Non-Destructive Evaluation of Quality of Concrete Elements in Existing Buildings for Structural Stability in Onitsha, Anambra State, Nigeria

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Abstract: - Recently, concrete is the most common building material in Nigeria construction industry but had also been reported as one of the major causes of structural failure. However, in spite of the popularity of concrete structures, if not properly constructed and the quality maintained, it can deteriorate prematurely which is often referred to as our crumbling infrastructure. The study aims at evaluating the quality of concrete elements in existing buildings in Onitsha, Anambra State, with a view to establishing their states of stability. The methodology involved a review of the relevant literature and Non-destructive testing of the structural elements (columns, beams and slabs) in two selected buildings in the study area that have existed for more than thirty years. The study reveals apparently that the buildings and their state of structural stability are inadequate. The buildings are associated with heavy structural defects like cracks, spalling, exposed/corrosion of the embedded metals etc and were observed to have recorded very poor compressive strengths. Based on the deductions made from the low compressive strength test results analysis and the visual observations conducted on the buildings in regards to consideration for strength and quality of the Structural elements, it can be said that one of the buildings have lost its residual design life span and ability to sustain future loads. The study strongly advocates the indulgence of Non-Destructive Test especially in existing deteriorated buildings to avoid building failures and collapses. The study also recommends continuous survey and monitoring of concrete structures during service life as to detect impending failure and examine the performance of the buildings in order 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.

Key Words: — ***Non-Destructive Evaluation, Quality, Concrete Elements, Buildings, Structural Stability.***

I. INTRODUCTION

Buildings are structures which 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. [1] posits buildings as systemic; they have many interacting systems and subsystems both as part of the physical infrastructure and how human activity is organized within and in relation to them. The work involved in the design and construction stages are largely those of selecting materials, component and structures that will meet the expected building standards and aesthetics on an economic basis [2]. Thus, some of the factors to be considered in measuring the standard of the building include strength and adequate stability to prevent its failure [3]. Structural stability can be attributed to be the main concerns in building industry. The determination of the stability state is usually carried out at the initial stage of construction, but sometimes it is necessary to determine the stability of an existing structure in order to improve its reliability [4]. Stability is the ability of a structure to retain under load its original state of equilibrium [5]. It can mean anything from resistance to a minor degree of movement to resistance to sliding overturning partial or complete collapse. Any phenomenon which will be a potential source of load that can alter the load carrying behavior of a structure, if not properly taken care of can lead to instability, a condition in which the support reaction is less than applied load. Structural stability represents a fundamental

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problem in building which must be mastered to ensure the safety of structure against collapse [6]). Every component of a structure must be stable otherwise the whole structure is assumed to be unstable. Structural stability is the ability of a structure to retain under load its original state of equilibrium [5]. Relatively, concrete is a major aspect of structural stability.

Essentially, concrete is the basis for infrastructural civilization and its physical development. Concrete is an ancient and universal building material [7]. Concrete is recently the most common building material in Nigeria construction industry [8]. It is the major composite component of most of our infrastructural facilities today in the 21st century because of its versatility in use. [9] defined concrete as one of the most important construction material, comparatively economical, easy to produce, offering continuity and solidity and fast to bind with other materials. In other words concrete could be a composite material, which is made up of filler and a binder [10; 11; 12; 13; 14; 15]. Concrete is used in the essential parts of the building like foundations, slabs, columns, beams, lintels, roof, staircases, walls, arches, etc. Concrete quality is reported as one of the causes of building collapse [16]. The aim of quality evaluation is to limit the variability as much as practicable [17]. [18] asserted that the large incidence of failure of concrete structures in recent years is an indication that the professionals in the industry do not always know enough about concrete. The conventional design framework for concrete structures is primarily based on safety and currently focused on the aspects of quality.

On this note, [14] is of the opinion that merely choosing the appropriate constituent materials for a particular concrete is a necessary but not a sufficient condition for the production of high-quality concrete. If not properly mixed and placed, the life span gets affected, thus deteriorating prematurely [19]. A quality concrete is that which is capable of meeting the requirements of the job in terms of strength, durability and appearance. Previous studies revealed that concrete structures are designed and constructed so that they maintain their required serviceability, durability and performance for a sufficiently long period of time, which is expected to be above 60 years.

