PREDICTION OF COMPRESSIVE STRENGTH USING GENETIC PROGRAMMING INVOLVING NDT RESULTS

A thesis submitted in partial fulfillment of the requirements for the degree of

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In

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By

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CERTIFICATE

This is to certify that this report entitled, **"PREDICTION OF COMPRESSIVE STRENGTH USING GENETIC PROGRAMMING INVOLVING NDT RESULTS**" submitted by **Prashant Kumar (111CE0462)** in partial fulfillment of the requirement for the award of Bachelor of Technology Degree in Civil Engineering at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision.

To the best of my knowledge, the matter embodied in this report has not been submitted to any other university/institute for the award of any degree or diploma.

Date :11/05/2015

Prof. Asha Patel
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(Research Guide)

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This project consumed huge amount of work, research and dedication. Still, implementation would not have been possible if I did not have a support of many individuals and organizations. Therefore I would like to extend our sincere gratitude to all of them.

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PRASHANT KUMAR

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ABSTRACT

Compressive strength of concrete is major parameter to assess the overall quality of concrete as other mechanical prosperities are directly related to the compressive strength. It can be determined using the destructive (DT) and non-destructive testing (NDT) methods. The destructive testing method is carried out by crushing the specimen to failure while the non-destructive is carried out without destroying the concrete specimen. The destructive method is time taking process and required equipment's and power. Whereas the NDT methods like the rebound (Schmitz) hammer and Ultrasonic Pulse velocity (UPV) are most popular because they are handy, quicker and easy to use. Though the NDT methods are much quicker; their values are more of an approximation than exact compressive strength values. They are also machine specific, hence a calibration curve is provided by supplier which may not be reliable. The Indian code recommends about 25% variation in results, which is very high. The newly developed soft computing techniques like ANN, Fuzzy logic, Genetic programming etc. may be used to prepare a better numerical model correlating DT and NDT results.

Hence the aim of the present study is to propose a model correlating the compressive strength obtained from destructive and non-destructive methods by using Genetic Programming. The whole work involves casting of 100 cubes of 150mm size belonging to of different grades of concrete. They were tested under compression following DT and NDT methods. These data were used for modelling ie.(70% for training and 30% for testing) in GP. The modelling is done two ways, first by using variables as weight and Rebound values and secondly by using weight, rebound values and UPV values. The models obtained were found to be in good agreement with actual values imparting 6.744 % and 7.4434% error respectively. To further check the efficiency of predictions Regression analysis were conducted for actual and predicted values and found to be in good agreement.

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INTRODUCTION

1.1 OBJECTIVE

The objective of the present work was to propose a model correlating the compressive strength obtained from destructive and non-destructive methods by using Genetic Programming. The whole work involves casting of 100 cubes of 150mm size belonging to of different grades of concrete. They were tested under compression following DT and NDT methods. These data were used for modelling in GP. 60 % data were for training and 30% for testing .The modelling is done in two steps, first by taking variables as weight and Rebound values and secondly by taking weight, rebound values and UPV values.

1.2 INTRODUCTION

WHAT IS NDT..?

Nondestructive testing (NDT) is a method to find indirectly the different parameters of hardened concrete like strength, durability and other elastic properties without loading the specimen till failure.

It is noted that the values obtained from NDT method are not so accurate. The error percentage are generally (30 to 40) % .Therefore these values need to be correlated with actual values obtained from destructive method by using compressive testing machine.

Therefore the main objective of this project is to develop an empirical relation between the values obtained by DT and NDT methods by the means of empirical equation developed by using GP. The variable involved in modelling are results obtained from NDT equipment's and weight of samples.

Instruments used are

1. REBOUND HAMMER
2. ULTRASONIC PULSE VELOCITY TESTER

(1) REBOUND HAMMER

DESCRIPTION: - Ernst Schmidt, a Swiss engineer, developed the modern rebound hammer in 1948.It is one of the most famous instrument for the Non-destructive testing of concrete specimen. Its popularity is due to its simplicity in using and also due to its low cost.

PRINCIPLE:-

It basically comprises of spring control hammer that slides on a plunger within the tubular housing. When the rebound hammer is pressed against the concrete specimen which is to be checked, the mass rebound from the plunger. This amount of rebound is measured which gives "REBOUND NUMBER". This rebound hammer is basically measured on a scale which is between 10 to 100.It basically measures the surface hardness of concrete. It is also known as impact hammer.

It depends upon the surface hardness as stated earlier. For any concrete specimen it shows different value of rebound number at different age of concrete. At early stage when concrete is weak and soft, it shows lesser value than when the concrete becomes strong and hard in later stage.

Factors on which rebound hammer depends:-

1. Hardness of surface
2. Size and shape of concrete specimen
3. Age of concrete
4. Presence of moisture in concrete
5. Carbonation
6. Types of cement and types of admixtures used
7. Location of reinforcement.
8. Type of coarse aggregate.

Since rebound hammer value depends upon so many factor, it is very necessary to use it as per standard procedure as given below.

1. The minimum area which is tested must be more than or equal to 150 mm.
2. The specimen should be properly fixed during testing.
3. The surface of specimen should be flat and no loose mortar should be present as it would affect the rebound value.
4. The surface to be tested must be completely dry that is free from moisture.
5. Frozen concrete should be avoided from testing.

6. The rebound hammer must be kept at right angle to the specimen as even a small inclination may vary the results considerably.
7. The cover over the reinforcement in the specimen should be more than 20 mm.
8. At least 10 reading must be taken for each specimen and the impact point should be at least 1 inch apart.
9. The average value of all the readings gives the rebound number for that specimen.

FIG- 1.1 REBOND HAMMER

(2)ULTRASONIC PULSE VELOCITY TESTER

Ultrasonic pulse velocity tester is a type of Non-destructive testing (NDT) equipment, which is used to determine the quality and homogeneity of concrete. It determines the quality and homogeneity of concrete by detecting cracks, flaws etc., within the specimen. From this equipment two parameters ultrasonic velocity and time of travel of ultrasonic waves through the specimen are determined.

PRINCIPLE:-

It consists of generation of ultrasonic pulse produced by an electro-acoustical transducer, held in contact with one surface of the concrete member under test and receiving the same by a similar transducer in contact with the surface at the other end. With the path length (L) and time of travel (T), the velocity of pulse (V) is measured (V=L/T).higher the velocity of pulse better is the quality of concrete in terms of quality, homogeneity and density.

PROCEDURE:-

1. First the specimen to be tested is cleaned properly to make it free from dust or other impurities.
2. Then grease is applied to the two opposite faces of cube and transducers are pressed hard on the surface of greased material.
3. Transducers are held fixed during measurement as even a slight movement could vary the results.
4. Transducers are held till the reading on the machine becomes constant.
5. Two reading i.e. velocity (m/s) and time (microsecond) is noted down.

Pulse velocity is affected by:-

1. Path length
2. Lateral dimension of specimen tested
3. Presence of reinforcing steel
4. Presence of moisture in concrete.

Pulse velocity is not affected by path length unless the path length is less than 100 mm when 20mm aggregate is used and 150mm when 40mm aggregate is used In reinforcing bars the velocity of wave is more than in concrete. Therefore presence of bars can lead to wrong values. Presence of moisture leads to variation in pulse velocity, Higher the moisture content more will be the velocity.

Table: 1 – General Guidelines for Concrete Quality based on UPV

PULSE VELOCITY	CONCRETE QUALITY
>4.0 km/s	Very good to excellent
3.5 – 4.0 km/s	Good to very good, slight porosity may exist
3.0 – 3.5 km/s	Satisfactory but loss of integrity is suspected
<3.0 km/s	Poor and los of integrity exist.

FIG-1.2 ULTRASONIC SONIC PULSE VELOCITY TESTER

1.3 GENETIC PROGRAMMING

Genetic programming is a model of programming which uses the ideas (and some of the terminology) of biological evolution to handle a complex problem. Genetic programming can be viewed as an extension of the *genetic algorithm*, a model for testing and selecting the best choice among a set of results, each represented by a string.

In this work Genetic Programming (GP) is used to predict an empirical model for the convoluted non-straight relation between the actual compressive strength obtained by compressive testing machine with the result obtained by NDT methods. It is a manifestation of artificial intelligence and thoughts, which is focused around the Darwinian hypothesis of evolution and genetics.

