REAL TIME CORROSION MONITORING OF STEEL BARS EMBEDDED IN CONCRETE USING PIEZO-ELECTRIC SENSORS

A

PROJECT REPORT

Submitted in partial fulfillment of the requirements for the award of the degree

of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision

of

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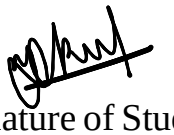
STUDENT'S DECLARATION

I hereby declare that the work presented in the Project report entitled **"Real time corrosion monitoring of steel bars embedded in concrete using Piezo-electric sensors"** submitted for partial fulfillment of the requirements for the degree of Bachelor of Technology in Civil Engineering at **Jaypee University of Information Technology, Waknaghat,** is an authentic record of my work carried out under the supervision of **Dr. Saurav, Assistant Professor.** This work has not been submitted elsewhere for the reward of any other degree/diploma. I am fully responsible for the contents of my project report.



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CERTIFICATE

This is to certify that the work which is being presented in the thesis titled "**Real time corrosion monitoring of steel bars embedded in concrete using Piezo-electric sensors**" in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering submitted to the Department of Civil Engineering, **Jaypee University of Information Technology, Waknaghat** is an authentic record of work carried out by **Mukul Prashar(161636) and Harshit Saxena(161613)** during a period from July 2019 to December2019 under the supervision of **Dr. Saurav, Assistant Professor**, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

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ABSTRACT

One of the most important factor which is causing problems in the life cycle of infrastructure across the world is corrosion and in the infrastructure which are very old, corrosion can severely affects their mechanical strength. That's why a cost effective structural health monitoring (SHM) technique plays a necessary role during the remarking and managing of the structure. Detection mechanism is based on the fact that the occurrence of corrosion changes structural stiffness, mass and damping, which in turn causes the response of the system to change. Structural health monitoring (SHM) endeavored by measuring static strain or low frequency vibration data. These procedures normally depend upon traditional sensors, for example, strain gages or accelerometers, which can just concentrate burden or strain. But in the recent years the use smart materials such as piezoelectric materials, optical fibers, shape memory has created a new dimension to SHM, by the development of faster respone and greater reliability. Through this report we present a new approach for detecting and quantifying corrosion of steel bars by using piezoelectric ceramic (PZT) patch surface bonded on steel bar with use of structural parameters. The EMI method uses the electro-mechanical coupling property of piezoelectric materials for harm determination. The equal mass loss and stiffness loss relates well with the genuine mass loss and stiffness loss and gives an elective consumption evaluation worldview appropriate for diagnosing erosion in steel bars.

Keywords: piezoelectric transducers, electromechanical impedance, non-destructive testing, impedance-based health monitoring.

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LIST OF ABBREVIATIONS

AE	Acoustic Emission
CA	Coarse Aggregates
CS	Compressive Strength
EMI	Electromechanical Impedance
EN	Electrochemical Noise
FA	Fine Aggregates
FBG	Fiber Bragg Grating
GPM	Galvanostatic Pulse Method
GPR	Ground Penetrating Radar
HYD	High Yield Deformed
LPR	Linear Polarization Resistance
OCP	Open Circuit Potential Monitoring
OPC	Ordinary Portland Cement
OPC	Ordinary Portland Cement
PZT	Lead Zirconate Titanate
RCC	Reinforced Concrete
RMSD	Root Square Deviation
SCC	Stress Corrosion Cracking
SG	Specific Gravity
SHM	Structural Health Monitoring
SSD	Saturated Surface Dry

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CHAPTER 1
INTRODUCTION

1.1 General

Solid structures built around the world are reliant upon a wide extent of conditions of use and introduction to common conditions, including erosion, loads, atmosphere conditions and contamination. These factors, close by the verifiable quality joined with the structure, demonstrate that the underlying disintegration time may contrast. Security frameworks are expected to give a limit among cement and its condition, just as the operational prerequisites constrained on the structure. The obstruction will develop the time until the underlying crumbling. Concrete gets its quality from hydration items for the most part through the C-S-H gel. The property of the solid that made it well known is its capacity to withstand compressive burdens [1].

