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Compressive Strength of Concrete based on Ultrasonic and Impact Echo Test

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Abstract

Background/Objectives: This paper presents development of non destructive testing methods for calculating the compressive strength of concrete. **Methods/Statistical Analysis:** The compression tests along with impact echo tests and Ultrasonic Pulse Velocity (UPV) tests are carried out at different load which was the increased compressive loadat certain interval on concrete cubes of various mixes. The frequency spectrum and the ultrasonic pulse time are recorded. A MATLAB based code is used to calculate the maximum frequency of the sound signals corresponding to each impact echotest under a certain compressive load. The graphs for frequency and compressive load are plotted. The graph for ultrasonic pulse velocity on the various compressive load are also plotted for different samples of concrete. **Findings:** Important observations are found from the graphs of frequency and ultrasonic pulse velocity. The frequency and ultrasonic pulse velocity peak values were continuously found decreasing under the increase in the compressive load. After initial crack formation with the further increase in load the frequency was found increasing trend but with showing a small increased value. Whereas the ultrasonic pulse velocity was found reducing trend in nature. These plots give the clear indication of crack formation. **Application/Improvements:** These graphs are used for comparison of variation of frequency and ultrasonic pulse velocity to predict the undamaged and damaged state of concrete under compression. A mathematical expression is developed between compressive strength, frequency and ultrasonic pulse velocity.

Keywords: Compressive Load, Frequency Spectrum, Impact Echo Test, MATLAB, Non Destructive Testing, Ultrasonic Pulse Velocity

1. Introduction

Vibration based methods and ultrasonic methods areimportant techniques for the damage detection of concrete. Vibration based experiment and ultrasonic based experiment response of under different loading may give some strength measurement criteria. In this paper, frequency based tests i.e., impact echo test and ultrasonic pulse velocity teston concrete cubes are carried out to predict its compressive strength. Frequency parameter is tried to develop the Structural Health Monitoring (SHM) criteria. It is being used for the prediction of cracks in concrete. The vibration signature in a structure is induced by the impact hammer loading on the side face of concrete cube along with the axial compressive strength loading.

The frequency response under cracked and uncracked conditions are different. After crack formation the natural frequency of the structure will reduce since the stiffness of the damaged structure is reduced. Reduction of the natural frequency of the reinforced concrete members due to flexural cracks or shear cracks is presented by[1]. They are conducted cyclic load testing and impact vibration test. The frequency reduction due to flexural damage in reinforced concrete beams is also presented by[2]. This was helped them to model the degradation using Fictitious Crack Modeling (FCM). The role of frequency response methods in SHM is described by[3]. They have done structural health monitoring in composite materials using frequency response and concluded that this method will besuitable for detecting the global

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stiffness changes and hence damages in the material. It is clear that the crack will reduce the stiffness. In addition to this, damage will change the dynamic parameters such as mode shape and its derivatives. The mode shape is mainly associated with the Eigen parameters such as natural frequency, damping values etc. In[4] presented a mode shape based method to identify the crack in reinforced concrete beams[5]. Describes damage detection of flexural structural systems using damage index method. In their work, they are efficiently used the changes in the natural frequency to predict the damaged and undamaged conditions of the beam. The vibration methods are not so accurate. In general, the accuracy of vibration based methods are depends on the type of sensors used, number of sensors, quality of sensor, arrangement of sensors, surrounding conditions etc.

Ultrasonic Pulse Velocity (UPV) is being used to detect and predict the damage in concrete. In this test, the time travel of an ultrasonic pulse through concrete is measured. Then the velocity is calculated from the fundamental relation. Higher velocity is obtained when the concrete is of good quality in terms of homogeneity, uniformity, density etc. Damaged concrete shows less velocity. In[6] described a damage assessment FRP-encased concrete using UPV. From their experiment, it is clear that there is a significant reduction in the ultrasonic pulse velocity after a particular value of load for both plain concrete and FRP-encased concrete under monotonic loading. They are also explained the comparison of UPV response for both type of concrete. Ultrasonic velocity response depends on the type of concrete. In[7] presented that the velocity reduction in normal strength concrete occurs at 30-40% of the ultimate load, whereasin high strength concrete it is about 70% of the ultimate load. Because normal strength concrete is more ductile when compared to high strength concrete. The heterogeneities in the concrete also affect the ultrasonic wave scattering and attenuation. In[8] presented ultrasonic evaluation of damage in heterogeneous concrete materials. In their study, they found that small heterogeneities do not increase the ultrasonic wave scattering and do not affect the attenuation. They have plotted the velocity response under axial compression using laboratory results and finite element models. In both the cases the velocity variation is almost same. UPV can effectively used for the determination of depth of crack in concrete. In[9] pointed out the theoretical expression used to calculate the depth of surface cracks in concrete.