CHAPTER ~ 2

LITERATURE REVIEW

- Turgut.P (2004) has done the study on correlation between ultrasonic pulse velocity values and actual compressive strength. The data was obtained from many cores taken from different reinforced concrete structures having different ages and unknown ratios of concrete mixtures. The main motive of his work was to develop the formula which correlates between the actual data and UPV values without taking the mix ratio in consideration. He concluded that the value of UPV increases with increase in compressive strength of concrete. He also stated that ultra-sonic test on the higher strength concrete is more reliable. Rebound values gives more precise and correct values as compared to UPV values under certain conditions. Also it is always advisable to go for combined results of both the NDT test as this gives more trustworthy results.
- Shariati M et al. (2011) paper gave a relation between the actual compressive strength of a structure in compression test with that of NDT (Non Destructive Test) values. The NDT test has been done to test the quality of concrete structure and the correlation is done using regression analysis method between test values and actual in situ value of compressive strength of structure. The members of structure which is tested id Beams, Column and Slabs. The values obtained from the crashing records of specimen is compared with the test values to examine the variation in both the results. The result finally shows that Rebound Hammer test is more efficient in predicting the result under certain condition. But the application of the combined results of both NDT test provide more reliable results.
- Sbartai Zoubir-mehdi (2012) presented a paper which deals with the strategy employed and the first results obtained from a comprehensive experimental database of NDT techniques. It also emphasizes how the variability of measurements can be taken into account and how statistical analyses can be used to evaluate the relevance of the available NDT techniques. He stated that the degree of complementarity between NDT techniques was quantified using Principal Component Analysis. Several combinations have been identified which appear to be very relevant, when porosity and water saturation have to be evaluated.
- Shankar Siddharth et al. (2010) had done the research which deals with the comparison of actual compressive strength of cubes with those of NDT values. The methodology used in this research work is laboratory works and experiments based. The research was done on various samples of concrete cubes and cylindrical cubes. They concluded that the results of NDT values should always be compared with the actual compressive strength and the best value should be taken as final estimate. And also the NDT test should always be performed with two NDT equipment and the best out of them should be taken as final value.

CHAPTER ~ 3

METHEDOLOGY

The steps followed were

- Mix Design of concrete of different grades ranging from M15 to M40 following .
- Casting of standard cubes of 150mm size for different grades of concrete.
- Testing of cubes after 7 days, 28 days,90 days by using NDT equipments following testing under compression testing machine till failure.
- The observed data i.e. rebound value, velocity, weight, actual compressive strength were used for the analysis in Matlab through its tool Genetic Programming.
- Through genetic programming the difference in NDT values and actual values are optimized to generate an empirical model which could correlate them.

CHAPTER ~ 4

EXPERIMENTAL PROGRAMME

4.1 METHODS FOLLOWED:-

- Firstly cube(150*150*150) of different proportions have been cast using Mix design(IS 10262-2009):-
- The cubes were cast for concrete of following proportions obtained from mix design. To get mixes of higher strength various proportions of cement is replaced by silica fume.
    1. 1:1.7:3.4
    2. 1:1.5:3
    3. 1:1.3:2.6
    4. 1:1.1:2.2
    5. 1:1:2
    6. 1:1.3:2.6 with 5% replacement of cement by silica fume.
    7. 1:1.1:2.2 with 5% replacement of cement by silica fume.
    8. 1:1:2 with 7% replacement of cement by silica fume.
    9. 1:1:2 with 10% replacement of cement by silica fume.
- The cubes were tested by using NDT equipments and Compressive testing machine. The observed values are given in table 4.1 to 4.9.

TABLE 4.1-MIX PROPORTION – 1:1.7:3.4

SL NO.	WEIGHT(KG)	ACTUAL Fcu(N/mm^2)	REBOUND HAMMER	VELOCITY (m/s)
1	8.2	14.43	30	4321
2	8.12	14.8	32.2	4223
3	8.23	14.3	31.9	4312
4	8.28	14.67	30.1	4518
5	8.33	17.33	34.9	4425
6	8.29	15.11	32.6	4298
7	8.20	23.11	38	6024
8	8.23	26.67	39	5682
9	8.28	26.67	41.1	5792
10	8.22	21.78	41.2	5906

TABLE 4.2-MIX PROPORTION – 1:1.5:3

SL NO.	WEIGHT(KG)	ACTUAL Fcu(N/mm^2)	REBOUND HAMMER	VELOCITY (m/s)
1	8.18	15.8	31.6	5432
2	8.32	16.1	35.5	5231
3	8.12	19.32	31.4	5432
4	8.21	30.22	40	5682
5	8.26	32	41.6	5792
6	8.19	29.33	37.5	6024
7	8.13	31.11	43.3	5906
8	8.19	32	39.8	6148
9	8.24	27.11	42.5	5792
10	8.20	30.67	40.3	5682
11	8.23	29.87	38.21	5790
12	8.21	28.33	39.77	5432

TABLE 4.3-MIX PROPORTION – 1:1.3:2.6

SL NO.	WEIGHT(KG)	ACTUAL Fcu(N/mm^2)	REBOUND HAMMER	VELOCITY (m/s)
1	8.17	20.88	32.8	4360
2	8.14	18.67	33.6	4237
3	8.11	20.44	33.8	4121
4	8.106	26.22	35.8	4598
5	8.124	24.44	39	4559
6	8.128	25.33	36	4491
7	8.178	32	37.33	4491
8	8.026	29.77	38.20	4298
9	8.122	31.11	36.90	4425
10	8.114	30.22	37.80	4360
11	8.124	24.44	39	4559

TABLE 4.4-MIX PROPORTION – 1:1.1:2.2

SL NO.	WEIGHT(KG)	ACTUAL Fcu(N/mm^2)	REBOUND HAMMER	VELOCITY (m/s)
1	8.01	21.78	32.7	4298
2	8.22	22.22	34	4360
3	8.21	22.22	37.9	4178
4	8.126	28.44	41.7	4559
5	8.20	30.67	36.7	4425
6	8.262	28.44	38.5	4360
7	8.246	32.44	41.4	4464
8	8.242	33.03	41.8	4335
9	8.186	31.78	39.4	4298
10	8.298	30.67	40.7	3580
11	8.262	28.44	38.5	4360

TABLE 4.5-MIX PROPORTION – 1:1.3:2.6(HSC SILICA 5%)

SL NO.	WEIGHT(KG)	ACTUAL Fcu(N/mm^2)	REBOUND HAMMER	VELOCITY (m/s)
1	7.48	28.89	42.5	4298
2	7.6	32	40.1	4360
3	7.66	32	40.1	4360
4	7.86	26.22	39.2	4178
5	7.84	32.88	39.3	4178
6	7.64	27.55	40.1	4298
7	7.86	29.33	40	4360
8	7.94	27.11	41.7	4386
9	7.86	26.22	39.2	4178
10	7.88	27.31	40.32	4352
11	7.83	28.36	38.8	4288

TABLE 4.6-MIX PROPORTION – 1:1.1:2.2(HSC SILICA 5%)

SL NO.	WEIGHT(KG)	ACTUAL Fcu(N/mm^2)	REBOUND HAMMER	VELOCITY (m/s)
1	8.14	34.22	37.5	4630
2	8.22	38.22	39.9	4559
3	8.14	35.55	38.7	4464
4	8.36	36.22	40.3	4559
5	8.26	34.66	39.3	4587
6	8.28	36.88	38.8	4630
7	8.28	37.33	42.5	4559
8	8.29	36.2	41.7	4386
9	8.36	36.22	40.3	4559
10	8.31	37.21	42.36	4667
11	8.28	36.88	38.8	4630

TABLE 4.7-MIX PROPORTION – 1:1:2(HSC SILICA 5%)

SL NO.	WEIGHT(KG)	ACTUAL Fcu(N/mm^2)	REBOUND HAMMER	VELOCITY (m/s)
1	8.28	35.55	41.6	4274
2	8.26	35.55	40.8	4491
3	8.24	34.22	42.5	4425
4	8.22	40.44	40.3	4386
5	8.32	36.44	42	4261
6	8.26	33.77	41	4335
7	8.36	36.44	41	4312
8	8.16	39.55	40.1	4518
9	8.26	33.77	41	4335
10	8.24	34.22	42.5	4425
11	8.27	33.78	39.56	4478

TABLE 4.8-MIX PROPORTION – 1:1:2

SL NO.	WEIGHT(KG)	ACTUAL Fcu(N/mm^2)	REBOUND HAMMER	VELOCITY (m/s)
1	8.13	38.6	35.6	4630
2	8.28	38.6	35.78	4630
3	8.27	35.11	36	4464
4	8.164	32.88	36.8	4298
5	8.201	31.11	36.7	4360
6	8.212	30.22	32.7	4237
7	8.24	41.77	34	4491
8	8.242	42.22	37.9	4518
9	8.18	41.77	41.7	4399
10	8.29	39.7	36.7	4580
11	8.24	41.77	34	4491

TABLE 4.9-MIX PROPORTION – 1:1:2(HSC 10% SILICA)

SL NO.	WEIGHT(KG)	ACTUAL Fcu(N/mm^2)	REBOUND HAMMER	VELOCITY (m/s)
1	8.28	47.55	45.7	4559
2	8.214	47.55	44	4587
3	8.239	46.66	47.9	4601
4	8.27	40.44	41.7	4360
5	8.22	40.88	46.7	4559
6	8.281	38.92	48.5	4532
7	8.26	39.11	41.4	4630
8	8.263	40	41.8	4360
9	8.25	35.55	39.4	4491
10	8.258	39.7	40.7	4580
11	8.213	39.11	41.4	4630

4.2 GENETIC PROGRAMMING:-

GP is a domaininant 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 GP 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: it is a recombination technique, where two parent results are picked and parts of their sub-tree are exchanged in light of fact that each function holds the property 'closure' (each tree member can transform all possible argument values), every crossover operation ought to bring a legal structure. It follows the following principle:

1. Two trees are selected from the population lot.
2. One node is randomly selected from each trees
3. Selected nodes sub trees are exchanged to bring two children of new population

MUTATION: it is responsible for irregular changes in a tree before it is brought into the next population. Dissimilar to crossover, it is a biogenetic and works on one single individual. Throughout mutation process either all functions or terminals are separated underneath 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 as the structures that experiences adaptation are

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

FLOWCHART:-

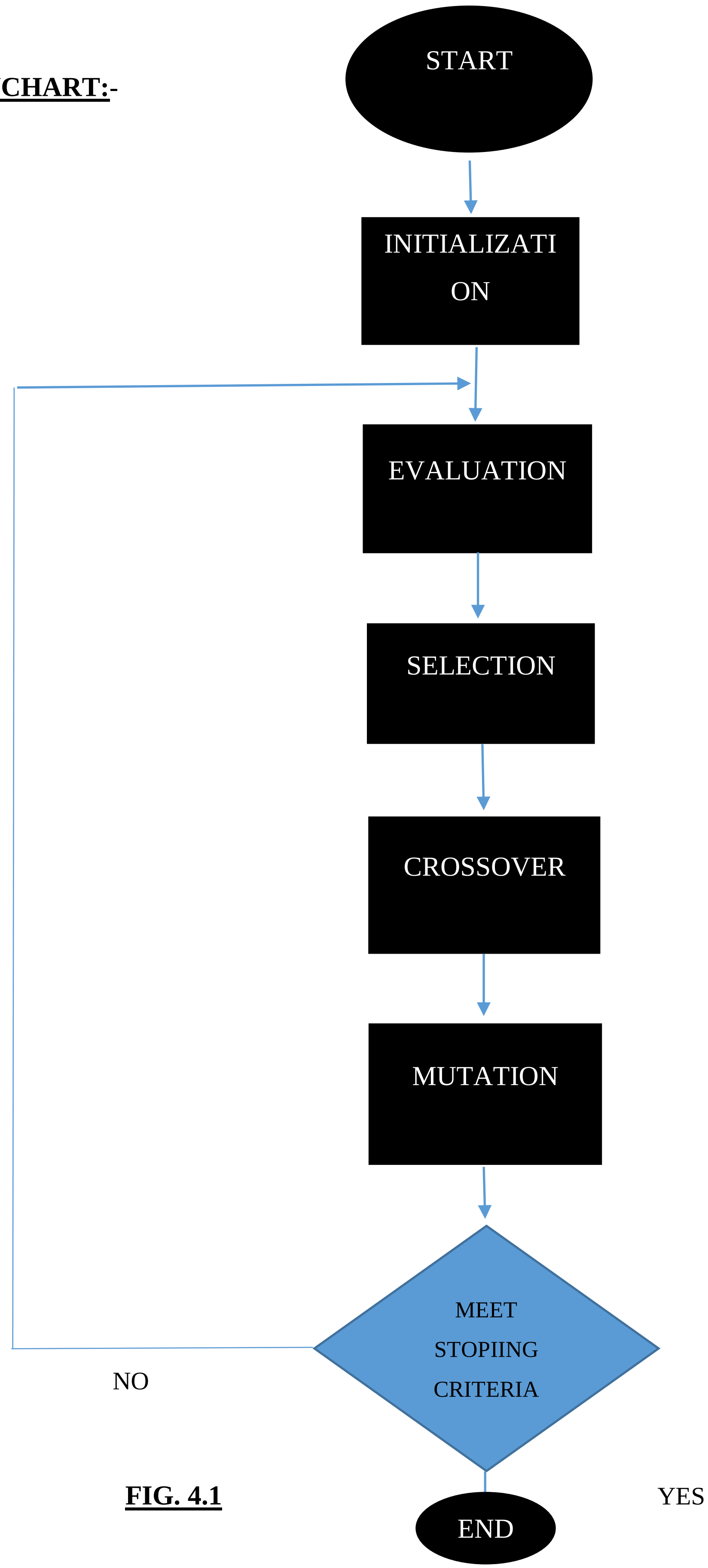

FIG. 4.1

Following above principle, an empirical model was generated which selected the most fittest chromosomes to obtain the optimized result.it used about 60% of test data for training and rest 40% data was used for testing.

The modelling is done in two sets

1. Two variables weight and rebound values were involved in modelling.
2. Three variables weight, rebound values and UPV values were involved in modelling

CHAPTER ~ 5

MODELLING USING GENETIC PROGRAMMING (GP)

5.1 MATLAB MODEL:-

Genetic programming, a tool in Matlab was used for correlating the values of actual compressive strength using destructive test with the NDT values obtained by rebound hammer and ultrasonic pulse velocity tester. Here the difference in values obtained using both DT and NDT 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 :-

5.2 PROCEDURAL STEPS FOR MODELLING

5.2.1 MODELLING FOR REBOUND HAMMER DATA-

In modelling 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 from table 4.1 to 4.8 for analysis and specifying training data and test data.

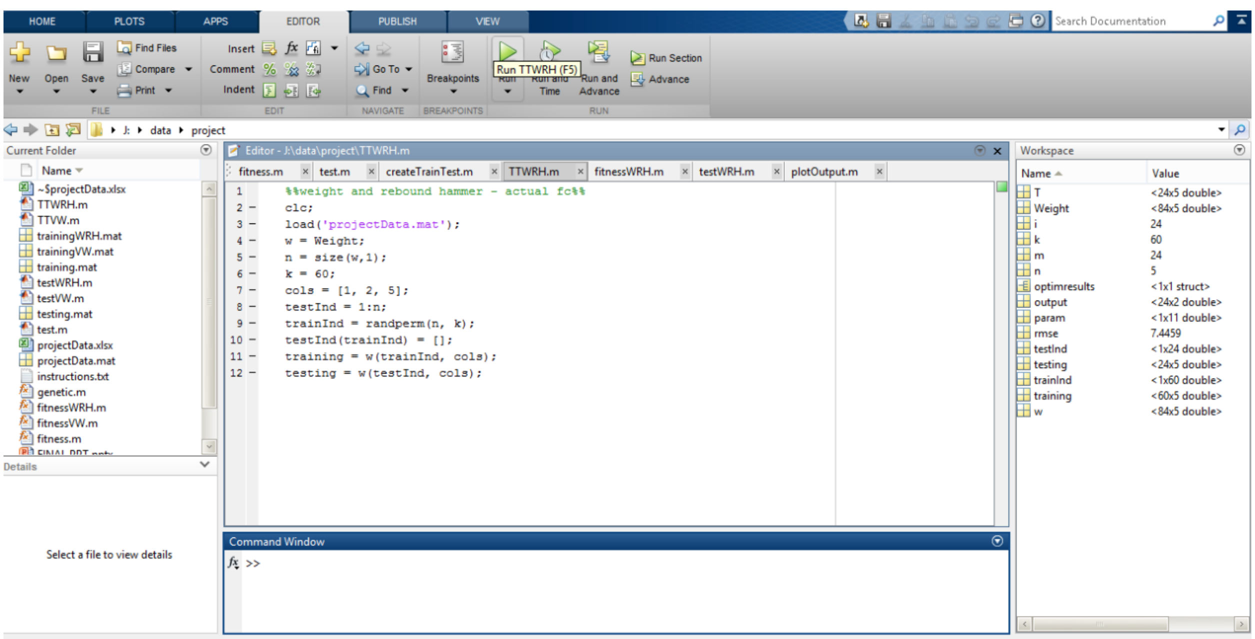

Fig 5.1

STEP 2- Apps ⟶ Optimisation tool ⟶ Solver ⟶ Genetic Algorithm

It is optimizing the values of specified chromosomes as per the specified operators.