Because of the presentation of RCC structures to the unmistakable sorts of environment that influence the support of the RCC causing harm that prompts beginning misfortunes and business misfortunes [1]. One of the principle weakenings of the RCC is the point at which the embedded steel corrodes.the pivotal quality and bowing of the parts, making them generally weak. In spite of the fact that erosion of inherent steel bars can't be seen from outside the structure and structure may appear to be steady, yet in actuality, eroded structures become helpless against configuration loads (extraordinary loads), for instance, strong ground development can assemble pressure exercises past the area limit. Quality misfortune can happen in strong strengthened and steel structures. We can see the greater part of the time, RC structures are solid and intense, functioning admirably during their lives. Be that as it may, in a few cases, they don't work fittingly in view of a couple of clarifications and corrosion of the steel is one of main factor Consumption is an electrochemical reaction which is begun from the iron-based metal when it comes in the exposure of condition, which is the reason for material weakening. Due to the corrosion in steel rebars cracks are formed in concrete.

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1.2 What is corrosion

The attack of corrosion may destroy the material of its surroundings. Corrosion can be an all procedure that changes to some substance in an additional structure that is steady, as a sulfide, oxide, hydroxide, It's the moderate pulverization of substances (normally metals) of electrochemical reaction by utilizing their condition. Iron oxides can be an exceptional example of electrochemical erosion. Erosion can happen in substances besides metals. For instance, polymers and earthenware production [8]. Erosion influences the supportive properties of materials and structures, including liquid and gas obstruction, appearance and porousness.

1.2.1 Type of corrosion

a) Uniform Corrosion

In uniform corrosion, a uniform and steady abatement in thickness over the entire surface of the metal happens. The uniform erosion rate can be adequately constrained by estimating the mass loss or the measure of hydrogen released [9].

b) Localized Corrosion

This type of corrosion can be found explicitly composed in a zone with metal surface. Limited corrosion can be considered as a quickened attack of a passive metal in destructive environment surroundings.This corrosion occur during working with diffent destructive procedures for example stess fatigue.

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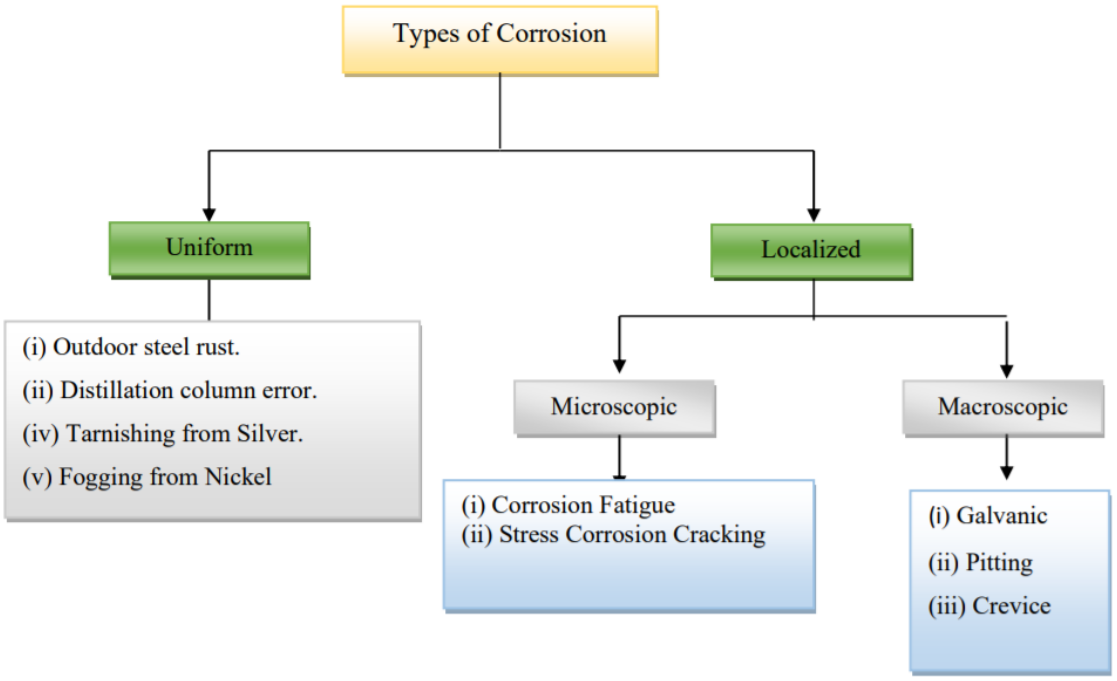

