Use of Non-Destructive Tests for Reinforced Concrete Damage Assessment

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Abstract. Worldwide, the debilitation of structures over the last few decades has been a cause for concern. This has led to the need to create awareness among engineers, and home owners about the different ways in which a structure can be checked for structural safety. To assess the behavior of new and existing buildings to varying loads over time, numerous methods have been developed and a major breakthrough for concrete and steel structures is the introduction of Non-destructive tests. This project was aimed at highlighting the common methods while also giving an in-depth investigation into the use of Non-destructive tests in Nigeria as well as their efficiency in the determination of building properties. The widely used methods in Nigeria includes: Schmidt hammer test, Ultrasonic pulse velocity test and the Rebar locator test and the properties the tests considered include: strength, surface hardness, homogeneity, reinforcement location and bar size. After successful execution of the tests, it was discovered that the Schmidt hammer is capable of giving an estimate of concrete strength not too far from the strength obtained from carrying out destructive tests on the same sample. From the pulse velocity test, it was observed that the method is not a reliable test of strength but rather, a determinant for uniformity and homogeneity in the tested samples. Thus, it can be concluded that in carrying out assessments of structures, the Schmidt hammer, ultrasonic velocity tester and the rebar locator should simultaneously be used to give a proper assessment on the structural integrity of structures.

Keywords: Concrete, Compressive Strength, Non-destructive Tests, Pulse Velocity Test, Rebar Locator, Schmidt Hammer

1. Introduction

Due to a high rate of failures in structural members worldwide, the need to carry out structural assessment has reached a level of great economic importance in the post construction phase of all structures [1]. As we have come to know, structural assessment is concerned with discovering the potential failures in a structure and it involves numerous processes and methods to check the reliability of a structure to ensure that it is safe to perform its functions throughout the entirety of its design life. This ability to monitor a structure and detect damage at the earliest possible stage has been of great interest to the engineering community as it permits the safety of valuable human lives and the conservation of economic resources [2-5].

The traditional method of estimating the strength of structural members has been through carrying out destructive tests such as the compressive strength test by crushing the test samples however due to the disadvantages of this method, it has been imperative to explore other options which brings us to the use of Non-destructive tests. The mode of operation of NDTs rely on the fact that some physical and chemical
properties of concrete and other materials which can be tested can be related to strength and durability of the structure. These methods have been employed for decades for evaluating and assessing the condition of a structure; now in the present century NDTs have become smarter and more precise as it has developed from the use of just visual inspection apparatus to the use of Rebound hammers (Schmidt hammer), Impact Echo and Impulse response techniques [6]. For concrete structures, the most common methods involve the Rebound hammer, Profoscope (proformeter)/rebar locator, and Ultrasonic pulse velocity tester.

2. Literature Review

The agony of building collapses among all other things has become an endemic plague constantly striking in recent years without any seeming possibility of it being properly addressed or prevented [7]. The causes for the failure of such buildings has been under scrutiny for a long time with fingers being pointed to contractors, consultants, and even mother nature herself [8]. However, a major cause of collapse and failure in structures is negligence on the part of different members of the project team which has brought about the need to constantly carryout quality control tests on structures at different stages of its lifecycle.

Quality control tests vary in terms of applicability but to concrete structures, the traditional method involves the use of Destructive tests. Destructive tests encompass structural assessment methods that tend to totally destroy the sample that is been tested. This method however poses limitations in terms of its applicability to existing structures as the standing quality of the concrete cannot be gotten without harming the existing structure. Additionally, the test samples are crushed immediately the test is performed and consequent assessment of the same sample isn't conceivable. Therefore, the impact of delayed curing, weathering activity and other time subordinate attributes cannot be effectively computed [9]. On the other hand, the use of non-conventional methods such as Non-destructive tests (NDTs) will allow for the detection of internal and external flaws without affecting the integrity of the tested structure/sample. NDTs such as Rebound hammer test, Visual testing, Liquid Penetrant (Dye penetrant) testing, Magnetic particle testing, Ultrasonic testing, Radiographic testing and Eddy current method are very well accommodated in structural assessment because they provide an increase in the safety and reliability of a structure throughout its entire useful life [10]. In summary, this study will focus on giving an all-round view into structural assessments using Non-destructive tests based on previously conducted research, and newly developed procedures for assessment.

