Correlation between Non-destructive Test Results and Mechanical Properties of Concrete

By

Devins K.Patel

12MCLC18

DEPARTMENT OF CIVIL ENGINEERING

INSTITUTE OF TECHNOLOGY

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Correlation between Non-destructive Test Results and Mechanical Properties of Concrete

Major Project

Submitted in Partial Fulfillment of the Requirements for the

MASTER OF TECHNOLOGY

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(Computer Aided Structural Analysis And Design)

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May-2014

Declaration

This is to certify that

i) The thesis comprises my original work towards the degree of Master of Technology in Civil Engineering (Computer Aided Structural Analysis and Design) at Nirma University and has not been submitted elsewhere for a degree.

ii) Due acknowledgement has been made in the text to all other material used.

Patel Devins K.

Certificate

This is to certify that the Major Project Report entitled **"Correlation between Non-destructive Test Results and Mechanical Properties of Concrete"** submitted by **Mr. Devins K. Patel (Roll No: 12MCLC18)** towards the partial fulfillment of the requirements for the degree of Master of Technology in Civil Engineering (Computer Aided Structural Analysis And Design) of Nirma University is the record of work carried out by him under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

Date:

Dr. Urmil Dave
Guide and Professor,
Department of Civil Engineering,
Institute of Technology,
Nirma University,
Ahmedabad.

Dr. P. V. Patel
Professor and Head
Department of Civil Engineering,
Institute of Technology,
Nirma University,
Ahmedabad.

Dr.K.Kotecha
Director
Institute of Technology
Nirma University
Ahmedabad

Examiner

Date of Examination

Abstract

The NDT of concrete in today's scenario has received a great importance in terms of practical and engineering value. The subject has received a growing attention during recent years, especially the quality characterization of damaged structure made of concrete using NDT testing. Massive structure like dams, bridges requires their continous quality checking. For this purpose many techniques are involved which causes damage to the structure such as extraction of cores for checking the strength. Extraction of core is not advisable as it would results in damaging the structure and also very expensive procedure. In non-destructive testing, number of advantages reduction in nos. of labours, lesser structural damage, prediction of concrete strength without extraction of cores,lesser cost of testing etc. These techniques are used to predict the strength of the structure with acceptable approximation.

Therefore, in order to find the strength of the concrete structure, investigations were carried out for generating the correlation between the NDT results and the mechanical properties of concrete. The aim of present investigation is to develop correlation curves between compressive strength and NDT testing for concrete of different grades(M15, M20, M25, M30, M40, M50). It is proposed to develop multiple regression curves from the results of UPV and Rebound Hammer in determining the compressive strength of concrete at different ages 7, 28, 90 days for better assessment of structure.

Total 252 specimens are casted for the present investigation. M15, M20, M25, M30, M40, M50 grades of concrete using OPC and PPC are used for the present investigation. A standard size of cubes, beams and cylinders as per IS provisions are used for evaluating the compressive strength, modulus of elasticity, flexural strength and split tensile strength. Cube specimens have been tested at the age of 7, 28 and 90 days respectively. Beam and cylinder specimens have been tested at the age of 28 days for

both non-destructive and destructive testing. For cube specimens, both direct and semi-direct methods are adopted for finding out UPV results. In surface hardness test, cube specimens are tested by keeping position of rebound hammer both vertical and horizontal. Same methodology has been adopted for beam and cylinder specimens for rebound hammer test. UPV results are taken by direct method for beam & cylinder specimens. Correlations are carried out between compressive strength and NDT results i.e. rebound no. & UPV at different ages 7, 28, 90 days. For other mechanical properties correlation with NDT results are also carried out. Compilation of results of RCC members are carried out from different sites. Also NDT results are taken on RCC laboratory specimens of different grades. Correlation of NDT results are carried out with compressive strength of RCC members both in-situ and laboratory specimens. Combination of results of RCC and PCC specimens are carried out for finding the correlation of compressive strength with NDT results.

From the Correlation curves indicated that, there is good linear correlation between mechanical properties and NDT results. Combination of both NDT methods gives reliable results than one method. NDT method is most suitable for predicting the strength results without disturbing the structure.

Acknowledgement

I would like to thank my guide **Dr. Urmil V. Dave**, whose keen interest and knowledge base helped me to carry out the major project work. His constant support and guidance during my project work equipped me with a great understanding of different aspects of the project work. He has shown keen interest in this work right from beginning and has been a great motivating factor in outlining the ow of my work.

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Devins Patel

12MCLC18

Abbreviations, Notations and Nomenclature

NDT .... Non-destructive testing

UPV .... Ultrasonic pulse velocity

RN .... Rebound number

f_{cu} .... compressive strength of concrete

E_c .... Modulus of elasticity of concrete

F_c .... Flexural strength of concrete

OPC .... Ordinary Portland cement

PPC .... Portland Pozzolana Cement

f_{ck} .... Characteristic strength of Concrete

P .... failure load of concrete cube

S .... Split tensile strength of concrete

RCC .... Reinforce cement concrete

PCC .... Plain cement concrete

GGBFS .... Ground granulated blast furnace slag111

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Chapter 1

Introduction

1.1 General

Concrete is one of the material which is widely used in all over the world. Determination of compressive strength has become the most important concern of researchers since its usage and usually regarded as the main criteria to judge the quality of concrete. Instead of the good care in the design and production of concrete mixture, many variations are happened in the conditions of mixing, degree of compaction or curing conditions which make many variations in the final production. Usually, this variation in the produced concrete have been assessed by standard tests to find the strength of the hardened concrete, and inspire of the type of these tests, considered a good one to determine the quality during the process of producing concrete but they have some considerable disadvantages, such as the test sample may be not present the concrete in the structure actually. So, as a results, many trials were carried out in the world to develop fast and cheap non-destructive methods to test concrete in the labs and structures and to observe the behavior of the concrete structure during a long period, such these tests are ultrasonic pulse velocity test and surface hardness test. The NDT of concrete in today's scenario has received a great importance in terms of practical and engineering value. The subject has received a growing attention during

recent years, especially the quality characterization of damaged structure made of concrete using NDT testing.[1]
The direct determination of the strength of concrete implies that concrete specimens must be loaded to failure. Therefore, the determination of concrete strength requires special specimens to be taken, shipped, and tested at laboratories. This procedure may result in the actual strength of concrete, but may cause trouble and delay in evaluating existing structures. Because of that, special techniques have been developed in which attempts were made to measure some concrete properties other than strength, and then relate them to strength, durability, or any other property. However, the term "non-destructive" is given to any test that does not damage or affect the structural behavior of the elements and also leaves the structure in an acceptable condition for the client.

1.2 NDT Tests and Properties of Concrete

Non-destructive testing is generally defined as not impairing the intended performance of the element or member under test, and when applied to concrete is taken to include methods which cause localized surface zone damage. Such tests are commonly described as partially destructive. All non-destructive methods can be performed directly on the in-situ concrete without removal of a sample, although removal of surface finishes is likely to be necessary. Among the available nondestructive methods, the rebound hammer and the ultrasonic pulse velocity testers the most commonly used ones in practice. This is true in many developing countries where the lack of technology and funds requires the optimization of available methods and techniques. Also, in many developing countries, records of tested concrete constituents may not be available, or the available data lack some of the requirements for strength estimation by means of ultrasonic pulse velocity (or any other nondestructive testers).[10]

1.3 Research Significance

Various methods like destructive and non-destructive test (NDT) methods have been developed for determining the compressive strength. Nevertheless, the destructive methods are expensive and time consuming. In addition, cube and cylinder concrete specimens prepared in laboratory are not representing in situ concrete because of different placing, consolidation and curing condition. Furthermore, getting core specimens from structural element reduces the load carrying capacity of structural elements.[3]

Structure like dams necessitates their health monitoring with age. For these different destructive techniques involves extraction of core for finding the strength. Puncturing the body of dams is not advisable as it would unnecessarily result in damaging the structure and the procedure is also too expensive to be used. Therefore in order to monitor the post construction performance of concrete investigations were carried out for developing the relationship between UPV and the compressive strength of concrete. Actually, non-destructive testing may be applied to both new and existing structures. With respect to new structures the principal application is for quality control, whereas for existing structures non- destructive testing is carried out to assess structural integrity.

The concrete strength taking from cubes made from same concrete is different from in situ concrete strength. Also the results taking from the non destructive tests(rebound no. and UPV) are predicted results. Correlations are used for this prediction influences by various factors like type of aggregate, mixing curing, consolidation condition, different site condition. Non-destructive tests are used for finding the strength of structure without damage. So, this study aims to find a correlation between results of the non-destructive test(UPV & Rebound Hammer) and mechanical properties of concrete by statistical method.

1.4 Objective of Study

Following objectives are decided for major project.

- Generate the correlation between Non-destructive test(NDT) i.e. rebound no, UPV results and mechanical properties of concrete like compressive strength, modulus of elasticity, flexural strength and split tensile strength of concrete at the age of 7, 28, 90 days for both OPC & PPC based concrete.
- Generate the correlation between NDT results of RCC specimens from laboratory as well as from data collected different sites and compressive strength of concrete of same specimens.

1.5 Scope of The Work

To achieve above objectives the scope of work has been identified as follows:

- The properties of constituents required to produce the concrete mix such as coarse aggregate, fine aggregate, cement are to be studied.
- Cube specimens of size (150X150X150) mm, cylinder specimens of 150 mm dia. and 300 mm height, Beam specimens of size (100X100X500) mm, with different grades (M15, M20, M25, M30, M40, M50), using OPC are to be cast. It is planned to cast 15 cube specimens, 3 cylinder specimens, 3 beam specimens for each grade of concrete. It is planned to cast 15 cube specimens, 6 cylinder specimens, 3 beam for each grade of concrete by OPC & PPC.
- Curing is to be done for 28 days from the day of casting.
- UPV results, rebound hammer results and compressive strength of cubes are to be found out at age of 7 days, 28 days, 90 days. For all mixes using both OPC & PPC UPV results , Rebound hammer and compressive strength of concrete are to be correlated.

- Modulus of Elasticity of cylinder is to be evaluated.UPV results and Rebound hammer results are to be evaluated at age of 28 days. UPV results, Rebound hammer results and modulus of Elasticity of concrete are to be correlated.

- Modulus of Rupture of beam specimens are to be evaluated. UPV results and Rebound hammer results are to be taken on concrete specimens at age of 28 days. UPV results, Rebound hammer results and modulus of rupture of concrete are to be correlated.

- Split tensile strength is to be find out from cylinder specimens. UPV results, Rebound hammer results are to be taken on cylinder specimens. UPV results, Rebound hammer results and spli tensile strength of concrete are to be correlated.

- Compilation of results of RCC members from different sites are to carried out. Also results are taken on RC specimens of laboratory. NDT results and compressive strength are to be correlated.

- By the use of SPSS software for statistical method correlation of combinations between both NDT methods and compressive strength are to be carried out.

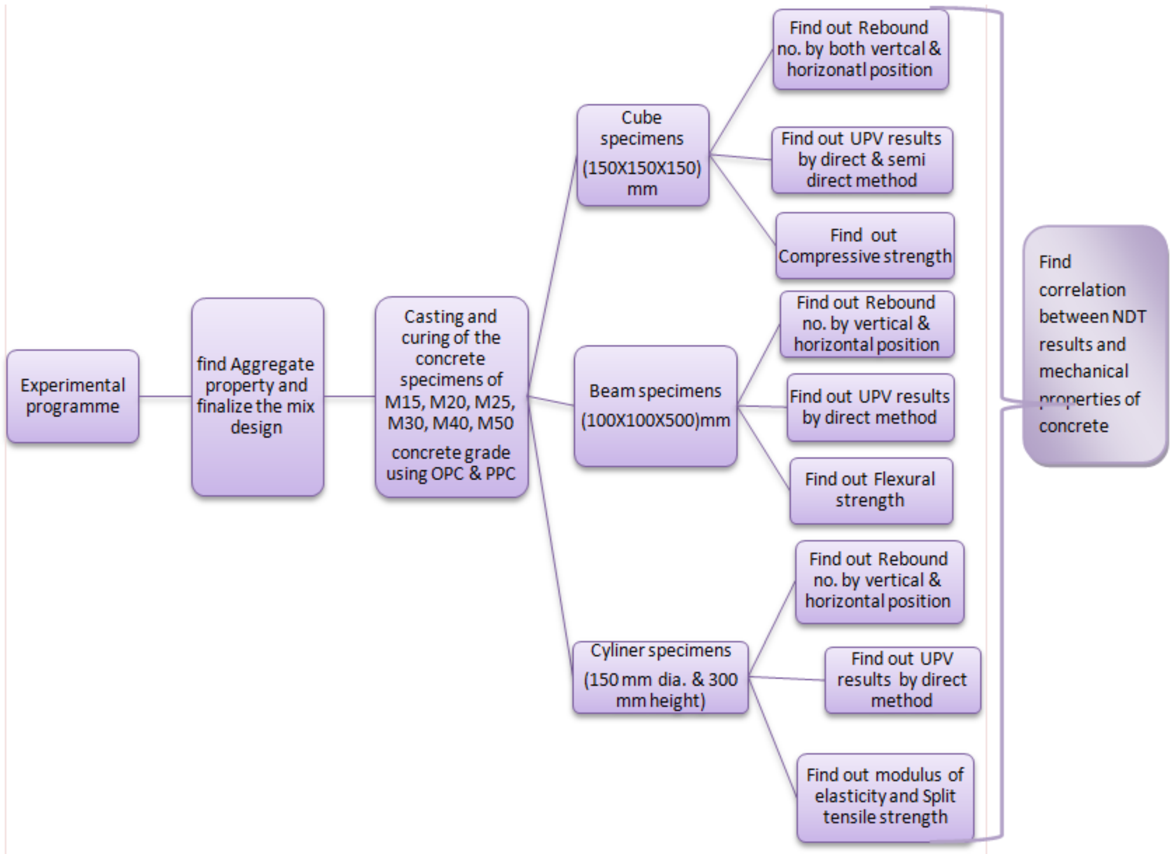

Figure 1.1: Flow chart

1.6 Layout of Report

The report of major project is divided into five chapters as given below.

Chapter 1 incorporates discussion about introduction and need of study, Objectives of study and scope of work are included in this chapter.

Chapter 2 includes the literature review based on previous research work related to the major project. It includes basic information of various Non-destructive methods, its use, advantages & disadvantages various correlation between NDT results and mechanical properties of concrete.

Chapter 3 describes the details of experimental programme. Material used in the investigation, concrete mix design and the test procedure used are reported in this chapter.

Chapter 4 includes results results and discussion. In this chapter various correlations are to be carried out and find proper correlation of NDT results and mechanical properties like compressive strength, modulus of elasticity, flexural strength and split tensile strength of concrete. Various combinations are carried out to generate the correlation between NDT results and compressive strength.

Chapter 5 is having summary, concluding remarks and future scope of work for the major project work.

Chapter 2

Literature Review

2.1 General

This chapter presents brief detail of Non destructive methods. Various types of non-destructive methods its principle, operation, use and merits & demerits are included. Various papers by researchers who derive such relations between NDT results and mechanical properties of concrete have been study.

2.2 Surface Hardness Test

One of many factors connected with the quality of concrete is its hardness. Efforts to measure the surface hardness of a mass of concrete were first recorded in the 1930s; tests were based on impacting the concrete surface with a specified mass activated by a standard amount of energy. Early methods involved measurements of the size of indentation caused by a steel ball either fixed to a pendulum or spring hammer, or fired from a standardized testing pistol. Later, however, the height of rebound of the mass from the surface was measured. Although it is difficult to justify a theoretical relationship between the measured values from any of these methods and the strength of a concrete, their value lies in the ability to establish empirical relationships between test results and quality of the surface layer. Unfortunately these are subject to many specific restrictions including concrete and member details, as well as equipment reliability and operator technique. Indentation testing has received attention in Germany and in former states of the USSR as well as the United Kingdom, but has never become very popular. The rebound principle, on the other hand, is more widely accepted: the most popular equipment, the Schmidt Rebound Hammer, has been in use worldwide for many years. Recommendations for the use of the rebound method are given in BS EN 12504-2, ASTM C805, IS 13311 part-2[15].

2.2.1 Principle of Rebound Hammer Test

When the plunger of rebound hammer is pressed against the surface of the concrete, the spring controlled mass rebounds The most satisfactory way of establishing a controlled mass rebounds and the extent of such rebound depends upon the surface hardness of concrete. The surface hardness and therefore the rebound is taken to be related to the compressive strength of concrete of concrete. The rebound is read off along a graduated scale and designated as the rebound hammer rebound index.[15]

2.2.2 Rebound Test Equipment and Operation

The Swiss engineer Ernst Schmidt first developed a practicable rebound test hammer in the late 1940s, and modern versions are based on this. Figure 2.1 shows the basic features of a typical type N hammer, which weighs less than 2 kg, and has an impact energy of approximately 2.2 Nm. The spring controlled hammer mass slides on a plunger within a tubular housing. The plunger retracts against a spring when pressed against the concrete surface and this spring is automatically released when fully tensioned, causing the hammer mass to impact against the concrete through the plunger. When the spring-controlled mass rebounds, it takes with it a rider which slides along a scale and is visible through a small window in the side of the casing. The rider can be held in position on the scale by depressing the locking button. The equipment is very simple to use Figure 2.2, and may be operated either horizontally or

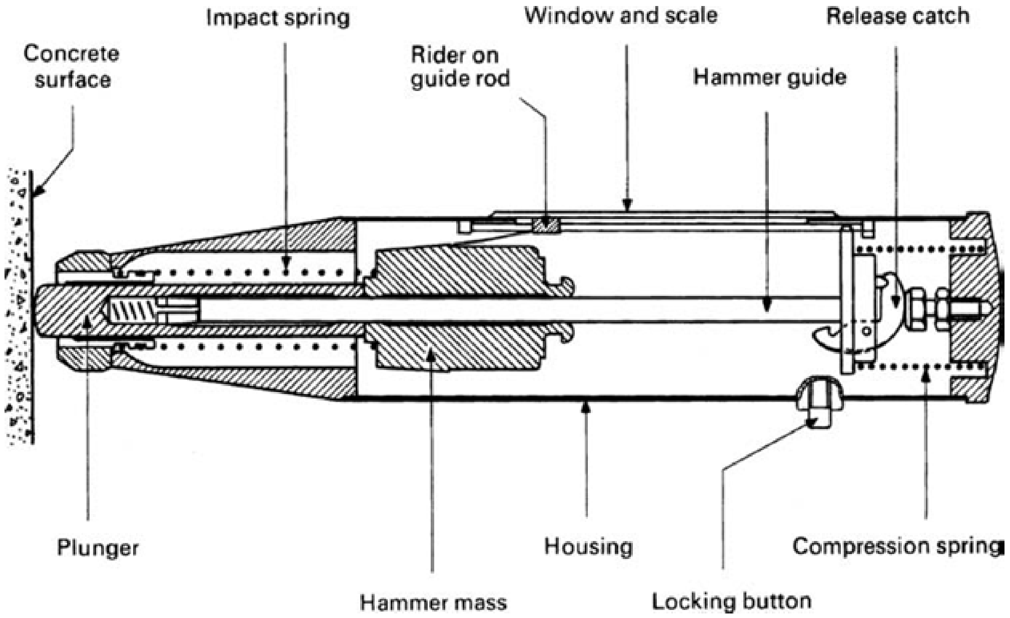

Figure 2.1: Typical Rebound hammer

vertically, either upwards or downwards. The plunger is pressed strongly and steadily against the concrete at right angles to its surface, until the spring-loaded mass is triggered from its locked position. After the impact, the scale index is read while the hammer is still in the test position. Alternatively, the locking button may be pressed to enable the reading to be retained, or results can be recorded automatically by an attached paper recorder. The scale reading is known as the rebound number, and is an arbitrary measure since it depends on the energy stored in the given spring and on the mass used. This version of the equipment is most commonly used, and is most suitable for concretes in the 20-60 N/mm^2 strength range.

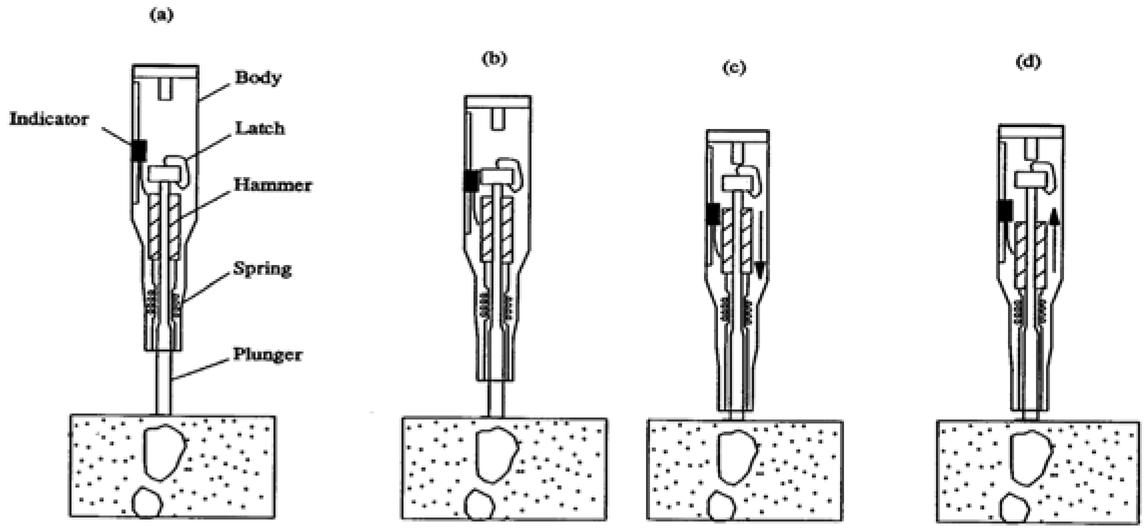

Figure 2.2: Methodology Rebound hammer

2.2.3 Advantages and Disadvantages

The rebound hammer provides a quick and inexpensive means of assessing the general quality of concrete and for locating areas of of poor quality. A large number of readings can be taken rapidly so that large exposed area can be scanned in few hours. To ensure more reliable results, project specific calibrations are necessary when estimating the in place concrete compressive strength. Because the test only measure the rebound of a given mass on the concrete surface, the results reflect only the quality of the surface, and not the entire depth of the section being tested. The results of the rebound hammer test are affected by the smoothness of the test surface, type of coarse aggregate, age of concrete being tested, moisture content, type of cement and surface carbonation.[18]

2.3 Ultrasonic Pulse Velocity Method

The first reports of the measurement of the velocity of mechanically generated pulses through concrete appeared in the USA in the mid-1940s. It was found that the velocity depended primarily upon the elastic properties of the material and was almost independent of geometry. The potential value of this approach was apparent, but measurement problems were considerable, and led to the development in France, a few years later, of repetitive mechanical pulse equipment. At about the same time, work was undertaken in Canada and the United Kingdom using electro-acoustic transducers, which were found to offer greater control on the type and frequency of pulses generated. This form of testing has been developed into the modern ultrasonic method, employing pulses in the frequency range of 20-150 kHz, generated and recorded by electronic circuits. Concrete testing is thus at present based largely on pulse velocity measurements using through-transmission techniques. The method has become widely accepted around the world, and commercially produced robust lightweight equipment suitable for site as well as laboratory use is readily available.

If the method is properly used by an experienced operator, a considerable amount of information about the interior of a concrete member can be obtained. However, since the range of pulse velocities relating to practical concrete qualities is relatively small (3.5-4.8 km/s), great care is necessary, especially for site usage. Furthermore, since it is the elastic properties of the concrete which affect pulse velocity, it is often necessary to consider in detail the relationship between elastic modulus and strength when interpreting results. Recommendations for the use of this method are given in BS EN 12504-4, IS 13311 part-1[14] and also in ASTM C597.

2.3.1 Principle of Ultrasonic Pulse Velocity Method

The ultrasonic pulse is generated by an electroacoustical transducer. When the pulse is induced into the concrete from a transducer, it undergoes multiple reflections at the boundaries of the different material phases within the concrete. A complex system of stress waves is developed which includes longitudinal, shear and surface waves. The receiver transducer detects the onset of the longitudinal waves, which is the fastest. Because the velocity of the pulse is almost independent of the geometry of the material through which they pass and depends only on its elastic properties, pulse velocity method is a convenient technique for investigating structural concrete.

The underlying principle of assessing the quality of concrete is that comparatively higher velocities are obtained when the quality of concrete in terms of density, homogeneity and uniformity is good. In case of poorer quality, lower velocities are obtained. If there is a crack, void or flaw inside the concrete which comes in the way of transmission of the pulses, the pulse strength is attenuated and it passes around the discontinuity, thereby making the path length longer. Consequently, lower velocities are obtained. The actual pulse velocity obtained depends primarily upon the materials and mix proportions of concrete. Density and modulus of elasticity of aggregate also significantly affect the pulse velocity.[14]

2.3.2 Pulse Velocity Equipment and Use

The test equipment must provide a means of generating a pulse, transmitting this to the concrete, receiving and amplifying the pulse and measuring and displaying the time taken. The basic circuitry requirements are shown in Figure 2.3. Repetitive

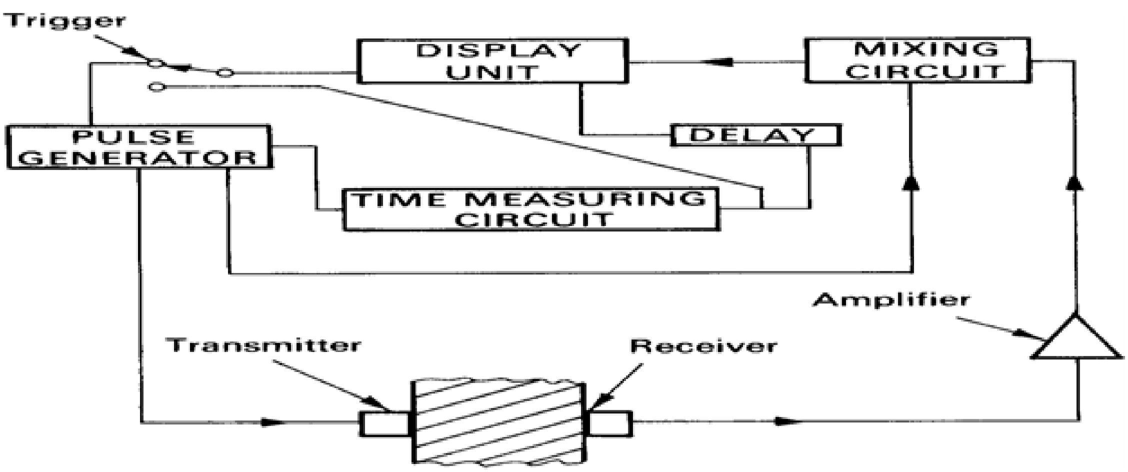

Figure 2.3: Typical UPV testing equipment.

voltage pulses are generated electronically and transformed into wave bursts of mechanical energy by the transmitting transducer, which must be coupled to the concrete surface through a suitable medium. A similar receiving transducer is also coupled to the concrete at a known distance from the transmitter, and the mechanical energy converted back to electrical pulses of the same frequency. The electronic timing device measures the interval between the onset and reception of the pulse and this is displayed either on an oscilloscope or as a digital readout. The equipment must be able to measure the transit time to an accuracy of ± 1 %. To ensure a sharp pulse onset, the electronic pulse to the transmitter must have a rise time of less than one-quarter of its natural period. The repetition frequency of the pulse must be low enough to avoid interference between consecutive pulses, and the performance must be maintained over a reasonable range of climatic and operating conditions.

Use of Ultrasonic Pulse Velocity Method

Operation is relatively straightforward but requires great care if reliable results are to be obtained. One essential is good acoustical coupling between the concrete surface and the face of the transducer, and this is provided by a medium such as petroleum jelly, liquid soap or grease. Air pockets must be eliminated, and it is important that only a thin separating layer exists any surplus must be squeezed out. A light medium, such as petroleum jelly or liquid soap, has been found to be the best for smooth surfaces, but a thicker grease is recommended for rougher surfaces which have not been cast against smooth shutters. If the surface is very rough or uneven, grinding or preparation with plaster of Paris or quick-setting mortar may be necessary to provide a smooth surface for transducer application. It is also important that readings are repeated by complete removal and re-application of transducers to obtain a minimum value for the transit time. Although the measuring equipment is claimed to be accurate to ±0.1 % microseconds, if a transit time accuracy of ±1 % is to be achieved it may typically be necessary to obtain a reading to ±0.7 %s over a 300 mm path length. This can only be achieved with careful attention to measurement technique, and any dubious readings should be repeated as necessary, with special attention to the elimination of any other source of vibration, however slight, during the test.

