

PAPER 89 – STRUCTURAL INTEGRITY ASSESSMENT OF THE ACADEMIC AND HOSTEL BUILDINGS AT UNIVERSITY OF ILORIN USING NON_DESTRUCTIVE METHODS

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ABSTRACT

Quality and condition assurance assessment of concrete for structural adequacy have been performed by visual inspection and sampling by coring concrete using standard tests on specimens. They result in superficial local damage. Test methods that will not impair the function of structures and permit re-testing to measure their in-place properties at any time are, therefore necessary. Blocks 7-10 of the University of Ilorin, constructed with concrete walls and commissioned in 1980, were tested to determine the residual life of the buildings. The walls were subjected to non-destructive tests and a strength-Ultrasonic Pulse Velocity model in the form $a \ln x + c$ at R^2 of 96.5%. The resulting Pulse Velocities were then injected into the model to determine the residual life of the walls, and hence the buildings. The strength results were 21.81, 21.62, 21.65 and 21.35N/mm² for the blocks, respectively. These are less than 25N/mm² adopted for the structures at design stage, but greater than the expected remaining compressive strengths of 11.75N/mm² after 43 years of use, confirming that the conditions of the buildings are adequate. This method can be employed to identify dilapidated buildings to be demolished before sudden collapse to prevent loss of lives and properties.

KEYWORDS: Concrete blocks, Quality assurance, Ultrasonic pulse velocity, Compressive strength, Residual life

1. INTRODUCTION

Design of concrete requires an accurate knowledge of concrete properties under anticipated loading conditions. A large number of information is available on behaviour of concrete under static loading condition. However, when concrete is subjected to dynamic loadings, such as traffic on highway pavements and bridges, railroad bridges, building structures, airport pavements and marine structures, the fatigue behaviour/mechanism needs to be properly modelled. Fatigue is a process of progressive permanent internal changes in the materials that occur under the actions of cyclic loadings (Hiller and Roesler, 2016), which can cause progressive growth of cracks in the concrete and eventual failure of structures when high levels of cyclic loads (for shorter times) or low levels of loads (for longer times) are applied. Fatigue strength data of concrete and other materials that are used for development of load-induced stresses are needed for safe, effective and economical design. Indeed, fatigue cracking in concrete is a key failure mechanism and is the result of repeated applications of load at stress levels even below the flexural strength of the concrete slab (Roesler et al., 2013).

The mechanical response of a material is substantially altered by cyclic loadings. In the case of metals, it depends greatly on hardness of materials and experimental conditions. Under cyclic loading condition, a metal may harden, soften, remain stable or have mixed behaviour (soften or harden depending on strain level) (Bannantine et al., 2017). On the other hand, concrete which is a complex hybrid composite material under cyclic loading can experience fracture due to fracture of the cement paste, fracture of aggregate, failure of bond between the cement paste or combination of these mechanisms. Compared to metals, concrete is prone to have large number of flaws resulting from hydration, shrinkage and other causes. Mechanism of fatigue in concrete is not well established irrespective of the numerous hypotheses related to track initiation and propagation based on fracture of concrete mix (Bannantine et al., 2017).

Non-destructive test (NDT) methods are increasingly applied for the investigation of concrete for qualitative and quantitative explanation of the effects of structures due to (i) technological improvements in hardware and software for data collection and analysis, (ii) the economic advantages in assessing large volumes of concrete

compared with the acquisition of cores from existing structure, (iii) ability to perform rapid, comprehensive assessment of existing construction, and (iv) specification of NDT methods for quality assurance of deep foundations and concrete repairs (Verbeek and Stet, 2016). There has always been a need for test methods to measure the in-place properties of concrete. Ideally, these methods should be non-destructive so that they do not impair the function of the structure and permit re-testing at the same locations to evaluate changes in properties with time; and also serve as appropriate strength deterioration model for concrete design and maintenance purposes.

