ANALYSIS

54(268), April 1, 2018

ISSN 2278–5469
EISSN 2278–5450

Discovery

Damage assessment of reinforced concrete beams for differential degree of corrosion

Balakrishna MN[1☼], Fouad Mohammad[2], Robert Evans[2], Rahman MM[2]

1.School of Architecture, Design and the Built Environment, Research scholar, Nottingham Trent University, Nottingham, NG1 4FQ, UK

2.School of Architecture, Design and the Built Environment, Faculty of Engineering, Nottingham Trent University, Nottingham, NG1 4FQ, UK

☼**Corresponding Author:**
School of Architecture,
Design and the Built Environment,
Research scholar,
Nottingham Trent University,
Nottingham, NG1 4FQ,
UK
Email: - N0413461@my.ntu.ac.uk

Article History
Received: 02 February 2018
Accepted: 11 March 2018
Published: 1 April 2018

Citation
Balakrishna MN, Fouad Mohammad, Robert Evans, Rahman MM. Damage assessment of reinforced concrete beams for differential degree of corrosion. *Discovery*, 2018, 54(268), 147-156

ABSTRACT

The damage assessment of civil structural members is one of the most important and recently emerging fields in engineering. Deterioration of a structure may occur due to a host of factors such as poor workmanship, improper maintenance, atmospheric effects, accidents, natural calamities. Certain causes like environmental effects, natural calamities could not be controlled. Therefore, durability of concrete structures especially those exposed to aggressive environments is of great concern. In spite of many deterioration causes in turn corrosion of steel reinforcement was found to be one of the major deterioration problems. Thus, an Engineer may need to examine the state of reinforcement in structures for a number of reasons including assessment for change of use or exposure, routine maintenance, or investigating signs of distress. In turn, there is a requirement for a method that can determine simply, accurately and non-destructively not only whether corrosion of reinforcement is taking place but also its intensity and the rate of damage. The main aim of this paper is to assess and evaluate the corrosion condition of reinforced concrete beams by using Non-destructive test (NDT) methods such as Half-cell potential test, Rebound hammer test, and Ultrasonic pulse velocity test. Also another thrust of this pilot program is to establish a correlation between Rebound hammer number, and Ultrasonic pulse velocity variation versus concrete compressive strength for different degree of corrosion. In turn to interpret the effectiveness of degree of corrosion on NDT values as well as concrete compressive strength. For that a total of six reinforced concrete beams (125x250x3200) mm were considered. An impressed current was applied to beams with different degree of corrosion (5%, 15%, and 20%) in order to accelerate steel corrosion. Mean while electrochemical measurements were carried out to obtain open circuit potential. Finally the results show that the Linear regression analysis is the best fit for the compressive strength prediction relationship by using Rebound hammer and Ultrasonic pulse velocity test at compression as well as tension side of reinforced concrete beam with different degree of corrosion (5%, 15% & 20%).

Keywords: Corrosion, Electrochemical test, Ultrasonic pulse velocity test, Rebound hammer test, Compressive strength, Regression analysis

1. INTRODUCTION

The corrosion of reinforcing steel in concrete leads to the premature failure of many structures exposed to harsh environments. Rust products form on the bar, expanding its volume and creating stress in the surrounding concrete. This leads to cracking and spalling, both of which can severely reduce the service life and strength of a member. Corrosion of reinforcing steel in concrete structures is one of the most expensive problems facing civil engineers all around the world. There have been many tests reported in literature for the assessment of the corrosion of steel in concrete. Most of the earlier tests, primarily through field exposure could provide only qualitative information. While in the recent year researchers have been utilizing some of the techniques like electrochemical tests as well as non-destructive methods to establish precise and quantitative results. The non-destructive testing is one such method, which is often necessary to test concrete structures after the concrete has hardened to determine whether the structure is suitable for its designed use. Ideally, such testing should be done without damaging the concrete. The tests available for testing concrete range from the completely non-destructive, where there is no damage to the concrete, through those where the concrete surface is slightly damage, to partially destructive tests, such as core tests and pullout and pull off tests, where the surface has to be repair after the test. The range of properties that can be assess using non-destructive tests and partially destructive tests is quite large and includes such fundamental parameters as density, elastic modulus and strength as well as surface hardness and surface absorption, and reinforcement location, size and distance from the surface. In some cases, it is also possible to check the quality of workmanship and structural integrity in order to detect voids, cracking and delamination. There are many methods of non-destructive testing available out of which rebound hammer, Ultrasonic pulse velocity, and Half-cell electrical potential test are very commonly used. Schmidt/rebound hammer test, used to evaluate the surface hardness of concrete. Although the rebound hammer does provide a quick, inexpensive method of checking the uniformity of concrete, it has some serious limitations. The results are affected by: 1. Smoothness of the test surface; 2. Size, shape and rigidity of the specimen; 3. Age of the specimen; 4. Surface and internal moisture conditions of concrete; 5. Type of coarse aggregate; 6. Type of cement; 7. Carbonation of the concrete surface. Half-cell electrical potential method, which was use to detect the corrosion potential of reinforcing, bars in concrete. Ultrasonic pulse velocity test was mainly use to measure the sound velocity as well compressive strength of the concrete. Also the following factors influences the Ultrasonic pulse velocity such as: 1. Moisture content; 2. Temperature of the concrete; 3. Path length; 4. Shape and size of specimen; 5. Effect of reinforcing bars; 6. Determination of concrete uniformity. In this experimental work for different degree of corrosion, Ultrasonic pulse velocity is use to determine the quality of concrete both at the compression as well as tension side of reinforced concrete beams. A pair of piezoelectric sensors is place at opposite ends of the reinforced concrete member at an equidistant. Knowing the distance travelled, propagation velocity is calculated and based on the velocity, condition of the concrete is determined. In addition, Schmidt/rebound hammer test is use to evaluate the surface hardness of concrete both at the compressive as well as tension side of reinforced concrete beams at an equal interval along the longitudinal direction. From the test results, correlation between degree of corrosion/days, Ultrasonic pulse velocity and Rebound hammer number/concrete compressive strength is interpreted by using Regression analysis.

