SIGNIFICANCE OF STRUCTURAL INTEGRITY ASSESSMENT IN THE SUSTENANCE OF NIGERIA'S INFRASTRUCTURAL DEVELOPMENT

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Abstract: In recent years, Nigeria has made important strides towards improving its infrastructural sector of the economy, spending billions of naira yearly on the construction of infrastructure but with little provision for operations and maintenance. Thus, there has been extensive damage and consequent under-utilization of various civil engineering infrastructure; highways, buildings, pipelines, railways, refineries and so on. Structural Integrity is a crucial component of the engineering field and is considered essential for engineers to learn and apply to their work. Consequently, consistent inspections must be carried out on most structures to ensure that they do indeed possess adequate structural integrity.

For regular inspections, non-destructive test (NDT) methods may provide a relatively swift and inexpensive means to establish whether a structure is still in a serviceable condition or not without impairing parts or the entire structure. Results of these investigations, which may improve the quality of information by eliminating the prejudice, associated with current visual inspection techniques.

This paper examines the mode of assessing the structural integrity of concrete structures under the destructive and non-destructive approaches, considering the various tools that are in use and introducing preferred tools and their nondestructive applications taking as a case study, the structural integrity assessment of Ijora-Apapa bridge, in Lagos, southwest Nigeria, on which various tests such as the compressive strength, degree of deterioration and surface delamination, and reinforcement cover measurements were carried out, in the capacity of inspection and analyses of in-situ concrete structures, in an attempt to proffer solutions to the extensive damage of the civil engineering infrastructure and allow Nigeria to retain wealth as a nation and expand upon a solid industrial philosophy.

Keywords: Infrastructure, Non-destructive Tests NDT, Structural Integrity, Strength.

1.0 INTRODUCTION

It is logically true that a nation's economic growth can also be an index of its available infrastructure; Roads, Buildings, and Dams etc. The inadequacy of these infrastructures to serve their intended use during their lifespan is a major factor to the nation's economic drawbacks. The developed nations, who distinguished the relevance of civil infrastructure, and their significance to the nation's economy and quality of life, have taken extra care to build, and sustain them [1]. Such is in the United States, where plants built in the 1930s are still fully operational.

1.1 Engineering Infrastructure in Nigeria

An infrastructure is a basic physical and organizational structure needed for the operation of a society or enterprise; civil engineering structures are sets of interconnected structural elements or physical component of interrelated systems as shown in figure 1.0, which are based on civil engineering principles, necessary for the functionality of an economy and judging its development.

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Compared to many African peers, Nigeria has relatively advanced power, road, rail, and information and communications technology (ICT) networks that cover extensive areas of the nation's territory. In recent years, Nigeria has conducted several important infrastructure sector reforms in improving economic strength. Nigeria currently spends $5.9 billion per year on federal infrastructure, equivalent to about 5% of GDP. Existing spending patterns are heavily skewed towards construction and installation, with little provision for operations and maintenance [2]. Nigeria is majorly faced with the challenges of sustaining and maintaining the existing infrastructure. Government ownership and operation of public utilities does not have to result in inefficient operation and low level of service, but it has always been so. The incessant collapse of buildings in some major parts of the country seems to have become a norm despite the efforts of the various bodies concerned.

Quite a number of Nigeria's road networks are in relatively poor condition, testifying that assets are not being adequately maintained. Roads have been failing in Nigeria because government at all levels concentrate majorly on construction without putting a strategy in place for their maintenance. These huge investments are allowed to deteriorate without any visible strategy, leading to the observed state of Nigerian roads today [8]. All the foregoing factors had been and are still causing major set-backs to the Nigerian economy. It is therefore imperative, to seek a way out of this menace, in order to improve the country's economy and save the image of the civil engineering profession at large.

