ARTIFICIAL INTELLIGENCE-BASED NONDESTRUCTIVE TESTING FOR PREDICTING THE COMPRESSIVE STRENGTH OF ROLLER-COMPACTED CONCRETE

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Abstract

The term "nonslump concrete" refers to roller-compacted concrete (RCC), which is a type of concrete with substantially less water content than regular concrete but same fundamental ingredients. A very good option for assessing the strength and quality of concretes like RCC is nondestructive testing, or NDT. Additionally, to being inexpensive, these tests are simple, quick, and effective. Using appropriate mathematical formulas based on nondestructive test findings, the study's objective is to estimate the compressive strength of RCC. This is accomplished by creating and testing a large number of RCC samples, both with and without fibers, using nondestructive methods including Schmidt hammer and ultrasonic testing, as well as concrete breaking tools. Ultimately, appropriate relations were discovered using the values from both destructive and nondestructive tests and Artificial Intelligence (AI) ideas. In real-world projects, the RCC compressive strength can be accurately determined using the suggested relations by doing nondestructive testing instead of destructive testing. Accuracy rises when Schmidt Hammer and ultrasonic tests are applied together.

Keywords-roller-compacted concrete; nondestructive test; Schmidt hammer; ultrasonic test; artificial intelligence

1. INTRODUCTION

Nondestructive testing (NDT) methods like Schmidt hammer techniques and ultrasonic pulse velocity (UPV) are highly useful for assessing the strength and quality of concrete in existing structures. These tests are inexpensive, quick, and simple to conduct. As a result, several researchers and engineers are considering using these techniques to evaluate the strength and condition of concrete [1–5]. Generally speaking, there is no physical correlation of any significance between the properties of concrete and the results of NDT.

As a result, there are certain mistakes when evaluating the desirable properties of concrete using these methods, particularly compressive strength, and calibration graphs for each type of concrete are required. For their tests, the makers of these gadgets frequently suggest empirical connections. Many of these relationships need to be modified because they aren't appropriate for all kinds of concrete.

For this purpose, the use of mathematical and evolutionary models such as fuzzy logic, neural networks, artificial intelligence and genetic algorithm which can be managed based on empirical studies have been developed [6-8].

The concrete type known as Roller Compacted Concrete (RCC) derives its name from the construction technique employed in its creation. Using standard asphalt paving machinery, it is laid down, and then rubber-tired or steel-drum rollers are used to compact it. Portland cement, coarse and fine particles, and water make up RCC, much like regular concrete does. On the other hand, zero slump concrete has significantly lower water content. Because it produces strength, density, and surface texture, compaction is the most crucial stage in RCC building. The characteristics and strength of RCC concrete have been studied by numerous researchers due to its significance and applicability in various constructions such as pavements and dams [9–11].

Using Schmidt hammer and ultrasonic pulse velocity (UPV) methods, this study suggests several models to forecast the compressive strength of RCC. For this reason, numerous RCC samples—both with and without fiber—are created and examined. After examining significant variables that impact test outcomes, artificial intelligence (AI) ideas are applied to estimate the strength of concrete. The suggested relationships are appropriate for assessing the compressive strength of RCC in the ongoing projects and are straightforward, accurate, and easy to apply. This research primarily focuses on using a combination of nondestructive testing (NDT) approaches to accurately estimate the compressive strength of concrete. To determine the strength of the current roller compacted concrete, data from Schmidt hammer tests and ultrasonic pulse velocity measurements are combined.

2. METHODOLOGY

2.1 Material Properties And Mix Design

Three different varieties of RCC were manufactured and cast into cubes measuring 15 by 15 cm in order to determine the compressive strength of RCC based on findings from nondestructive tests. Type A was the initial variety of RCC, and it lacked fiber. In Type B, the second type, 1 kg of polypropylene (PP) fiber was utilized in 1 m3 of concrete. Type C was the third type, consisting of 2 kg of PP fiber in 1 m3 of concrete. The 10 mm-long PP fibers were white in color. Additionally, each of the concretes A, B, and C contained three distinct sizes of coarse particles, or gravel. These three different varieties of gravel have maximum sizes of aggregates (MSA) of 12.5, 19 and 25 mm respectively. 108 concrete samples were made and evaluated for this investigation. A total of 36 samples, consisting of 12 distinct mix designs and 3 specimens in each mix design, were prepared for each type of concrete (A, B, and C). Following 28 days of moist curing, every specimen underwent testing. The mean value of test findings for three specimens is taken into consideration as the final test result for each mix design.

