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Relationships Between Concrete Tester (CTS02v4) and Ultrasonic Pulse Velocity in Determining Quality of Concrete; a Case Study of Atimbo Bridge in Nigeria

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Abstract: The research examines the relationship between the use of a concrete tester (CTS02v4) and ultrasonic pulse velocity (UPV) based on the strength characteristics of the Atimbo bridge in the cross-river state of Nigeria. The best fit approach for the cts02v4-UPV relationship under various circumstances is developed by carefully analyzing the correlation between these data sets. As a result, the relation between concrete strength and the CTS-UPV formula is developed by this investigation. From the technical investigation, the residual compressive strength of the concrete abutment was found to be between 29.0 N/mm2 and 40.0 N/mm2. This value is still within the range compared to the expected design value of about 40 N/mm2. The cover to the reinforcement of certain capping beams has an outline of reinforcements, which signifies poor concrete cover, and the mean compressive strength is less than 20 N/mm2. The objectives of this paper are to increase the understanding of processes and the applicability of versatile equipment by making comparisons between the experimental results for both the concrete tester (CTS02v4) and the ultrasonic pulse velocity (UPV), which were used to evaluate the structural integrity of the Atimbo Bridge. Comparisons were made between the UPV method and the concrete tester method using statistical analysis.

Keywords: Bridge, Concrete, UPV, CTS02V4, Atimbo

1. Introduction

Bridges are intricate infrastructures that are frequently subjected to adversities such as thermal stress, wetness, and dynamic loads. As a result, they are tough to inspect. A detailed investigation on the dependability of manual examination revealed substantial shortcomings in completeness and objectivity [1]. The association between concrete testers utilizing cts02v4 and UPV was one of the tasks examined in this study.

Non-destructive testing (NDT) is defined as the sequence of examining, testing, or assessing materials, components, or assemblies without destroying the serviceability of the part or system [2]. Different methods of non-destructive testing are interrelated with each other for improved diagnosis of defects in a concrete element and to reduce the number of tests [3]. The type of NDT method required for the inspection should incorporate the most practical and cost-effective technique to successfully assess the condition of the structural components and to determine the need for maintenance and repair action [4].

Casting of concrete during construction in some cases is carried out with uncertainties resulting from poor supervision and low-quality materials. The application of the non-destructive testing method in bridge inspections has gained interest among researchers due to its effectiveness in evaluating the structural condition of the bridge [5]. Therefore, it is essential to conduct a non-destructive analysis after the concrete has been set to ensure that the construction satisfies the predetermined specifications. The main aim of non-destructive testing is to evaluate the integrity of the component material and its reliability without distorting or hampering the structure's ability to achieve the designed functions. The relationship between ultrasonic pulse velocity and strength is affected by a number of factors, including age, curing condition, moisture condition, mix proportion, type of aggregate, and type of cement [6]. Non-destructiveness is different from non-invasiveness. Testing methods that have no effect on the future usefulness of a part or the full structure can be considered non-destructive even if there are invasive actions [7]. To keep bridges in good condition, accurate assessment of bridge condition has become a daunting challenge. As a result, bridge management standards, methods, and strategies have been continuously developed to meet this challenge [8].

Bridges are an essential component of a country's infrastructure, which contributes significantly to its social and economic well-being and accounts for a significant amount of its national economy. The overall worth of bridge infrastructure in Nigeria is estimated to be millions of dollars [9]. The Atimbo Bridge is a typical dual bridge channelized and composed of a 498-meter-long precast concrete slab; a visual assessment reveals that the bridge is structurally sound. However, eight expansion joints, including those at the abutments, are spaced 400 meters apart and have very visible and conspicuous failure. No expansion joint is okay apart from the two at the abutment ends.

Figure 1. *Longitudinal Section of the Atimbo bridge.*

2. Methodology

2.1. Ultrasonic Pulse Velocity Test

The equipment used was made up of an electrical pulse generator, an emitter transducer, a receiver transducer, an amplifier, and an electronic timer for measuring the time taken by the ultrasound to move from the emitter transducer to the receiver transducer. The pulse velocity test was determined using cuboid specimens in accordance with the requirements of British Standard BS 4408 (Part V—1974), BS 1181 [10], and ASTM C597-02 [11]. Ideally, pulse velocity should be related to the results of tests on structural components, and if a correlation can be established with the strength or other required properties of these components, it should be desirable to make use of it [12].

The ultrasonic pulse velocity test meter is as shown in Figure 2 while the working principles are represented in Figure 3.