Howbeit, to operate safely, structures and components need to be inspected or monitored either periodically or in real time for potential failure. For this purpose, ultrasonic non-destructive test (NDT) has been used extensively [20]. NDT allows inspection of the concrete components or structure without interfering on its service properties or final use [21]. As a result, they can be used to carry out test and examination the same components and structures numerous times and at different times without any worry of change in their properties [22]. The primary goal of non-destructive testing is to predict or assess the service life and performance of concrete structure at different stages of its service cycles [21]. The service life of a concrete structure is governed by parameters such as strength, quality of concrete, concrete cover, age, and most significantly by exposure conditions [23].

However, the evaluation of existing concrete components is usually carried out to assess their structural integrity [24]. A major component of building evaluation is detection and characterization of anomalies such as defects, stresses and micro-structural degradations in materials [25]. NDT evaluation of the quality of concrete elements in buildings can be done in both old and new structures.

This study will conduct a Non-destructive evaluation of the quality of concrete elements in buildings in Onitsha, Anambra State, Nigeria with a view to enhancing structural stability in the study area.

II. LITERATURE REVIEW ON NON-DESTRUCTIVE TESTING (NDT) OF CONCRETE ELEMENTS IN EXISTING BUILDINGS

To operate safely, buildings and components need to be inspected or monitored either periodically or in real time for potential failure for this purpose, ultrasonic non-destructive testing (NDT) techniques have been used extensively The evaluation of existing and ageing concrete structures is usually carried out to assess their structural integrity asserted that most of the existing concrete buildings which are in service around the world are aging and deteriorating due to harsh environmental exposure conditions and are damaged by natural earthquakes, hydrologic forces, etc. or man-made collisions, fire, road, etc. This is because the structural capacity of an existing structure is typically less than the structural capacity of just-built. According to [27] the standard method of evaluating the quality of concrete in buildings or structures is to test specimens cast simultaneously for compressive, flexural and tensile strengths. Non-Destructive Test (NDT) in concrete as defined by [28] is the measurement, inspection, or analysis of materials, existing structures, and processes of manufacturing without destroying the integrity of the materials and structures.

Non-Destructive as the name implies means that the material under the test is not damaged during the test. A non-destructive test is accomplished by establishing a correlation between a

Non-Destructively measured physical/derived parameter and quantitative information on defects, stresses and microstructures. According to [29] the growing demand for characterization of ruined concrete structures, together with the crisis of aging infrastructure has highlighted the need for reliable NDT techniques that can be employed to evaluate the quality of reinforced concrete constructions.

III. MATERIALS AND METHODS

3.1 Ultrasonic Pulse Velocity Measurement (Bs 1881: Part 203, 1986).

Ultrasonic pulse velocity measurements made on concrete structures are used for quality control purposes. In comparison with mechanical test on control samples such as cubes or cylinders, pulse velocity measurements have the advantage that they relate directly to the concrete in the structure rather than to samples, which may not be always truly representative of the concrete in situ.

Then, the velocity is calculated as:

V= L/T, where V = pulse velocity (N/mm2), L = length (m), and T = effective time (s), which is the measured time minus the zero time correction. The zero time correction is equal to the travel time between the transmitting and receiving transducers when they are pressed firmly together.

The UPV results can be used to check the uniformity of concrete, to detect cracking and voids in concrete, to control the quality of concrete and concrete products by comparing results to a similar made concrete and to determine the strength if previous data are available.

3.2 Principle

The ultrasonic pulse is generated by an electro-acoustical transducer. When the pulse is induced into the concrete from a transducer, it undergoes multiple reflections at the boundaries of the different material phases within the concrete. A complex system of stress waves is developed which includes longitudinal (compressional), shear (transverse) and surface (rayleigh) waves. The receiving transducer detects the onset of the longitudinal waves, which is the fastest. Because the velocity of the pulses is almost independent of the geometry of the material through which they pass and depends only on its elastic properties, pulse velocity method is a convenient technique for investigating structural concrete.