The path length must also be measured to an accuracy of ±1 %. This should present little difficulty with paths over about 500 mm, but for shorter paths it is recommended that calipers be used. The nominal member dimensions shown on drawings will seldom be adequate.

There are three basic ways in which the transducers may be arranged, as shown in Figure 2.4. These are:

(a) Opposite faces (Direct transmission)

(b) Adjacent faces (Semi-direct transmission)

(c) Same face (Indirect transmission)

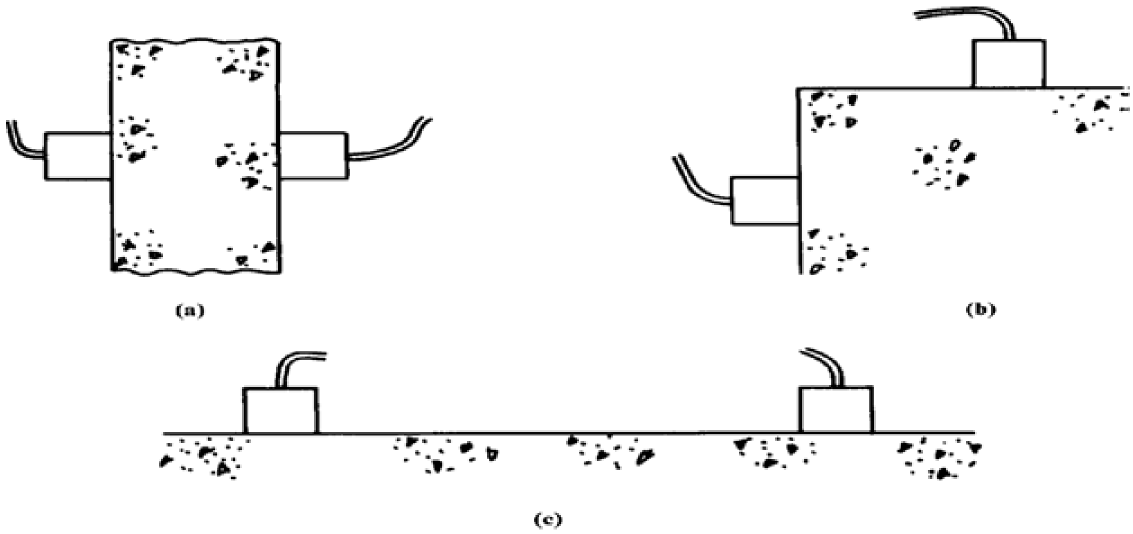

Figure 2.4: Different UPV methods

The quality of concrete in terms of uniformity, incidence or absence of internal flaws, cracks and segregation, etc, indicative of the level of workmanship employed; can thus be assessed using the guidelines given in Table2.1., which have been evolved for characterizing the quality of concrete in structures in terms of the ultrasonic pulse velocity.

Table 2.1: Velocity Criterion for quality grading of concreting as per the IS: 13311 part-1[14]

Pulse velocity(m/sec)	Quality of concrete
4500 and above	Excellent
3500 to 4500	Good
3000 to 3500	Medium
Below 3000	Doubtful

2.3.3 Advantages and Disadvantages

The pulse velocity method is an excellent means for investigating the uniformity of concrete. The test procedure is simple and the equipment is readily available, portable, and it is as easy to use on the construction site and as it is in the laboratory. Because the pulse velocity is truly nondestructive and several tests can be run in a short amount of time, this equipment is becoming more popular as a means for estimating early age concrete strength development. A large number of variables can affect the relation between the strength properties of concrete and its pulse velocity; therefore, it is important that a correlation between pulse velocity and compressive strength be developed for project mixes prior to any measurements in situ.[18]

2.4 Study on Correlation between NDT Results and Compressive Strength

Nash't et al.[1] presented unified relationship connect the results of these tests and correlate them with the results of crushing strength of cubes by using statistical methods in the analyzing process depending on laboratory tests carried on concrete cubes with different mixing ratio and different curing conditions, and finding correlation curves to predict the strength of concrete much better. The regression analysis was done using

STATISTICA ver. 5.5 pc software, whereas this program depends upon the least square theory. Many trials were carried to predict the correlation between rebound no. and crushing strength for the samples, and obtained better correlation by the following power equation:

Sc = 0.788 R1.03, R square = 0.77

The same trials carried to predict the correlation between UPV and Crushing strength, obtained following equation:

SC = 1.19 EXP 0.715U, R square = 0.59

Where:

Sc = crushing strength N/mm2

R = Rebound No. U = UPV (m/sec)

Above equation related to each other to find different regressions and obtained better correlation between R and U presented by the following equation:

Sc = 0.356 R0.866 EXP 0.302, R square = 0.8

Combination of both methods give more accurate results, graphical representation of above relation is presented as shown in Figure 2.5.

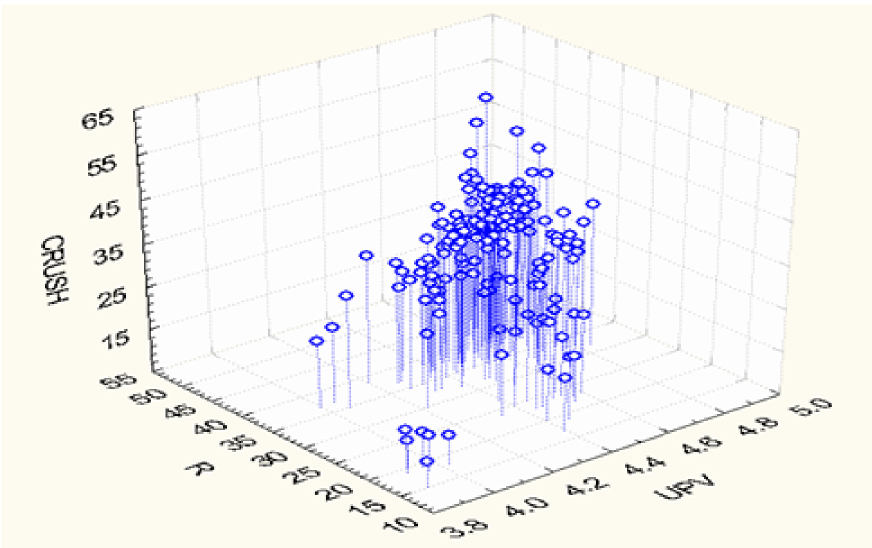

Figure 2.5: Relation between crushing strength, Ultrasonic pulse velocity and Rebound no.

Mahure et al.[**2**] proposed the UPV and strength relationship curves for different concrete mixes/grades used in concrete structures of Tehri Hydro Electric Project, Uttarakhand. The estimated correlation curves are verified to be suitable for prediction of hardened concrete strength with a measured UPV value in the health monitoring of structures under reference during its service period. The UPV measurement and compressive strength tests were carried out on concrete cubes at the age of 7 and 28 days. The relationship developed in the study is case specific as the UPV and the compressive strength of concrete depends on various factors such as cement-mortar paste content, water-cement ratio and coarse aggregate content and its quality, admixtures. Hardened concrete (at an age of 28 days) was selected as the subject for analysis in the current study. It is found that with the same grade of concrete, a clear relationship curve can be drawn to describe the UPV and compressive strength of hardened concrete.
The correlation factors/equations for the simulation curves for M15, M20 and M35 grades of concrete are given below as eq.1, eq.2 and eq.3 respectively:
CS = 9.502UPV - 18.89 (1) R square = 0.244
CS = 2.701UPV + 17.15 (2) R square = 0.027
CS = 4.104UPV + 19.23 (3) R square = 0.025
where CS and UPV represent the compressive strength (MPa) and the ultrasonic pulse velocity (km/s), respectively.

Hajjeh[**3**] In this study, the destructive and non-destructive tests were performed on totally 120 laboratory made concrete cubes. Regression analysis using MATLAP software was carried out. Simple relationships were determined and correlated between non-destructive testing (NDT) named as schmidt rebound hammer test and concrete destructive compression test. The Schmidt rebound hammer is principally a surface hardness tester with an apparent theoretical relationship between the strength of concrete and the rebound number of the hammer. Schmidt hammer was applied in both vertical and horizontal positions. The standard concrete cubes were prepared with various mix proportions that yielded standard cubes crushing strengths fcu within a range of 10 to 35 MPa.

For vertical and horizontal position, three relation generated linear, quadratic, cubic equation between crushing strength and rebound no.

Vertical position

f = 0.9888x1 - 14.2361 (linear)

f = 0.0114x12 + 0.8497 x1- 30.1834 (Quadratic)

f = -0.0032x13+0.3497x12+134.7075 (cubic)

Horizontal position

f = 1.050x1 - 11.8402(linear)

f = 0.0078x12 + 1.5979 x1- 21.1986 (Quadratic)

f = -0.0029x13+0.2975x12+94.4267 (cubic)

f = crushing strength (MPa)

x1 = rebound no

Jain et al.[4] presented results of an experimental investigation on the effects of concrete materials, mix and workmanship related variables, on the rebound Number and ultrasonic pulse velocity of concrete, are presented. The investigations aimed at developing a method of combined use of both the non-destructive tests for assessment of strength of concrete with greater accuracy. Workmanship variables included different lengths of moist curing, incomplete compaction and intentionally induced flaws. Rebound hammer readings increased with the compressive strength of concrete. Ultrasonic pulse velocity values were greatly influenced by the cements and aggregate, extent of moist curing and presence of flaws and voids in concrete, more than their influence on the measured strengths. This demonstrates the limitation of using ultrasonic pulse velocity tests for estimating compressive strength of concrete.IS: 13311 advocates combined use of Ultrasonic pulse velocity (UPV) and rebound hammer tests for assessment of concrete strength in structures with greater reliability. However, the approach is qualitative. Adopting such an approach in a quantitative manner, multiple regressions of both rebound numbers and ultrasonic pulse velocity on compressive strength of concrete, led to a series of graphs for better assessment of strength.

Aydin and Saribiyik[5] correlated between non-destructive testing (NDT) named as schmidt rebound hammer test and concrete destructive compression test. The schmidt rebound hammer is principally a surface hardness tester with an apparent theoretical relationship between the strength of concrete and the rebound number of the hammer. In order to calibrate the schmidt hammer with the various aged concrete, cube specimens of 28-90 days and a number of core samples from different reinforced concrete structures have been tested. This calibration has been done to get the related constant obtained from schmidt and compression tests. The best fit correction factors for the concrete compressive strength-schmidt rebound hammer relationship are obtained through processing correlation among the data sets. The correction factors can be easily applied to in situ concrete strength as well as existing concrete structures.

Al-Ameeri et al.[6] constructed a mathematical models to predict some mechanical properties of concrete from Nondestructive testing, in addition the study of (NSC and HSC) properties (density, compressive strength ,modulus of elasticity and modulus of rupture) of concrete grade (20-100) MPa) by using NDT methods namely; Schmidt Hammer test (RN)and Ultrasonic Pulse Velocity test (UPV) with destructive test methods at different four ages (7, 28, 56 and 90) days. This study used ready mixes (1:2:4 and 1:1.5:3) and design mixes (C40, C50, C60, C70, C80, C90 and C100), in order to find the relationship between these properties. Of concrete with (RN and UPV), and compressive strength of concrete-combined NDT(RN and UPV) relationship, for all mixes (as freelance and as group). The results of compressive strength for both types of concrete NSC and HSC exhibit an increase with the increase of bulk density and time of curing. Also, the results show a good correlation between compressive strength and (RN) and the relationship between the two is not affected by maximum aggregate size (MAS). Also, a good correlation between compressive strength and ultrasonic pulse velocity (UPV) and the value of UPV in HSC increased 8% from 28 days to 90 days. Also, the results indicated that the percentages of increase in relationship between static modulus of elasticity and compressive strength for 28 days to 90 days are 15 % at low strength, 5.6 % at high strength and the relationship between static modulus of elasticity and rebound number for 28 days to 90 days is3.3 %.The results indicate that the percentage of increase in direct method to surfacing method of UPV for (7, 28, 56 and 90) days is (7 %, 5 %, 4 % and 3.5 %) respectively, due to the higher the continuity of hydration of cement. Also, the pulse velocity of concrete is decreased by increasing the cement paste, especially for concrete with high w/c.

fcu =1.5676 RN -18.537 [28 days, R square = 0.964]

fcu =1.5896 RN -10.66 [90 days, R square = 0.973]

fcu =0.5993 $e^{0.9981v}$ [28 days, R square = 0.9755]

fcu = 0.4736 $e^{1.10351v}$ [90 days, R square = 0.9753]

The using combination of test results of UPV and RN to estimate compressive strength of multiple linear regression analysis using (SPSS.19) computer program to obtained mathematical expression, graph it by (axcel.2010), it becomes easy to obtain an expression which represents the relation between UPV and rebound number versus compressive strength as shown in Figure 2.6.

fcu = 0.42 RN0.63$e^{0.58v}$ [28 days, R square = 0.9929]

fcu = 0.25 RN0.45$e^{0.85v}$ [90 days, R square = 0.9954]

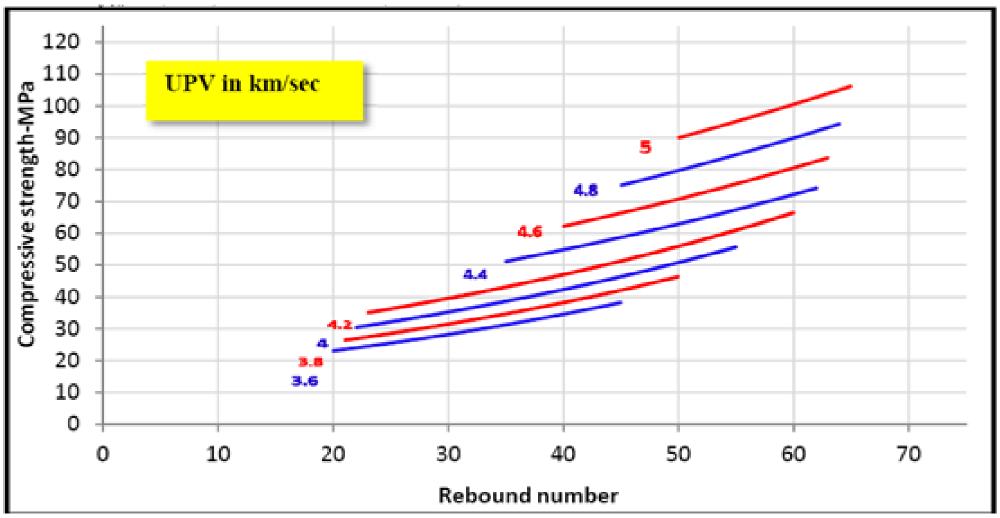

Figure 2.6: Relation between crushing strength, UPV and Rebound no.

Demirboga et al.[8] suggested that, ultrasound is used to evaluate the compressive strength of concrete with mineral admixtures. In addition, the relationship between ultrasound velocity and compressive strength of concrete are evaluated. High-volume fly ash (FA), blast furnace slag (BFS) and FA+ BFS are used as the mineral admixtures in replacement of Portland cement (PC). Compressive strength and ultrasonic pulse velocity (UPV) were determined at the 3, 7, 28 and 120 day curing period. Both compressive strength and UPV were very low for all the levels of mineral admixtures at an early age of curing, especially for samples containing FA. However, with the increase of curing period, both compressive strength and UPV of all the samples increased. The relationship between UPV and compressive strength was exponential for FA, BFS and FA+ BFS. However, constants were different for each mineral admixture and each level replacement of PC.

Bogas et al.[9] evaluated compressive strength of a wide range of structural lightweight aggregate concrete mixes by the non-destructive ultrasonic pulse velocity method. This study involves about 84 different compositions tested between 3 and 180 days for compressive strengths ranging from about 30 to 80 MPa. The influence of several factors on the relation between the ultrasonic pulse velocity and compressive strength is examined. These factors include the cement type and content, amount of water, type of admixture, initial wetting conditions, type and volume of aggregate and the partial replacement of normal weight coarse and fine aggregates by lightweight aggregates. It is found that lightweight and normal weight concretes are affected differently by mix design parameters. In addition, the prediction of the concretes compressive strength by means of the non-destructive ultrasonic pulse velocity test is studied. Based on the dependence of the ultrasonic pulse velocity on the density and elasticity of concrete, a simplified expression is proposed to estimate the compressive strength, regardless the type of concrete and its composition. More than 200 results for different types of aggregates and concrete compositions were analyzed and high correlation coefficients were obtained.

2.5 Summary

In this chapter brief explanation of various NDT method, their principle, use, advantages & disadvantages are carried out. Also contain various correlation of NDT results with mechanical properties of concrete. In most of paper correlation between NDT results and compressive strength are included. From this study combination of both NDT method give more reliable results for predicting the strength.

Chapter 3

Experimental Programme

3.1 General

The chapter describes the material properties which have been used in concrete as a fine aggregate, coarse aggregates and super plasticizer. Further concrete mix proportion, methods followed for the casting and curing of the concrete specimens are given. This is followed by description of types of specimens used, test parameters, and test procedures. Different types of tests with their procedures are explained in detail in this chapter.

3.2 Material

Materials used during this experimental work are cement, aggregates, water, super plasticizer. Details about various ingredients of the concrete are as follows.

3.2.1 Cement

Ordinary Portland cement of OPC53 grade and PPC are used. Various tests are performed to find the physical properties of cement. Physical properties of OPC and PPC are as shown in Table 3.1 & Table 3.2 respectively.

Table 3.1: Physical properties of cement(OPC)

Properties	Results Achieved	Specification in IS 12269:1987 for 53 grade OPC
Fineness in m^2/Kg	351	Min 225
Soundness By Le chatelier method in mm	0.4	Max. 10
Initial setting time in minutes	35	Min. 30
Final setting time in minutes	240	Max. 600
3 days compressive strength in MPa	28.75	Min. 27
7 days compressive strength in MPa	39.85	Min. 37
28 days compressive strength in MPa	54.47	Min. 53

Table 3.2: Physical Properties of Cement(PPC)

Properties	Results Achieved	Specification in IS: 1489 for PPC
Fineness in m^2/Kg	351	Min 225
Soundness By Le chatelier method in mm	0.4	Max. 10
Initial setting time in minutes	120 ± 15	Min. 30
Final setting time in minutes	180 ± 15	Max. 600
3 days compressive strength in MPa	28 ± 2	Min. 16
7 days compressive strength in MPa	38 ± 2	Min. 22
28 days compressive strength in MPa	50 ± 2	Min. 33

3.2.2 Aggregates

Locally available 10 mm and 20 mm aggregates crushed have been used as coarse aggregates. Locally available river sand is used as fine aggregate in the mixes. Tests for fine and coarse aggregates were conducted as per IS : 2386-1963[11]and IS : 383-1970[12]. The sieve analysis of the coarse aggregate is shown in Table 3.3 and Table 3.4 for 20 mm and 10 mm respectivly. The sieve analysis of the fine aggregate is shown in Table 3.5.

Table 3.3: Gradation of Coarse Aggregate (20 mm)

Sieve Size	Mass Retained (gms)	% of Mass retained	Cumulative % of Mass retained	Cumulative % of Passing
80 mm	0.0	0.0	0.0	100.0
40 mm	0.0	32.0	0.0	100.0
20 mm	640.0	32.0	32.0	68.0
10 mm	1280	64.0	96.0	4.0
4.75 mm	80.0	4.0	100.0	0.0
2.36 mm	0.0	0.0	100.0	0.0
1.18 mm	0.0	0.0	100.0	0.0
600	0.0	0.0	100.0	0.0
300	0.0	0.0	100.0	0.0
150	0.0	0.0	100.0	0.0
Lower than 150	0.0	0.0	-	0.0
Total	2000	100	728	
Fineness Modulus = 728/1000 = 7.28				

Table 3.4: Gradation of Coarse Aggregate (10 mm)

Sieve Size	Mass Retained (gms)	% of Mass retained	Cumulative % of Mass retained	Cumulative % of Passing
80 mm	0.0	0.0	0.0	100.0
40 mm	0.0	0.0	0.0	100.0
20 mm	0.0	0.0	0.0	100.0
10 mm	51.0	5.1	5.1	94.9
4.75 mm	913.0	91.3	96.4	3.6
2.36 mm	36.0	3.6	100.0	0.0
1.18 mm	0.0	0.0	100.0	0.0
600	0.0	0.0	100.0	0.0
300	0.0	0.0	100.	0.0
150	0.0	0.0	100.0	0.0
Lower than 150	0.0	0.0	-	0.0
Total	1000	100	601.5	
Fineness Modulus = 601.5/100 = 6.01				

Table 3.5: Gradation of Fine Aggregate

Sieve Size	Mass Retained (gms)	% of Mass retained	Cumulative % of Mass retained	Cumulative % of Passing
80 mm	0.0	0.0	0.0	100.0
40 mm	0.0	0.0	0.0	100.0
20 mm	0.0	0.0	0.0	100.0
10 mm	0.0	0.0	0.0	100.0
4.75 mm	0.0	0.0	0.0	100.0
2.36 mm	192.0	19.2	19.2	80.8
1.18 mm	215.0	21.5	40.7	59.3
600	77.0	7.7	48.4	51.6
300	362.0	36.2	84.6	15.4
150	117.0	11.7	96.3	3.7
Lower than 150	37.0	3.7	-	0.0
Total	1000	100	245	
Fineness Modulus = 245/100 = 2.45 and zone III				

3.2.3 Superplasticizer

To achieve proper workability of M50 grade concrete superplastisizer has been used. Master Polyheed 8981 has been used to improve workability of fresh concrete. Table 3.6 shows the chemical properties of admixture.

Table 3.6: Chemical properties of Admixture

Parameter	Specifications (AS PER IS 9103)	Results
Physical state	Reddish brown liquid	Reddish brown liquid
Chemical name of active ingradient	Modified polymeric ether	Modified polymeric ether
Relative density at 25^0C	1.08 ±0.01	1.082
PH	Min. 6	6.91
Chloride ion content(%)	Max 0.2	0.0014
Dry material content	24 ±(5%)	22.77

3.3 Concrete Mix Design

According to IS 10262- 2009[16] and IS 456-2000[17] mix design of M15, M20, M30, M40, M50 are finalized based on trial. For all grades of concrete both OPC and PPC cement have been used used for casting the specimens.The amount of 0.8 % of total mass of cement was taken as a super plasticizer for M50 grade of concrete. No superplastisizer is used for remaining grades of concrete. Table 3.7 presents concrete mix proportioning for all concrete grades.

Table 3.7: Finalized concrete mix design

Parameters	M15	M20	M25	M30	M40	M50
Cement(kg/m^3)	300	350	375	400	433	450
Fine Aggregate(kg/m^3)	750	708	696	665	655	634
Coarse Aggregate(kg/m^3)	1305	1280	1264	1242	1220	1190
Water(kg/m^3)	165	175	176	180	160	157
W/C Ratio	0.55	0.5	0.47	0.45	0.37	0.35
Superplasticizer(%)	-					0.8

3.4 Casting and Curing of Concrete Specimens

This process plays very important role with respect to all properties of fresh as well as hardened concrete. First of all weighing and batching process of all ingredients of concrete i.e. cement, fine aggregate and coarse aggregate i.e. 10 mm and 20 mm, water and super plasticizer is to be done at laboratory temperature with accuracy before starting the mixing process. Dry mix is to be made in the drum mixer for 20 to 30 seconds to make the consistent mix by mixing only fine and coarse aggregate first. Cement is added in to mix. After mixing of all ingredient is to be done then gradually water is added in to the mix. Moulds of the specimens are made ready for pouring the fresh concrete in it by applying proper lubricant. The mixing of concrete is done using Drum mixer as shown in Figure 3.1. The mixing process for all the mixes is same as conventional mixing method. The mixing is continued for 3 to 4 minutes. For the concrete grade M50, the chemical admixture i.e. superplasticizer is to be added to the water prior to adding in the concrete mix.

Figure 3.1: Drum mixture for mixing of concrete

The concrete is poured into the moulds specimens immediately after the mixing of in three layers. Each layer of concrete mix is compacted using 20 mm dia. tamping rod with 25 to 30 manual strokes.The concrete mix is vibrated further until using table vibrator which is shown in Figure 3.2and make sure that over compaction is not to be done.Figure 3.3 shows the concrete specimens is to be casted.

Figure 3.2: Table vibrator for compacting concrete mix

Figure 3.3: concrete specimens

After compaction, concrete surface is leveled using trovel and sides of the mould are stuck bye hammer in order to expel air if any present inside and make cube surfaces smooth. After casting, the concrete specimens remain as rest period of 24 hours as per IS : 516-1959[13]and then remove the mould. Curing of concrete specimens are to be done for 28 days. Immersion curing is to be adopted for the concrete specimens. Curing of concrete specimens is shown in Figure 3.4.

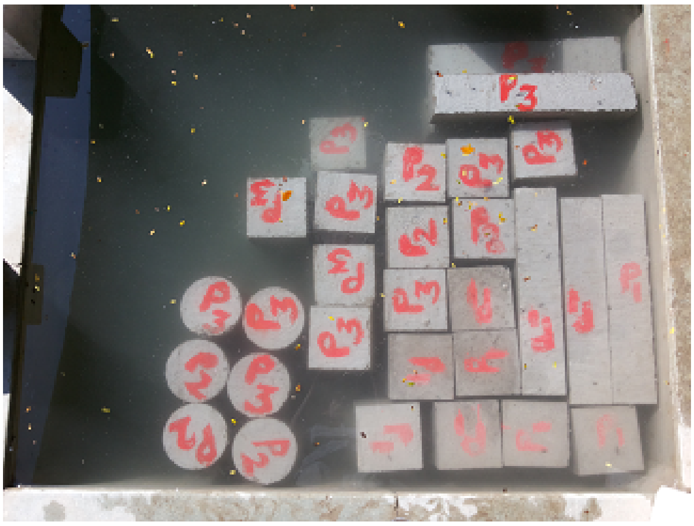

Figure 3.4: Curing of concrete specimens

3.5 Testing of Concrete Specimens

3.5.1 Compressive Strength

The compressive strength of concrete has been evaluated using 2000 kN capacity hydraulic testing machine. For compressive strength test cube of size 150mm × 150mm × 150mm are tested in compression accordance with test procedure given in IS : 516-1959[13]. Figure 3.5 shows the cube specimen which is being tested in compression testing machine.

Figure 3.5: Compression testing machine

Finding out compressive strength of cube specimen following Eq 3.1 is used :

$$Compressive\ strength\ of\ concrete\ (N/mm^2) = \frac{P \times 10^3}{A} \tag{3.1}$$

Where

P = failure of load of cube (kN)

A = area of concrete cube specimen in mm^2 (150 mm × 150 mm)

3.5.2 Flexural Strength

The flexural strength for concrete specimens is measured on a 250 kN capacity hydraulic testing machine as shown in Figure 3.6. For every flexural strength test, beam of size 100mm × 100mm × 500mm has been tested in accordance with the test procedures given in IS : 516-1959[13].

Figure 3.6: Testing of Flexural strength

Finding out Flexural strength of the beam specimens following Eq 3.2 is used :

$$Flexural\ strength\ of\ concrete\ (N/mm^2) = \frac{P \times L \times 10^3}{b \times d^2} \tag{3.2}$$

Where

P = Failure Load of Beam(kN)

L = Span of Beam (400 mm)

b = Width of Beam (100 mm)

d = Depth of Specimen (100 mm)

3.5.3 Split Tensile Strength

The Split Tensile strength of concrete has been evaluated using 2000 kN capacity hydraulic testing machine. For this test 150 dia. and 300 mm height cylinder specimen is tested as per the test procedure given in IS : 5816-1999[19]. This method is used for finding out tensile strength of concrete.