2. Materials Used

Concrete cubes with different mixes are used for both impact echo test and ultrasonic pulse velocity test under axial compression. In this paper, mainly ten types of mixes are used. For each mix, twenty four samples are tested. Concrete cubes of size 10cubic cm are used for all samples. The details of the mixes are given in Table 1.

Notation Used:

1. M-40-20 represents, M for mix of the concrete containing 0.1% fiber, 40% of sand is replaced by fly ash and 20% of sand is replaced by pond ash.
2. C-20-10 represents, C for mix of the concrete containing no fiber, 20% of sand is replaced by fly ash and 10% of sand is replaced by pond ash.

Table 1. Mix proportion details of different samples used for the experiment

Sl No.	Mix	Cement (kg/m^3)	Sand (kg/m^3)	Aggregate (kg/m^3)	Fly Ash (kg/m^3)	Pond Ash (kg/m^3)	Fiber (kg/m^3)	Water (kg/m^3)
1	M-0-10	413.4	835.83	952.6	0	73.52	2.65	177.95
2	M-0-20	413.4	761.85	952.6	0	147.05	2.65	181.23
3	M-20-0	330.72	908.9	952.6	82.68	0	2.65	174.01
4	M-40-0	248.04	908.9	952.6	165.36	0	2.65	173.38
5	M-40-10	248.04	835.83	952.6	165.36	70.8	2.65	178.54
6	M-40-20	248.04	761.85	952.6	165.36	141.6	2.65	178.54
7	C-0-0	413.4	908.9	952.6	0	0	0	174.67
8	C-0-20	413.4	761.85	952.6	0	141.6	0	181.23
9	C-20-0	360.0	911.37	955.19	90.0	0	0	166.83
10	C-20-10	330.72	835.83	952.6	82.68	70.8	0	176.85

3. Experimental Setup

The experiment consists of compression test, impact echo test and ultrasonic pulse velocity test. The concrete cubes are first put at the compression testing machine. A transducer is attached on one vertical face of the specimen and is connected to the computer. Then load is increased gradually. After each incremental load of 50 KN intervals, the impact echo test as well as UPV test are carried out. A rebound hammer is used to make a constant impact on the concrete specimens. The frequencies for each impact are recorded by the transducer using a MATLAB program. Along with the impact test the UPV test is also conducted according to[10]. The time to travel for ultrasonic waves from one face to the opposite face of the concrete specimen is recorded for each load increment of different specimens.