The underlying principle of assessing the quality of concrete is that comparatively higher velocities are obtained when the quality of concrete in terms of density, homogeneity and uniformity is good. In case of poorer quality, lower velocities are obtained. If there is a crack, void or flaw inside the concrete which comes in the way of transmission of the pulses, the pulse strength is attenuated and it passes around the discontinuity, thereby making the path length longer. Consequently, lower velocities are obtained. The actual pulse velocity obtained depends primarily upon the materials and mix proportions of concrete. Density and modulus of elasticity of aggregate also significantly affect the pulse velocity.

3.3 Apparatus:

The apparatus for ultrasonic pulse velocity measurement shall consist of the following:

- Electrical pulse generator,
- Transducer - one pair,
- Amplifier, and
- Electronic timing device.
- Couplant gel

3.4 Procedure

A Non-Destructive Evaluation is accomplished by establishing a correlation between a Non-Destructively measured physical/derived parameter and quantitative information on defects, stresses and microstructures. Non-Destructive as the name implies means that the material under the test is not damaged during the test. This test is performed using Portable Ultrasonic Non-Destructive Digital Indicating Tester (PUNDIT).

The Standard Portable Ultrasonic Non-Destructive Digital Indicating Tester **(PUNDIT)** machine should be calibrated before starting the observation and at the end of test to ensure accuracy of the measurement and performance of the equipment. It is done by measuring transit time on a standard calibration rod supplied along with the equipment. The testing procedure should start by verifying that the device measures the transit time, *t*, properly. A reference bar is usually provided by the manufacturer for this purpose. In order to carry out the testing procedure efficiently and to produce accurate test results, an experienced operator is necessary.

In this test method, the ultrasonic pulse is produced by the transducer which is held in contact with one surface of the concrete member under test. After traversing a known path length in the concrete, the pulse of vibrations is converted into an electrical signal by the second transducer held in contact with the other surface of the concrete member.

Once the ultrasonic pulse impinges on the surface of the material, the maximum energy is propagated at right angles to the face of the transmitting transducer and best results are, therefore, obtained when the receiving transducer is placed on the opposite face of the concrete member (direct transmission or cross probing).

To ensure that the ultrasonic pulses generated at the transmitting transducer pass into the concrete and are then detected by the receiving transducer, it is essential that there be adequate acoustical coupling between the concrete and the face of each transducer. Typical couplants are petroleum jelly, grease; liquid soap and kaolin glycerol paste. If there is very rough concrete surface, it is required to smoothen and level an area of the surface where the transducer is to be placed. A minimum path length of 150mm is recommended for the direct transmission method involving one unmoulded surface and a minimum of 40mm for the surface probing method along an unmoulded surface.

The presence of reinforced concrete elements in a completed building can be detected with the use of an instrument called profoscope or profomete. The profometer is a light and compact metal non-destructive testing technique used to detect location and size of reinforcement bars, measure bar diameter and determine concrete cover. The profometer weighs less than 2kg, works on normal batteries, and thus does not require any electrical connections.

IV. EXPERIMENT

In order to determine the structural stability of the existing buildings, experiments were conducted on the major structural elements by performing a Non-Destructive Test (NDT). 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).** In general, visual inspection was undertaken on each of the selected building while the analysis of the test results 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. Two different buildings from the area of study was selected and tested. Three (3) numbers test points were randomly selected on the concrete elements and the average taken to get a good representation/result on each structural element. This study evaluated the compressive strengths of the specimens as specified in British Standard of Non-Destructive Testing of Concrete Methods-of Test: Part 203 of 1986 for Ultrasonic Pulse Velocity.

4.1 Visual Observation of the Tested Building A.

- The tested structure is a 4-floor completed building located at Francis street Onitsha, Anambra State.
- The ground and first floor of the building are being used for commercial purpose (warehouse and offices respectively), while the second and third floor are being used for residential purpose.
- The structure is bounded on the left hand side by an on-going building at first-floor slab level and on the right hand side by a 3-floor completed building.
- Exposed/Corrosion of the embedded metals was observed in the ground, first, second and third floor slab soffits.
- Diagonal and vertical cracks were also observed on second floor internal block wall.
- Dampness was observed in the ground, first and second floor external walls.
- Dilapidated plumbing works were noticed especially in the inspection chambers.
- One of the flats on the third floor was locked and therefore not accessible for test.