The ingredients of RCC are similar to those of normal concrete. In this research, the RCC mix was composed of Portland cement, coarse aggregates (gravel), sand, filler (fine sand) and water with different water-cement ratios. A summary of the concrete mix designs are presented in Table 1. The mix designs of the three types A, B and C are quite similar but with different weights of fibers.

TABLE I. SUMMARY OF THE ROLLER COMPACTED CONCRETE MIX DESIGNS

Mix No.	MSA(mm)	Cement (kg)	Water (kg)	Filler(kg)	Sand (Kg)	Fine Gravel (kg)	Coarse Gravel(kg)
1	12.5	192	118	280	701	801	0
2		235	122	280	701	801	0
3		281	106	280	701	801	0
4		329	110	280	701	801	0
5	19	192	88	276	736	407	353
6		235	101	276	736	407	353
7		281	114	276	736	407	353
8		329	118	276	736	407	353
9	25	192	148	183	824	353	405
10		235	152	183	824	353	405
11		281	176	183	824	353	405
12		329	171	183	824	353	405

2.2 Ultrasonic Pulse Velocity Test

In this study, the ultrasonic pulse velocity (UPV) instrument is used to determine the P-wave velocity of the concrete. The standard method of ultrasonic test is described in ASTM C-597 [12]. The apparatus is portable and easy to use and includes a processor unit that sends and receives ultrasonic pulses and measures the time between the two operations (sending and receiving). It also has two probes connected to two cables, which perform the transmission of ultrasonic pulses. Fig. 1 illustrates a UPV device.

Figure 1. Ultrasonic pulse velocity device

Higher quality concrete will yield a higher velocity; as Fig. 2 illustrates, there are three different types of probe arrangements for UPV tests: direct, semi-direct, and indirect, or surface transmission. In this study, only the indirect transmission is taken into account for compliance testing in the field and laboratory; each cubic sample was tested at multiple points and from different sides; the velocity of the P-wave for each sample is determined by the mean value of all measurements on that sample; the final result for each mix design is the average of the test results of the three specimens.

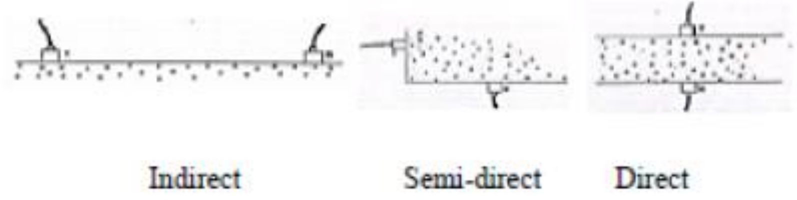

Figure 2. Types of arrangements of probes in a UPV test

2.3 Schmidt Hammer Test

The Schmidt hammer, often called the rebound hammer, is a tool used to gauge the strength or surface hardness of rocks or concrete. It operates on the tenet that the hardness of the surface an elastic mass impinges against determines how quickly the mass bounces back. ASTM C-805 [13] provides a description of this test's standard methodology. Since a rebound value is measured rather than the compressive strength, this NDT approach is an indirect method.

The strength of concrete and the hammer's rebound number have minimal theoretical association. Nonetheless, there are documented empirical relationships between the rebound number and strength attributes. The process is quick, affordable, simple to use, and it doesn't harm the concrete like destructive procedures do. A concrete structure's whole surface can be examined in-situ, allowing for the testing of the structure's quality rather than only a small number of specimens that have been destructively crushed. The Schmidt Hammer Test is generally helpful for determining the homogeneity of concrete and contrasting different types of concrete. A Schmidt hammer apparatus is shown in Fig. 3.

Figure 3. Schmidt hammer device

In this study, each cubic specimen was tested at various points and at different sides. For each specimen 9 tests were performed and the average of these measurements is considered as the result for that specimen. The mean value of the test results of the three specimens is considered as the final result for each mix design.

3. TEST RESULTS

Each specimen in this experiment underwent three distinct tests—two destructive and one nondestructive—on each one. Each cubic sample was first subjected to UPV and Schmidt hammer tests, as previously mentioned, and after that, each cube was broken using a concrete compression test equipment. Tables 2 through 4 display a summary of the test results. These tables show the results of destructive testing using a compression test machine in the third column, and the results of nondestructive tests using Schmidt hammer and UPV techniques in the fourth and fifth columns, respectively.