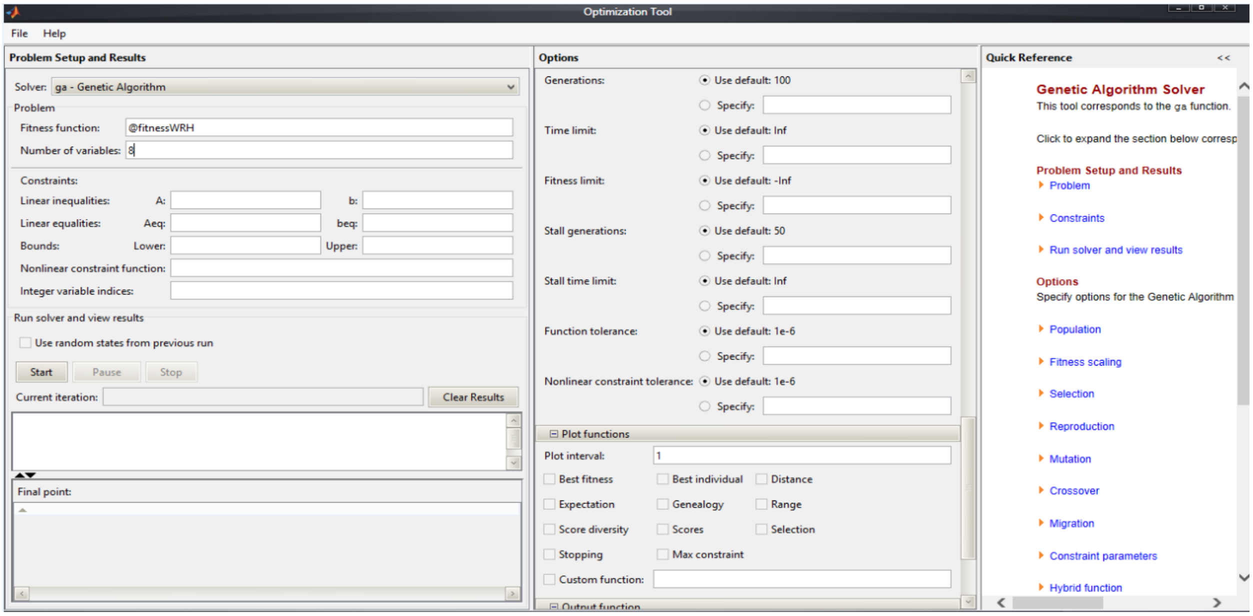

Fig 5.2

STEP 3- fitness function ⟶ @fitnessWRH ⟶ No. of variables ⟶ 8 ⟶ start

Fittest value of chromosomes were obtained.

