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Original Article

Assessment of Concrete Elements of A Collapsed Building Using Ultrasonic Pulse Velocity Test

Timothy Danjuma[1], Aliyuda Yohanna Adamu[2], Mbimda Ali Mbishida[3*], Benjamin Yusuf Mailafiya[4]

[1,2,3,4]*Nigerian Building & Road Research Institute (NBRRI) North Central Zonal Office Jos, Plateau State (Federal Ministry of Science & Technology, Nigeria)*

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Abstract *- Some ugly trends have bedeviled the construction industry in Nigeria for about a decade now, including building collapse. One of these incidences that occurred in 2018 was the catastrophic collapse of the hall/office complex of the Nigerian Medical Association. This research presents the findings from the Ultrasonic Pulse Velocity Test (UPVT) carried out on the concrete elements of the collapsed building with the sole purpose of prognosis, diagnosis and quality control by the Nigerian Building and Road Research Institute (NBRRI) and other relevant stakeholders in the construction industry. The results of the UPVT on all the beams and slabs showed that the quality of the concrete is quite below the recommended standard of 3.0km/s. The UPVT performed on the selected ground floor columns was found to be good as the Pulse Velocity (PVs) averagely more than 3.5 km/s. However, the part of the column below the ground floor level is doubtful (PV<3.0 km/s). These clearly show that the columns above the ground floor level are good, but those below are the suspected cause of the collapse.*

Keywords *- Building collapse, Concrete quality, Ultrasonic pulse velocity.*

1. Introduction

A building is a roofed and walled structure built for permanent use. A building can serve as living quarters, storage, an office or a factory. A building is a human aesthetically and artistically created space that provides a habitat for humans and other living things for their comfort to prevent the adverse effects of the natural and artificial environmental conditions for their survival. A building is an enclosure for spaces designed for a specific use, for example, religious activities, control of local climate, distributing services and evacuating waste [1].

There are two main components to a building, namely, the structural components and the non-structural components. The structural components bear the entire weight of the building structure and effectively transmit that weight to the ground. Examples of these include columns, beams, slabs, etc. Non-structural components carry only their own weight, and they transmit that weight to the structural components. Examples of these include doors, windows, partition walls, etc. The primary supporting structure of a building can be made with different materials; the most frequent materials used include steel, timber and reinforced concrete. However, the use of reinforced concrete is most common [2], [3].

It has been concluded by [4], [5] that more than 90% of storey buildings in Nigeria have been made from reinforced concrete. Therefore, studying the concrete used is important to know the quality of buildings constructed in Nigeria. According to [6], studies were carried out in Nigeria which revealed the effects and showed a low level of awareness of the applications of cement strength class in concrete production. In construction work, buildings are made to stand firm and strong; a building is held primarily by its structural components; once there is a problem with the structural components of a building, then failure of that building is inevitable. In Nigeria, most of the structural building components are made of concrete.

Then it can be concluded that the highest percentage of building structural failure is as a result of concrete failure. The concrete could fail due to the production of lower concrete quality below the capacity to resist its imposed load effectively, service factors that deteriorate a good concrete to a quality decrease below the service requirement like the ingress of nitrates in concrete service conditions [7] and once the concrete structure is loaded beyond its service limits like in upward building adaptations.

Collapse refers to an instance of a structure falling down as a result of being weak. In architecture and construction, collapse is considered to be a mechanical failure of a building. Globally, building collapse is considered to be caused by one of the two major factors: the natural or man-made factor [8], [9]. Building collapse has gradually made the headlines in most developing countries today, and this has become rampant and devastating. The effects of each building collapse are felt and not forgotten, especially by its victims. These include loss of lives, huge loss of money spent on investment, property, jobs, trust in building professionals, increasing uncertainty among stakeholders, and environmental disaster [2].

