GEOFORENSIC ANALYSIS OF RECENT BUILDING COLLAPSE IN PORTHARCOURT, NIGERIA

By

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1.0 ABSTRACT:

Only recently, PortHarcourt witnessed four incidences of building collapse within a span of two months. The paper uses observation, field and laboratory testing and deductions to figure out the cause of the collapse. In order to explain the role of the foundation, a back-analysis of the load bearing capabilities of the sub-soil was carried out at the collapsed building sites using results of boring and cone penetration tests (CPT). This analysis indicated the allowable bearing pressures for Abacha Road, Tombia Street and Tourist beach sites as'80kPa, 50kPa and 30kPa respectively. In comparison with the loadings of the failed structures, these values of allowable bearing pressure were considered unsatisfactory with operational factors of safety less than 1 and significantly high values of consolidation settlement. On the contrary, the site at the old GRA with an allowable bearing pressure of 150kPa could not be explained by the incompetence of the foundation. This failure was probably caused by structural defects. Based on the spatial distribution of collapsed buildings and experience of soil variability in PortHarcourt metropolis, the area within the flood plain of the Ntawoba creek (from Abacha Road to Amadi Creek) and the reclaimed mangrove swamp can be designated as marginal lands, requiring ground improvement prior to foundation construction.

2.0 INTRODUCTION

The coastal city of PortHarourt (Figure 1) witnessed four (4No.) incidences of building collapse between August and September 2005. The collapsed buildings, which were at different stages of construction are located at Abacha Road, Tombia Street, Old GRA and at Tourist beach in a reclaimed mangrove swamp. The high levels of casualty caused by the collapse triggered widespread public outcry and condemnation of practioneers in the building sector for not enforcing pertinent standards. The reasons for the building collapse were ascribed to inadequate foundations, structural defects, inferior construction aggregates, poor workmanship, absence of any form of Quality assurance and quality control QA/QC, non conformance to building codes and standards among several others. Among these, the combination of inadequate foundation and poor sub-soil conditions were the most recurrent.

In order to assess the possible contribution of sub-soil conditions, geotechnical investigations were carried out in the areas surrounding the collapsed structures. The investigations involved the drilling of a borehole to 20m and CPT sounding at each of the collapsed building site. This investigation determined the litho-stratigraphy of the superficial deposit underlying the site to a depth of 20m as well as relevant engineering properties of the deposits. Using this information in combination with field observation, a back analysis was carried out in order to determine the likely cause of building collapse. A similar approach had been adopted by Day (1998) in the geoforencic analysis of various civil structures.

3.0 SITE DESCRIPTION AND GEOLOGY

The Abacha Road and Tombia street sites are located on the Ntawoba Creek flood plain. The Ntawoba creek is the primary runoff channel by which PortHarcourt metropolis is drained. This area is subject to periodic inundation, particularly, at the peak of the wet season. Flood incidences have been on the rise, following increased infrastructural development in the last 5years. This is because, several of these developments are located on the path of the runoff channel, where they impeded the discharge of flood water.

The OLD GRA Site is underlain by firm silty clay sediments belonging to the Pleistocene Formation. This site is in the old township of PortHarcourt with significant infrastructural developments, including 7- 9 storey building complexes. Previous soil investigations within the metropolis (Enoch George Associates 1992-2004, Trevi 1992-2000) described the superficial sediments in the area as undergoing lateritisation, a process in which ferrous iron oxides are progressively transformed into ferric irons.

The surface deposits in this area comprises silty and sandy- clays. The near surface silty clays are subjected to mild desiccation during the dry season. Substantial seasonal variations in moisture occurs in the upper sections of the sub-soil and frequently results in some false enhancement of strength in the dry season.

The Tourist Beach Site is marginal between Mangrove swamp and Coastal plain sand. The site was recently sandfilled by hydraulic means. The Mangrove sub-environment consist of soft to firm silty clay with significant decomposing organic matter. The water table in this area is usually close to the ground surface (generally less than 0.75m below ground surface).

According to NEDECO (1961) and amplified by NDES (1999), the general geology of the area essentially reflects the influence of movements of rivers, in the Niger delta and their search for lines of flow to the sea with consequent deposition of transported sediments.

4.0 METHODS OF INVESTIGATION

At each of the four collapsed building sites, a boring and CPT were executed. The boring was extended to 20m using the light cable shell and auger percussion technique with in situ SPT and undisturbed sampling. The 25KN capacity, GMF type, static penetrometer was used in the cone resistance soundings. The Cone Penetration Tests were driven to refusal.