According to these tables, there is a 5–15% variation in compression strength between fiber RCC (types B and C) and conventional RCC (type A). Stated differently, there is little to no impact of polypropylene fibers on the compressive strength of RCC. However, adding polypropylene fibers has typically been utilized to decrease pavement thickness, regulate plastic shrinkage and cracks, and enhance certain mechanical qualities of concrete.

Based on an analysis of the test results, it can be inferred that RCC's compressive strength increases significantly with an increase in the nominal maximum size of aggregates; this effect is also somewhat similar for fiber RCC. UPV test results indicate that as compressive strength increases, the velocity of P-wave. Also, results of Schmidt hammer tests show that by increasing the compressive strength, the rebound value of RCC usually increases.

TABLE II.RESULTS OF PERFORMED TESTS ON TYPE A CONCRETE (WITHOUT FIBER)

Mix.No	MSA (mm)	f_c (MPa)	V_c(km/S)	Rebound
A1	12.5	7.82	3.68	10.07
A2		12.59	3.75	10.30
A3		17.56	3.87	11.70
A4		23.28	3.97	13.52
A5	19	15.04	4.07	11.37
A6		15.73	4.09	10.52
A7		21.06	4.14	13.07
A8		28.71	4.14	14.67
A9	25	18.05	3.91	10.96
A10		22.08	3.94	12.37
A11		28.42	3.96	13.85
A12		34.07	4.03	15.85

TABLE III. RESULTS OF TYPE B CONCRETE (WITH 1 KG/M3 PP FIBER)

Mix. No	MSA (mm)	f_c (MPa)	V_c (km/S)	Rebound
B1	12.5	8.34	4.20	10.04
B2		15.79	4.20	11.00
B3		17.79	4.14	11.19
B4		24.00	4.05	11.11
B5	19	16.74	4.12	11.22
B6		17.07	4.18	12.22
B7		23.28	4.22	13.59
B8		29.04	4.21	12.19
B9	25	18.93	4.06	12.48
B10		23.94	4.05	12.76
B11		33.81	4.05	13.07
B12		36.07	4.08	15.96

TABLE IV. RESULTS OF PERFORMED TESTS ON TYPE C CONCRETE (WITH 2 KG/M3 PP FIBER)

Mix. No	MSA (mm)	f_c (MPa)	V_c (km/S)	Rebound
C1	12.5	13.93	4.25	11.70
C2		16.84	4.34	12.04
C3		21.58	4.39	12.33
C4		24.65	4.22	13.67
C5	19	17.89	4.43	12.26
C6		20.60	4.42	12.3
C7		25.21	4.53	13.44
C8		31.19	4.21	14.81
C9	25	19.49	4.32	12.81
C10		24.30	4.35	13.92
C11		33.52	4.46	14.96
C12		37.92	4.49	15.99

4. PREDICTION OF CONCRETE COMPRESSIVE STRENGTH USING THE ARTIFICIAL INTELLIGENCE APPROACH

The exact relationship between the rebound value or P-wave velocity and the compressive strength of concrete is unknown. However, by measuring the P-wave velocity or rebound value and the compressive strength of concrete at the same time, empirical connections can be presented. For instance, fitting the appropriate diagram between experimental test findings can be accomplished using the least squares method. The curve with the least sum of squared distances between the experimental points is the best one. Concrete compressive strengths can also be estimated using Artificial Intelligence (AI) method in addition to curve fitting methods like least squares method. A subfield of computer science called artificial intelligence aims to give computers and other machines the same level of intellect as the human mind. Large quantities of processing power are needed for curve fitting, modeling, and complicated system optimization using conventional approaches. However, good substitutes for effectively resolving civil engineering challenges can frequently be found in artificial intelligence-based solutions. AI can make use of a wide range of methods, such as neural networks, fuzzy logic, and evolutionary algorithms (which include genetic algorithms and gene expression programming).