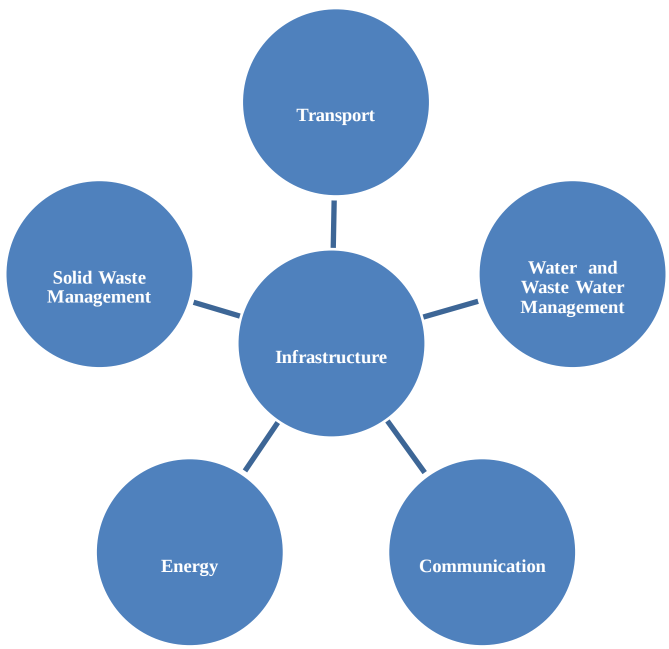


Figure 1.0: Engineering Infrastructure Classification

1.2 Structural Integrity and Its Assessment

Structural Integrity is a component of the field of engineering, specifically in a field of civil engineering known as structural engineering. Structural integrity refers to those structures' soundness of design and construction, including safety and workability. Structural Integrity is an essential component of all structural engineering projects, viz; buildings, bridges, dams and other structures that play important roles in daily grind of the society.

Structural Integrity Assessment is an important stratagem for knowing the real status of structures. The assessment should highlight & investigate all the critical areas and whether or not the structure needs immediate attention. It should also cover the structural analysis of the existing frame and pinpoint the weak structural areas for static and dynamic loads.

Just last year, in order to save one of Africa's busiest bridges, the third mainland bridge in Lagos, southwest Nigeria, from extensive deterioration, the Federal Executive Council approved the award of contract worth about 290.7 million naira for an advanced integrity assessment on the structure for comprehensive underwater inspection, assessment of pilings, river bed bathymetric survey, profiling and echometric test [3].

2.0 METHODOLOGY

The approach to assessing the integrity of structures is generally classified in two ways viz.; Destructive and Non Destructive Methods. The destructive methods are the ones in which parts of the existing structure are impaired in a bid to evaluate the inherent properties of such parts of the structure. Non-destructive testing (NDT) methods on the other hand relates to the examination of materials for flaws without harming the entity being tested. As an industrial test method, NDT provides a cost effective means of testing while protecting the object's usability for its designed purpose. Both methods are carried out with the use of various tools which are discussed herein.

2.1 Assessment of Concrete Structures

2.2 Destructive Techniques

The most common destructive technique in assessing the integrity of concrete structures is the **Core Drilling Technique.** Core samples are drilled on in-situ structures to be tested and then then analyzed in the laboratory.

Figure 2.0: Plate Showing a Typical Core Drilling Machine (Source: INTECON PARTNERSHIP LTD –IPL.)

2.3 Non-Destructive Techniques

NDT has been practiced on concrete structures for decades, initiated by visual inspection in the early days. Over the years, technological advances have spurred rapid developments in the methodology, which began prior to the 1920s but the awareness of different methods evolved in the 1920s during which primary purpose was the detection of defects. In 1880, the 'Oil and Whiting' method of crack detection was used and this staged the ground for the present day liquid penetrant test [6]. According to applications, there are three general categories of NDT methods used for inspection of concrete structures and civil engineering constructions;

i. The first category includes the tests which estimate the in-situ strength indirectly, such as surface hardness, and directly, such as penetration resistance and pullout techniques.
ii. The second category includes the tests which measure the material properties of concrete, such as moisture, density, modulus of elasticity, thickness, compressive wave velocity, and temperature.
iii. The third category includes the tests, which are used to detect and locate the defective areas within concrete structures and rock masses such as honeycombing, fractures, flaws and delamination [4].

Typical situations where non-destructive testing may be useful are, as follows [5]:

- quality control of pre-cast units or in-situ construction
- monitoring of strength development in relation to formwork removal, cessation of curing, pre-stressing, load application or similar purpose
- location and determination of the extent of cracks, voids, honeycombing and similar defects within a concrete structure
- determining the position, quantity or condition of reinforcement

2.4 Different Tools

As part of "safe life" design, it was intended that a structure should not develop any macroscopic defects during its serviceable life [5]. In response to this, increasingly sophisticated techniques employing the services of various calibrated machines such as;

- Rebound/Schmidt Hammer
- Concrete Tester and Surveyor –CTS
- Ultrasonic Thickness Gauges
- Pundit Lab
- Profoscope.

