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Causes And Remedial Measures Of Building Cracks: A Case of Enugu Area, Southeastern Nigeria

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ABSTRACT
The problem of cracking in building is becoming difficult task for engineers in recent time. This study therefore investigates the causes of building cracks on a two-floor structure in Awgu, Enugu State, South-eastern Nigeria. Four basic methods comprising of building inspection, foundation probe, non-destructive evaluation and cone penetration test were methods employed to determine the exact cause(s) of the cracks on structure. The width, pattern and conditions of the cracks were identified during the building inspection. Test results from Non Destructive Evaluation indicate that about 65.1% of the structural elements – columns, beams and slab met acceptable levels of concrete strength while about 34.9% fell below the threshold value of 25N/m2 and this is most unlikely to have contributed to the building defects. It was established from analyses of other tests conducted on the building that inadequate foundation considerations which resulted in differential settlements is a key factor responsible for the various cracks. The foundation footings were found to be inducing variations in the settlement rates due to the adverse impact of seasonal water level thereby resulting in differential settlement. The imposed stresses of metal roof structure on inadequately-sized columns is considered another construction error that could have induced the observed punching shear failure at the base joint and the cracks on the walls.
Keywords: Cracks, Building, Foundation, Concrete, Tests.

INTRODUCTION

Virtually all parts of buildings are subjected to continuing size changes, expanding or perhaps contracting as the materials used in their construction respond to changes in temperature or moisture content. Cracks are inevitable in almost all types of construction because of the kind of materials we use, the ways in which we use or misuse them and the service conditions that our buildings experience. These cracks develop whenever the stress in a building component overcomes the capacity of such component. Some common causes of cracks in buildings are poor workmanship, faulty design, structural overloading, moisture changes, thermal variations, elastic deformations, chemical reaction, permeability of concrete, creep, foundation movement and settlement of soil.

Cracks which arise as a result of faulty design, faulty construction and overloading are classified as structural cracks examples are cracks on beam, column, slab and footing whereas those from internally induced stresses are non-structural such as cracks on wall, parapet wall, driveway. Internally induced stresses in building components lead to dimensional changes and whenever there is a restraint to movement as is generally the case, cracking occurs. Non-structural cracks generally do not affect the safety of structure but develop an anaesthetic appearance and create an impression of faulty construction work. These defects can be seen in various forms on the walls of building like dampness, paint peeling, cracks. plaster rendering etc. On the other hand, structural cracks are the ones which may cause the failure of the structure during its life period if not checked (Ajagbe and Ojedele, 2018; Bonshor et. al, 2016; Johnson, 2001; More and Hirlekar, 2017).

The most commonly appearing cracks on buildings are cracks on walls and they are non-structural. Wall cracks occur usually due to poor construction practice and are common both in new and old buildings. Some of the causes for the cracks on walls include slab (roof) deflection, differential strain from stress and temperature changes, roof expansion and construction, creep and shrinkage cracking, poor details and improper construction foundations and settlements.

On the basis of their widths, cracks have been categorized into three - Thin Cracks (>1 mm in width), Medium Cracks (1 to 2 mm in width) and Wide Cracks (> 2 mm in width). The magnitude of the risk caused due to a crack can be characterized in terms of its direction, and dimensions. Cracks can be horizontal, vertical, diagonal or random. Horizontal cracks run zigzag 45-degree angle and reason for this zigzag form might be severe such as foundation shifting or water damage. Severe cracks usually require immediate attention and might include some reconstruction to prevent further damage. Vertical cracks which usually start near the junction where the wall and ceiling meet, indicate that it developed when the foundation settled after construction. Vertical cracks run the same direction as drywall. A stair-step crack looks like a flight of stairs and runs in both vertical and horizontal directions across the wall. The continuous pattern usually follows the brick line or the stone block and can be seen in unfinished basements due to the result of soil settling beneath the centre of the wall. For the rehabilitation of such cracks the soil test and the core test is recommended to encounter the probable damage to the building (Rishabh and Deepak, 2017).

