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Structural Investigation into the Causes of Cracks in Building and Solutions: A Case Study

Ajagbe W.O[* 1], Ojedele O. S. [#2].
[*1] *Department of Civil Engineering, University of Ibadan, Oyo State, Nigeria*
[# 2]*Michael Okpara University of Agriculture, Umudike P.M.B. 7267, Umudike, Abia State, Nigeria*
**Corresponding Author: Ajagbe W.O.*

ABSTRACT *-Cracks are commonly found on and in structures and are usually undesirable features naturally occurring due to age, workmanship and other natural and environmental causes. This study is set to characterize cracks with the principal aim of recommending proper maintenance and efficient repair actions. Crack occurrence in an office building (storey with basement) was investigated as a case study. Reconnaissance survey was carried out to locate and note the tools that would be required for the investigation of the cracks. Visual examination and measurement of cracks to know the cause and type of each crack were performed. Strength test of all the structural members was done using Schmidt hammer to determine the residual strength of the members on which they appear and the results were analyzed. The results of the reconnaissance survey revealed that most of the cracks are located at the left side than at right side elevation of the building. The nature of the cracks showed that 91% are dormant cracks, while 9% are active cracks. Some of the cracks extended to the plastered surface, while the rest extended to the structural elements region. Therefore, the cracks in this building were found to be caused by the drying shrinkage at the wall section, the compressive force from the beams exceeding the ultimate strength of the affected blocks, foundation settlement at the courtyard was also discovered through topographical survey, due to underground erosion of the foundation wall footing. The results of the non-destructive test (NDT) indicated that, the average strength of the structural elements is within acceptable limit.*

KEYWORD*-Cracks, Drying Shrinkage, Non-destructive Test, Building, Structural Elements.*

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I. INTRODUCTION

Cracks are signs of structural movement, during and after construction. Such movement occurs all the time, and usually its magnitude is so small that it passes unnoticed [1].

Most buildings crack at some time during their service lives. The appearance of cracks is a symptom of distress within the fabric of the building. According to [2], crack is an evidence of gradual deterioration and damage to structures. Often the cracking is of little consequence and once it is established as static, simple repair by filling or re-pointing is all that is required. However, a crack may be the first sign of a serious defect which may affect the serviceability or the stability of the building [3].

Crack is a structural defect consisting of complete or incomplete separation within a single element or between contiguous elements of construction. It can also be defined as a line along which a material is broken into parts.

Every crack is an indication that the building is becoming unsafe, though the factor of safety for structural walling is high and the relative importance of many cracks is low [4]. Rarely does a building collapse soon after the appearance of a crack, even if the crack is large, nevertheless, it is important to note this in order to prevent any undesired loss of life or property. Therefore, correctly assessing the significance of cracks is essential. Many cracks have similar appearance, though their causes are different [5]. An engineer should have a sound knowledge of causes, effect and types of cracks likely to occur from the behavior of construction materials and construction techniques, which will enable him, proffer the appropriate prevention and remedial measures [6]. The side effect of cracks affects the integrity, permeability, structural and mechanical properties of buildings.

Cracks could be broadly classified as structural or non-structural. Non-structural cracks develop due to the inducement of internal stresses in the building materials and their depth is less, only a few mm i.e. they exist on the surface only. Typically, causes of these cracks are poor workmanship, inappropriate joint detailing, and higher shrinkage of concrete. While Structural cracks develop due to the following causes; design deficiency, construction deficiency, settlement of foundation, reinforcement corrosion, and effect of temperature variation, overloading, swelling of soil below the foundation of the structure [7]. The nature of cracks according to [8] can be classified as active crack which is still in progress, that is, the crack is still developing, and dormant cracks, in which the development is not observed during a considerable period of time, and then this crack is known as dormant crack.

It is also important to assess causes of cracks through measurement of cracks' characteristics, which are location, nature, direction, width, depth, position and extent of cracks, and how to repair them.

Cracks may appreciably vary in width from very thin hair cracks barely visible to naked eye (about 0.01 mm in width) to gaping cracks 5 mm or more in width. A commonly known classification' of cracks, based on their width is: (a) *thin* - less than1 mm in width, (b) *medium*- I to 2mm in width, and (c) *wide*- more than 2 mm in width[9].