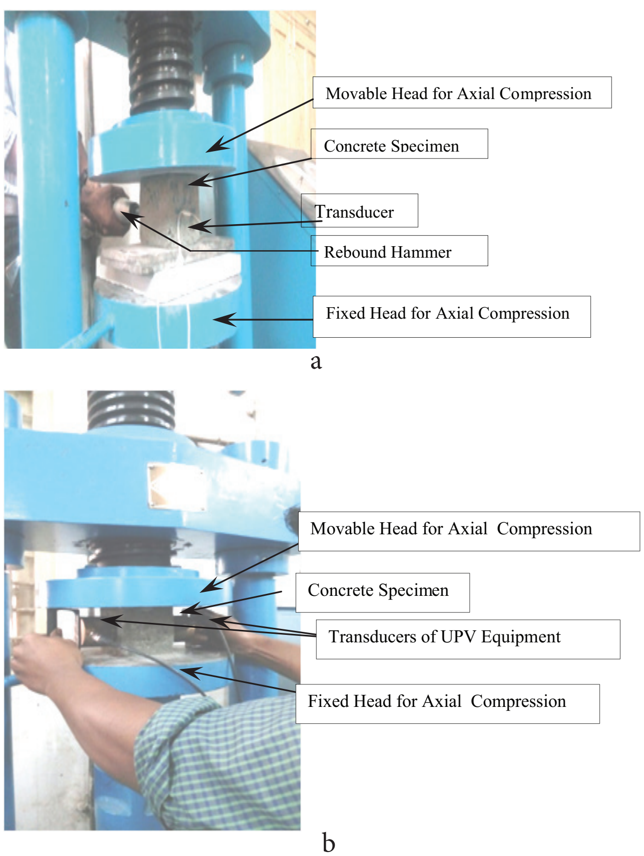


Figure 1. Experimental arrangements showing axial compression along with impact echo test and ultrasonic pulse velocity test. (a) Compression along with impact echo test. (b) Compression along with UPV test.

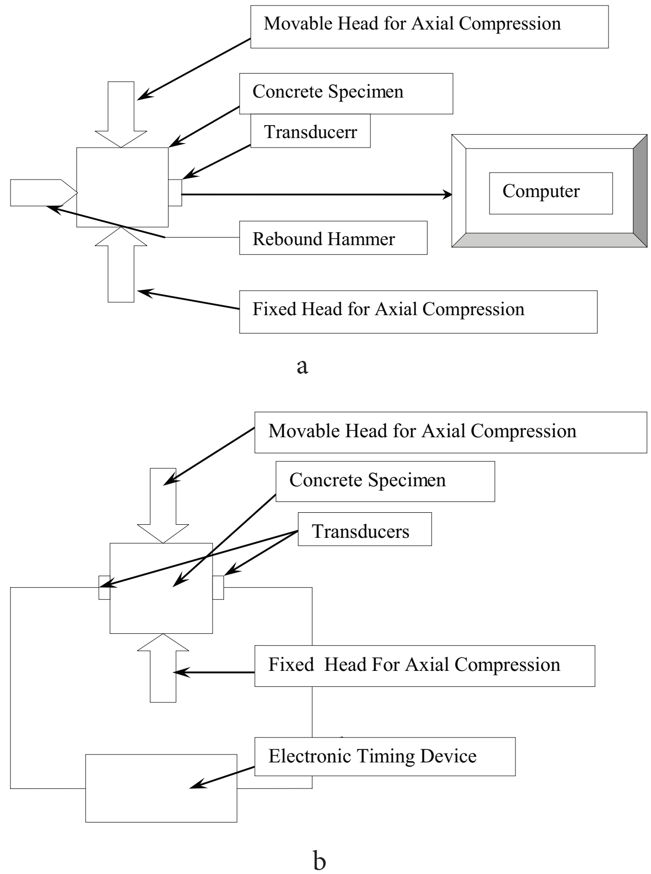
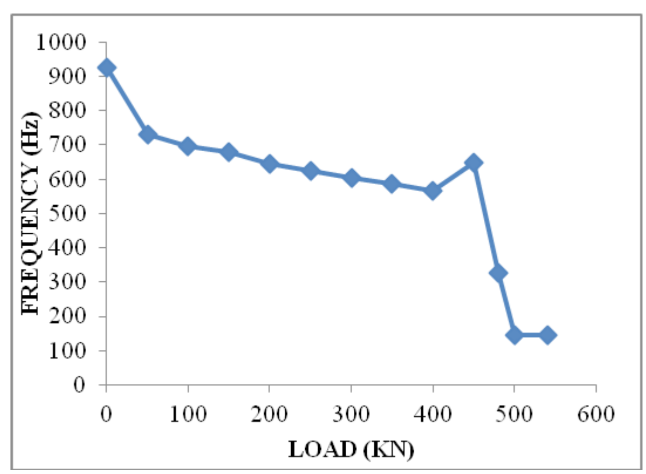


Figure 2. Schematic diagram showing axial compression along with impact echo test and UPV test. (a) Compression along with impact echo test. (b) Compression along with UPV test.



