Measurement and Documentation for Structural Intergrity Assessment of In-Service Building At Risk.

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Keywords: Structural Integrity Assessment, Differential Settlement, Strain, Stress and Consolidation

SUMMARY

Structural integrity assessment is a process by which we determine how reliable an existing structure is able to carry current and future loads and fulfil the task for a given time period. When there are noticeable defects in a structure such as visible cracks in a building, a study to determine the condition of the building is carried out.

In structural monitoring, periodic measurement of displacements, strains, stresses and damage evaluation (e.g. crack width) and vibration characteristics are carried out. This is necessary in order to detect the changes that have taken place in the structure or where the structure appeals to be at risk so as to plan for evacuation as in the current case study.

In order to carry out inspection and monitoring, the surveyor requires some basic equipment to be used during the survey. Such equipment include those used for visual inspection such as digital camera, stress and strain tests are carried out to test the structural integrity of various components of the building structure. They enable for the detection of the sources of bending cracks and displacement. In this instance, a combination of structural, Geotechnical and Geomatics Engineering methods were applied in assessing the structural integrity of In-service school building in Benin City.

Analysis of the Geotechnical results along with Total Station surveys and Schmidt Hammer tests revealed that the large cracks occurring in the building were as a result of differential settlement in the building foundation.

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1. INTRODUCTION

Measurement and documentation for the integrity of in-service buildings are necessary to provide information for maintenance planning and prevent complete collapse of an in-service building.

Structural integrity assessment is a process by which we determine how reliable an existing structure is able to carry current and future loads and fulfil the tasks for a given time period (Rucker, Hiller and Rohrmann, (2006)). The main task for assessment is to ensure that a structure or part of the structure don't fail under loading.

As a result, it has become more common for responsible authorities or owners of properties which are subjected to regular or periodic loading to carryout monitoring of structural elements or carryout observation to determine the level of structural integrity of buildings.

In structural monitoring, periodic measurement of displacement, strains, stresses, damage evaluation (e.g. crack width) and vibration characteristics are carried out with the sole objective of either detecting the changes that have taken place in the structure or where the structure appears to be at risk to plan for its evacuation.

When there are noticeable defects in the structure such as visible cracks in a building, a study to determine the condition of the building is carried out. Such investigation should identify the type of defect such as cracking and subsidence, settlement or movement of the structure. Technical expertise and an understanding of building construction is essential to correctly identify the cause of building defects and the remedial measures required to put the defects right.

1.1 Building Defects Inspection

Building inspection is a general surface examination of those parts of a property which are accessible. In other words, the area should be visible and readily available for examination without risk of causing damage to the property of injury to the surveyor (Che – Ani et al).

In order to carry out the inspection, the surveyor requires some basic equipment to be used during the survey. In general four types of inspection are distinguishable: these include visual inspection, concealed object inspection, Dampness inspection, stress and strain survey.

In visual inspection, the equipment include digital camera, binoculars, magnifying glass, video recorder etc. Concealed object inspection may be carried out by the use of cover meter, fibrescope, endoscope etc. Dampness inspection may be carried out using digital thermometer, hygro test kit, wheel etc.

Stress and strain tests are carried out to test the structural integrity of various component of the building structure. They enable for the detection of sources of bending, cracks and displacement in the structures. Some of the equipments for this test include strain gauge, ultrasound and Geodetic survey methods. In carrying out building defects inspection, Hoxley

(2002) and Ramly (2004) have suggested that the essential elements of survey is to become familiar with the building before actual inspection commences.
From the original site visit to the building being investigated, the most common feature was the development of several cracks, hence the causes, effects and measures for the control of these cracks assume greater importance in this study.

2. CRACKS IN BUILDINGS.

Cracks are common occurrence in buildings. Cracks develop in a building or sections of a building whenever stress in the component exceeds its strength. Stress in the building component may be caused by externally applied forces such as dead and live load or foundation settlement or it could be induced internally by thermal variation, moisture changes, chemical actions etc.