Figure 1.1: Type of uniform and localized corrosion

Types of Localized Corrosion:

i. Galvanic Corrosion

This type of corrosion can also be called bimetallic corrosion. At the point when two detached metals have physical or electrical contact with each other and are lowered in a run of the mill electrolyte then galvanic corrosion occurs. It happens at a moderate pace.

ii. Pitting Corrosion

Pitting corrosion can be considered as a limited type of corrosion by which pits or "openings" are created inside the material. Pitting is viewed as riskier than uniform corrosion damage since it is increasingly hard to recognize, anticipate, and structure against. Erosion items frequently spread the pits.

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iii. Crevice Corrosion

Another dangerous type of limited corrosion. it attack on metal surface which is directly adjacent to a void that join two retaining surfaces.the void could form between metals or a non metallic materials. In absence of the void the two materials are corrosion resistant.

iv. Corrosion Fatigue

Pitting was seen as related with constituent particles in the gap and pit development frequently included blend of individual molecule nucleated pits. Fatigue splits are regularly nuclearized by a couple of the greatest wells, and the size of the pit where the fatigue break assembles is a segment of the stress level and load frequency. When there is a joint movement and cyclic load, there is occurrence of degradation in material. Excellent structure materials around has a significant role in the weakening of material, for instance, aluminum alloy, steel and titanium alloys. It depends upon the relations between the load, environmental and metallurgical elements.

v. Stress Cracking

Growth of crack in a corrosive environment is termed as Stress Corrosion Cracking (SCC). It causes an amazing unpredicted disappointment of generally ductile metal alloys under tension, particularly at high temperatures. SCC is very chemically specific as some alloys are probable to change from SCC when introduced to a minute number of chemical

environments. The chemical surroundings that SCC causes for a specific alloy is frequently one that is just slightly corrosive to the metal. Hence, metal parts with genuine SCC can show up bright and shining while at the same time being charged with microscopic slits.

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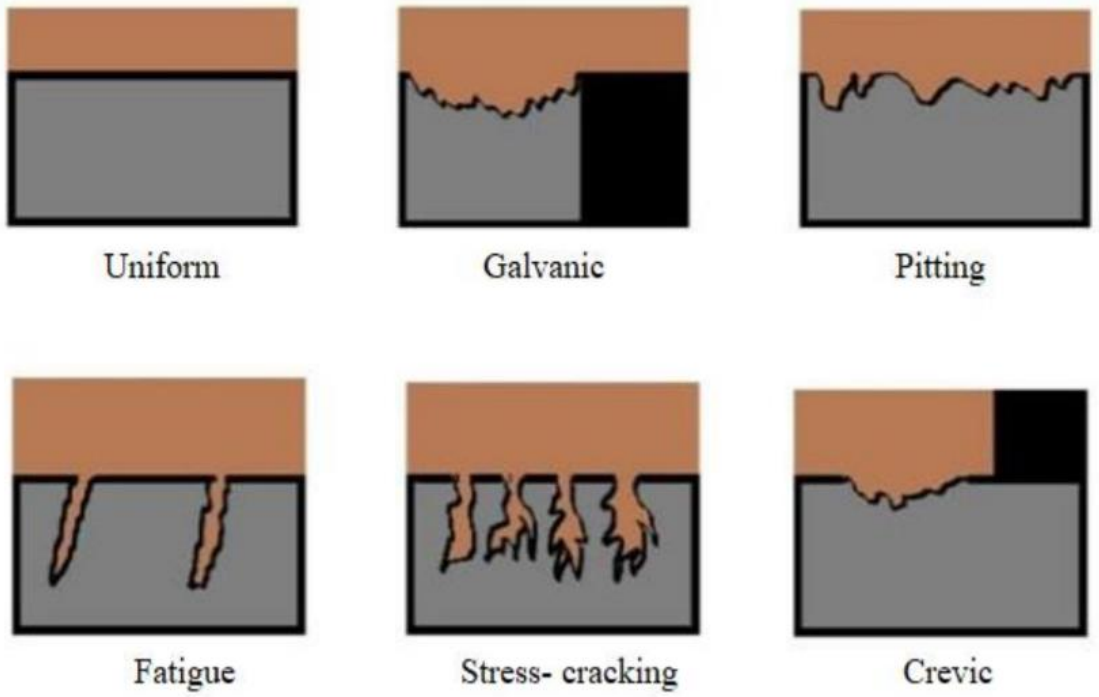