The research study of the causes, effects and solutions of cracks in building is of importance and would be of benefit to the country by reducing the alarming rate of building collapse.The results of the study helped to create awareness on the types and causes of building cracks and the dangers attached if it is not arrested on time. It will also help in providing information necessary to prevent its occurrence, and at the same time emphasizing the need for periodic maintenance as a way of preventing loss of life, and property due to building collapse.

The study of causes and solutions to cracks was considered in the study using a case study of a two-storey office building in the University of Ibadan, which has different categories of cracks and it is making the use of the building uncomfortable by the occupants. Appropriate remedial measures will be proposed to save the building from further deterioration and to extend the life of the structure.

II. METHODOLOGY

A. Area of Study

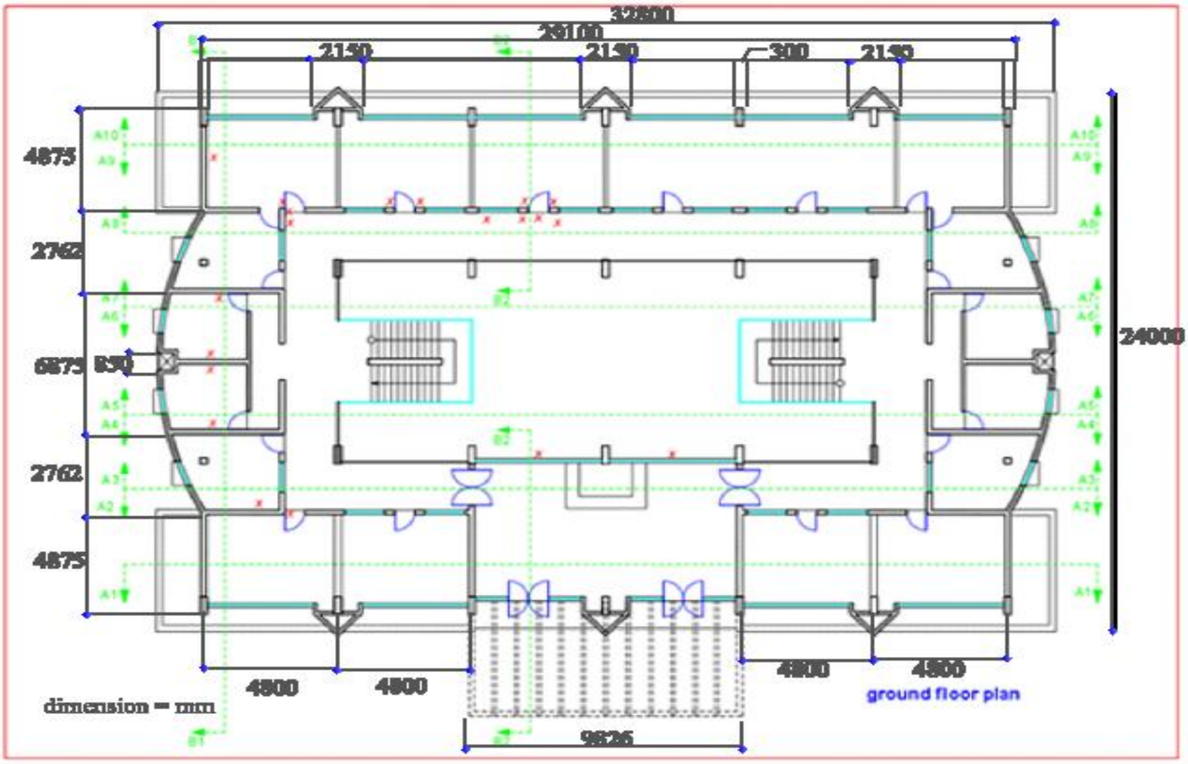
The study on the investigation of the causes and solutions to cracks in buildings was undertaken in a two-storey building, located in the Faculty of Technology, University of Ibadan. The University of Ibadan is the oldest Nigerian University, and is located five miles (8 kilometers) from the center of the major city of Ibadan in western Nigeria [10]. The building was commissioned on the 20th of December, 2008, and it was meant to accommodate staffs and students for lectures. It is located at Latitude 7.43^{o}N and Longitude 3.88^{o}E. Fig. 1 and 2 show the ground and second floor plans of the building respectively.