NDT methods, defined as testing that causes no structurally significant damage to concrete, are used to determine hardened concrete properties and to evaluate the condition of concrete in deep foundations, bridges, buildings, pavements, dams and other concrete construction. These test methods are applied to concrete construction for four primary reasons: (i) quality control of new construction; (ii) troubleshooting of problems with new construction; (iii) condition evaluation of older concrete for rehabilitation purposes; and (iv) quality assurance of concrete repairs. NDT emphasizes on methods that have been applied to measure physical properties other than the strength of concrete in structures with the later inferable from the former. The various NDT methods can be divided into two groups: those whose main purpose is to (a) estimate strength; and (b) evaluate conditions other than strength, that is to evaluate integrity. Generally, the most reliable tests for strength are those that result in superficial local damage. The integrity tests, on the other hand, are non-destructive and mostly based on visual inspections.

Ultrasonic Pulse Velocity (UPV) is a non-destructive technique that involves measuring the speed of elastic waves through materials in order to predict material strength, calculate low-strain elastic modulus and/or detect the presence of internal flaws such as cracking, voids, honeycomb, decay and other damages. The technique is found much applicable where intrusive (destructive) testing is not desirable and can be applied to concrete, ceramics, stone and timber. Absolute measurements need to be treated with caution. However, the UPV technique is not always practicable in testing sound concrete especially in the investigation of crack depth, where the crack is water-filled. The performance may also often be poor in very rough surface because sometimes good contact requires the use of a coupling gel between the transducer and the structure. This may be aesthetically unacceptable on some structures. Studies have proved the rational in using UPV for concrete testing. The studies concluded that for concrete with a particular mix proportion, there is a good correlation between UPV and the compressive strength; although there still exists a high uncertainty when one tries to make use of UPV to predict the strength of concrete in different mix proportions. It has also been established that UPV of hardened concrete is predictable based on its mix proportion. In addition, it has been shown that the compressive strength of concrete corresponds with the mix proportion (Mahure et al., 2018).

In taking measurements with the Pundit apparatus, pulses of longitudinal, elastic stress waves are generated by an electro-acoustical transducer that is hold in direct contact with the surface of the concrete under test (Komlos et al., 2016). After traversing through the material, the pulses are received and converted into electrical energy by a second transducer. The direction in which the maximum energy is propagated is at right angles to the face of the transmitting transducer; though, it is possible to detect pulses travelling through concrete in some other direction. In effect, it is possible to measure pulse velocity by placing the two transducers on either (a) opposite faces - direct transmission in accordance with BS 12504-4 (2004) as shown in Figure 1a; (b) adjacent faces - semi-direct transmission as shown in Figure 1b; or (c) the same face - indirect or surface transmission as shown in Figure 1c. The direct wave transmission is the most sensitive, while the indirect is the least but most appropriate for in-situ testing for a slab (rigid pavement).

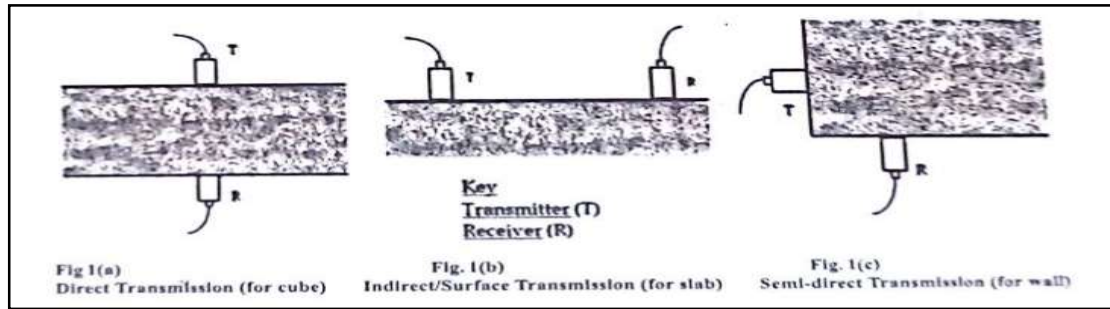


Figure 1: Methods of Propagation and Receiving Ultrasonic Pulses (BS 12504-4,2004)

Indirect transmission is used only when one face of the concrete is accessible, when the depth of a surface defect or crack is to be determined or when the quality of the surface concrete relative to the overall quality is of interest. The quality of concrete and concrete structure in terms of uniformity and incidence assessed shown in Table 1 (IS Code, BS 1881, 1986; BSI, 1986) evolved for characterizing of concrete structure in terms of ultrasonic pulse velocity. Ulucan et al. (2017), Mahure et al. (2018) and Lawson et al. (2015) explored the relationship between ultrasonic pulse velocity and compressive strength of concrete at various mix proportions and water/cement ratio at R² value ranging from 80-96.5%. Yusuf (2013) also noted that there is a unique relationship between strength and UPV logarithm model of the form $a \ln x + c$ that can be used to describe the strength of palm kernel shell concrete at R² value of 94.9-99.3%.