In this study, the compressive strength of RCC was predicted using the Gene Expression Programming (GEP) technique. According to this approach, computer programs are intricate tree structures that, like living things, can learn and adapt by modifying their sizes, compositions, and shapes. Genetic programming and genetic algorithms are closely related to GEP, which is a member of the evolutionary algorithm family. This technique makes use of linear chromosomes, which are made up of genes arranged in a head and a tail. The chromosomes function as a single genome and can be altered by recombination, one- and two-point recombination, gene recombination, root transposition, and mutation. To indicate how accurate the associations are and how well they match test results, one can use a correlation coefficient (R). R being close to 0 means that there is little relation between the variables and when it is close to 1 there is strong relation between the variables. To show the percentage of variables explained by a suggested model (fitted curve), the correlation coefficient (R) can be substituted with the R-squared (R2) approach or coefficient of determination.

Since polypropylene fibers have a small impact on RCC's compressive strength, a single relationship is suggested for each of the three types of concrete used in this investigation. Using GEP, the initial stage was determining the relationship between the compressive strength of the RCC and the P-wave velocity. With the use of equation (1), the compressive strength of RCC may be predicted using P-wave velocity data from an ultrasonic pulse velocity test. The 28-day concrete cubic sample's compressive strength (fC) is expressed in MPa in this equation, and the P-wave velocity (vc) is expressed in km/Sec.This equation's coefficient of determination, R2=0.73, shows that the relationship's accuracy is comparatively good. This formula enables one to predict concrete strength of existing RCC pavement whose concrete properties and mix design is not available.

$$f_c = 30.2\, v_c - 103 \qquad (1)$$

In the second phase, GEP was used to compute the relationship between the rebound value and the compressive strength of the RCC. Based on the rebound value (Re) from the Schmidt hammer test, equation (2) is calculated. The 28-day concrete cubic sample's (fC) compressive strength is expressed in MPa in this relationship. When compared to the findings of other researchers, this equation's R-square of 0.71 indicates a good estimate.

$$f_c = 3.87\, R_e - 27.3 \qquad (2)$$

Equations (1) and (2) can be used to determine the compressive strength of RCC using only rebound value or P-wave velocity data. Lastly, combining the outcomes of the two NDT methods can improve accuracy. Equation (3) can be used to determine the compressive strength of RCC based on the simultaneous measurement of the rebound value (Re) and P-wave velocity (vc). The 28-day concrete cubic sample's compressive strength (fC) is measured in MPa in this connection, and vc is measured in km/sec. This equation's R-square, which is 0.80, is higher than the values in equations (1) and (2).

$$f_c = 0.136\mathrm{Re}^2 - \frac{2.59}{v_c(\mathrm{Re} - 9.93)} \qquad (3)$$

All of the aforementioned equations are straightforward, useful, and easy to use, with good accuracy. GEP, on the other hand, has more difficult-to-use formulas and can produce more precise relations with better R-squares. The study's findings indicate that, in comparison to utilizing a single NDT approach, combining multiple NDT techniques yields a more accurate estimate of the compressive strength of concrete. It should be noted that to convert the compressive strength of the cube specimens to compressive strength of the cylinder specimens, the coefficient of 0.833 can be used.

5. CONCLUSIONS

In this study, the compressive strengths of the conventional and fiber roller compacted concretes were estimated using two distinct nondestructive methods. The ultrasonic pulse velocity test was the first technique, and the Schmidt hammer test was the second. Certain relevant formulae for concrete strength prediction were suggested using gene expression programming and artificial intelligence principles. The following is a summary of the research's findings:

- The compressive strength of fiber-reinforced concrete (RCC) and ordinary concrete increases significantly when aggregate sizes are increased.
- P-wave velocity increases as concrete's compressive strength increases.
- The rebound value of RCC typically increases as concrete's compressive strength does.
- The addition of polypropylene fibers to RCC only slightly increases its compressive strength—between 5 and 15%.
- Using the results of NDT, the artificial intelligence (GEP) approach predicts the compressive strength of RCC with high accuracy and efficiency.
- The suggested equations can yield reasonably accurate results when used to evaluate the strength of concrete in an existing RCC with an unknown mix design.
- The forms of all suggested relationships are straightforward and useful, making it simple to utilize them to calculate the compressive strength of current RCCs. This can be accomplished by simply subjecting the existing RCC to a few nondestructive tests, like ultrasonic or Schmidt hammer.
- The outcomes demonstrate the effectiveness and capability of combining two distinct NDT techniques (UPV and Schmidt hammer) to determine the current RCC's compressive strength.

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