The study was carried out in three stages; firstly, identification of cracks and their causes by reconnaissance survey; desk study; visual observation; identification of tools; survey/investigation of the cracks; secondly, strength assessment of the building structural elements; and thirdly analysis of data to proffer solutions to the causes of these cracks.

B. Identification of Cracks and their Causes

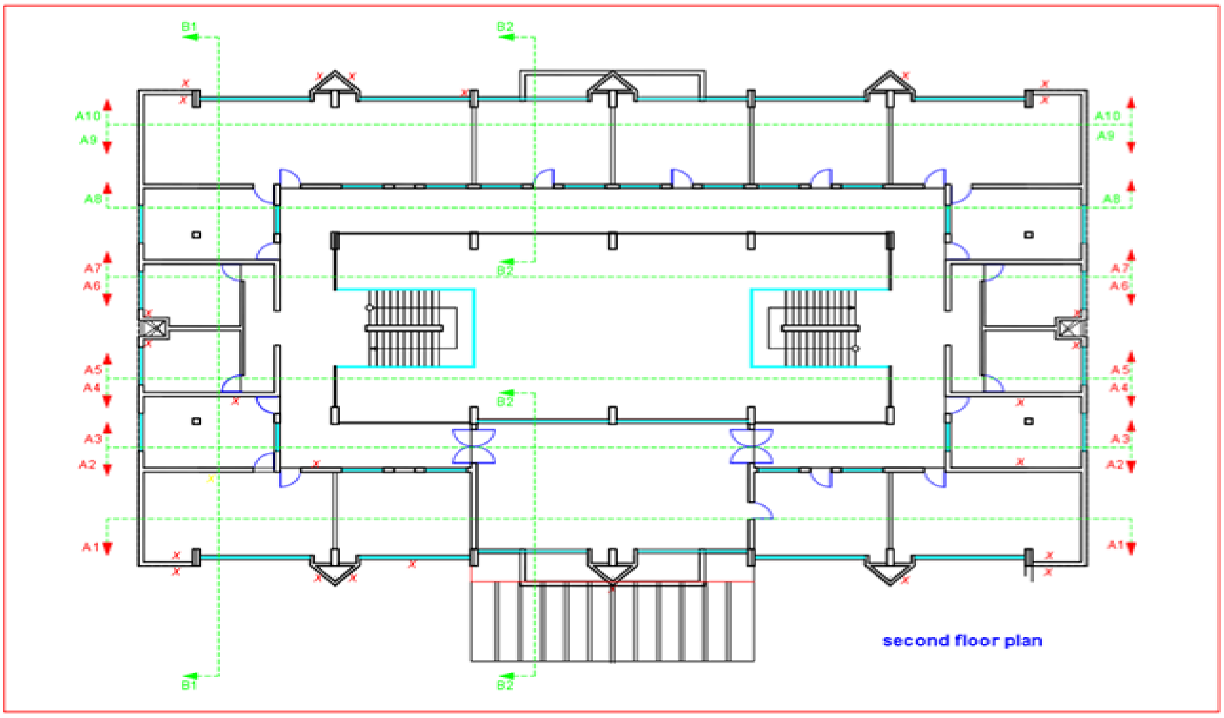
In reconnaissance survey, the building inspection was carried out to diagnose the cracks in the building, by looking at the whole building from a distance, walking round the building, and observation of each room to locate the cracks, and detail measurement of each crack, and their location in the building. The desk study was performed using the architectural design plan to: Check the layout of the building and location of each structural member. It was used to create the identification codes and the detailed observation procedure. Each floor was divided into two wings WING A (named as A) and WING B (named as B). The rooms were named as "R", the walls were named as W1 (Wall 1), W2 (Wall 2), etc. The cracks were named as CR 1, CR 2, etc. Other structural elements which are Floor Slabs, Beams, and Columns were coded as FL, BM, and Col respectively. (See Table 1).It was used to create design manifest for recording the observation of the cracks (See Table 2) and design manifest to record Rebound Hammer Readings (See Table 3).Other areas of investigation include critical visual observation of key areas of the building such as; the pattern of cracks' defects on load bearing/shear walls, floor slab, beams, columns, examination of floor finishes and walls, the examination of column interface with ground floor slab to establish possible foundation settlement, the study of available relevant architectural plan, in order to affirm the consistency of the design concepts interpreted in detailed drawings and finished construction. The tools used for the study were (a) Measuring tape: to determine the depth and width of cracks. (b) Needle or Needle-typed wire: to determine the depth of cracks. (c) Tell-tale tool: to determine the nature of the cracks/monitor the cracks. (d) Schmidt Hammer: to determine the strength of the structural elements (Floor Slab, Beams, and Columns of the building). Survey/Investigation of the cracks was done to investigate on what might have caused the occurrence of each crack in the building. The cracks were grouped based on the findings, which are drying shrinkage, architectural design fault, foundation settlement, and movement due to creep.