2. RESEARCH SIGNIFICANCE

The impact of reinforcing steel corrosion on performance of reinforced concrete structures is of paramount importance in concrete material and structural design. The objective of this study was to provide a reliable database for effectiveness of different degree of corrosion on corrosion damage assessment of reinforced concrete beams. This research illustrates the interactions among degree of corrosion rate with age in days, ultrasonic pulse velocity, rebound hammer number, concrete compressive strength of reinforced concrete beams. Thus, the results may provide researchers' insight into corrosion damage evaluation of reinforced concrete beams by using NDT methods. In addition, the results may provide correlation between Rebound hammer number/Compressive strength and Ultrasonic pulse velocity/Compressive strength, which is interpreted by Regression analysis.

3. LITERATURE REVIEW

The concrete construction relies on the composite interaction of concrete and steel. The alkaline environment within good quality concrete offers a high degree of protection to the embedded reinforcement against aggressive agents that promote the corrosion of steel. The most significant causes that lead to corrosion of reinforcement steel and corrosion induced damage such as cracking and spalling and consequent reduction in structural capacity are poor quality of concrete, inadequate cover to reinforcement, chlorides in the concrete. This means that in a conventional RC Beam, loss of steel section, corrosion induced cracks will develop leading to delamination and loss of bond between the concrete and steel [1]. The Non-destructive test (NDT) methods are commonly using for quality control of various construction elements [2]. The development of NDT methods is important from a technical and an economical point of view. Contrary to destructive methods, NDT techniques give information about material properties without deteriorating material microstructure and serviceability. By comparison, to other construction materials like steel, the development of NDT methods for concrete-like composites has progressed at a slower pace because these kinds of composites are difficult to test [3]. This is due to Concrete is heterogeneous, intrinsically conductive (because the pore solution is an ionic electrolyte), and usually contains steel reinforcement. Literature reports different approaches to concrete strength estimation based on the correlation between physical parameters and concrete strength [4-5, 13-17] and its correlation with the compressive strength is a classical technique that can be apply to each concrete after a calibration campaign. Thus, they are representative of region with limited and supposedly homogenous size. The manufacturers of NDT provide correlation charts with their equipment and recommended their use for estimating strength properties of concrete. These charts do not appear to be satisfactory because their development is base on the use of certain types and size of aggregates, test specimens, and test condition [6]. In a recently published review article, Popovics [7] discusses the accuracy of strength predictions made by ultrasonic pulse velocity methods. He concludes that predictions based on through transmission experiments can currently achieve an accuracy of ±20% under laboratory conditions.

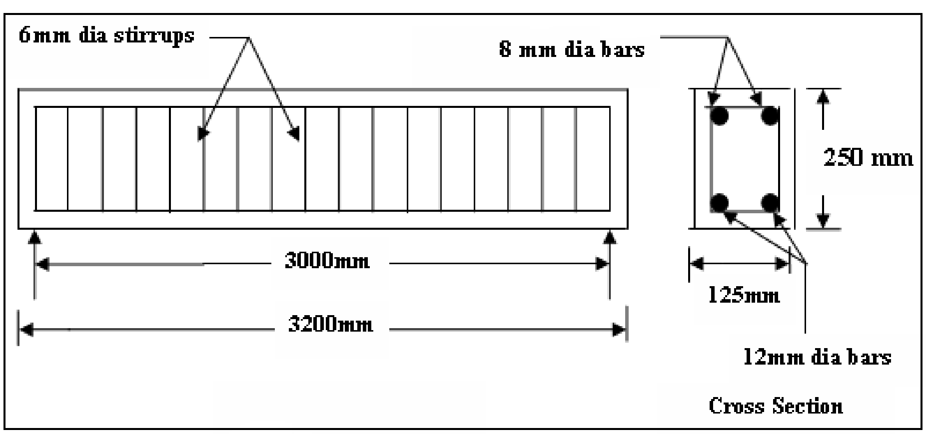


Figure 1 Reinforcement details of beam

4. EXPERIMENTAL WORK

The dimensions (125 mmx250 mmx3200mm) of the six RC beams with an effective span of 3000 mm were cast using 2-12mm ϕ bars (yield strength of 415 N/mm2) as tension reinforcement, 2-8 mm ϕ bars as compression reinforcement, and 22 numbers of 6 mm ϕ at 125 mm c/c stirrups. The concrete mix used was 1:1.53:3.2 by weight with a water-cement ratio of 0.49. Out of six beams, each two beams were subjected to different degree of corrosion (Dc) under accelerated corrosion by constant current source (Dc = 5%, 15% and 20% of rebar mass loss). The details of reinforcement within the reinforced concrete beam are as shown below in Fig.1.