Buildings are usually constructed with different rigid materials. Hence, when movement occurs, there are bound to be cracks. A proper understanding of the type of movement that has caused the crack, and the rate at which this movement is to be expected in the future, is a key step in analysing and providing specifications for the repairs of the cracks.

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 on which the building is built, or a small portion of it. Thus, crack is not the cause, but rather the sign that shows that the building is undergoing movement [Dickson (2004)].

There are two major reasons why buildings move, and they include:

- Movement as a result of conditions below ground; and
- Movement as a result of conditions above ground.

Movement due to conditions below ground

Some of the conditions below ground that could cause buildings to move as listed in a publication by the faculty of Built Environment, Bristol University in Chelsea.

- Seasonal movements as found in clay soils
- Frost heave as found mainly in sandy soils
- Geological faults and mining subsidence
- Variable ground conditions
- Differential movement
- Chemical attack
- Soil creep
- Tree roots
- Broken drains

Movement due to conditions above ground

Some of the conditions above ground that could also cause buildings to move are:

- Thermal movement
- Moisture movement
- Corrosion of embedded steel
- Lack of lateral restraint
- Excess loading or change in loading patterns
- Impact damage
- Chemical attack
- Poor workmanship

2.1. Equipment for Measuring Cracks In Buildings

Crack widths in buildings can be measured using different equipment ranging from simple and less accurate to more sophisticated and precise equipment. Examples of some equipment used for measuring crack widths as given in Freeman, Little John and Driscolli (1994) include:

- Steel rule
- Magnifying glass fitted with a graticule
- Demec gauge
- Caliper

Schutter (2002) also demonstrated that cracks in buildings can be measured using a video microscope, and introduced the video microscope crack monitoring system.

2.2 . Methods for Measuring Cracks In Buildings

There are several methods/ techniques that have been used for measuring and monitoring cracks in buildings, some of them have been discussed here:

- ***Magnifier and graticule:*** This method can be used to measure internal cracks in plaster or other smooth finishes. A description of this method is shown in Figure 2. It involves measuring the offset between two pencil marks using a magnifying glass fitted with a graticule. It can measure crack widths to an accuracy of 0.1mm.
- ***Plastic tell – tales:*** This method involves screwing two overlapping plates to the wall where the crack is, each plate mounted on opposite sides of the crack. One of the platesis usually marked with a cursor while the other with a scale graded in millimetres. The cursor is initially placed at the centre of the scale, thus any subsequent movement of the building can be measured to the nearest millimetre from the scale.
- ***Demec points:*** This method involves fixing two small stainless steel discs on opposite sides of the crack, and measuring the distance between them using a demec gauge. Demec gauge can measure movements in buildings to high accuracies up to 0.02mm.

A major setback it has is that it can only be used on flat surfaces and not corners. It can also detect changes due to temperature and moisture, which sometimes can lead to misleading results.

- ***Brass screws:*** This is a simple technique recommended by BRE [1989] that can be used to measure cracks in walls. Small brass screws are fixed on opposite sides of the crack on the wall, and the distance between them is measured with calipers. This has the advantage of being used to measure cracks both on flat surfaces and corners.

- ***Non –destructive methods:*** There are several non – destructive techniques that can be applied in monitoring/ measuring cracks in buildings/ structures. The video microscope, which was discussed extensively by Schutter [2002] can measure crack widths to accuracies ranging from 0.02mm to 0.002mm, depending on the magnification. Acoustic emission techniques have also been used for crack monitoring and this has been reported by several authors [Maltreral (2004), Kepta, Jiwen (2007) and Kr (2007)]. Also, Orlando and several others [Leckbeusch (2003), Pierakinieral (2004), Whiteral and Slob (2009)], have reported the use of ground – penetrating radar (GPR) in the monitoring of movements in buildings. Niemeirer et al (2008) also reported the development of a digital crack monitoring system (DCMS) consisting of a camera device and processing software. The accuracy of the equipment is reported to be in the range of 0.05mm.

3. SITE DESCRIPTION

St. Mary dedication international school is located along Sapele road in Benin City at a distance of about 0.75Km from the city centre. The school consist of blocks of classrooms, offices and dormitories.

