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The Correlation between Destructive and Non-Destructive Methods of Testing Concrete at the University of Guyana

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Abstract:
Concrete compressive strength is evaluated by both non-destructive and destructive methods oftesting. The former method does not represent the in-situ strength of the concrete under its loadingconditions. Conversely, the latter method is affected by the location of the reinforcement, moisture,aggregates, among others. The evaluation of the concrete strength can be found using the hammer rebound and pulse velocity ultrasonic devices. The combination of these two is referred to as theSONREB method which present a determination of the strength utilising a linear regression. This paperpresents a correlation between non-destructive and destructive methods for testing of concretestrength from M15 to M40 grades.At the University of Guyana in the Faculty of Engineering and Technology, the pulse velocity ultrasonic test was conducted, while the rebound hammer and compressive strength tests were done at the Civil Engineering Lab Guyana (CELG).The results were used to develop a mathematical equationusing the rebound hammer and pulse ultrasonicvelocity results to predict theconcrete compressive strength.

Keywords **—Destructive test, Non-destructive test, Rebound hammer, Ultrasonic pulse velocity, SONREB.**

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I. INTRODUCTION

The quality of control of concrete depends on both Portland cement concrete and the proportions of its components. This responsibility lies in the civil and construction engineers in the field. Although the quality is affected by the placement, consolidation, and curing; it is also affected by the Portland cement, hydration development of the microstructure, admixtures, and aggregate characteristics. Hardened concrete properties are determined from testing. These testing can either be destructive or non-destructive. While there are numerous tests that can be performed in a laboratory or in the field; they are usually conducted to ensure quality control and quality assurance [1].

One of the most common tests that is performed on hardened concrete is the compressive strength test. Other tests include split tension, flexure strength, rebound hammer, penetration resistance, ultrasonic pulse velocity, and maturity test [1]. This research was done to determine an equation through a correlation of destructive and non-destructive testing methods of hardened concrete which will enable the determination of thecompressive strength of concrete without the crushing of cubes.

II. PURPOSE OF STUDY

This study aimed to determine a correlation using SONREB and destructive methods of testingconcrete at the University of Guyana, Turkeyen Campus and CELG, this will result in the valuation of the concrete compressive strength in the laboratory and infrastructure works.

III. OBJECTIVES OF THE STUDY

1) Use various mix proportions to produce concrete strength ranging from 2200 psi to 6000psi.
2) Assess the compressive strengththat is in the concrete using the rebound hammer,compressive strength test,and the pulse ultrasonic velocity device.
3) Develop an equation which will produce the compressive strength using the SONREB method.

IV. SCOPE OF WORKS

This investigation was done at the University of Guyana, Turkeyen Campus, Civil Engineering Laboratory and CELG. From the outset, forty-two concrete cubes with various strengthswere produced and their compressive strengths were evaluated using three methods oftesting.

V. TESTING

1) **Compressive strength test:**Numerous tests are performed on hardened concrete. One of these tests include the compressive strength test. This is done to ensure the requirements needed for the structural design and to certify that the intended load will be supported by the structure[1].
2) **Hammer Rebound Test:**The Schmidt rebound hammer was developed to test the hardness of a surface. The rebound ofan elastic mass is a function of the surface hardness for which the mass is acting. The maincomponents of the device include a plunger rod locked to the hammer mass by a mechanism that latches and a sliding rider which measures the mass hammer rebound. To determine the rebound height, a random scale marked 10 to 100 is utilized[2].
3) **Ultra-sonic Pulse Velocity Test:** An electro-acoustical transducer produces vibrations that are longitudinal when it is placed on the concrete surface being tested. The vibrations are aided by a cellulose paste or grease found in a liquid coupling material. As a result, stress waves system is generated which includes both the shear and longitudinal waves which are transmitted through the concrete. A second transducer is used to convert the longitudinal waves to an electrical signal [2]. The pulse longitudinal velocity is known by:

$$v = \frac{L}{T} \text{ .... Equation 1}$$

v - pulse longitudinal velocity
L - path length
T - timethe pulse takes to traverse that length

VI. MATHEMATICAL EQUATION

The compressive strength of concrete utilising the SONREB method can be modelled using the following *Equation 2*. The equation is a function of *v*, the pulse ultrasonic velocity in $m/s, s$, therebound number, and three constants which can be determined by utilizing the LINEST function ofMicrosoft Excel[3]. The function evaluates the statistics for a line using the *least*squares method. Below is the format of the curve used to model the strength:

$$f_{ck} = a^v b^s c \text{ .... Equation 2}$$

VII. PREVIOUS RESEARCH

Researchers evaluated concretes of low and middle strength usingrebound, SONREB and UPV methods. They developed equations using linear, polynomials of thesecond and third degrees, power, and an exponential nature for all three methods.
Subsequently, they were amalgamated under the SONREB method [4]. The equations developed areshown in *Table 1*:

TABLE I
EQUATIONS DEVELOPED BY ASAN, ETAL.

Concrete Type	Correlation Equation	r^2
Low	$F = 0.6768R + 0.002414V - 11.88$	0.9207
	$F = -1.819R - 0.0046V + 0.0059R^2 - 0.0006RV - 1.157e - 0.7V^2 + 17.6$	0.9494
Middle	$F = 5.286R + 2.514V + 28.25$	0.9163
	$F = 4.83R - 2.73V + 0.5083R^2 - 4.121RV + 3V^2 + 28.46$	0.9329
All	$F = 13.69R - 2.011V + 17.74$	0.9219
	$F = 7.968R + 5.03V - 1.252R^2 + 7.63RV - 2.035V^2 + 13.81$	0.9775

Researchers checked the accuracy of previously developed equation for the compressive strength determination against the non-destructive tests alongwith their r^2 values. However, for concrete strength above 40 MPa, the accuracy ofprediction decreased for all mathematical equations [5].