2.4.1 Rebound/Schmidt Hammer

Due to its simplicity of use and low cost, the Schmidt rebound hammer is the most widely used device for nondestructive testing of concrete in Nigeria. The rebound value is primarily influenced by the elastic modulus and strength of the concrete near the surface. While the test may be simple to perform, the relationship between measured rebound and in-place concrete strength is sensitive to a number of parameters. In particular, the results are influenced by the moisture condition, carbonation, and surface texture of the concrete, as well as hammer inclination. Because the plunger's rebound depends on the energy being restituted from the substrate, it is expected that incidence of bruising and cracking in the surface layer will reflect in the recorded values. Limited of this instrument are:

- Time wasting while taking multiple rebound test on area surface
- Data need correcting based on directions of test.

Figure 3.0: Plate showing a typical the use of the Rebound Hammer. (Source: IPL.)

2.4.2 Concrete Tester and Surveyor –CTS

This portable device has the capacity to determine the compressive strength of concrete structural elements, as well as the detection of delamination near concrete surface and also surface deteriorations, without causing damage to the structure. It also comes with a logging platform for the storage of raw data, which in turn can be further, processed in a comprehensive mode with the use of applications such as CTS-O2V4 and excel spreadsheets. This is one of the latest instrument used for the investigation of compressive strength distribution across and on the surface of a concrete structural element, in buildings; beams, columns, slabs, in bridges; piers, decks, in concrete water reservoirs, retaining walls etc. Its advantages over the Rebound Hammer includes but not limited to: **Easy to use** as an impact sounding method and highly accurate at estimating concrete strength, **Real time detection** and localization of defects, and **Cost savings**: although cost may vary by testing conditions.

Owing to its capability of logging data simultaneously as it is being used on concrete, the CTS aids the representation of results in a definite and comprehensive graphical form. The raw data, after downloaded from the device is transferred into the excel spreadsheet for further processing, such as to give the strength distribution in a concrete structural unit. Figure 4.0 shows a typical graphical representation of the compressive strength (in N/mm^2) of a slab unit of a high-rise building.

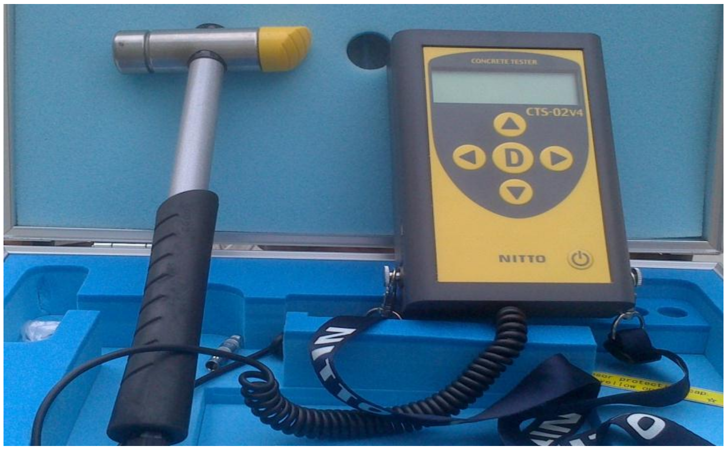


Figure 4.0: Concrete Tester and Surveyor CTS and Hammer Unit. (Source: IPL.)

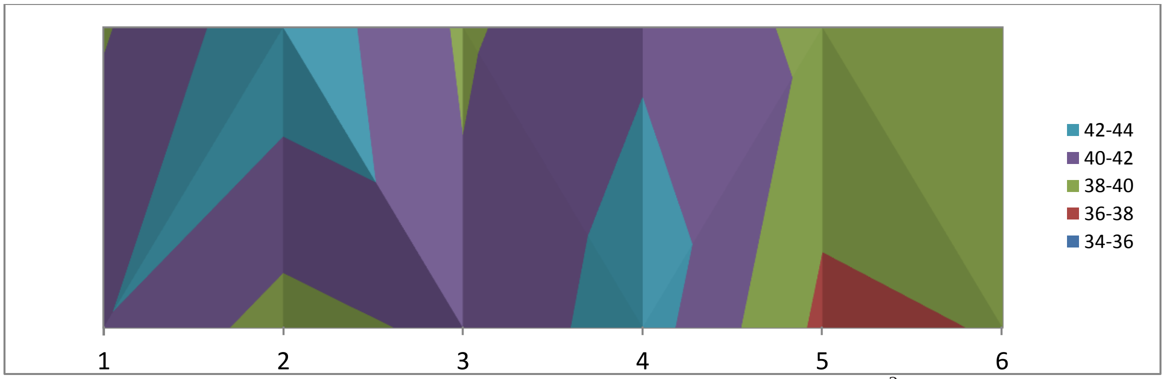


Figure 5.0: Representation of CTS Compressive Strength Result (in N/mm^2) on a Reinforced Concrete Slab Unit. (Source: Field Work Data; IPL.)