Table 1: Suggested Quality Criteria for Concrete

Pulse Velocity (m/sec)	Quality of Concrete (Grading)
Above 200	Very Good
100 – 200	Good
50 – 100	Medium
Below 50	Poor

The first set of buildings comprising ten blocks (Blocks 1-10) accommodating the Faculties of Science, Engineering and Technology, and seven Hostel Blocks at the then main campus of University of Ilorin, Ilorin, Nigeria, were commissioned for use in 1980. Over the past 43 years, various forms of rehabilitation exercises have been done on these buildings. Blocks 1-10 were constructed with concrete walls; however, two of the engineering blocks (blocks 7 and 9) house machineries and equipment, experiencing various forms of vibrations.

Thus, the aim of the study reported on in this paper is to determine the residual life of blocks of Faculty of Engineering buildings (Blocks 7-10) as case study using UPV technique, which is a non-destructive method. The specific objectives are: (i) collection of data on the specifications (concrete mix proportion, 28-day concrete strength, water/cement ratio and workability) adopted for the design and construction of the buildings, (ii) measurement of the ultrasonic pulse velocity in the concrete walls using Pundit equipment, (iii) estimation of the remaining compressive strength in the concrete walls by employing an appropriate compressive strength-age transfer models, and (iv) determination of the residual life (integrity) of the concrete structures and compare with the expected value obtained from literature.

Traditionally, quality assurance of concrete construction for structural adequacy has been performed but does not provide data on the in-place properties of concrete. Coring to examine internal concrete conditions and obtain specimen for testing results in the introduction of weak spots to the whole structure. This approach also limits what can be detected; while the cores only provide information at core locations and core holes needed to be repaired. Furthermore, though assessment of in-situ compressive strength of a concrete structure plays a key role in the evaluation of its safety, strength integrity and concrete properties at the time of production, it does not adequately reflect actual loading forms on the concrete. NDT method however offer the advantage of providing information on the realistic in-plane properties of hardened concrete, such as the elastic constants, density,

resistivity, moisture content and hardness characteristics. Maintenance of concrete structures is more effective if the deterioration rate of the strength could be monitored as the concrete is being affected by load and weather conditions.

2. THEORETICAL ANALYSIS

Neville (2004) noted that the service life of concrete structures is affected by the exposure to severe environmental conditions, and that among the different types of attack of concrete structures, sulphate attack is the most destructive resulting in significant compressive strength reduction of concrete. The prediction of service life of concrete structures needs constant overview due to sulphate attack; and the long term assessment of concrete properties needs a more appropriate method (Cohen and Mather, 2011). Orejarena and Fall (2014) used numerical modelling methods, which are increasingly used in civil engineering applications, for the purpose of interpolating concrete properties. The authors noted that polynomial interpolation is inappropriate and may yield unsatisfactory results when used to predict intermediate values, and that linear regression can exclude illegitimate results. However, Savidemir (2016) stated that the expectation of long-term concrete properties is very difficult with this approaches; and to remove this subjectivity, some criterion must be advised to establish a basis for the prediction. He therefore suggested interpolation regression by employing a technique for accomplishing this objective as presented in Figure 2. The expected compressive strength loss percentage is estimated by inputting the required parameters, thereby predicting the service life of concrete structures.

