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Application of Genetic Programming to Predict Concrete Compressive Strength Based on Non-Destructive Tests

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Abstract- The compressive strength of concrete is a major aspect to determine the quality of concrete. The determined in-situ strength of concrete can never be same to cube strength determined in the laboratory. Taking core from the structure is not possible as it may damage the structure. Therefore, Non Destructive tests are mostly preferred than destructive testing for monitoring reinforced concrete structures. Though NDT gives quicker results, their values are not exact but gives approximate values. The manufacturers of test equipments provides a calibration chart to predict some desired property of concrete. These charts do not appear to be satisfactory because their development is relies on their own test conditions. The Indian code recommends about 25% variation in results, which is incredibly high. Therefore for prediction of strength, the artificial intelligence can be effectively adopted. Also the statistical methods are generally adopted in the form of regression analysis. The aim of this study is to correlate the compressive strength obtained by Destructive and Non Destructive Testing using Genetic Programming. MATLAB software was used for predicting the results using GP. The modeling of data sets was done using 70% for training and 30% for testing. The modeling includes two ways, firstly by using variables as weight and Rebound values and secondly by using weight, rebound values and UPV values. The models obtained are found to be in good agreement with actual values imparting 5.7825% and 6.2498% error respectively.

Keywords — Compressive Strength, Genetic Programming, MATLAB, Non-destructive testing, Rebound hammer, Ultrasonic pulse velocity

I. INTRODUCTION

Concrete is a very complex composite construction material. Modeling using computing tools to predict concrete strength is a tedious task. In this work, Genetic Programming (GP) is used to predict compressive strength of concrete after 28 days of curing. The data for analysis mainly consists of mix design parameters of concrete, weight of cubes casted, rebound numbers, ultrasonic pulse velocity. GP generates an equation as its output making its plausible tool for predicting strength of concrete. Non destructive test does not give accurate results due to surrounding conditions and hence predicting the exact strength of concrete becomes difficult in situ. GP will help us with the hectic calibration computing and will provide accurate results.

Non destructive test (NDT) is generally defined as a method of test that does not impair the intended performance of the element or member under investigation [5]. It can be done during and after construction, in-service, maintenance [6]. The main objective of non destructive tests are for quality control and monitoring of strength in long term development and the later to establish structure adequacy and material deterioration against time or environment. Many types of NDT methods have been applied to investigation of the concrete structure in respect of its strength, modulus of elasticity, deformation, rigidity and the present condition of the concrete. It is therefore important to understand NDT methods in regards to the principle, techniques and limitations.

II. LITERATURE REVIEW

Palika Chopra, Rajendra Sharma & Maneek Kumar (2015) had studied the prediction of compressive strength of concrete using ANN and GP. The models were made with the help of these two data mining techniques. The compressive strength of 28, 56 and 91 days were collected for the development of model and analysis. The in situ data was also taken into consideration for the model. The comparison of both the models gave the prediction results [1]. John R. Koza (1992) found that genetic programming paradigm described provides a way to search the space of possible computer programs for highly fit individual computer program to solve a surprisingly variety of

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different problems from different fields [2]. In genetic programming, populations of computer programs are genetically bred using Darwinian principle of survival of the fittest and using genetic crossover operator appropriate for genetically mating computer programs [2]. Jerzy Hola and Krzysztof Schabowicz (2005) showed that neural identification of the compressive strength of concrete on the basis of non destructively determined parameters. They used ANN to determine the strength [3]. Faezehossadat Khademi and Sayed Mohammadmehdi Jamal (2016) done the research dealing with predicting the compressive strength of concrete using artificial neural network. They used specific concrete characteristics as input variables and constructed ANN model to predict 28 days compressive strength of concrete [4].

III. Experimental Program

A. Methods Followed

1. Initially cube (150mm*150mm*150mm) of different proportions have been casted using mix design (IS 10262-2009)

2. The concrete cubes were casted of following proportions obtained from mix design.

   a) 1:2:4
   b) 1:1.5:3
   c) 1:1:2
   d) 1:1:3

3. In total 50 cubes of above ratios were casted and cured for 28 days.

4. Rebound hammer test was performed over all the cubes to obtain rebound number.

5. Ultrasonic pulse velocity test was also performed over the cubes to get the velocity and time required to travel through the concrete cubes.