From figure 5.0, it can be interpreted that the compressive strength distribution of the slab varies over the area. With an average strength of about $42N/mm^2$ on the left side, the strength of the slab is a bit relatively lower on the right side, i.e. $39N/mm^2$. This gives a concise idea of the integrity of the slab unit and of course, other structural components such as the beams, columns, lift shafts and so on; hence, the integrity of the entire structure can be adequately evaluated.

2.4.3 Profoscope

The Profoscope uses electromagnetic pulse induction technology to detect rebars. Coils in the probe are periodically charged by current pulses and thus generate a magnetic field. This is a versatile, fully-integrated rebar detector and covermeter. Its compact and lightweight design allows an easy and one-handed real-time reinforcement bar location and detection. It also allows for rebar grid layout examination and helps to map out areas free of rebar for coring and drilling purposes [7]. It performs the following functions:

- Localization of a rebar
- Localization of the mid-point between rebars
- Determination of the concrete cover
- Estimation of the bar diameter.

Figure 6.0 Profoscope (Source: Proceq)

3.0 FIELD EXPERIENCES

Investigations were carried out on a bridge, located at the right- hand side of Ijora 7UP and Ijora Oloye axis towards Ijora Olopa bowel line along Moshood Abiola Way in Lagos, Nigeria. This project was necessitated by the fire incidence at a section of the bridge structure. Thus, the investigation was to know the degree or the severity of the damage caused by the fire to the bridge and the rehabilitation measures to be carried out to restore the bridge to its serviceable condition.

The Ijora-Apapa bridge is a major part of the network of bridges linking the Lagos island to the mainland area of Lagos State. The bridge which was constructed in the 1970s provides access for traffic travelling for various economic activities within the Lagos metropolis. It also provides access to important economic centres of Lagos especially the Apapa wharf. But many illicit trading activities were being carried out under the bridge, such as: sales of oil products like diesel, petrol etc. which lead to conflagration of the bridge and consequent exposure of the bridge to fire for about 5-6 hours. In order to ascertain the structural integrity of the structure the following assessments were carried out:

3.1 Non-Destructive Tests

The engineering assessments comprised the following tests:

i. Compressive Strength test: the compressive strength of the bridge members was measured using the Concrete Tester and Surveyor (CTS). Several analyses of up to an average of twenty per point were taken on different parts of the bridge elements. The equipment automatically detects and selects the most accurate average results per point and provides the mean strength of the point on the member, taking into consideration the non-validity of extreme results. The equipment is also used to determine the extent of deterioration of concrete member exposed to undesirable conditions.

ii. Delamination and Surface Deterioration: the degree of delamination and surface deterioration of the burnt concrete members were tested and determined using the concrete tester and surveyor. The various waveform charts shown in Appendix I show the degree of delamination and surface deterioration of the affected members.

iii. Concrete Cover: the residual concrete cover of the burnt bridge was determined using our Profoscope cover meter.

iv. Bar Location and Diameter: the position of bars and approximate diameter of bars within the concrete members were also determined using the Profoscope.

3.2 Non-Destructive Compressive Strength Test Results

The results of NDT conducted to evaluate the residual compressive strength of the concrete elements of the bridge i.e. piers, beams, and deck using Concrete Tester and Surveyor equipment are presented in Table 1. The same equipment was used to determine the surface deterioration of the concrete elements using appropriate charts as presented in the Test Manual of the Equipment used for test. The detailed test results are presented below. Table 1 gives the Summary of the results of the NDT compressive strength and surface deterioration parameters measured from the concrete bridge elements tested in spans 11 and 12 of the bridge section affected by the fire.

From the results shown in Table 1; the compressive strength results of Beam 1, 2, 3 and 4 of span 11 were estimated to be 41.70, 39.40, 45.50 and 45.10 N/mm^2 respectively. The mean strength was found to be 42.92 N/mm^2. The NDT compressive strength results of the beams B1, B2, B3 and B4 in span 12 of the bridge section affected by the fire were estimated to be 54.4, 57.1, 60.1 and 56.7 N/mm^2 respectively. The mean compressive strength of the four beams was estimated to be 57.075 N/mm^2.

