A Study of the Use of Ground Investigation Reports during Foundation Design in Kampala

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ABSTRACT
Foundations transfer loads from the super structure to the soils. For a structure not to collapse due to foundation failure; the pressure exerted by the foundation to the soil must not be greater than the bearing capacity of the soil and the settlement should be uniform and not greater than the permissible value. A number of structures have collapsed in and around Kampala with foundation failure being suggested as one of the several likely causes. Kampala is located on a number of hills dissected by swamps with consequent varying soil properties. Structures in Kampala are founded on virgin lands, fills and previously disturbed soils such as grave yards and built up areas with pit latrines. This makes soil Investigation a pre-requisite before undertaking design. This research sought to investigate the importance attached to soil investigation before design and construction of building structures around Kampala. The number of structural plans submitted and approved by Kampala City Council (KCC) between 2000 and 2005 were about 2524 according to data extracted from Council's records. Soil tests carried out to determine the bearing capacity from the only four known soil testing laboratory in Kampala during the same period were only 173. A survey of consultants and soil testing laboratories revealed that for the few sites whose soil bearing capacities were determined, the commonly used methods were standard penetration (SPT) for insitu methods, shear box and triaxial tests for laboratory testing and that most consultants based their calculations of bearing capacity on Terzaghi's method. In this investigation, soil tests were carried out for a typical site in Kampala. This involved application of laboratory un-drained shear box test to determine shear parameters. Then both Meyerhof and Terzaghi's methods were used to determine the bearing capacity and the results compared. Suggestions were made on how to improve the practice of soil investigation by the Engineers and thus minimize structural collapse due to foundation failure.

Keywords: Bearing Capacity, Collapsing structures, Foundations, Improved Practice, Soil Tests

1.0 INTRODUCTION

All constructed facilities rest on soils that should be able to safely take the loads imposed by these facilities. The bearing capacity of the soils should be greater than the pressure exerted to the soils by the structures if failure of the soil and the structure are to be avoided. According to the statistical Abstract (2005), the percentage contribution of the construction sector to the National Gross Domestic Product (GDP) in the fiscal year 2004/05 was 11.7%. Buildings comprise one of the major areas of the construction industry. Kampala, the capital city of Uganda, has some of the major forms of building structures; residential, institutional, commercial as well as industrial buildings. In addition most consultants, contractors and soil testing organizations are located in Kampala. The city has five political and administrative divisions of Nakawa, Kawempe, Makindye, Rubaga and Central division. The whole city is located on several hills dissected by valleys often carrying small streams or water channels. It is therefore expected that soil properties vary from site to site. Moreover some of the areas where multi-storey structures have been proposed for construction have been either villages or slums for at least 50 years. Therefore their soils have been disturbed by activities of human settlements such as graves, pit latrines.

According to the Public Health Act (1964), Building Rules, Part VII-Structure; rule 142 the pressure on the foundation beds of a building should be evenly distributed and should not exceed the safe bearing capacity of the foundation bed. Certain permissible loads are given in Table 10 of the Act. It is noted as well that the building owner shall satisfy himself by means of trial pits or loading tests or other measures that the safe bearing capacity of the ground on which the building rests is not exceeded. This paper presents results of the study carried out to investigate the methods used to determine the bearing capacity of soils while designing structures in Kampala.

The determination of bearing capacity of soils is obtained from tests on soils carried out to determine the cohesion of the soil, c, and the angle of shearing resistance, ϕ. The determination of these two parameters can be carried out in the laboratory using a soil sample obtained from the site where the structure is to be located with loading and drainage conditions approximating those in the field as possible. Tests generally in use are: direct shear test, the triaxial test, unconfined compression test and vane shear test. Tests can also be carried out in the field, that is, insitu testing.

The bearing capacity failure of a foundation is caused by several factors including general soil shear failure, local soil shear failure and punching shear failure. The evaluation of ultimate bearing capacity is usually obtained from an analysis of general shear failure since for local and punching shear failure, settlement considerations are more critical than those of bearing capacity (Smith, 1998).