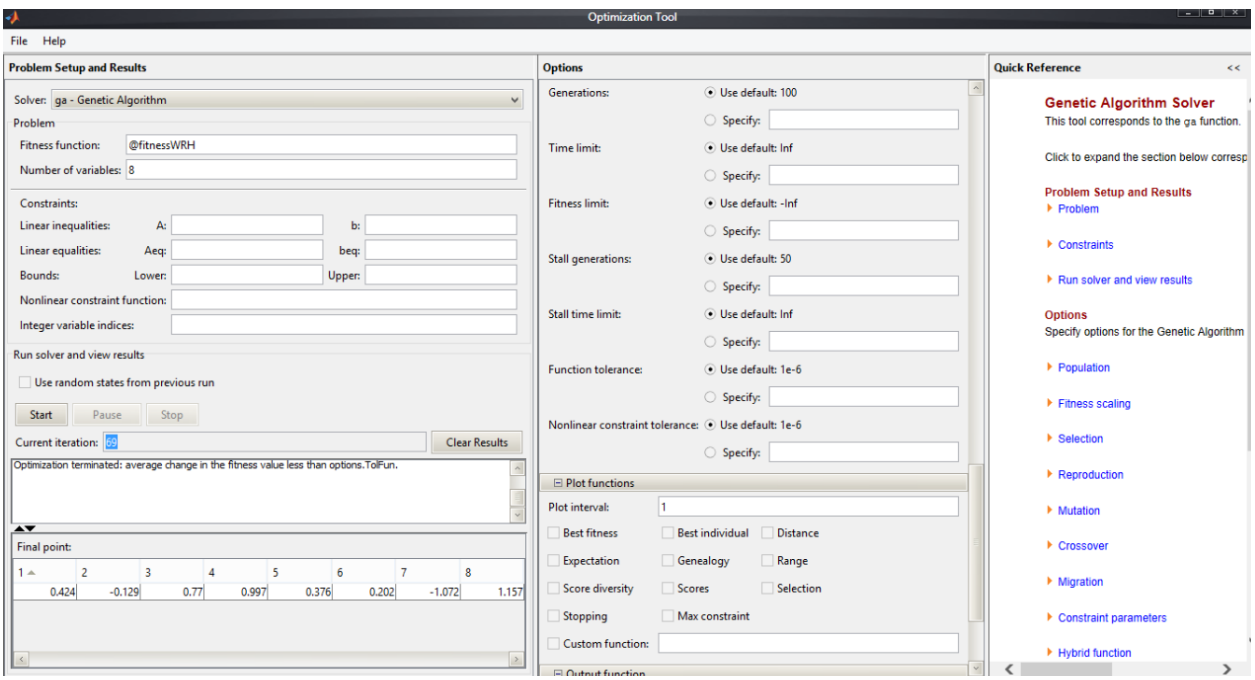

Fig 5.3

STEP 4-File ⟶ Export to workspace ⟶ Export to a MATLAB structured named ⟶ ok

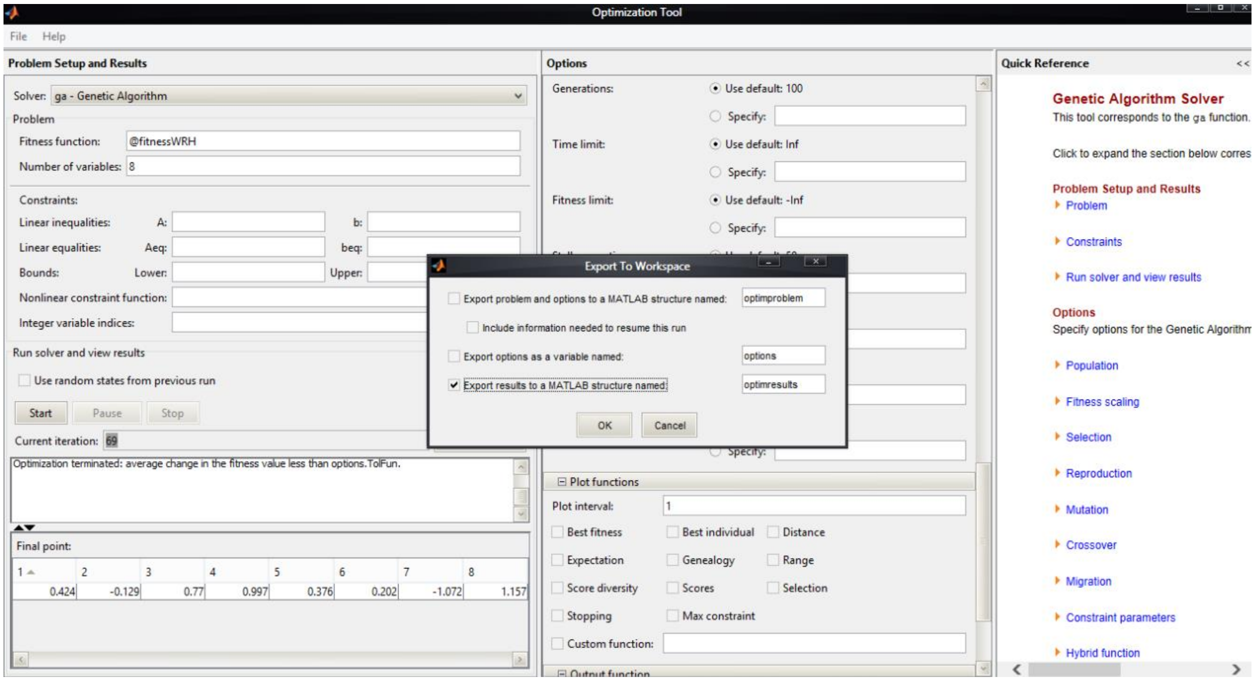

Fig 5.4

STEP 5- Editor ⟶ testWRH.m

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

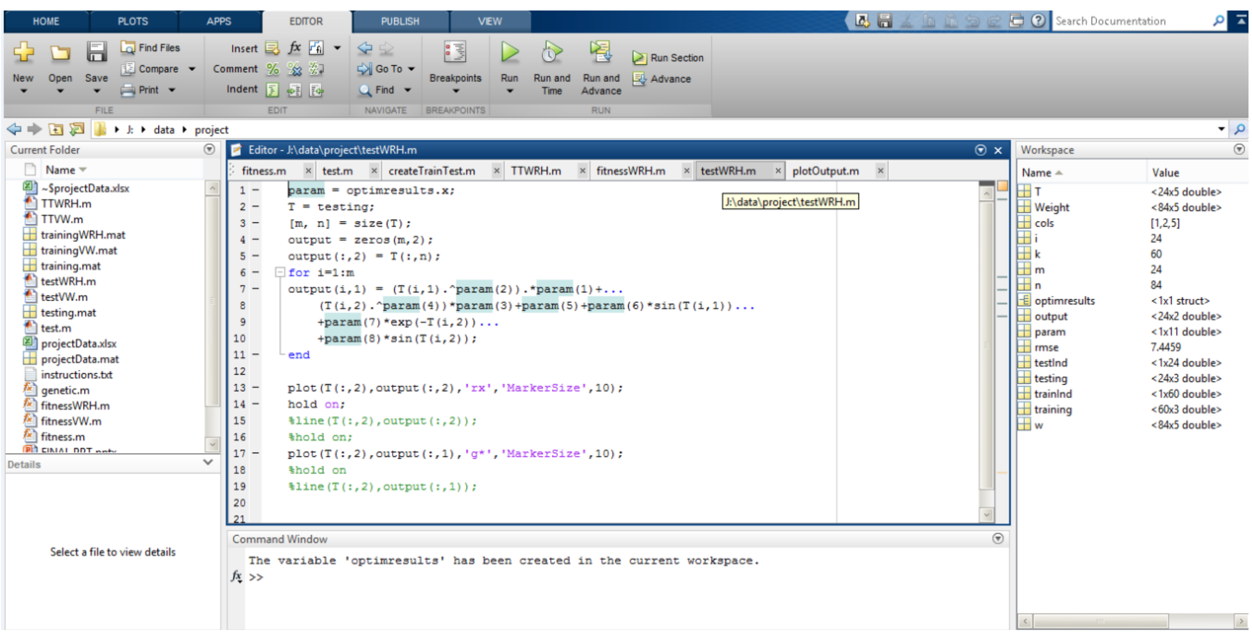

Fig 5.5

STEP 6- Run

The testing data were checked and Root mean square error was found to be 6.744%

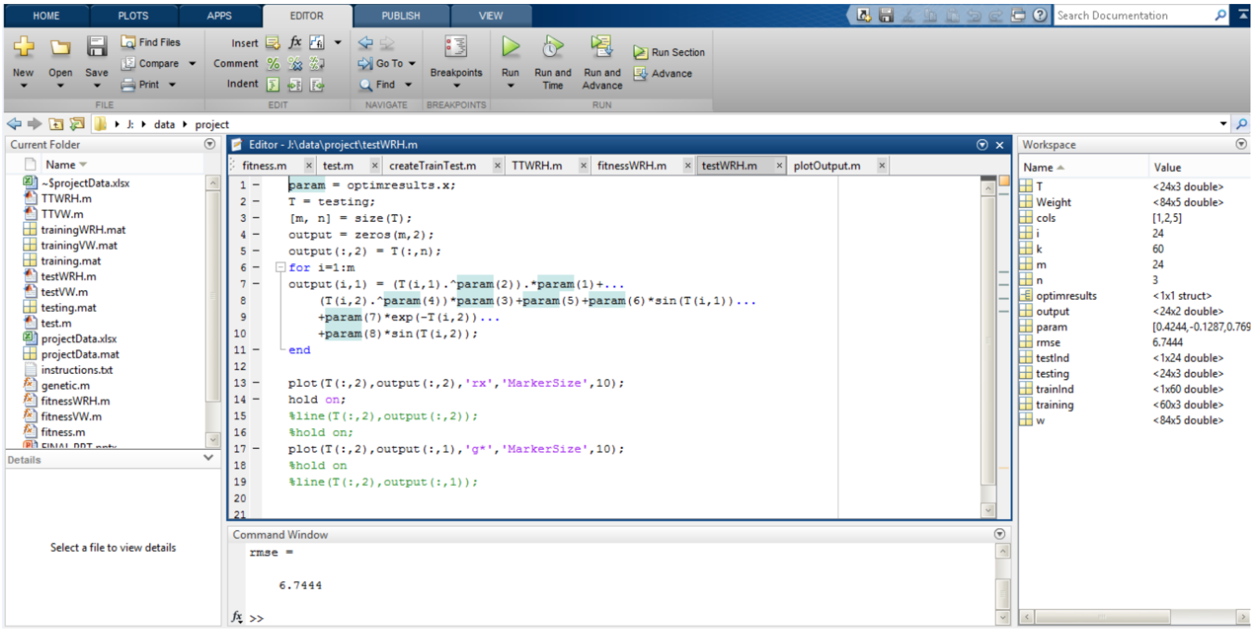

Fig 5.6

5.2.2 MODELLING FOR REBOUND HAMMER & ULTRASONIC PULSE VELOCITY DATA-

STEP 1- Same procedure is followed here

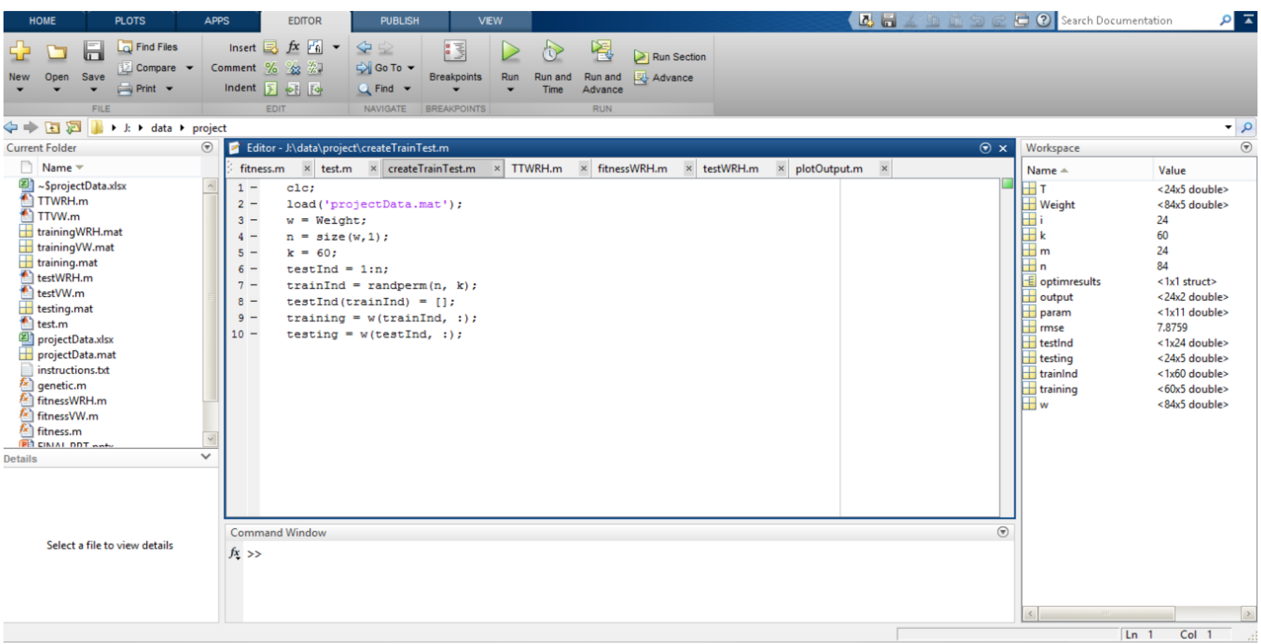

Fig 5.7

STEP 2- Apps ⟶ Optimisation tool ⟶ Solver ⟶ Genetic Algorithm

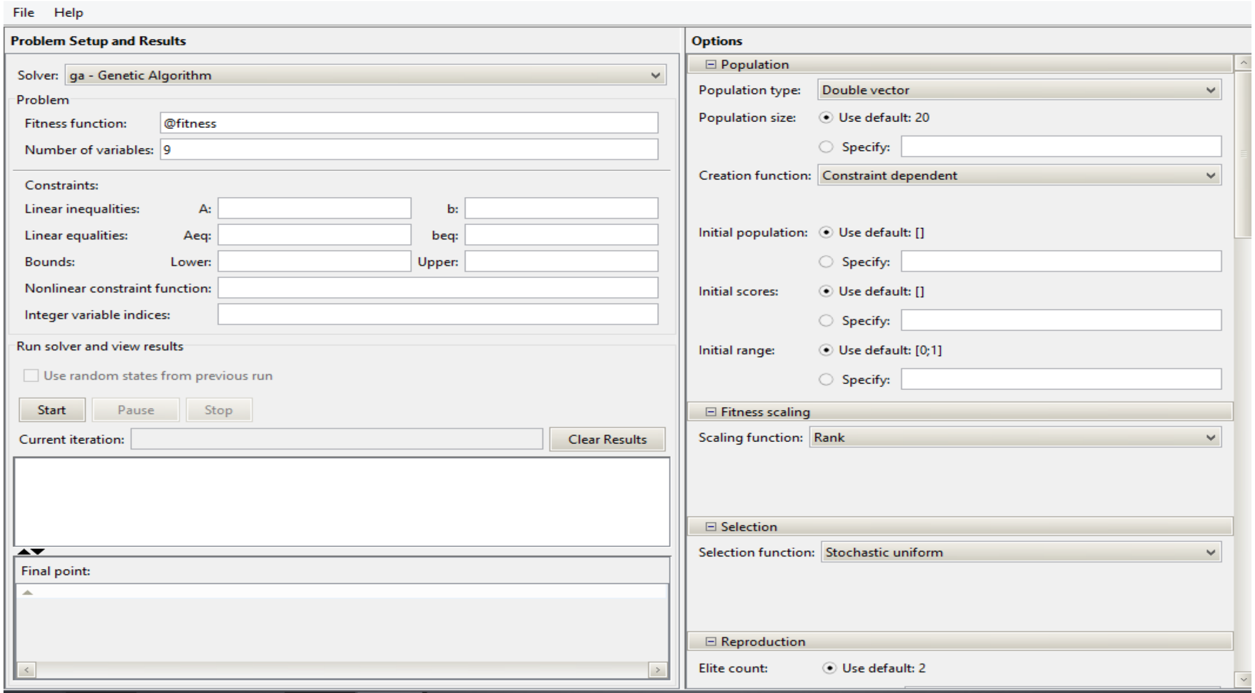

Fig 5.8

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

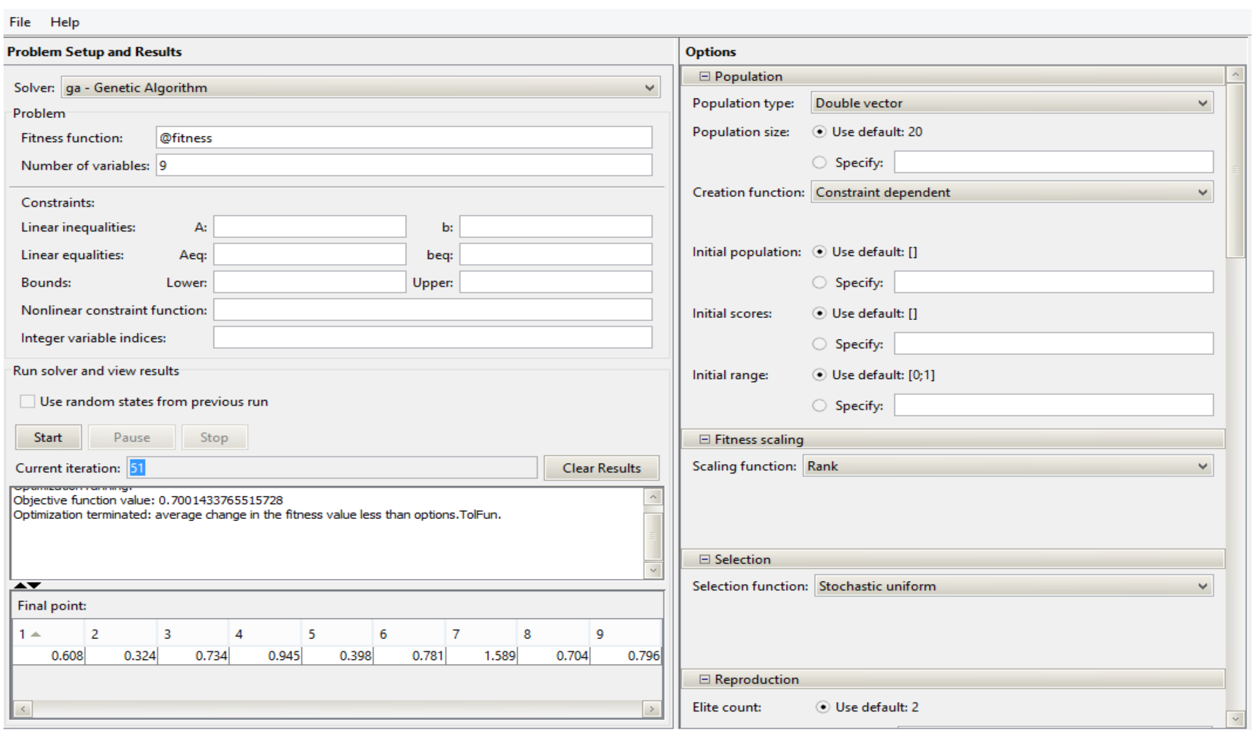

Fig 5.9

STEP 4- File ⟶ Export to workspace ⟶ Export to a MATLAB structured named ⟶ ok

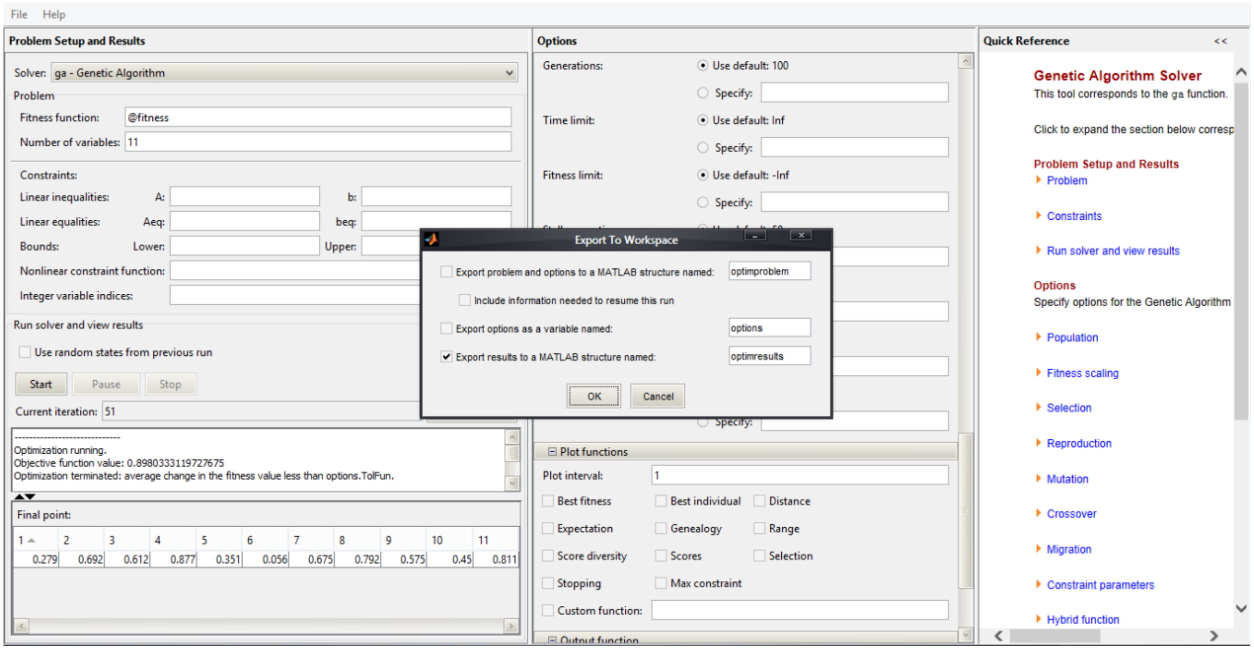

Fig 5.10

STEP 5- Editor ⟶ test.m

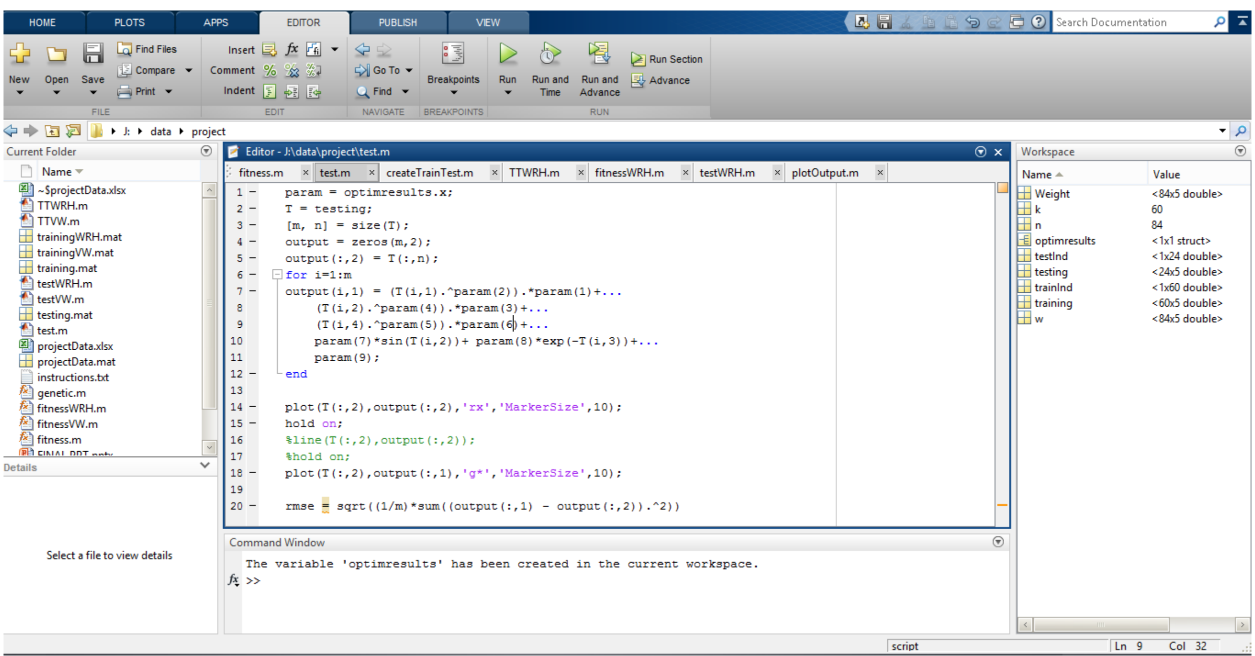

Fig 5.11

STEP 6- Ok

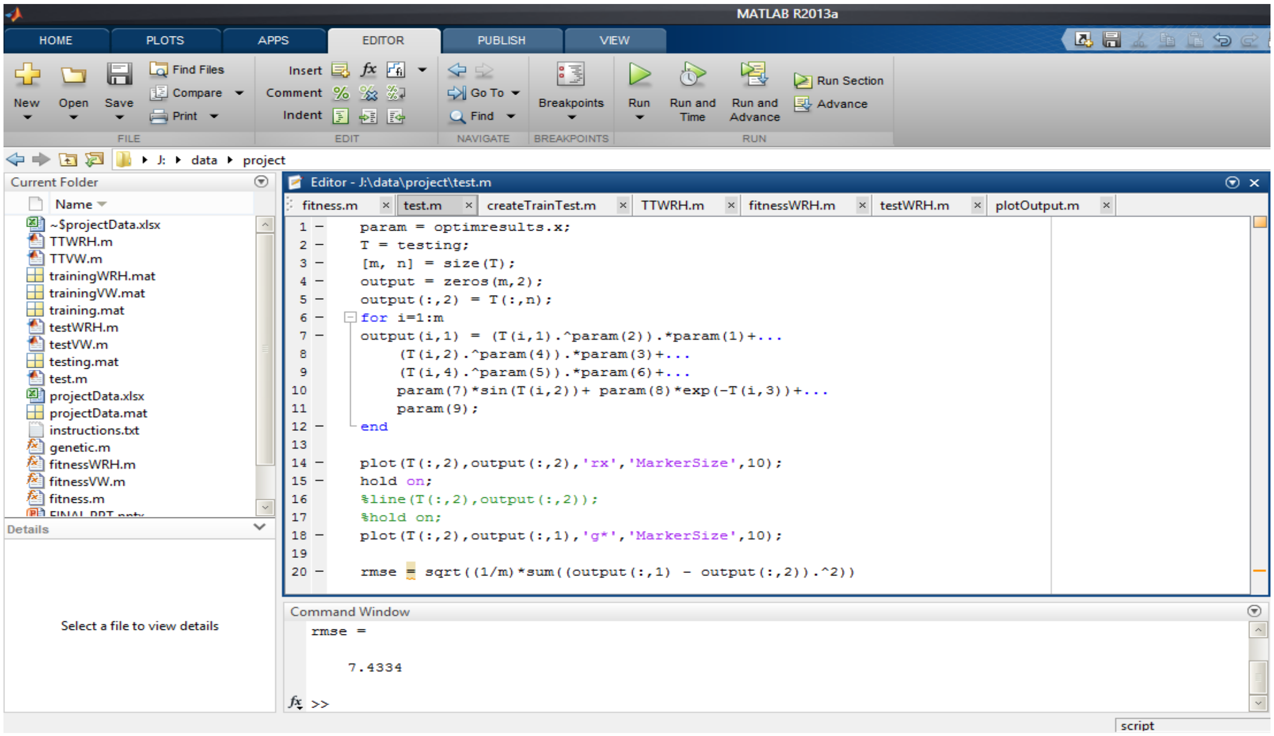

Fig 5.12

CHAPTER ~ 6

RESULTS AND DISCUSSIONS

6.1 EMPIRICAL EQUATION:-

6.1.1 EMPRICAL EQUATION RELATING REBOUND HAMMER VALUE WITH ACTUAL

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,