Figure 1.2: Different types of corrosion [10]

1.3 Mechanisms of corrosion steel

Erosion of steel in any environmental factor is a procedure that joins the dynamic departure of iron particles (Fe) from corroded steel. The iron is cleared by an electrochemical reaction and broke up in the near to water arrangement, appearing as ferrous particles (Fe2+). In installed solid steel, disintegration occurs in the pores of the solid when a limited volume of water arrangement present in encompassing the steel. Because of the disintegration steel loses its mass, for example, its transverse district diminishes. In the event that steel is a piece of strengthened solid structures under the burden, the strain of the cross-fragment that is kept up will increment on a very basic level. In exceptional cases, for instance, the expansion can represent a security hazard or even reason a blunder. This is one of the unquestionable perils identified with steel consumption in concrete.

Broken down iron particles in solid pore water arrangements plans commonly respond with hydroxide particles (Goodness) and disintegrated oxygen particles (O_2) to show one of a couple of combinations of rust, which is a strong component for consumption reaction. Oxide is typically put away in space attached to concrete around steel. Its improvement inside this restricted space

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has caused sweeping strains that can break the solid rooftop. This thus can cause the dynamic decay of cement, particularly when freezing and defrosting or other ecological effects win.

1.4 Causes of corrosion

1.4.1 Chloride induced corrosion in concrete

Among the most well-known reasons because of which corrosion happens in solid structure is the holding of chloride particles. They instigate the confined break of this latent film that makes for the most part around the steel because of the alky idea of the solid pore game plan [16]. The most basic destructive operators, for instance, chlorides, can go inside the solid from numerous assets. From debased blending components a solid chloride particle can affect (give concrete as a groundwater paper/seawater from the debased mix of totals or in light of the fact that of sprinkles of ocean salt/lead wetting or deicing salt) from the pristine state or by the close by environmental factors from the solidified state. The alkalinity of the pore game plan diminishes when 10 chlorides diffused in concrete (in the first pH.13 to more than 7) after consumption [14, 17]. In prior times it's been accepted the start of erosion happens when the centralization of chloride at rebar the level shows up at a fundamental level, which can be added as often as possible known as the edge level.

1.4.2 Carbonation of concrete

The carbonation rate is essentially genuinely limited by the carbon dioxide dispersion process what's more, synthetically by the solid calcium hydroxide stock. Carbon dioxide spreads from the condition into the slender pores of the solid and is gotten together with carbonic corrosive, which at that point reacts with basic hydroxide, sodium, potassium, and calcium, framing carbonates.

1.5 Structural health monitoring

The offices are regular or exceptional; these are significant parts and are essentially associated with living what's more, non-living animals. Occasionally a minor distortion inside the structure could impact the entire body and lead to tumble down of the structure that could make an immense loss of property and people too. Thusly, the extended responsiveness of this observing procedure and likewise gives an answer for the influenced structures because of maturing.

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Individuals the day going before just used a visual examination to detect absconds, however unprecedented and more awful harm to foundation prompts to the advancement of new innovations for the affirmation of new techniques for basic wellbeing checking as harm discovery devices. Different sorts of sensors are related to the PC framework alongside uncommon equipment and programming that gives the imprint and assists with underlining the risk zone.