Table.1. Compressive Strength Test Analysis Results for Building A.

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).

4.2 Visual Observation of the Tested Building B.

- The tested structure is a 2-floor completed building.
- The structure is located at Modebe Avenue, Odoakpu Onitsha, Anambra State.
- The structure is bounded on the right hand side by a 2-floor building and on the left hand side by a mechanic workshop.
- The structure was constructed for residential purpose.

- The structure was constructed as a load bearing structure as there was no vertical support reinforcement concrete column noticed.
- Vertical and diagonal cracks were observed on both the external and internal walls.
- Excessive exposed/corrosion of the embedded metals was seen on the 1st floor slab.
- Slabs were tested on the ground & first floors of the building as the structural element identified.

Table.2. Compressive Strength Test Analysis Results for Building B.

Ground Floor			First Floor		
Structural Elements	ACS (N/mm²)/ Remarks		Structural Elements	ACS (N/mm²) / Remarks	
	Good	Poor		Good	Poor
-	-	-	Slab (4)	-	(4) 100%

Source: Field Survey (2021).

V. Results And Discussion

5.1 Compressive Strength Test Analysis Results for Building A.

From analysis of test conducted on the building as shown in table1, it was proved 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 15N/mm2 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 1st 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 results indicate that most of the structural elements were characterized by poor quality concrete mix.

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

5.2 Compressive Strength Test Analysis Results for Building B.

From analysis of test conducted on the building as shown in table 2 and the visual observation, it was deduced that the building footprint is mostly made of masonry load bearing walls. The only reinforced concrete structural elements identified as the slab failed to meet the required compressive strength of 15N/mm2 and above as the building very likely had exceeded its design life.

The visual observation shows that vertical and diagonal cracks were noticed on the internal and external walls and this may have been as a result of differential settlement of the building. Excessive exposed/corrosion of the embedded metals was also seen on the 1st floor slab. Based on the deductions made from the compressive strength test results and the visual observations conducted on the building in regards to consideration for strength and durability of the structure, it is considered that the structure has lost its residual design life and ability to sustain future loads.

VI. Conclusion

- Concrete has been proven to be the major component that majority of modern buildings in the study area used in the building construction. It then becomes essential that the quality of concrete elements in buildings is of paramount. To this end, it is necessary to ensure the stability of the concrete elements throughout the life span of the buildings.
- The structural stability of the concrete elements in the study area is not adequate. Hence, from the visual observation it was deduced that the structural elements are characterized with defects such as deep vertical, horizontal and diagonal cracks, exposed/corrosion of embedded metals, spalling; and these defects have contributed to the low compressive strength of the building which leads to structural instability.
- The compressive strength results analysis indicate that most of the structural elements in the existing buildings are characterized by poor quality concrete strength, as they fall below 15N/mm2 which is acceptable strength. All the dilapidated buildings

associated with heavy structural defects like cracks, spalling, exposed/corrosion and of the embedded metals etc were observed to have recorded very poor compressive strengths.

- Based on the deductions made from the low compressive strength test results analysis and the visual observations conducted on the buildings in regards to consideration for strength and quality of the Structural elements, it can be said that some of the buildings have lost their residual design life span and ability to sustain future loads.

VII. RECOMMENDATION

From the findings and conclusion of the research, the following recommendations are made for effective implementation of quality in concrete elements and enhancement of structural stability of buildings in Onitsha.

- Since the state of structural stability was found to be inadequate, the study recommends that the regulatory bodies in charge of non-destructive testing of existing building should gear into action in ensuring that buildings in the study area especially old buildings undergo NDT. People should be evacuated from structurally deteriorated buildings since most of them have lost their residual design life and ability to sustain future loads, to avoid incidents of building collapse.
- There is need for Government Agencies, Professionals and other key stakeholders that determine the success of construction projects to implement regular inspections and testing of concrete structures during and after constructions in order to prevent unnecessary injury or death caused by failure of these concrete structures.
- The study recommends continuous survey and monitor of concrete structures during service life as to detect impending failure and examine the performance of the buildings in order 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.

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