Assessment of the Structural Integrity of an In-service School Building at Risk Using Geotechnical Measurement Parameters

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Abstract
The rate of building collapse and subsequent loss of lives and properties in Nigeria has become a major concern to both government and researchers. This is why it is necessary to carry out integrity assessment anytime there appear to be any sign of distress in major public and private buildings. This paper examines the Structural Integrity of an In-service School Building located in Benin City, Nigeria. Visual inspection of the buildings within the school showed long shear cracks in some of the buildings, particularly Block A. In order to determine if foundation problems were responsible for the cracks, soil samples were collected from different locations around the buildings for laboratory analysis. Dutch Cone Penetrometer Tests (CPT) were also conducted. The soil samples collected were taken to the laboratory for test and analysis. The results of the tests showed that the depositional pattern at the location ranged from clay to sandy soils. Particle size distribution results showed that the clay content vary from between 40 and 60%. The results from the Cone Penetrometer Tests indicate that the soil consolidates from a depth of 4m below ground level. Thus, it can be assumed that the surface of the foundation soils should be at 4m below ground levels. However, the foundation depth of the building is 2.1m below ground floor. This indicates that the foundation of the building is located at 2m above the foundation soils. From the studies, it was observed that the isolated foundation footings are conducting relatively high bearing pressure in a consolidating soil resulting in high differential settlement. This has resulted in series of cracks noticeable particularly in Block A. In order to remedy the situation, a raft foundation slab is proposed to replace the existing ground floor of the building.

Keywords: structural integrity, differential settlement, consolidation, raft foundation.

INTRODUCTION
Structural Integrity Assessment is a process by which we determine how reliable an existing structure is able to carry current and future loads and fulfill the tasks for a given time period (Rucker et al 2006). It is necessary to ensure that a structure or part of it does not fail under loading. When there are noticeable defects in the structure such as visible cracks, a study to determine the condition of the structure is carried out. Such investigation should identify the type of defects such as cracking and subsidence, settlement or movement of the structure (Ehiorobo et al 2013).

Cracks occur in structures such as buildings whenever stress in the component exceeds its strength. Stress may be caused by applied forces or by foundation settlement (Tomlinson 2001, Kaniraj 2011). Whenever there is a foundation settlement, there is a tendency for a building to move. Buildings can move in several directions and this movement can be in various forms. It could be the building moving itself or a small portion of it, or it could be the soil or portion of it.

Therefore, crack is not the cause, but rather the sign that shows that the building is undergoing movement (Dickinson 2004 Day R A 1998a). Two reasons identified by Dickson why buildings move include movement as a result of conditions above ground and movements as a result of conditions below ground. Some of the conditions below ground that can lead to movement of buildings include: seasonal movement as found in clay soils, variable ground conditions, differential settlement, soil creep, tree roots e.t.c (Bone 1996, Grant et al 1974, Day 1999). Settlement of the building foundation may occur due to shock, vibration and subsidence (Tomlinson and Boorma 1999). Expansion and contraction of soils under and around a building lead to cracking in walls. Excessive runoff water around the building foundation can cause weakening of the foundation leading to cracks (Ehiorobo et al 2013).

Soil with the potential to shrink or swell creates problems for building foundation. In general, there has been an increase in damages to buildings due to collapsible soils. Collapsible soils can be classified as soils that are susceptible to a large and sudden reduction in volume upon wetting (Day 1999). Collapsible soils usually have low density and low moisture content. Such soils can withstand a large applied vertical stress with a small compression but
then experiences much larger settlements after wetting with no increase in vertical pressure (Jennings and Knight 1957, Day 1999). The triggering mechanism for the collapse of natural soils is in the introduction of moisture from rain water soaking into the building foundation. Expansion and contraction of soils under and around a building leads to cracking in the walls. Soil Erosion can be a fundamental problem as excessive water from erosion around the foundation can pull away at foundation walls, causing movements of the building structure, cracks and foundation failure. If soil around the building is not compacted properly, erosion may occur around the foundation and this can lead to foundation failure and cracking.

In order to determine the causes of cracks in building and foundation failure, foundation inspection and ground condition surveying need to be carried out. Sampling boreholes and trial pits need to be located close to the building foundation, soil samples are collected and subjected to laboratory tests and analysis. This is necessary to correctly access the causes of the building defects and take appropriate remedial measures.

SITE DESCRIPTION
The site under investigation is a school building about 0.8km from the city centre in Benin City the capital of Edo State. The site layout is shown in Fig 1. There are five blocks of buildings within the site labeled blocks A, B, C, D, and E. The main building is Block A which functions as block for staff officers, classrooms, laboratories and dormitories. Shear cracks are noticeable in this building particularly on the left wing of the expansion joint and also on the perimeter fence behind block A. Most of these cracks run from the ground floors and are continuous on the upper floors (see fig 2 – 5).

DATE COLLECTION
Soil sampling was conducted both by field and laboratory procedures. Subsoil geotechnical assessment was conducted by Dutch cone penetrometer testing and Auger drilling method. The field exploration was conducted by borehole drilling and sampling at four test locations, also by Dutch cone penetrometer testing at eight test locations. The
recovered samples were identified and taken to the laboratory in cellophane bags for laboratory tests and analysis. The tests carried out included moisture content test, specific gravity, particle size distribution, shear strength and consistency tests.