5. ACCELERATED CORROSION PROCESS

The reinforced concrete beams were subjected to an accelerated corrosion process in an electrolytic cell by means of a direct current supply. An electric current was passed through the main longitudinal bottom reinforcing bars of about maximum 5000 mA. The beams were placed on the stainless steel plate SS316 grade acting as a cathode (Non-corrosive plate) and this set up was placed in the 3.5% NaCl solution, which acted as an electrolyte and the solution level in the tank was adjusted to slightly exceed the concrete cover plus rebar diameter in order to ensure adequate submission of longitudinal reinforcement. The layout of corrosion setup and corrosion monitoring are shown in the Fig.2 and Fig.3. It is possible to convert the current flow in to metal loss by Faraday's law. According to Faraday's law, the time for accelerated corrosion was calculated as 45.31 hr, 135.94 hr, and 181.25 hr for 5%, 15%, and 20% mass loss (corrosion) of tension steel. The copper-copper sulphate (Cu-CuSO4) half-cell electrode was select for corrosion measurement in the present research. The testing procedure in this research which was followed the standard test method for half-cell potentials of reinforcing steel in concrete (ASTM C 876) as per code (8). This test can give the probability of corrosion activity that taking place at the point where the measurements of potentials are taken from a half-cell, typically a copper-copper sulphate half-cell. An electrical contact is established with the steel and the half-cell is move across the surface of concrete for measuring the potentials. According to ASTM C 876, if the copper-copper sulphate half-cell potential reading is more positive than -0.20 V CSE (copper-copper sulphate electrode), there is a greater than 90% probability that no reinforcement steel corrosion is occurring in the area at the time of measurement. If the potential reading is in the range of -0.20 to -0.35 V CSE, corrosion activity of the reinforcing steel is assume uncertain. If the potential reading is more negative than -0.35 V CSE, it's assumed that a greater than 90% probability of the reinforcing steel corrosion is occurring. The half-cell potential readings are taken two times per day at eleven different locations that are equally distributed along a beam.

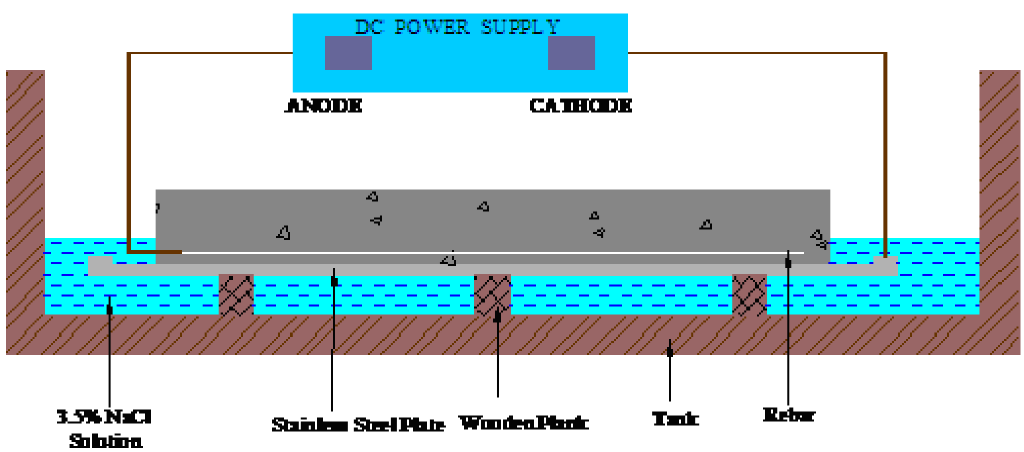


Figure 2 Layout of corrosion setup

Furthermore, impact hammer or simply Schmidt Rebound hammer test was carried out on compression as well as tension side before and after corrosion damage inducement in RC beams for different degree of corrosion at eleven different locations that are equally distributed along a beam to measure the surface hardness of concrete by releasing a spring loaded plunger which impacts the concrete and measures the rebound distance. It is also well known fact that the test method of rebound hammer for normal concrete has been well documented by IS:13311-Part2(9), in turn this code procedure was followed in the present study for the evaluation of the rebound hammer number. Also Ultrasonic pulse velocity test with opposite faces (direct transmission) was carried out as per IS: 13311-Part1(10) on corrosion damaged RC beams for different degree of corrosion at eleven different locations that are equally distributed along a beam and ultrasonic pulse velocity reading are recorded both at compression as well as tension side. This test is conduct for assessing the quality and integrity of concrete by passing ultrasound waves through the specimen or RCC member under test. This test can also be use to determine the presence of honeycombs, voids, and cracks. The instrument consists of a transmitter and a receiver (two probes). The time of travel for the wave to pass from the transmitter to the receiver when kept opposite to each other is record in the ultrasonic instrument. The distance between the two probes (path length) can be physically measure. Hence, the ultrasonic pulse velocity is defined as the ratio between path length and time.