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

The rmse (root mean square error) obtained after optimization = 6.774%

The effectiveness of proposed model is summarized below in Table 6.1

PREDICTED RESULTS FOLLOWING PROPOSED MODEL

TABLE 6.1

WEIGHT	RH	Actual f_{ck}	Predicted f_{ck}
8.2	30	14.43	21.61158
8.12	32.2	14.8	22.24864
8.23	31.9	14.3	23.73456
8.28	30.1	25.67	25.70461
8.33	34.9	17.33	27.07767
8.29	32.6	15.11	20.79439
8.2	38	23.11	27.17456
8.23	39	26.67	28.70381
8.28	41.1	26.67	27.88225
8.22	41.2	21.78	27.85298
8.18	31.6	15.8	22.18368
8.32	35.5	23.1	26.98687
8.12	39.4	19.32	23.04721
8.21	40	30.22	32.21161
8.26	41.6	32	31.76373
8.19	37.5	29.33	29.22385
8.13	43.3	31.11	33.13056
8.19	39.8	32	32.19735
8.24	42.5	27.11	32.09263
8.2	40.3	30.67	32.17359
8.17	32.8	20.88	27.02117
8.14	33.6	20.67	23.44011
8.11	33.8	20.44	27.44266
8.106	35.8	26.22	27.0718
8.124	39	24.44	27.71115
8.128	36	25.33	27.17014
8.178	37.33	32	28.90702
8.026	38.2	29.77	30.54902

8.122	36.9	31.11	28.17223
8.114	37.8	30.22	29.80194
8.01	32.7	21.78	26.92645
8.22	34	22.22	27.40438
8.21	37.9	22.22	25.98585
8.126	41.7	28.44	31.76952
8.2	36.7	30.67	27.87142
8.262	38.5	28.44	31.03711
8.246	41.4	32.44	31.79567
8.242	41.8	33.03	31.76621
8.186	39.4	31.78	32.04294
8.298	40.7	30.67	32.03587
7.48	42.5	28.89	32.09758
7.6	40.1	32	32.21562