The ultimate net bearing capacity qn of a shallow foundation was calculated using essentially the Terzaghi's Method (Terzaghi etal 1996), based on the relationship:

(for strip) $q_{nu} = CN_c + P_o(N_q) + 0.5\gamma BN\gamma$

(for Square or Rectangular foundation) $q_{nu} = 1.2CN_c(1+0.3B/L) + P_o(N_q) + 0.5BN$ $(1- 0.2B/L)$

where: γ = the bulk density of the soil below the foundation level

C = the undrained shear strength of the soil

P_o is the effective overburden pressure at the foundation level $N_c N_q N_\gamma$ = Terzaghi's bearing capacity factors obtained from charts

The undrained strength (C_u) values substituted into this equation were obtained from laboratory triaxial test and derived directly from Cone Penetration Tests results based on the well established equation (Meigh 1987):

$$C_u = \frac{q_c - \sigma^1_{vo}}{N_k}$$

Where

$qc - \sigma'_{vo}$ = net cone resistance

N_k = Cone factor

Due to the wide natural variabilities in soil properties within the compressible zone at these sites, the result of the Cone Penetration were used directly to predict the possible settlement of a foundation placed on the soil tested. The method used is that proposed by de Beer and Martens (1957) and Meyerhoff (1965), which evaluates the Constant of compressibility: $C_s = 1.9 \frac{C_r}{Po_i}$

Where Cr = static one resistance (kN/m^2)

Po_i = effective overbunden pressure at point tested.

The total immediate settlemΔnt, was then computed by $p_i = \frac{H}{C_s} Log_e \frac{Po_2 + \sigma_z}{Po_2}$

Δ

Where σ_z = vertical stress increase at the center of the consolidating layer of thickness H.

Po_2 = effective overburden pressure at the center of the layer before any excavation or load application.

H = thickness of compressible layer

σ_z = increase in vertical stress due to applied pressure

5.0 RESULTS

The litho- Stratigraphy within 20 m at each of the collapsed building sites is presented in Figure 2. The Abacha Road and Tombia Street sites have similar stratigraphic sequence. The stratigraphic evaluation at both sites identified three primary soil zones beneath the site. The upper part consists of a soft to firm top soil comprising silty clay (0.0-4.25m). This is followed by a firm sandy clay (4.25m 6.75m). The sandy clay layer is underlain by loose-medium dense and medium to coarse grained sand. This stratigraphic sequence appears to be extended for much of the Ntawogba Creek as revealed by soil boring at the D-line segment of the creek (Groundscan 2007).

The stratigraphic evaluation at Old GRA site also uncovered three primary soil zones beneath the site but of very different consistency. A typical soil profile characterizing the site consists of a firm to stiff lateritic normally consolidated soil comprising silty clay (0.0-12.0m), followed by a firm to stiff sandy clay (12.0m- 4.0m). The sandy clay layer is then underlain by loose-medium dense sand.

The tourist Beach site on the other hand is characterized by a soft to firm soil with fairly desiccated top soil comprising silty clay and very weak zone between 2 and 4m below ground level. This very weak layer is underlain by a firm sandy clay (4.0m 9.5m) and loose-medium dense, and medium to coarse grained sand. A summary of the basic geotechnical parameters required for the assessment of bearing capacity are presented in Table 1. The variation of cone penetration resistance, undrained

strength, bearing pressure with depth at the various collapsed building sites are illustrated in Figures 3 to 5.

6.0 DISCUSSION

The ground investigation was conducted with the principal intention to determine the prevailing subsoil conditions at the collapsed building sites and assess the role or significance of foundation in the collapse of the building. Since shallow foundations were adopted at all four sites, the bearing capacity analysis in the underlying soils was limited to the near surface silty clay.
Using combinations of relationships above, the ultimate bearing pressures were obtained for each of the sites (Table 2). Safety factors of about 3.0 were applied to the ultimate bearing pressures to obtain the maximum safe pressures of the soil.