2.0 METHODOLOGY

Records of structural plans/drawings of multi-storey buildings submitted to KCC for approval during the period 2000 to 2005 were obtained from each of the five political divisions of Kawempe, Nakawa, Makindye, Rubaga and Central division. The plans were classified as commercial, Residential, Institutional and Industrial.

A list of consulting engineering firms was obtained from the Uganda Association of Consulting Engineers (UACE) for purposes of identifying firms that provide structural and geotechnical services. Other known firms offering the same service who are not members of UACE were included on the list of ten firms that were identified. Questionnaires were delivered to each of these firms and responses were obtained from nine.

Questionnaires were also administered to four organizations involved in soil testing in Kampala. These included Central Materials Laboratory, Makerere University, Techlab and Kyambogo University. A case study of a virgin site in Kampala was carried out to determine the bearing capacity of the soil.

3.0 RESULTS AND DISCUSSIONS

Table 1 shows details of structural drawings submitted to KCC from 2000 to 2005 inclusive. From the table, it is observed that the number of structural plans/Drawings submitted to KCC for approval increased three times from 248 in 2000 to 785 in 2005.

Table 1: Structural Drawings submitted to KCC for Approval in 2000-2005

Type of Structure	Year						Total
	2000	2001	2002	2003	2004	2005	
Residential	165	219	238	219	311	602	1754
Commercial	63	118	86	100	101	150	618
Institutional	14	20	10	19	21	15	99
Industrial	6	6	8	3	12	18	53
Total	248	363	342	341	445	785	2524

3.1 Methods used to determine bearing capacity

Table 2 shows the methods used to determine the bearing capacity by the respondents. All the nine (09) firms indicated that they used laboratory tests to determine the soil parameters and then calculate the bearing capacity. Six (06) indicated that they also used in-situ tests and three (03) admitted to the use of visual inspections. One firm indicated that in addition to carrying out laboratory tests, it also depended on use of presumed (tabulated) bearing capacity values.

Table 2: Determination of Bearing Capacity by Firms

Methods used	Respondent/Firm								
	A	B	C	D	E	F	G	H	I
Laboratory Test	√	√	√	√	√	√	√	√	√
Insitu Tests	√	√	×	√	√	×	√	√	×
Visual Inspection	√	×	×	×	×	√	×	√	×
Presumed	×	×	×	×	×	×	×	×	√

Table 3 shows the methods used by the respondents for determining bearing capacity. For the few sites where the soils were tested, the laboratory methods using shear box and triaxial tests were common. This could be attributed to the fact that the laboratory tests are less involving and are cheaper compared to insitu tests. The standard penetration test (SPT) was the most commonly used in-situ method. The plate loading test was not used yet services were available at the Central Materials Laboratory.

Table 3: Laboratory and Insitu methods for Determination of Bearing Capacity

Methods used		Respondent/Firm								
		A	B	C	D	E	F	G	H	I
Laboratory Tests	Shear box	√	×	√	×	√	√	√	×	×
	Triaxial	√	×	×	√	×	√	√	√	×
	Unconfined Compression	×	√	×	×	×	×	×	×	×
	Vane shear	×	×	×	×	×	×	×	×	×
Insitu Tests	Plate Loading	×	×	×	×	×	×	×	×	×
	Standard Penetration	√	×	√	√	√	×	√	×	×
	Dynamic Probing	×	×	×	×	×	√	×	√	×
	Static Cone Penetration	×	×	×	√	×	×	×	×	×

Table 4 shows details of whether the firms hire out the soil testing services or use their own equipment. Only two of the firms indicated that they often used their own equipment. All the firms hired soil testing services mainly from the Central Materials Laboratory. This means that if the actual number of tests carried out by the laboratory were obtained, it would be possible to know the number of soil tests carried out with a good degree of certainty.

