A Comparative Analysis of the Rebound Hammer and Pullout as Non-Destructive Method in Testing Concrete

Festus. C. Onyeka

***Abstract*—A comparative analysis between Rebound Hammer and Pullout method in testing concrete was conducted in this study. Experimental analysis was carried out to compare the correctness between the two testing method in estimating the strength of concrete. Different cube (cubes of 175 x 175 x 175) samples were prepared using two mix designs of 1:2:4 and 1:3:6 with a constant w/c ratio of 0.45 and were tested at 7, 14, 21 and 28 days. The rebound hammer readings had a correlation coefficient of 0.695 while the pullout had a correlation coefficient of 0.725 for the 1:2:4 mix and the rebound hammer readings for 1:3:6 was 0.724 and that for the pullout was 0.675. From the results obtained, it is observed that the non-destructive testing methods were correlated with the compressive strength results which showed that a higher correlation existed between the Rebound Hammer and the compressive strength than the Pullout. Statistical analysis of the results obtained showed that there was no significant difference between the means of the two methods for both mix at a 0.05 level of significance. However, rebound hammer method can be recommended as it provides a quicker, less-expensive means of checking the uniformity of concrete even though it shows less sensitivity as concrete matures, unlike the Pullout test in which measuring strength is affected by the arrangement of the embedded insert, the dimensions of bearing ring, the depth of embedment, the concrete age and the type of aggregates uses in concrete.**

***Index Terms*—Concrete, Non-Destructive Testing, Compressive Strength, Rebound Hammer, Pullout Test.**

I. Introduction

Concrete differs from other construction materials because it can be made from infinite combination of suitable materials and the final properties depend on the treatment it undergoes after arriving at the job site. The efficiencies of the consolidation and effectiveness of curing are critical for attaining the full potential of a concrete mixture [16].

Though concrete is well known for its high stress resistance and workability, except for some environmental degradation which can limit its performance. It is as a result of this environmental degradation that there becomes a need for test methods evaluate and estimate concrete features for quality assurances.

Nondestructive test (NDT) is the way of obtaining the information about the state, properties of material without interfering with the attributes of the object or structure [1]. They are those tests that do not alter the concrete and after conducting they do not destroy the concrete.

It can also be said to be cause of inspecting, testing or evaluating materials, components assemblies without destroying the serviceability of the part or system [20]. A lot of effort has been dedicated to develop NDT approach capable of indicating mechanical, chemical and physical properties of materials. One of the earliest documented attempts of NDT dates to the 19th century where cracks were detected in the railroad wheels by means of acoustic tap testing [19]. It is important to mentioned that procedures from different national standards presents small differences and the use off one or another should be decided previous to test. These allow a more extensive analysis of structures covering a larger extension, which in another way wouldn't be possible.

The use of NDT methods on normal and high strength concrete elements will be evaluated on this paper qualitatively, taking as reference five different test methods, which imply the measurement of etc. Such properties include the measurement of the surface hardness, ultra-sonic pulse velocity, penetration resistance, pull-out force or test.

Some of these methods which include surface hardness methods (Rebound hammer and indentation method), penetration resistance methods, resonant frequency methods, pullout resistance methods, pullout resistance methods, permeation test method, corrosion of reinforcement method. NDT have materialized as a response to the need for structural damage detection and prevention to ensure safety [13, 8].

Failure in concrete strength has been discovered in some structures as a result of some concrete made of low strength ductile materials and some made of high strength but low toughness materials. This has led to more demand levels and to increase the use of destructive and non-destructive test in manufacture. Therefore, achieve a successful application of any of the NDT method; it is vital to observe major factors that influence the success of a non-destructive survey which includes: depth of penetration, vertical and lateral resolution, contrast in physical properties, signal to noise ratio and existing information about the structure [15].

The objectives of this research work is to determine a non-destructive test that can be more suitable for estimating the strength of concrete considering Rebound hammer method and Pullout testing methods. This will be done by identifying the potential and limitations of the various methods in investigating the strength of concrete and identify the most economical method for investigating the strength of concrete.

This research work is to investigate the applicability of tools and techniques to determine the in place strength and durability of concrete using the rebound hammer method and the pullout method. This objective can be achieved by identifying the best selection procedure to achieve effective cost, speed and reliability of concrete, to identify the most economic method for investigating the strength of concrete

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F. C. Onyeka, Edo University, Iyamho, Edo State, Nigeria.
(e-mail: onyeka.festus@edouniversity.edu.ng)

and identify the potential and limitations of the various methods in investigating the strength of concrete.