Since information on the structural loading for the collapsed buildings were not available, the assumption was made that each floor exerted $50kN/m^2$. Based on this, various net foundation loads corresponding to the number of floor were adopted in the estimation of the operational factor of safety as well as the consolidation settlement. The operational factors of safety (FS) against foundation failure were derived by comparing the

allowable bearing pressure with the foundation load, such that:

FS = (Allowable bearing pressure x 3)/foundation load

A further analysis of the variation of settlement with foundation loading was carried out as shown in (Figure 6). This gives the consolidation settlement for different structural loads and provided indications of the possibility of differential settlement. The figure further indicates a linear relationship, in which incremental loads resulted in correspondingly higher settlements. Based on this trend, it is clear that the differential loading of the church tower at the tourist beach caused differential settlement, leading ultimately to its collapse.

Table 2: Allowable bearing pressures and settlement for the respective sites are summarized as follows:

S/No.	Site	Structure type and assumed foundation load (FL)	Allowable Bearing Pressure kN/m^2	Settlement(mm) for a loading of 150 kN/m^2	Operational FS and Remarks
1	Abacha Road	3 storey 200 kN/m^2	80	23.5	1.2 unsatisfactory
2	Tombia Street	4 storey Hotel complex 250 kN/m^2	50	22	0.6 unsatisfactory
3	OLD GRA	2 storey 150 kN/m^2	150	13.5	3 satisfactory
4	Tourist Beach	1 storey Church with Tower 100 kN/m^2	30	98.3	0.9 unsatisfactory

The bearing characteristics of the surface layers within normal shallow foundation placement at Abacha Road are poor to moderate. Allowable bearing pressure for shallow foundation was estimated at 80kN/m^2. Although consolidation settlement (23.5 mm) was within the acceptable limit, the operational safety factor was marginal indicating that the collapse was most probably due to incompetent foundation.

At the Tombia Street site, the bearing characteristics of the surface layers within normal shallow foundation placement are also poor to moderate with allowable bearing pressure of 50kN/m^2. Although settlement was within allowable limit, the operational safety factor was similarly below 1, confirming that the collapse was due to incompetent foundation.

The sub-soil at OLD GRA: exhibited a moderate to high bearing characteristics. Both allowable bearing pressure and settlement values indicated that the foundation was competent. The collapse at this site could not therefore be due incompetent sub-soil.

At the Tourist Beach, the bearing characteristics of the surface layers within normal shallow foundation placement were very poor with an allowable bearing pressure for of 30kN/m^2. The predicted settlement was well outside the tolerable limit. The collapse at this site was due to a combination of very poor foundation and differential settlement between tower and the rest of the building.

7.0 CONCLUSIONS

The results indicate that although all the sites are underlain by coastal plain sand, the allowable bearing pressures were widely variable, largely because of the diversity of geomorphic sub-environments. The sites within the flood plain of the Ntawoba creek from Tombia Street, through D-Line to Amadi Creek and the reclaimed mangrove swamp exhibited low allowable bearing pressures, with operational factors of safety less than 1 and significant consolidation settlement. These conditions justify the development of foundation failure at the Tombia, Abacha Street and Tourist beach sites, which explains the observed building collapse within these areas. On the contrary, the collapse at the old GRA site can not be explained by the incompetence of the foundation. This failure was probably caused by structural defects.

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Borehole No.	Depth (m)	Natural Moisture Content (%)	Bulk Unit Weight γ (kN/m^3)	Vane Shear Strength (kN/m^2)	Undrained Cohesion Cu (kN/m^2)	Friction Angle φ(Degree)	Description of Sample
ABACHA ROAD	1.5	19.2	20.5	30.6	40	10	Soft-Firm reddish brown silty clay
	3.0	20.2	20.3	37.2	55	6	Soft-Firm reddish brown silty clay
	6.0	19.2	20.2	51.6	42	9	Soft-Firm reddish brown silty clay
TOMBIA STREET	1.5	22.2	21.4	28.5	30	3	Soft dark brown sandy clay
	3.0	21.9	20.8	21.6	28	4	Soft dark brown sandy clay
	6.0	21.9	21.1	40	26	1	Soft dark brown sandy clay
OLD GRA	1.5	18.1	19.2	62.5	71	8	Firm -stiff dark grey brown silty clay
	3.0	17.5	19.8	70.6	70	10	Firm –Stiff reddish brown silty clay
	6.0	17.2	19.3	77.5	78	9	Firm –Stiff reddish brown silty clay
TOURIST BEACH	1.5	17.1	19.7	41.5	45	11	Soft-Firm reddish brown silty clay
	3.0	25.2	16.5	10	8	2	Very Soft-Firm reddish brown silty clay
	6.0	17.1	19.7	41.5	45	11	Soft-Firm reddish brown silty clay