Prevailing circumstances of a crack determines whether a crack is cause for concern or not, while correct diagnosis of the nature of the problem that brought it about determines whether subsequent action is needed. Cracks from different causes have varying characteristics and it is by careful observation of these characteristics that one can correctly diagnose the cause or causes of cracking and adopt appropriate remedial measures (Johnson, 2002; Mohammed, 2014; Shri Banerjee et.al., 2004).

Presence of cracks in buildings allows penetration of moisture through them thus marring the beauty of such buildings and invariably adding to cost of maintenance. It is therefore, necessary to adopt measures for prevention or minimization of these cracks.

Some remedial measures for cracks in buildings as compiled by Chetan and Yogesh (2018) and Doshi, et al. (2018) are:

i. Surface Filling Method: This is the simplest crack-repairing technique useful for only shallow surfaces (micro-cracks of width less than 0.2mm) It involves applying brush polymer or elastomeric sealant on the surface in order to prevent moisture content, carbon dioxide and other harmful materials.

ii. Crack Repair by Grouting Method: This involves the use of Portland cement grouting or chemicals grouting. Repairing of wide cracks by applying cement-based grouts is economical, safe to handle and do not require skilled worker or special equipment to apply. These materials tend to have similar properties to the parent concrete and mortar, and have the ability to undergo autogenous healing due to subsequent hydration of cementitious materials at fracture surfaces.

iii. Epoxy Resin Grout: This involves pouring of low viscous resins to fill the cracks under the action of gravity. Once the injected epoxy has cured, the surface seal should be removed by draining or other means deemed appropriate

iv. Crack Stitching: stitching procedure consists of drilling holes on both sides of the crack, cleaning the holes, and anchoring the legs of the staples in the holes, with either a non-shrink grout or an epoxy resin-based bonding system.

This study deals with diagnosis of the causes of building cracks with respect to a severely cracked 2-floor building and the appropriate remedial measures. The primary objectives of this research include to assess and confirm the type of cracks that have occurred in the case study in order to understand the causes. Knowing the cause of cracks helps understanding of the probability for future movement or damage. The nature of the foundation of the project building and the bearing pressure of the subsoil will be determined. We will also ascertain the present structural strength of the crack-laden building by performing a Non-Destructive Evaluation (NDE) to determine the compressive strength of the existing concrete structural components (Columns, Beams & Slab) with respect to standards. A major component of Non-Destructive Evaluation (NDE) is detection and characterization of anomalies such as defects, stresses and microstructural degradations in materials.

Study Area Description

Regional Geology of Enugu:

The distressed building is in Awgu, Enugu State and Enugu sheet is located within southern part of the Anambra and Lower Benue basins, and the northeast portion of the Niger Delta Complex. The main exposed lithologies are therefore Cretaceous sandstones, shales and siltstones; Tertiary clay, sandstones and shales; and Pleistocene-Oligocene sand and clays (Obaje, 2009). Awgu is situated at 6^0 4’ 0” North and 7^0 29’ 0” East with an elevation of 122m. Fig. 1 presents the map of Awgu in Enugu State showing the location of study area.

Fig 1: Map of Awgu Local Government Area in Enugu State showing the study area (Modified from Goggle)

RESEARCH METHODS

The cracked building was subjected to thorough examination and the tests employed include Visual Inspection, Non Destructive Structural Integrity Tests, Cone Penetration Test and Foundation Probe/Analysis.

Visual Inspection

Visual inspection is the moment of asking questions, observing and gathering data. The strategy is an iterative process that is reviewed and amended throughout the investigation. In other words, this observation is not conclusive but it can help with deciding on the next stage of the investigation.

Physical observation was the first stage of this study and the research team went round the building taking notes on structural or any other alterations to the building, construction materials, structural integrity and age of the building, pattern and type of the cracks. This preliminary stage helped the team to conceptualize the link between the symptom and cause of the cracking. It also assisted in deciding how the building was behaving and in developing the systematic strategy for moving the investigation forward.