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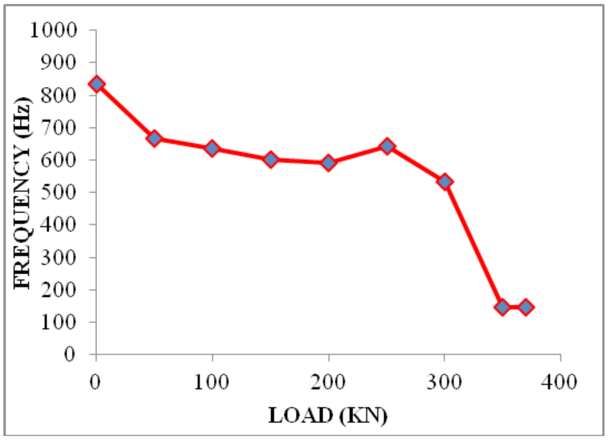

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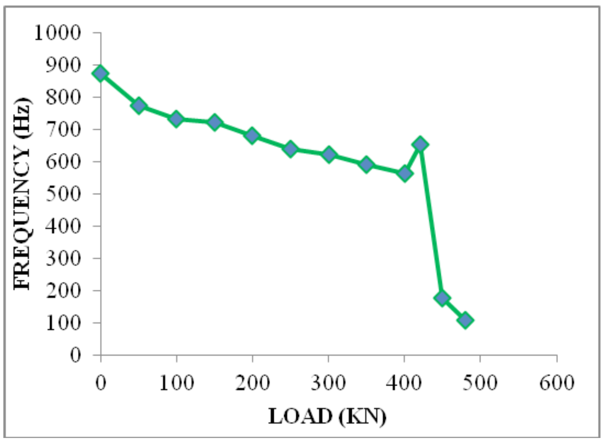

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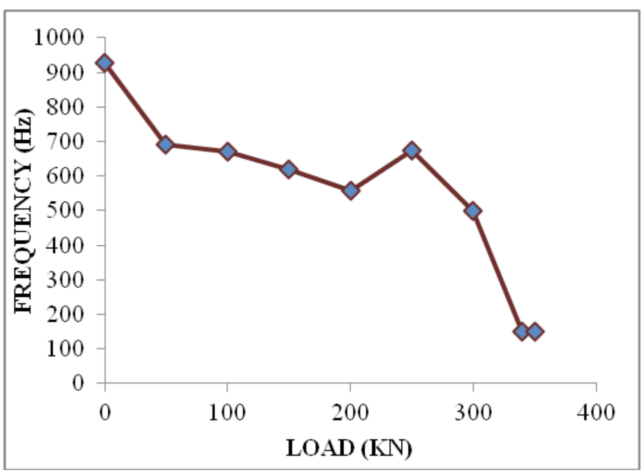

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Figure 3. Typical frequency vs load diagram of different mixes of concrete under axial compression due to impact echo test. (a) M-0-10. (b) M-0-20. (c) M-40-0. (d) M-40-20.

After the experiment part, the dominant frequency values for each impact are calculated using a Fast Fourier Transform based MATLAB code. The ultrasonic velocities are calculated from the basic relationship between velocity, distance and time. The set ups for the experiment are shown in Figure 1. The schematic diagrams of the same are shown in Figure 2.

4. Result and Discussion

The frequency and ultrasonic pulse velocity as obtained under various axial compression loads on concrete cubes are plotted. For explaining the frequency response under the compression, on typical four different tests of impact echo results are shown below:

4.1 Frequency Variation under Axial Compression

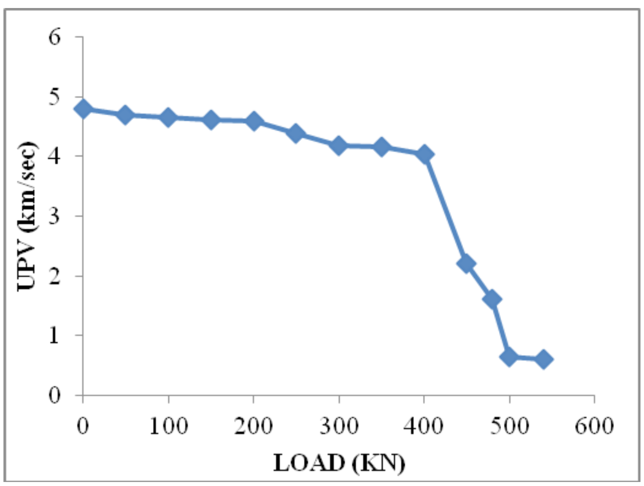
From the above graphs it can be observed that for all types of concrete as the compressive load increase the frequency value reduces. In all the cases initially the frequency values are much higher for no load condition butwith increasing the compressive load, the decreasing of frequency canclearly be seen. Here it can say that due to load increase the stiffness is reducing. Sothe frequency is also reducing. Another interesting observation could be seen that, at a particular load the frequency increased suddenly before it comes down in all the samples. It occurs just after the initial major crack formation. Because, after major crack formed the concrete specimen separated into pieces. This caused to the reduction of thetotal length of the specimendue to crack. So the length reduction caused the reduction in frequency also. In[11] mentioned a relationship between natural frequency and the length of simply supported beam. The relation showing between frequency and length is given by[12]. Here also it can see that the inverse relation between frequency and length. The effect of axial force on the value of frequency also given in the same equation. They are mainly concentrated on the effect of pre-stressing force on the vibration characteristics of concrete bridges. In[13] studied the vibration characteristics of different length metal beams. From their experiment, they are getting higher values of frequency for small length beams compared to large length beams.

After major crack formation, further increase in the compressive load caused sudden reduction in the frequency to very low values (see Figure 3(a), (b), (c) and (d)). Here we can say that, after concrete is failed the stiffness of concrete is reduced deeply. Hence the frequency also reduced to very low value.

4.2 Ultrasonic Pulse Velocity Variation under Axial Compression

The ultrasonic pulse velocity as obtained under various axial compression loads on concrete cubes are plotted. For explaining the ultrasonic pulse velocity response under the compression, on typical four different tests of ultrasonic pulse velocity results are shown below:

Figure 4 shows the variation of ultrasonic pulse velocity under axial compression for different mixes of concrete. From all different types of concrete it is observed that, in the initial stage of loading the ultrasonic velocity decreases very slowly. Here the velocity values are



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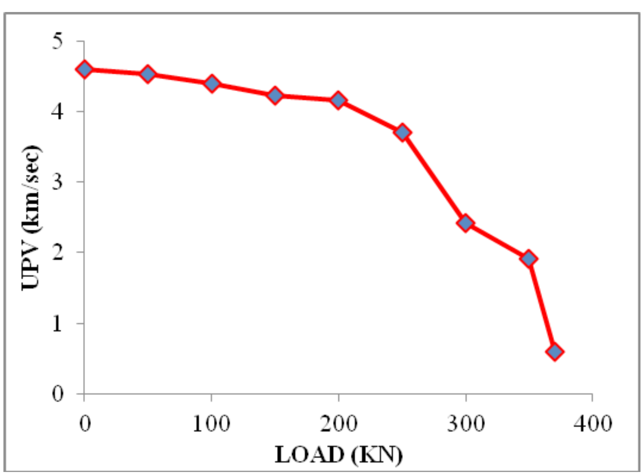

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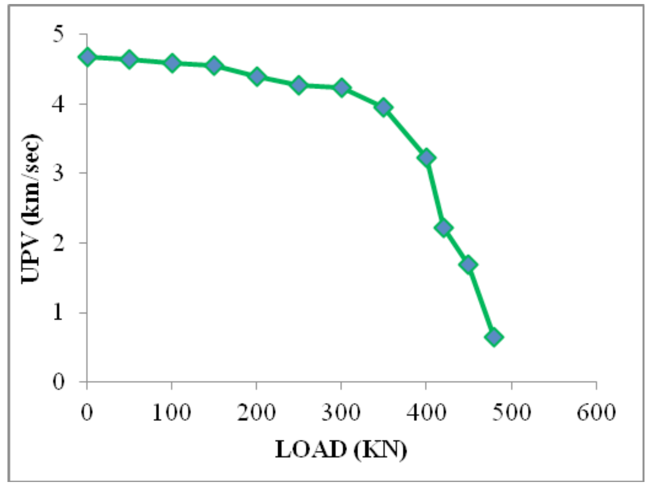