Table 2: Design soil properties at collapsed building sites

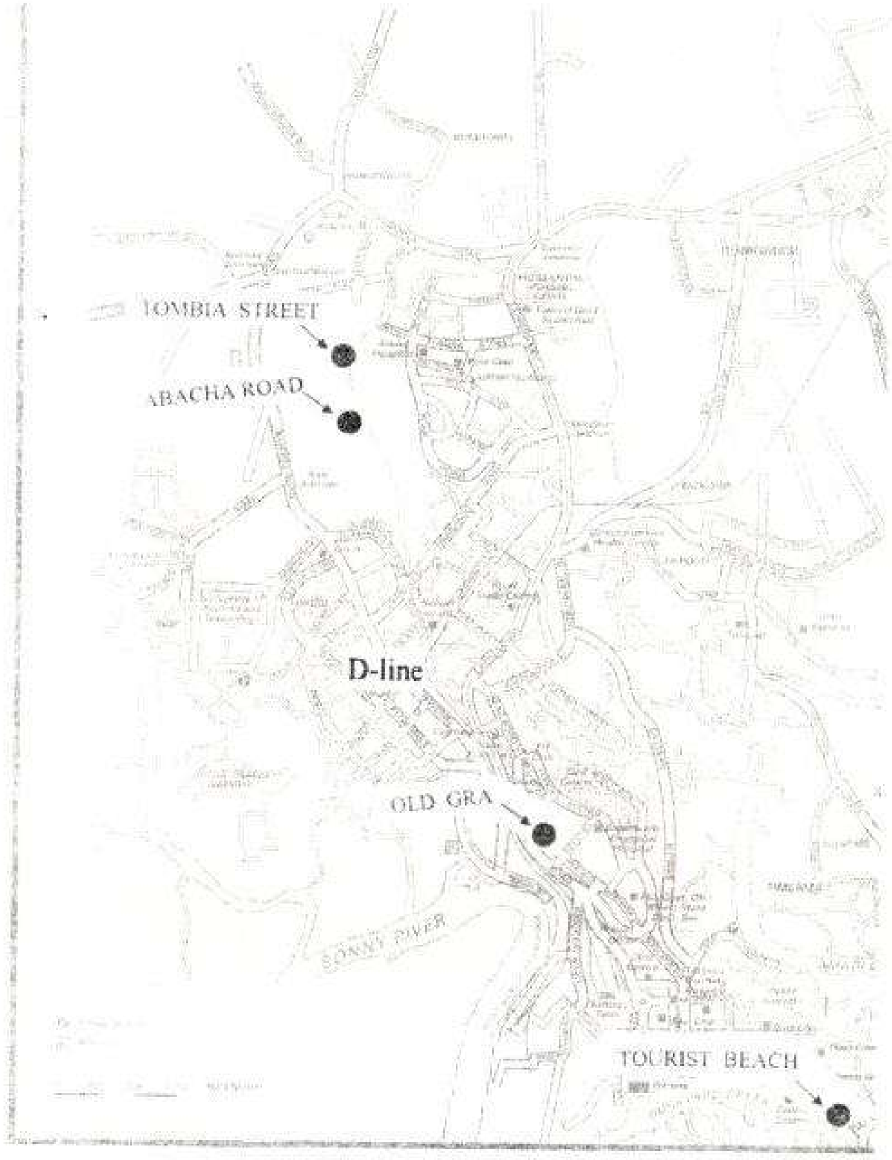

Figure 1: Map of Port