Figure 3 Layout of corrosion monitoring

6. RESULTS AND DISCUSSION

In fact the corrosion of reinforcing steel can damage or reduce the serviceability of concrete structures in several different ways. First, corrosion produces expansive products that generate tensile stresses in the concrete surrounding the reinforcing steel, which may cause concrete cracking. In turn, Cracks can reduce the overall strength and stiffness of the concrete structure and accelerate the ingress of aggressive ions which leading to other types of concrete deterioration and resulting in further cracking. Second, corrosion products are highly porous, weak, and often form around reinforcing steel, thus decreasing the bond strength between the reinforcement and concrete (11). Thus, the impact of reinforcing steel corrosion on performance of reinforced concrete structures is of paramount importance in concrete material and structural design. The variations of Half-cell potential versus Distance for different degree of corrosion such as 5%, 15%, and 20% are plot as shown in (Fig.3a-Fig.3c). As observed from (Fig.3a) that, the half cell potential reading was varied somewhere between -245 to -350 mv which in turn informs statistical risk of corrosion was around 40%-50%. It was also confirmed from (Fig.3b) that, the half cell potential reading was varying somewhere between -210 to -400 mv which in turn indicates statistical risk of corrosion was around 50%-75%.It was concluded from (Fig.3c) that, the half cell potential reading was varying somewhere between -215 to -455 mv which in turn indicates statistical risk of corrosion was around 50%-85%. Actually, the Half-cell potentials are measure on the surface of the concrete that is remote from the reinforcing steel, several factors such as concrete cover depth, surface condition, and electrical resistance may influence the potential reading. Thus, potential readings only indicate the probability of corrosion activity (12).

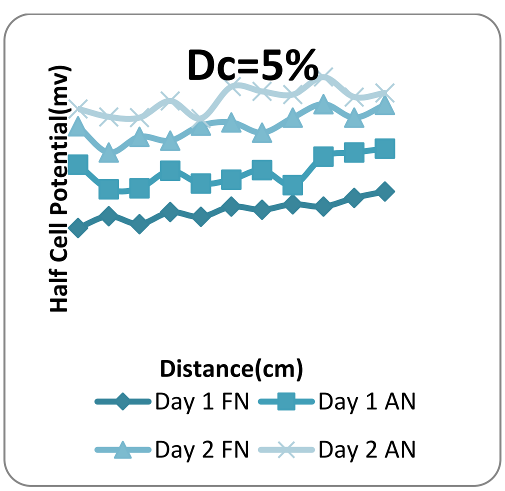


Fig.3a Half cell Potential Vs Distance

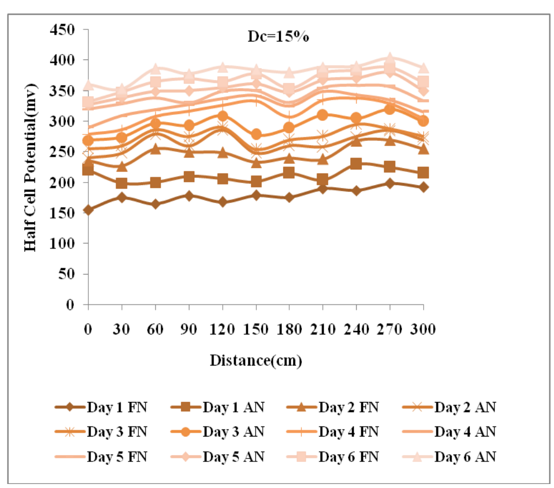


Fig.3b Half cell Potential Vs Distance

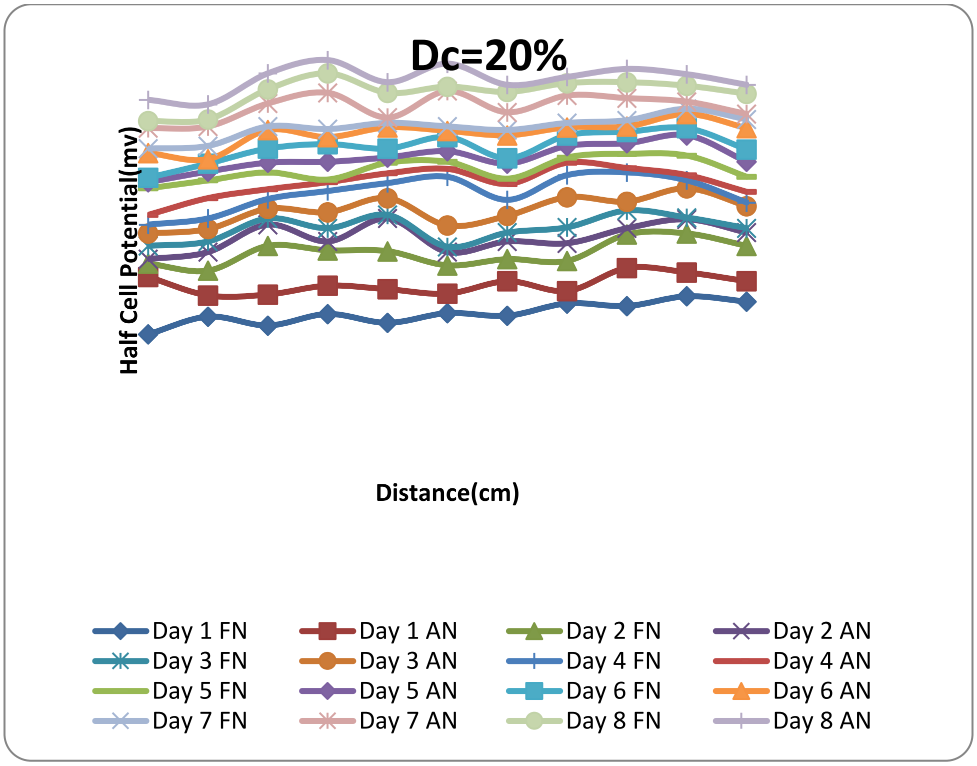
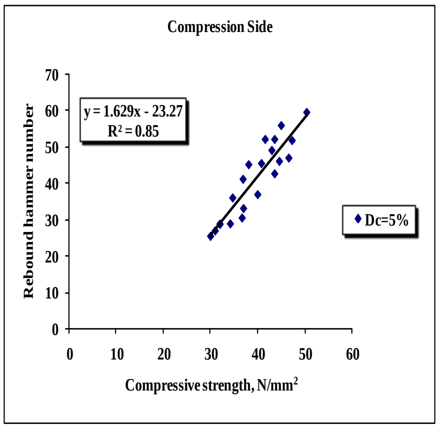
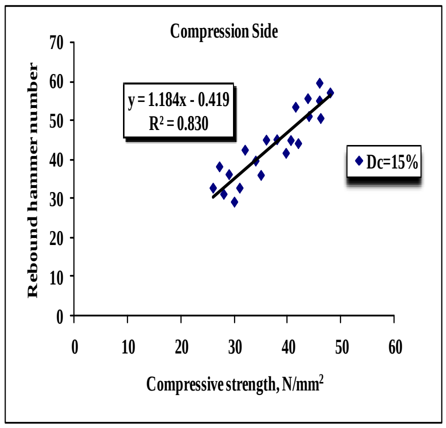