The layout of the building at the school is shown in Fig 1 while the attribute descriptions of the building are shown in Table 1.

Table I: Attribute Characteristics of School Building

Block – ID	Floors (Nos)	Uses
Block - A	4	Offices, classroom, Laboratories and dormitory
Block - B	3	Offices and classroom
Block - C	2	Ceremonial and Assembly hall
Block - D	3	Offices and classroom
Block - E	3	Kitchen, offices and stores

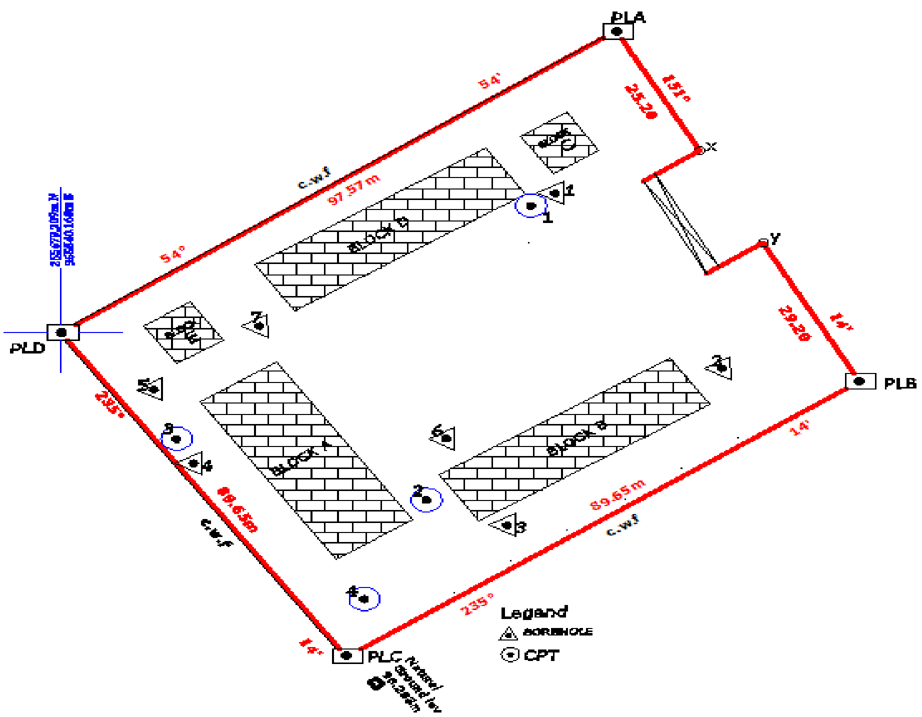

Fig 1: Plan of the Compound showing Building with sampling points

There are five blocks of buildings within the school compound.
Shear cracks are noticeable in many of the buildings particularly block A which is multi functional block having offices, classrooms, Laboratories and dormitories. The cracks are more noticeable on the west wing of the building separated by expansion joint. Most of the cracks run from the ground floor to the roof.

3.1 Data Collection.

The first phase of work involved a review of the original designs and construction documents and drawings with the necessary approval by the Edo Development and Property Authority (EDPA). These were used to

- Assess the structural layout of the buildings
- Identify critical areas for inspection
- Identify the specified loads to assess usage and possibility of overloading.
- Verify if unauthorised addition or alteration have been carried out in the building strucutures.

Based on these evaluations, the following field surveys were carried out:

i. Topographical survey of the project site
ii. As Built surveys of the buildings.
iii. Geotechnical investigation within the building area and Georeferencing of borehole and CPT locations.
iv. Visual inspection of building

v. Measurement of crack width and length.
vi. Rebound hammer tests on concrete column.

3.2 Visual Inspection

Visual inspection is usually the first step in the investigation of the causes, nature and extent of deterioration in structures. The equipment used for visual inspection in this study includes a digital camera, video recorder; touch light, magnifying glasses and a steel tape.
During inspection, it was discovered that the situation in the building endangers the safety of the children using the building. The school authority was therefore informed both orally and in writing to evacuate the building and recommended that appropriate action be taken in a timely manner.