6. After performing the NDT tests the Actual Compressive Strength was determined using Compressive Testing Machine.

B. Genetic Programming

GP is a dominant autonomous, problem-solution approach through which computer programs are generated to find solutions for the problems. The technique is based on the Darwinian hypothesis of 'survival of the fittest'. Every result predicted by GP is compiled from two sets of primary nodes; terminals and functions. The terminal set holds nodes that provide a framework to the GP system while the function set contains nodes that processes values already inside the system. There are three major evolutionary operators within a Genetic Programming framework :

Reproduction: It chooses an individual from the initial population to be replicated exactly into the subsequent generation. In reproduction a strategy is made to kill the underperformed program. There are few methods of selection from which individual is duplicated which includes fitness measure, selection, rank selection and tournament selection.

Crossover: Crossover is a recombination technique where two program that are chosen as per their fitness and produces two subprograms [1]. It's a genetic operator used to combine the genetic information of two parents to generate new offspring. From each program two random nodes are chosen and the resultant sub-tress are swapped using two new programs. These new programs turned into a part of the new generation of programs to be participated.

Mutation: It becomes a significant operator that provides assortment to the population [1]. It is responsible for irregular changes in a tree before it is brought into the next population. It is a biogenetic and works on one single individual which means one individual is chosen as per fitness. Throughout mutation process either all functions are separated under an arbitrarily determined node and a new limb is randomly generated or a single node is exchanged with each other.

Perspective to portray GP as far because the structures that experiences adaptation are:

- Initial structure generation
- Fitness measure test, which assess the structure
- Operation which change the structure
- The state of the framework at each stage
- The system for terminating the process
- The system for designating an output, and also the parameters that control the process

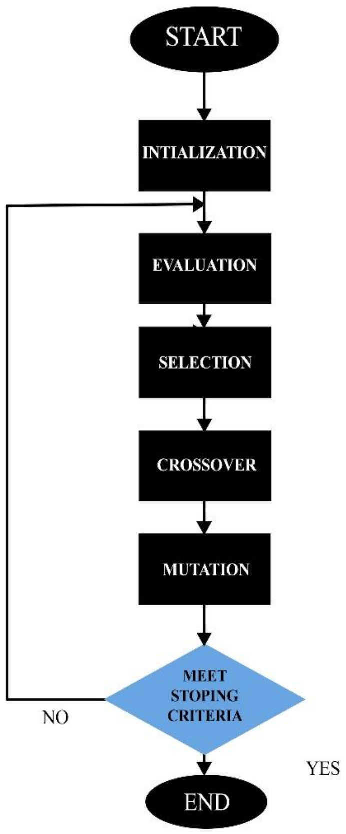

Figure 1. Genetic Programming Flowchart

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Following above principle, an empirical model was generated which selected the most fittest chromosomes to obtain the optimized result. It used about 70% of test data for training and rest 30% data was used for testing.
The modeling is done in two sets

- Two variables; weight and rebound values are involved in modeling.
- Three variables; weight, rebound values and UPV values are involved in modeling.

IV. Modeling Using Genetic Programming

A. MATLAB Model

Genetic programming, a tool in MATLAB was used for correlating the values of actual compressive strength using destructive test with the Non Destructive Testing values obtained by rebound hammer and ultrasonic pulse velocity tester. Here the difference in values obtained using both Destructive Testing and Non Destructive Testing results were optimized and a general formula was obtained to relate both the values so that the difference in both the value can be minimized. The following steps were followed in MATLAB :-

B. Procedural Steps for Modeling

Modeling For Rebound Hammer Data

In modeling variables taken were weight and rebound hammer value. The value of rebound hammer were found to be about 30% more than actual compressive strength.