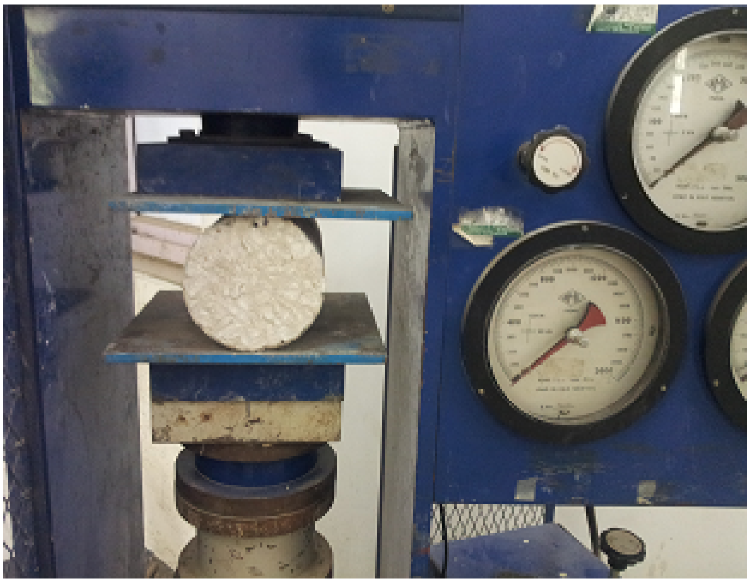

Figure 3.7: Testing of Split tensile strength

For finding out split tensile strength of the cylinder specimens following Eq 3.3 is used.

$$Split\ Tensile\ strength\ of\ concrete\ (N/mm^2) = \frac{2 \times P \times 10^3}{\Pi \times L \times d} \tag{3.3}$$

Where

P = Failure load of cylinder (kN)

L = Height of Specimen (300 mm)

d = Diameter of Specimen (150 mm)

3.5.4 Modulus of Elasticity

Modulus of Elasticity of concrete specimens has been evaluated with the help of extensometer.Cylinder specimen of 150 mm dia. and 300 mm height has been used for finding out the modulus of elasticity of concrete as per the test procedure given in IS : 516-1959.[13]. The extensometers are to be fixed with the recording points at the same end. The specimen shall be immediately placed in the testing machine and accurately centred. The load shall be applied continuously and without shock.One third load of Average cube compressive is applied. Displacement is to be measured at certain load interval. From above results plot is to be drawn stress Vs. strain. Slope of the Above plot give modulus of elasticity of cylinder specimen. Arrangement of specimen is as shown in Figure 3.8.

Figure 3.8: Testing of Modulus of Elasticity

3.5.5 Surface Hardness Test

Surface hardness test is used for finding the the hardness of concrete surface.rebound hammer is used to find out the surface hardness of concrete surface. Rebound hammer is applied on the concrete surface either perpendicular or horizontal test procedure given in IS 13311-1991(part 2)[15]. Based on the scale given on rebound hammer. On cube specimen each face 5 readings are taken, hence total 30 readings for each position of rebound hammer. Same case are adopted for beam and cylinder specimens.

Figure 3.9: Rebound hammer in horizontal and Horizontal position for cube

Figure 3.10: Rebound hammer in Vertical and Horizontal position for cylinder

3.5.6 Ultrasonic Pulse Velocity

The quality of concrete is measured by the ultrasonic pulse velocity (UPV) test. In this method, an ultrasonic pulse of longitudinal vibration is produced by an electro-acoustical transducer which is held in contact with surface of concrete. Proper airtight medium like grease is applied between the transducers and the concrete surface to avoid the entrapment of air. Both Direct and semi direct method is adopted for cube specimes. For beam and cylinder specimen direct method is adopted. The test procedure is given in IS 13311-1991(part 1)[14].

Figure 3.11: UPV testing of cube specimen by Direct and Semi direct method

Figure 3.12: UPV testing of Beam and cylinder specimen by Direct method

3.6 Testing of Reinforced Concrete Specimens

Testing of RCC laboratory specimens are carried out. Both rebound hammer and UPV methods are adopted. Also the readings are taken on site on RCC reclaimares of gantry girder near bharuch. Due to reinforcement in specimens there are no change in rebound no. because it gives surface hardness of concrete. But presence of reinforcement increase the UPV results because lesser time required for waves to pass through concrete via reinforcement. Testing of RCC specimens are carried out by both vertcal & horizontal position of rebound hammer and direct & semi direct method for UPV. Procedure of testing of RCC members on site and laboratory specimens are as shown in Figure 3.13, Figure 3.14, Figure 3.14, Figure 3.14.

Figure 3.13: Surface hardness testing of RCC members on site

Figure 3.14: UPV testing of RCC members on site

Figure 3.15: Surface hardness testing of RCC members in Laboratory

Figure 3.16: UPV testing of RCC members in Laboratory

Chapter 4

Test Results

4.1 General

This chapter contains test results of non-destructive testing i.e. rebound hammer and UPV of concrete specimens of different grade i.e. M15, M20, M25, M30, M40, M50 of both OPC based concrete and PPC based concrete at various age period of 7, 28, 90 days followed by compressive strength of concrete. This chapter also includes test results of mechanical properties such as flexural strength, split Tensile strength, modulus of elasticity of of concrete at age of 28 days.From above test results correlation is done between NDT results and mechanical properties of OPC and PPC based concrete for for different age.

4.2 Correlation of Compressive Strength and NDT Results for OPC Based Concrete

For all age 7, 28, 90 days first of all rebound hammer results are to be taken by keeping rebound hammer in horizontal and vertical position. At 7 days 3 nos. of cube specimens were tested for NDT results and compressive strength. For 28 and 90 days 6 nos.of specimens were tested. In each cube total 30 readings are to be taken, 5 from each face for horizontal and vertical position of rebound hammer. Then UPV results are to be taken by direct and semi direct method. After non-destructive testing compressive strength of concrete specimens are to be found by compression testing machine.28 days compressive strength for M15, M20, M25, M30, M40, M50 grades are compared with target mean strength of each grade for OPC based concrete. From the Table 4.1, it is observed in case of OPC based concrete experimental compressive strength is higher than target mean compressive strength.

Table 4.1: Strength Comparision

Grade	Compressive strength(MPa)(OPC)	Compressive strength(MPa)(PPC)	Target mean strength(MPa)
M15	24.15	20	20.78
M20	27.4	25.59	26.6
M25	32.12	29.11	31.6
M30	38.32	37.26	38.25
M40	48.36	46.52	48.25
M50	58.46	56.22	58.25

Above results for 7,28 and 90 days are presented for OPC based concrete in Table4.2,Table4.3 and Table4.5 respectively.

Table 4.2: 7 days results of compressive strength of OPC based concrete

Mix	Density(kg/m^3)	Rebound no. (vertical)	Rebound no. (horizontal)	UPV(m/sec) (direct method)	UPV(m/sec) (semi direct method)	compressive strength(MPa)	Average compressive strength(MPa)
M15	2510	21.64	24.52	4050	3850	16.25	17.97
	2595	22.42	23.89	4110	3910	18.67	
	2475	23.82	25.34	3990	3835	19	
M20	2530	24.34	28.53	4087	4030	24.44	24.3
	2554	24.51	28.84	4189	4075	24.89	
	2604	22.77	26.53	4230	4178	23.56	
M25	2613	28.64	30.81	4159	4050	25	24.78
	2568	30.12	31.25	4151	4080	25.33	
	2595	26.23	28.62	4133	4110	24	
M30	2450	30.81	32.28	4170	3945	26.35	27.21
	2447	29.4	30	4250	4050	26	
	2485	33.25	35.41	4319	4175	29.28	
M40	2524	38.96	40.5	4374	4292	36.67	33.97
	2521	34.28	36.21	4366	4213	31.25	
	2542	37.1	37.4	4390	4320	34	
M50	2512	42.62	44.28	4400	4329	41.36	42.67
	2536	44.36	46.42	4425	4365	44.44	
	2554	43.85	45.7	4532	4390	42.22	

Table 4.3: 28 days results of compressive strength of OPC based concrete

Mix	Density(kg/m^3)	Rebound no. (vertical)	Rebound no. (horizontal)	U.P.V(m/sec) (direct method)	U.P.V(m/sec) (semi direct method)	compressive strength(MPa)	Average compressive strength(MPa)
M15	2589.9	30.21	31.5	4141	4118	29.78	24.15
	2542.2	26.51	28.33	4094	4062	25.34	
	2518.5	25.23	26.14	4019	3973	24.45	
	2524.4	22.73	24.3	4052	4037	20.89	
	2554.1	24.53	26.78	4125	3872	24.89	
	2530.4	20.56	21.73	4092	3994	19.56	
M20	2604.4	23.03	25.16	4119	3965	22	27.4
	2498	27.56	29.4	4002	3962	26.44	
	2610.4	33.61	35.56	4169	3891	32	
	2560	25.2	28	4081	4148	21.78	
	2651.9	26.76	29.33	4366	4280	23.56	
	2648.9	32.03	35.66	4203	4020	28.44	
M25	2643	30.73	33.13	4382	4168	28.89	32.12
	2524	29.67	32.8	4220	4003	29.78	
	2616	30.83	32.67	4332	4251	31.11	
	2613	31.07	33.1	4312	4180	28.89	
	2596	30.27	34.13	4302	4008	33.11	
	2546	31.07	32.63	4263	4202	30.22	

Table 4.4: 28 days results of compressive strength of OPC based concrete

M30	2436	38.56	40.25	4415	4325	38.44	38.32
	2483	38.25	39.54	4464	4450	37	
	2474	40.64	42.34	4438	4435	39.11	
	2465	38.86	40	4434	4390	38	
	2450	37.64	38.36	4387	4295	37.5	
	2444	41.62	43.12	4417	4375	39.33	
M40	2533	45.12	46.85	4415	4434	46.22	48.36
	2560	42.32	43.89	4464	4516	44	
	2507	45.32	47.21	4438	4494	47.33	
	2548	46.86	48.2	4434	4476	48	
	2503	46.68	48.16	4387	4480	48.89	
	2459	46.95	48.64	4417	4499	49.78	
M50	2563	50.36	51.89	4613	4472	53.78	58.46
	2533	54.26	55.45	4559	4593	58.67	
	2566	53.21	55.12	4640	4454	56	
	2578	56.12	57.34	4723	4479	59.78	
	2575	56.42	57	4694	4503	57.78	
	2560	55.46	57.74	4583	4536	58.22	

Table 4.5: 90 days results of compressive strength of OPC based concrete

Mix	Density(kg/m^3)	U.P.V(m/sec) (direct method)	U.P.V(m/sec) (semi direct method)	Rebound no. (vertical)	Rebound no. (horizontal)	compressive strength(MPa)	Average Compressive strength(MPa)
M15	2589.9	4230	4185	30.21	31.5	29.78	28.64
	2542.2	4195	4190	29.14	30.18	28.5	
	2518.5	4216	4096	29.1	29.94	27.65	
M20	2584	4290	4210	32.21	33.54	30.25	29.44
	2654	4385	4232	31.65	32.84	29.64	
	2594	4345	4196	30.03	31.66	28.44	
M25	2636	4490	4265	35.12	36.54	33.54	33.71
	2596	4375	4186	36.54	37.21	34.64	
	2554	4363	4310	33.66	34.63	32.96	
M30	2584	4450	4395	41.25	41.56	40.74	41.98
	2612	4464	4450	43.42	43.96	42.36	
	2698	4550	4510	43.14	43.56	42.84	
M40	2634	4565	4434	48.72	49.1	48.56	48.72
	2646	4586	4485	48.32	48.89	48.28	
	2558	4610	4421	49.32	50.21	49.33	
M50	2726	4722	4515	60.42	61.21	60.24	59.27
	2687	4694	4503	59.84	60.24	59.34	
	2654	4680	4510	58.46	59.14	58.22	

Regression analysis were conducted using Ms Excel software to study the correlation between NDT results and compressive strength of standard concrete cube for the both positions under consideration. Graphical representation of correlation between Compressive strength and NDT results for age of 7 days for OPC based concrete are as shown in Figure 4.1, Figure 4.2, Figure 4.3, Figure 4.4.

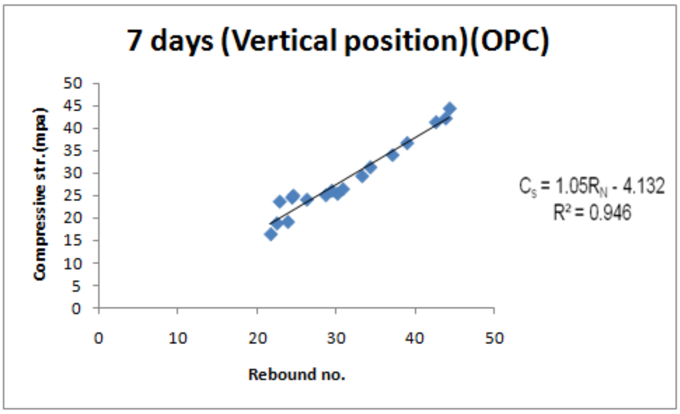

Figure 4.1: Correlation between Compressive strength and Rebound no.(vertical position) for 7 days OPC

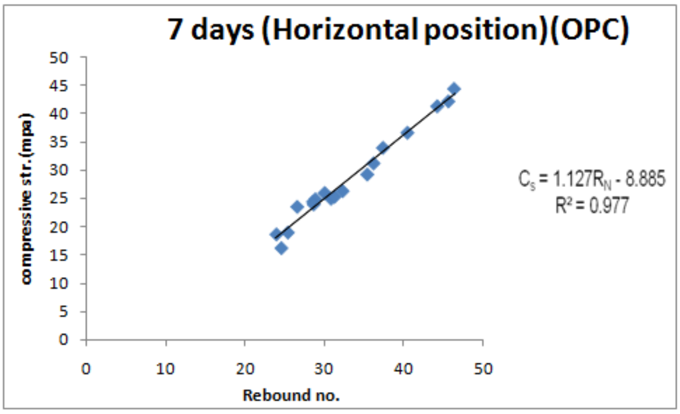

Figure 4.2: Correlation between Compressive strength and Rebound no.(Horizontal position) for 7 days OPC

The scatter plot (Figures 4.1 & 4.2) representing the rebound no versus concrete compressive strength could give the following linear equations are concluded for the predicted values of the concrete compressive strength(MPa) at 7 days for OPC based concrete :

$$S_c = 1.05R_N - 4.132\ (Vertical\ position) \tag{4.1}$$

$$S_c = 1.127R_N - 8.825\ (Horizontal\ position) \tag{4.2}$$

Where,

S_c = Compressive strength of concrete(N/mm^2)

R_N = Rebound no.

R square value for Eq.4.1 and Eq.4.2 are 0.946 and 0.977 respectively. 0.946 value explained that 94.6 % of the variability for the data around the regression line and 5.4 % of the residual data could not explained by Eq.4.1. In the case of Eq.4.2 97.7 % of the variability for the data around the line and 2.3 % remain unexplained.

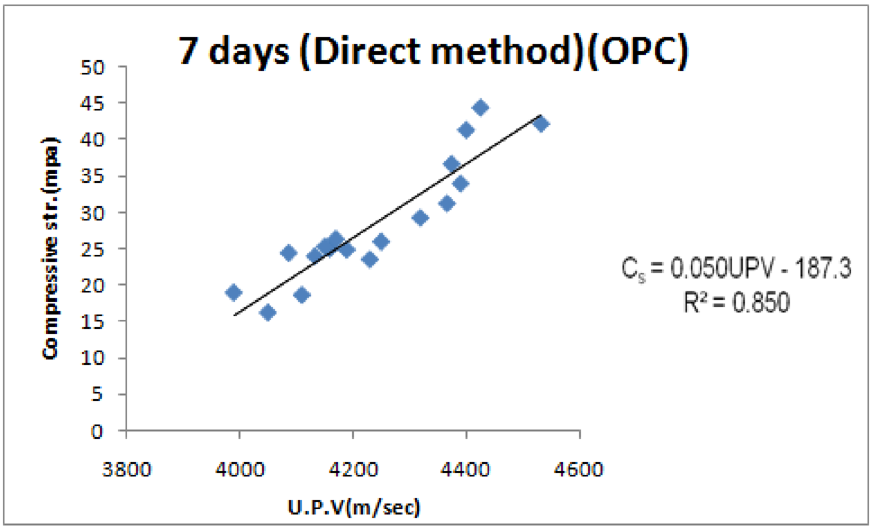

Figure 4.3: Correlation between Compressive strength and UPV(Direct method) for 7 days OPC

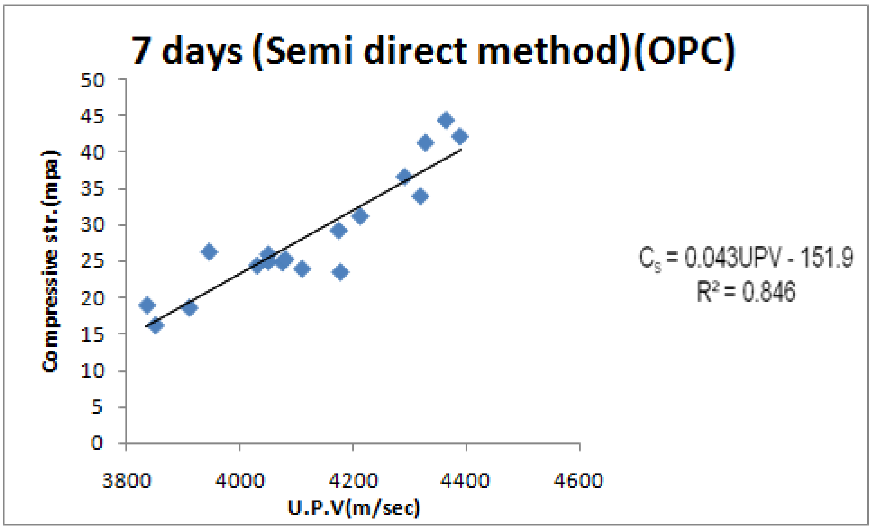

Figure 4.4: Correlation between Compressive strength and UPV(Semidirect method) for 7 days OPC

The scatter plot (Figures 4.3 & 4.4) representing the UPV results versus concrete compressive strength could give the following linear equations are concluded for the predicted values of the concrete compressive strength(MPa) at 7 days for OPC based concrete :

$$S_c = 0.05UPV - 187.3 \ (Direct\ method) \tag{4.3}$$

$$S_c = 0.043UPV - 151.9 \ (Semidirect\ method) \tag{4.4}$$

Where,

S_c = Compressive strength of concrete(N/mm^2)

UPV = Ultrasonic pulse velocity(m/sec)

R square value for Eq.4.3 and Eq.4.4 are 0.850 and 0.846 respectively. 0.850 value explained that 85 % of the variability for the data around the regression line and 15 % of the residual data could not explained by Eq.4.3. In the case of Eq.4.4 84.6 % of the variability for the data around the line and 15.4 % remain unexplained.

Graphical representation of correlation between Compressive strength and NDT results for age of 28 days for OPC based concrete are as shown in Figure 4.5, Figure 4.6, Figure 4.7, Figure 4.8.

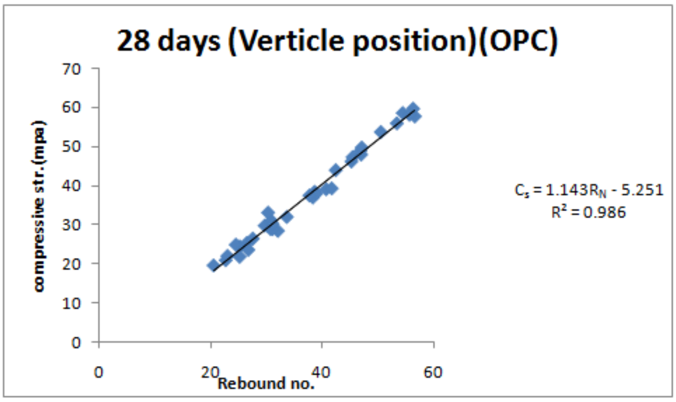

Figure 4.5: Correlation between Compressive strength and Rebound no.(Vertical position) for 28 days OPC

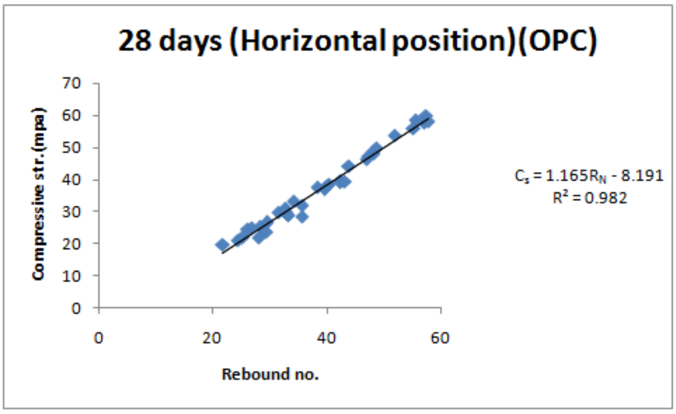

Figure 4.6: Correlation between Compressive strength and Rebound no.(Horizontal position) for 28 days OPC

The scatter plot (Figures 4.5 & 4.6) representing the rebound no versus concrete compressive strength could give the following linear equations are concluded for the predicted values of the concrete compressive strength(MPa) at 28 days for OPC based concrete :

$$S_c = 1.143R_N - 5.251\ (Vertical\ position) \tag{4.5}$$

$$S_c = 1.165R_N - 8.191\ (Horizontal\ position) \tag{4.6}$$

Where,

S_c = Compressive strength of concrete(N/mm^2)

R_N = Rebound no.

R square value for Eq.4.5 and Eq.4.6 are 0.986 and 0.982 respectively. 0.986 value explained that 98.6 % of the variability for the data around the regression line and 1.4 % of the residual data could not explained by Eq.4.5. In the case of Eq.4.6 98.2 % of the variability for the data around the line and 1.8 % remain unexplained.

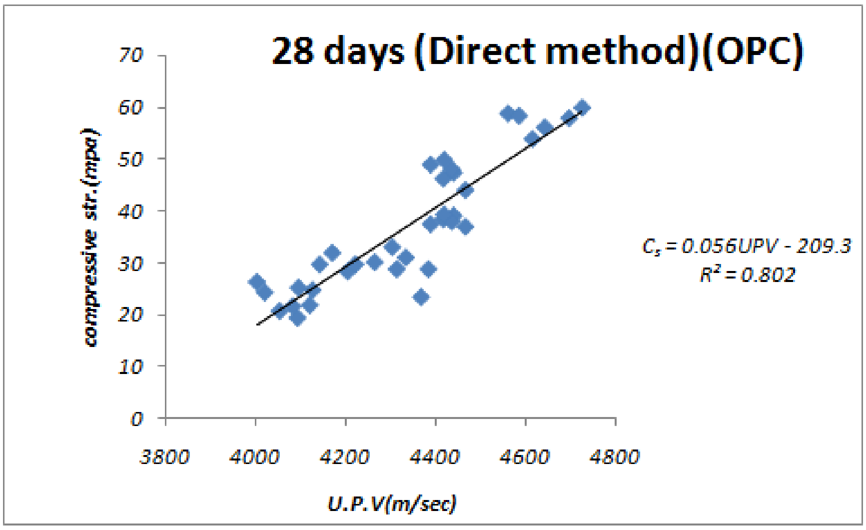

Figure 4.7: Correlation between Compressive strength and UPV(Direct method) for 28 days OPC

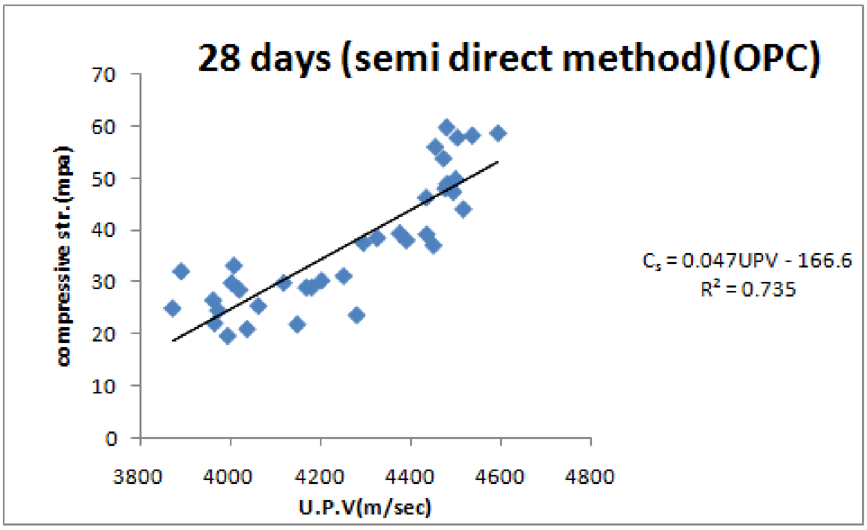

Figure 4.8: Correlation between Compressive strength and UPV(Semidirect method) for 28 days OPC

The scatter plot (Figures 4.7 & 4.8) representing the UPV results versus concrete compressive strength could give the following linear equations are concluded for the predicted values of the concrete compressive strength(MPa) at 28 days for OPC based concrete :

$$S_c = 0.056UPV - 209.3\ (Direct\ method) \tag{4.7}$$

$$S_c = 0.047UPV - 166.6\ (Semi\ direct\ method) \tag{4.8}$$

Where,

S_c = Compressive strength of concrete(N/mm^2)

UPV = Ultrasonic pulse velocity(m/sec)

R square value for Eq.4.7 and Eq.4.8 are 0.802 and 0.735 respectively. 0.802 value explained that 80.2 % of the variability for the data around the regression line and 19.8 % of the residual data could not explained by Eq.4.7. In the case of Eq.4.8 73.5 % of the variability for the data around the line and 26.5 % remain unexplained.

Graphical representation of correlation between Compressive strength and NDT results for age of 90 days for OPC based concrete are as shown in Figure 4.9, Figure 4.10, Figure 4.11, Figure 4.12.

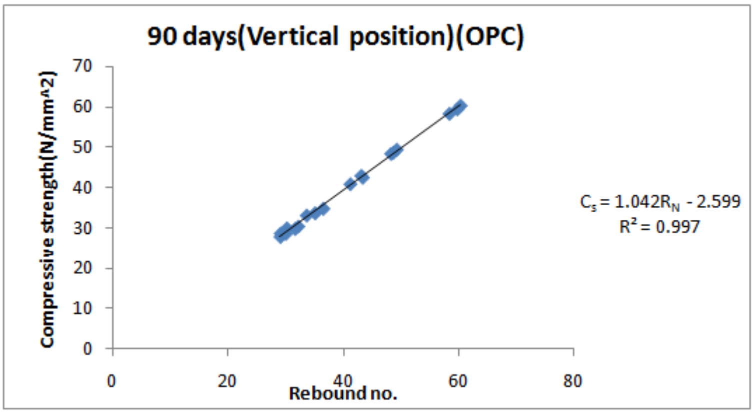

Figure 4.9: Correlation between Compressive strength and Rebound no.(Vertical position) for 90 days OPC

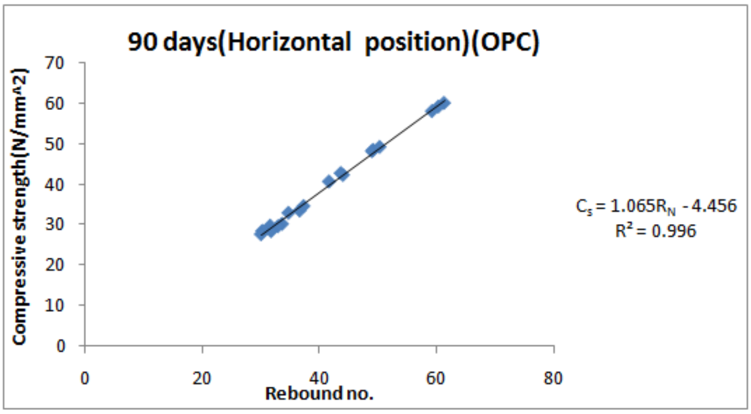

Figure 4.10: Correlation between Compressive strength and Rebound no.(Horizontal position) for 90 days OPC

The scatter plot (Figures 4.9 & 4.10) representing the rebound no versus concrete compressive strength could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa) at 90 days for OPC based concrete :

$$S_c = 1.042R_N - 2.599\ (Vertical\ position) \tag{4.9}$$

$$S_c = 1.065R_N - 4.456\ (Horizontal\ position) \tag{4.10}$$

Where,

S_c = Compressive strength of concrete(N/mm^2)

R_N = Rebound no.

R square value for Eq.4.9 and Eq.4.10 are 0.997 and 0.996 respectively. 0.997 value explained that 99.7 % of the variability for the data around the regression line and 0.7 % of the residual data could not explained by Eq.4.9. In the case of Eq.4.10 99.6 % of the variability for the data around the line and 0.4 % remain unexplained.