3.3 Topographical Survey and As-Built Survey of the Project

The topographical survey was carried out to determine the direction of ground slope and level of water soaking into the foundation of block A which may be responsible for weakening foundation soils and contributing to the differential settlement.
As-built survey of the building was carried out using a Total Station instrument. The building interiors were measured with a steel tape. The purpose of the As-built survey was to determine if there was any marked deviation of the constructed building from the original design in terms of numbers of columns, beams and their sizes, block sizes etc their alignment and placement.

3.4 Geotechnical Investigation

Soil condition assessment was carried out by both field and laboratory procedures. Subsoil geotechnical investigation was carried out by borehole drilling using hand auger and in-situ bearing capacity determination using Dutch Cone Penetrometer.
The soil sampling points and the DCPT tests points were Geo-referenced using the Total Station instrument. Recovered samples were identified and taken in cellophane bags to the laboratory for testing for specific gravity, moisture content, Particle Size distribution, Shear strength and consistency tests.

3.5 Assessment of Concrete Strength Using Rebound Hammer.

Structural material assessments were conducted using non destructive testing procedures. The structural elements of the buildings after visual assessment were subjected to non destructive strength assessment. These involved the columns, beams, slabs and isolated foundation footings. The tests were carried out using the Schmidt Hammer techniques.

3.6 Measurement of Cracks in Building

Cracks widths were measured using a combination of metric rule and magnifying glass fitted with graticule. The method involved measuring the offset between two pencil marks using a magnifying glass fitted with graticule (see figure 2)

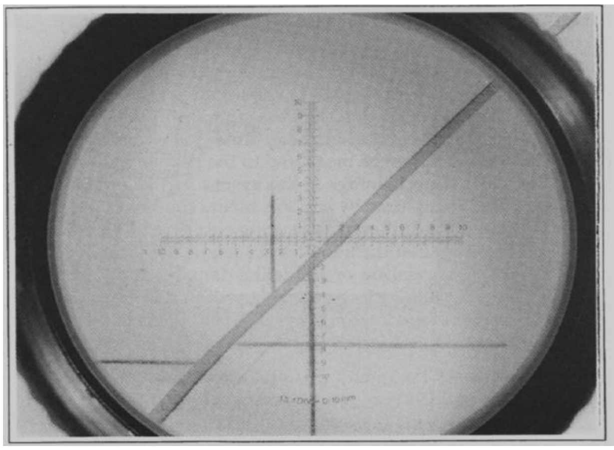

Figure 2: Measuring crack width using a magnifying glass and graticule

4. RESULTS AND DISCUSSION

4.1 Visual Inspection

Visual inspection of various parts of the building show that Block A has sufficiently suffered serious structural deterioration. Several cracks both longitudinal and transverse were observed particularly in the west wing of the block. Many of the cracks run from the ground floor to the roof. Photographic images of many of the cracks are shown in fig 3 to fig 8.

Fig 3: crack in office wall

Fig 4: crack along outside Column D4

Fig 5: crack around Beams

Fig 6: major crack in wall

Fig 7: diagonal crack on wall

Fig 8: crack in Window

4.2 Topographical and As-Built Details

The total station survey results were used to develop a 3D terrain model of the site in order to determine the direction of runoff. Contour lines were created using the Graded TIN interpolation. From the contours, slopes were generated as required. The 3D model and contour plan are shown in Fig 9 and 10 respectively.

The purpose of the survey was to determine if the percolation of storm water in to the ground at the foundation of the building is responsible for weakening of the soil and creating differential settlement. The results showed the ground slopes in the direction of the building and runoff entering the weak soil as the foundation is a contributing factor to the foundation settlement in Block A.