The aim of this research is to compare some non-destructive testing methods in order to deduce which of the methods gives more features on the characteristics of concretes.

A. Rebound Hammer

The Rebound Hammer test is basically a surface hardness test used to assess the in-place uniformity of concrete, to delineate regions in a structure of poor quality or deteriorated concrete, and to estimate in-place strength development. Due to different effects of gravity on the rebound as the test angle is changed, the rebound number will be different for the same concrete and require separate calibration or correlation charts [12-13]. The only known instrument to make use of the rebound principle for concrete testing is the Schmidt hammer

This method does destroy concrete surface and can be used to evaluate the interior mass of concrete elements [8]. One of the most generalized equipment used on concrete is the Digital Rebound Hammer Non-destructive Digital Indicating Tester (PUNDIT) with electro-acoustical transducers of natural frequency of 54 kHz (Fig. 3) [4]. We can find recommendations for its use, for example, on British Standards Institution BS: 1881: Part 203 [6].

Due to its simplicity and low cost, the Schmidt rebound hammer is by far, the most widely used non-destructive test device for concrete. It is reported that about 500,000 rebound hammers were sold worldwide by 1986 [14].

Its use is covered by various national standards such as the Recommendations from British Standard [5]. Hardness test operate, it demands only a free surface, it does not cause damage and less cost than majority of the other non-destructive tests. However, its use to estimate directly the in-situ compressive strength using general established correlations is not recommended by many authors [8].

This may limit the use of the technique in some situations. Usually this method is recommended for elements of large surfaces like slabs or elements of large cross sections [4].

Fig. 1. Digital Concrete Hammer Kit

Fig. 2. Concrete Test Hammer Kit

B. Pullout Test

The pull-out technique when the insert is extracted, a conic frustum of concrete is also pulled out. The ultimate force therefore measures a strength property of the concrete. This characteristic gives it its superiority over other indirect methods such as rebound hammer.

Pull-out tests are recognized among the non-destructive tests as the method which offers more accuracy on the estimation of the in-situ concrete compressive strength [7, 8]. Recommendations for its used are provided by British Standards BS 1881: Part 207 [8].

One of the techniques used for this purpose is the CAPO-TEST System developed by “Germann Instruments A/S” in 1962 [11]. In this technique the load is applied to the capo-insert by means of a hydraulic jack and a reaction ring of 55 mm inner diameter. The capo-insert (25 mm diameter ring) is laced at a depth of 25mm (Fig. 6 and Fig. 7). The pull-off tests enable the determination of direct tensile strength in-situ. The possibility of using this method with partial coring enables the measurement of such property at different depth. For this test method, recommendations are made [7].

Fig. 3. Pullout tester

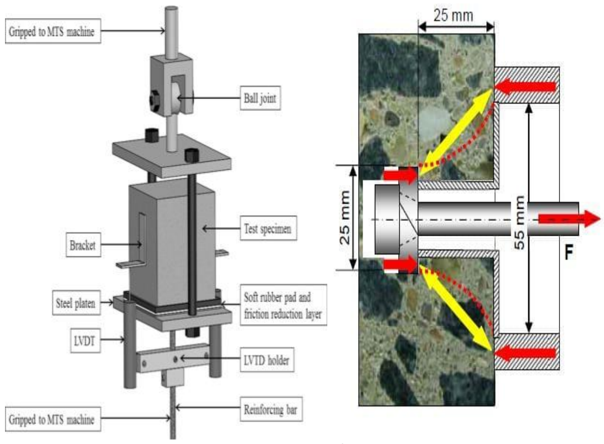

Fig. 4 and Fig. 5. Schematic of Pullout test apparatus

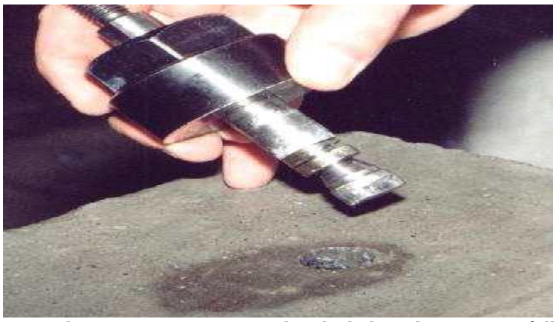

Fig. 6. The expansion unit inserted in the hole and capo-insert fully expanded to 25 mm diameter

Fig. 7. Failure type observed for validation of result

A consensus has been achieved regarding the existence of a triaxial state of stress highly non uniform on the concrete involved the capo-insert during extraction [8-9].

