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# Defects in Concrete Elements: A Study of Residential Buildings of 30 Years and above in Onitsha Metropolis, Anambra State, Nigeria

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## Abstract

Building defect is an issue in existing buildings that needs urgent tackling to prevent further problems. This study assessed the defects in concrete elements in residential buildings of 30 years and above in the Onitsha metropolis of Anambra State, Nigeria. Data collection instruments in the study include structured questionnaire, interviews, visual inspection/observations, archival records, recordings, photographs; and non-destructive testing of the concrete elements in an existing building in the study area. The population of this study constituted of the construction registered professionals and the existing buildings in study area. The sample for the study was based on the calculated sample size using Taro Yamani Formula. A total of 158 registered professionals were sampled from the population of 260. The questionnaires were purposively distributed to the registered professionals up to the required sample sizes of 158 and 129 questionnaires were properly filled and returned. The study used the SPSS and Microsoft Excel to analyze the data. The results were analyzed in percentages and figures using descriptive statistics and presented in the form of pie charts and tables. The finding of the study revealed that the causes and effects of structural defects on the concrete elements in existing buildings in the study area according to the rating are; exposed/corrosion of the embedded metals, faulty workmanship, overload and impacts, chemical attack, freeze-thaw deterioration, fire/heat, restraint to volume change. The visual observation revealed that the structural elements are characterized by heavy defects such as deep vertical, horizontal and diagonal cracks, exposed/corrosion of the embedded metals, spalling of the concrete slabs. The existence of defects in the concrete members led to the low compressive strength of the concrete elements and the structural instability of the existing buildings as revealed by the non-destructive test. The non-destructive test result revealed that most of the tested concrete elements have low compressive strength value and such were remarked poor as they did not satisfy the assumed value. Essentially, the study concluded by recommending that regular monitoring, inspections and non-destructive testing of concrete elements should be conducted on existing aged and defected buildings to detect the structural stability of the buildings; and it is imperative to evacuate occupants from heavy structurally deteriorated and defected buildings since most of them have lost their residual design life span and ability to sustain imposed loads.

**Keywords**

Construction Industry, Building Professionals, Concrete Elements, Defects, Residential Buildings, Structural Stability, Non-Destructive Test, Compressive Strength

## 1. Introduction

The construction sector plays an active role in the formation of fixed assets in any economy [1]. There is a need for continuous survey and monitoring of concrete structures during service life to detect an impending failure and examine the performance of the buildings to save lives and properties, as the investigation will show the performance of the structural elements and suggest measures for their maintenance in order to sustain structural stability [2]. Building been its product is as old as humanity and has evolved through centuries of activities, from dwelling in caves to skyscrapers and recently to intelligent structures that can smartly respond to stimuli in its environment [3]. [4] posits building as systemic; having many interacting systems and subsystems both as part of the physical infrastructure and how human activity is organized within and concerning them. Consequently, the work involved in the design and construction stages is largely those of selecting materials, components and structures that will meet the expected building standards and aesthetics on an economic basis [5]. Buildings are structures that provide shelter for man, his properties, and programs and as such, they must be properly planned, designed, and constructed to enhance desired satisfaction for man and his environment [6]. A building is a place where people are accommodated or come to work together and the major purpose of a building is to give a comfortable and healthy surrounding for people to conduct activities, to provide security, sustain the load and environmental shelter [7]. Residential buildings are buildings which are used for normal residential purposes and should facilitate activities such as sleeping, living and cooking.

Concrete is recently the most common building material in Nigeria's construction industry [8]. Concrete has been proven to be the major component that the majority of modern buildings in the study area used in building construction [2]. Concrete is the most widely used construction material in the world today [9]. [10] states that concrete is one of the most important construction materials, comparatively economical, easy to produce, offering continuity and solidity, and fast to bind with other materials. Concrete is an artificial stone that is cast in place in a plastic condition, in other words, concrete could be a composite material, which is made up of filler and a binder ([11] [12] [13] [14]). Concrete structures are designed and constructed so that they maintain their required serviceability, durability, and performance for a sufficiently long period, which is expected to be a design life of 50 years. Concrete quality is reported as one of the causes of building collapse [15]. Thus, some of the factors to be considered in measuring the standard of the building include strength, quality, and adequate stability to prevent its failure [16]. [17] asserted that building failures and collapses occur when there are structural defects on the concrete elements of the building.

On this note, the increase in the rate of concrete defects and deterioration in buildings in Onitsha Anambra State, Nigeria is worrisome [2]. Defects are a major issue in construction industry that needs attention and the occurrence of defects and failures in the buildings are due to various causes [7]. Concrete defect means any defect in a concrete element of a building that is attributable to defective design, faulty workmanship or defective material and sometimes any combination of these. Concrete defects in a building can occur over time due to deterioration, wear and tear, overloading, and poor maintenance. Concrete elements include earth retaining walls, columns, beams and flat slabs.

Building defect is one of the major components of building problems that significantly needed attention [18]. Concrete elements are susceptible to different forms of defects during their lifetime. These defects in concrete structures can lead to structural instability. However, various defects are more common in an old structure and are said to mean deterioration of building features and services to unsatisfactory quality levels of the users.

According to [19], aging of concrete structures is a natural process, that has become an urgent and critical problem in recent years and a large number of infrastructures all over the world are over 50 years and suffer from the extensive deterioration that affects serviceability. Concrete structures are generally designed for a service life of 60 years, but experience shows that in urban and coastal environments many structures begin to degrade in 20 to 30 years or even less time [20]. Existence of such defects in concrete structures severely affects the quality, service life and, in some cases, the structural integrity of concrete structures.