Table 4: Hire of Testing Services

Methods used		Respondent/Firm								
		A	B	C	D	E	F	G	H	I
Tests	Use own Equipment	×	×	√	×	×	√	×	×	×
	Hire Services/Equipment	√	√	√	√	√	√	√	√	√
Hire services from	Central Materials Lab	√	√	√	√	√	√	√	√	√
	Makerere University	×	×	×	√	×	×	√	×	×
	Teclab	×	√	×	√	×	√	×	√	×
	Kyambogo University	×	×	×	×	×	×	×	×	×

Table 5 shows the different methods used for calculating the bearing capacity from the test results. Terzaghi's method was mainly used in Uganda as elsewhere in the world. But with the increasing changes in the way structures are loaded, there is need to embrace Meyerhof's method which considers inclined loads, foundation depth and shape of the foundation.

Table 5: Methods used for Calculating Bearing Capacity

Methods used	Respondent/Firm								
	A	B	C	D	E	F	G	H	I
Terzaghi's Method	×	×	√	√	√	√	×	×	√
Prandtl's Method	×	×	×	×	√	×	×	×	×
Meyerhof's Method	√	×	×	×	√	√	×	√	×
Rankine's Analysis	√	√	×	×	×	×	√	×	×

Table 6 compares the total number of structural plans submitted to KCC with the Total number of soil tests (Insitu and Laboratory) carried out in corresponding years. It is observed that while the number of structural plans/drawings submitted to KCC for approval was increasing, the number of soil investigations remained constant. Out of 2,524 structural plans submitted, the number of tests in the period 2000 to 2005 was only 173, representing only 7% and 93% of the plans having no soil test records.

Table 6: Comparison of Submitted Structural Plans and Soil Tests

Year	No of Structural Plans	Total No. of soil tests	% of structures with soil tested	% of structures-Site soil not tested
2000	248	28	11	89
2001	363	26	7	93
2002	342	27	8	92
2003	341	31	9	91
2004	445	27	6	94
2005	785	34	4	96
Total	2524	173	7	93

It was very difficult to establish the number of soil tests/investigations actually carried out. None of the structural engineering firms was willing to indicate that they had not done any tests. It was assumed that individuals who did not have the capacity to form consultancy firms may also not have been in position to buy their own soil testing equipment. Therefore the best source of data on actual tests carried out were the organizations carrying out soil tests. Even here little efforts were made to keep records tests carried out.

3.2 Use of presumed bearing capacity

One of the consultants indicated that he used tabulated values of bearing capacities. Asked to indicate when this may be acceptable, all consultants indicated that they are applicable in the case of: (a) a non-critical single storied structures; (b) the structures are of up to two levels on hill sides; (c) the site is familiar; (d) the client can not afford a detailed soil investigation; and (e) the cost of the structure does not justify use of more elaborate methods.

3.3 Results of the case study

An undisturbed soil sample was extracted from a site at Kyambogo University. Tests were carried out at the Central Materials Laboratory, including particle size distribution analysis, moisture content, Atterberg limits, specific gravity, shear box and consolidation test.

A graph of normal stress against shear stress drawn from the results of the shear box test is shown in Figure 1. From the figure, cohesion c = 6.74kPa while the angle of shearing resistance (angle of friction) in the undrained condition ϕ = 30°. The safe bearing capacities calculated using Meyerhof's and Terzaghi's methods are q_c= 615 kN/m^2 and 414 kN/m^2, thus Terzaghi's method was more conservative compared to Meyerhof's.

Another graph of void ratio against effective vertical pressure was plotted as shown in Figure 2. From the graph, using the Casagrande construction, the preconsolidation pressure was found to be P_c = 191.094 kPa. The existing effective pressure P_o = 3.608 kPa. The over-consolidation ratio, OCR = (P_c/ P_o) = (191.094/3.608) = 53 >> 1.0. The soils were very heavily over-consolidated indicating that several tens of metres of soil could have been removed, up to the present time. Thus the effect of mechanical disturbance on the structure founded on the site will be less.