In spite of some divergences as the basic failure mechanism is concerned, a consensus exists regarding the fact that the last pull-out load is influenced by the same properties that influence the concrete compressive strength [8-9]. However, its use to estimate directly the in-situ compressive strength using general established correlations is not recommended by many authors [8].

Other notable contributors were [18, 15 and 10]. As reported [3], correlation testing performed at six test sites using the same test system gave straight lines that differed from that supplied by the manufacturer.

II. Materials and Methods

Materials used for this investigation were ordinary Portland cement, fine and coarse aggregates. Various tests were carried out as well to classify these aggregates. The non-destructive methods used in this research include the rebound hammer test, and the pullout test. For the both method, the correlation is achieved by measuring the force required to pull a 25 mm diameter cast in steel disc. Steel disc is embedded 25 mm in depth in fresh concrete at a time of concreting. The steel disc should be precisely embedded in concrete so that air voids are not formed below the steel disc. Pull bolt is attached to the steel disc and after the curing period, the 25 mm steel disc is pulled until failure occurrence in the concrete.

A. Sample Preparations

In this work, cubes of dimension 175 x 175 x 175mm were cast. The two mix design for the cubes cast was one part of cement to two parts of fine aggregates to four parts of coarse aggregate (1:2:4). Also, one part of cement to three parts of fine aggregates to six parts of coarse aggregates (1:3:6). Water-cement ratio of 0.45 and were mixed properly. After placing of concrete in the moulds, compaction of concrete was carried out manually. The cubes were allowed to stay for 24 hours, the moulds dismantled and the cubes transferred to a curing tank. A total of eighty cubes were molded and its test were conducted after 7, 14, 21 and 28 days respectively.

B. Sample Preparations

The Rebound Hammer test, the cube compressive test [17] and Pullout test and were performed. The pullout tests are carried out for early age strength estimation, to find out the compressive strength with help of calibration curve. It is prepared based on laboratory and field tests conducted on concrete cubes and pull out sample cast with various grades of concrete.

This was done by subjecting the 175 x 175 x 175mm cubes to Rebound Hammer testing using digital Rebound Hammer test kits. Thereafter Pullout test was conducted on the same specimen. After NDT, the compressive tests were carried out by crushing the cubes.

A total of 10 readings were taken on each test surface as recommended by ASTM C805 and the average rebound number was then obtained. Each cube was then placed in the testing machine in between two metal plates. Having properly positioned each cube, load was gradually applied without shock until the cube failed and the loads at failure were recorded for each sample. The load at failure was then divided by the effective area of the cube in square millimeters to obtain the compressive strength of the cube.

III. Results and Discussions

The moisture content, specific gravity, bulk density and other properties of the various materials was carried out to determine the effectiveness of the two method under study thus yielding the following results.

TABLE I: Moisture Content Of Fine Aggregate

Test Data	Sample 1	Sample 2
Mass of container M_1(g)	31.2	33.0
Mass of wet sample + container M_2(g)	341.9	326
Mass of dry sample + container M_3(g)	332.1	317.0
Mass of moisture M_2- M_3)(g)	9.8	9.0
Mass of dry sample (g)	300.9	284
Moisture content (%)	3.3	3.2
Average moisture content (%)	3.3	

TABLE II: Moisture Content Of Coarse Aggregates

Test Data	Sample 1	Sample 2
Mass of container M_1(g)	31.2	25.5
Mass of wet sample + container M_2(g)	590.89	490.6
Mass of dry sample + container M_3(g)	580.4	483.1
Mass of moisture M_2- M_3) (g)	10.4	7.5
Mass of dry sample (g)	549.2	457.6
Moisture content (%)	1.9	1.6
Average moisture content (%)	1.8	