In recent times, concrete defects are also one of the major problems in residential buildings and it takes a good amount of maintenance to fix the defects. If not properly handled, these defects may cause various complications for the residents of the building which might lead to damage to the property or human life [21]. It is important to study and also fix the structural defects and carry out the necessary maintenance work for the proper functionality of a building to avoid building collapse. Failure and collapse of residential buildings is a key challenge facing the building industry in Anambra State. According to a recent report made by Anambra State Materials Testing Laboratory (ASMTL) Awka based on a structural integrity assessment conducted on existing buildings in Anambra State, over 100 buildings are in critical structural distress as a result of concrete deterioration and defects. On this note, a dilapidated building collapsed on the 20th of September 2020 at Obosi Anambra State, killing a nursing mother and leaving the child badly injured.

Consequently, previous studies from [22] identified problems with the stability of the structure as the most important construction defects in housing and no study was carried out in Nigeria, the research presented in this paper examines the defects in concrete elements in residential buildings of 30 years and above in Onitsha metropolis of Nigeria. This study revealed the structural state and conditions of the old residential buildings as some of them have outstayed their design life span.

## 2. Review of Related Literature on Building Defects

Defects occur in buildings as a result of various flaws and lacks such as design defects, construction, execution of work, materials performance or selection [21]. [18] described building defect is one of the major components of building problems that needs significant attention. Building defects have been defined in many ways in previous studies ([22] [23]). Defects have remained continuously prevalent, particularly amongst registered builders ([24]: [22]). [25] opined that defect is a failing or shortcoming in the function, performance, statutory or user requirements of a building, and might manifest itself within the structure, fabric, services or other facilities of the affected building. [26] posits many building defects as latent in-nature and do not appear early in the construction stage; however, other studies suggested that important defects arise during the first stage of the construction process and identified the problems with the stability of the structure as the most important construction defects in housing. [22] further analyzed the causes of defects in new homes in Australia and observed that, if house framing is properly executed, most faults may not arise.

[24] has categorized defects into three namely technical, aesthetic and functional. 1) Technical defect occurs when the materials or building elements do not meet functional performance and leads to damages to human life and assets. 2) Aesthetic defect negatively affects the appearance of the building material. aesthetic defects lead to discoloration, dampness, corrosion, efflorescence, tile delamination, etc. 3) Functional defect causes building failure and deviation to function as it was planned and designed. These defects are related mainly to the planning, design, and location of the building [24].

[7] asserted that defects in a building can be broadly classified into two types—1) structural defects (defect in the structural elements such as beam, column etc.), 2) non-structural defects (including defects in bricks, dampness,

defects in plaster works etc.) Non-structural defect according to Northern Territory Consolidated Regulation is described as a defect in a non-structural element of the building as a result of defective work.

[27] in their study described structural defect as any defect in a structural element of a building that is attributable to defective material, design, faulty workmanship and sometimes any combination of these. The structural elements include retaining walls, columns, beams and flat slabs. Structural defect can be categorized as cracks in foundations (Substructure), cracks in floor or slabs (superstructure), and cracks in walls (superstructure) and these defects can be caused by improper soil analysis, inappropriate site selection, and the use of defective materials [27]. The structural defects in a building can occur over time due to deterioration, wear and tear, overloading, and poor maintenance and the structural defect that always occurs are steel corrosion, cracks, and deflection [27]. A non-structural defect in a residential building is described as a defect in a non-structural element of the building as a result of defective residential building work and the non-structural defect includes defect that occurs in the non-structural components of the building, services like brickwork, dampness in old structures, and defects in plaster works [27].

[28] their study on structural defects of existing reinforced concrete buildings in Eskisehir Province revealed that the buildings were represented with structural defects such as gaps between adjacent buildings, strong beam-weak column, mezzanine floor, short column, corner column, discontinuous frame, anchorage beams, long span, segregation, corrosion, inconvenient column/beam lateral reinforcement, low concrete strength and inconvenient steel reinforcement were determined in the study. It was also determined that 35% of existing buildings have discontinuous frames and 16% of them have long-span problem.

According to [29] defects of structural elements could occur as a result of corrosion of reinforcement caused by carbonation and chloride ingress, cracking caused by overloading, subsidence or basic design faults, and construction defects. [18] also asserted that the study of defects can be done in two ways: 1) Stock condition survey which includes a questionnaire and physical observation and 2) day-to-day survey. This study deployed the first method. The causes and effects of concrete defects which were reviewed in this study are as follows:

## 2.1. Causes and Effects of Concrete Defects

### 2.1.1. Spalling in Roofs/Ceilings and Corrosion of the Embedded Metals

Corrosion of reinforcing steel and other embedded metals is one of the leading causes of deterioration in concrete [30]. [28] opined that inadequate concrete coating leads to corrosion on the reinforced concrete members and has negative impacts on the adherence between concrete and steel reinforcements. Spalling occurs when the edges or surfaces of concrete blocks chip off or break from the main element. Normally, this is due to a combination of several factors such as poor installation and environmental aspects like freezing temperatures which stress the concrete, inducing some damage. Failure to timely repair it, spalling can occasionally prompt structural damages like rusting of reinforcing steel. [30] corrosion of reinforcing steel and other embedded metals is the leading cause of deterioration in concrete. When steel corrodes, the resulting rust occupies a greater volume than the steel. This expansion creates tensile stresses in the concrete, which can eventually cause cracking, delamination, and spalling. Steel corrodes because it is not a naturally occurring material. Rather, iron ore is smelted and refined to produce steel. The production steps that transform iron ore into steel add energy to the metal.

[31] Spalling in roofs/ceilings occur due to water seepage or water leakage from the roof slab and this causes bulging, pattern cracking and falling off the clear cover from concrete which would expose the reinforcement. Then the reinforcement becomes rusted by the corrosion effect; water leakage may also react with adjacent walls which might cause plaster or tile delamination. bars located in the concrete.