In Nigeria, building collapse occurs either by natural elements or man's negligence. The frequency of building collapse in the construction industry has become worrisome to the extent that research has begun in order to find lasting solutions. The recorded incident of building collapse has occurred in buildings under construction, buildings undergoing renovation, and buildings in service [10]. There have been several building collapses in Nigeria which have had a negative impact on the socio-economic status of the citizens. [11] have shown that no loss of life occurred in 20.3% of the occurrence of building collapses, while in 44.4% of the recorded incident, between 1 and 5 lives were lost, while the worst-case condition was the death of more than 21 people in 9.3% of the incidents. [12] carried out the analysis and evaluated the death rate involved in 47 reported cases of building collapses verified between 2000 and 2010; over 300 death rates were recorded for Lagos, Abuja and Port Harcourt, which are the three major areas with high rates of casualties. According to [1], the increase in population in cities as a result of migration created the specific problem of inadequate building structures. This resulted in an increase in building projects from various contracting firms of doubtful competence. [13] pointed to the fact that building collapse has cast a stain on the competence of the nation's building community of professionals responsible for designing and monitoring construction work at building sites. Experts in the field of building construction have suggested that the blame should not be on the professionals alone. This is due to the following reasons:

- It has been proven that owners of buildings under construction derail from their approved plans.
- The authorities supposed to monitor the implementation and compliance of the approved plans also fail to do their job.
- Some building owners shun professionals in order to cut costs.
- Some greedy contractors do not go for the high-cost standard building materials but rather patronize the substandard building materials.

All these factors contribute to the failure and collapse of buildings in Nigeria.

1.1. Ultrasonic Pulse Velocity Test (UPVT)

Ultrasonic Pulse Velocity Test is a non-destructive test employed for compressive strength estimation and quality assessments of concrete samples. It is used to test the homogeneity and integrity of the concrete. The UPVT detects some imperfections in homogeneous materials, and its results are reliable. Total control of a structure can be obtained when the properties variation with the time is used. When the analysis of the propagation variations of ultrasonic velocity wave is used, it is possible to detect heterogeneous regions in the concrete [14]. The UPVT results can be used for prognosis, diagnosis and quality control.

The following can be accessed on the concrete using the ultrasonic pulse velocity test.

- Quality assessment of the strength of concrete, its gradation in different locations of structural members and the plotting of the same.
- Any discontinuity in cross-section like cracks, cover concrete delamination etc.
- Depth of the surface crack.
- To check the uniformity of concrete
- To control the quality of concrete and concrete products by comparing results to similarly made concrete.

According to [15] and [14], the UPVT method is based on the propagation of high-frequency sound wave which passes through the material. The wave's speed varies in function of the density of the material, making it possible to estimate the porosity and the discontinuity detection. The idea is to transmit sound inside a material and measure the time necessary for the wave to propagate through it. Having known the distance, the pulse velocity can be determined, which is a function of several factors, such as the nature of the material, the presence of water in the pores, etc. Though there is no clearly defined relationship between compressive strength and pulse velocity, however, it can be used to determine the homogeneity and the integrity of the concrete [15].

Table 1. Concrete quality based on ultrasonic pulse velocity test

S/N	Pulse Velocity	Concrete Quality
1	>4.0km/s	Excellence
2	3.5-4.0km/s	Good
3	3.0-3.5km/s	Medium
4	<3.0km/s	Poor

Quality of concrete in terms of strength, homogeneity, trapped air, internal flaws, cracks, segregation, honeycombing, compaction, workmanship and durability can be conducted from this test (ASTM C597-09 Standard Test Method for Pulse Velocity through Concrete-astm.org)

1.2. The NMA Collapsed Building

The Collapsed building in question belongs to the Nigerian Medical Association sited at Gura-Zot B, Kwang, Jos South Local Government Area of Plateau State, Nigeria. The site lies in the savanna vegetation belt of Northern Nigeria with coordinates of 9.878°N and 8.918°E. It is an ongoing 2-storey building plan of which the work was taken up to the 1st floor. The building was reported to have collapsed on Thursday, 6th September 2018.

The aim of carrying the Ultrasonic Pulse Velocity Test (UPVT) on the different concrete structures of the collapsed building is for the purpose of prognosis, diagnosis and quality control by the Nigerian Building and Road Research Institute (NBRRI) and other relevant stakeholders in the construction industry.

2. Materials and Method

2.1. Materials and Equipment

The materials used for the purpose of this test are the concrete slabs and columns of the collapsed structure. While the equipment used was the Ultrasonic Pulse Velocity Tester.