3. Methodology

On-site investigations of some select structures which included those that were damaged as a result of fire accidents (St Paul’s Church Breadfruit Development Company Limited) as well as structures still undergoing construction (Total E&P Nigeria staff Multipurpose Cooperative society limited) and concrete cube samples were carried out. The reason for this variation in the test samples was to ensure that vast data is obtained as regards how different working conditions can affect the strength of a structure when tested using NDTs as against using destructive tests. During the course of the inspections, special attention was paid to the strength of the structure, the homogeneity of the materials in the structure, the presence of visual flaws, and the location of rebars for the test structures.
In carrying out the Rebound Hammer test, it was ensured that the hammer was first calibrated using a test steel anvil having a Brinell hardness of 5000N/mm² after which the hammer is then held at an angle perpendicular to the test surface as shown in Figure 1 and pressed firmly against it till a rebound is felt in the hammer. The rebound value is known as the Rebound Index and will be used in determining the actual compressive strength of the test structure/sample by using the conversion chart of that particular Rebound hammer. Figure 2 depicts a typical conversion chart for a rebound hammer. It is important to ensure before carrying out the test that, the test surface is smooth and free of dust so as to prevent any shift in perpendicularity while performing the test. The rebound process is then repeated twelve (12) times after which the highest and lowest values will be dropped and then the average of the remaining ten (10) readings will be recorded as the rebound index for that surface.

![Figure 1](image1.png)

Figure 1. Positioning of hammer against test surface
To execute the ultrasonic velocity test on the samples, a couplant (grease) is first applied to the surface of the transducers of the apparatus after which the two (2) probes (transducers) are held firmly at either ends of the test sample and the pathlength of the waves released by the transducers is read from the apparatus. This process can be repeated up to ten (10) on the sample after which the values are then converted using Figure 3 below to determine the compressive strength of the sample.

Figure 2. Conversion curve for Digi-Schmidt hammer 2000
4. Results and discussions

The tests carried out on St Paul’s Church Breadfruit Development Company Limited (the fire damaged structure) revealed that the design compressive strength and the strength observed from the rebound hammer test were not too far off however, the pulse velocity test indicated a reduction in strength in the structure. Figures 4 and 5 detail the results of the tests carried out on the structure.

![Figure 3 Relationship between pulse velocity and compressive strength of concrete](image.png)
For the tests carried out on Total E&P Nigeria staff Multipurpose Cooperative society limited (the structure undergoing construction), it was noted that strengths observed using the rebound hammer were in line with the design strength of the structural members. The results from the test are detailed in Figure 6.
As depicted in Figure 7, the application of the NDTs on the cube samples of different compositions indicated disparities in the strength which can be attributed to the fact that each apparatus has different applications and are affected by a wide range of factors. However, it can be seen that the results obtained from the use of the Schmidt hammer and that obtained from the total destruction of the cube samples are not so far apart while that of the pulse velocity test is of a higher value.
5. Conclusions

From the different test samples, a large disparity was observed in the values gotten from carrying out the Schmidt hammer test, ultrasonic velocity test and destructive test. The results are such that:

- The values obtained from the Schmidt hammer and those obtained from the destructive test were not so far apart;
- The values obtained from the ultrasonic pulse velocity test and those obtained from the destructive test are very far apart

All these attests to the fact that the Schmidt hammer test is a better method of assessing the integrity of existing structures in terms of strength given that the conditions are suitable. While the ultrasonic test is one of the best methods of checking the level of homogeneity in the samples while also assessing deep seated defects, presence of cracks or voids, changes in properties with time and in the determination of dynamic physical properties rather than in the direct measurement of the compressive strength of concrete.

However, despite the fact that Schmidt hammer tests reflect higher values for the compressive strengths of the tested samples and structures than the ultrasonic test, it is not advised that this should be used to make a decision on the exact in-situ grade or strength of concrete in the structural elements of the building. The outcome of the tests should certainly not form the basis for determining the stability of any building as the Schmidt hammer test only gives an indication of the surface hardness of a structural member and not necessarily the absolute compressive strength of the member.

In addition, fire damaged structures are very delicate sites when the assessment of their strength levels is being done and as such, the use of non-destructive tests for their assessment should not be limited to the use of just one single equipment. The different available tests such as the rebound hammer tests, pulse velocity test, and rebar locator test should be used concurrently.

5.1. Recommendations

The Schmidt hammer and pulse velocity tests as well as the rebar locator test should be carried out simultaneously on test structures to generate an assessment of relatively high accuracy. An assessment of this caliber will ensure that every factor pertaining to the test structure is considered without ambiguity.
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