#### 2.1.2. Freeze-Thaw Deterioration

[30] opined that as the water in moist concrete freezes, it leads to pressure in the capillaries and pores of the concrete, then if the pressure surpasses the tensile strength of the concrete, it causes the cavity to dilate and rupture. The author further asserted that the accumulative effect of successive freeze-thaw cycles the disruption of paste and aggregate will eventually cause significant expansion and cracking, scaling, and crumbling of the concrete. As stated by [32], Freeze-thaw damage is a major cause of deterioration of concrete structures in regions with extreme temperature variations. In their study, the authors carried out a series of experiments on concrete specimens and determined the freeze-thaw-based damage variable. The authors further proposed an equation for the stress-strain constitutive relation including the freeze-thaw damage variable and pointed out the observed changes in the elastic modulus with an increase in the freeze-thaw cycle number.

#### 2.1.3. Chemical Attack

Concrete performs well when exposed to various atmospheric conditions, water, soil, and many other chemical exposures however, some chemicals can attack and destroy high-quality concrete elements. [30]. Development of concrete strength can be limited by sulphate, chloride magnesium or multiple combined chemical attacks at the early stage and this results to the compressive strength of the concrete element as the years roll by [33]. However, the authors further opined those internal chlorides accelerate the degradation induced by external sulfate attack. Sulphuric acid promotes corrosion to the steel reinforcement and also erodes some stones causing blisters and spalling whereas carbon die oxide leads to erosion of limestone and concrete [7]. [7] also in their study revealed that the interaction of building material with surrounding environmental agencies such as rain, temperature variation and fumes can also lead to defects and deterioration of the building.

Sulfate attack on cement concrete is one of the reasons for defects of concrete durability and subsequently reduces the service life of the concrete structures pointed out that the sulfate attack has double effects on mechanical properties of specimens. Sulfate attack on cement concrete can degrade the durability and reduce the service life of concrete building structures [34].

The more sulfate ion intrudes into the concrete element and a good number of expansive substances are generated, but if the expansive substances generated by sulfate attack can be accommodated by pores in concrete, the sulfate attack has a positive effect on the performance of the specimens but conversely, the sulfate attack destroys the thermodynamic equilibrium state of the concrete element and results in micro damage, so it has a negative effect [35]. The effect of the sulfate decreases the compressive strength of the concrete element.

#### 2.1.4 Alkali-Aggregate Reactivity

The deterioration caused by the alkali-carbonate reaction is similar to that caused by alkali-silica reaction. However, the alkali-carbonate reaction is relatively rare because aggregates susceptible to this reaction are less common and are usually unsuitable for use in concrete for other reasons, such as strength potential.

#### 2.1.5. Abrasion

According to [28], abrasion damage occurs when the surface of the concrete is unable to resist wear caused by rubbing and friction. As the outer paste of concrete wears, the fine and coarse aggregate is exposed and abrasion and impact will cause additional degradation that is related to the aggregate-to-paste bond strength and hardness of the aggregate.

#### 2.1.6. Fire/Heat

Concrete and steel both are affected by fire and the heat of fire along with the water used for firefighting leads to distortion, cracking, spalling and swelling of all components [7]. Concrete that went through thermal cycling suffers the greater loss of strength than concrete that is held at a constant temperature, although much of the strength loss occurs in the first few cycles [29].

#### 2.1.7. Restraint to Volume Changes/Cracking

[7] posits that cracks are formed due to overloading, foundation movement and settlement of soil or due to the effect of environmental agencies. Cracking affects the visual appeal of the concrete. Occasionally, it also affects structural durability and strength [20]. In reinforced concrete, cracking enables air and moisture to reach the reinforcement bars causing the steel to corrode, and consequently weakening the entire structure. Cracking either occurs before the concrete hardens or after hardening. Cracks occurring before hardening are a result of the movement of concrete before the concrete has set. These types of cracks fall into three categories; first, plastic shrinkage cracks which are common in hot and windy environments and usually develop as straight lines, either parallel or pat-

tern; second, plastic settlement cracks that tend to follow the lines of reinforcement and often appear while concrete is still plastic and; and third, cracks caused by movement of the formwork which occurs during positioning and compaction and is caused by movement of a weak formwork [36]. On the other hand, cracks may appear after hardening and are caused by settlement, drying shrinkage, as well as structural cracks. These cracks may necessitate structural renovation using high-pressure epoxy. Temperature variation causes thermal and moisture movements in concrete which results in shrinkage and settlement of cracks [7].

#### 2.1.8. Overload and Impact

A building is designed to support a certain maximum load but collapses if there is more weight on a portion of it than the structure is designed to support. [28] in their research asserts that overload damage can occur during construction when concrete has not yet reached design strength. Early removal of formwork or the storage of heavy materials or operation of equipment on and around the structure can result in the overloading of certain concrete members. A common error occurs when precast members are not properly supported during transport and erection. Errors in the usage of building, such as improperly timed or sequenced strand release, as well as excessive loading can also cause overload and cracking of the building components. Damage caused by the impact is another form of overload.

#### 2.1.9. Faulty Workmanship Defects

The most significant factor contributing to poor workmanship is lack of experience and experience of labour. On the other hand, the most important cause is poor workmanship, especially not complying with the instruction given [27]. According to [29], segregation occurs on the concrete as a result of the workmanship flaws that occur during the fresh concrete production and placing which also causes voids in the concrete. These voids have negative effects on the concrete strength and its performance [29].