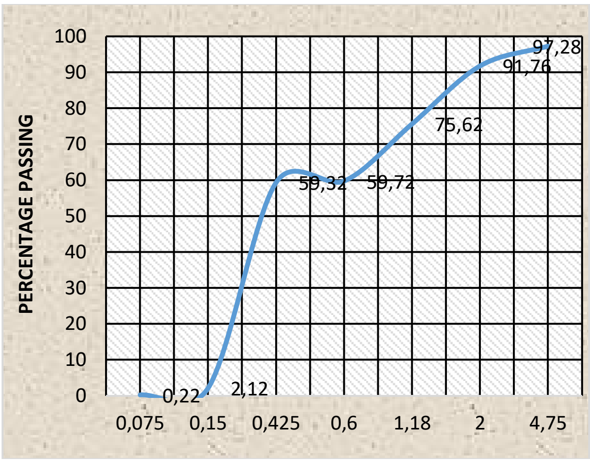

Fig. 8. Particle Size Graph on a Fine Sand

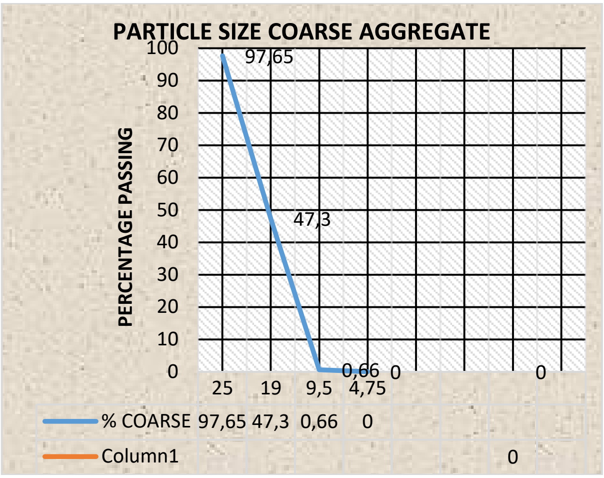

Fig. 9. Particle Size Graph on a Coarse Aggregate

IV. Specific Gravity Of Aggregates

The specific gravity at various which was carried out which yielding the following results.

TABLE III: The Specific Gravity Of Sand

Descriptions	Sample A	Sample B
Mass of vessel (g)	618.7	618.7
Mass of vessel + sample (g)	1054.3	1023.9
Mass of sample (A) (g)	435.6	405.2
Mass of vessel + sample + water (B) (g)	1749.0	1704.9
Mass of vessel + water (C) (g)	1493.0	1493.0
$P = \frac{A}{A-(B-C)}$	2.42	2.10
Average specific gravity	2.26	

TABLE IV: The Specific Gravity Of Coarse Aggregates

Descriptions	Sample A	Sample B
Mass of Air Dried Sample (A)	2266.2	2375
Mass of Basket + Sample in Water (B)(g)	1566.7	1754.8
Mass of Basket in Water (C) (g)	244.6	246.7
$P = \frac{A}{A-(B-C)}$	2.40	2.74
Average specific gravity	2. 57	

TABLE V: The Bulk Density Of Fine Aggregates

Descriptions	Un-compacted	Compacted
Weight of mould + sample (g)	16140	17315
Weight of mould (g)	6420	6420
Volume of mould (Cm^3)	7226.6	7226.6
Bulk density (g/Cm^3)	1.34	1.51

TABLE VI: The Bulk Density Of Coarse Aggregates

Descriptions	Un-compacted	Compacted
Weight of Mould + sample (g)	16590	18155
Weight of mould (g)	6420	6420
Volume of mould (Cm^3)	7226.6	7226.6
Bulk density(g/cm^3)	1.41	1.62

A. *Specific Gravity of IBETO Cement*

The specific gravity was determined on relative paraffin value for the OPC cement (IBETO) at room temperature to obtain the results below:

TABLE VII: The Specific Gravity Of Ibeto Cement

Descriptions	Sample A	Sample B
Mass of empty bottle (W_1) (g)	28.0	27.6
Mass of bottle + cement (W_2) (g)	50.1	49.5
Mass of bottle + cement + kerosene (W_3)	85.0	85.4
Mass of bottle + kerosene (W_4) (g)	68.4	68.0
Mass of bottle + water (W_5) (g)	77.8	78.4
$SP\ of\ kerosene = \frac{W_4 - W_1}{W_5 - W_1}$	0.81	0.80
$SP\ of\ Cement = \frac{W_2 - W_1}{(W_5 - W_1) - (W_5 - W_1)}$	3.06	3.13
Average specific gravity	3.09	

V. Compressive And NDT Test Result Comparison

From the analysis carried out on the constituents of the samples, sand had a specific gravity of 2.26 and a bulk density of 1510 kg/m^3. The coarse aggregate had a specific gravity of 2.57 and a bulk density of 1690 kg/m^3. Ibeto Portland cement used for this work had a specific gravity of 3.09. Regression analysis was computed on the data obtained was using 'MS Excel' software. The rebound hammer readings had a correlation coefficient of 0.695 while the pullout had a correlation coefficient of 0.725 for the 1:2:4 mix and the rebound hammer readings for 1:3:6 was 0.724 and that for the ultrasonic pulse velocity was 0.675. This is in agreement with the results obtained previous scholars [2] where the rebound hammer correlation coefficient was 0.783. This shows that a better correlation with compressive strength can be obtained using the rebound hammer than the Pullout.