X =



X = Location of the cracks

Fig.1. Ground floor plan of the building



X = Location of the cracks

Fig.2.Second floor plan of the building

C. Strength Assessment of the Building Structural Elements

A Schmidt hammer was used to assess the strength of the structural elements (See Plate 6). The strength of each structural element was obtained by taking the average of seven recorded values of Schmidt Hammer Reading. The Non-Destructive Schmidt Hammer Test conducted on the building under appraisal comprises of the basement, ground, first, and second floors. The summary of the findings were presented in Table 4.

TABLEI:Definition of the Codes Used for the Building

BUILDING ELEMENT	DEFINITION
FB-R1	BASEMENT FLOOR-ROOM 1
F0-A-R1	GROUND FLOOR-WING A-ROOM 1
F0-B-R1	GROUND FLOOR-WING B-ROOM 1
F1-A-R1	FIRST FLOOR-WING A-ROOM 1
F1-B-R1	FIRST FLOOR- WING B- ROOM 1
F2-A-R1	SECOND FLOOR- WING A- ROOM 1
F2-B-R1	SECOND FLOOR- WING B- ROOM 1
W1	WALL 1
W1/CR1	WALL 1/ CRACK 1
FL	FLOOR SLAB
BM 1	BEAM 1
Col.1	COLUMN 1

III. RESULTS AND DISCUSSIONS

A. Brief Discussion on the Building Understudy

Emmanuel Egboga building has 53 rooms, and four floors, which are basement floor (named as FB), ground floor (named as F0), first floor (named as F1), and second floor (named as F2) as shown in Plate 1. The structural frame members consist of 129 beams, 92 columns, and 240 walls in total. It is covered at the roof with aluminium roofing sheets, and contains roof gutter for proper drainage. It also contains retaining wall that links the basement floor to the ground floor. The predominant nature of cracks observed was dormant. The dirty surface of the cracks also indicated that they were dormant.

Plate 1. Front view of the building

The parts of the building caused by drying shrinkage are: F0-A-R4-W4, F1-A-R4-W1, F2-A-R2-W6.The cracks were caused by shrinkage of the plastering, since it is a surface crack; the shrinkage may be due to use of high ratio of cement to sand, and inadequate curing. Shrinkage crack occurs during the first dry spell after plastering. Their measured values were shown in Tables 2 and 3, and picture in Plate 2.The proffered solution is that, this type of crack could be left unattended up to the normal time for renewal of finishing coat when this will get filled up, or the surface is scrap and refill with good mix ratio of cement and sand and proper curing.