2.2. Method

The test was performed in accordance with the provision of BS 1881: Part 203 (1986) on the concrete specimen of the collapsed building. The equipment used is called "Ultrasonic Pulse Velocity Tester". Ultrasonic testing equipment includes a pulse generator circuit, consisting of an electronic circuit for generating an electronic pulse into a mechanical pulse with an oscillation frequency of 40 KHz to 50 KHz and a pulse reception circuit that receives the signals. The transducer, clock, oscillation circuit and power source are assembled for use. After calibration to a standard sample of the material with known properties, the transducers are placed on opposite sides of the material. The pulse is obtained by applying a rapid potential change from a transmitting transducer to the receiving transducer. The path of the travel of the emitting pulse between the specimens (path length) by the two transducers was noted and fed into the Tester [16]. The Pulse velocity was then read out and recorded accordingly.

Pulse velocity is measured by a simple formula:

$$Pulse\ Velocity = \frac{Path\ Length\ (L)}{Travel\ Time\ (T)} \quad (1)$$

3. Result and Discussion

3.1. Concrete Beams

Table 2 shows the test performed on the un-collapsed beam samples collected from the collapsed building site.

The results of the Ultrasonic Pulse Velocity test on the beam samples, as shown in Table 1, attest to the poor nature of the beam of the collapsed building as the Pulse Velocity (PV) recorded were less than 3.0 km/s as it should have been (See Table 1). This indicated a poor quality of workmanship, and concrete was doubtful. It is pertinent to note that these tests were performed on the un-collapsed beams that were yet to be loaded on the second floor.

Table 2. Beams Ultrasonic Pulse Velocity (UPV) test result

Element ID	**Path Length** (mm)	**Transit Time** (μs)	**Pulse Velocity** (km/s)
Beam 9 (main beam)	230	85.1	2.7
Beam 6 (secondary beam)	230	99.5	2.3

3.2. Concrete Slab

Table 3 shows the test performed on the slap sample collected from the collapsed building site.

Table 3. Slab ultrasonic pulse velocity test result

Element ID	**Path Length** (mm)	**Transit Time** (μs)	**Pulse Velocity** (km/s)
Slab (150mm)	150	59.9	2.5

Due to the insignificant rebound number obtained, the compressive strength cannot be read from the graph. This further shows that the concrete is of poor quality and strength, despite using machine-crushed granite aggregate and well-graded fine aggregate for the construction. The cement content in the concrete mix may be grossly inadequate in content since the mix was not designed according to any known standard.

3.3. Concrete Columns

Table 4 below shows the results of different concrete columns collected from the site of the collapsed building. A remark on each was made after comparing the result of each column with a standard, as shown in Table 1.

Table 4. Columns ultrasonic pulse velocity test result

Element ID		**Path Length** (mm)	**Transit Time** (μs)	**Pulse Velocity** (km/s)	**Remark**
Column P2	Ground Floor	230	66.6	3.5	Good
Column 08	Ground Floor	240	64.2	3.7	Good
Column B8	Foundation Concrete	230	91.8	2.5	Doubtful
	Ground Floor	240	61.9	3.9	Good
Column G1	Ground Floor	230	65.9	3.5	Good
Column K1	Ground Floor	240	73.8	3.3	Medium
Column F8	Ground Floor	400	103	3.9	Good

From the UPV test performed on all the ground floor Columns, as shown in Table 4, they were found to be good as the PVs were, on average more than 3.5 km/s, as suggested in Table 1. The part of the column below the Ground floor level is doubtful (PV<3.0). It shows that the Columns above the ground floor level were good, but below it was suspected of failure.

4. Conclusion

From the results obtained, the building may have collapsed due to the following reasons:

- Poor workmanship is evident in the poor quality and strength of the concrete.
- The cement content in the concrete mix may be grossly inadequate in content since the mix was not designed according to any known standard.
- There may be a compromise in the foundation depth and thickness as the ultrasonic pulse velocity test shows that the columns above the ground floor were very good, but below it was suspect for failure.

Recommendation

- Subsequent construction and use of the same building should be stopped by the relevant government authority as the un-collapsed part of the building is liable to total failure.
- The relevant Government authorities and building owners should ensure that relevant construction professionals are actively engaged during the design and construction process of buildings.
- Relevant Government authorities and regulatory bodies responsible for the approval and supervision of the project at any point should do that with all diligence.

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