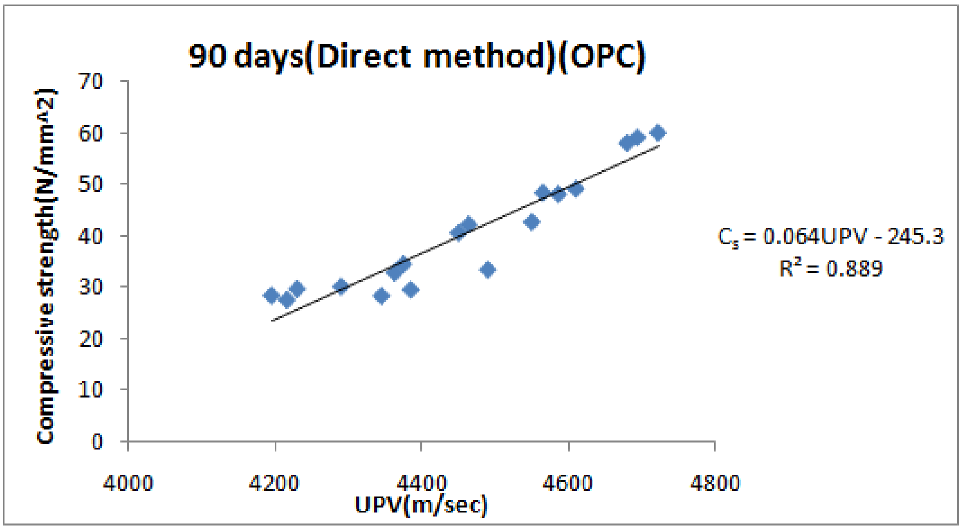

Figure 4.11: Correlation between Compressive strength and UPV (Direct method) for 90 days OPC

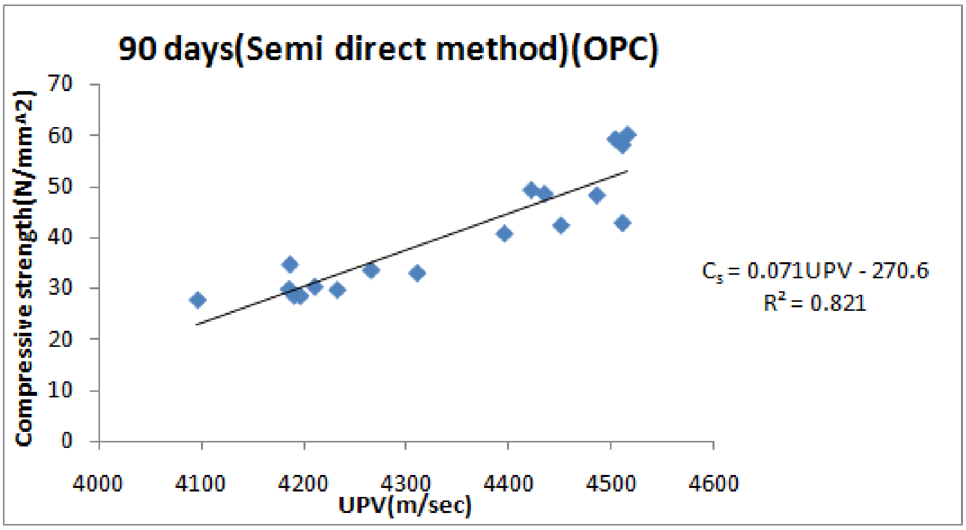

Figure 4.12: Correlation between Compressive strength and UPV (Semidirect method) for 90 days OPC

The scatter plot (Figures 4.11 & 4.12) representing the UPV results versus concrete compressive strength could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa) at 90 days for OPC based concrete :

$$S_c = 0.064UPV - 245.3 \ (Direct\ method) \quad (4.11)$$

$$S_c = 0.071UPV - 270.6 \ (Semi\ direct\ method) \quad (4.12)$$

Where,

S_c = Compressive strength of concrete(N/mm^2)

UPV = Ultrasonic pulse velocity(m/sec)

R square value for Eq.4.11 and Eq.4.12 are 0.889 and 0.821 respectively. 0.889 value explained that 88.9 % of the variability for the data around the regression line and 11.1 % of the residual data could not explained by Eq.4.11. In the case of Eq.4.12 82.1 % of the variability for the data around the line and 17.9 % remain unexplained.

4.3 Correlation between NDT Results and Compressive Strength for PPC Based Concrete

For all age 7, 28, 90 days first of all rebound hammer results are to be taken by keeping rebound hammer in horizontal and vertical position. At 7 and 90 days 3 nos. of cube specimens were tested for NDT results and compressive strength. For 28 days 6 nos.of specimens were tested. In each cube total 30 readings are to be taken, 5 from each face for horizontal and vertical position of rebound hammer. Then UPV results are to be taken by direct and semi direct method. After non-destructive testing compressive strength of concrete specimens are to be found by compression testing machine.28 days compressive strength for M15, M20, M25, M30, M40, M50 grades are compared with target mean strength of each grade for PPC based concrete. From the Table 4.1, it is observed in case of PPC based concrete target mean compressive strength is higher than experimental compressive strength. Hence it concluded that 28 days compressive strength of PPC based concrete is less. Results for 7, 28 and 90 days PPC based concrete are presented in Table 4.6,Table 4.7 and Table4.9 respectively.

Table 4.6: 7 days results of compressive strength of PPC based concrete

Mix	Density(kg/m^3)	Rebound no. (vertical)	Rebound no. (horizontal)	U.P.V(m/sec) (direct method)	U.P.V(m/sec) (semi direct method)	compressive str.(MPa)	Average compressive strength(MPa)
M15	2512	21.1	22.73	3944	3716	15.11	16.96
	2604	21.26	22.6	4011	3907	17.11	
	2465	22.53	23.03	3930	3772	18.67	
M20	2590	24.42	26.38	4171	3998	20.67	19.93
	2557	22.94	25.12	4107	3855	20.00	
	2548	22.32	25.3	4027	3951	19.11	
M25	2584	24.15	26.45	4095	4039	22.67	21.93
	2548	22.28	25.94	4084	4035	21.33	
	2519	24.32	26.5	4065	4022	21.78	
M30	2539	27.42	30.65	4175	4099	25.11	25.63
	2498	29.57	31.52	4144	4096	26.44	
	2616	28.68	30.8	4179	4104	25.33	
M40	2610	35.14	37.38	4362	4218	32.89	32.81
	2575	36.21	38.94	4360	4216	33.33	
	2542	34.95	37.08	4357	4198	32.22	
M50	2566	39.12	40.78	4403	4348	38.89	39.04
	2581	41.25	43.31	4425	4405	40	
	2557	37.94	40.23	4418	4360	38.22	

Table 4.7: 28 days results of compressive strength of PPC based concrete

Mix	Density(kg/m^3)	Rebound no. (vertical)	Rebound no. (horizontal)	U.P.V(m/sec) (direct method)	U.P.V(m/sec) (semi direct method)	compressive strength(MPa)	Average compressive Strength (MPa)
M15	2562.96	22.17	26.63	4081	3910	19.56	20
	2521.48	22.27	26.73	4032	3890	18.67	
	2571.85	22.13	25.97	4069	3990	19.78	
	2613.33	24.07	26.13	4002	3992	21.78	
	2574.81	22.17	27.4	4113	3984	20.44	
	2607.41	21.33	27.1	4028	4058	19.78	
M20	2604.44	24.73	30.37	4076	3865	24.89	25.59
	2509.63	23.1	29.77	4145	3979	25.33	
	2625.19	24.87	29.93	4202	3965	25.78	
	2536.30	26.17	29.6	4129	4114	26.22	
	2604.44	24.67	30.07	4165	4167	25.11	
	2551.11	26.17	30.13	4148	4015	26.22	
M25	2500.74	27.53	33.63	4235	4112	30.00	29.11
	2565.93	26.57	31.17	4150	4117	27.78	
	2536.30	26.91	30.9	4163	4150	29.11	
	2545.19	27.23	30.83	4216	4180	27.56	
	2548.15	28.13	32.87	4147	4008	30.22	
	2536.30	30.17	34.13	4274	4197	30.00	

Table 4.8: 28 days results of compressive strength of PPC based concrete

M30	2589.63	36.24	38.4	4320	4300	36.89	37.26
	2604.44	36.11	37.5	4323	4293	36.00	
	2634.07	38	39.25	4379	4311	37.56	
	2607.41	35.8	36.95	4333	4259	36.89	
	2560.00	39.31	40.24	4315	4252	38.00	
	2613.33	39.84	42.35	4354	4297	38.22	
M40	2607.41	45.62	47.54	4468	4408	45.78	46.52
	2571.85	44.34	46.59	4383	4366	46.44	
	2598.52	46.5	47.12	4465	4342	46.89	
	2577.78	46	46.34	4445	4371	46.22	
	2589.63	44.98	45.24	4456	4344	46.67	
	2651.85	46.34	47.21	4487	4422	47.11	
M50	2586.67	54.34	55.23	4535	4429	57.33	56.22
	2604.44	54.12	54.56	4516	4457	57.11	
	2634.07	53.24	55.21	4555	4390	56.00	
	2613.33	53.12	53.31	4552	4468	56.67	
	2607.41	53.24	54.18	4549	4500	55.78	
	2693.33	54.1	55.12	4583	4494	54.44	

Table 4.9: 90 days results of compressive strength of PPC based concrete

Mix	Density(kg/m^3)	U.P.V(m/sec) (direct method)	U.P.V(m/sec) (semi direct method)	Rebound no. (vertical)	Rebound no. (horizontal)	compressive strength(MPa)	Average Compressive strength(MPa)
M15	2589	4190	4065	29.86	30.35	28.64	27.62
	2564	4125	4135	28.24	30.18	26.96	
	2624	4232	4120	28.54	29.36	27.25	
M20	2560	4196	4190	31.41	32.54	29.84	28.62
	2678	4265	4135	30.65	31.64	28.64	
	2684	4294	4085	29.65	30.47	27.38	
M25	2613	4315	4305	34.12	34.68	32.72	32.68
	2698	4430	4265	34.94	36.2	33.36	
	2546	4284	4234	33.66	34.63	31.97	
M30	2630	4420	4321	41.25	41.56	41.74	40.98
	2564	4365	4364	41.22	42.34	40.36	
	2684	4468	4408	41.18	42.57	40.84	
M40	2614	4486	4524	46.72	47.1	46.56	46.89
	2730	4532	4434	47.32	47.89	46.78	
	2694	4576	4462	48.34	49.33	47.33	
M50	2694	4594	4510	56.42	57.2	56.78	58.17
	2726	4623	4621	58.88	59.17	58.64	
	2764	4654	4543	59.4	59.68	59.1	

Graphical representation of correlation between Compressive strength and NDT results for age of 7 days for PPC based concrete are as shown in Figure 4.13, Figure 4.14, Figure 4.15, Figure 4.16.

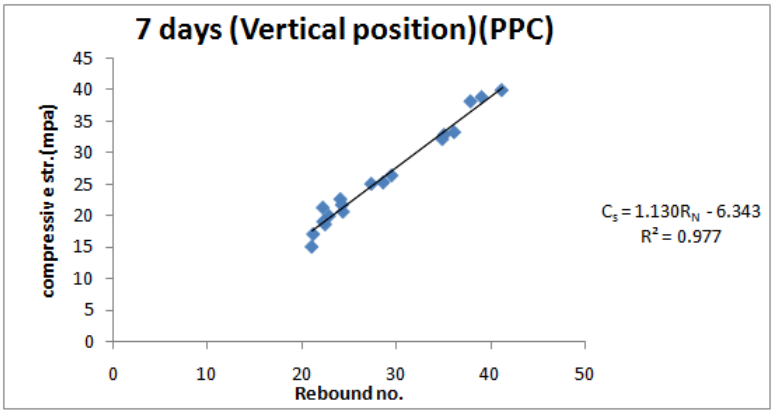

Figure 4.13: Correlation between Compressive strength and Rebound no.(Vertical position) for 7 days PPC

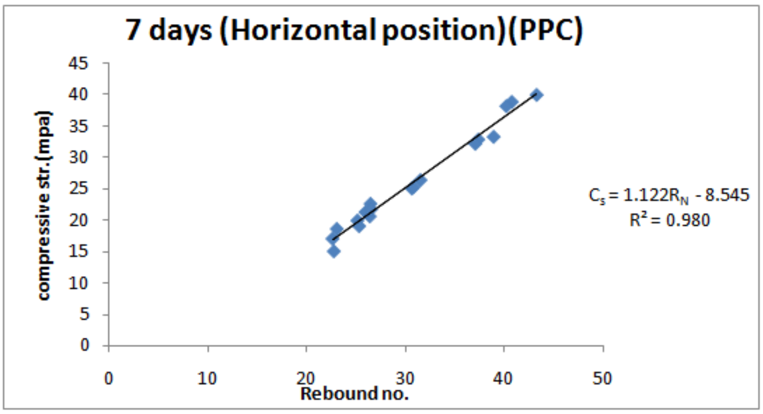

Figure 4.14: Correlation between Compressive strength and Rebound no.(Horizontal position) for 7 days PPC

The scatter plot (Figures 4.13 & 4.14) representing the rebound no. versus concrete compressive strength could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa) at 7 days for PPC based concrete :

$$S_c = 1.130R_N - 6.343\ (Vertical\ position) \tag{4.13}$$

$$S_c = 1.122R_N - 8.545\ (Horizontal\ position) \tag{4.14}$$

Where,

S_c = Compressive strength of concrete(N/mm^2)

R_N = Rebound no.

R square value for Eq.4.13 and Eq.4.14 are 0.977 and 0.98 respectively. 0.977 value explained that 97.7 % of the variability for the data around the regression line and 2.3 % of the residual data could not explained by Eq.4.13. In the case of Eq.4.14 98 % of the variability for the data around the line and 2 % remain unexplained.

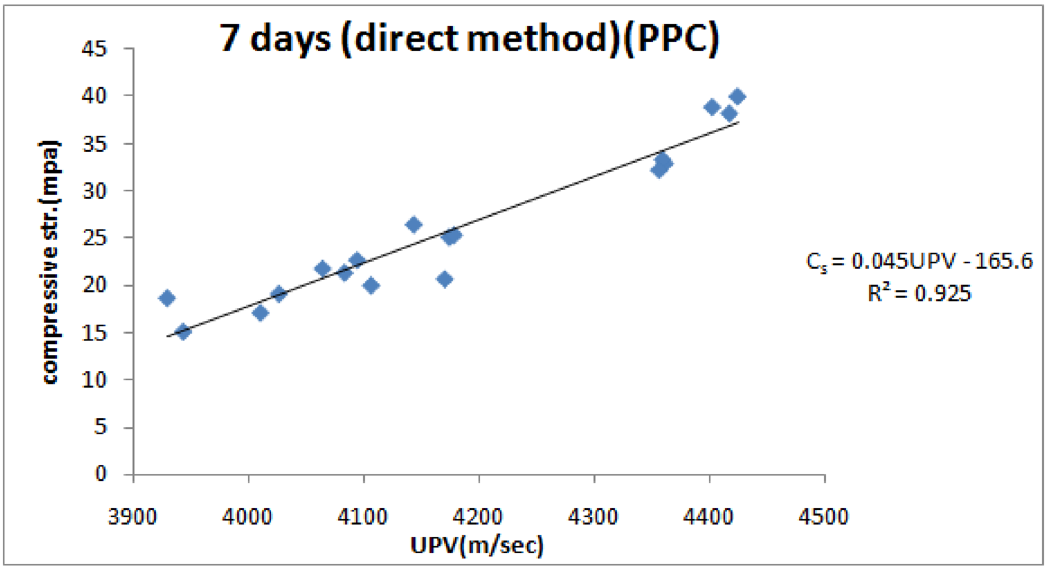

Figure 4.15: Correlation between Compressive strength and UPV (Direct method) for 7 days PPC

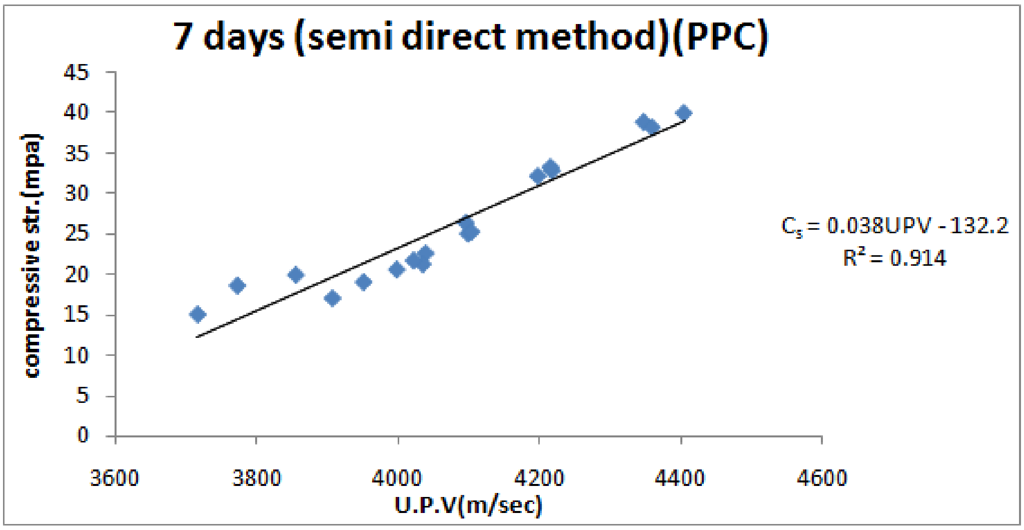

Figure 4.16: Correlation between Compressive strength and UPV (Semidirect method) for 7 days PPC

The scatter plot (Figures 4.15, 4.16) representing the UPV results versus concrete compressive strength could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa) at 7 days for PPC based concrete :

$$S_c = 0.045UPV - 165.6 \ (Direct\ method) \tag{4.15}$$

$$S_c = 0.038UPV - 132.2 \ (Semi\ direct\ method) \tag{4.16}$$

Where,

S_c = Compressive strength of concrete(N/mm^2)

UPV = Ultrasonic pulse velocity(m/sec)

R square value for Eq.4.15 and Eq.4.16 are 0.925 and 0.735 respectively. 0.949 value explained that 92.5 % of the variability for the data around the regression line and 7.5 % of the residual data could not explained by Eq.4.15. In the case of Eq.4.16 73.5 % of the variability for the data around the line and 26.5 % remain unexplained.

Graphical representation of correlation between compressive strength and NDT results for age of 28 days for PPC based concrete are as shown in Figure 4.17, Figure 4.18, Figure 4.19, Figure 4.20.

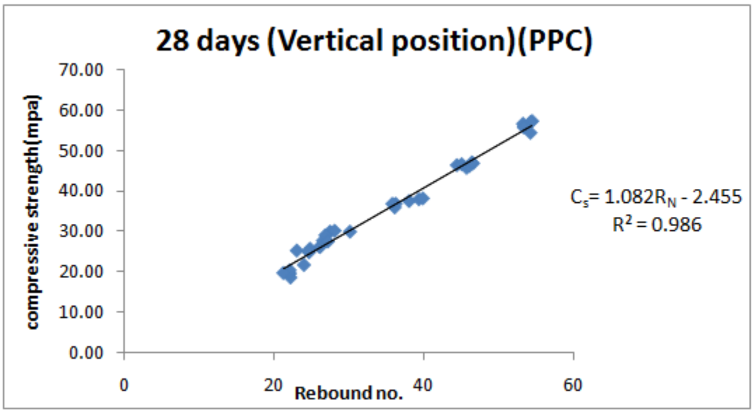

Figure 4.17: Correlation between Compressive strength and Rebound no. (Vertical position) for 28 days PPC

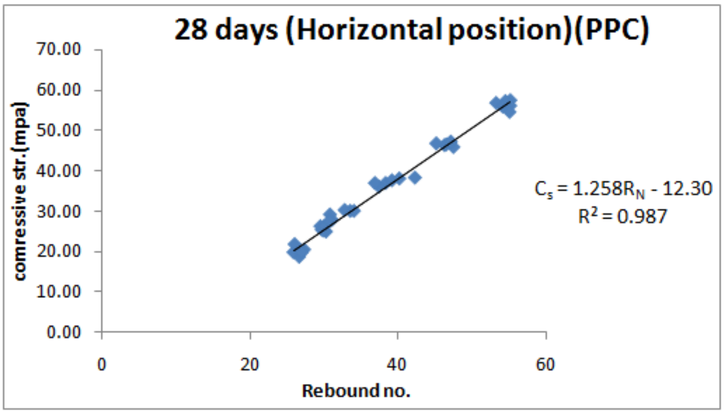

Figure 4.18: Correlation between Compressive strength and Rebound no. (Horizontal position) for 28 days PPC

The scatter plot (Figures 4.17 & 4.18) representing the rebound no versus concrete compressive strength could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa) at 28 days for PPC based concrete :

$$S_c = 1.082R_N - 2.455\ (Vertical\ position) \tag{4.17}$$

$$S_c = 1.258R_N - 12.30\ (Horizontal\ position) \tag{4.18}$$

Where,

S_c = Compressive strength of concrete(N/mm^2)

R_N = Rebound no.

R square value for Eq.4.17 and Eq.4.18 are 0.986 and 0.987 respectively. 0.986 value explained that 98.6 % of the variability for the data around the regression line and 1.4 % of the residual data could not explained by Eq.4.17. In the case of Eq.4.18 98.7 % of the variability for the data around the line and 1.3 % remain unexplained.

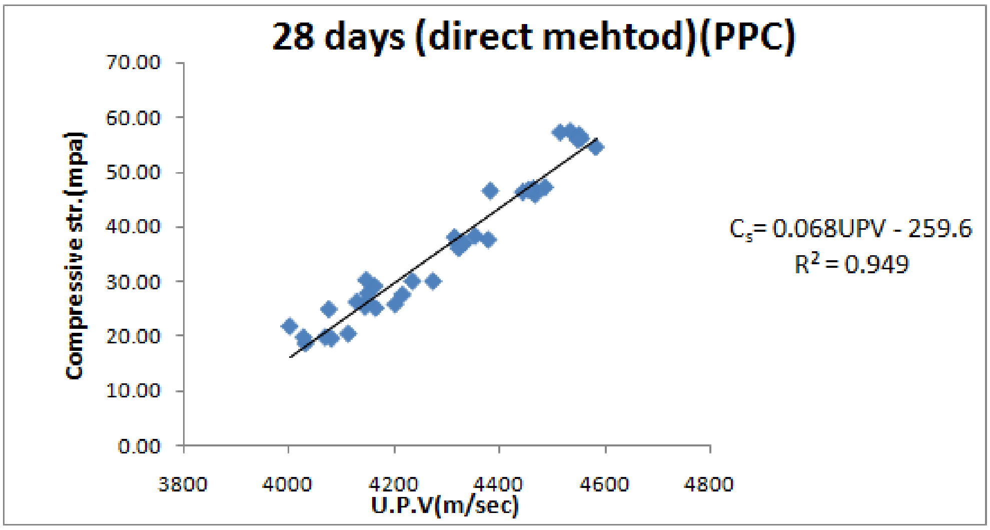

Figure 4.19: Correlation between Compressive strength and UPV (Direct method) for 28 days PPC

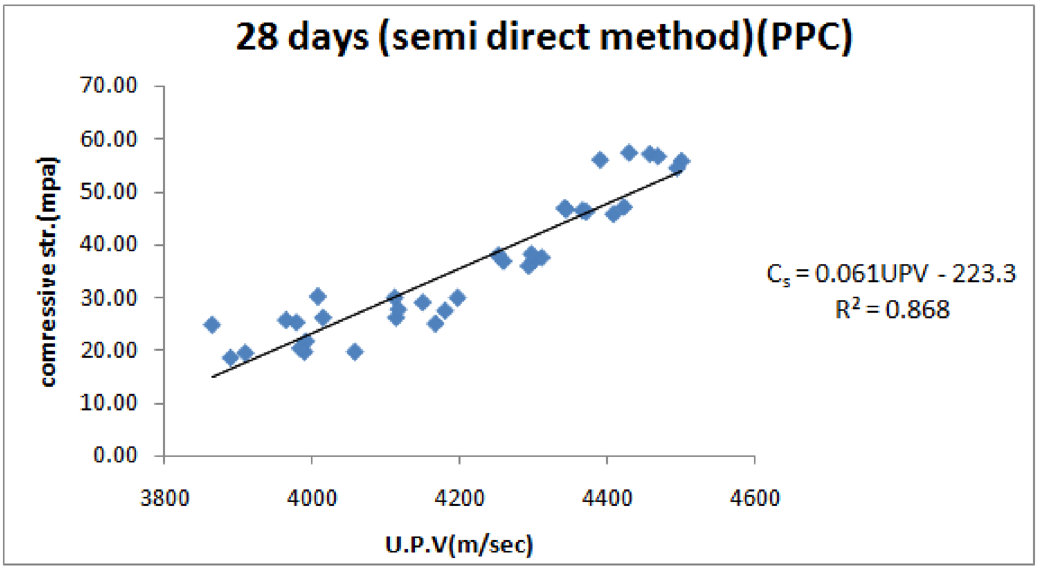

Figure 4.20: Correlation between Compressive strength and UPV (Semidirect method) for 28 days PPC

The scatter plot (Figures 4.19 & 4.20) representing the UPV results versus concrete compressive strength could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa) at 28 days for PPC based concrete :

$$S_c = 0.068UPV - 259.6 \ (Direct\ method) \tag{4.19}$$

$$S_c = 0.061UPV - 223.3 \ (Semidirect\ method) \tag{4.20}$$

Where,

S_c = Compressive strength of concrete(N/mm^2)

UPV = Ultrasonic pulse velocity(m/sec)

R square value for Eq.4.19 and Eq.4.20 are 0.949 and 0.868 respectively. 0.949 value explained that 94.9 % of the variability for the data around the regression line and 5.1 % of the residual data could not explained by Eq.4.19. In the case of Eq.4.20 86.8 % of the variability for the data around the line and 13.2 % remain unexplained.

Graphical representation of correlation between Compressive strength and NDT results for age of 90 days for PPC based concrete are as shown in Figure 4.21, Figure 4.22, Figure 4.23, Figure 4.24.

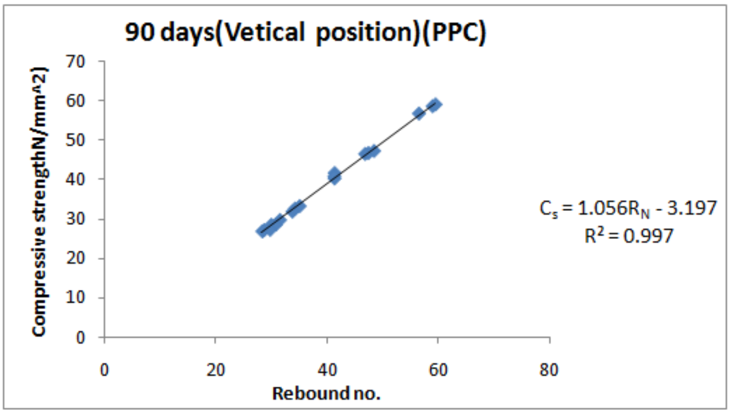

Figure 4.21: Correlation between Compressive strength and Rebound no.(Vertical position) for 90 days PPC

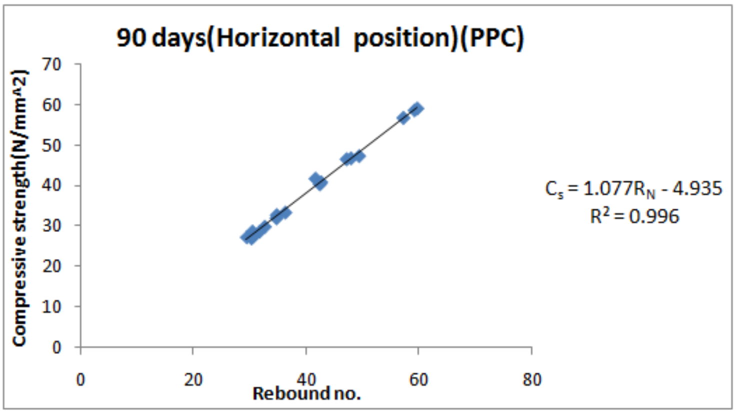

Figure 4.22: Correlation between Compressive strength and Rebound no.(Horizontal position) for 90 days PPC

The scatter plot (Figures 4.21 & 4.22) representing the rebound no. versus concrete compressive strength could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa) at 90 days for PPC based concrete :

$$S_c = 1.056R_N - 3.197 \ (Vertical \ position) \tag{4.21}$$

$$S_c = 1.077R_N - 4.935 \ (Horizontal \ position) \tag{4.22}$$

Where,

S_c = Compressive strength of concrete(N/mm^2)

R_N = Rebound no.

R square value for Eq.4.21 and Eq.4.22 are 0.997 and 0.996 respectively. 0.997 value explained that 99.7 % of the variability for the data around the regression line and 0.7 % of the residual data could not explained by Eq.4.21. In the case of Eq.4.22 99.6 % of the variability for the data around the line and 0.4 % remain unexplained.