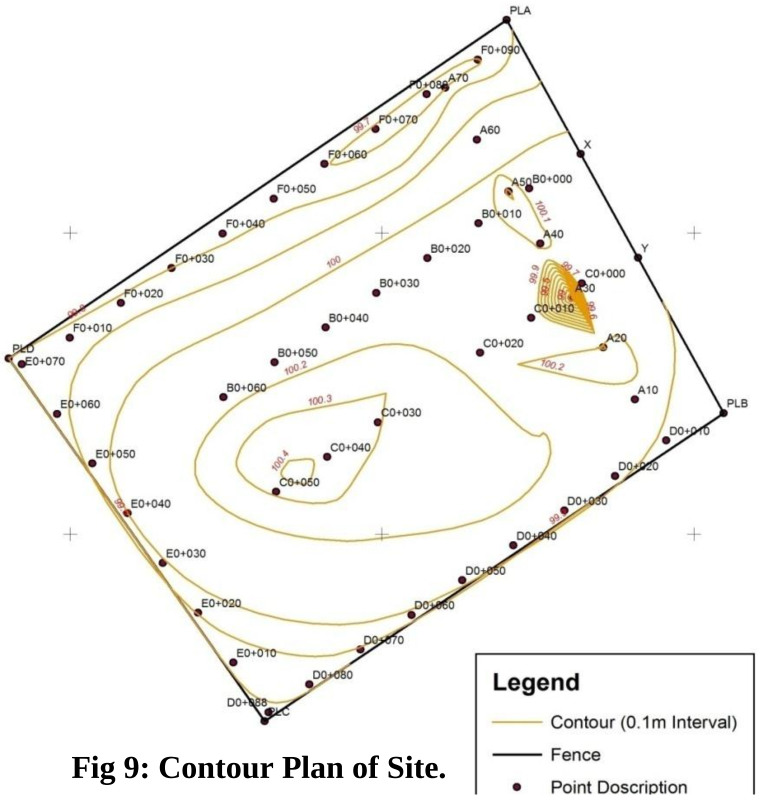

Fig 9: Contour Plan of Site.

The As-Built surveys were used to fix the position of the various structural elements of the building including column position to see if the buildings as constructed differ appreciably from design. The results of the survey showed no marked variation of the building As-built from the final design.