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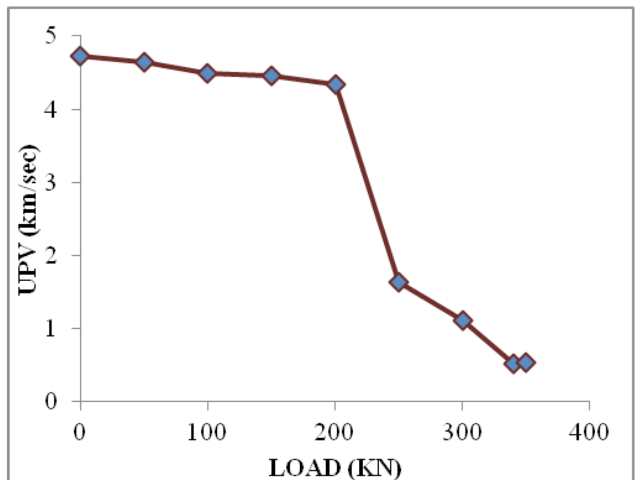

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Figure 4. Typical ultrasonic pulse velocity vs load diagram of different mixes of concrete under axial compression. (a) M-0-10. (b) M-0-20. (c) M-40-0. (d) M-40-20.

between 5-4 km/sec. This slow reduction is observed up to the formation of initial major crack. After crack formation the reduction of velocity is large. Because the time of travelling the ultrasonic pulses from one face to another face of concrete cube is increased largely. This sudden reduction of velocity can be seen in Figure 4(a), (b), (c) and (d). Finally, after failure the ultrasonic velocity values came below 1 km/sec.

4.3 Mathematical Expression for Calculating Compressive Strength

A mathematical relation between compressive strength, frequency and ultrasonic pulse velocity is developed

Table 2. Actual and predicted compressive strength of different mixes of concrete

Sl No	Mix	Actual Compressive Strength (N/mm²)	Frequency (Hz)	Ultrasonic Pulse Velocity(km/sec)	Predicted Compressive Strength (N/mm²)	Percentage Error
1	M-0-10	54	924	4.94	53.83	0.31
2	M-0-20	37	836	4.55	40.43	9.27
3	M-20-0	45	940	4.65	45.96	2.13
4	M-40-0	48	874	4.81	48.83	1.74
5	M-40-10	47	926	4.74	48.17	2.5
6	M-40-20	35	928	4.52	41.94	19.81
7	C-0-0	52	898	4.85	50.6	2.7
8	C-0-20	59	870	5.02	54.73	7.23
9	C-20-0	34	829	4.5	40.62	19.47
10	C-20-10	48	855	4.90	51.92	6.07

Notation Used:

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2. C-20-10 represents, C for mix of the concrete containing no fiber, 20% of sand is replaced by fly ash and 10% of sand is replaced by pond ash.

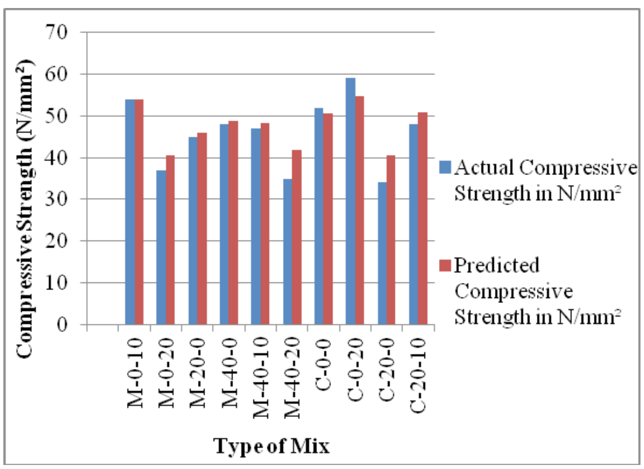

Figure 5. The predicted compressive strength comparison with the actual compressive strength of concrete.

using linear regression analysis. The regression analysis is done from the values of frequency and ultrasonic pulse velocity at no loading condition. The result of the analysis is given in Table 2. Actual compressive strength values and predicted compressive strength values for different concrete samples using Equation 1 are given in the table. A bar diagram of the same is given in Figure 5. The mathematical expression for calculating compressive strength using frequency and ultrasonic pulse velocity is given as,

$$c = 28.37v + 0.0257f - 111.05 \tag{1}$$

Where, c = Compressive strength of concrete in N/mm².

v = Ultrasonic pulse velocity in km/sec.

f = Frequency in Hz.