Fig.3c Half cell Potential Vs Distance

The most significant causes that which may lead to variation in corrosion rate of reinforcement steel and corrosion induced damage in turn as a result of cracking and spalling, poor quality of concrete, inadequate cover to reinforcement, chlorides in the concrete. In addition, if p^H value of the concrete adjacent to reinforcement is above 10, a protective surface oxide layer forms on the metal surface. The rate of corrosion under these circumstances is insignificant. In addition, the presence of oxygen and sufficient quantity of free chloride ions in the pore water of concrete can increase or decrease the rate of reinforcement corrosion even in highly alkaline conditions. The minimum total chloride content of concrete and threshold level required for corrosion rate enhancement in turn cannot be represent by a single factor. It is influence by several factors such as w/c ratio, cement type, p^H of the pore solution, and exposure conditions. In fact, carbon dioxide from various sources diffuses into concrete in moist conditions. This ingresses carbon dioxide reacts with the hydrated cement to form calcium carbonate which lowering the p^H of the cement matrix system. Because of that over a period of time when the P^h is reduce to a point below 9-10 then the passivity of steel is lost. The Schmidt rebound hammer is basically a surface hardness test with little apparent theoretical relationship between the strength of concrete and the rebound number of the hammer. Rebound hammer test assessed the surface hardness of concrete. There is a considerable amount of scatter in rebound numbers because of the heterogeneous nature of near surface properties (principally due to near-surface aggregate particles). There are several factors other than concrete strength that influence rebound hammer test results, including surface smoothness and finish, moisture content, coarse aggregate type, and the presence of carbonation. In the present study Rebound hammer test was carried out both at compression side as well as tension side of the beam before and after the corrosion damage inducement in the beam with different degree of corrosion. The variations of Rebound hammer number versus Compressive strength for compression side as well as tension side of beam with different degree of corrosion such as 5%, 15%, and 20% are plotted as shown in (Fig.4a-Fig.4c) and (Fig.4d-Fig.4f).

As observed from (Fig.4a-Fig.4c) in which an experimental calibration equation for the Rebound hammer test that derived from this research at the compression side of the beam was y = 1.629x-23.27, R^2 = 0.85, Dc = 5%; y = 1.184x-0.419, R^2 = 0.83, Dc =15%; and y = 1.44x-14.52, R^2 = 0.801, Dc = 20% and also as observed from (Fig.5d-5f) an experimental calibration equation for the Rebound hammer test that derived from this research at the tension side of the beam was y = 1.716x-24.77, R^2 = 0.87, Dc = 5%; y = 1.432x-17.00, R^2 = 0.857, Dc =15%; and y = 1.548x-18.24, R^2 = 0.808, Dc = 20%. Whereas y = rebound hammer number, x = compressive strength (N/mm^2), and R^2 = coefficient of correlation. As observed from (Fig.4a-Fig.4c) that, the rebound hammer number was varied on compression side of the beam in the range of 30-55 (Dc = 5%), 25-50 (Dc =15%), and 20-48 (Dc = 20%) which in turn indicates the quality of concrete varied from fair to very good hard layer. As observed from (Fig.4d-4f) that, the rebound hammer number was varied on tension side of the beam in the range of 39-56 (Dc = 5%), 30-53 (Dc =15%), and 26-50 (Dc = 20%) which in turn indicates the quality of concrete varied from good layer to very good hard layer. There could be more 85% (correlation coefficient) of rebound hammer number and compressive strength data values at compression side of the beam was correlated for in case of (Dc=5%) as when compared to that of correlation coefficient of about 83% (Dc=15%) and 80.1% (Dc=20%) when they are in the linear regression. The coefficient of correlation was vary extensively both on (compressive and tensile side) of the beam for in case of Dc = 5% as when compared to higher degree of corrosion such as Dc = 15% and Dc = 20%. This coefficient of correlation in turn depends on degree of corrosion as well as test results which are affected by test surface smoothness, size, shape, and rigidity of the specimens, age of specimen, surface and internal moisture conditions of concrete, coarse aggregate type, cement type, and carbonation of concrete surface. Also as observed that, there could be 87% of (correlation coefficient) rebound hammer number and compressive strength data values at tension side of the beam was correlated for in case of (Dc=5%) as when compared to that of 85.7% (Dc=15%) and 80.8% (Dc=20%). Finally it was observed that there could be more increased percentage (correlation coefficient) of about 2.3% (Dc=5%), 3.15% (Dc=15%), and 0.87% (Dc=20%) rebound hammer number and compressive strength data values for in case of tension side was correlated as when compared to that of compression side of the beam with different degree of corrosion in turn this may be due to uniform compactness of concrete at tension side.