According to [28], segregation is seen on the concrete due to the workmanship flaws during the fresh concrete production and placing. This also causes voids in concrete and these voids have negative effects on the concrete strength and its performance. The inadequate concrete coating causes corrosion on the reinforced concrete members. It is determined that many buildings have the segregation and corrosion defects. The segregation and corrosion will reduce the load-bearing capacity of reinforced concrete members. This will also have negative impacts on the adherence between concrete and steel reinforcements.

## 3. Methodology

This study deployed a mixed research method which includes both survey and experimental research methods. A survey-research method is one in which people or items are studied by collecting and analyzing data from a few people or items considered to be representations of the entire group. This is often used where large volumes of data are involved with quantitative methods of analysis. Experimental process involves adopting a defined procedures and condition to carry out tests with appropriate equipment with the aim of either to discover something new about an object or to evaluate the effect of several factors or conditions on some parameters of interest in a study. The experimental method was used to carry out tests in the buildings in study area, which helped to determine the present compressive strengths of the concrete elements in the study area after existing for so many years. The experiments also helped in determining the structural stability of the existing buildings. Data collection instruments in the study include questionnaire, interviews, visual inspection/observations, archival records, recordings, photographs and non-destructive compressive test. Some of these instruments were qualitative, and others quantitative. The qualitative instruments (interviews) was concerned with the perceptions of the construction professionals about the defects and state of concrete elements in buildings; while the quantitative instruments (questionnaires, visual inspection and non-destructive test results) was concerned with issues relating to the ranking of defect indicators. The sample for the study was based on the calculated sample size using Taro Yamani Formula. A total of 158 registered professionals were sampled from the population of 260. The questionnaires were purposively distributed to the registered professionals up to the required sample sizes of 158. 129 professionals filled and returned their questionnaires. The population of this study constituted of the construction registered professionals and existing buildings in Onitsha Anambra State. The building professionals were fully registered professionals particularly; Architects, Builders, Structural Engineers and Quantity surveyors residing practicing in Anambra state and these professionals were obtained from the various secretariats in the state. The residential buildings in question are two (2) floors or more, and have been occupied for at least thirty (30) years and above. The study used the SPSS and Microsoft Excel to analyze data. The data generated from the study were subjected to descriptive and quantitative analyses. The results were analyzed in percentages and figures using descriptive statistics and presented in the form of pie charts and tables.

## 4. Results and Discussion.

### 4.1. Presentation of Demographic Characteristics of Respondents

The number of samples used for the questionnaire analysis is 129 professionals, their demographic composition was analyzed in this section with 14 frequency tables and 11 charts (8 pie charts and 3 bar charts).

Table 1 revealed that 158 questionnaires were distributed to the registered professionals but 129 questionnaires were responded to and returned.

Table 2 and Figure 1 revealed that 75% of the respondents are male whereas 25% of the respondents are female.

Table 3 and Figure 2 revealed that 12% (15) of our respondents are within ages 20 - 30 years, whereas, 76% (98) are within ages 30 - 40 years, finally, 12% (16) of our respondents are within ages 40 - 50 years of age.

Table 1. Population distribution of questionnaire and percentage response.

| Categories | Number of questionnaires distributed | Number of questionnaires received | Percentage (%) |
|---|---|---|---|
| Registered Building Professionals | 158 | 129 | 81.6 |

Source: Field Survey (2021).

Table 2. Gender distribution of respondents.

| Gender | Frequency | Percentage (%) |
|---|---|---|
| Male | 97 | 75.2 |
| Female | 32 | 24.8 |
| Total | 129 | 100.0 |

Table 3. Age distribution of respondents.

| Age | Frequency | Percentage (%) |
|---|---|---|
| 20 - 30 yrs | 15 | 11.6 |
| 30 - 40 yrs | 98 | 76.0 |
| 40 - 50 yrs | 16 | 12.4 |
| Total | 129 | 100.0 |

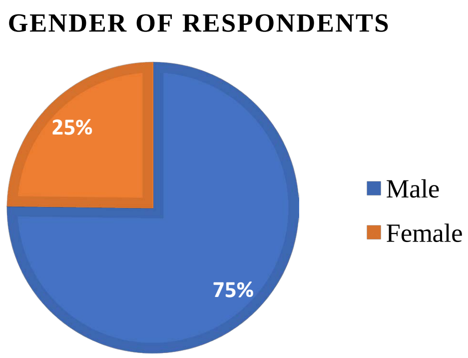


Figure 1. A pie chart representing the gender of respondents.

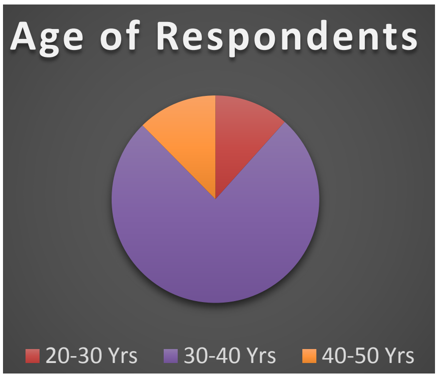


Figure 2. A pie chart representing the age of respondents.

Table 4 and Figure 3 show that 60% of our respondents are PGD/MSc/ PhD holders, whereas 40% were BSc/HND/Equivalent holders.

Table 5 and Figure 4 show that 47% of respondents are Builders, 5% are Architects, 28% are Structural Engineers, and 12% are Quantity Surveyors whereas 9% are of other professions that are not listed.

Table 6 and Figure 5 show that 36% of the respondents are registered members of CORBON, 5% are registered members of ARCON, 20% are registered members COREN, 8% are registered members of QSRCON whereas 32% do not belong to any of the listed professional bodies.

Table 7 and Figure 6 show that 60% of the respondents have 10 - 15 years of working experience, 31% have 5 - 10 years of working experience and 9% have 0 - 5 years of working experience.