The results of statistical analysis show that at a 0.05 level of significance. This means that there is no significant difference exists between the set of results obtained from both methods, hence both methods can be used in estimating in-situ strength.

The hardness test performed shows that the rate of gain of surface hardness of concrete is rapid up to the age of 7 days, following which there is little or no gain in the surface hardness.

It is concluded that hardened concrete show that the sensitivity of the pullout test in measuring strength is affected by the arrangement of the embedded insert, the dimensions of bearing ring, the depth of embedment, the concrete age and the type of aggregates uses in concrete, the sensitivity of the Pullout to strength gain or achieved by the concrete increases.

TABLE VIII: Results Obtained From Rebound Hammer Using The Regression Equations For 1:2:4 Mix

S/No.	Age (Days)	Rebound number	Compressive strength (N/mm^2)	Average strength
	7	11.80	13.19	
	7	11.40	14.62	
1	7	11.80	15.14	13.98
	7	12.60	12.17	
	7	12.60	14.78	
	14	12.60	12.88	
	14	13.40	14.78	
2	14	13.60	14.70	14.79
	14	14.40	14.97	
	14	14.20	16.62	
	21	16.60	17.63	
	21	14.60	13.89	
3	21	17.80	20.10	16.98
	21	17.40	16.95	
	21	15.60	16.30	
	28	21.80	23.28	
	28	23.80	25.30	
4	28	21.00	22.50	22.97
	28	22.60	24.09	
	28	19.20	19.65	

TABLE IX: RESULTS OBTAINED FROM REBOUND HAMMER USING THE REGRESSION EQUATIONS FOR 1:3:6 MIX

S/No.	Age (Days)	Rebound number	Compressive strength (N/mm^2)	Average strength
	7	9.00	7.44	
	7	9.10	6.72	
5	7	9.20	7.45	7.77
	7	9.90	8.33	
	7	10.10	8.89	
	14	10.40	8.99	
	14	10.30	9.30	
6	14	11.10	9.78	9.11
	14	10.90	7.68	
	14	10.60	9.78	
	21	12.60	12.26	
	21	11.20	10.39	
7	21	12.50	11.99	12.48
	21	14.20	14.40	
	21	13.60	13.30	
	28	15.90	16.33	
	28	15.10	15.75	
8	28	14.40	13.98	15.62
	28	15.20	16.30	
	28	15.10	15.74	

TABLE X: RESULTS OBTAINED FROM PULLOUT USING THE REGRESSION EQUATIONS FOR 1:2:4 MIX

S/No.	Age (Days)	Rebound number	Compressive strength (N/mm^2)	Average strength
	7	3.80	15.65	
	7	3.50	14.22	
1	7	3.70	13.12	14.72
	7	3.90	14.53	
	7	3.96	15.99	
	14	4.00	16.67	
	14	3.98	16.38	
2	14	4.30	17.81	6.56
	14	4.02	16.77	
	14	3.88	15.15	
	21	4.25	19.93	
	21	3.90	17.25	
3	21	4.37	20.10	18.49
	21	4.98	19.88	
	21	3.96	16.50	
	28	4.41	24.44	
	28	4.70	25.13	
4	28	4.24	22.75	23.93
	28	4.50	23.78	
	28	4.42	23.55	

TABLE XI: RESULTS OBTAINED FROM PULLOUT USING THE REGRESSION EQUATIONS FOR 1:3:6 MIX

S/No.	Age (Days)	Rebound number	Compressive strength (N/mm^2)	Average strength
	7	3.60	9.34	
	7	3.47	8.20	
5	7	3.39	6.55	7.30
	7	3.45	5.98	
	7	3.44	6.44	
	14	3.72	10.55	
	14	3.62	8.99	
6	14	3.64	8.90	9.42
	14	3.60	8.87	
	14	3.72	9.77	
	21	3.85	13.65	
	21	3.79	12.48	
7	21	3.87	13.67	13.5
	21	3.96	14.20	
	21	3.91	13.50	
	28	4.15	16.45	
	28	4.17	16.97	
8	28	4.40	17.30	16.92
	28	4.14	17.35	
	28	4.13	16.55	

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