1.5.1 Methods of SHM

a) Destructive method:

In ruinous tests (or in damaging physical examinations, DPA) are performed for test disappointment in order to comprehend the introduction of an example or the exhibition of the material under different burdens. In this method, the example is broken to choose physical and mechanical properties, (for instance, quality, and liability). The kinds of damaging tests are cracks and mechanical tests, weariness tests, hydrogen tests, and lingering pressure estimation.

b) Non-destructive method:

Non-damaging testing strategies are every now and again applied in ventures where part disappointment would cause noteworthy dangers or monetary misfortunes, for example, transportation, pressure vessels, development structures, pipes, and lifting hardware. In this strategy, we discover the qualities of the material to detect the imperfection without annihilating the material.

1.6 Accelerated corrosion testing

Commonly concrete gives incredible consumption opposition because of its huge trademark, especially the raised alkalinity of the fake arrangement, which incorporates essentially of sodium hydroxide and potassium joined with a pH running from 12.6 to 13.8. This inactive film can create a thickness of 10-3 to 10-1 μm and contains hot iron oxides. The idea of the presence of the inactive covering depends on circuitous signs of anodic polarization estimation. There is still a lot to comprehend concerning this detached film, for example, the arrangements of its own items notwithstanding its synthetic and mineralogical creation. It is likely this detached film incorporates a few phases. The solid spread likewise gives fantastic physical security to the steel

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chloride particles and furthermore keeps away from carbonation. In this manner, the steel requests a protracted period to depassivate and permit the erosion procedure to begin. This makes it very hard to recreate examine and comprehend erosion happenings in labs. [25].

1.6.1 Impressed current technique

Impressed current procedure is utilized to quicken the consumption in strengthening steel. The current system moreover called a galvanostatic strategy; steel inserted in the solid with consistent current gracefully is to make huge consumption in a fast time length. After this procedure, Faraday's law is utilized to compute initiated consumption with the help of a gravimetric test performed on the removed bars in the wake of experiencing quickened consumption

1.6.2 Static atmosphere testing

Static condition tests are only one where a test room is utilized to make and keep up one encompassing during testing. Most much of the time utilized consumption trial of its sort is the salt mist test (ASTM B 117). The pieces are exposed to steady environmental factors of 35 or even 100% relative stickiness, utilizing a sodium chloride arrangement of 5 percent (by weight) atomized to get a foreordained second. The pH of this assortment option ought to be 6.5 to 7.2. The length of the test perhaps 48-2,000 hours dependent on the substance being tried. Regardless of the ongoing disappointments, the salt spray testing remains a useful quality control survey apparatus for use after a standard was set up.

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CHAPTER 2

LITERATURE REVIEW

2.1 General

This part tends to the assessment of the writing with respect with the impacts of consumption. The erosion has been activated by the current system and the things were likewise explored. The writing on consumption measurement methods was likewise talked about. This part talks about how the examinations directed by agents to audit techniques used in the information on results and assessments arrangement. This section covers these outcomes and rules for the up and coming assessment.

2.2 Literature survey

The PZT model and host structure were logically examined using the wave state to clarify how the electrical hindrance changes in the connected PZT is identified with the recurrence response of the strategy at high frequencies. At the hour of dissemination, there was no connection among the adjustment in the electrical obstruction inside the PZT and a change of the mechanical properties of the framework. Ghostly innovation was utilized to develop an open pillar assessment portrayal comprising of ten unearthly parts. The harm was brought about by expanding the number of waves related to the adjustment in firmness and module of the youthful structure. A harm locator vector shows the harm level of each part and precisely recognizes the harmed section.