In this test procedure, the ultrasonic pulse is generated by the transducer, which is kept in close proximity to the surface of the concrete part being tested. The second transducer maintained in touch with the opposite surface of the concrete part converts the vibrational pulse into an electrical signal after it has traveled a known route length L through the concrete. An electronic timing circuit then allows the transit time (T) of the pulse to be measured. The pulse velocity (V) is determined by:

$$V=L/T \tag{1}$$

Therefore V=Ultrasonic Velocity
L=Length of the Concrete
T= Transit Time

Figure 2. *UPV Testing machine.*

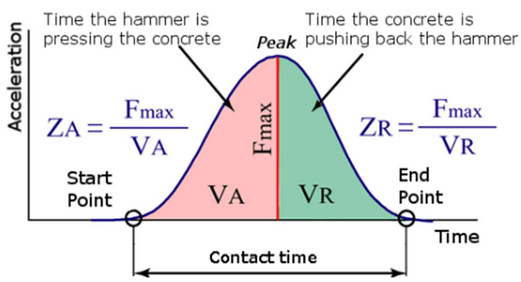
Figure 3. *Testing of Piers using UPV.*

2.2. Concrete Tester

CTS-02v4 was developed after the collapse at a railroad tunnel in 1999, existing inspection methods were insufficient to assess the condition of concrete in terms of measurement accuracy, convenience of data analysis, objectivity and traceability of measured data [13]. CTS-02v4 is an ideal non-destructive testing equipment to solve these issues. Estimated compressive strength of target concrete will displayed on the display right after the hammer blow, and the data can be transferred to your PC with USB connection.

This wave form generate in CTS2V4 is measured by an accelerometer that installed on the hammer unit. Measured wave form can be divided into two parts. The first half of the waveform shows the process that the hammer is pushing on the concrete surface. This process includes plastic deformation first, then elastic deformation of concrete surface. The second half of the waveform is the process that the hammer is rebounding from the concrete surface. In other words, the second half of the waveform is only affected by the characteristics of elasticity of concrete, and compressive strength of the concrete that is not affected by deterioration of concrete surface can be estimated [13].

Figure 4. CTS02v4 Testing Machine.



ZR= Compressive strength value

$\frac{ZR}{ZA}$= Index value of deterioration

Number of local peaks = Index value of delamination

Figure 5. Using of Concrete Tester (CTS2v4).

In this test procedure, the concrete structure is considered the ideal elastic body, and the hammer, whose mass is M, strikes the concrete surface with the starting velocity V and the spring coefficient K, as depicted in Figure 4 above. In such a case, the elastic deformation of the concrete surface is generated by the kinetic energy of the hammer. When the displacement of the concrete surface caused by the hammer collision is denoted by x, it can be shown in Equation (3.1) from the law of energy equilibrium.

3. Discussion & Result

3.1. CTS02V4

For the concrete tester, the results of the test that are automatically saved are downloaded from this instrument by a special program. The overall compressive strength result was developed into contour graphs that show the strength distribution across the members tested. A smooth and bell-shaped waveform indicates an acceptable degree of delamination, while an uneven waveform indicates an unacceptable degree of delamination, as shown in the figure below.

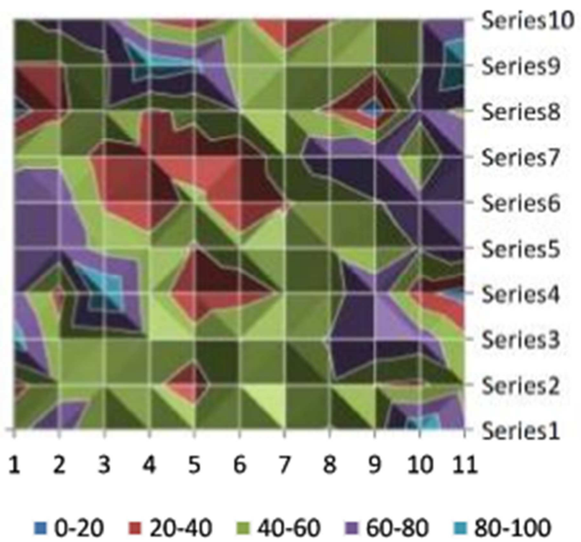


Figure 6. Representation of Compressive Strength using Surface graph.