Harcourt showing Collapsed Building Sites

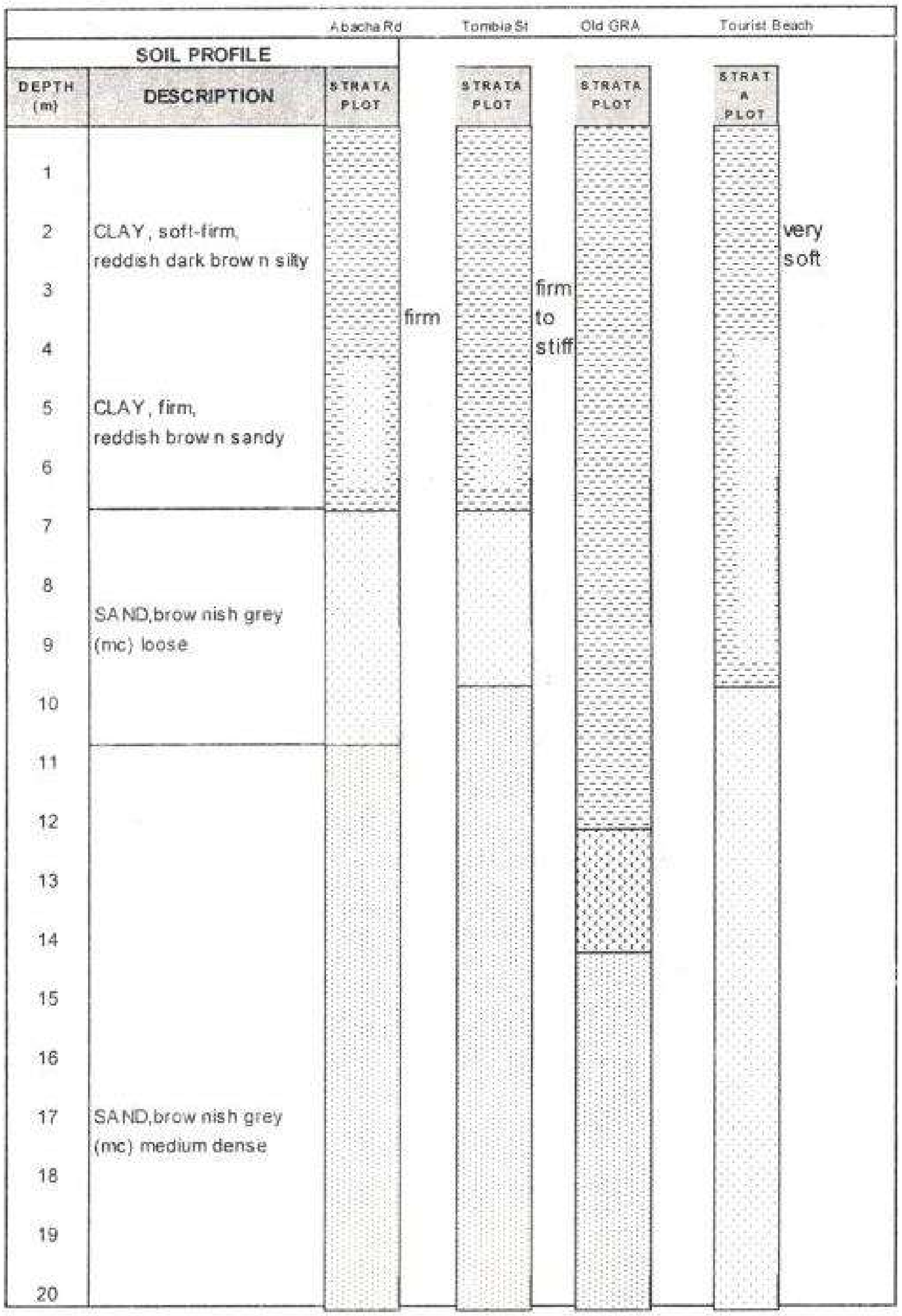

Figure 2: Litho-stratigraphy at collapsed building sites