Plate 2. Picture of random cracks due to drying shrinkage

The second type of cracks observed (F0-Female Toilet-W1, F0-Male Toilet-W1, F1-Male Toilet-W2, F1-Male Toilet-W3, F0-A-R4-W4) were primarily on the sandcrete wall under a 7.3m span flanged beam. The cracks on F0-Female Toilet-W1, F0-Male Toilet-W1, F1-Male Toilet-W2, and F1-Male Toilet-W3 were similar in their cause. It was observed that the long spanned beam (7,226mm=7.3m), rested on the non-load bearing wall for support due to sagging at the mid-span thus subjecting the wall to stresses that it was not designed to sustain (See Tables 2 and 3, and Plate 3). The sagging effect of the beam may be as a result of faulty design or inadequate reinforcement provided during construction. The suggested solution is to introduce a column (preferably a steel section) to support the beam along the mid span while the cracked wall should be removed and replaced with load bearing wall. In addition, two columns should be erected from the basement to support the slab at the lobby of the toilet entrance.

Plate 3. Picture of crack on male toilet (internal view) due to long span

Plate 4. Picture of cracks on F0-A-R4-W4 (external view) due to long span

The type of crack shown in Plate 4 occurred at wallF0-A-R4-W4 (External View). This type of crack generally occurs when windows and room spans are very large. The horizontal cracks at the window lintel level (See Table 2 and Plate 4) are due to pressure exerted on the wall by slab, because of drying shrinkage and thermal contraction. This pressure resulted in bending of the wall, which caused cracking at a weak section, that is, at the lintel level of the window openings. These cracks could have been avoided if slip joint at beam supports on the walls have been provided, to permit movement without encountering much restraint. The cracks can be repaired by filling with a mastic compound after widening and cleaning the cracks. These cracks if repaired with strong mortar have a tendency to occur again [12, 29].

The third type of cracks observed at F0-B-R4-W1-CR1, F0-B-R4-W1-CR2, F0-B-R4-W1-CR3, F0-B-R4-W1-CR4, Door Frame, Ground floor Walkwaywere caused by foundation settlement (See Table 2, Plate 5 and 6).

Plate 5: Picture of Crack on room 4 and ground floor's walkway, wing B, due to foundation settlement

Plate 6: Picture of cracks on room 4, wing B, due to foundation settlement

It was discovered through topographical survey, that lack of drainage at the open courtyard allows percolation of water into the soil and thus this crack undermines the sand under the floor and including the wall strip footing. This could be said to be responsible for the cracks in the region, for the cracks occurred due to settlement of soil at the region of the courtyard. The settlement also caused crack along the wooden frames of the door, which distorted the frame making it difficult to close and open the door.For Ground Floor Walkway, the crack was caused by poor drainage of water due to heavy runoff getting into the foundation at this region. The terrazzo floor settled under human traffic load (live load) and cracked across the corridor to the adjacent room. Such a settlement generally not being uniform in different parts resulted in cracking of the ground floor walkway. The provision of appropriate drainage and reconstruction of the wall footing and the floor in the affected area will eradicate the cracks and prevent future ones. Cracking due to shrinkage of wood can be concealed with the help of architraves and will not present much of a problem [29]. For cracking due to slack between holdfasts, the only satisfactory remedy is to dismantle the masonry so as to remove the frame and to reaffix with seasoned frame after securely fastening the holdfasts to the frame.