7.66	40.1	32	32.21798
7.86	39.2	26.22	31.91077
7.84	39.3	32.88	31.98909
7.64	40.1	27.55	29.21727
7.86	42	29.33	31.82196
7.94	41.7	27.11	26.77717
8.14	37.5	30.22	29.2272
8.22	39.9	38.22	32.20765
8.14	38.7	35.55	31.34141
8.36	40.3	36.22	33.15944
8.26	39.3	34.66	31.9705
8.28	38.8	36.88	31.46424
8.28	42.5	37.33	32.08923
8.29	41.7	36.2	31.75722
8.28	41.6	35.55	31.762
8.26	40.8	35.55	31.99997
8.24	42.5	34.22	32.09263

8.22	40.3	40.44	37.17208
8.32	42	36.44	31.79805
8.26	41	33.77	31.9212
8.36	41	36.44	31.9118
8.16	40.1	39.55	32.20973
8.01	32.7	38.6	30.92645
8.22	34	38.6	33.40438
8.21	37.9	35.11	29.98585
8.126	41.7	32.88	31.76952
8.2	36.7	31.11	27.87142
8.262	38.5	30.22	31.03711
8.246	41.4	40.77	36.79567
8.242	41.8	36.22	33.76621
8.186	39.4	35.77	31.04294
8.298	40.7	39.7	32.03587
8.28	45.7	47.55	36.8151
8.214	44	47.55	39.40622
8.239	47.9	46.66	36.5331
8.27	41.7	40.44	35.75899
8.22	46.7	40.88	35.91034
8.281	48.5	38.92	36.66017
8.26	41.4	39.11	31.7945
8.263	41.8	40	35.76446
8.25	39.4	35.55	32.03802
8.258	40.7	39.7	32.03939

The more variation is observed for the concrete of lower strength.To compare the actual value and the predicted value a regression ananlysis was performed using Excel .The regression model is shown in fig. 6.1. The linear regression coefficient was found to be 0.9569 which is in good agreement