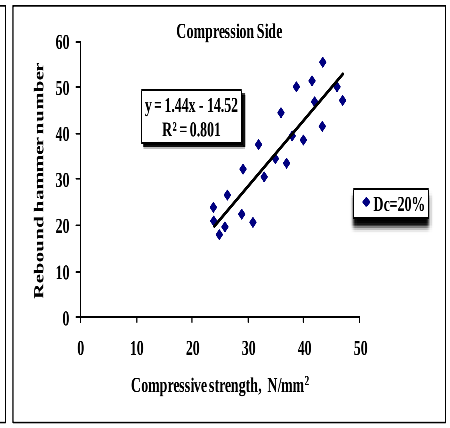
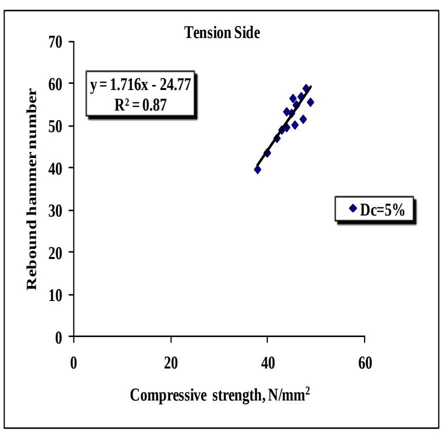
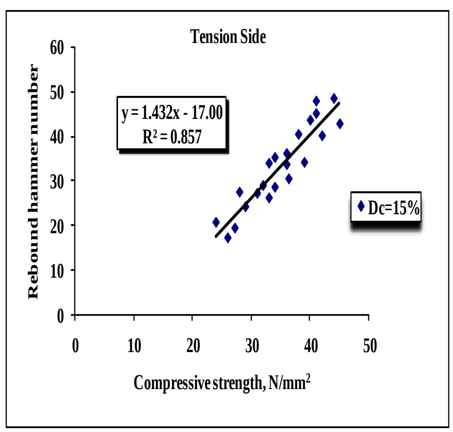


Fig.4a RHN Vs Compressive strength **Fig.4b** RHN Vs Compressive strength **Fig.4c** RHN Vs Compressive strength





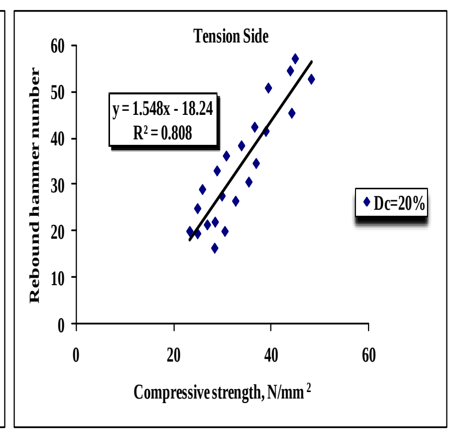


Fig.4d RHN Vs Compressive strength **Fig.4e** RHN Vs Compressive strength **Fig.4** fRHN Vs Compressive strength

The Ultrasonic pulse velocity test involves measuring the velocity of sound through concrete for strength determination. Since, concrete is a multi-phase material, speed of sound in concrete depends on the relative concentration of its constituent materials, degree of compacting, moisture content, and the amount of discontinuities present. This technique is applied for measurements of composition (e.g. monitor the mixing materials during construction, to estimate the depth of damage caused by fire), strength estimation, homogeneity, elastic modulus and age, & to check presence of defects, crack depth and thickness measurement. Generally, high pulse velocity readings in concrete are indicative of concrete of good quality. Also in the present study Ultrasonic pulse velocity test was carried out both at compression side as well as tension side of the beam before and after the corrosion damage inducement in the beam with different degree of corrosion (5%, 15% & 20%). The variations of Compressive strength versus Ultrasonic pulse velocity for compression side as well as tension side of beam with different degree of corrosion such as 5%, 15%, and 20% are plotted as shown in (Fig.5a-Fig.5c) and (Fig.5d-Fig.5f).