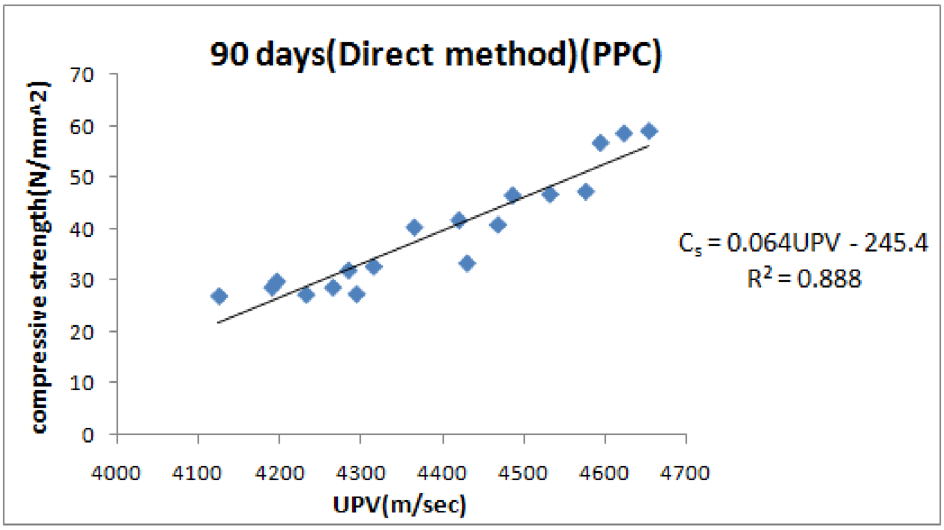

Figure 4.23: Correlation between Compressive strength and UPV(Direct method) for 90 days PPC

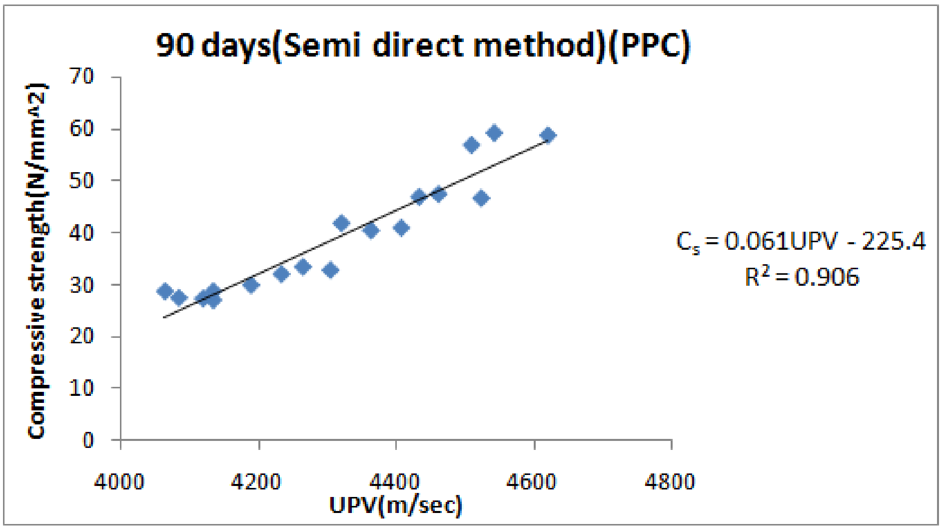

Figure 4.24: Correlation between Compressive strength and UPV(Semidirect method) for 90 days PPC

The scatter plot (Figures 4.23 & 4.24) representing the UPV results versus concrete compressive strength could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa) at 90 days for PPC based concrete :

$$S_c = 0.064UPV - 245.4 \ (Direct\ method) \tag{4.23}$$

$$S_c = 0.061UPV - 225.4 \ (Semi\ direct\ method) \tag{4.24}$$

Where,

S_c = Compressive strength of concrete(N/mm^2)

UPV = Ultrasonic pulse velocity(m/sec)

R square value for Eq.4.23 and Eq.4.24 are 0.888 and 0.906 respectively. 0.888 value explained that 88.8 % of the variability for the data around the regression line and 11.2 % of the residual data could not explained by Eq.4.23. In the case of Eq.4.24 90.6 % of the variability for the data around the line and 9.4 % remain unexplained.

4.4 Correlation between Compressive Strength and NDT Results for OPC & PPC Separately for All Ages

Graphical representation of correlation between compressive strength and NDT results for ages for OPC based concrete are as shown in Figure 4.25, Figure 4.26, Figure 4.27, Figure 4.28.

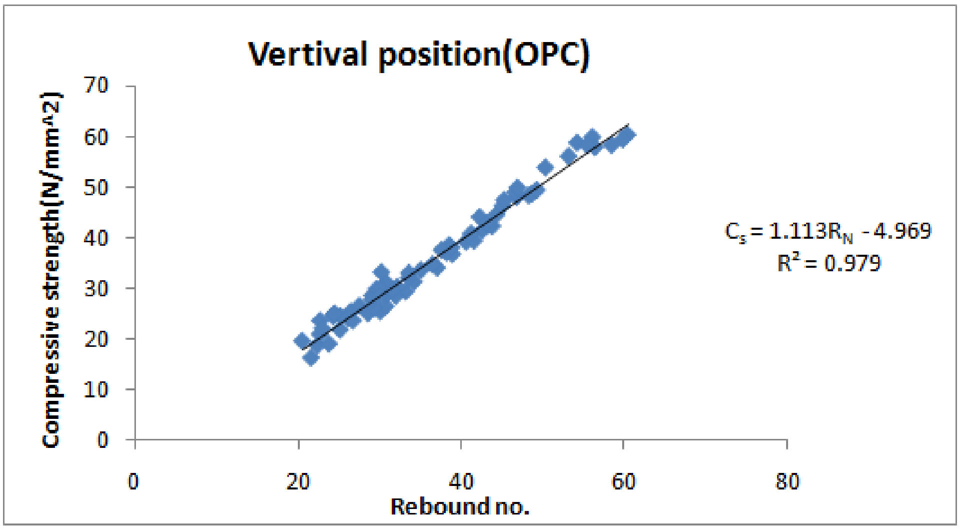

Figure 4.25: Correlation between Compressive strength and Rebound no.(Vertical position) for all age(OPC)

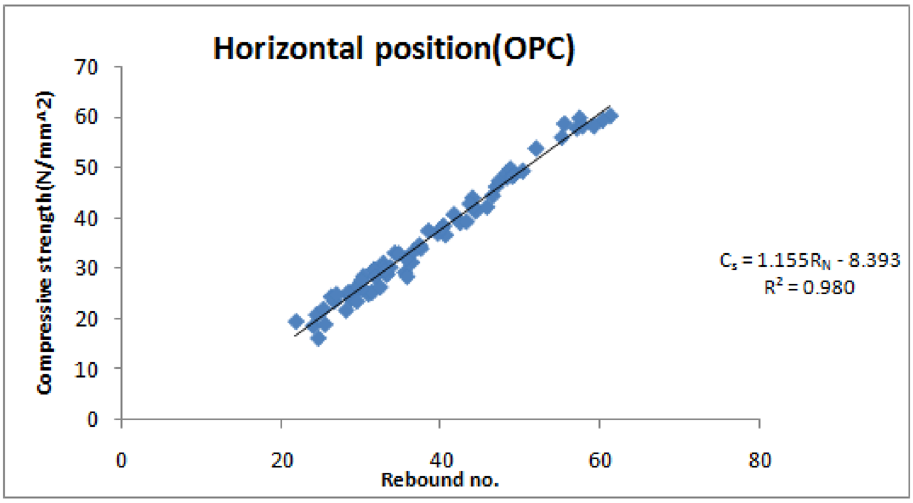

Figure 4.26: Correlation between Compressive strength and Rebound no.(Horizontal position) for all age(OPC)

The scatter plot (Figures 4.25 & 4.26) representing the rebound no. results versus concrete compressive strength could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa) for all ages for OPC based concrete :

$$S_c = 1.113R_N - 4.969 \ (Vertical\ position) \tag{4.25}$$

$$S_c = 1.155R_N - 8.393 \ (Horizontal\ position) \tag{4.26}$$

Where,

S_c = Compressive strength of concrete(N/mm^2)

R_N = Rebound no.

R square value for Eq.4.25 and Eq.4.26 are 0.979 and 0.980 respectively. 0.979 value explained that 97.9 % of the variability for the data around the regression line and 2.1 % of the residual data could not explained by Eq.4.25. In the case of Eq.4.26 98 % of the variability for the data around the line and 2 % remain unexplained.

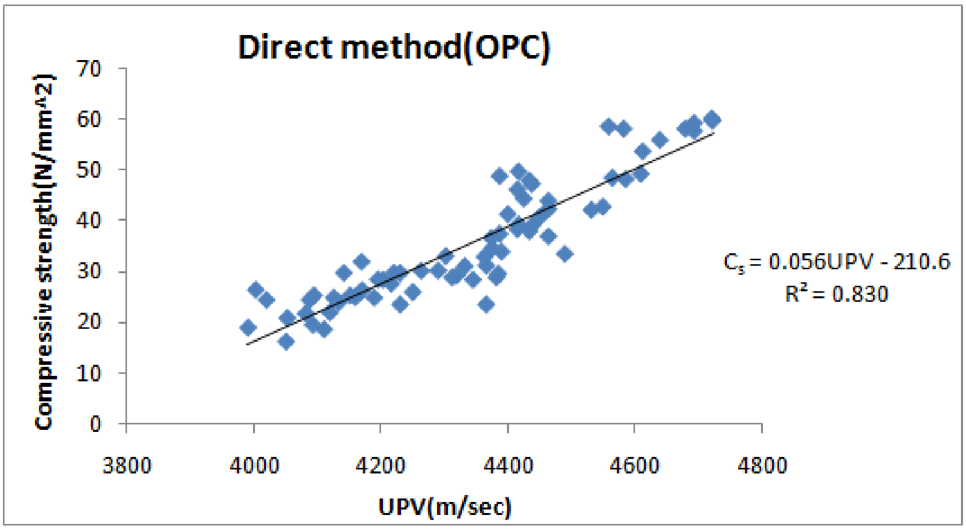

Figure 4.27: Correlation between Compressive strength and UPV(Direct method) for all age(OPC)

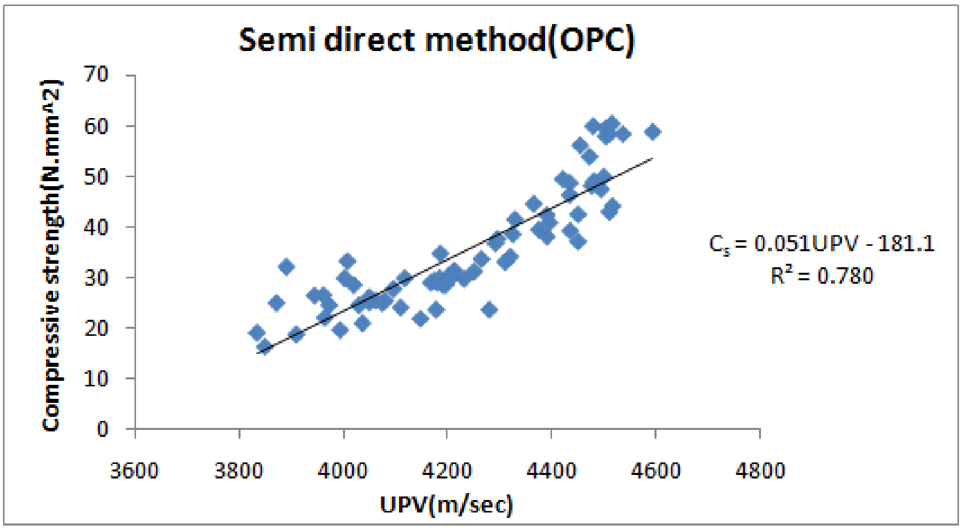

Figure 4.28: Correlation between Compressive strength and UPV(Semidirect method) for all age(OPC)

The scatter plot (Figures 4.27 & 4.28) representing the concrete compressive strength versus UPV results could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa) for all ages for OPC based concrete :

$$S_c = 0.056UPV - 210.6\ (Direct\ method) \tag{4.27}$$

$$S_c = 0.051UPV - 181.1\ (Semi\ direct\ method) \tag{4.28}$$

Where,
S_c = Compressive strength of concrete(N/mm^2)
UPV = Ultrasonic pulse velocity(m/sec)

R square value for Eq.4.27 and Eq.4.28 are 0.830 and 0.780 respectively. 0.830 value explained that 83 % of the variability for the data around the regression line and 17 % of the residual data could not explained by Eq.4.27. In the case of Eq.4.28 78 % of the variability for the data around the line and 22 % remain unexplained.
Graphical representation of correlation between compressive strength and combination of both NDT methods for all ages for OPC based concrete are as shown in Figure 4.29, Figure 4.30, Figure 4.31, Figure 4.32.

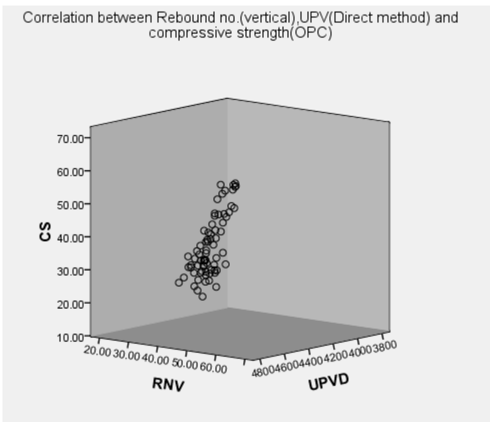

Figure 4.29: Correlation between Compressive strength and combination of Rebound no.(Vertical position), UPV(Direct method) for all age(OPC)

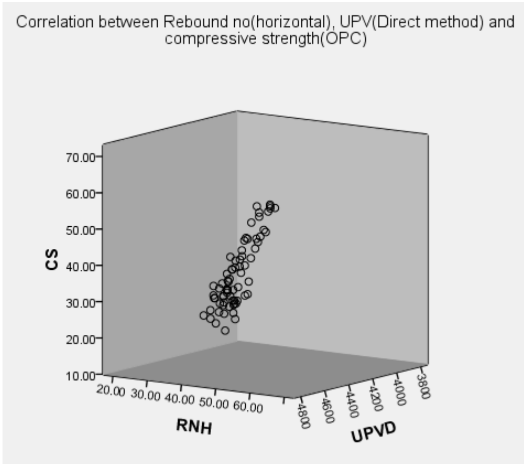

Figure 4.30: Correlation between Compressive strength and combination of Rebound no.(Horizonal position), UPV(Direct method) for all age(OPC)

The scatter plot (Figures 4.29 & 4.30) representing the concrete compressive strength versus combination of NDT results could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa) for all ages for OPC based concrete :

$$S_c = 1.115R_N + 0.02UPV - 4.543\ (Vertical\ position\ \&\ Direct\ method) \quad (4.29)$$

$$S_c = 1.141R_N + 0.01UPV - 11.434\ (Horizontal\ position\ \&\ Direct\ method) \quad (4.30)$$

Where,
S_c = Compressive strength of concrete(N/mm^2)
R_N = Rebound no.
UPV = Ultrasonic pulse velocity(m/sec)
Regression analysis are done using SPSS software. R square value for Eq.4.29 and Eq.4.30 are 0.979 and 0.981 respectively. 0.979 value explained that 97.9 % of the variability for the data around the regression line and 2.1 % of the residual data could not explained by Eq.4.29. In the case of Eq.4.30 98.1 % of the variability for the data around the line and 1.9 % remain unexplained.

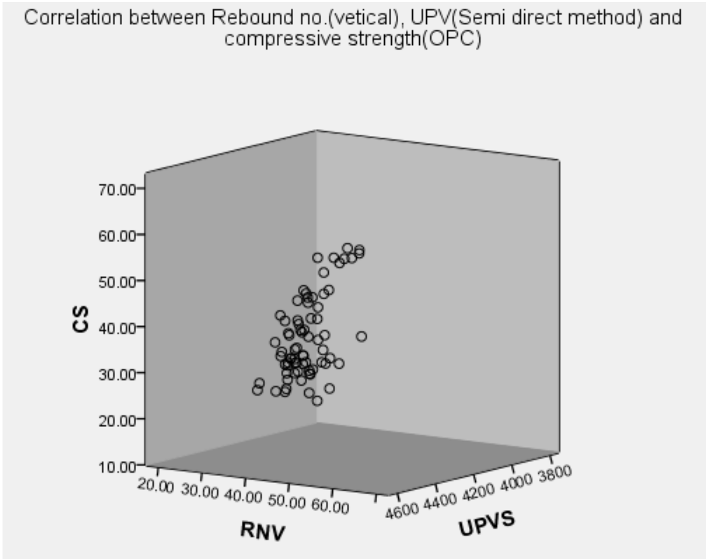

Figure 4.31: Correlation between Compressive strength and combination of Rebound no.(Vertical position), UPV(Semi direct method) for all age(OPC)

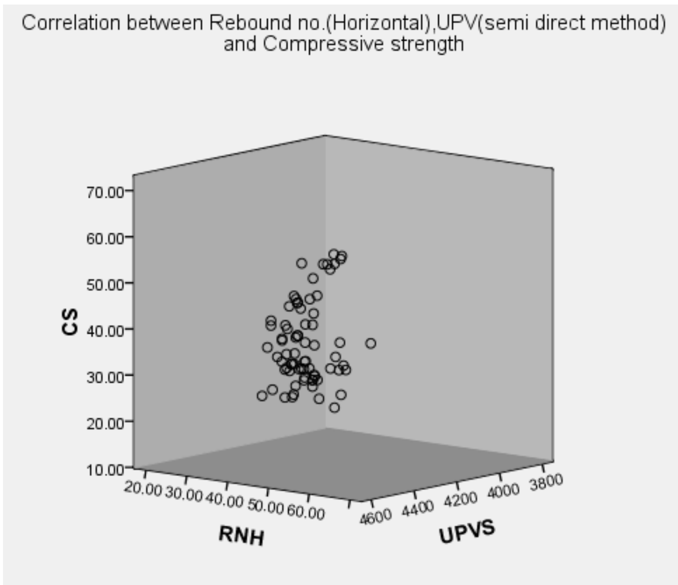

Figure 4.32: Correlation between Compressive strength and combination of Rebound no.(Horizonal position), UPV(Semi direct method) for all age(OPC)

The scatter plot (Figures 4.31 & 4.32) representing the concrete compressive strength versus combination of NDT results could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa) for all ages for OPC based concrete :

$$S_c = 1.053R_N + 0.04UPV - 17.764\ (Vertical\ position\ \&\ Semi\ direct\ method) \quad (4.31)$$

$$S_c = 1.075R_N + 0.05UPV - 24.615\ (Horizontal\ position\ \&\ Semi\ direct\ method) \quad (4.32)$$

Where,
S_c = Compressive strength of concrete(N/mm^2)
R_N = Rebound no.
UPV = Ultrasonic pulse velocity(m/sec)
Regression analysis are done using SPSS software. R square value for Eq.4.31 and Eq.4.32 are 0.98 and 0.981 respectively. 0.98 value explained that 98 % of the variability for the data around the regression line and 2 % of the residual data could not explained by Eq.4.31. In the case of Eq.4.32 98.1 % of the variability for the data around the line and 1.9 % remain unexplained.

Graphical representation of correlation between Compressive strength and NDT results for ages for PPC based concrete are as shown in Figure 4.33, Figure 4.34, Figure 4.35, Figure 4.36.

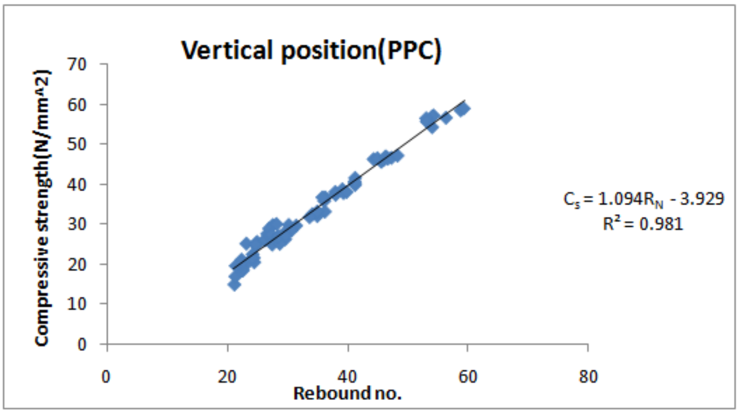

Figure 4.33: Correlation between Compressive strength and Rebound no.(Vertical position) for all age(PPC)

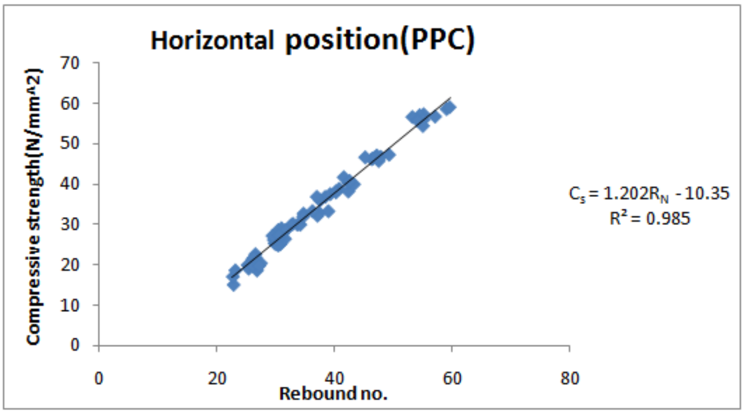

Figure 4.34: Correlation between Compressive strength and Rebound no.(Horizontal position) for all age(PPC)

The scatter plot (Figures 4.33 & 4.34) representing the rebound no. results versus concrete compressive strength could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa) for all ages for PPC based concrete :

$$S_c = 1.094R_N - 3.929\ (Vertical\ position) \tag{4.33}$$

$$S_c = 1.202R_N - 10.35\ (Horizontal\ position) \tag{4.34}$$

Where,

S_c = Compressive strength of concrete(N/mm^2)

R_N = Rebound no.

R square value for Eq.4.33 and Eq.4.34 are 0.981 and 0.985 respectively. 0.981 value explained that 98.1 % of the variability for the data around the regression line and 1.9 % of the residual data could not explained by Eq.4.33. In the case of Eq.4.34 98.5 % of the variability for the data around the line and 1.5 % remain unexplained.

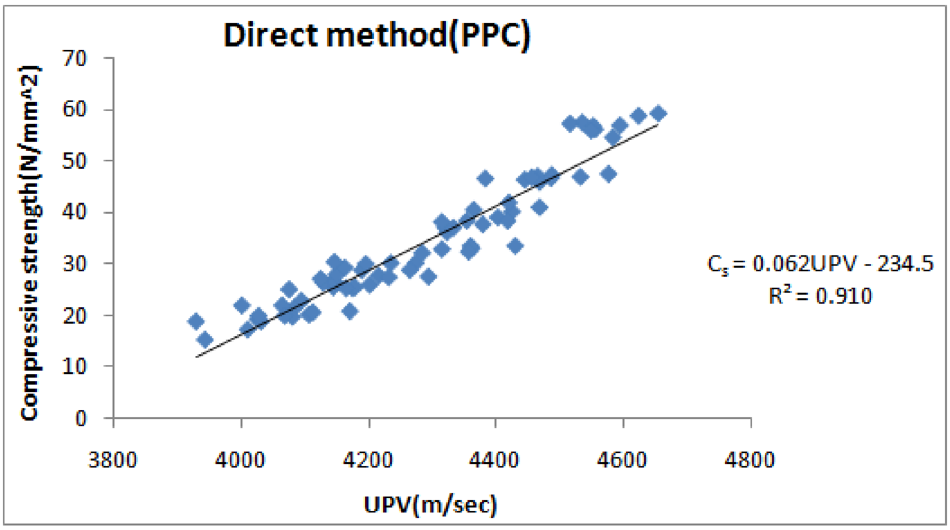

Figure 4.35: Correlation between Compressive strength and UPV(Direct method) for all age(PPC)

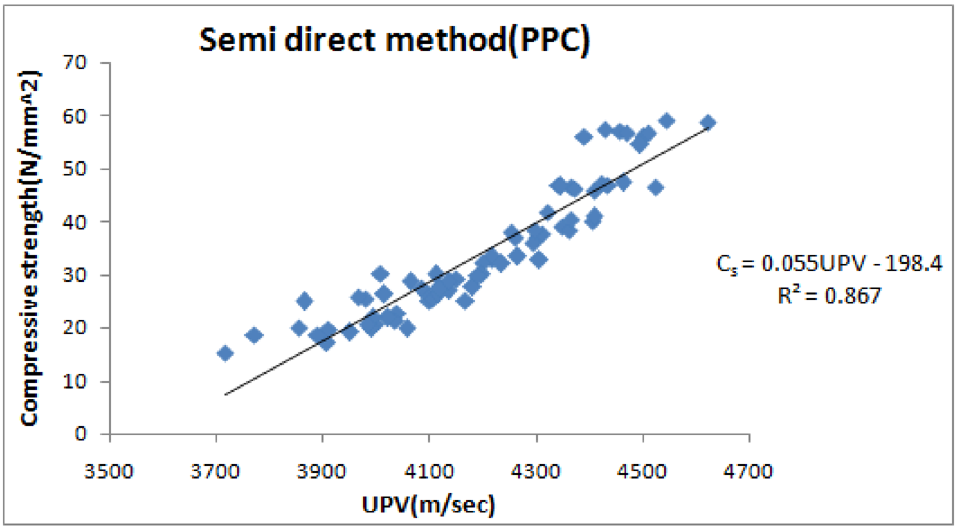

Figure 4.36: Correlation between Compressive strength and UPV(Semidirect method) for all age(PPC)

The scatter plot (Figures 4.35 & 4.36) representing the concrete compressive strength versus UPV results could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa) for all ages for PPC based concrete :

$$S_c = 0.062UPV - 234.5\ (Direct\ method) \tag{4.35}$$

$$S_c = 0.055UPV - 198.4\ (Semi\ direct\ method) \tag{4.36}$$

Where,

S_c = Compressive strength of concrete(N/mm^2)

UPV = Ultrasonic pulse velocity(m/sec)

R square value for Eq.4.35 and Eq.4.36 are 0.910 and 0.867 respectively. 0.910 value explained that 91 % of the variability for the data around the regression line and 9 % of the residual data could not explained by Eq.4.35. In the case of Eq.4.36 86.7 % of the variability for the data around the line and 13.3 % remain unexplained.

Graphical representation of correlation between Compressive strength and combination of both NDT methods for all ages for PPC based concrete are as shown in Figure 4.37, Figure 4.38, Figure 4.39, Figure 4.40.

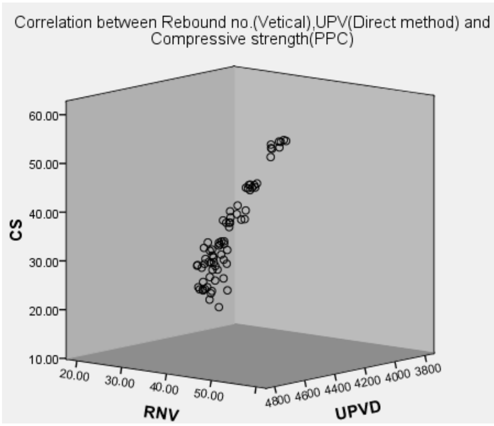

Figure 4.37: Correlation between Compressive strength and combination of Rebound no.(Vertical position), UPV(Direct method) for all age(PPC)

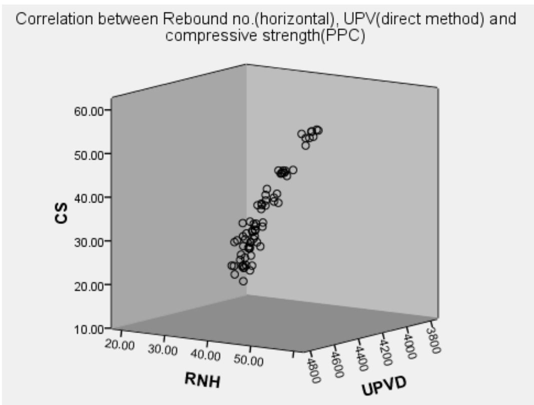

Figure 4.38: Correlation between Compressive strength and combination of Rebound no.(Horizonal position), UPV(Direct method) for all age(PPC)

The scatter plot (Figures 4.37 & 4.38) representing the concrete compressive strength versus combination of NDT results could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa) for all ages for PPC based concrete :

$$S_c = 1.026R_N + 0.04UPV - 19.728\ (Vertical\ position\ \&\ Direct\ method) \quad (4.37)$$

$$S_c = 1.132R_N + 0.059UPV - 24.922\ (Horizontal\ position\ \&\ Direct\ method) \quad (4.38)$$

Where,
S_c = Compressive strength of concrete(N/mm^2)
R_N = Rebound no.
UPV = Ultrasonic pulse velocity(m/sec)
Regression analysis are done using SPSS software. R square value for Eq.4.37 and Eq.4.38 are 0.982 and 0.986 respectively. 0.982 value explained that 98.2 % of the variability for the data around the regression line and 1.8 % of the residual data could not explained by Eq.4.37. In the case of Eq.4.38 98.6 % of the variability for the data around the line and 1.4 % remain unexplained.