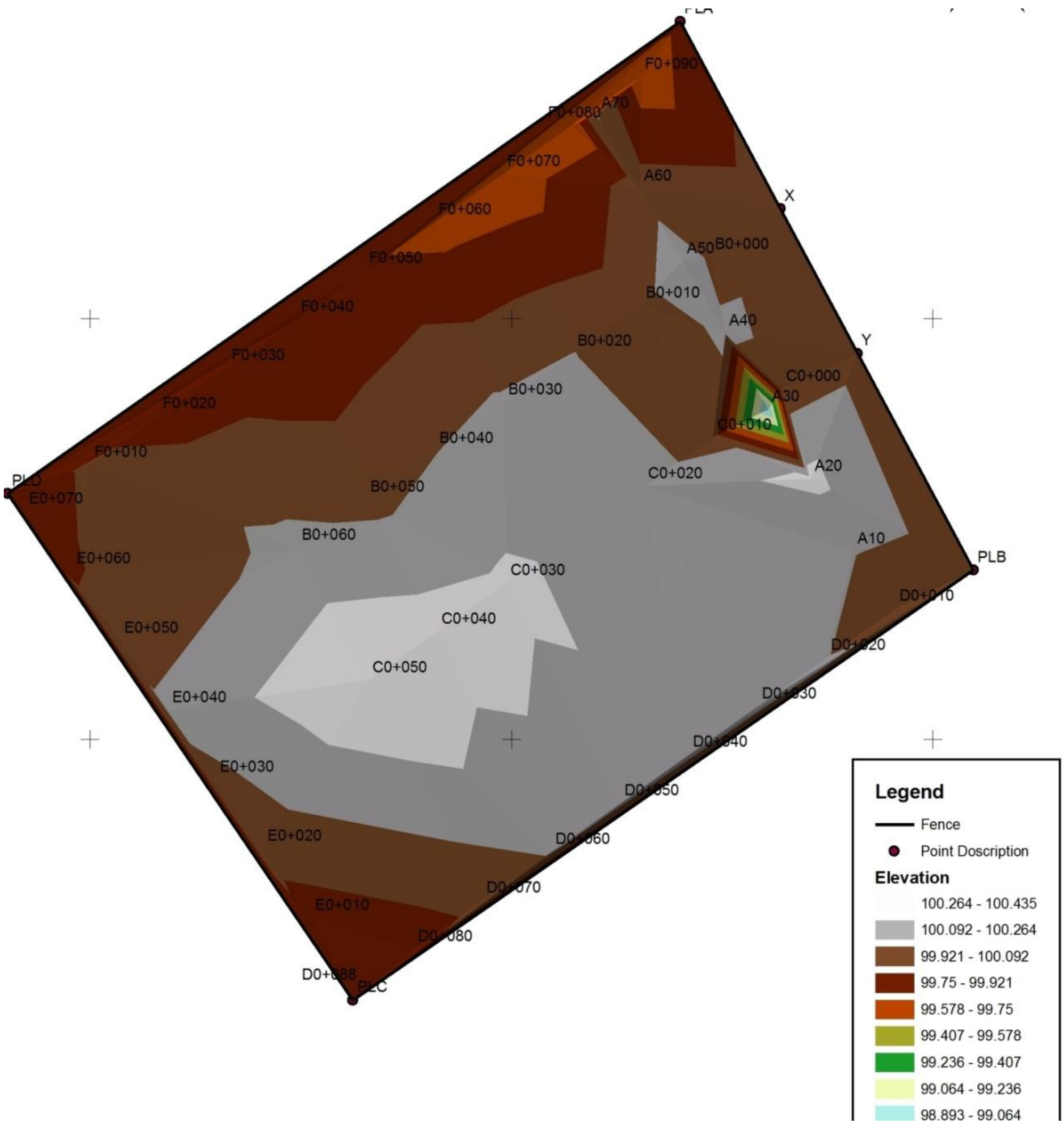

Fig 10: 3D model of the Project Site.

4.3 Geotechnical Investigation Results.

The location coordinates of the Boreholes and CPT points are shown in table II.

Tabe II: BOREHOLE CORDINATES

S/N	Borehole No.	NORTHING	EASTING
1	BH 1	255705.126	355611.103
2	BH 2	255672.550	355635.118

3	BH 3	255643.349	355604.164
4	BH 4	255654.869	355559.144
5	BH 5	255668.597	355553.450
6	BH 6	255659.494	355595.450
7	BH 7	255680.397	355568.598
8	CPT 1	255702.777	355607.655
9	CPT 2	255648.049	355592.627
10	CPT 3	255659.595	355556.686
11	CPT 4	255629.595	355583.672

The results of the geotechnical investigation show that the specific gravity of the soil varied from 2.46 to 2.64 indicative of sandy clayed soils. The liquid limit varied from 20% to 80% while the plasticity index was generally in the range of 20 – 50%. Particle size distribution in the soil showed clayed content varying from 40 – 60%. Optimum moisture content in the soil ranged from about 10 – 18%. From the structural analysis point of view, the isolated footings existing in the site are expected to have a maximum settlement varying from 13.88 to 104.89mm with an average of 53.66mm and the maximum differential settlement about 91.01mm (in standard practice, maximum differential settlement should be 25mm and the maximum differential settlement is limited to half of the total allowable settlement i.e. 12.50mm). In the site under consideration, there is a considerable amount of clay content in the soil and the clay is likely to be saturated. In such case, settlement is likely to occur over a period of about 25years; and within 5years maximum differential settlement would have reached 40mm.

As a result, structural distress would have become noticeable as evidenced from the different types of cracks (both longitudinal and transverse) and map shaped cracks noticeable in Block A. A plot of the differential settlement – duration curve is shown in fig 11 below.