Plate 7: Picture of crack due to differential stress

Plate 8: Picture of crack due to differential stress

The fourth type of observed cracks at F0-B-R4-W1-CR5 (External View), F2-A-R2-W3 (Internal and External view), F2-A-R6-W3 (Internal and External view), F2-B-R2-W3, F2-B-R7-W3. (Internal and External view) was caused by movement due to creep. The crack on F0-B-R4-W1-CR5 (External View) is a diagonal crack (See Tables 2 and 3, Plate 7), which occurred as a result of differential stress and strain between different regions of the wall. It can be seen that portions of wall beside the window act as pillars and are stressed much more than the portions below the window. Thus, as a result of differential stress, vertical shear cracks occurred in the wall. To minimize these cracks, too much disparity in stress in different walls or parts of a wall should be avoided. If RC slabs, RC lintels over openings and masonry in plinth and foundation have good shear resistance, cracking in question would not be very significant. The proffered solution for crack on F0-B-R4-W1-CR5 can be sealed up with mortar mix ratio of 1 Cement: 1 lime : 6 Sand in the dry season or 1 Cement:2 Lime:9 Sand in the rainy season, with the avoidance of sharp sand for plastering it, and proper curing should be done for up to 7-10 days. For F2-A-R2-W3/ F2-A-R6-W3 (Internal and External view), F2-B-R2-W3/F2-B-R7-W3 (Internal and External view) as shown in plate 8, these cracks are of the same pattern, which occurred at the internal and external view is a sign of total crack of the wall (See Table 3 and Plate 8), on a load bearing structure having mostly sandcrete block walls for supporting loads of roof beam and other roof loads, roof gutter, long-span aluminium roof covering, timber purlins, timber strut, timber wall plate, and wind load. Because of these loads, in course of time, RC columns undergo some shortening due to elastic deformation, creep and shrinkage and because of difference in the strains in RC columns and masonry; vertical shear crack appeared at junction of the two materials. The preferred solution for F2-A-R2-W3/ F2-A-R6-W4 (Internal and External view), F2-B-R2-W3/F2-B-R7-W3 (Internal and External view) is that, the cracked region could be repaired by first removing the cracked or affected portion of the block, and replaced with good quality, high strength block, properly cured and allowed to dry so as to undergo initial shrinkage and then bonded to the column with the use of correct mix ratio mortar 1 cement: 2 lime: 9 sand, and curing should follow to avoid shrinkage by thermal effect. Secondly, since the wall is built right up to the soffit of the roof beam, horizontal joint should be opened out, and filled up with some joints about 10mm in width formed at the top of the wall.

Table II:Observed Cracks at the Ground Floor in the Building

Location	View	Nature	Position	Direction	Width (mm)	Depth (mm)	Extent
F0-A-R4-W4	Internal	Dormant	1100mm from W1	Vertical	0.58	2.0	Plastered surface
F0-Female Toilet-W1	Internal	Dormant	1100mm from W6	Diagonal	3.0	30.0	Block region
F0-Male Toilet-W1	Internal	Dormant	1100mm from W6	Diagonal	3.0	30.0	Block region
F0-A-R4-W4	External	Dormant	2200mm from ground	Horizontal	3.0	40.0	At lintel level
F0-B-R4-W1-CR1	External	Dormant	1700mm from floor slab	Diagonal	2.00	265.0	Totally cracked
F0-B-R4-W1-CR2	External	Dormant	1680mm from floor slab	Horizontal	3.00	265.0	Totally cracked
F0-B-R4-W1/CR3	External	Dormant	2000mm from floor slab	Horizontal	3.00	265.0	Totally cracked
F0-B-R4-W1/CR4	External	Dormant	1770mm from floor slab	Horizontal	1.55	25.0	At block region
Door Frame	External	Dormant	At the top of the door frame	Horizontal	5.00	90.0	Separation of the door frame from beam
Ground Floor Walk Way	External	Dormant	1700mm from door frame	Vertical	0.55	70.0	At block region
F0-B-R4-W1-CR5	External	Dormant	1700mm from door frame	Diagonal	0.55	70.0	At block region

Table III: Observed Cracks at the First and Second Floor in the Building

Location	View	Nature	Position	Direction	Width (mm)	Depth (mm)	Extent
F1-A-R4-WI	External	Dormant	2070mm from the floor slab	Horizontal	0.55	35.0	Plastered surface
F2-A-R2-W6	External	Active	Surface of W6	Random	0.3	0.4	Plastered surface
F1-Male Toilet-W2	Internal	Dormant	380mm from W3	Diagonal	3.0	225.0	The whole depth of block
F1-Male Toilet-W3	External	Dormant	300mm from W3	Diagonal	3.0	225.0	Totally cracked
F2-A-R2-W3	Internal	Dormant	250mm from the edge of Col.1	Vertical	5.2	265.0	Totally cracked

F2-A-R2-W3	External	Dormant	250mm from Col.1	Vertical	8.0	265	From top of the wall to the floor, wider at the top
F2-A-R6-W4	External	Dormant	1690mm from the edge of Col.2	Vertical	6.0	265.0	Totally cracked
F2-B-R2-W3	Internal	Dormant	250mm from the edge of Col.1	Vertical	7.5	265.0	Totally cracked
F2-B-R7-W3	Internal/External	Dormant	795mm from Col.1	Vertical	8.00	265.0	From the top of the wall to the floor slab

