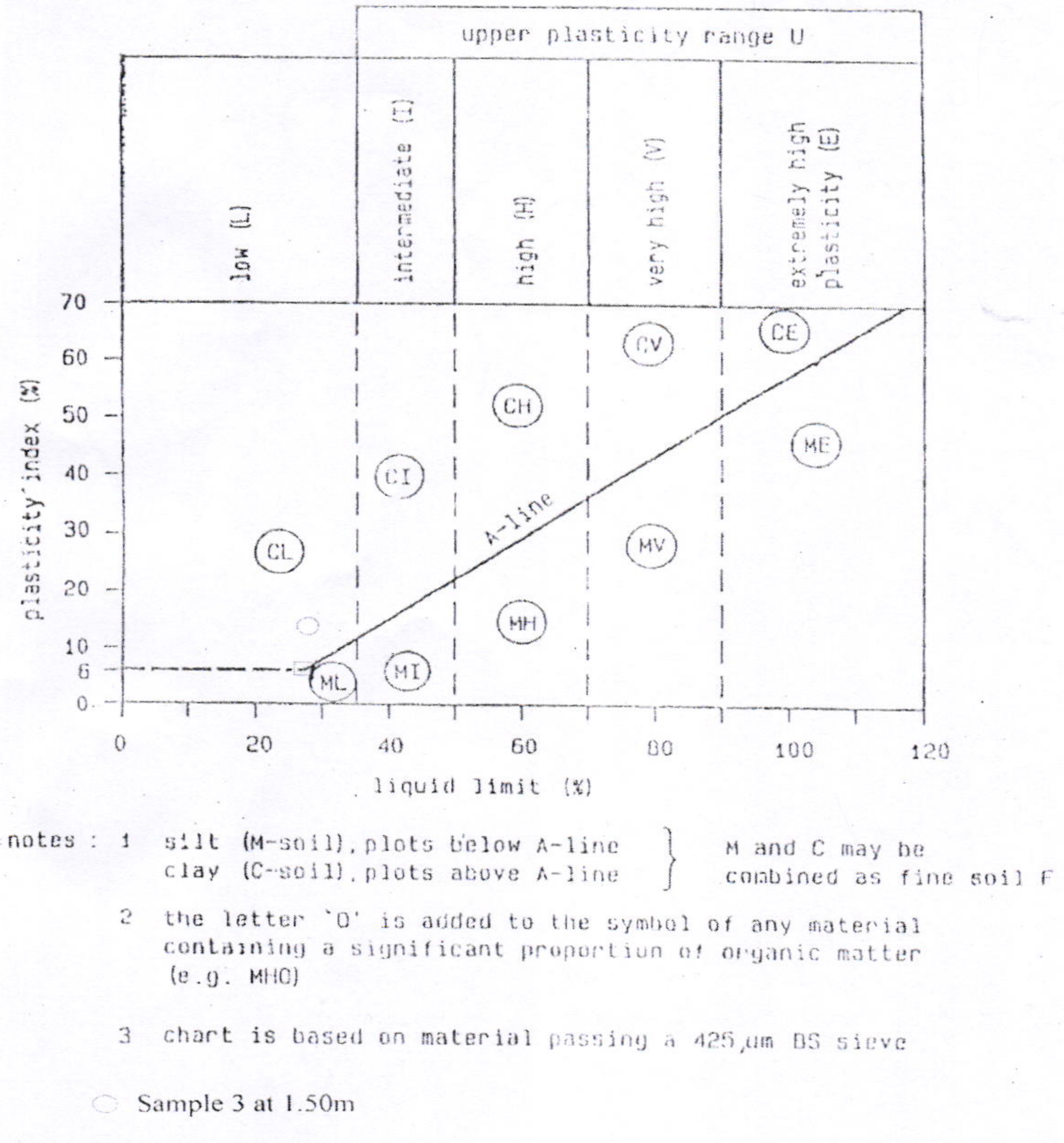

Fig. 4. Plot of plasticity index (%) versus liquid limit (%)