Foundation Probe/Analysis

Foundation probe which involves excavation of the soil below the foundation depth (Fig. 2) was conducted on the building to visualize how the foundations were resting on the soil and to also determine foundation type/depth adopted for the construction with respect to the terrain.

Fig 2: Foundation probe showing (a) the column base at the left hand side of the building (b) the measurement of foundation depth

Foundation Probe was also conducted to determine the integrity of the building foundations with respect to possible foundation soil defects, if any, and in addition perform an analysis of the foundation system for its suitability.

These investigations are intended to show the performance of the structural elements and determine if the forces in terms of imposed loads will be at equilibrium, hence their structural stability.

Non-Destructive Structural Integrity Tests

The Non-Destructive Structural Integrity Test was conducted to ascertain the capabilities of the structure in bearing imposed loads (Fig. 3). This test is related to an assessment of structural adequacy and reliability. The test was performed by using Portable Ultrasonic Non-Destructive Digital Indicating Tester (PUNDIT) which works on the principle of ultrasonic pulse velocity (UPV). Three (3) test points were randomly selected to get a good representation/result on each structural element for the building.

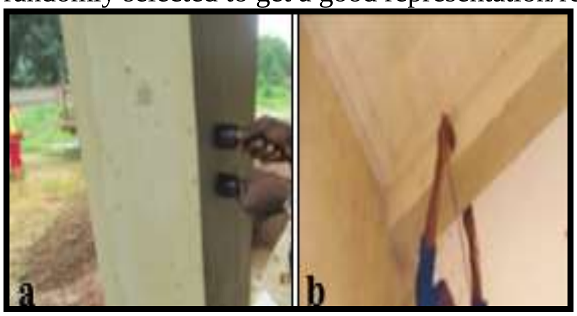

Fig. 3: testing the structural elements with PUNDIT, (a) ground floor column (b) first floor beam.

The apparatus of this method consists of a transmitter and a receiver which are held against the surfaces of concrete with couplant as a lubricant. The apparatus generates pulses of ultrasonic frequency which are transmitted through concrete by the transmitter. The receiver receives the pulses and the apparatus records them. The time of travel between initial onset and the reception of the pulse measures electronically.

The average velocity of wave propagation can be measured by dividing path length between the transducer and receiver by the time of travel. The velocity of pulses and the strength of concrete are correlated. Lower velocity of pulses implies lower strength of concrete and vice versa (Doshi et. al., 2018).

Cone Penetration Test (CPT)

The Cone Penetration test is one of the most effective means for investigation of soils in their natural state. It provides information on the type of soils and their stratification for load bearing purposes.

Cone Penetration Tests (3-nos) were executed using the Dutch Cone Penetrometer Machine. This machine is a precise instrument which measures the resistance to penetration into soil layers. The sequence of layers is interpreted from the variations of the cone resistance with depth. The cone was pushed into the ground for 20cm or 25cm by means of attached winch system at a uniform rate of about 20mm per second.

The resistance to penetration of the cone registered on the pressure gauge connected to the pressure capsule was recorded. The tube was then pushed down to the cone and the process described above was repeated.

From the series of recorded gauge readings, a plot of the cone resistance against depth is made which forms a resistance profile that indicates the strata sequences penetrated.

RESULTS AND DISCUSSION

Visual Inspection Notes

The distressed building is a 2-floor on-going building located at Awgu, Enugu State and bounded on the right and left hand sides by undeveloped plots of land and an untarred road respectively. At the rear is a Community Primary. The terrain of the building was observed to be a water-logged area Construction work on the building was at finishes *(tiling)* stage. There was no effective storm water drainage system observed within the premises of the building at the time of test.

The sizes of columns and beams seen were (225mm x 225mm) and (225mm x 350mm) respectively. Information gathered on site revealed that metal roof trusses were used for the construction of the roof structure.