Table 8 and Figure 7 show that 84% of the buildings in the study area are made of concrete blocks and 16% of the buildings are made of other forms not listed.

Table 9 and Figure 8 show that 118 respondents have been involved in concrete evaluation before, whereas 11 respondents have not been involved in concrete evaluation before.

Table 4. Academic qualification of respondents.

| Academic Qualification | Frequency | Percentage (%) |
|---|---|---|
| BSc/HND/Equivalent | 51 | 39.5 |
| PGD/MSc/PhD | 78 | 60.5 |
| Total | 129 | 100.0 |

Table 5. Field of discipline of respondents.

| Discipline | Frequency | Percentage (%) |
|---|---|---|
| Building | 61 | 47.3 |
| Architecture | 6 | 4.7 |
| Structural Engineering | 36 | 27.9 |
| Quantity Surveying | 15 | 11.6 |
| None of the Above | 11 | 8.5 |
| Total | 129 | 100.0 |

Table 6. Professional registration status of respondents.

| Professional Registration | Frequency | Percentage (%) |
|---|---|---|
| CORBON | 46 | 35.7 |
| ARCON | 6 | 4.7 |
| COREN | 26 | 20.2 |
| QSRCON | 10 | 7.8 |
| NONE | 41 | 31.8 |
| Total | 129 | 100.0 |

Table 7. Working experience of respondents.

| Working Experience | Frequency | Percentage (%) |
|---|---|---|
| 0 - 5 yrs | 11 | 8.5 |
| 5 - 10 yrs | 40 | 31.0 |
| 10 - 15 yrs | 78 | 60.5 |
| Total | 129 | 100.0 |

Table 8. Response to building form in the area of study.

| Building Form | Frequency | Percentage (%) |
|---|---|---|
| Concrete blocks | 109 | 84.5 |
| Other | 20 | 15.5 |
| Total | 129 | 100.0 |

Table 9. Involvement in concrete evaluation.

| Concrete Evaluation | Frequency | Percentage (%) |
|---|---|---|
| Yes | 118 | 91.5 |
| No | 11 | 8.5 |
| Total | 129 | 100.0 |

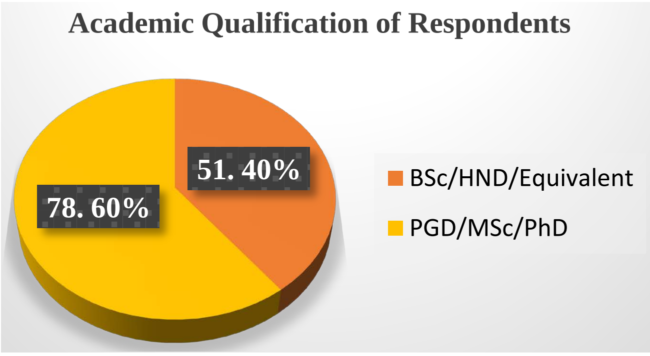


Figure 3. A pie chart representation of academic qualification of respondents.

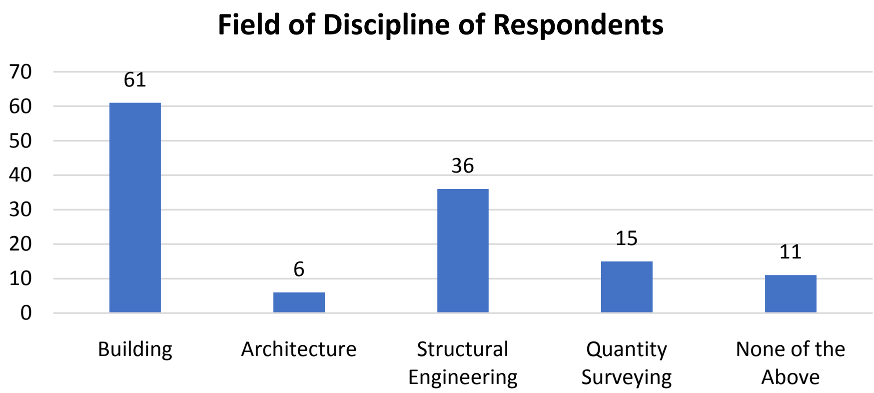


Figure 4. A bar chart representing the field of discipline of respondents.

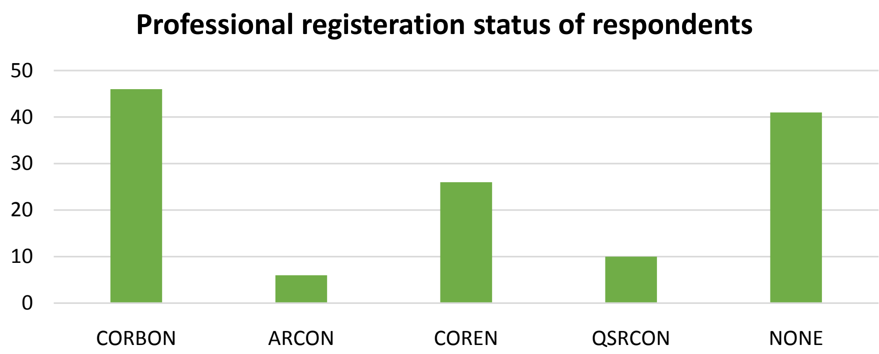


Figure 5. Bar chart representation of professional registration of respondents.