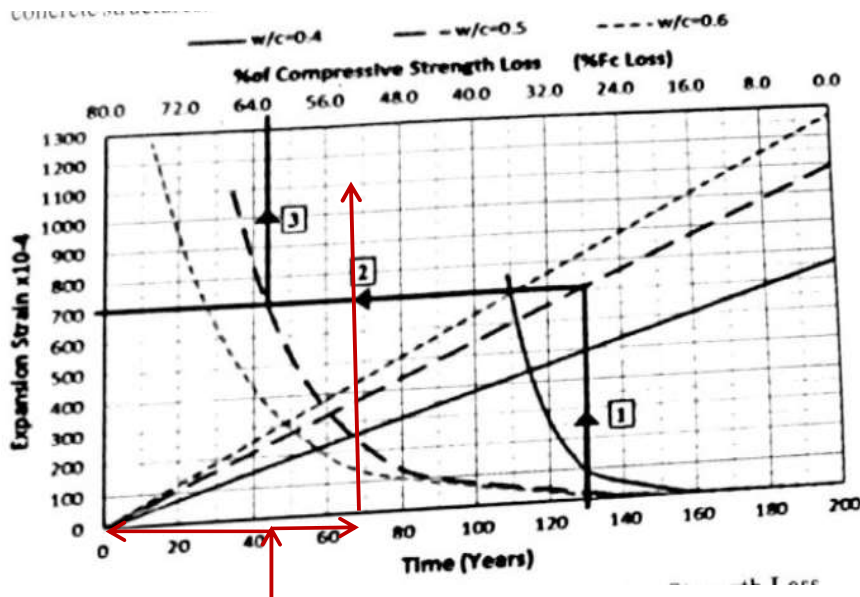


Figure 2: Expansion-Time and Expansion-Compressive Strength Loss Relationship of Concrete Structures

(Source: Savidemir, 2016)

3. METHODOLOGY

Generally, the residual lifespan of concrete is a necessary factor, and can only be deduced after an informed monitoring of strength subjected to many repetitions of loads. The influence of the frequency of loading on fatigue properties of the concrete buildings was examined with the PUNDIT apparatus. The NDT was performed using the experimental set-up shown schematically in Figure 3 in order to determine the ultrasonic pulse velocity of waves passing through the concrete walls. The Portable Ultrasonic Non-Destructive Digital Indicating Tester (PUNDIT, Model PC 1006), manufactured by CNS Farnell, London (Figure 4), was used to measure the velocity of propagation of a compression wave through a testing specimen. The dimension of the equipment which weighed 3kg was 185 x 130 x 185mm. The specified ambient temperature range of the equipment operation of 0 to 45C, which incidentally reflected the prevailing temperature in a tropical region, was ensured. The test equipment

provided a means of generating a pulse, transmitting it to the concrete walls, receiving and amplifying the pulse, measuring and displaying the time taken.

The concrete walls were subjected to the non-destructive test using the semi-indirect transmission. For each test procedure, the pulse velocity, transit time taken by the wave to pass through the PKS concrete and path length through the concrete wall were measured in accordance with the provisions of the British standard (BS EN12504-4, 2004). The 28-day compressive strength value of 25N/mm² adopted for the structures at design and construction stages were previously obtained from the Physical Planning Unit of University of Ilorin, Ilorin, Nigeria. The data set for the Ultrasonic Pulse Velocity (UPV), transit time and path length of the wave for each set of test was recorded. A logarithm compressive strength-UPV transfer model in the form $a \ln x + c$ at R² value of 96.5% was employed to determine compressive strengths in the concrete walls. The remaining compressive strength values were then compared with the expected values obtained from Figure 2.

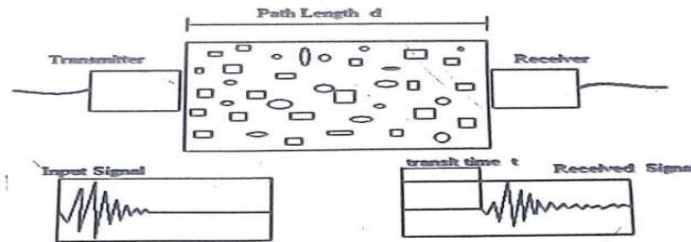


Figure 3: Ultrasonic Pulse Velocity Testing



Figure 4: The PUNDIT Plus Set (Source: Pundit, 1993)

4. RESULTS AND DISCUSSIONS

4.1 Results

The results of the average transit times, average path lengths and velocity of waves through the concrete walls of blocks 7- 10 of the Faculty of Engineering and Technology, University of Ilorin are presented in Tables 2--5.