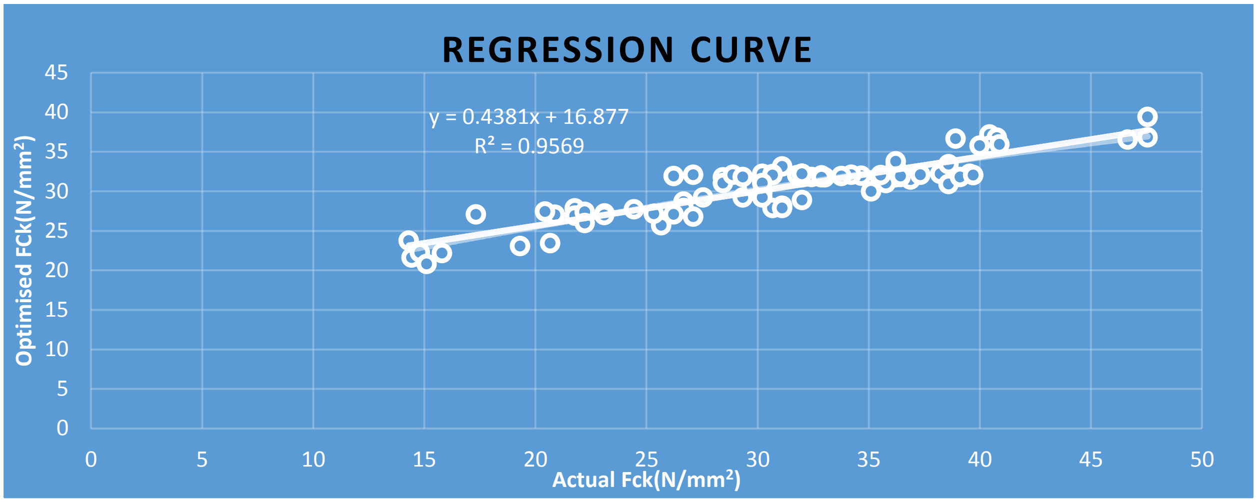

Fig 6.1 Regression curve for Rh data

6.1.2 EMPRICAL EQUATION RELATING REBOUND HAMMER & ULTRASONIC PULSE VELOCITY VALUES WITH ACTUAL

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

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,

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

The Root mean square error obtained after optimization = 7.4334%

PREDICTED RESULTS FOLLOWING PROPOSED MODEL

TABLE 6.2

WEIGHT	RH	VELOCITY	TIME	Actual f_{ck}	Predicted f_{ck}
8.2	30	4321	34.2	14.43	25.15644592
8.12	32.2	4223	33.6	14.8	26.74137311
8.23	31.9	4312	33.2	14.3	26.40651042
8.28	30.1	4518	33.2	14.67	24.95571518
8.33	34.9	4425	33.9	17.33	27.18276204
8.29	32.6	4298	34.9	15.11	25.35879159
8.2	38	6024	24.9	23.11	27.22824088
8.23	39	5682	26.4	26.67	27.36409748
8.28	41.1	5792	25.9	26.67	27.24847296
8.22	41.2	5906	25.4	21.78	27.08615968
8.18	31.6	5432	31.4	15.8	25.67408319
8.32	35.5	5231	34.3	16.1	27.22540447
8.12	39.4	5432	34.8	19.32	26.71031449
8.21	40	5682	26.4	30.22	27.57782166
8.26	41.6	5792	25.9	32	29.16783552
8.19	37.5	6024	24.9	29.33	28.7713884
8.13	43.3	5906	25.4	31.11	27.62787209
8.19	39.8	6148	24.4	32	29.03214768
8.24	42.5	5792	25.9	27.11	27.29388604
8.2	40.3	5682	26.4	30.67	27.54658709
8.17	32.8	4360	34.4	20.88	27.32164625
8.14	33.6	4237	35.4	18.67	26.75735572
8.11	33.8	4121	36.4	20.44	26.00181762
8.106	35.8	4598	32.3	26.22	26.70865587
8.124	39	4559	32.9	24.44	27.06423478
8.128	36	4491	33.9	25.33	27.16634272
8.178	37.33	4491	33.4	32	27.86393389

8.026	38.2	4298	34.9	29.77	29.01420844
8.122	36.9	4425	33.9	31.11	27.63380724
8.114	37.8	4360	34.4	30.22	28.540276
8.01	32.7	4298	34.9	21.78	27.38440958
8.22	34	4360	34.4	22.22	27.48423953
8.21	37.9	4178	35.3	22.22	26.86967444
8.126	41.7	4559	32.9	28.44	28.99437739
8.2	36.7	4425	33.9	30.67	27.50135566
8.262	38.5	4360	34.4	28.44	29.15021508
8.246	41.4	4464	33.6	32.44	29.21498527
8.242	41.8	4335	34.6	33.03	29.44025027
8.186	39.4	4298	34.9	31.78	29.73513161
8.298	40.7	3580	41.9	30.67	27.44720853
7.48	42.5	4298	34.9	28.89	27.57387248
7.6	40.1	4360	34.4	32	29.60456404
7.66	40.1	4360	34.4	32	29.61075909
7.86	39.2	4178	35.9	26.22	27.89080324
7.84	39.3	4178	35.9	32.88	29.92407541
7.64	40.1	4298	34.9	27.55	27.73610785
7.86	42	4360	34.4	29.33	29.36204973
7.94	41.7	4386	34.2	27.11	27.30894125
8.14	37.5	4630	32.4	34.22	29.75471241
8.22	39.9	4559	32.9	38.22	29.29172576
8.14	38.7	4464	33.6	35.55	29.07302601
8.36	40.3	4559	32.9	36.22	29.27354748
8.26	39.3	4587	32.7	34.66	29.14954866
8.28	38.8	4630	32.4	36.88	28.84108928
8.28	42.5	4559	32.9	37.33	29.14372633
8.29	41.7	4386	33	36.2	29.03555786
8.28	41.6	4274	35.2	35.55	29.60396292

8.26	40.8	4491	33.4	35.55	29.28967637
8.24	42.5	4425	33.9	34.22	29.39644461
8.22	40.3	4386	34.2	40.44	29.5929236
8.32	42	4261	35.2	36.44	29.61237372
8.26	41	4335	34.7	33.77	29.57561834
8.36	41	4312	35.3	36.44	29.73862254
8.16	40.1	4518	33.4	39.55	29.40604531
8.01	32.7	4630	34.9	38.6	28.38675099
8.22	34	4630	34.4	38.6	28.48613101
8.21	37.9	4464	35.3	35.11	28.87175421
8.126	41.7	4298	32.9	32.88	28.99252307
8.2	36.7	4360	33.9	31.11	28.95008904
8.262	38.5	4237	34.4	30.22	29.14931646
8.246	41.4	4491	33.6	41.77	29.21517506
8.242	41.8	4518	34.6	42.22	29.4415508
8.186	39.4	4399	34.9	41.77	29.73586147
8.298	40.7	4580	41.9	39.7	29.45491827
8.28	45.7	4559	35.9	47.55	31.13174378
8.214	44	4587	34.8	47.55	30.71499768
8.239	47.9	4601	34.1	46.66	31.43271353
8.27	41.7	4360	34.9	40.44	29.52131495
8.22	46.7	4559	36.3	40.88	29.22977971
8.281	48.5	4532	35.4	38.92	28.80730526
8.26	41.4	4630	35.6	39.11	29.72916499
8.263	41.8	4360	36.6	40	29.95114203
8.25	39.4	4491	33.9	35.55	29.48686008
8.258	40.7	4580	40.3	39.7	29.0560001

The more variation is observed for the concrete of lower strength.To compare the actual value and the predicted value a regression ananlysis was performed using Excel .The regression model is shown in fig. 6.2. The linear regression coefficient was found to be 0.945 which is in good agreement.

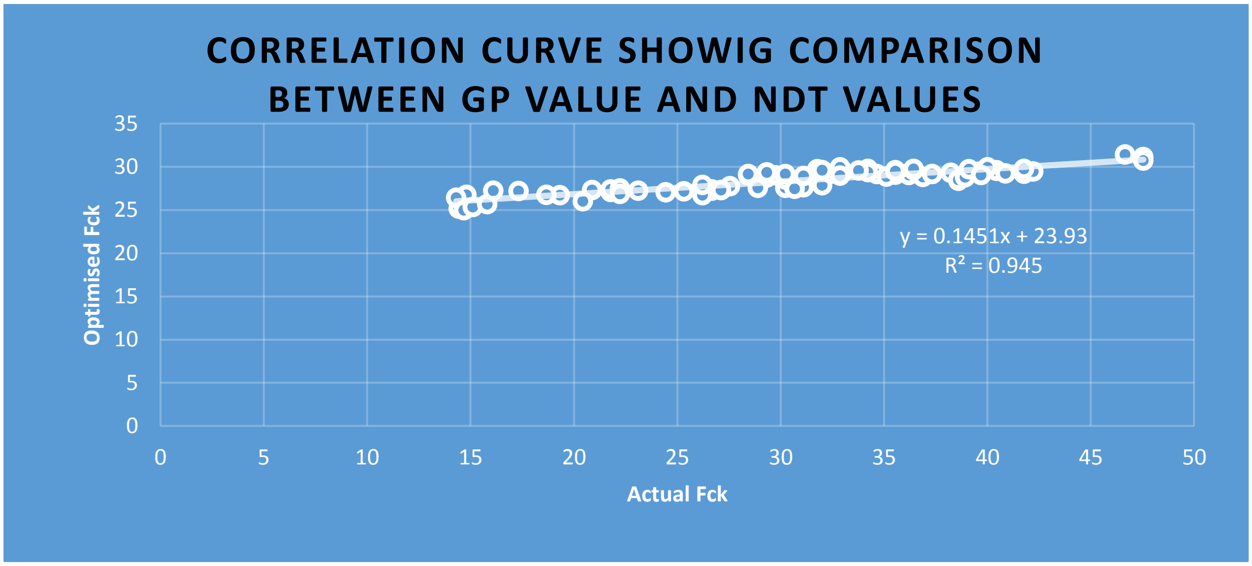

Fig 6.2

CHAPTER ~7

CONCLUSION

7.1 CONCLUSION:-

The present work is an attempt to formulate the correlation equation using rebound hammer value and rebound hammer value, UPV value and actual compressive strength of cubes. The techniques used for correlation in genetic programming. The following conclusion are drawn from the study:-

1. The GP technique is convenient tool for accurate prediction of cube compressive strength from NDT results. The proposed models provide good accuracy in order of 6.74% using RV and 7.44% involving RV and UPV values.
2. The proposed models showed higher accuracy for cubes of higher strength.
3. The model involves only rebound value provided higher accuracy. This showed that UPV values are not reliable to predict the compressive strength. They only represent the homogeneity and soundness of the concrete specimen.
4. The regression analysis between the actual strength and predicted strength from proposed models showed better correlation with only RH values.
5. The regression coefficients 0.95 and 0.94 are obtained when RH values and RH & UPV values are considered respectively.
6. The errors from the empirical models are in order of 6.744% (for RH values) and 7.4434% (for RH and UPV values), which are much less than the code specified value of ±25%.
7. The prediction would have been more accurate if more experimental data have been available.

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