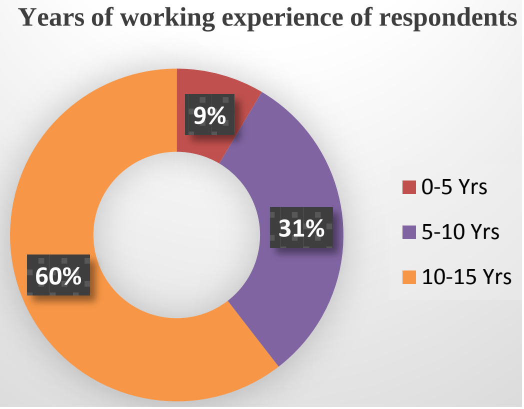


Figure 6. A pie chart representation of years of working experience of respondents.

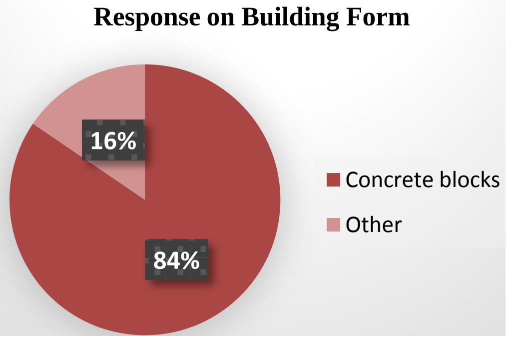


Figure 7. A pie chart representation of the building form in the study area.

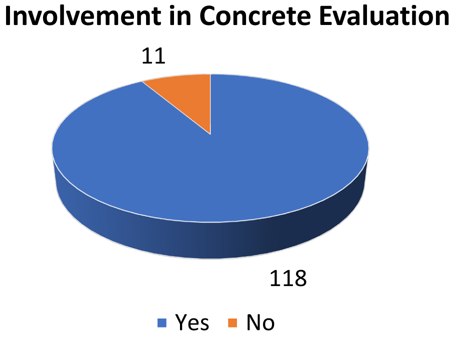


Figure 8. A pie chart representation of respondents' involvement in concrete evaluation.

Table 10 and Figure 9 show that 64% of our respondents have been involved as site supervisors, 24% as Material tester/quality control and 12% as contractors.

Table 11 and Figure 10 show responses on whether the existence of defects affects the quality of concrete elements and the structural stability of the building, 96% agreed to the fact and 4% rejected it.

Table 10. Area involved in concrete evaluation.

| Area of Involvement | Frequency | Percentage (%) |
|---|---|---|
| Site Supervisor | 83 | 64.3 |
| Material tester/Quality Control | 31 | 24.0 |
| Contractor | 15 | 11.6 |
| Total | 129 | 100.0 |

Table 11. The Existence of defects affects the quality of concrete elements and the structural stability of the building.

| Response | Frequency | Percentage (%) |
|---|---|---|
| Yes | 124 | 96.1 |
| No | 5 | 3.9 |
| Total | 129 | 100.0 |

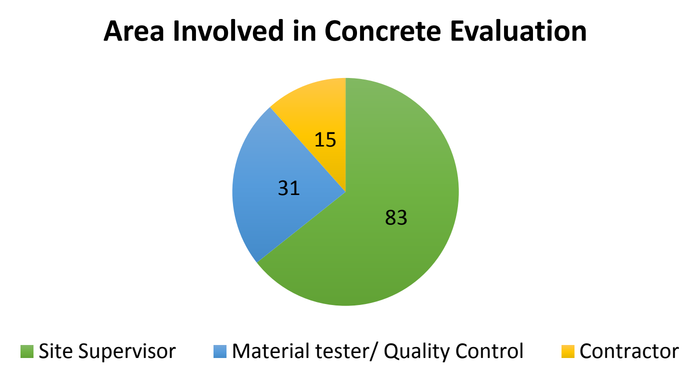


Figure 9. A pie chart representing the area involved in concrete evaluation.

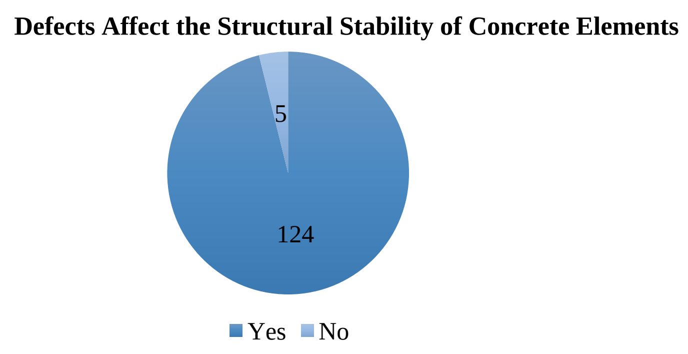


Figure 10. a pie chart representation of responses on whether the existence of defects affects the quality of concrete elements and the structural stability of the building.

Table 12 and Figure 11 show responses to causes and effects of defects on concrete elements in existing buildings. Responses gotten on each subject show that 400 (34.5%) responses were strongly agreed, 485 (41.8%) responses were agreed, 206 (17.7%) responses were undecided, 55 (4.7%) responses were disagreed, whereas 15 (1.3%) responses were strongly disagreed.

### 4.2. Testing of Significant and Non-Significant Constraint Factors

For this section of the analysis, the most significant factor will come first in the order of appearance in the table.

The analysis in Table 13 show that all the factors considered on the causes and effects of defects on concrete elements in existing buildings were significant considering the significant value and the mean value, however, the mean difference and the relative importance index (RII) shows that exposed/corrosion of the embedded metals was the most significant factor and Alkali-aggregate reactivity was the least significant.