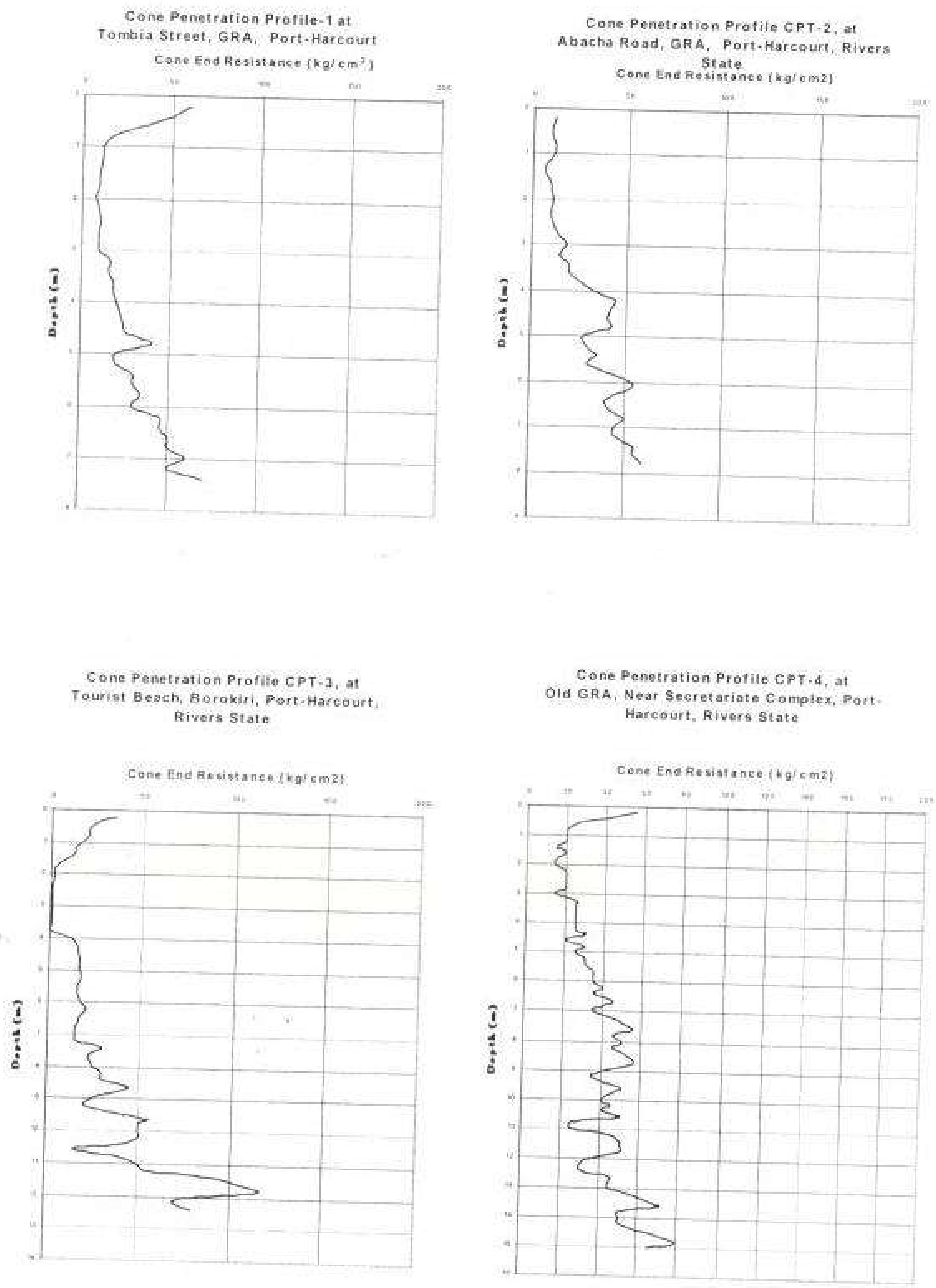

Figure 3: Cone penetration sounding profiles at collapsed building sites