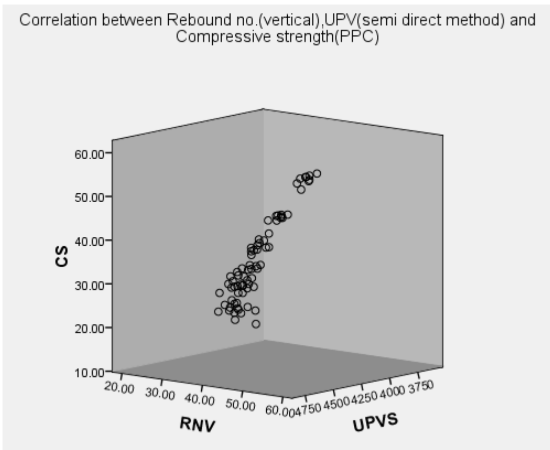

Figure 4.39: Correlation between Compressive strength and combination of Rebound no.(Vertical position), UPV(Semi direct method) for all age(PPC)

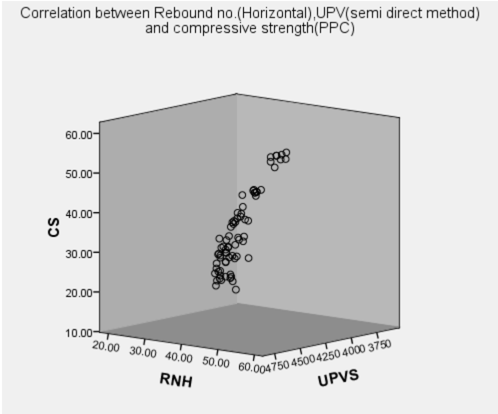

Figure 4.40: Correlation between Compressive strength and combination of Rebound no.(Horizonal position), UPV(Semi direct method) for all age(PPC)

The scatter plot (Figures 4.39 & 4.40) representing the concrete compressive strength versus combination of NDT results could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa) for all ages for PPC based concrete :

$$S_c = 1.016R_N + 0.05UPV - 20.199 \; (Vertical\ position\ \&\ Semi\ direct\ method) \quad (4.39)$$

$$S_c = 1.116R_N + 0.05UPV - 26.457 \; (Horizontal\ position\ \&\ Semi\ direct\ method) \quad (4.40)$$

Where,

S_c = Compressive strength of concrete(N/mm^2)

R_N = Rebound no.

UPV = Ultrasonic pulse velocity(m/sec)

Regression analysis are done using SPSS software. R square value for Eq.4.39 and Eq.4.40 are 0.982 and 0.986 respectively. 0.982 value explained that 98.2 % of the variability for the data around the regression line and 1.8 % of the residual data could not explained by Eq.4.39. In the case of Eq.4.40 98.6 % of the variability for the data around the line and 1.4 % remain unexplained.

4.5 Correlation between Compressive Strength and NDT Test Results for Combination of Both OPC & PPC Based Concrete

Graphical representation of correlation between Compressive strength and NDT results for all ages for combination of both OPC & PPC based concrete are as shown in Figure 4.41, Figure 4.42, Figure 4.43, Figure 4.44.

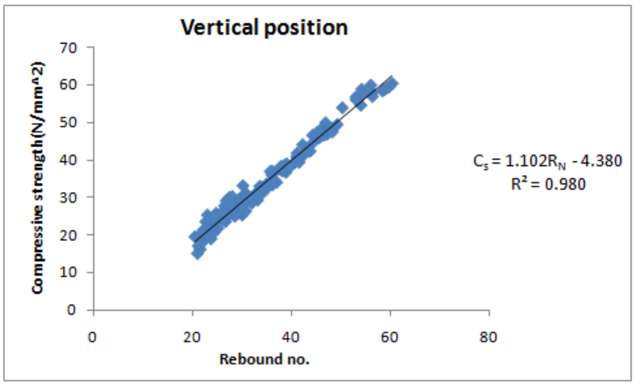

Figure 4.41: Correlation between Compressive strength and Rebound no.(Vertical position) for all ages for combination of OPC & PPC

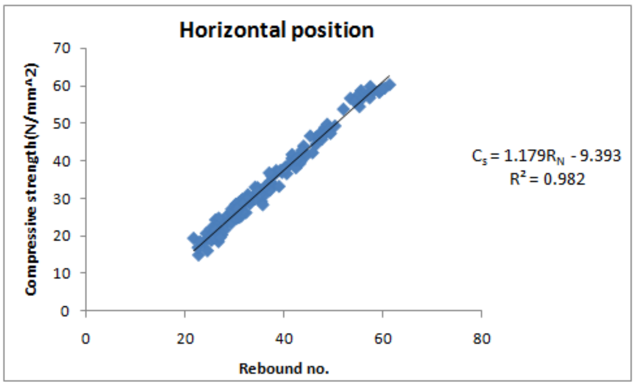

Figure 4.42: Correlation between Compressive strength and Rebound no.(Vertical position) for all ages for combination of OPC & PPC

The scatter plot (Figures 4.41 & 4.42) representing the concrete compressive strength versus rebound no.(vertical position) could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa) for all ages for combination of OPC & PPC based concrete :

$$S_c = 1.102R_N - 4.380 \ (Vertical\ position) \tag{4.41}$$

$$S_c = 1.179R_N - 9.393 \ (Horizontal\ position) \tag{4.42}$$

Where,
S_c = Compressive strength of concrete(N/mm^2)
R_N = Rebound no.

R square value for Eq.4.41 and Eq.4.42 are 0.98 and 0.982 respectively. 0.98 value explained that 98 % of the variability for the data around the regression line and 2 % of the residual data could not explained by Eq.4.41. In the case of Eq.4.42 98.2 % of the variability for the data around the line and 1.8 % remain unexplained.

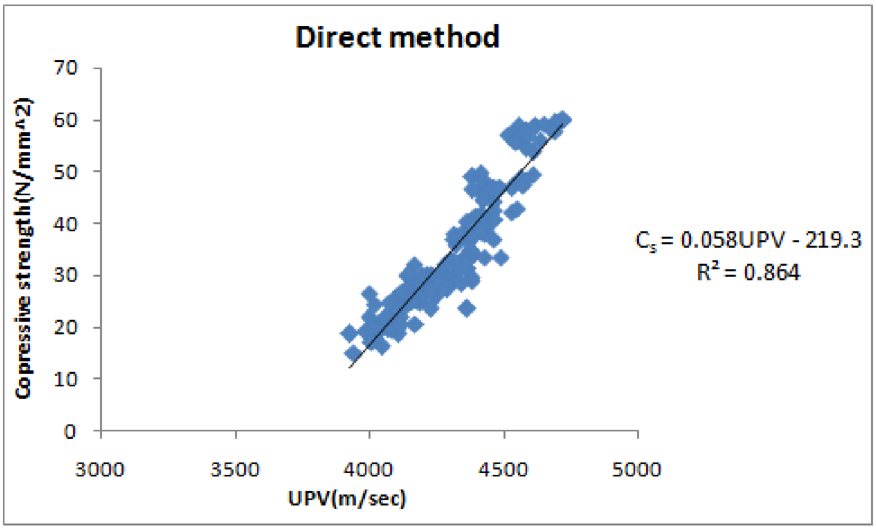

Figure 4.43: Correlation between Compressive strength and UPV(Direct method) for all ages for combination of both OPC & PPC

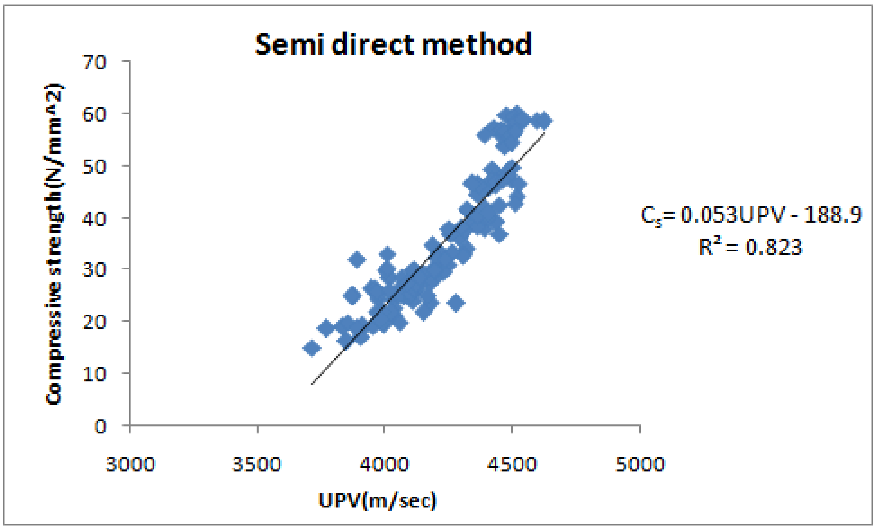

Figure 4.44: Correlation between Compressive strength and UPV(Semi direct method) for all ages for combination of both OPC & PPC

The scatter plot (Figures 4.43 & 4.44) representing the concrete compressive strength versus NDT results could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa) for all ages for combination of both OPC & PPC based concrete :

$$S_c = 0.058UPV - 219.3 \ (Direct\ method) \tag{4.43}$$

$$S_c = 0.053UPV - 188.9 \ (Semi\ direct\ method) \tag{4.44}$$

Where,

S_c = Compressive strength of concrete(N/mm^2)

UPV = Ultrasonic pulse velocity(m/sec)

R square value for Eq.4.43 and Eq.4.44 are 0.864 and 0.823 respectively. 0.864 value explained that 86.4 % of the variability for the data around the regression line and 13.6 % of the residual data could not explained by Eq.4.43. In the case of Eq.4.44 82.3 % of the variability for the data around the line and 17.7 % remain unexplained.

Graphical representation of correlation between Compressive strength and NDT results for all ages for combination of both OPC & PPC based concrete are as shown in Figure 4.45, Figure 4.46, Figure 4.47, Figure 4.48.

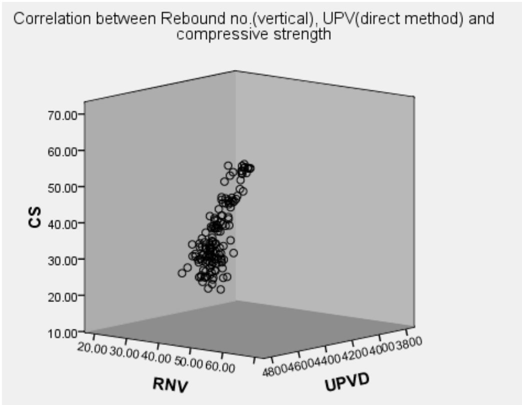

Figure 4.45: Correlation between Compressive strength and Rebound no.(Vertical), UPV(Direct) for all ages for combination of OPC & PPC

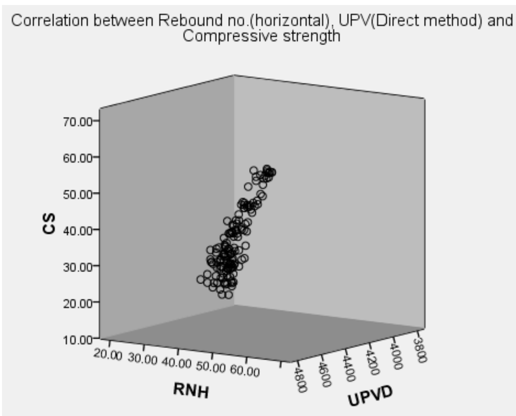

Figure 4.46: Correlation between Compressive strength and Rebound no.(Horizontal position), UPV(Direct) for all ages for combination of OPC & PPC

The scatter plot (Figures 4.45 & 4.46) representing the concrete compressive strength versus NDT results could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa) for all ages for combination of both OPC & PPC based concrete :

$$S_c = 1.088R_N + 0.01UPV - 7.487\ (Vertical\ position\ \&\ Direct\ method) \quad (4.45)$$

$$S_c = 1.140R_N + 0.02UPV - 17.544\ (Horizontal\ position\ \&\ Direct\ method) \quad (4.46)$$

Where,
S_c = Compressive strength of concrete(N/mm^2)
R_N = Rebound no.
UPV = Ultrasonic pulse velocity(m/sec)
Regression analysis are done using SPSS software. R square value for Eq.4.45 and Eq.4.46 are 0.98 and 0.983 respectively. 0.98 value explained that 98 % of the variability for the data around the regression line and 2 % of the residual data could not explained by Eq.4.45. In the case of Eq.4.46 98.3 % of the variability for the data around the line and 1.7 % remain unexplained. The scatter plot (Figures 4.47 &

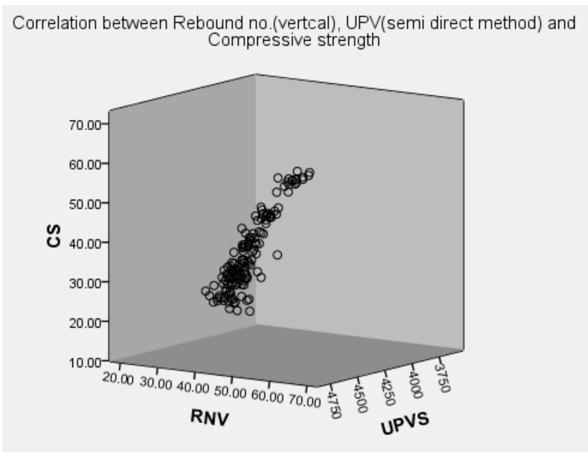

Figure 4.47: Correlation between Compressive strength and Rebound no.(Vertical), UPV(Semi direct) for all ages for combination of OPC & PPC

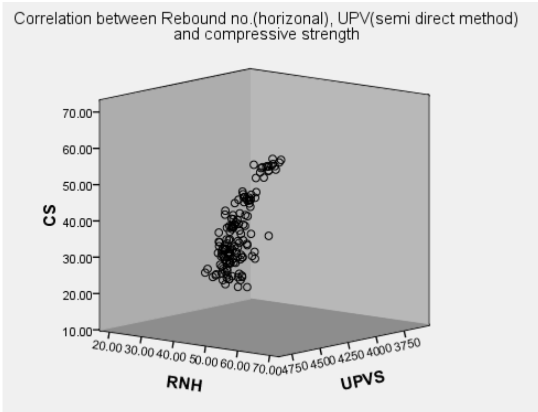

Figure 4.48: Correlation between Compressive strength and Rebound no.(Horizontal position), UPV(Semi direct) for all ages for combination of OPC & PPC

4.48) representing the concrete compressive strength versus NDT results could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa) for all ages for combination of both OPC & PPC based concrete :

$$S_c = 1.038R_N + 0.04UPV - 17.751\ (Vertical\ position\ \&\ Semi\ direct\ method) \quad (4.47)$$

$$S_c = 1.091R_N + 0.005UPV - 26.303\ (Horizontal\ position\ \&\ Semi\ direct\ method) \quad (4.48)$$

Where,
S_c = Compressive strength of concrete(N/mm^2)
R_N = Rebound no.
UPV = Ultrasonic pulse velocity(m/sec)
Regression analysis are done using SPSS software. R square value for Eq.4.47 and Eq.4.48 are 0.981 and 0.984 respectively. 0.981 value explained that 98.1 % of the variability for the data around the regression line and 1.9 % of the residual data could not explained by Eq.4.47. In the case of Eq.4.48 98.4 % of the variability for the data around the line and 1.6 % remain unexplained.

4.6 Correlation between Compressive Strength and NDT Results for RCC Members

Results of UPV, rebound hammer results & compressive strength finding from rebound no. collected from different sites and Results taken from RCC laboratory specimens are given in Table 4.10 and Table 4.12 respectively.

Table 4.10: Test results for in situ RCC members(1)

Sr. no	Rebound no.	UPV (m/sec)	Compressive strength(N/mm^2)	Sr. no	Rebound no.	UPV (m/sec)	Compressive strength(N/mm^2)
1	20.3	3690	18	30	17.5	2450	6.57
2	21	3790	19	31	22.17	2310	12.79
3	22.9	2940	13.5	32	25.83	2350	17.74
4	18.7	3820	16.5	33	20.17	2580	10.44
5	17.6	3380	15.5	34	22.5	2740	13.5
6	25.7	3430	25	35	35.33	2950	33.47
7	21.4	3540	19	36	37	3280	36.3
8	19.6	3400	17	37	41.83	3850	44.47
9	14.8	2790	12	38	39.83	3870	41.22
10	14.9	2380	12	39	43.5	3840	47.82
11	12.9	3140	10.5	40	44	3850	47.27
12	19.5	3170	17	41	42.67	3750	46.31
13	25.1	2430	24	42	41.5	3590	44.19
14	24.2	2330	23	43	42	3470	45.08
15	23.5	3700	24.5	44	40.5	3510	42.39
16	32	2960	36	45	45.17	3370	50.89
17	16.2	3410	13.5	46	41.5	3270	44.17
18	16.1	3710	13.5	47	42.83	3330	46.59
19	17.2	3430	14.5	48	41.5	3160	44.17
20	20.7	3280	18	49	42.83	3320	46.59
21	20.83	1880	11.14	50	39.5	3080	40.62
22	22.5	2840	13.5	51	41.67	3110	44.49
23	22.5	2580	12.78	52	18.67	2180	7.69
24	23.83	3020	15.31	53	24	2150	15.67
25	21.5	2580	12.08	54	21	2430	11.37
26	25.5	2190	17.9	55	28.5	2610	22.84
27	22.67	2140	14.22	56	26.17	2230	19.54
28	25.33	2040	20.14	57	19.17	2610	9.06
29	19	2530	8.6	58	24.33	2390	15.68

Table 4.11: Test results for in situ RCC members(2)

Sr. no	Rebound no.	UPV (m/sec)	Compressive strength(N/mm^2)	Sr. no	Rebound no.	UPV (m/sec)	Compressive strength(N/mm^2)
60	24.83	2390	16.78	85	33.5	3370	30.44
61	24.17	2470	15.67	86	32.33	3570	28.53
62	28	2510	22.61	87	26.17	3410	19.54
63	24.5	2550	16.41	88	28.83	3520	23.86
64	22.17	2590	13.15	89	28	3470	21.69
65	28.5	2410	22.45	90	30	3400	25.2
66	28.5	2380	22.45	91	27.67	3480	20.15
67	27.83	2230	20.76	92	28.5	3400	22.44
68	29.67	3200	24.27	93	27.5	3520	21.3
69	34.33	3000	32.92	94	29.5	3470	24.01
70	36.5	3070	35.46	95	28.83	3340	21.99
71	38.5	3010	38.89	96	28.5	3520	23.23
72	33	3130	29.61	97	28.17	3470	23.22
73	32.83	3190	29.34	98	28.67	3340	21.68
74	34.83	3180	41.5	99	28.83	3380	23.24
75	33	3120	38.32	100	30.5	3470	25.59
76	37.5	3350	38.32	101	28.17	3440	22.45
77	40	3240	41.5	102	28.33	3530	21.68
78	38.17	3180	38.32	103	43	4420	50.09
79	38.17	3110	38.32	104	53.67	4300	61.21
80	38.67	3390	39.18	105	54.83	4250	63.51
81	40	3360	41.5	106	54.83	4102	63.51
82	34.17	3330	32.59	107	53.33	3650	61.24
83	34.67	3270	32.36	108	52.33	3770	60.75
84	35.83	3620	34.32	109	48.64	3890	54.32

Table 4.12: Test results for laboratory RCC members

Type of specimens	Sr. no	Grade	Rebound no.	UPV (m/sec)	Compressive strength(N/mm^2)
Beam	1	M20	27.16	4119	25.26
	2		29.4	4273	27.75
	3		28	4169	26.20
	4		30.33	4281	28.89
	5		32.16	4264	30.83
	6		28.20	4366	26.42
	7		30.65	4234	29.14
	8		31.42	4356	30.00
	9		29.64	4190	28.02
	10		26.54	4233	24.57
	11		31.74	4310	30.36
	12		30.24	4324	28.69
Column	13	M25 (OPC)	38.84	4425	34.91
	14		39.38	4365	35.52
	15		38.13	4245	34.12
	16		40.21	4310	36.44
	17		41.32	4354	37.68
Deep beam	18	M25	33.13	4234	28.54
	19		34.33	4195	29.88
Corbel	20		32.65	4325	28.01
	21		34.25	4265	29.79
RCC beam	22		31.96	4234	27.24
	23		32.67	4185	28.03
RCC Beam-Column junction	24		33.42	4272	28.87
	25		34.56	4310	30.14

Graphical representation of correlation between Compressive strength and NDT results of RCC members are as shown in Figure 4.49, Figure 4.50.

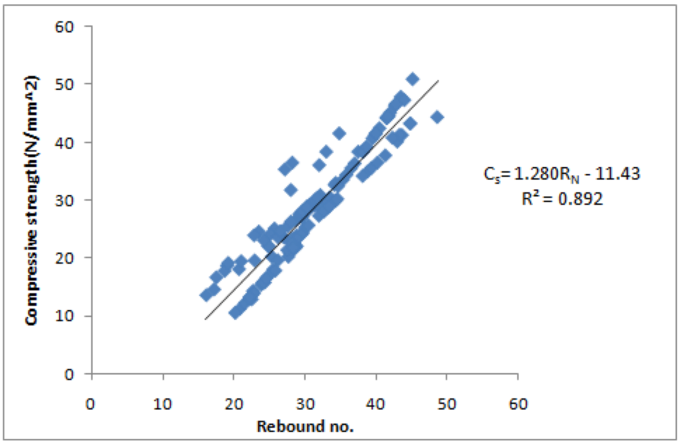

Figure 4.49: Correlation between Compressive Strength and Rebound no. for RCC Members

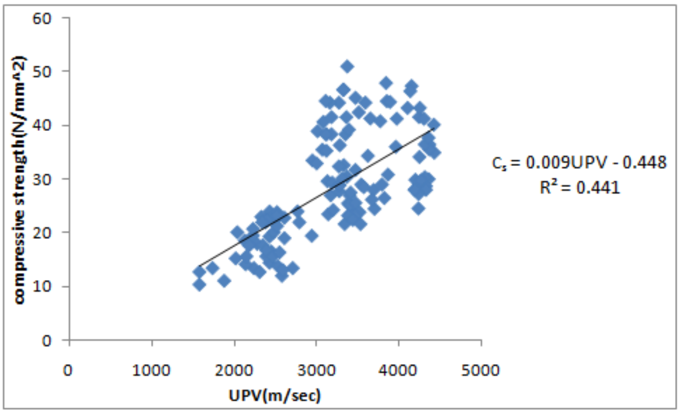

Figure 4.50: Correlation between Compressive Strength and UPV for RCC Members

The scatter plot (Figures 4.49 & 4.50) representing the concrete compressive strength versus NDT results for RCC members could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa):

$$S_c = 1.280R_N - 11.43 \tag{4.49}$$

$$S_c = 0.009UPV - 0.448 \tag{4.50}$$

Where,
S_c = Compressive strength of concrete(N/mm^2)
R_N = Rebound no.
UPV = Ultrasonic pulse velocity(m/sec)
R square value for Eq.4.49 and Eq.4.50 are 0.892 and 0.441 respectively. 0.892 value explained that 89.2 % of the variability for the data around the regression line and 1.8 % of the residual data could not explained by Eq.4.49. In the case of Eq.4.50 44.1 % of the variability for the data around the line and 55.9 % remain unexplained.
Graphical representation of correlation between results Compressive strength and combination of both non-destructive methods results for RCC members are as shown in Figure 4.51.

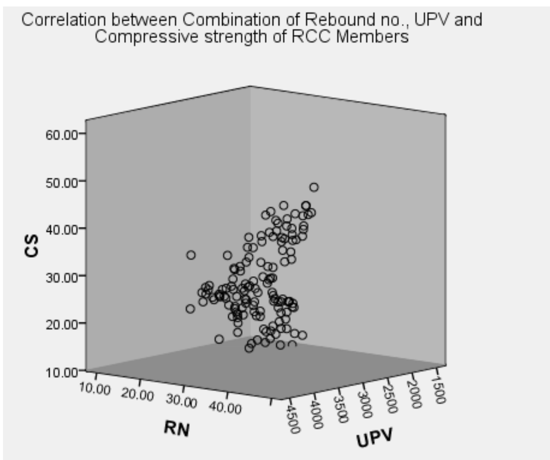

Figure 4.51: Correlation between Compressive Strength and UPV for RCC Members

The scatter plot (Figures 4.51) representing the results of concrete compressive strength versus combination of both non-destructive methods for RCC members could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa):

$$S_c = 1.193R_N + 0.001UPV - 12.512 \tag{4.51}$$

Where,

S_c = Compressive strength of concrete(N/mm^2)

R_N = Rebound no.

UPV = Ultrasonic pulse velocity(m/sec)

R square value for Eq.4.51 is 0.881 value explained that 88.1 % of the variability for the data around the regression line and 11.9 % of the residual data could not explained by Eq.4.25.

4.7 Correlation between Compressive Strength and NDT Results for Both PCC and RCC Members

Graphical representation of correlation between Compressive strength and NDT results for PCC and RCC members are as shown in Figure 4.52, Figure 4.53.

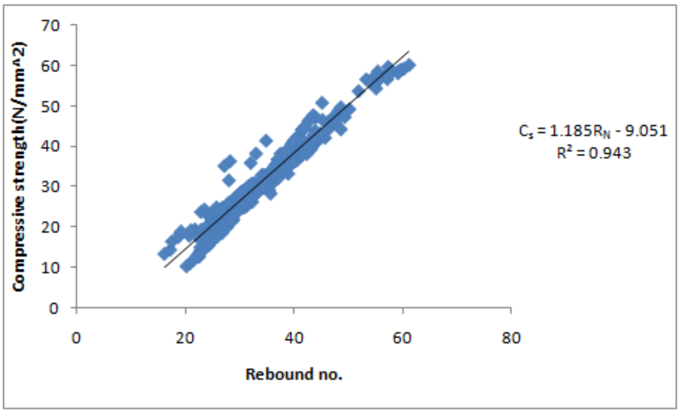

Figure 4.52: Correlation between Compressive Strength and Rebound no. for both PCC and RCC Members

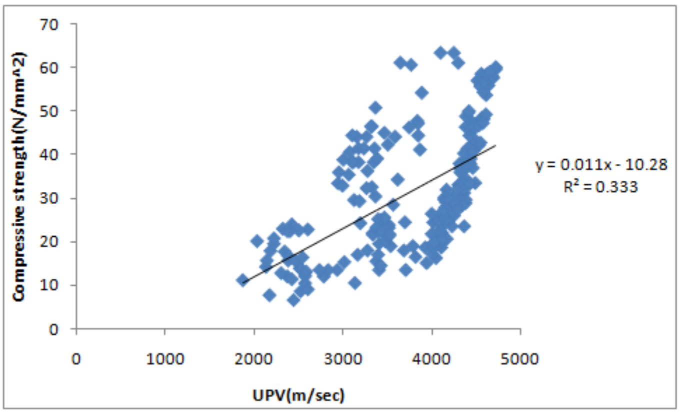

Figure 4.53: Correlation between Compressive Strength and UPV for both PCC and RCC Members

The scatter plot (Figures 4.52 & 4.53) representing the concrete compressive strength versus NDT results for both PCC and RCC members could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa):

$$S_c = 1.185R_N - 9.051 \tag{4.52}$$

$$S_c = 0.011UPV - 10.28 \tag{4.53}$$

Where,

S_c = Compressive strength of concrete(N/mm^2)

R_N = Rebound no.

UPV = Ultrasonic pulse velocity(m/sec)

R square value for Eq.4.52 and Eq.4.53 are 0.943 and 0.333 respectively. 0.943 value explained that 94.3 % of the variability for the data around the regression line and 5.7 % of the residual data could not explained by Eq.4.52. In the case of Eq.4.53 33.3 % of the variability for the data around the line and 67.7 % remain unexplained.

Graphical representation of correlation between results Compressive strength and combination of both non-destructive methods results for RCC and PCC members are as shown in Figure 4.54.