### 4.3. Experimental Results/Data

In order to determine the compressive strength and structural stability of the

Table 12. Response on causes and effects of defects on concrete elements in existing buildings.

| Causes of defects on concrete elements. | Strongly Agree & (%) | Agree & (%) | Undecided & (%) | Disagree & (%) | Strongly Disagree & (%) |
|---|---|---|---|---|---|
| **Exposed/Corrosion of the embedded metals** | 88 (68.2) | 41 (31.8) | | | |
| **Freeze-thaw deterioration** | 31 (24) | 63 (48.8) | 35 (27.1) | | |
| **Chemical Attack** | 41 (31.8) | 61 (47.3) | 22 (17.1) | 5 (3.9) | |
| **Alkali-aggregate reactivity** | 15 (11.6) | 67 (51.9) | 26 (20.2) | 21 (16.3) | |
| **Abrasion** | 21 (11.6) | 67 (51.9) | 25 (19.4) | 11 (8.5) | 5 (3.9) |
| **Fire/Heat** | 46 (35.7) | 37 (28.7) | 35 (27.1) | 6 (4.7) | 5 (3.9) |
| **Restraint to volume changes** | 35 (27.1) | 51 (39.5) | 26 (20.2) | 12 (9.3) | 5 (3.9) |
| **Overload and impacts** | 41 (31.8) | 61 (47.3) | 27 (20.9) | | |
| **Faulty workmanship** | 82 (63.6) | 37 (28.7) | 10 (7.8) | | |
| TOTAL | **400 (34.5)** | **485 (41.8)** | **206 (17.7)** | **55 (4.7)** | **15 (1.3)** |

**Table 13.** Likert scale rating on the causes and effects of defects on concrete elements in existing buildings.

| Causes of defects on concrete elements. | Test Value = 2.5 | | | | | | |
|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Mean Difference | RII | Sig. Value | Decision: Rank | Decision: Remark |
| Exposed/Corrosion of the embedded metals | 4.68 | 0.467 | 2.182 | 0.9364 | 0.000 | 1st | Significant |
| Faulty workmanship | 4.56 | 0.636 | 2.058 | 0.9116 | 0.000 | 2nd | Significant |
| Overload and impacts | 4.11 | 0.721 | 1.609 | 0.8217 | 0.000 | 3rd | Significant |
| Chemical Attack | 4.07 | 0.802 | 1.570 | 0.8139 | 0.000 | 4th | Significant |
| Freeze-thaw deterioration | 3.97 | 0.717 | 1.469 | 0.7937 | 0.000 | 5th | Significant |
| Fire/Heat | 3.88 | 1.075 | 1.376 | 0.7751 | 0.000 | 6th | Significant |
| Restraint to volume changes | 3.77 | 1.072 | 1.267 | 0.7534 | 0.000 | 7th | Significant |
| Abrasion | 3.68 | 0.976 | 1.182 | 0.7364 | 0.000 | 8th | Significant |
| Alkali-aggregate reactivity | 3.59 | 0.898 | 1.089 | 0.7178 | 0.000 | 9th | Significant |

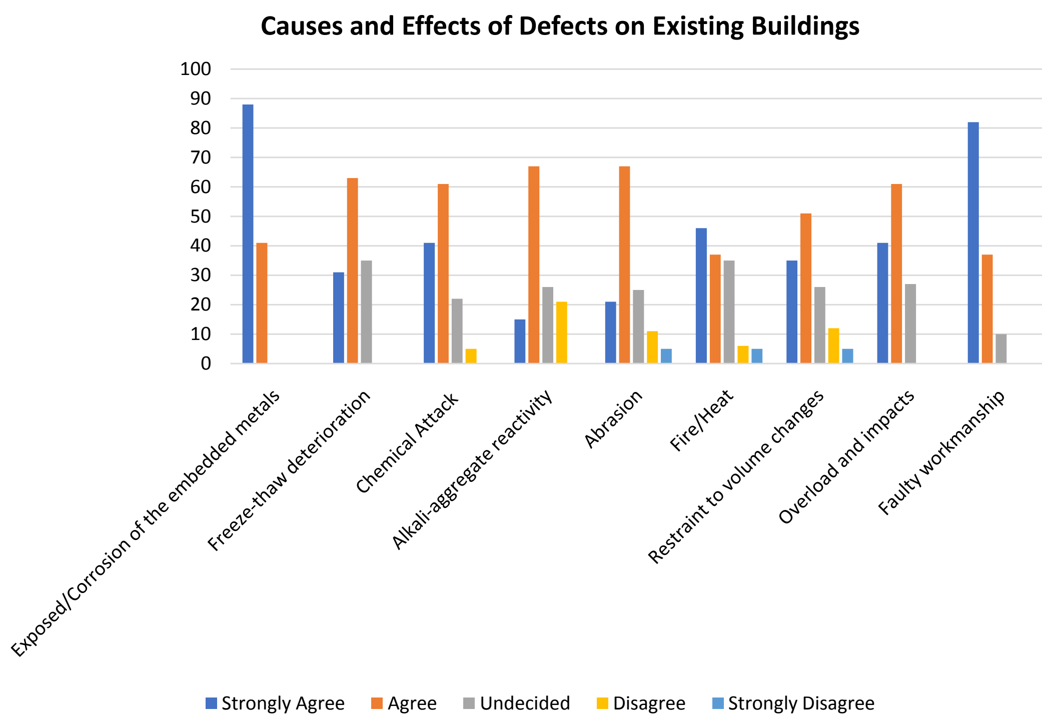


**Figure 11.** A bar chart representation of responses on causes and effects of defects on existing buildings.

existing building within the study area, experiments were conducted on the major structural elements by performing a Non-Destructive Test (NDT) on the columns, beams and slabs. A Non-Destructive Test and Evaluation is accomplished by establishing a correlation between a Non-Destructively measured physical/derived parameter and quantitative information on defects, stresses and microstructures. The experiment for the Non-Destructive Compressive Strength Test was carried out with the use of a Standard Portable Ultrasonic Non-Destructive Digital Indicating Tester (PUNDIT). Non-Destructive Testing is an inspection technique that investigates the internal defects of the structure without damaging it. The Non-Destructive Structural Integrity Test was carried out to ascertain the capabilities of the structures in bearing imposed loads. The study evaluated the compressive strengths of the specimens as specified in BS 1881: Part 203, 1986 (British Standard of Non-Destructive Testing of Concrete Methods-of Test: Part 203 of 1986 for Ultrasonic Pulse Velocity).