- The model selected is simple rational polynomial equation

The step by step procedure for modeling of Rebound hammer test:

STEP 1- The main program recalling the data provided for analysis and specifying training data and test data

STEP 2- Apps → Optimization tool → Solver → Genetic Algorithm

It is optimizing the values of chromosomes according to the operators.

STEP 3- fitness function → @fit WRH → No. of variables → 8 →start

STEP 4- File → Export to workspace → Export to a MATLAB structured named → OK

STEP 5- Editor → test WRH.m

In this step the remaining data are checked following GP optimized model.

STEP 6- Run

The testing data were checked and Root mean square error was found to be 5.7825%

Modeling For Rebound Hammer & Ultrasonic Pulse Velocity Data

The step by step procedure for modeling of Rebound hammer and UPV test:

STEP 1- Same procedure is followed here

STEP 2- Apps → Optimization tool → Solver → Genetic Algorithm

STEP 3- fitness function → @fitness → No. of variables → 09 → start

STEP 4- File → Export to workspace → Export to a MATLAB structured named → Ok

STEP 5- Editor → test.m

STEP 6- Ok

The testing data were checked and Root mean square error was found to be 6.2498%

V. Results and Discussion

Empirical Equation Relating Rebound Hammer Value With Actual Strength

Proposed Model :

$$Y = a_1 w^{b_1} + a_2 R^{b_2} + a_3 \sin w + a_4 e^{-R} + a_5 \sin R + a_6$$

Where,

$a_1, a_2, a_3, a_4, a_5, a_6, b_1, b_2$ are chromosomes
R = Rebound hammer values
W= Weight of the sample
Y = Compressive strength value obtained from empirical equation

After optimization the obtained value of the chromosome:-

$a_1 = 0.424$, $a_2 = 0.77$, $a_3 = 0.202$, $a_4 = -1.072$
$a_5 = 1.157$, $a_6 = 0.376$ $b_1 = -0.129$ and $b_2 = 0.997$

So the GP model is,

$$Y = 0.424 w^{0.129} + 0.77 R^{0.997} + 0.202 \sin w - 1.072 e^{R} + 1.157 \sin R + 0.376$$

The Root mean square error obtained after optimization = 5.7825%

The effectiveness of proposed model is summarized below in Table 1.

Table 1. Predicted Results Following Proposed Model

WEIGHT	RH	Actual fck	Predicted fck
8.2	18.8	14.43	15.1811
8.12	18.9	14.8	15.3781
8.23	18.7	14.3	14.9876
8.28	19	14.67	15.5575

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8.33	21	17.33	17.8691
8.29	18.7	15.11	14.9825
8.2	19.5	17.36	16.4716
8.23	19	16.67	15.5617
8.28	19.2	16.85	15.9335
8.22	23	19.78	17.4528
8.35	22.5	19.32	17.4764
8.26	18.5	14.2	14.6091
8.18	20	15.8	17.2902
8.32	20.5	16.1	17.675
8.12	25	19.32	19.8064
8.21	23	18.7	17.4536
8.26	23.5	18.9	17.6541
8.19	25	19.4	19.8018
8.13	22	17.6	17.6673
8.19	25.2	19.2	20.1848
8.24	24.8	18.6	19.4212
8.2	21	16.33	17.8802
8.23	22.5	17.9	17.4872
8.21	25	18.7	19.8004
8.32	25.2	19.67	20.1739
8.22	25	18.8	19.7996
8.17	26	20.88	21.5989
8.14	25	18.67	20.1881
8.11	25.8	20.44	21.2843
8.106	30.8	23.22	23.7003
8.124	31.5	24.48	24.9967
8.128	30.5	22.36	23.2218
8.176	31	23.45	24.0488
8.026	31.2	23.77	24.4286
8.122	26.5	21.11	22.2329
8.114	25.5	20.22	20.7554
8.124	31.2	24.44	24.4237
8.132	31.5	24.89	24.9962
8.01	28.5	21.78	22.3664
8.22	30.5	22.22	23.2155
8.21	30.5	22.24	23.2163
8.126	31.5	24.46	24.9966
8.2	31	23.67	24.0471
8.262	30.5	22.38	23.2121
8.246	30.5	22.34	23.2134
8.242	31	23.03	24.0439
8.186	29	21.78	22.228
8.298	32	24.67	25.9043
8.262	32.2	25.44	26.2384
8.21	31	23.44	24.0464

The more variation is observed for the concrete of lower strength. To compare the actual value and the predicted value a regression analysis was performed using Excel .The regression model is shown in figure 2. The linear regression coefficient was found to be 0.9721 which is in good agreement.