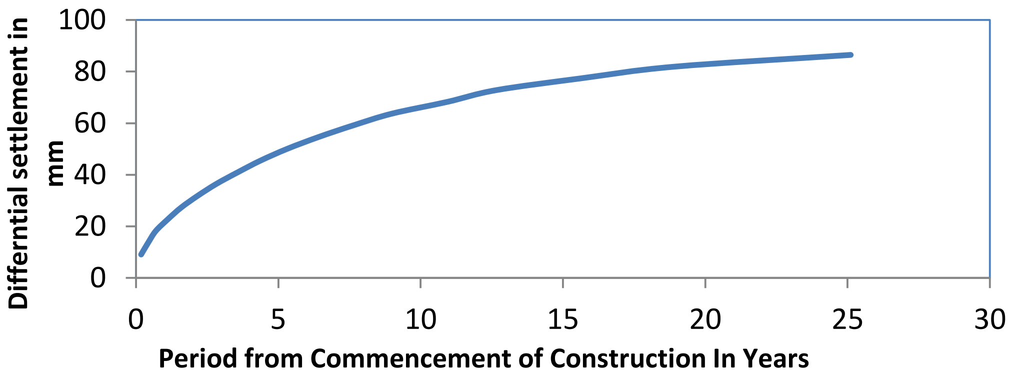

Fig-11 : Settlement-duration chart for the foundation footing

From an evaluation of the geotechnical results, the defects at the site can be said to have resulted from inadequate foundation consideration as the foundation has been designed on a consolidation soil (strata with high differential settlement.

4.4 Assessment of Concrete Strength Using Rebound Hammer.

Results of non destructive strength assessment of columns, beams and slabs using Schmidt Hammer tests are summarized in table III below:

Table III: summary of Non destructive Tests of structural Elements.

S/N	**Structural Element**	**Member**	**Mean compressive strength N/mm^2**
1	Column	D1	41
2	Column	D2	43
3	Column	D3	42
4	Column	D4	40
5	Beam – first Floor	D14	57
6	Beam – Second Floor	D14	50

In table III, the mean compressive strength for each of the structural element was > 25N/mm^2 which is the minimum acceptable compressive strength of concrete.

4.5 Crack Measurement

From the measurement carried out in block A on the major cracks, the longest of the cracks occurred along the column joint with the cracks varying from a minimum of 1.8m to 3.15m. The width of the cracks ranged from 1.75mm to 22.25mm.

Table IV: Summary of crack description for project site

S/N	Location Description	Type of cracks	Depth of crack (mm)	Crack mean width (mm)
1	Floor – BC 12	Horizontal	650	21.00
2	Wall – JK 3	Horizontal	2300	31.50
3	Column- D3	Vertical	3150	22.25
4	Column- D2	Vertical	2800	2.16
5	Wall – D E2	Vertical	750	23.00
6	Wall – D 23	Curvilinear	525	21.00
7	Column- H1	Vertical	1800	1.75
8	Wall – CD 3	Curvilinear	655	18.60
9	Beam- D34	Horizontal	600	0.75
10	Wall – DC 2	Horizontal	1200	18.50
11	Wall –PW 2	Curvilinear	620	15.51
12	Wall – PW 1	Diagonal	1250	20.62

Along the walls, the length of the cracks varied from 525mm to 2800mm while the width varied from 15.50mm to 31.50mm. The only crack noticeable on the beams was at D34 with a length of 600mm and mean width of 0.75mm. The cracking follows patterns characteristically associated with flexural and shear failure.
Diagonal cracking was found to be approximately 1.2m in length and initiated at about 0.55m from the support. In general, cracks vary in size from 0.75mm to 31.50mm.
The results of both visual inspection and instrumental measurement does show that extensive crack development and propagation occurred on the ground floor slab, columns and walls on every floor in block A.

5. CONCLUSION

This study has been carried out using a combination of structural, Geotechnical and Geomatics Engineering methods. From the investigation carried out, it has been established that inadequate foundation consideration has resulted in differential settlement which is responsible for the various cracks noticeable in building Block A. The foundation footing is found to be inducing high bearing pressure on the soil, thus resulting in substantial differential settlement.
The cracks within the building vary in width from 0.75mm to 31.50mm. As some of the cracks along the wall are more than 25mm, it means that the stability of the building is already being impaired. As these cracks taper and extend below doors and windows openings in many cases, we can conclude that the cracks has occurred as a result of subsidence.

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BIOGRAPHICAL NOTES.

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