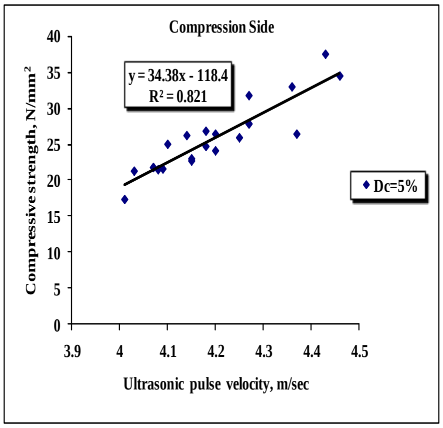


Fig.5a Compressive strength Vs UPV

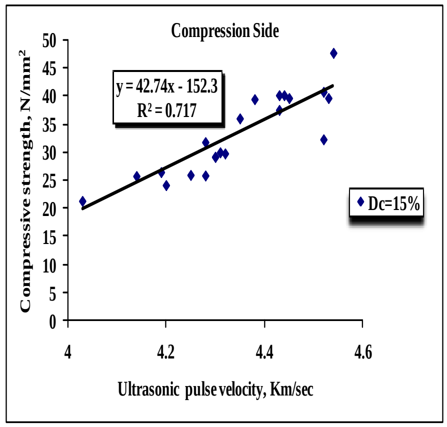


Fig.5b Compressive strength Vs UPV

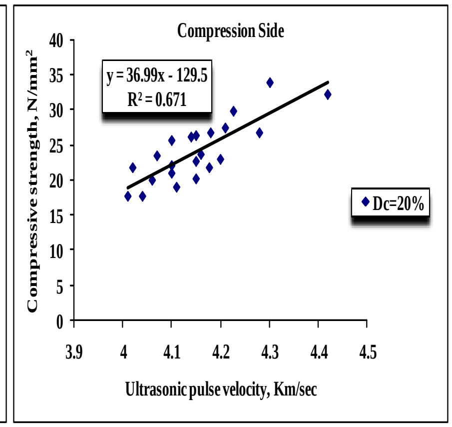


Fig.5c Compressive strength Vs UPV

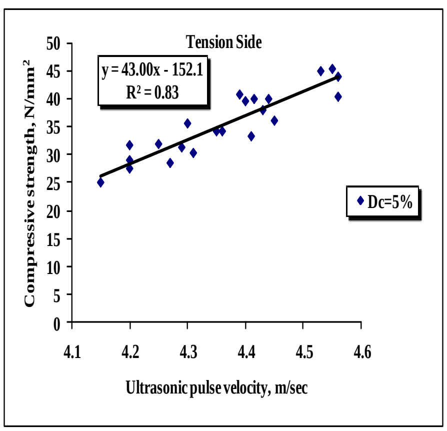


Fig.5d Compressive strength Vs UPV

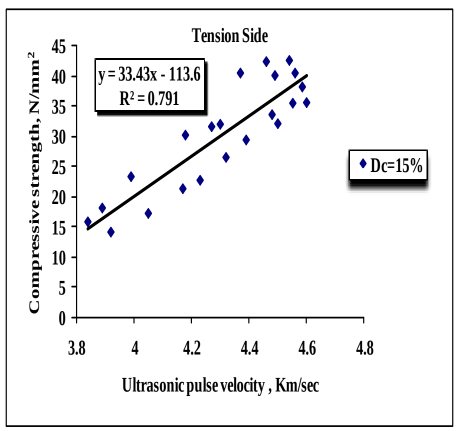


Fig.5e Compressive strength Vs UPV

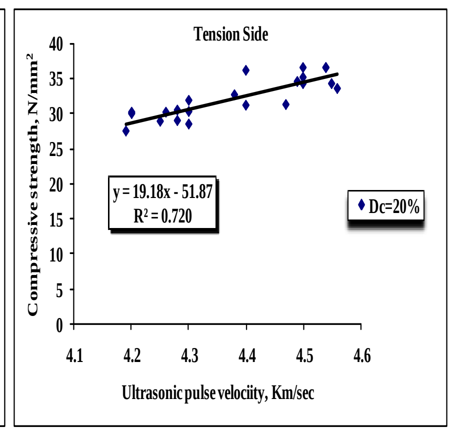


Fig.5f Compressive strength Vs UPV

As observed from (Fig.5a-Fig.5c) that, an experimental calibration equation for the Ultrasonic pulse velocity test that derived from this research at the compression side of the beam was y = 34.38x-118.40, R^2 = 0.821, Dc = 5%; y = 42.74x-152.30, R^2 = 0.717, Dc =15%; and y = 36.99x-129.50, R^2 = 0.671, Dc = 20% and also as observed from (Fig.5d-Fig.5f) that, an experimental calibration equation for the Ultrasonic pulse velocity test that derived from this research at the tension side of the beam was y = 43.006x-152.10, R^2 = 0.83, Dc = 5%; y = 33.43x-113.60, R^2 = 0.791, Dc =15%; and y = 19.18x-51.87, R^2 = 0.72, Dc = 20%, where y = compressive strength (N/mm^2), x = ultrasonic pulse velocity (Km/sec), and R^2 = coefficient of correlation. As observed from (Fig.5a-Fig.5c) that, the Ultrasonic pulse velocity value was varied on compression side of the beam in the range of 4.1-4.5 (Dc = 5%), 4-4.45 (Dc =15%), and 3.9-4.3 (Dc = 20%) which in turn indicates the quality of concrete varied from good but may be porous to very good. As observed from (Fig.5d-Fig.5f) that, the Ultrasonic pulse velocity was varied on tension side of the beam in the range of 4.2-4.6 (Dc = 5%), 4.15-4.55 (Dc =15%), and 4-4.4 (Dc = 20%) which in turn indicates the quality of concrete varied from good but may be porous layer to very good. There could be 82.1% compressive strength and ultrasonic pulse velocity data values at compression side of the beam was correlated for in case of (Dc=5%) as when compared to that of 71.7% (Dc=15%) and 67.1% (Dc=20%). There could be 83% (correlation coefficient) of compressive strength and ultrasonic pulse velocity data values at tension side of the beam was correlated for in case of (Dc=5%) as when compared to that of 79.1% (Dc=15%) and 72% (Dc=20%). Finally it was observed that there could be more increased convergence of correlation coefficient of about 1.08% (Dc=5%), 9.35% (Dc=15%), and 6.8% (Dc=20%) in compressive strength and ultrasonic pulse velocity data values for in case of tension side was correlated as when compared to that of compression side of the beam. This variation in coefficient of correlation (ultrasonic and compressive strength data values) may be due to certain difficulties, which are encounter by concrete when some of the established methods used in other areas of material testing are apply to concrete testing and in fact concrete is an in homogenous as well as porous building material.