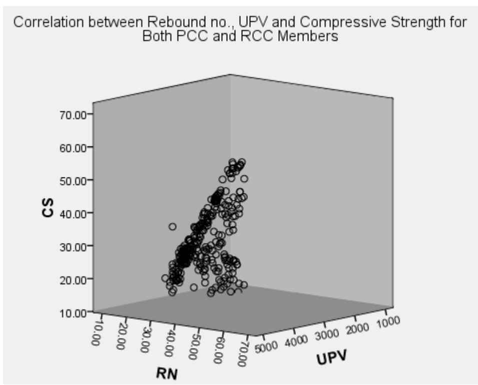

Figure 4.54: Correlation between Results of Compressive Strength and Combination of both Non-destructive methods for Both PCC and RCC Members

The scatter plot (Figures 4.54) representing the results of concrete compressive strength versus combination of both non-destructive methods for PCC and RCC members could give the following linear equations were concluded for the predicted values of the concrete compressive strength(MPa):

$$S_c = 1.186R_N - 0.00172UPV - 9.015 \tag{4.54}$$

Where,
S_c = Compressive strength of concrete(N/mm^2)
R_N = Rebound no.
UPV = Ultrasonic pulse velocity(m/sec)
R square value for Eq.4.54 is 0.944 value explained that 94.4 % of the variability for the data around the regression line and 5.6 % of the residual data could not explained by Eq.4.54.

4.8 Correlation between Modules of Elasticity and NDT Results

The load shall be apply continuously. Displacements are measured at certain load interval as shown in Table 4.13. By above results plot the graph between stress vs. strain from slope of above curve modulus of elasticity are measured. There are three methods for calculation modulus of elasticity. Here modulus of elasticity were calculated with secant modulus method as shown Figure 4.55.

Table 4.13: Results of load and displacement for M20 grade concrete cylinder

P (kN)	dl(mm)
0	0
50	1
100	3
150	4
200	6
250	7
300	10
350	13
400	17
450	20

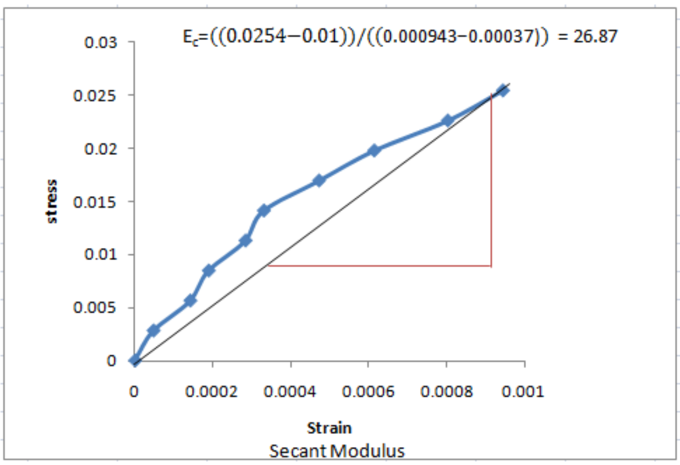

Figure 4.55: Stress versus strain calculation Modulus of Elasticity

Non-destructive testing of concrete cylinder are done at the age of 28 days then modulus of elasticity is found. Rebound hammer is applied on cylinder by both horizontal and vertical position. At least five readings are taken on each face.for UPV direct method is applied for cylinder specimens. Results for 28 days for OPC and PPC based concrete are presented in Table4.14and Table4.15 respectively.

Table 4.14: 28 days results of modulus of elasticity of OPC based concrete

Mix	Rebound no (vertical)	Rebound no (horizontal)	U.P.V(m/sec) (direct method)	Modules of Elasticity(N/mm^2)	Average M.O.E(N/mm^2)
M15	24.4	27.61	4087	22650	22340
	26.7	30.22	4108	23220	
	24.3	28.41	4138	21150	
M20	31.6	33.7	4250	23500	25006
	30.8	36.45	4240	26220	
	30	35.66	4100	25300	
M25	32.25	36.75	4267	28320	28536
	34.42	36.54	4261	27520	
	33.96	37.23	4261	29770	
M30	38.92	40.25	4304	30830	31713
	42.12	43.34	4438	32510	
	39.7	40.8	4354	31800	
M40	44.42	45.74	4464	35120	35366
	46.24	47	4451	36250	
	43.52	44.64	4504	34730	
M50	53.2	55.12	4587	40430	39297
	52.54	55.04	4573	38250	
	52.32	53.2	4464	39210	

Graphical representation of correlation between modulus of elasticity and NDT results for age of 28 days for OPC based concrete are as shown in fig.4.56,fig.4.57,fig.4.58.

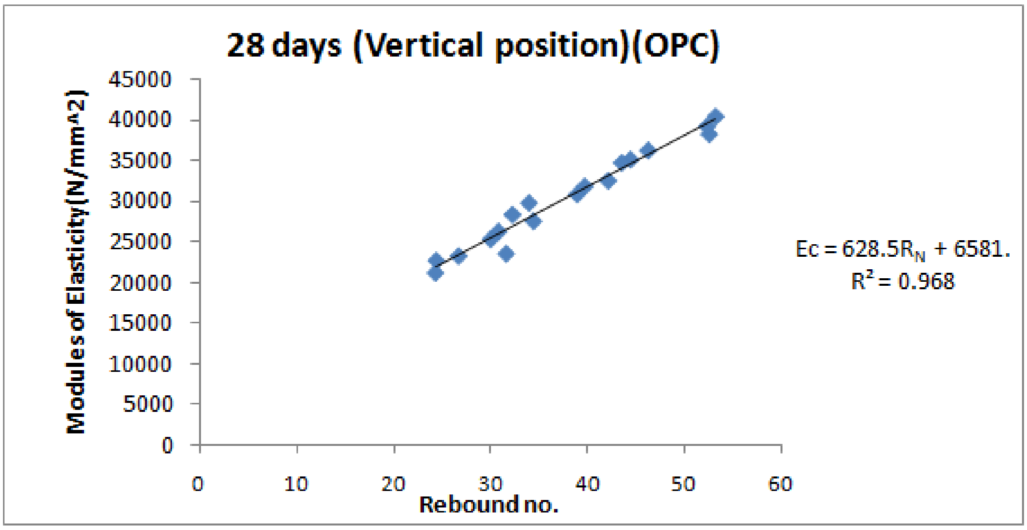

Figure 4.56: Correlation between Modulus of Elasticity and Rebound no. (Vertical position)(OPC)

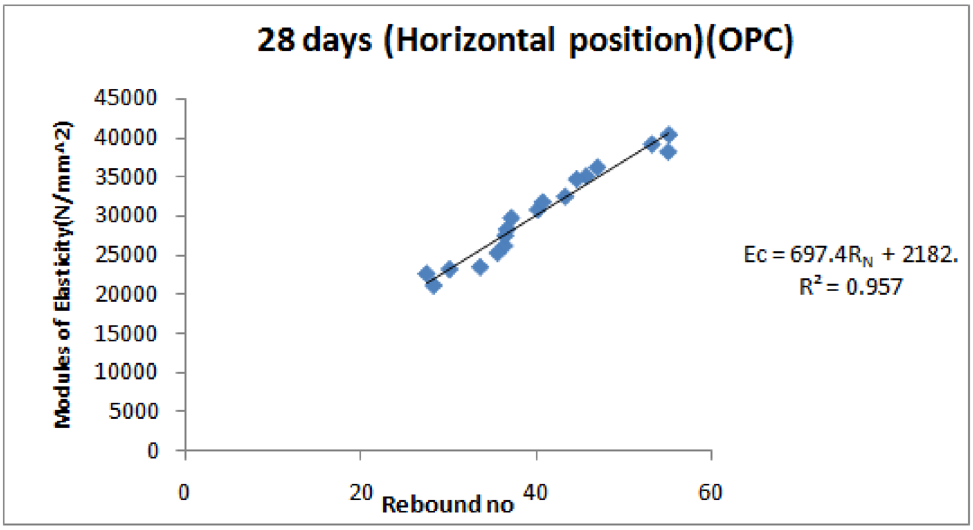

Figure 4.57: Correlation between Modulus of Elasticity and Rebound no. (Horizontal position)(OPC)

The scatter plot (Figures 4.56 & 4.57) representing the rebound no. versus concrete compressive strength could give the following linear equations were concluded for the predicted values of the modulus of elasticity of concrete(MPa) at 28 days for OPC based concrete :

$$E_c = 628.5R_N + 6581\ (Vertical\ position) \tag{4.55}$$

$$E_c = 697.4R_N + 2182\ (Horizontal\ position) \tag{4.56}$$

Where,
E_c = Modulus of Elasticity of concrete(N/mm^2)
R_N = Rebound no.

R square value for Eq.4.55 and Eq.4.56 are 0.968 and 0.957 respectively. 0.968 value explained that 96.8 % of the variability for the data around the regression line and 3.2 % of the residual data could not explained by Eq.4.55. In the case of Eq.4.56 95.7 % of the variability for the data around the line and 4.3 % remain unexplained.

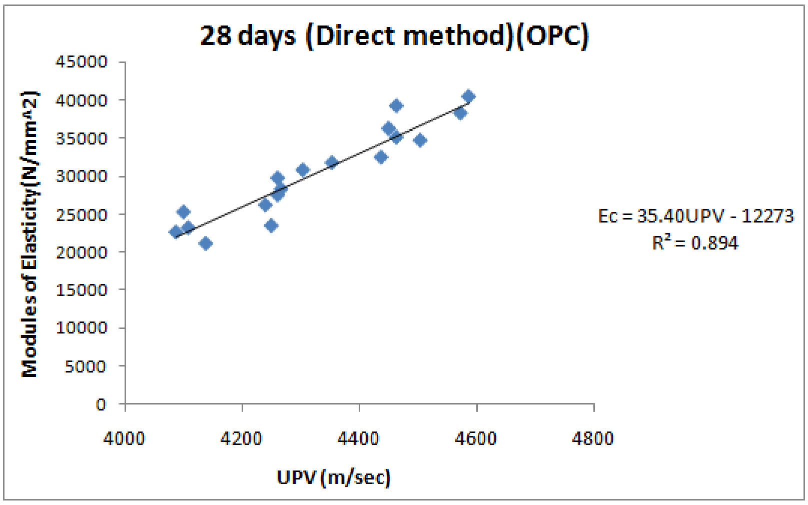

Figure 4.58: Correlation between Modulus of Elasticity and UPV (Direct method)(OPC)

The scatter plot Figures 4.58 representing the UPV results versus modulus of elasticity could give the following linear equations were concluded for the predicted values of the modulus of elasticity (MPa) at 28 days for OPC based concrete :

$$E_c = 35.40UPV - 12273 \ (Direct\ method) \tag{4.57}$$

Where,

E_c = Modulus of Elasticity concrete(N/mm^2)

UPV = Ultrasonic pulse velocity(m/sec)

R square value for Eq.4.57 is 0.894 value explained that 89.4 % of the variability for the data around the regression line and 10.6 % of the residual data could not explained by Eq.4.57.

Table 4.15: 28 days results of Modulus of Elasticity of PPC based concrete

Mix	Rebound no (vertical)	Rebound no (horizontal)	U.P.V(m/sec) (direct)	Modulus of Elasticity(N/mm^2)	Average M.O.E(N/mm^2)
M15	23.8	26.61	4021	22650	21340
	24.7	28.32	4010	21220	
	25.41	28.64	4021	20150	
M20	28.54	32.41	4060	26220	24923.33333
	27.24	30.2	4005	23250	
	29.34	33.3	4132	25300	
M25	31.02	33.21	4109	25630	26796.66667
	33.52	36.45	4225	28510	
	30.82	34.42	4167	26250	
M30	36.85	39.31	4314	28710	30233.33333
	40.64	43.25	4285	31270	
	37.54	40.2	4411	30720	
M40	42.14	43.52	4477	32050	34480
	45.32	46.25	4411	35180	
	44.31	46.2	4491	36210	
M50	51.92	53.12	4478	38250	38570
	53.44	54.26	4464	39450	
	50.2	51.82	4545	38010	

Graphical representation of correlation between modulus of elasticity and NDT results for age of 28 days for PPC based concrete are as shown in Figure 4.59, Figure 4.60, Figure 4.61.

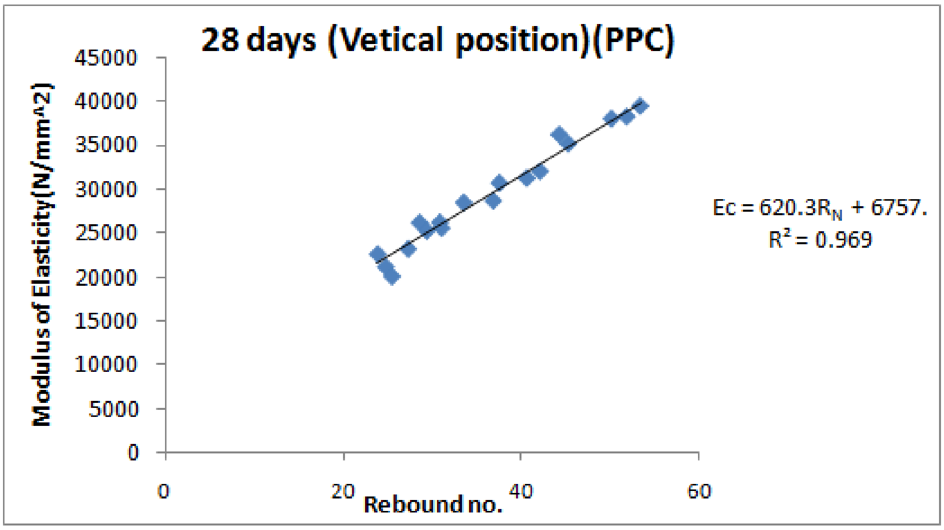

Figure 4.59: Correlation between Modulus of Elasticity and Rebound no. (Vertical position)(PPC)

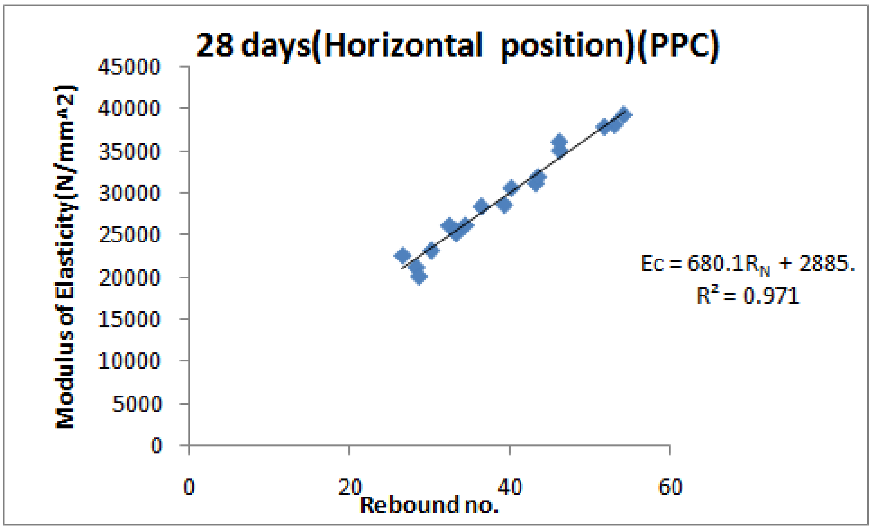

Figure 4.60: Correlation between Modulus of Elasticity and Rebound no. (Horizontal position)(PPC)

The scatter plot (Figures 4.59 & 4.60) representing the rebound no. versus modulus of elasticity of concrete could give the following linear equations were concluded for the predicted values of the modulus of elasticity of concrete(MPa) at 28 days for OPC based concrete :

$$E_c = 620.3R_N + 6757 \ (Vertical\ position) \tag{4.58}$$

$$E_c = 680.1R_N + 2885 \ (Horizontal\ position) \tag{4.59}$$

Where,

E_c = Modulus of Elasticity of concrete(N/mm^2)

R_N = Rebound no.

R square value for Eq.4.58 and Eq.4.59 are 0.969 and 0.971 respectively. 0.969 value explained that 96.9 % of the variability for the data around the regression line and 3.1 % of the residual data could not explained by Eq.4.58. In the case of Eq.4.59 97.1 % of the variability for the data around the line and 2.9 % remain unexplained.

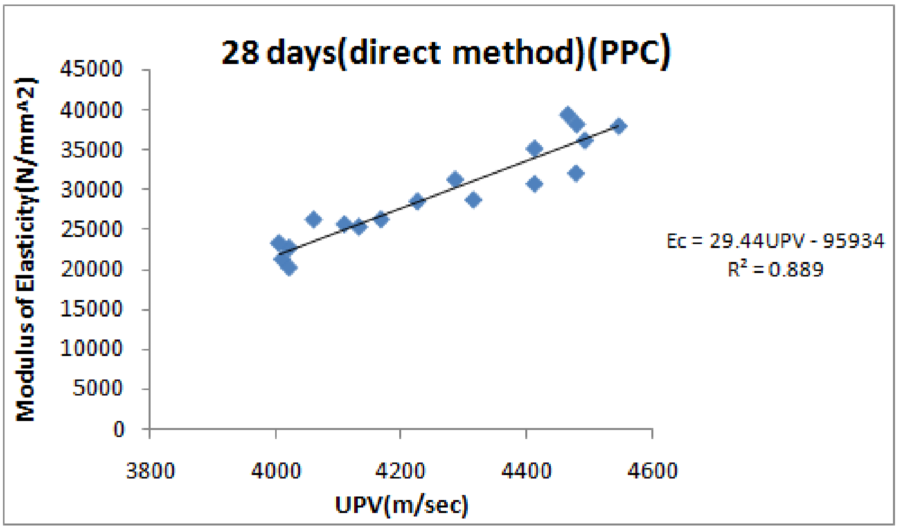

Figure 4.61: Correlation between Modulus of Elasticity and UPV (Direct method)(PPC)

The scatter plot (Figures 4.61) representing the UPV results versus modulus of elasticity could give the following linear equations were concluded for the predicted values of the modulus of elasticity (MPa) at 28 days for OPC based concrete :

$$E_c = 29.44UPV - 95934\ (Direct\ method) \tag{4.60}$$

Where,
E_c = Modulus of Elasticity concrete(N/mm^2)
UPV = Ultrasonic pulse velocity(m/sec)

R square value for Eq.4.60 is 0.889 value explained that 88.9 % of the variability for the data around the regression line and 11.1 % of the residual data could not explained by Eq.4.60.

4.9 Correlation between Flexural Strength and NDT Results

Non-destructive testing of concrete beam are done at the age of 28 days flexural strength is found. Rebound hammer is applied on beam by both horizontal and vertical position. At least five readings are taken on each face.for UPV direct method is applied for beam specimens. Results for 28 days for OPC and PPC based concrete are presented in Table4.16and Table4.17 respectively.

Table 4.16: 28 days results of Flexural strength of OPC based concrete

Mix	Rebound no (vertical)	Rebound no (horizontal)	U.P.V(m/sec) (direct method)	Flexural strength (N/mm^2)	Average Flexural strength (N/mm^2)
M15	26.73	28.3	4023	3.2	3.33
	24.67	26.42	4150	3.6	
	25.13	28.1	3890	3.2	
M20	28.07	31.25	4135	4.2	3.86
	28.27	30.15	4235	4	
	29.13	30.74	3956	3.4	
M25	31.1	33.24	4167	4.4	4
	30.96	34.52	4122	4	
	32.53	35.64	4202	3.6	
M30	38.74	41.65	4237	4.8	4.26
	40.21	42.86	4310	3.6	
	39.54	41.36	4273	4.4	
M40	45.64	46.24	4486	4.8	4.8
	42.87	44.15	4425	4.4	
	44.25	45.64	4386	5.2	
M50	56.24	57.31	4504	5.6	5.2
	53.62	55.24	4565	4.8	
	53.25	54.64	4591	5.2	

Graphical representation of correlation between flexural strength and NDT results for age of 28 days for OPC based concrete are as shown in fig.4.62,fig.4.63,fig.4.64.

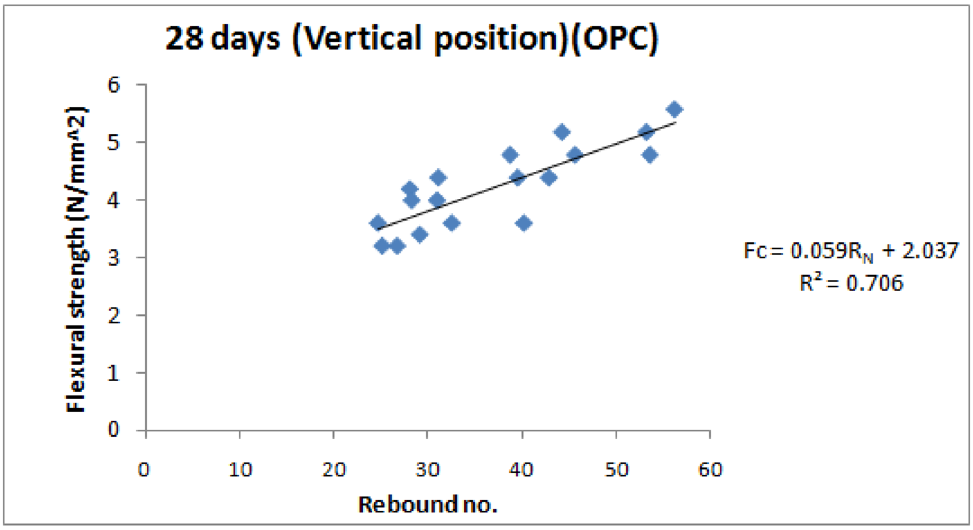

Figure 4.62: Correlation between Flexural strength and Rebound no. (Vertical position)(OPC)

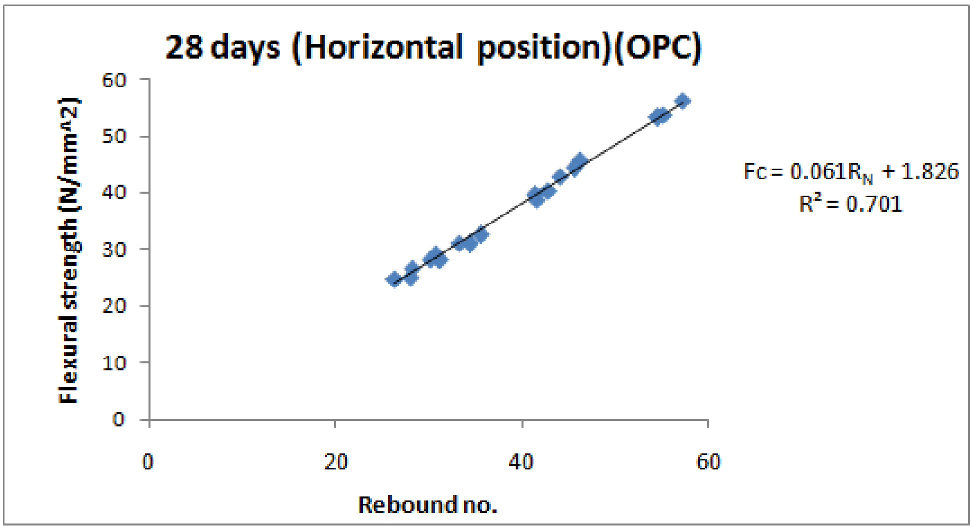

Figure 4.63: Correlation between Flexural strength and Rebound no. (Horizontal position)(OPC)

The scatter plot (Figures 4.62 & 4.63) representing the rebound no. versus flexural strength could give the following linear equations were concluded for the predicted values of the flexural strength of concrete(MPa) at 28 days for OPC based concrete :

$$F_c = 0.059R_N + 2.037\ (Vertical\ position) \tag{4.61}$$

$$F_c = 1.039R_N - 3.583\ (Horizontal\ position) \tag{4.62}$$

Where,
F_c = Flexural strength of concrete(N/mm^2)
R_N = Rebound no.

R square value for Eq.4.61 and Eq.4.62 are 0.706 and 0.994 respectively. 0.706 value explained that 70.6 % of the variability for the data around the regression line and 29.4 % of the residual data could not explained by Eq.4.61. In the case of Eq.4.62 99.4 % of the variability for the data around the line and 0.6 % remain unexplained.

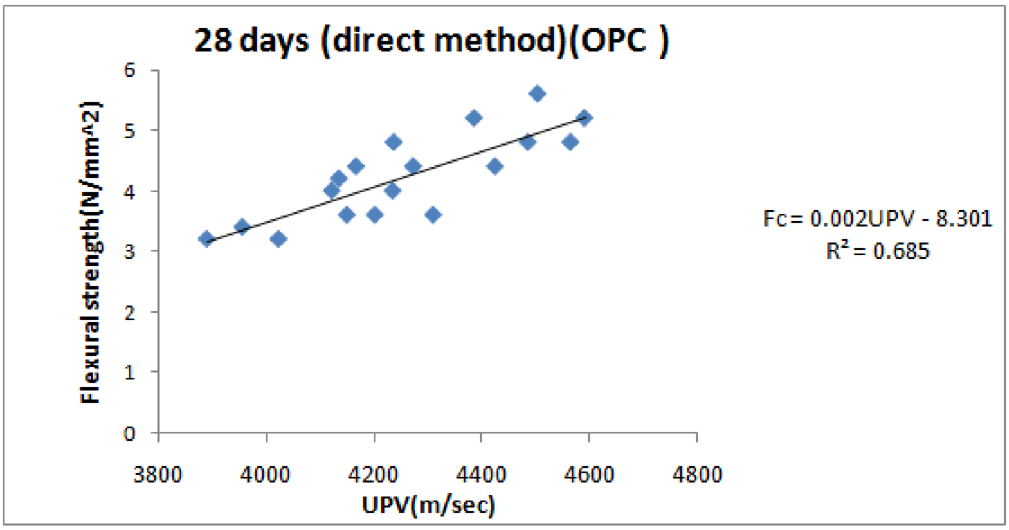

Figure 4.64: Correlation between Flexural strength and UPV (Direct method)(OPC)

The scatter plot (Figures 4.64) representing the UPV results versus flexural strength could give the following linear equations were concluded for the predicted values of the flexural strength (MPa) at 28 days for OPC based concrete :

$$F_c = 0.002UPV - 8.301\ (Direct\ method) \quad (4.63)$$

Where,

F_c = Flexural strength of concrete(N/mm^2)

UPV = Ultrasonic pulse velocity(m/sec)

R square value for Eq.4.63 is 0.685 value explained that 68.5 % of the variability for the data around the regression line and 31.5 % of the residual data could not explained by Eq.4.63.

Table 4.17: 28 days results of Flexural strength of PPC based concrete)

Mix	Rebound no (vertical)	Rebound no (horizontal)	U.P.V(m/sec) (direct method)	Flexural strength (N/mm^2)	Average Flexural strength (N/mm^2)
M15	25.85	27.23	4000	3.2	3.13
	24.67	26.42	3861	3	
	25.13	28.1	4032	3.2	
M20	27.87	30.23	4202	4	3.86
	27.24	30.15	4167	3.4	
	28.58	31.74	3967	3.6	
M25	30.55	33.74	4237	4.6	4.13
	29.96	32.12	4174	4.2	
	31.43	34.14	4280	3.6	
M30	38.24	40.7	4310	4.8	4.33
	39.31	41.66	4273	4.2	
	37.74	40.54	4291	4	
M40	43.54	44.72	4405	4.8	4.77
	44.87	45.65	4378	4.4	
	41.95	43.05	4425	5.12	
M50	53.4	54.31	4500	5.6	5
	55.62	56.01	4587	5	
	52.75	53.64	4464	4.4	

Graphical representation of correlation between flexural strength and NDT results for age of 28 days for PPC are as shown in Figure 4.65, Figure 4.66, Figure 4.67.