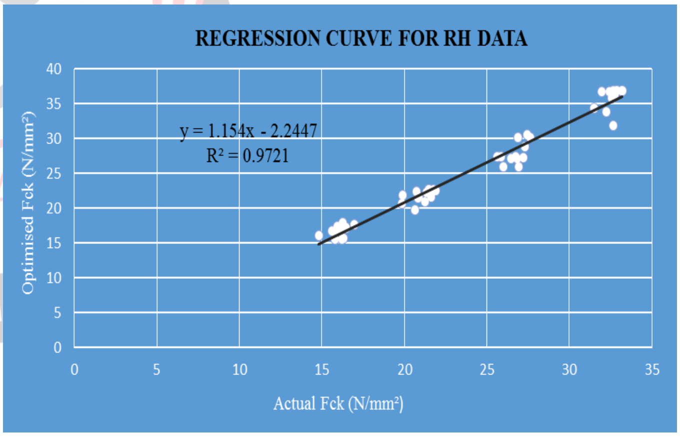

Figure 2. Regression Curve for RH Data

Empirical Equation Relating Rebound Hammer & Ultrasonic Pulse Velocity Values With Actual Strength

Proposed model:-

$$Y = a_1 w^{b_1} + a_2 R^{b_2} + a_3 v^{b_3} + a_4 \sin R + a_5 e^{-v} + a_6$$

Where,

$a_1, a_2, a_3, a_4, a_5, a_6, b_1, b_2, b_3$ are chromosomes

R = Rebound hammer values

W= Weight of the sample (Kg)

V = Ultrasonic pulse velocity (m/s)

Y = Compressive strength value obtained from empirical equation

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Now, the required values of the variables obtained after optimization are:-

$a_1 = 0.608$, $a_2 = 0.734$, $a_3 = 0.398$, $a_4 = 1.589$
$a_5 = 0.704$, $a_6 = 0.796$, $b_1 = 0.324$, $b_2 = 0.945$ and
$b_3 = 0.781$

So the GP model is,

$$Y = 0.608w^{0.324} + 0.734R^{0.945} + 0.398v^{0.781} + 1.589\sin R + 0.704e^{-v} + 0.796$$

The Root mean square error obtained after optimization = 6.2498%

The effectiveness of proposed model is summarized below in Table 2.