B. Rebound Hammer Reading Test

A Schmidt hammer was used to assess the strength of the structural. The strength of each structural member was obtained by taking the average of seven recorded values of Schmidt Hammer Reading. The Non-Destructive Schmidt Hammer Test conducted on the building under appraisal comprises of the basement, ground, first, and second floor. The rebound of an elastic mass depends on the hardness of the surface against which its mass strikes. When the plunger of the rebound hammer is pressed against the surface of the concrete, the spring-controlled mass rebounds and the extent of such a rebound depends upon the surface hardness of the concrete. The surface hardness generates the rebound which is directly related to the compressive strength of the concrete. The rebound value is read from a graduated scale and is designated as the rebound number or rebound index. The compressive strength can be read directly from the graph provided on the body of the hammer. The re-bound reading on the indicator scale has been calibrated by the manufacturer of the rebound hammer for horizontal impact, that is, on a vertical surface, to indicate the compressive strength. When used in any other position, appropriate correction as given by the manufacturer is to be taken into account.

The summary of the results of the Rebound Hammer Readings conducted on the structural elements of the building under study are indicated in Table 4. The minimum compressive strength required in 28 days is $25N/mm^2$. The minimum compressive strength required in one year is $31N/mm^2$. The adequacy of a reinforced concrete structural element to support loads imposed on it, is determined by the compressive strength of concrete, dimension properties, reinforcement constituent and tensile strength of the reinforcement bars. For the buildings under investigation, Grade 25 concrete with 28day compressive strength of $25N/mm^2$ is considered appropriate and adequate. This is expected to attain $31N/mm^2$in one year of the concrete age, and then marginally increase over the years. From the non-destructive Schmidt hammer rebound readings obtained for the structural elements, the average strength of the building varies between 36.8 and $48.2N/mm^2$respectively, this is within acceptable limit, and it is therefore satisfactory.

Plate 9: Picture showing the schmidthammer reading of ground floor column

Table IV:General Summary of Results for the Compressive Strength of the Structural Elements

Floor	Building Element	Average Compressive Strength (N/mm^2)
Basement	Slab	44.9
	Beam	36.8
	Column	36.9

Ground Floor	Slab	38.7
	Beam	48.2
	Column	38.6
First Floor	Slab	44.4
	Beam	45.4
	Column	39.7
Second Floor	Slab	47.9
	Beam	47.1
	Column	44.3

IV. CONCLUSION

After careful observation and study of the cracks in the building, their causes and a few solutions that could be applied to rehabilitate the building, including test of strength on structural members, it was concluded that most of the cracks are as a result of human carelessness in all the stages of construction. From the research survey, it was observed that each of the building team has great part to play in the cause of cracks in the building, and the results clearly revealed that most of the cracks in the building structure are not dangerous, except the case of the toilets at the ground floor, first floor, and the four corners of the edge of the second floor, and roof slabs, which need urgent intervention and repair. Urgent repair will prevent future collapse of the building. The appropriate remedy to crack failure is such that its nature and causes should be investigated and established before repair; otherwise wrongly treated cracks will reappear after sometime. However, causes of cracks investigation should be more concerned with what, rather than who is at fault. This will help to rectify and improve on designs, supervision, and construction of buildings to avoid building problems.

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AUTHOR PROFILE

AjagbeWasiuO.is a lecturer and researcher in University of Ibadan, Oyo, State. He holds B.Sc, M.Sc, and Ph.D award (Civil Engineering) from University of Ibadan, Ibadan, Nigeria. His areas of interest are in structural and materials engineering.

OjedeleOluwaseunis a lecturer and researcher in Michael Okpara University of Agriculture, Umudike, Abia State. He holds B.Tech and M.Sc award (Civil Engineering) from LadokeAkintola University of Technology, Ogbomoso, Oyo State and University of Ibadan, Ibadan, Nigeria respectively. His areas of interest are in farm structures, structural and materials engineering.