7. CONCLUSION

Thus, the NDT can play an important role in ensuring quality of any structural concrete material, reliably and safely, minimize cost and avoid the loss of human life. From this study, it can be conclude that:

1. It was confirmed from Half-cell potential test that, the probability of statistical risk of corrosion was around 40-50%, 50-75%, and 50-85% for in case of different degree of corrosion (Dc=5%, 15%, & 20%). Actually Half-cell potential mapping is the simplest technique. Although it's the most widely used, it does not give any indication of the extent or intensity of corrosion in turn it confirms the probability of statistical risk of corrosion for a specified degree of corrosion.
2. It was confirmed from the Rebound hammer test that performed at the compression and tension side of the beam depicts 85%, 83%, and 80% (coefficient of correlation convergence) rebound hammer number as well as compressive strength data was correlated on compression side as well as 87%, 85.7%, and 80.80%on tension side of the beam for different degree of corrosion (Dc=5%, 15%, & 20%).
3. It was confirmed from the Ultrasonic pulse velocity test that performed at the compression and tension side of the beam depicts 82.10%, 71.70%, and 67.10% (coefficient of correlation convergence) Ultrasonic pulse velocity as well as compressive strength data was correlated on compression side as well as 83%, 79.10%, and 72% on tension side of the beam for different degree of corrosion (Dc=5%, 15%, & 20%).
4. It was inferred from test result that Rebound hammer number as well as Ultrasonic pulse velocity and compressive strength data values was vary (coefficient of correlation convergence) extensively both in compression and tension side of the beam for in case of lower degree of corrosion (Dc=5%) as when compared to higher degree of corrosion (Dc=15% &20%). This variation (coefficient of correlation convergence) depends on degree of corrosion and test result in turn which are affected by test surface smoothness, size, shape, and rigidity of the specimen, age of specimen, surface and internal moisture conditions of concrete, coarse aggregate type, cement type.
5. The Linear regression analysis is the best fit for the compressive strength prediction relationship by using Rebound hammer and Ultrasonic pulse velocity test at compression as well as tension side of reinforced concrete beam with different degree of corrosion (5%, 15% & 20%).

REFERENCE

1. Al-Sulaimani, G.J., Kaleemullah, M., Basunbul, I.A. and Rasheeduzzafar, "Influence of Corrosion and Cracking on Bond Behaviour and Strength of Reinforced Concrete Members", ACI Structural Journal, V.87, No.2, 1990, pp.220-231.
2. Deputat. J, "Non-destructive evaluation methods of material properties", Gamma (in Polish), Warszawa 1997.
3. Carino.N.J, Non-destructive Test Methods, Concrete Construction Engineering Handbook, ed. E. G. Nawy, CRC Press, 19.1-19.67.
4. Mehta, P. K., and Gerwick, B. C., "Cracking-Corrosion Interaction in Concrete Exposed to Marine Environment," Concrete International, V. 4, No.10, Oct. 1982, pp. 45-51.
5. Wang, K., and Monteiro, P. I., "Corrosion Products of Reinforcing Steel and their Effects on the Concrete Deterioration," Third CANMET/ACI international Conference on Performance of Concrete in Marine Environment, P. K. Mehta, ed., New Brunswick, Canada, Aug. 4-9, 1996, pp. 83-97.
6. Malhotra.V.M."Insitu/Non-destructive testing on Concrete-A Global Review" (1984), Insitu/Non-destructive testing of Concrete, American Concrete Institute, Detroit.
7. Popovics, S., "Analysis of the concrete strength versus ultrasonic pulse velocity relationship", Materials Evaluation, V.59, No.2, 2001pp.123-129.
8. ASTM C 876-87, "Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete," ASTM, 1990, pp. 429-433.
9. IS:13311(Part2)-1992, Methods of non-destructive testing of concrete: part2 Rebound hammer.
10. IS:13311(Part1)-1992,"Methods of non-destructive testing of concrete", part1 Ultrasonic pulse velocity.
11. Wang, K., and Monterio, P.J., "Corrosion Products of Reinforcing Steel and their Effects on the Concrete Deterioration", Third CANMET/ACI Interaction Conference on Performance of Concrete in Marine Environment, P.K. Mehta, ed., New Brunswick, Canada, Aug.4-9, 1996, pp.83-97.
12. Explanatory Note on Half Cell Potential Testing, ICRI Concrete Repair Bulletin V.9, No.4, 1996, 7 pp.

13. Srinivasa Rao G, Manjula Vani K. Reuse of HDPE and Structure of Fiber Reinforced High Strength Concrete Containing Silica Fume and Metakaolin. Discovery, 2016, 52(247), 1563-1570
14. Vaidevi C. Study on marble dust as partial replacement of cement in concrete. Indian journal of engineering, 2013, 4(9), 14-16
15. Durai S, Boobalan SC, Muthupriya P, Venkatasubramani R. Behaviour of high performance concrete in exterior beam-column joint – a general review. Indian journal of engineering, 2013, 3(6), 18-20
16. Maruthachalam D, Muthukumar J. Flexural behaviour of hybrid fibre reinforced concrete beams: a general review. Indian journal of engineering, 2013, 2(3), 14-16
17. Maruthachalam D, Karthik MP. Shear Performance of Fibre Reinforced Concrete Beams: A General Review. Indian journal of engineering, 2013, 2(3), 1-2