Vertical, diagonal and horizontal cracks were noticed on the ground & first floors internal & external walls of the building (Fig. 4 and Fig. 5).

Fig. 4: Some of the observed cracks, (a) diagonal crack on ground floor internal wall (b) diagonal crack on ground floor external wall

Fig. 5: Vertical crack observed on first floor internal wall of the project structure.

Considering the vertical load and the imposed stresses of the metal roof structure, the sizes of columns may be considered inadequate for effective vertical load transmission to the substructure.

This is most likely considered as one of the errors leading to defect in the building which induced the punching shear failure at the column/base joint noticed.

Foundation Probe Findings

The foundations of the building consist essentially of isolated column pad footings about 1.6m x 1.6m x 0.3m (Depth) each located at about 1.7m from the ground floor slab to foundation depth.

The height of the substructure from natural ground level (NGL) to foundation depth is 1.3m and ground water table was noticed at 0.8m depth from NGL during probe.

The probe further indicates that the foundation type adopted for the building was not suitable for a water-logged area since it may not support even distribution of load over the entire area of the foundation when submerged or in its saturated state.

Isolated pad footings with strip foundation for the walls were adopted for the shallow foundation. Vertical wall heights are about 3.4m and 3.2m respectively for ground and first floor.

Vertical cracks were noticed on the substructure of the building during foundation probe.

Punching shear failure was also noticed at the foundation/column joint on the posterior right hand side of the building during the probe (Fig. 6). Foundation peripheral beams were evident at the upper layers of the foundation grid.

Fig. 6: punching shear failure on foundation column

The foundation type for the construction method adopted is designed to accommodate settlements within tolerable limits but rise in water table due to seasonal changes may have produced additional settlements which can threaten the integrity of the structure ultimately leading to cracks in walls.

Therefore, inadequate foundation consideration in view of the potential for differential settlement due to seasonal variations in the water table could have affected the integrity of the building.

This phenomenon is considered as one of the major construction errors that led to development of the cracks.

The Vertical and Diagonal cracks were caused by differential settlement of foundation elements while the Horizontal cracks may likely have been due to applied loading as a result of imposed stresses from the metal roof structure.

Non-Destructive Test Results

Tests results from Non Destructive Evaluation indicate that about 65.1% of the structural elements – columns, beams and slab met acceptable levels of concrete strength while about 34.9% were considered of poor quality concrete mix.

The results as above do not constitute very grave errors of construction and may not have contributed largely to the existence of cracks and defects as noticed.

Cone Penetration Test Results

The Cone penetration test results indicate soil with sufficient capacity for the imposed loads as the gravel/coarse aggregate content of the soil was relatively high. However, the effects of seasonal variations in the ground water table on granular soils could have adverse impact on the foundation soil thereby inducing differential settlement of foundation elements.

Under such conditions, the choice of foundation type becomes a critical and important consideration.

CONCLUSION AND RECOMMENDATIONS

Vertical, diagonal and horizontal Cracks in this study were induced by excessive roof load on the inadequately sized structural elements thereby putting the masonry walls in compression resulting to cracks. Contributory causes also include adverse effects of foundation inadequacy.

Recommendations for remedial measures include the following:

1. Increasing the sizes or stiffening the vertical support elements such as the columns. The adequacy of 450mm x 225mm size should be checked. All elements rated poor should equally be stiffened with particular attention paid to ground floor columns since they are responsible for transmission of load to the foundations.
2. Sections of the building where cracks were observed should be repaired by grouting the affected sections with adequate mortar mix.
3. Foundation underpinning which is the process of stiffening the foundation of an existing building be carried out.
4. Load analysis should be conducted in order to optimize the structural configuration of the building.
5. Construction of effective storm water drainage system, building perimeter apron, eavestroughs and roof gutter should be ensured to prevent degradation and saturation of the soils around the foundation.

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