Table 2. Predicted Results Following Proposed Model

Weight	RH	Velocity	Time	Actual fck	Predicted fck
8.2	18.8	4321	34.2	14.43	14.9199
8.12	18.9	4223	33.6	14.8	15.1128
8.23	18.7	4312	33.2	14.3	14.7023
8.28	19	4518	33.2	14.67	15.4011
8.33	21	4425	33.9	17.33	17.6513
8.29	18.7	4298	34.9	15.11	15.7021
8.2	19.5	4624	24.9	17.36	16.439
8.23	19	4682	26.4	16.67	15.4341
8.28	19.2	4792	25.9	16.85	15.8854
8.22	23	4906	25.4	19.78	18.4575
8.35	22.5	4882	31.4	19.32	19.9245
8.26	18.5	4465	34.3	14.2	14.3112
8.18	20	5432	34.8	15.8	17.3934
8.32	20.5	5231	26.4	16.1	17.7846
8.12	25	5432	25.9	19.32	18.6522
8.21	23	5682	24.9	18.7	16.4101
8.26	23.5	5292	25.4	18.9	16.4805
8.19	25	5436	24.4	19.4	18.9564
8.13	22	5308	25.9	17.6	17.0734
8.19	25.2	5498	26.4	19.2	19.1028
8.24	24.8	5342	34.4	18.6	18.2139
8.2	21	5682	35.4	16.33	17.9133
8.23	22.5	5390	36.4	17.9	16.6279
8.21	25	5432	32.3	18.7	18.6565
8.32	25.2	5631	32.9	19.67	19.137
8.22	25	5281	33.9	18.8	18.625
8.17	26	4360	33.4	20.88	20.4276
8.14	25	4237	34.9	18.67	18.3971
8.11	25.8	4121	33.9	20.44	20.0286
8.106	30.8	4598	34.4	23.22	21.1161
8.124	31.5	4559	34.9	24.44	22.5619
8.128	30.5	4491	34.4	22.36	20.5794
8.178	31	4491	35.3	23.45	21.4873
8.026	31.2	4298	32.9	23.77	21.8547
8.122	26.5	4425	33.9	21.11	21.0736
8.114	25.5	4360	34.4	20.22	19.4937
8.124	31.2	4559	33.6	24.44	21.9158
8.132	31.5	4369	34.6	24.89	22.5212
8.01	28.5	4298	34.9	21.78	20.2851
8.22	30.5	4360	41.9	22.22	20.5555
8.21	30.5	4178	34.9	22.22	20.5156
8.126	31.5	4559	34.4	24.46	22.562
8.2	31	4425	34.4	23.67	24.6752
8.262	30.5	4360	35.9	22.38	20.5575
8.24	30.5	4464	35.9	22.34	20.5789
8.24	31	4335	34.9	23.03	21.4566
8.18	29	4298	34.4	21.78	19.8826
8.29	32	4280	34.2	24.67	23.539
8.26	32.2	4360	32.4	25.44	23.9154
8.21	31	4367	32.9	23.44	21.4621

The more variation is observed for the concrete of lower strength. To compare the actual value and the predicted value a regression analysis was performed using Excel .The regression model is shown in figure 3. The linear regression coefficient was found to be 0.9703 which is in good agreement.

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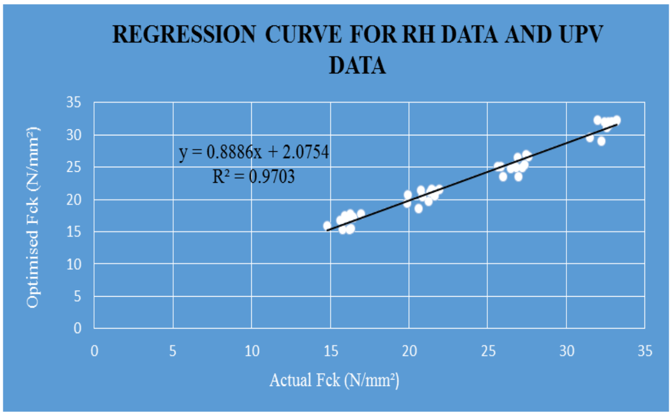

Figure 3. Regression Curve for RH Data and UPV Data

VI. Conclusion

Based on the experimental program and analysis of results following conclusion are drawn from the study :

1. The Genetic Programming technique is convenient and reliable tool for accurate prediction of cube compressive strength from NDT results. The proposed models provide good accuracy in order of 95.8464% using RH and 94.4597% involving RH and UPV values.
2. The regression coefficients 0.9721 and 0.9703 are obtained when RH values and RH & UPV values are considered respectively.
3. The proposed models showed higher accuracy for cubes of less than M30 Grade.
4. The errors from the empirical models are in order of 5.7825% (for RH values) and 6.2498% (for RH and UPV values), which are much less than the code specified value of ±25%.
5. The model involving only rebound value provides higher accuracy. This showed that UPV values are not reliable to predict the compressive strength.
6. The result prove that GP can work efficiently in predicting the compressive strength of concrete using non-destructive tests. Also from the results obtained it can be concluded that the GP can save a lot of computational effort compared to conventional methods significantly.

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