### Visual Observation of a Tested Building

1) The tested structure is a 4-floor completed building located at No. 48 Francis Street, Onitsha, Anambra State.

2) Exposed/Corrosion of the embedded metals was observed in the ground, first, second and third floor slab soffits.

3) Diagonal and vertical cracks were also observed on second floor internal block wall.

4) Dampness was observed in the ground, first and second floor external walls.

5) Dilapidated plumbing works were noticed especially in the inspection chambers.

From analysis of test conducted on the building as shown in **Table 14**, it was revealed that 17.1% of the structural elements tested met acceptable concrete compressive strength value while 82.9% did not meet the threshold value. An approximate 76.2% of the ground floor columns tested were classified with poor remarks and have values less than the acceptable concrete compressive strength values and such were remarked poor as they did not satisfy the assumed concrete compressive strength of 15 N/mm$^2$ and above despite been responsible for the transmission of loads from the upper floors to the foundation. 19.0% of the tested columns on the 1$^{st}$ floor are rated good while the remaining 81.2% are rated poor. Out of all the beams and slabs tested in all the floors only 25% was rated good, all the other members are poorly rated.

The visual observation revealed that exposed/corrosion of the embedded metals was observed in the ground, first, second and third floor slab soffits (see **Appendix**). Corrosion/exposed steel reinforcement are primarily due to dampness and seepage on the concrete floors concrete which leads to deterioration of

**Table 14.** Compressive strength test analysis results for a tested building.

| Ground Floor | | | First Floor | | | Second Floor | | | Third Floor | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Structural Elements | ACS (N/mm$^2$)/ Remarks | | Structural Elements | ACS (N/mm$^2$)/ Remarks | | Structural Elements | ACS (N/mm$^2$)/ Remarks | | Structural Elements | ACS (N/mm$^2$)/ Remarks | |
| | Good | Poor | | Good | Poor | | Good | Poor | | Good | Poor |
| Columns (21) | 23.8% (5) | 76.2% (16) | Columns (21) | 19.0% (4) | 81.20% (17) | Columns (18) | 33.3% (6) | 66.7% (12) | Columns (15) | 0% (0) | 100% (15) |
| | | | Beam (6) | 0% (0) | 100% (6) | Beam (6) | (0)% | 100% (6) | Beam (6) | 33.3% (2) | 66.7% (4) |
| | | | Slab (4) | 0% (0) | 100% (4) | Slab (4) | (0) 0% | 100% (4) | Slab (4) | 25% (1) | 75% (3) |

Source: Field Survey (2021).

structural elements. Thus, this phenomenon resulted to concrete spalling and algae growth on walls. Diagonal and vertical cracks were also observed on second floor internal block wall at the time of test.

## 5. Conclusions and Recommendations

Most of the respondents agreed to have defects in their buildings as showed by 64% of our respondents having defects in their buildings while 36% have none, thus a greater percentage have defects in their buildings and such is suitable for the study. Some defects in concrete elements were inflicted as backward as during construction processes and other factors such as faulty workmanship, overloading, spalling/corrosion of embedded metals, fire out-break, ageing of concretes structure, cracking, abrasion. Greater percentages of buildings in the study area are considerably old and have deteriorated. The study revealed that the major causes and effects of structural defects on concrete elements in existing buildings in the study area according to ranking are; exposed/corrosion of the embedded metals, faulty workmanship, overload and impacts, chemical attack, freeze-thaw deterioration, fire/heat, restraint to volume change, abrasion and alkali-aggregate reactivity. The existence of defects in the buildings affects the quality and compressive strength of the concrete elements and the structural stability of the building. The mean difference and the relative importance index (RII) show that exposed/corrosion of the embedded metals was the most significant factor and Alkali-aggregate reactivity was the least significant. There is need for regular monitoring, inspections and non-destructive testing of concrete elements should be conducted on existing aged and defected buildings to detect the structural stability of the buildings.

Moreover, the visual observation confirmed that the structural elements are characterized by defects such as deep vertical, horizontal and diagonal cracks, exposed/corrosion and spalling of the embedded metals (see **Appendix**); and these defects contributed to the low compressive strength of the concrete elements in the tested building as revealed by the non-destructive test.

Essentially, the following points are made from the finding for effective implementation and enhancement of structural stability of buildings in Onitsha metropolis; since most of the existing buildings in the study area that are 30 and above have concrete defects and their state of structural stability is found to be inadequate, therefore study recommends that people should be evacuated from heavy structurally deteriorated and defected buildings since they have lost their residual design life span and ability to sustain future loads, in order to avoid death from the incidents of impending building collapse. Hence, for successful implementation of quality in concrete elements, it should be made compulsory for all construction contracting firms, professionals, government agencies and other key stakeholders that determine the success of construction projects need to implement regular inspections and testing of concrete structures during and after construction to prevent unnecessary injury or death caused by failure of these concrete structures.

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## Conflicts of Interest

The authors declare no conflicts of interest.

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## Appendix. (Pictures of the Tested Building)

Plate I: Left hand side view of the tested building.

Plate II: Rear view of the tested building.

Plate III: Concrete spalling on first floor slab.

Plate IV: Concrete spalling observed on second floor slab.

Plate V: Tested point on first floor beam.

Plate VI: Tested point on a ground floor column.