RESULTS AND DISCUSSIONS

The specific gravity varied between 2.46 and 2.64 indicative of a depositional pattern that would range from clay to sand. The liquid limits are generally in the range of 40.0 to 70.0 percent with extreme low and high values of 20 and 80.0 percents respectively. The plasticity index is generally between 30.0 and 50.0 percent with the lowest recorded being 23.0 percent.

The particle size distribution shows that the clayey content vary between 40.0 and 60.0 percent (Fig-7 and Fig-8), these amounts are significantly high enough to impart clay characteristic behavior on the soil. The consistencies vary over wide range of between clays of intermediate to very high plasticity.

The moisture-density assessments of the soils samples indicate that the maximum dry density of the soil varied between 1.70 and 1.80 g/cm³ with an average of 1.75 g/cm³, while the optimum moisture content is in the range of 10.0 to 18.0 percent with an average of 15.0 percent.

The shear strength characteristics were investigated with the unconsolidated-undrained triaxial compression tests on the recovered samples. The measured undrained cohesion is between 30.00 and 60.00 kN/m² with isolated low values as low as 20.00 kN/m². Also the internal angle of friction varied between 8.50 and 20.00 deg.

The Dutch cone penetrometer test results are shown in Fig-9. The results show that the structural fill depth across parts of the site is about 2.00 metres below the existing ground level. The depth of the original surface soil deposit is about 2.00 m. Therefore the total low friction soil deposit has a depth of about 4.00 metres below ground level. The surface soil thickness of 4.00 m is expected to be of high compressibility with low frictional resistance. The soil normally consolidates from the depth of 4.00 metres below ground level. Therefore the surface of the foundation soil can be assumed to be at 4.00 metres below ground level, it is expected that foundation footings should be below this depth.

### Table 1: Cone resistance and inferred consolidation parameters

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Cone resistance Ckd (Kg/cm²)</th>
<th>Coefficient of volume compressibility Mv (m²/mN)</th>
<th>Coefficient of consolidation Cv (m²/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00 – 4.00</td>
<td>22.5</td>
<td>2.25</td>
<td>0.0662</td>
</tr>
<tr>
<td>4.00 – 8.00</td>
<td>50.0</td>
<td>5.00</td>
<td>0.0290</td>
</tr>
<tr>
<td>8.00 – 10.00</td>
<td>100.0</td>
<td>10.00</td>
<td>0.0150</td>
</tr>
<tr>
<td>&gt; 10.00</td>
<td>250.0</td>
<td>25.00</td>
<td>0.0060</td>
</tr>
</tbody>
</table>
The approximate average cone resistance and inferred consolidation parameters for various depths are presented in Table-1.

**FOUNDATION INTEGRITY**

Isolated pad foundation footings were provided for the project. The foundation depth is about 2.10m below the ground floor level and or 1.50m below the existing ground level. This implies that the foundations are located about 2.00m above the foundation soil.

The minimum and maximum foundation service pressures due to the structure and fill were estimated to be 141.98 and 1072.90kN/m² respectively, with average service pressures of 548.90kN/m². Except the foundation footings are placed on an incompressible deposit this wide variation of foundation pressures will result in substantial differential settlements with structural defect symptoms as have been observed with the structures at this site.

The use of uniform foundation footing dimensions of the size of 1875mmx1875mm has compromised the foundation integrity because of the wide range of bearing pressures. Because of the appreciable amount of clay content at the site which is likely to be saturated the settlement will occur over a period of time estimated to be about 25years. Although within 5years the maximum differential settlement would have reached 40.00mm and symptoms of structural distress would have started becoming evident and repairs commenced. A plot of the differential settlement-duration chart is provided in Fig-10.

**CONCLUSIONS**

The defects at the site have resulted from inadequate foundation consideration and provisions for the buildings structures at the site. Isolated foundation footings supporting an average of 400.00kN/m² on consolidating soil strata have resulted in relatively high differential settlements with a maximum of about 50.00mm. More than half of the settlement have already taken place and because the soil is consolidating, repairs will continually be undertaken for another 15-20 years, that is if the serviceability condition does not result in ultimate capacity impairments sufficient to cause collapse.

Therefore, it is recommended that a raft foundation slab should be provided to replace the existing ground floor. The slab would be supported by ground beams which will be anchored beneath the slab to the existing columns. This provision would reduce the range and average bearing pressures from 141.98-1072.90kN/m² to 505.05N/mm², 88.32-116.08 and 548.90 to 95.41kN/m² respectively.

The structural defects on the building at the site have been investigated by field, laboratory and detailed engineering assessments. It was observed that the isolated foundation footings are conducting relatively high bearing pressures in a consolidating soil environment; this has resulted in substantial differential settlements. The consolidating nature of the subsidence is such that the settlement is progressive or staged requiring periodical or continuous repairs which may be carried out over a period of 20years. A raft foundation replacement has been recommended. It is important that measures are taken to provide redress before the superstructure becomes non-recoverable.

**REFERENCES**