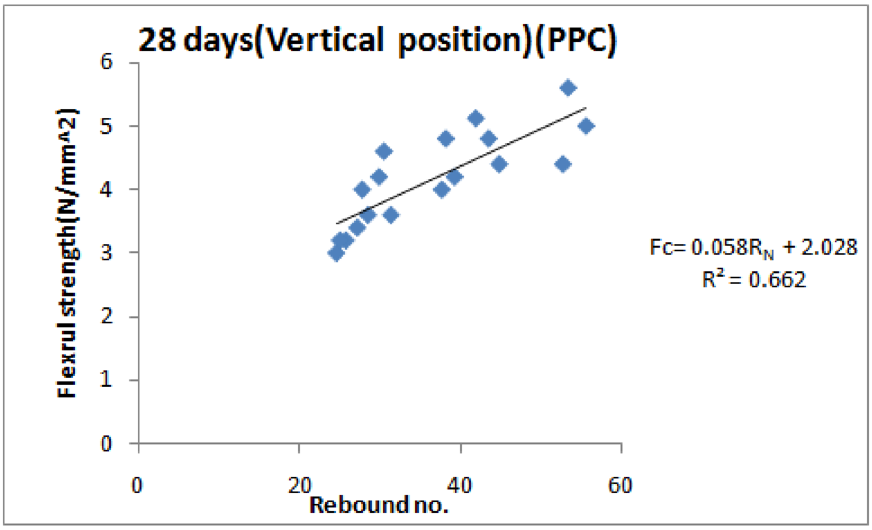

Figure 4.65: Correlation between Flexural strength and Rebound no.(Vertical position)(PPC)

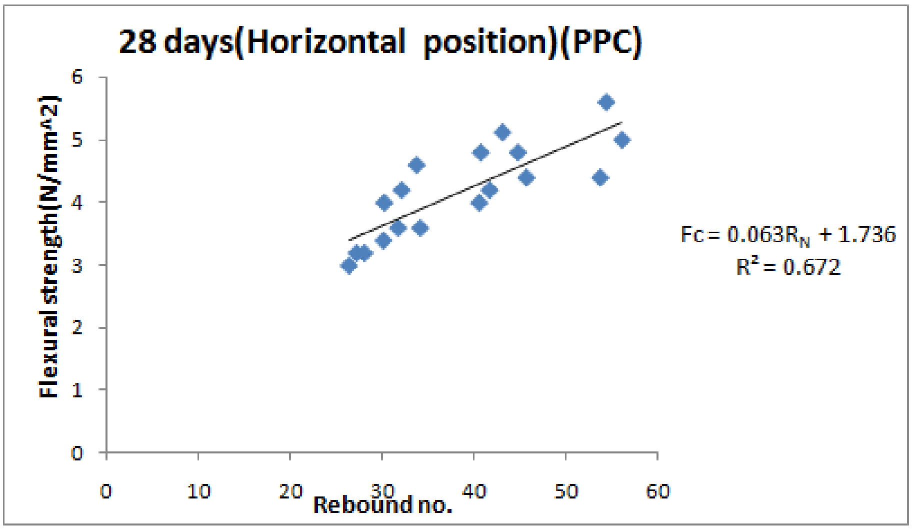

Figure 4.66: Correlation between Flexural strength and Rebound no.(Horizontal position)(PPC)

The scatter plot (Figures 4.65 & 4.66) representing the rebound no. versus flexural of concrete could give the following linear equations were concluded for the predicted values of the flexural strength of concrete(MPa) at 28 days for PPC based concrete :

$$F_c = 0.058R_N + 2.08\ (Vertical\ position) \tag{4.64}$$

$$F_c = 0.063R_N + 1.736\ (Horizontal\ position) \tag{4.65}$$

Where,

F_c = Flexural strength of concrete(N/mm^2)

R_N = Rebound no.

R square value for Eq.4.64 and Eq.4.65 are 0.662 and 0.672 respectively. 0.662 value explained that 66.2 % of the variability for the data around the regression line and 33.8 % of the residual data could not explained by Eq.4.64. In the case of Eq.4.65 67.2 % of the variability for the data around the line and 32.8 % remain unexplained.

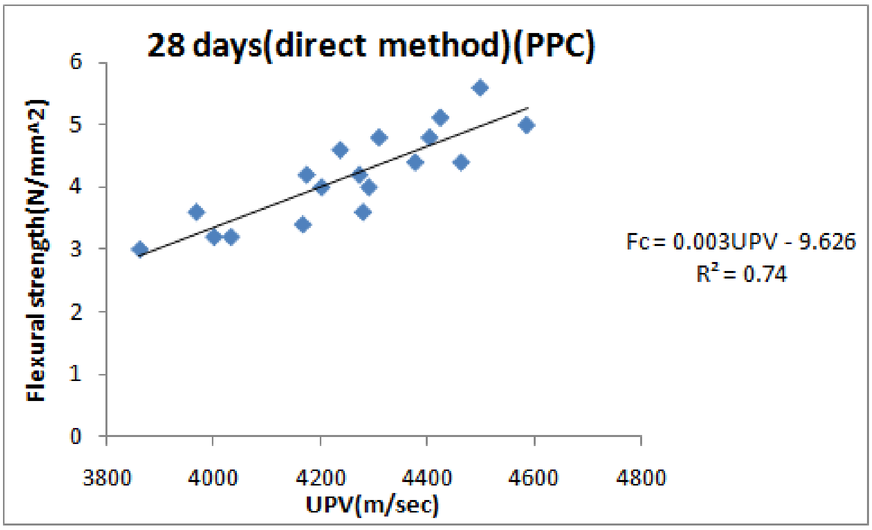

Figure 4.67: Correlation between Flexural strength and UPV (Direct method)(PPC)

The scatter plot (Figures 4.67) representing the UPV results versus flexural strength could give the following linear equations were concluded for the predicted values of the flexural strength (MPa) at 28 days for PPC based concrete :

$$F_c = 0.003UPV - 9.626\ (Direct\ method) \tag{4.66}$$

Where,

F_c = Flexural strength of concrete(N/mm^2)

UPV = Ultrasonic pulse velocity(m/sec)

R square value for Eq.4.66 is 0.744 value explained that 74.4 % of the variability for the data around the regression line and 25.6 % of the residual data could not explained by Eq.4.66.

4.10 Correlation of Split Tensile Strength and NDT Results

Non-destructive testing of concrete cylinder are done at the age of 28 days Split tensile strength is found. Rebound hammer is applied on cylinder by both horizontal and vertical position. At least five readings are taken on each face. For UPV direct method is applied for cylinder specimens.Results for 28 days for OPC and PPC based concrete are presented in Table 4.18and Table 4.19 respectively.

Table 4.18: 28 days results of Split tensile strength of OPC based concrete

Mix	Rebound no (vertical)	Rebound no (horizontal)	U.P.V(m/sec) (direct method)	Split tensile strength (N/mm^2)	Average split tensile strength (N/mm^2)
M15	24.2	27.46	4010	2.13	2.22
	25.32	29.4	3990	2.42	
	26.6	28.9	4120	2.1	
M20	29.8	33.2	4135	2.4	2.55
	31.2	34.25	4230	2.54	
	30.94	33.4	4254	2.7	
M25	33.4	36.5	4240	2.84	2.97
	32.45	35.25	4190	2.94	
	34.8	37.64	4290	3.12	
M30	38.76	41.65	4350	3.24	3.46
	40.1	42.86	4310	3.6	
	39.42	41.36	4270	3.54	
M40	45.64	47.2	4375	3.64	3.73
	46.87	47.1	4450	3.72	
	44.25	45.64	4425	3.84	
M50	54.2	57.31	4520	4.2	4.45
	55.64	55.9	4496	4.46	
	52.3	54.64	4568	4.68	

Graphical representation of correlation between split tensile strength and NDT results for age of 28 days for OPC based concrete are as shown in Figure 4.68, Figure 4.69, Figure 4.70.

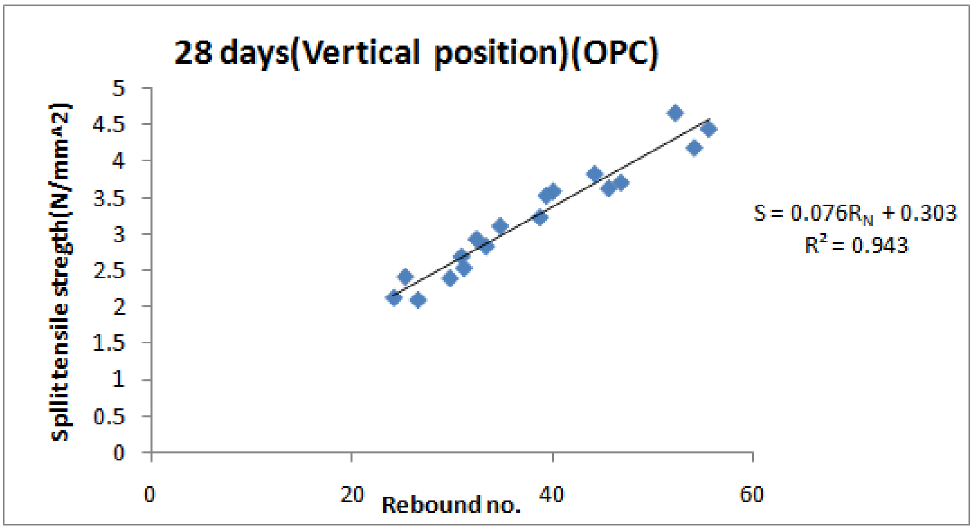

Figure 4.68: Correlation between Split tensile strength and Rebound no.(Vertical position)(OPC)

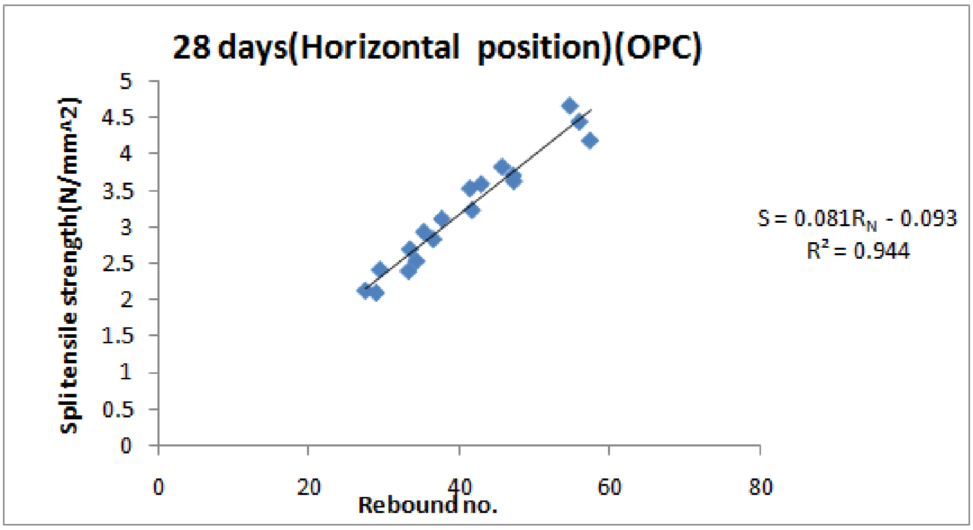

Figure 4.69: Correlation between Split tensile strength and Rebound no.(Horizontal position)(OPC)

The scatter plot (Figures 4.68 & 4.69) representing the Split tensile strength versus rebound no. of concrete could give the following linear equations were concluded for the predicted values of the split tensile strength of concrete(MPa) at 28 days for OPC based concrete :

$$S = 0.076R_N + 0.303\ (Vertical\ position) \tag{4.67}$$

$$S = 0.081R_N - 0.093\ (Horizontal\ position) \tag{4.68}$$

Where,

S = Split tensile strength of concrete(N/mm^2)

R_N = Rebound no.

R square value for Eq. 4.67 and Eq. 4.68 are 0.943 and 0.944 respectively. 0.943 value explained that 94.3 % of the variability for the data around the regression line and 5.7 % of the residual data could not explained by Eq. 4.67. In the case of Eq. 4.68 94.4 % of the variability for the data around the line and 5.6 % remain unexplained.

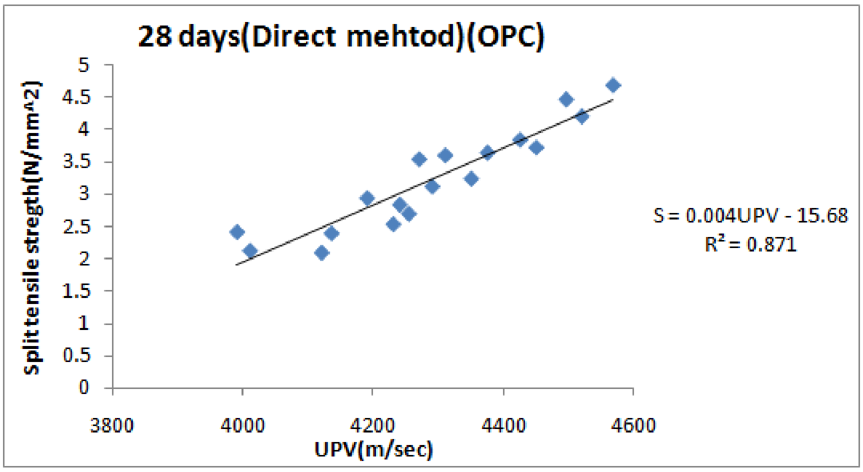

Figure 4.70: Correlation between Split tensile strength and UPV (Direct method)(OPC)

The scatter plot (Figures 4.69) representing the Split tensile strength versus UPV could give the following linear equations were concluded for the predicted values of the split tensile strength (MPa) at 28 days for OPC based concrete :

$$S = 0.004UPV - 15.68\ (Direct\ method) \tag{4.69}$$

Where,
S = Split tensile strength of concrete(N/mm^2)
UPV = Ultrasonic pulse velocity(m/sec)

R square value for Eq. 4.69 is 0.871 value explained that 87.1 % of the variability for the data around the regression line and 12.9 % of the residual data could not explained by Eq. 4.69.

Table 4.19: 28 days results of Split Tensile Strength of PPC based concrete

Mix	Rebound no (vertical)	Rebound no (horizontal)	U.P.V(m/sec) (direct method)	Split tensile strength (N/mm^2)	Average split tensile strength (N/mm^2)
M15	24.1	27.4	4035	2.13	2.22
	22.34	24.2	3910	2.32	
	23.4	26.34	4080	2.2	
M20	29.3	31.45	4085	2.38	2.48
	28.24	30.62	4164	2.42	
	30.46	33.1	4210	2.65	
M25	32.3	34.56	4230	3.15	2.96
	30.25	33.12	4165	2.8	
	31.94	35.2	4276	2.94	
M30	37.8	40.8	4285	3.36	3.45
	38.84	41.31	4320	3.52	
	37.6	40.25	4268	3.46	
M40	44.25	46.2	4370	3.76	3.66
	43.2	45.1	4420	3.58	
	42.5	44.64	4435	3.64	
M50	52.3	54.2	4490	4.3	4.40
	53.62	55.65	4425	4.25	
	51.45	52.64	4565	4.65	

Graphical representation of correlation between Split tensile strength and NDT results for age of 28 days for PPC based concrete are as shown in Figure4.71, Figure4.72, Figure4.73.

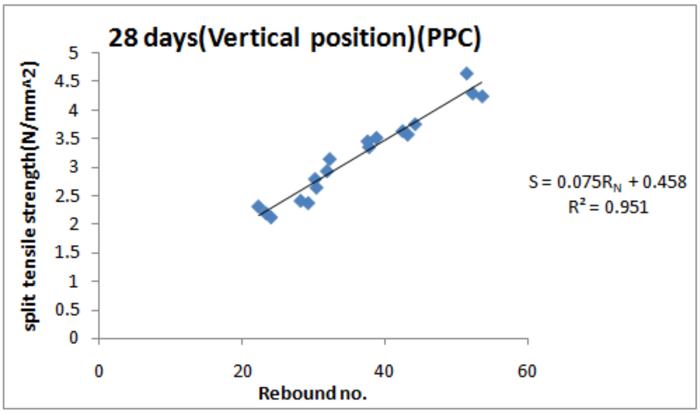

Figure 4.71: Correlation between Split tensile strength and Rebound no.(Vertical position)(PPC)

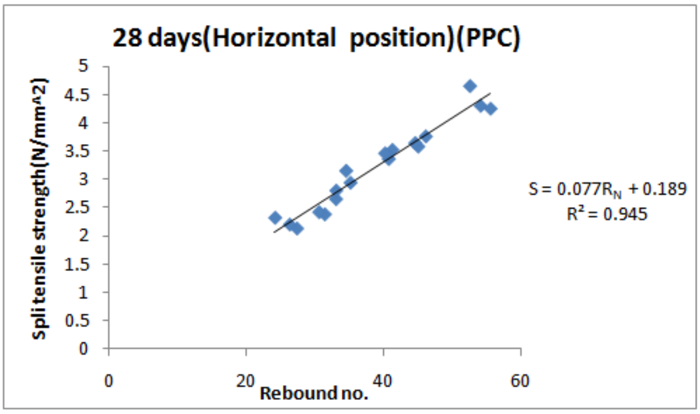

Figure 4.72: Correlation between Split tensile strength and Rebound no.(Horizontal position)(PPC)

The scatter plot (Figures 4.71 & 4.72) representing the rebound no. versus split tensile strength of concrete could give the following linear equations were concluded for the predicted values of the split tensile strength of concrete(MPa) at 28 days for OPC based concrete :

$$S = 0.075R_N + 0.458\ (Vertical\ position) \tag{4.70}$$

$$S = 0.077R_N + 0.189\ (Horizontal\ position) \tag{4.71}$$

Where,
S = Split tensile strength of concrete(N/mm^2)
R_N = Rebound no.

R square value for Eq.4.70 and Eq.4.71 are 0.951 and 0.945 respectively. 0.951 value explained that 95.1 % of the variability for the data around the regression line and 4.9 % of the residual data could not explained by Eq.4.70. In the case of Eq.4.71 94.5 % of the variability for the data around the line and 5.5 % remain unexplained.

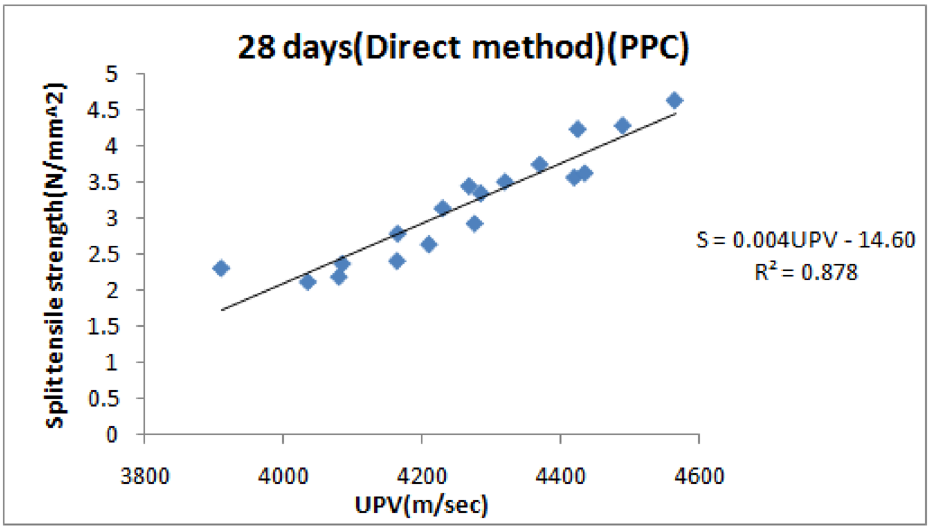

Figure 4.73: Correlation between Split tensile strength and UPV(Direct method)(PPC)

The scatter plot (Figures 4.73) representing the UPV results versus split tensile strength could give the following linear equations were concluded for the predicted values of the split tensile strength (MPa) at 28 days for PPC based concrete:

$$S = 0.004UPV - 14.60\ (Direct\ method) \tag{4.72}$$

Where,

S = Split tensile strength of concrete(N/mm^2)

UPV = Ultrasonic pulse velocity(m/sec)

R square value for Eq.4.72 is 0.878 value explained that 87.8 % of the variability for the data around the regression line and 12.2 % of the residual data could not explained by Eq.4.72.

4.11 Summary

This chapter deals with the 7, 28, 90 days results of both non-destructive test and compressive strength for both OPC and PPC based concrete. Also results are taken from RCC members and results from sites. These results are correlated with compressive strength of concrete. Also contains the 28 days results of non-destructive test and other mechanical properties like modulus of elasticity, flexural strength and split tensile strength of concrete specimens for both OPC and PPC based concrete. Various correlations are found between NDT results and mechanical properties by the use of MS EXCEL and SPSS software.

Chapter 5

Concluding Remarks and Future Scope of Work

5.1 Summary

The experiment is based on development of correlation between non-destructive test results and mechanical properties of concrete specimens. Two types of cements OPC and PPC are used in present investigation. In Non-destructive testing two methods are attempted i.e. rebound hammer and ultrasonic pulse velocity method. The aggregates used as a fine aggregate is river sand which is locally available. The coarse aggregates which are used in preparing concrete are of size 10 mm and 20 mm, respectively. Sieve analysis and specific gravity tests are performed for the aggregates. Concrete mix design is done for different concrete grades such as M15, M20, M25, M30, M40 and M50. Standard cube of size 150 $\times$ 150 $\times$ 150 mm has been used for the compressive strength test. For split tensile strength, modulus of elasticity and flexural strength, cylinder of size 150 $\times$ 300 mm and beam of size 100 $\times$ 100 $\times$ 500 mm have been used, respectively. High range water reducing admixtures has been used to improve the workability of fresh concrete of M50 grade.

Test specimens have been cast in the laboratory using the equipments normally used such as a pan mixer, standard steel moulds and vibrating table. Compressive strength are measured after finding the NDT results at the age of 7, 28, 90 days age period. On cube specimens 5 readings of rebound hammer are taken by each position of rebound hammer. For UPV in direct method 3 readings are taken on each cube and in semi-direct method 4 readings are taken. For beam and cylinder same method is adopted for rebound hammer. In case of UPV only direct method is adopted for beam and cylinder. Mechanical properties such as flexural strength, modulus of elasticity and split tensile strength of plain concrete specimens are measured after 28 days of moist curing for all grades. For surface hardness test both vertical and horizontal position are adopted. For UPV direct and semi direct methods are adopted. NDT results of in situ RCC members and laboratory RCC members are taken and correlations are carried out with compressive strength of concrete. Regression analysis is done using Ms Excel and SPSS software to develop the correlation between NDT results and mechanical properties of standard size specimens.

5.2 Concluding Remarks

The attempts are made towards evaluating the strength and different properties of concrete to come without disturbing the structure. In view of the trial works and studies, the following conclusions are drawn:

- Linear expressions are obtained to represent the relationship between compressive strength and Rebound no.(Vertical position) for all grades(M15, M20, M25, M30, M40, M50) for all ages respectively as follows:
  $S_c = 1.113R_N$-4.969 (For OPC based concrete) ($R^2 = 0.979$)
  $S_c = 1.094R_N$-3.929 (For PPC based concrete) ($R^2 = 0.981$)
  $S_c = 1.102R_N$-4.380 (For combination of OPC & PPC) ($R^2 = 0.980$)

- Linear expressions are obtained to represent the relationship between compressive strength and Rebound no.(Horizontal position) for all grades(M15, M20,

M25, M30, M40, M50) for all ages respectively as follows:
S_c = 1.155R_N-8.393 (For OPC based concrete) (R^2 = 0.980)
S_c = 1.202R_N-10.35 (For PPC based concrete) (R^2 = 0.985)
S_c = 1.179R_N-9.393 (For combination of OPC & PPC) (R^2 = 0.982)

- Linear expressions are obtained to represent the relationship between compressive strength and UPV(Direct method) for all grades(M15, M20, M25, M30, M40, M50) for all ages respectively as follows:
  S_c = 0.056UPV-210.6 (For OPC based concrete) (R^2 = 0.830)
  S_c = 0.062UPV-234.5 (For PPC based concrete) (R^2 = 0.802)
  S_c = 0.058UPV-219.3 (For combination of OPC & PPC) (R^2 = 0.864)

- Linear expressions are obtained to represent the relationship between compressive strength and UPV(Semi direct method) for all grades(M15, M20, M25, M30, M40, M50) for all ages respectively as follows:
  S_c = 0.051UPV-181.1 (For OPC based concrete) (R^2 = 0.780)
  S_c = 0.055UPV-198.4 (For PPC based concrete) (R^2 = 0.867)
  S_c = 0.053UPV-188.9 (For combination of OPC & PPC) (R^2 = 0.823)

- Correlation between compressive strength and NDT results of RCC members & combination of RCC and PCC members are done and linear relations are obtained:
  S_c = 1.280R_N-11.43 (For RCC members) (R^2 = 0.892)
  S_c = 1.185R_N-9.051 (For combination of PCC $ RCC members) (R^2 = 0.943)
  S_c = 0.009UPV-0.448 (For RCC members) (R^2 = 0.441)
  S_c = 0.011UPV-10.28 (For combination of PCC & RCC) (R^2 = 0.333)

- Linear expressions are obtained to represent the relationship between compressive strength and combination of both non-destructive methods for all grades as group for all ages respectively as follows:

Table 5.1: Correlation between NDT results by combination of both methods and compressive strength

Detail	Parameters	R square
$S_c = 1.115R_N$+0.02UPV-4.543	Vertical position for rebound hammer & Direct method for UPV(OPC)	0.979
$S_c = 1.141R_N$+0.01UPV-11.434	Horizontal position for rebound hammer & Direct method for UPV(OPC)	0.981
$S_c = 1.053R_N$+0.04UPV-17.764	Vertical position for rebound hammer & Semi-direct method for UPV(OPC)	0.98
$S_c = 1.075R_N$+0.05UPV-24.615	Horizontal position for rebound hammer & Semi-direct method for UPV(OPC)	0.981
$S_c = 1.026R_N$+0.04UPV-19.728	Vertical position for rebound hammer & Direct method for UPV(PPC)	0.982
$S_c = 1.132R_N$+0.059UPV-24.922	Horizontal position for rebound hammer & Direct method for UPV(PPC)	0.986
$S_c = 1.053R_N$+0.04UPV-17.764	Vertical position for rebound hammer & Semi-direct method for UPV(PPC)	0.982
$S_c = 1.116R_N$+0.05UPV-26.457	Horizontal position for rebound hammer & Semi-direct method for UPV(PPC)	0.986
$S_c = 1.088R_N$+0.01UPV-7.487	Vertical position & Direct method combination of both OPC & PPC	0.98
$S_c = 1.140R_N$+0.002UPV-17.544	Horizontal position & Direct method combination of both OPC & PPC	0.983
$S_c = 1.038R_N$+0.04UPV-17.751	Vertical position & Semi direct method combination of both OPC & PPC	0.981
$S_c = 1.091R_N$+0.05UPV-26.303	Horizontal position & Semi direct method combination of both OPC & PPC	0.984
$S_c = 1.193R_N$+0.001UPV-12.512	RCC	0.881
$S_c = 1.116R_N$+0.05UPV-26.457	Combination of PCC & RCC	0.944

- Linear expressions are obtained to represent the relationship between other mechanical properties and for all grades as group for combination of 28 days as follows:

Table 5.2: Correlation between NDT results and mechanical properties of concrete

Detail	Parameters	R square
$E_c = 697.4R_N + 2182$	Horizontal position for rebound hammer(OPC)	0.957
$E_c = 628.5R_N + 6581$	Vertical position for rebound hammer(OPC)	0.968
E_c = 35.40UPV − 12273	Direct method for UPV(OPC)	0.894
$E_c = 680.1R_N + 2885$	Horizontal position for rebound hammer(PPC)	0.971
$E_c = 620.3R_N + 6757$	Vertical position for rebound hammer(PPC)	0969
E_c = 29.44UPV − 95934	Direct method for UPV(PPC)	0.889
$F_c = 1.039R_N - 3.583$	Horizontal position for rebound hammer(OPC)	0.994
$F_c = 0.059R_N + 2.037$	Vertical position for rebound hammer(OPC)	0.706
F_c = 0.002UPV 8.301	Direct method for UPV(OPC)	0.685
$F_c = 0.063R_N + 1.736$	Horizontal position for rebound hammer(PPC)	0.672
$F_c = 0.058R_N + 2.08$	Vertical position for rebound hammer(PPC)	0.662
F_c = 0.003UPV − 9.626	Direct method for UPV(PPC)	0.744
S = $0.081R_N - 0.093$	Horizontal position for rebound hammer(OPC)	0.944
S = $0.076R_N + 0.303$	Vertical position for rebound hammer(OPC)	0.943
S = 0.004UPV − 15.68	Direct method for UPV(OPC)	0.871
S = $0.077R_N + 0.189$	Horizontal position for rebound hammer(PPC)	0.945
S = $0.075R_N + 0.458$	Vertical position for rebound hammer(PPC)	0.951
S = 0.004UPV − 14.60	Direct method for UPV(PPC)	0.878

- The correlation of rebound no. and compressive strength are compared with standard curve of rebound hammer, which is provided by company. Variation has been found less than 10%. Hence above correlation are useful for predicting the strength without damaging the structure.

5.3 Future Scope of Work

The study may be further extended to include following aspects in the work:

- Further work may be carried out using higher grade of concrete like M60, M70, M80, M90, M100 by use of OPC and PPC.
- Core may be extracted from each grade of concrete cubes and correlations are generated between compressive strength of cores and NDT i.e. rebound no and UPV results of core.
- Replacement of cement by different cementetious material like fly ash, silica fume, GGBFS and same study may be repeated.
- By using different types of aggregate like replacing basalt with granite aggregate and similar studies may be conducted.
- Similar study may be repeated using different curing condition water curing, steam curing etc. Also comparision of non-destructive & destructive testing of dry and wet concrete specimens may be conducted.

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