Consolidation Test

The compression index (Cc) was computed from the empirical formula 0.009(LL-10) and it ranges from 0.15 % to 0.17 % with a mean value of 0.16 %. The coefficient of volume compressibility (M_v) varies from 0.104 m^2/MN to 0.156 m^2/MN with a mean value of 0.1266 m^2/MN and is of medium compressibility (Weltman and Head, 1983). The mean of the coefficient of consolidation (M_v), is 22.90 m^2/yr and ranges from 2.72 m^2/MN to 58.40 m^2/MN (Table 8).

The bulk density of the subsoil varies from 1.70 kg/m^3 to 2.14 kg/m^3 with a mean value of 1.92 kg/m^3. The moisture content ranges from

14.38% to 21.50% with an average value of 17.62% (Table 8).

FIELD OBSERVATION AND DISCUSSION

The ground floor of the collapsed building was made up of several shops while the remaining three floors served as residential apartments. Further investigation revealed that the site was used previously as a refuse dump. The ground was hollow, before being turned to a refuse dump where wood, nylon, plastic and other types of waste materials were deposited. The excavation carried out revealed that the fill materials were composed of different types of materials including plastic, nylon, poorly sorted sand, clay, wood, and silt. These non-degradable and highly compressible materials account for the wide range of coefficient of consolidation observed at the site. The extensive ranging values will lead to differential settlement of column bases of a redundant structural frame of the type used for the four storey building at Ebute-Metta. A column base in a 4.5m frame span with a differential settlement of 25mm would develop bending moment of 80kNm at the ends of beams framing into it at the first floor level. Redistribution of this moment will take place in the frame, but if yielding of any cross section starts, additional secondary stresses that could then start a chain reaction will be induced in the structure which will eventually lead to collapse. The extent of collapse would depend on the quality of construction and available alternate load paths. Where good quality construction is lacking a pile of rubble would result. This phenomenon known as progressive collapse has been observed in structural collapse of buildings (Shankar, 2006). With reinforced concrete having density of 24 KN/m^3, concrete structures have high dead loads compared to live loads particularly for a residential building and the onset of differential settlement on a column base of a redundant structural frame can lead to total collapse of building under dead loads. Structural frames are sensitive to differential settlements; therefore the higher the degree of redundancy of a structural frame, the bigger the danger of a differential settlement of a column base to the whole structure.

RECOMMENDATION

With occurrence of silty-clayey materials to about 10.50m from ground surface and compressible waste materials at 3.5m at the building site investigated, the use of conventional near surface foundations such as strips, continuous strips and isolated footing would be likely causes of structural failure. The type of soil at the building site could readily produce differential settlements that are dangerous to structural frames that inevitable results from isolated pad footings. The slab and beam type of raft foundation or mat foundation for the building would have been a better alternative to shallow foundation. For high loading conditions, the use of pile foundation could be considered. Steel driven, cast-in place or bored piles may be founded on this site within the medium dense and dense sand deposit occurring from 10.50m to 25.50m depth. Alternatively, the bearing capacity of the soil could be enhanced to eliminate differential settlement by high pressure jet grouting.

CONCLUSION

The geotechnical characteristics of the subsoil of the collapse building site evaluated from field observation, and laboratory analysis of soil samples recovered have revealed the factors that contributed to the failure of the four storey building structure at Ebute-Metta on July 26, 2006. Two unfavourable soil conditions identified are: the existence of reddish brown, lateritic, stiff, silty clay of 10.50m thickness on which a shallow foundation was founded and the presence of highly compressible materials like wood, plastic, and nylon at the foundation level. The choice of a strip foundation for this soil contributed to the collapse of the building. The prior knowledge of these unfavourable conditions based on pre construction geotechnical survey and selection of a more suitable foundation type could have prevented the collapse of the building.

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