Table 2: UPV Readings of Concrete Walls (Block 7)

Reading	Transit time (micro secs)	Path length (mm)	Velocity (m/sec)
1	206	22.50	109.2
2	210	22.79	108.5
3	209	22,78	109.0
Average	208.33	22,69	108.9

Table 3: UPV Readings of Concrete Walls (Block 8)

Reading	Transit time (micro secs)	Path length (mm)	Velocity (m/sec)
1	212	27.52	129.8
2	208	26.60	127.8
3	214	27.41	128.1
Average	211.33	27.18	128.6

Table 4: UPV Readings of Concrete Walls (Block 9)

Reading	Transit time (micro secs)	Path length (mm)	Velocity (m/sec)
1	211	22.13	104.9
2	208	21.99	105.7
3	204	21.54	105.6
Average	207.67	21.89	105.4

Table 5: UPV Readings of Concrete Walls (Block 10)

Reading	Transit time (micro secs)	Path length (mm)	Velocity (m/sec)
1	212	23.43	110.5
2	214	23.45	109.6
3	209	22.59	108.1
Average	211.67	23.16	109.4

Yusuf (2013) established a relationship between compressive strength (Y) and ultrasonic pulse velocity (x) as shown in Equation (1).

$$Y = 4.890 \ln(x) + 0.869; R^2 = 0.965 \quad (1)$$

The residual compressive strengths of blocks 7-10, calculated from Equation (1) are as presented in Table 6.

Table 6: Computed Residual Compressive Strengths in the Walls of Blocks 7 - 10

Block	Property	
	Ultrasonic Pulse Velocity (m/sec)	Compressive strength (N/mm ²)
7	108.9	23.81
8	128.6	24.62
9	105.4	23.65
10	109.4	24.65

4.2 Discussions

The UPV is the measure of the quality of concrete. The UPV values of the concrete structures for the four blocks under study fall within 104.9 and 129.8 m/sec. Compared with the UPV values for quality criteria in the IS Code (Table I), the structures are still good.

The results show that the average UPV values for block 7, 8, 9 and 10 are 108.9, 128.6, 105.4 and 109.4 m/sec, respectively as presented in Tables 2 to 5. The corresponding compressive strengths obtained for the blocks when the UPV values were input in Equation (1) were 23.81, 24.62, 23.65 and 24.65 N/mm², respectively.

Figure 2 was used to validate the compressive strength results obtained for the blocks. This figure shows that, for the period of 43 years after the blocks were commissioned for use, the estimated expansion strain of the concrete structures is 300×10^{-4} . This produced an expected compressive strength loss of 53% implying that the structures should have lost 53% of its original strength, that is, 25 N/mm. This translates to 13.25 N/mm² lost by 2023, with

remaining strength of 11.75 N/mm². However, the residual compressive strengths obtained for the four blocks are much higher than 11.75 N/mm²; thereby confirming the adequacy of the concrete structures.

5. CONCLUSIONS

Based on the outcome of the study, the following conclusions were drawn:

- (a) The concrete walls of the Faculty of Engineering blocks, and hence the whole blocks in the academic and hostels of University of Ilorin, Nigeria, commissioned in 1980 are in good conditions.
- (b) The ultrasonic pulse velocities of waves through the concrete material of blocks 7 to 10 are 108.9, 128.6, 105.4 and 109.4 m/sec, respectively.
- (c) A logarithm relationship between compressive strength and UPV at R² value of 96.5% produced residual compressive strengths of 23.81, 24.62, 23.65 and 24.65 N/mm², respectively for blocks 7, 8, 9 and 10.
- (d) The respective residual strength values are greater than the expected remaining life of 11.75 N/mm² for concrete structures of the same age (43 years). This confirms that the academic and hostel blocks of the University of Ilorin are still adequate for use.

RECOMMENDATIONS

From the study, the following recommendations are made:

- (a) The UPV results should be used to (i) check the uniformity of concrete, (ii) detect cracking and voids in concrete, (iii) control the quality of concrete and concrete products by comparing results to a similar concrete, and (iv) detect the depth of a surface crack.
- (b) For further studies, the effect of changes in the volume fraction of cement paste, the source of coarse aggregate, the weather combined with traffic, the UPV strength relationship should be examined for development of fatigue and other performance based characteristics of concrete.

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