5. Conclusion

Non destructive tests using impact echo and ultrasonic pulse velocity tests were carried out for the prediction of compressive strength of concrete. A mathematical expression is developed using the liner regression analysis for calculating compressive strength of concrete.

The predicted compressive strengths were compared to the actual compressive strengths. The values were found to be very close to the actual compressive strengths. From the frequency response and ultrasonic pulse velocity responseof different concrete samplestests, the following observations were made:

- Compression reduces both frequency and ultrasonic pulse velocity values.
- Up to the initial crack formation, frequency reduction was observed in impact echo tests.
- After initial crack formation the frequency increases further if the load is increased in

impact echo tests. This is due to length reduction of sample due to crack formation.

- The reduction in ultrasonic pulse velocity was observed in UPV test as an indication of crack formation.
- Inultrasonic pulse velocity test the pulse velocity was found reducing deeply upto the failure.

Hence one can observed the crack formation clearly from the graphs. Therefore it can be said that the impact echo test and the ultrasonic pulse velocity test both can predict the compressive strength of concrete.

6. References

1. Nagatha S, Miyagawa Y, Kanazawa K. Reduction of natural frequency due to flexural cracks or shear cracks in reinforced concrete members. 15th World Conference on Earthquake Engineering (WCEE); Japan. 2012. p. 1-8.
2. Hamad WI, Owen JS, Hussein MFM. Modeling the degradation of vibration characteristics of reinforced concrete beams due to flexural damage. Structural Control and Health Monitoring. 2015; 22(6):939–67.
3. Seth S, Kessler K, Spearing MS, Mauro J, Atalla A, Carlos ES, Cesnik C, Soutis C. Structural health monitoring in composite materials using frequency response methods. Nondestructive Evaluation of Materials and Composites V. 2001Aug; 1.
4. Dawari V, Vesmawala G. Identification of crack damage in reinforced concrete beams using mode shape based methods. Civil and Environmental Research. 2013; 3(13):24–9.
5. Eraky A, Ahmed M, Anwar A, Saad A, Abdo A. Damage detection of flexural structural systems using damage index method – experimental approach. Alexandria Engineering Journal. 2015 Sep; 54(3):497–507.
6. Mirmiran A, Wei Y. Damage assessment of FRP-encased concrete using ultrasonic pulse velocity. Journal of Engineering Mechanics. 2001 Feb; 127(2):126–35.
7. Santhanam M. Ultrasonic characterization of damage in concrete. tech science press. 2010; 3(2):111–25.
8. Pawel P, Smolarkiewicz S, Carnot L, Nogueira N, Kaspar J, Willam W. ultrasonic evaluation of damage in heterogeneous concrete materials. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS); 2000 Sep. p. 1–13.
9. Kalyan ST, Kishen CJM. Experimental evaluation of cracks in concrete by ultrasonic pulse velocity. 2013; 95(1):27–36.
10. IS 13311 (Part I)- Indian standard non-destructive testing of concrete - methods of test. New Delhi; 1992. p. 1–14.
11. Sudhir K, Jain J, Murty CVR, Kamle S. Experimental study on natural frequency of prestressed concrete beams. 1997; 19(9):718–23.
12. Arora SS. Study of vibration characteristics of cantilever beams of different materials [M Tech thesis]. Patiala: Department of Mechanical Engineering, Thapar University; 2012 Jul. p. 693–708.
13. Saiidi M, Douglas B, Feng S. Prestress force effect on vibration frequency of concrete bridges. Journal of Structural Engineering. 1994; 120(7):2233–41.