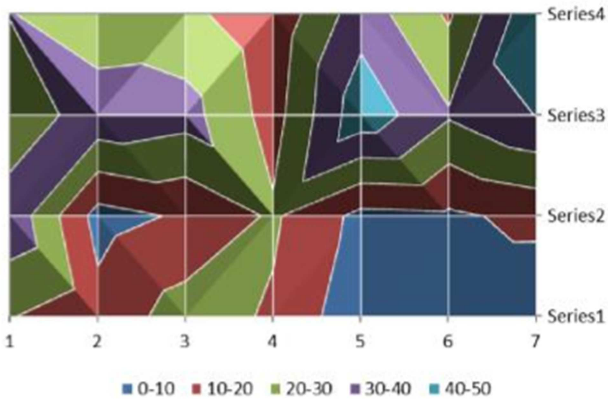


Figure 7. Representation of Compressive Strength using Surface graph.

For the CTS02v4, the result for the piers shows the average STR value (strength) for the tested segment is 32.84 N/mm^2. The average Index Value on Strength Estimation, INDX Value (Index), for the tested segment of the structural elements shows a value of 1.12. Therefore, it can be concluded that the strength in this stretch is "really suitable," revealing no structural defects or damages. However, since the INDX value is below 1.50, it is judged to have unlikely surface deterioration. The average STAT value is 0, which is judged to be an unlikely surface delamination.

The average STR Value (Strength) for the tested segment is 39.42 N/mm2. The average Index Value on Strength Estimation, INDX Value (Index) for the tested segment of the structural elements shows a value of 1.14. Therefore, it can be concluded the strength in this stretch is ‘really suitable’, revealing no structural defects, damages. However, since the INDX value is below 1.50, it is judged as un likely surface deterioration. The average STAT value is 0, it is judged as unlikely surface delamination.

3.2. Ultrasonic Pulse Velocity

The test instrument consists of a means of producing and introducing a wave pulse into the concrete (a pulse generator and transmitter) and a means of sensing the arrival of the pulse (a receiver) and accurately measuring the time taken by the pulse to travel through the concrete. The equipment may also be connected to an oscilloscope or other display device to observe the nature of the received pulse. A complete description is provided in ASTM Test Method C 597.11 [13]. The table below shows the concrete quality grade in kilometers per hour.

Table 1. *UPV Concrete Quality Grade.*

S/N	Pulse Velocity (km/sec)	Concrete Quality Gradient
1	Above 4.5	Excellent
2	3.5 to 4.5	Good
3	3.5 to 3.0	Medium
4	Below 3.0	Doubtful

An ultrasonic pulse velocity test is based on the principle of passing high-frequency sound waves through a body of concrete and measuring the time taken to travel a known distance. It is primarily used to assess the homogeneity of the concrete and to detect voids, porosity, and crack depths. The pulse velocity method has wide applications in assessing the quality of concrete.

The device measures the travel time of the pulse between transmitter and receiver through the given medium. The indirect method was used for the abutment, while the direct method was used on the piers.

Table 2. *Atimbo Bridge UPV Result.*

Ultra Sonic Pulse Velocity Tester Result						
Location: Atimbo Bridge Cross River State						
S/N	**Beam NO**	**Transit Time**	**Length (mm)**	**Pulse Velocity (m/s)**	**Average Pulse Velocity**	**Concrete Quality Grading**
		199.9		3.501750875		
1	A	200	700	3.5	3.472128341	Medium
		205		3.414634146		
		213.9		3.27255727		
2	B	229	700	3.056768559	2.829939885	Doubtful
		324		2.160493827		
		194.9		3.591585428		
3	C	203.4	700	3.441494592	3.539103137	Good
		195.3		3.584229391		
		207		3.381642512		
4	D	209	700	3.349282297	3.031929891	Medium
		296		2.364864865		

4. Conclusion

The following conclusion was reached after using the two equipment to determine the quality of the concrete for Atimbo bridge in cross river state Nigeria. The two equipment has differences in terms of operation which is presented in the table below:

Table 3. *Difference between CTS02v4 and UPV.*

S/N	Concrete Tester (CTS02V4)	UPV
1	It can be operated by one person	It’s difficult to operate with one person
2	It gives the actual compressive strength of a concrete	Its gives range value for the quality of a concrete
3	It automatically calculates the compressive strength	It requires manual calculation to get the range of values for the quality of the concrete.

It is recommended that the two pieces of equipment be used at all times to ensure the strength of the concrete. The most significant conclusion is that UPV and Concrete Tester (CTS02V4) are similar in nature because they both achieve the same purpose. The two-method approach is an excellent means for investigating the uniformity of concrete. The test procedure is simple, and the available equipment on the market is easy to use in the laboratory as well as in the field.

The testing procedures have been standardized by ASTM and other organizations, and test equipment is available from several commercial sources. With the availability of small portable digital instruments, which are relatively inexpensive and easy to operate, the two types of equipment add a new dimension to quality control of concrete in the field.

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