The compressive strength of the three piers named as P10, P11 and P12 supporting the bridge between the spans 11 and 12 affected by the fire was found to be 49.7, 33.5 and 54.2 N/mm^2. The middle pier P11 was more affected and most damaged by the fire, the condition of the pier which was then characterized by concrete spalling exposing the internal aggregate and some reinforcement bars gave the least results of 33.50 N/mm^2. The compressive strengths of the two adjacent piers P10 and P12 which were not seriously affected by the fire were found to be 49.7 N/mm^2 and 54.2 N/mm^2.

From the results, no surface deterioration was found for beams B1, B2, B3 and B4 in span 12. Piers P10 and P12 were also not affected by the fire and so had no surface deterioration. However pier P11 had severe surface deterioration due to concrete spalling as a result of the degree of fire suffered which led into expansion of the concrete and the eventual spall. Beams B1 and B2 in span 11 also show some degree of surface deterioration of about 2m while beam B2 showed a surface deterioration of about 1.5m.

TABLE 2: SUMMARY OF COMPRESSIVE STRENGTH, DEGREE OF DELAMINATION/SURFACE DETERIORATION TEST RESULTS

MEMBER		AVERAGE COMPRESSIVE STRENGTH (N/mm^2)	DEGREE OF DELAMINATION/SURFACE DETERIORATION	REMARKS
SPAN 11				
	Beam 1	41.7	Portion (about 2m) of beam length show delamination and surface deterioration.	Not OK
	Beam 2	39.4	Portion (about 1.5m) of beam length show delamination and surface deterioration.	Not OK
	Beam 3	45.5	Partial surface deterioration	Compressive strength still OK
	Beam 4	45.1	Partial surface deterioration	Ditto
SPAN 12				
	Beam 1	54.4	Minor surface deterioration around the support.	Ditto
	Beam 2	57.7	Minor surface deterioration around the support.	Ditto
	Beam 3	60.1	Minor surface deterioration around the support.	Ditto
	Beam 4	56.7	Minor surface deterioration around the support.	Ditto
PIERS				
	Pier 10	49.7	No surface deterioration or delamination.	Ditto
	Pier 11	33.5	Larger portions (about 3.5m) of the pier show delamination and surface deterioration.	Not OK
	Pier 12	54.2	No surface deterioration or delamination.	Compressive strength still ok

(Source: Field Work Data; IPL.)

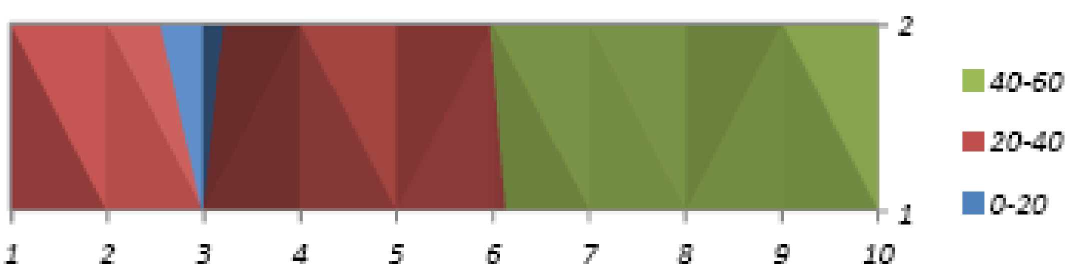
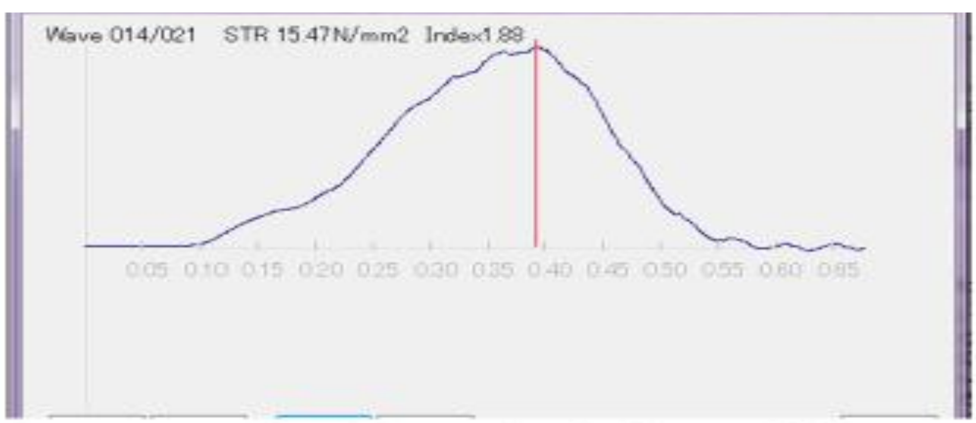


Plate 1: Showing The Strength Distribution **(in N/Mm^2)** of Span 11 Beam 1, Red and Blue Region Shows the Portion Exposed to Fire Which Resulted in a weak Compressive Strength as Shown in the Legend.