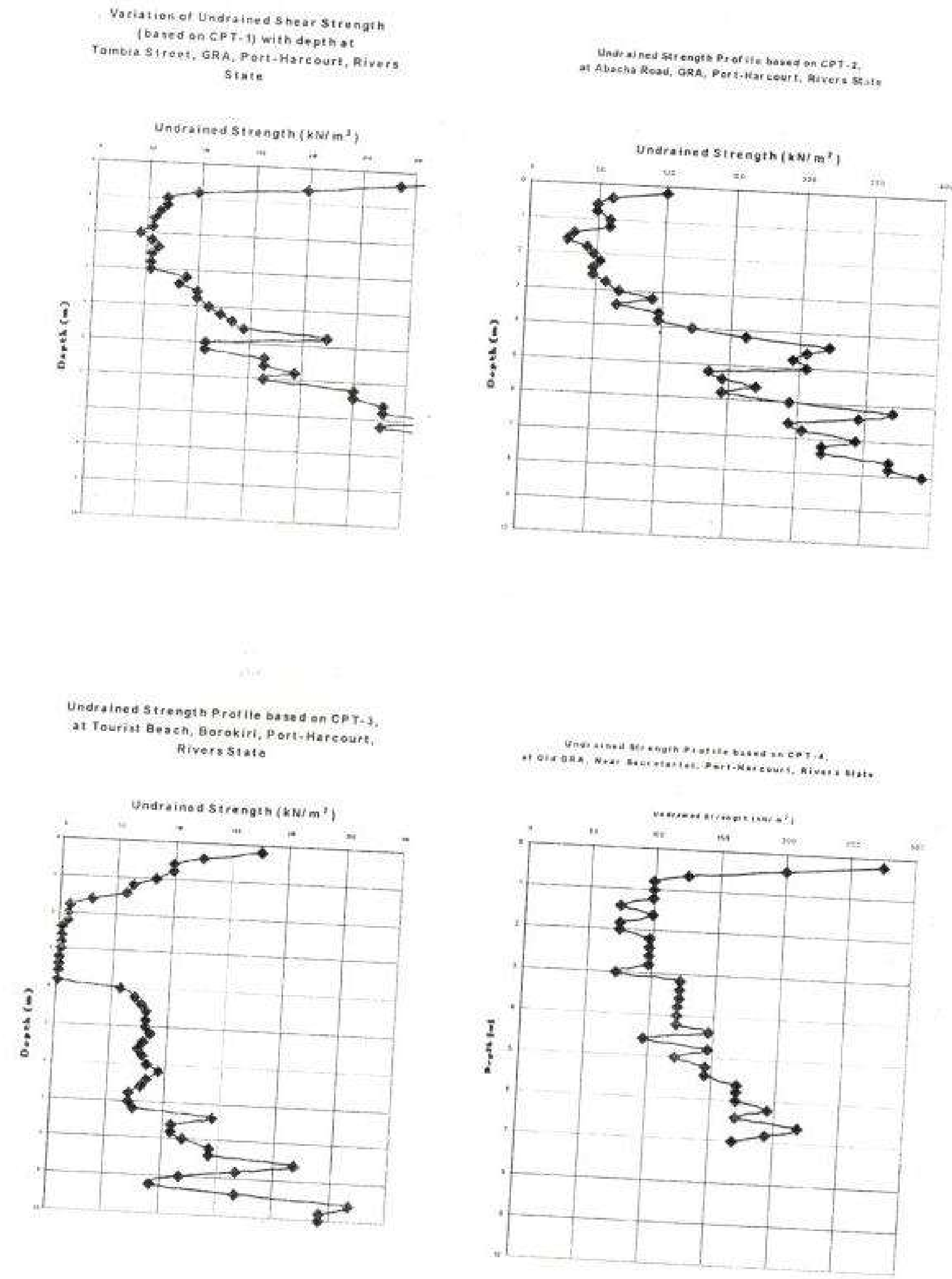

Figure 4: Undrained strength profiles (derived from CPT) at collapsed building sites