VIII. PRACTICAL WORK

1) Acquisition of Materials: The researchers purchased materials necessary to produce the required volumeof concrete which were tested later. These included cement, fine and coarse aggregates.
2) Concrete Production: The concrete production was influenced by the nominalconcrete mix to produce concrete having strengths from 2200 to 6000psi. The concretes were produced using a nominal mix ranging from M15 to M40 grades. The mixproportion of $C{:}\,FA{:}\,CA$ (Cement: Fine Aggregates: Coarse Aggregates) correspondingto the concrete grades were identified, followed by the water-cement ratio. Subsequently,the volume required to produced six 6-inch cubes along with wastage were calculated.Thereafter, the weight of each component, that is, aggregates that are fine, cement,coarse aggregates,and water (volume in litres is more appropriate) were measured. The components weresubsequently mixed thoroughly until the concrete had a uniform colour and consistencyand placed in six concrete moulds. For each mould, the concrete was compacted inthree layers; each layer was subjected to twenty-five tamps by a 1-inch steel rod.The following day, the concrete cubes were removed from the moulds and placed in thewater bathe for twenty-eightdays curing period.

3) Laboratory Testing: The cubes compressive strengths were evaluated after the requisitecuring process using the compression strength test, the ultrasonic pulse velocity device,and the hammer rebound device. All the tests were performed in using thefollowing standards:
    a) ASTM C39: Standard Method Test for Compressive Strength of Concrete Cylindrical Concrete Specimen.
    b) ASTM-C597-09: Pulse Velocity Through ConcreteStandard MethodTest.
    c) ASTM C805/C805-16a: HardenedConcreteStandardMethod Test Rebound Number.

TABLE 2
CONCRETE MIX RATIOS AND WATER/CEMENT

Concrete Grade	Ratio (C: FA: CA)	Water/Cement Ratio
M15	1:2:4	0.82
M20	1:1.5:3	0.68
M25	1:1:2	0.63
M30	1:0.75:1.5	0.45
M35	1:0.5:1	0.45
M40	1:0.25:0.5	0.37

IX. RESULTS AND ANALYSIS

A total of forty-two cubes were produced ranging from M15 to M40 grades. The results from the three tests were used to obtain the SONREB equation which each set of data formulating aseries. The equation can be linearised using logarithms, however, this was used prior to using theLINEST function in Microsoft Excel. The average values of the compressive strengths, pulsevelocities, and rebound numbers are shown below:

TABLE 3
AVERAGE OF EACH METHOD OF TESTING

Compressive Strength (MPa)	Pulse Velocity (m/s)	Rebound Value	Concrete Grade
10.95	4132	17	M15
17.04	4155	15	M20
18.48	4225	18	M25
37.19	4341	27	M25
38.38	4547	32	M30
39.46	4154	31	M35
41.74	4379	29	M40

The mathematical equation to predict the compressive strength was found to be:

Equation 3:

$$f_{ck} = exp\ (9.06981)\ v^{-1.2480} R^{1.4234}$$

X. DISCUSSION

The compressive strength, pulse velocity, and the rebound results for the M15 concrete were in dispute along with other rebound values for other concrete grades. For the former, this concretecorresponded to a compressive strength of $2175 psi$. The average compressive strength wasfound to be 1588 psi, average pulse velocity was found to be $4132 m/s$, and average reboundnumber was 17. The compressive strength was within the range of the target strength and the pulsevelocity verified that the concrete was "good". However, the compressivestrength using the average rebound value provides a value of less than 1500 psi. All reboundvalues with the exception of the second M25, were performed by CELG technicians. However,ASTM C805 recommends a minimum of ten readings to approximate the compressive strength.

Unfortunately, taking less readings diminishes the precision and accuracy of the rebound values.The rebound hammer utilised for the research was a Humboldt concrete rebound hammer: H-2987-H. This type yield economical values compared to the original Schmidt hammer. Schmidttest hammers are produced with two energies 2.207 Nm and 0.735 Nm for type N and type L,respectively. At least one sample of the M35 and M40 produced a rebound value of 28 whichcorresponds to an approximate strength of 3800 psi .The ultra-sonic pulse velocity values indicated the concrete produced can be qualitativelyclassified as either good or excellent concrete. This test was conducted utilising the direct
method.
The linear regression analysis produced anr^2value of 0.68 which indicated the samples has a goodamount of variance for the model. However, the hammer type, repetition, handling of thesamples, and plumbness would significantly affect the model.

XI. CONCLUSION

Based on the three defined objectives, it can be concluded that concrete with strengths ranging from M15 to M40 grades were produced. However, for M15 and M20, the cubesdid not reach the target strength. In addition, the various tests were performed on the cubes with the rebound values being extremely low in particular for the M15 cubes and in some instances for the higher concrete grades. Furthermore, the model produced *Equation 3*, with a r^2 value of 0.68. This value validates a correlation between the destructive and non-destructive method of testing; however, the model needs to be improved by producing more samples and using an original

Schmidt hammer with the required impact energy.

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