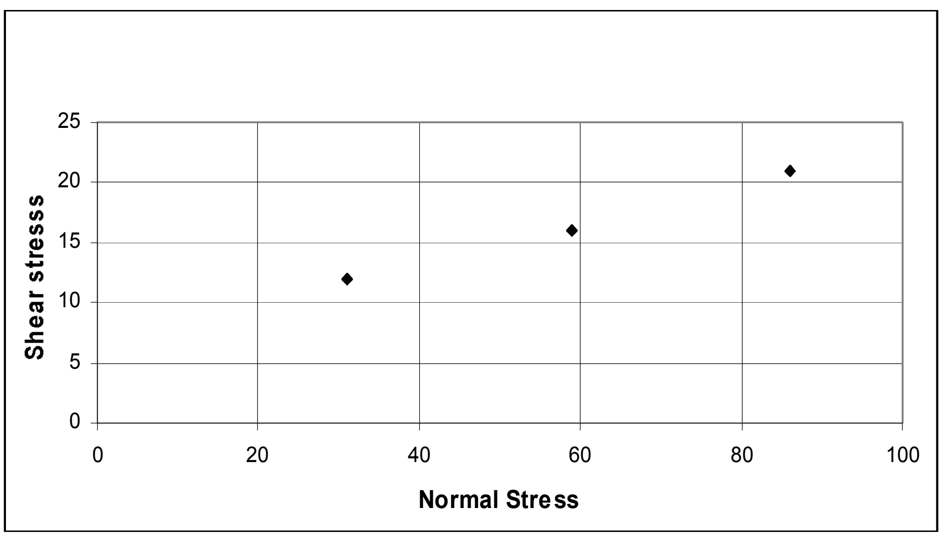

Figure 1: Plot of shear stress against normal stress

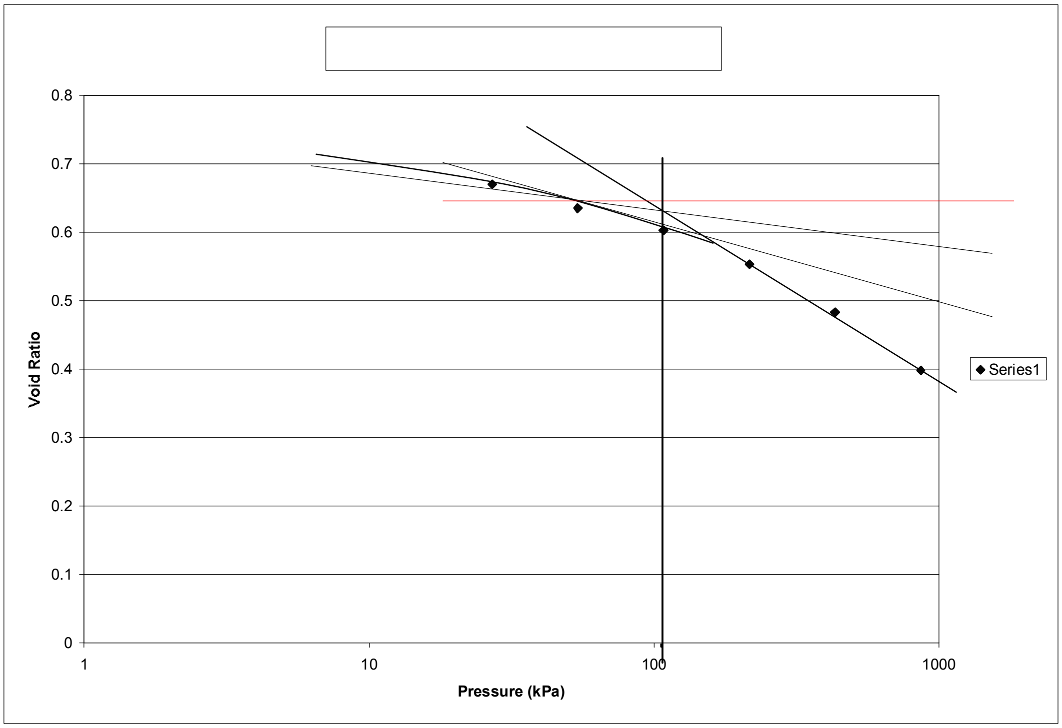

Figure 2: Plot of void ratio against vertical effective pressure

4.0 CONCLUSIONS

From the results of investigations carried out, the following conclusions have been made:

(i) There were actually very few soil tests done to determine the bearing capacity of the site soil where the structure being designed was to be constructed. Only about 7% of the structures were constructed after carrying out soil tests.

(ii) For those few structures where soil tests were carried out the commonly used insitu method was standard penetration test and the most commonly used laboratory methods are the shear box and triaxial tests.

(iii) The most commonly used methods for calculating bearing capacity are Terzaghi's method.

5.0 RECOMMENDATIONS

In order to be able to make meaningful recommendations, one must first answer two questions: one is "Why were only a few tests carried out?" and two is, given that very few tests were carried out, "Why have fewer collapses of structures been witnessed?" The period 2000 and 2005, about 10 cases of collapsing of structures were recorded. The major ones included Hotel at Bwebajja, Church at Kalerwe, School in Naalya, Hotel in Kawempe, and Building next to King Fahd Plaza on Kampala Road. They could have been far more given the fewer soil tests being carried out. An informal survey carried out with several practicing Structural Engineers revealed the following answers:

5.1 Why were only a few tests carried out?

(i) Most of these structures were residential as shown in Table 1, carried out by private developers. These private developers normally approach the architect for the architectural plans, the architect usually gives a rough estimate of the cost of the structural plans/drawings and these never include allowances for geotechnical testing.

(ii) A large number of structural designs were carried out by individuals who, unlike established firms, did not have the negotiating muscle needed for such tasks. The amount of money given for the structural designs is usually very low, not enough to include geotechnical investigations.

(iii) The cost of geotechnical investigations is usually high compared to the cost of, say, architectural and structural designs/drawings. It follows standard rates laid down by the soil testing firms and does not fluctuate like that of other designs.

(iv) A number of clients are not aware of the need for soil tests.

5.2 Why have fewer collapses of structures been witnessed?

(i) When designing most residential and other relatively light structures, the Engineers tend to underestimate the bearing capacity of the ground. For instance tests carried out on a typical site in Kyambogo University had a safe bearing capacity varying from, q_c= 615 kN/m^2 to 414 kN/m^2. However, without testing an Engineer may use a value of q_c= 200 kN/m^2, or even less. Thus the client ends up paying twice or three times for the foundation.

(ii) The test on the soils at Kyambogo indicated that it was very heavily overconsolidated. Similar experience had been obtained on a number of sites on hills and slopes of hills in Kampala. This could be attributed to erosions on these slopes over time. For simple residential structures, with over designed footings, the preconsolidation pressure may not be reached.

(iii) Most of the structures have been constructed on virgin sites without previous disturbances such as graves, pit latrines or varying properties. In such situations the dangers of differential settlements are minimal. However, as virgin sites get exhausted and redevelopment picks up extensive geotechnical investigations are a must. There have been reports that some collapsed buildings were erected on previously grave yards – indicating cases of disturbed ground. Filled sections of such a site would be expected to settle rates different from those of undisturbed sections especially when structures are constructed on isolated pad foundations.

5.3 Recommendations

(i) Clients and architects should be sensitized on the importance of carrying out a geotechnical investigation of each site. It must be pointed out that if this is not done a prudent Engineer will have no alternative than over designing.

(ii) Architectural and structural plans for multi-storey structures should not be approved without a detailed geotechnical investigation report from a soil testing laboratory accredited by the National Bureau of Standards, UIPE or Engineers Registration Board.

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