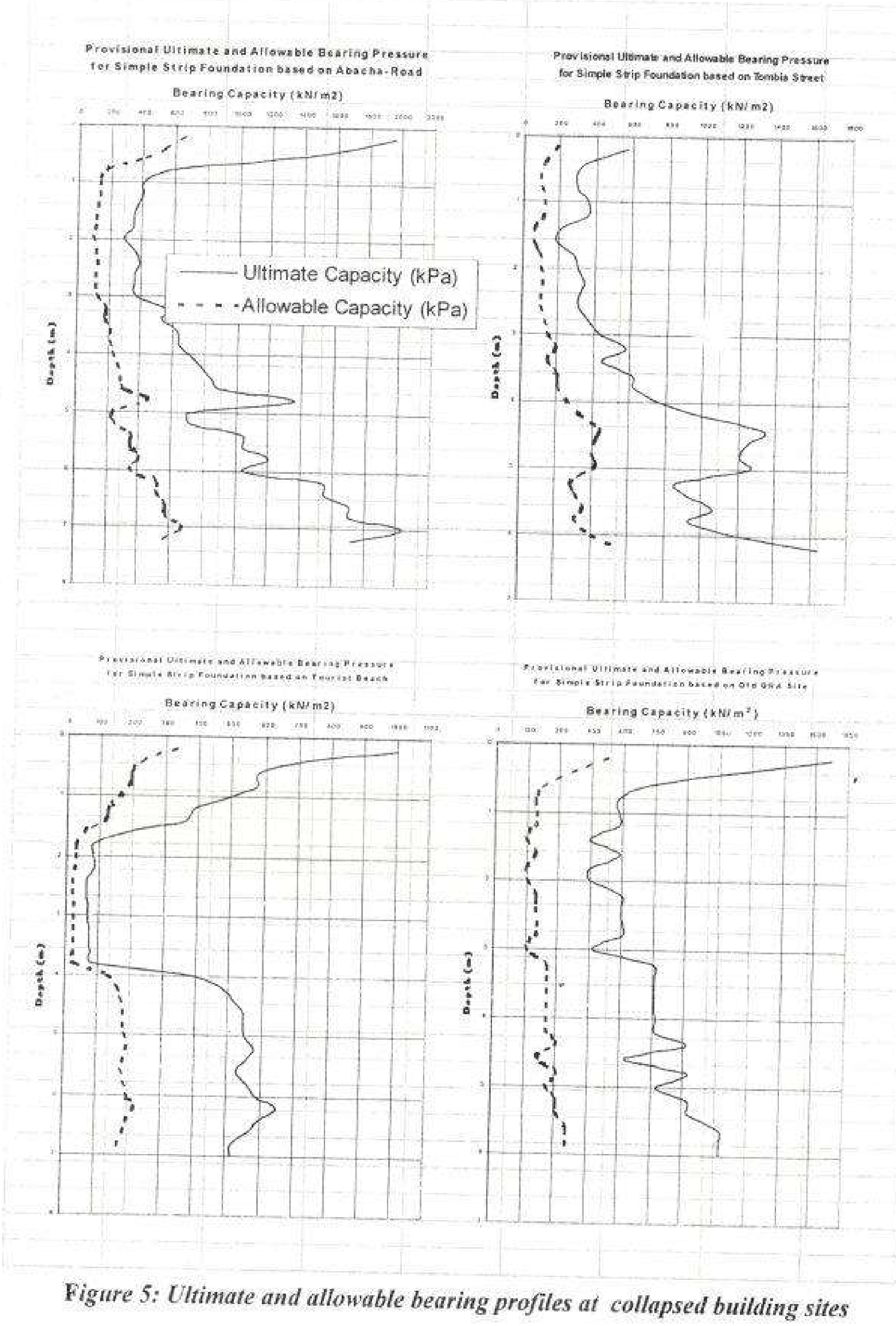

Figure 5: Ultimate and allowable bearing profiles at collapsed building sites

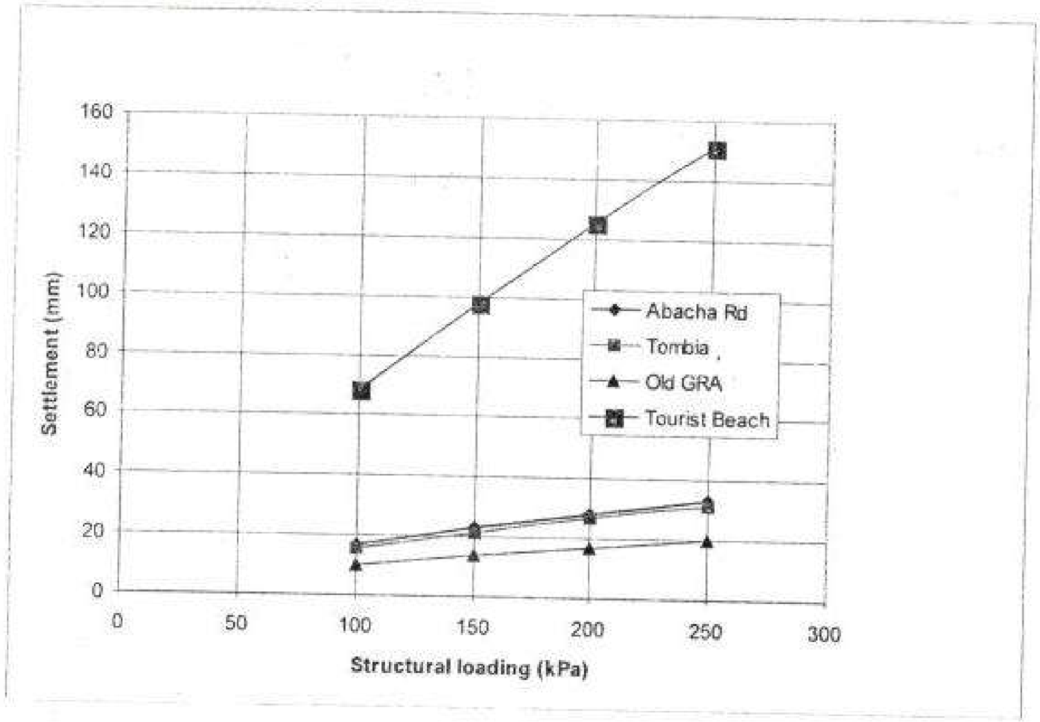

Figure 6: Variation of settlement with structural loading at the collapsed building sites