TABLE 3: SUMMARY OF CONCRETE COVER AND BAR DIAMETER RESULTS

MEMBER		MEAN COVER (mm)	MEAN BAR DIAMETER (mm)	REMARKS
SPAN 11				
	Beam 1	29	40	Concrete cover reduced by fire.
	Beam 2	16	40	Ditto
	Beam 3	48	40	Ditto
	Beam 4	51	40	Satisfactory
SPAN 12				
	Beam 1	57	40	Satisfactory
	Beam 2	53	40	Satisfactory
	Beam 3	46	40	Concrete cover reduced by fire.
	Beam 4	47	40	Concrete cover reduced by fire.
PIERS				
	Pier 10	55	40	Satisfactory
	Pier 11	47	40	Concrete cover reduced by fire.
	Pier 12	55	40	Satisfactory

(Source: Field Work Data; IPL.)



The near support face of the Beam has high degree of delamination and high surface deterioration

Plate 2: Waveform Diagram Showing the Degree of Delamination and Surface Deterioration of Span 11, Beam1

4.0 CONCLUSION

Maintenance culture through inspections is a philosophy that until it is fully absorbed, reality may be gray. It is imperative that the culture of inspections and proactive repair be not only encouraged by the government but mandated. This will allow Nigerians to retain wealth as a nation and expand upon a solid industrial philosophy.

With the advent of these tools and techniques for non-destructive testing, it has become possible to tolerate structures containing defects of known sizes and severity. This has formed a basis for the philosophy of “damage tolerant design”. Components having known defects could continue in service as long as it could be established that those defects would not grow to a critical failure over a predictable period of time.

Non-destructive testing of concrete structures is very important for optimal serviceability life. With the use of the Concrete Tester and Surveyor CTS, the structural integrity of concrete structures has been greatly enhanced at Intecon Partnership Ltd.; an indigenous civil engineering consulting firm. Vibrations, fire resistance, cracks and so on of known magnitude are some of the various allowable defects, to which NDT can be the yardstick.

However, there is need for improvement in the area of nondestructive evaluation of infrastructures in the country, for sustainable infrastructural development to truly occur. The involvement of foreign investors, institutions and organisations in the area of training, technical know-how and practice on the present and probable future of NDT at this period of global industrial revolution is highly desirable in Nigeria.

5.0 RECOMMENDATIONS

1. Nigeria being a country so dependent on crude oil and its products, it is only wise that the government crafts an entity to oversee the maintenance of its infrastructures, which must be jurisdictional according to global industrial values.
2. The emergence of quantitative nondestructive testing/evaluation (QNDT or QNDE) as a new major engineering/research discipline in the Nigerian civil engineering profession is long overdue.
3. Structural integrity of various infrastructural facilities should be carried out periodically throughout the life span of various infrastructure, starting from the construction stage and after construction as part of contract agreement, due to the viral “individual integrity challenges” in Nigeria..
4. The tertiary institution curriculum in the country should be reviewed to incorporate NDT as a significant arm in civil engineering.
5. As the attention of the entire world is focused on the developing and promising economies such as Nigeria and Africa at large, it is a good opportunity for foreign companies and organisations to offer their expertise in the area of NDT, in Nigeria.
6. There is great need for the Nigerian Institution of Civil Engineers (NICE) to partner with foreign institutions and organisations that are well ahead and grounded in proven NDT practices, as well as training and certification of NDT personnel in the civil engineering and other relevant professions in Nigeria.

PLATE 3: ENGINEER TESTING FOR CONCRETE COVER AND BAR LOCATION/DIAMETER ON THE BURNT BEAMS

PLATE 4: SHOWING ENGINEERS TESTING THE BRIDGE BEAMS USING THE CONCRETE TESTER & SURVEYOR (CTS).

(Source: Field Work Data; IPL.)

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