The test was enhanced by the blend of a few patches with a free pillar, and impedance tests were performed at 70-90 kHz. Screws have been valuable to the development to shift the mass properties and firm frameworks. This check used the real piece of the impedance signal was utilized for assessment since it is fragile to the distinction in nonexistent parts or probably sizes that are capacitive and less sensitive to changes. Accordingly, accelerometers were related with pillar response capacities and the recurrence was assessed the longitudinal way. The results show

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a tolerable match among explanatory and exploratory models, which demonstrates the helpfulness of impedance.- subordinate auxiliary watching

D.M. Peairs et al. [29] have amassed at least exertion, a scaled down assessing instrument, to construct the accessibility and versatility of the obstacle system. Previously, completing the impedance technique required costly, tremendous and over the top deterrent analyzers for example, HP4194A (Impedance/Gain-Phase Analyzer). The monetary innovation has supplanted the obstruction analyzer with a FFT analyzer and a nonstop estimation track. Since beneficial hardware and programming as of now empower FFT on a lone chip, the whole course of action can be conveyed on one PC (process) chip. The cost compelling impedance procedure is adjusted in an impedance analyzer and tried on pipes and complex structures to exhibit the exactness of the straightforwardness method in authentic structures. In spite of the fact that this financially savvy elective has not been tried for erosion harm, it is a need for future independent SHM gadgets, contingent upon the deterrent.

M.F. Montemor et al [30] clarify that the fundamental driver of erosion of steel in the event of chloride particles. They cause a limited break of the latent film, which was initially shaped on the steel because of the alky idea of the game plan of the solid pores. Risky chloride particles can start with the use of unclean blended segments or close by climate. As a first way to deal with the framework study, the conceivable mapping strategy for recognizing destructive support was recommended. The technique has ended up being suitable to on-the-spot checking; be that as it may, the result must be painstakingly deciphered, especially under the restricted O2 flexibly. Some Immediate current had the alternative to figure the assurance from polarization. The precision of the strategy has been enormously improved by the usage of evaluating instruments that work as per the rule of defensive ring innovation. The advancement of versatile and straightforward-to-use perception frameworks makes the procedure appropriate for a quick consumption rate nearby. The transitional procedures utilized in the field of time have ended up being effective implied for on-the-spot checking. These systems are brisk and non-harming and give data on steel conditions similarly as information on solid restriction. The proximity of methods other than structures that are limited by actuation can reason deviations from the typical exponential activities, and in this way, it is difficult to figure framework parameters, which can prompt an underestimation of the corrosion rate

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F. Hey, et al [31] concentrated some specific issues in regards to the execution of electromagnetic impedance (EMI) strategy set up Auxiliary wellbeing observing and recommended the most recent sensors assessment estimations utilizing the sensor multiplexing technique to diminish the period requested in inspecting lead zirconate titanate (PZT) fixes individually. Any adjustment in the mass, firmness, or damping of the structure (due to harm) would prompt a move in the permission contact of the lead zirconate titanate (PZT) fix. The permission contact of the PZT fix is promptly gotten utilizing any modern impedance analyzer.PZT patches have quick reactions and have the ability to act as assembled sensors and actuators, in this way chopping down the measure of the device alongside the partnered wiring. For the most part, the issues tended to be the different mark handling instruments out therefor computing harm limitation, use of an equal examination strategy, security of sensors, and perception of solid restoring. During the use of simultaneous examination, the examination time could be fundamentally lessened. The harm limitation calculations performed agreeably concerning advancing the time essential for harm confinement and furthermore the reality of the establishment of damage.

D. Ai et al. [35] explored an imaginative electromechanical lack procedure (EMI) with the assembled mechanical obstacles (UMI) of a lead-zirconium titanium sensor (PZT) and proposed a host structure for observing an erosion harmed steel pillar at disparate occasions. Two PZT surface-reinforced sensors were associated with the steel bar and were used to screen the progression of disintegration hurt by recognizing changes in electromechanical induction. Affirmation electromechanical was assessed for the time of the first, 22nd, 45th, and 117th days, which were used to check the assembled mechanical obstructions. While computing the recurrence pay of the reverberation pinnacles of the assembled mechanical obstacles bends, the disintegration of the mischief can be abstractly remedied. Normal root square deviation esteems (RMSDs) acquired from the real division of the unified mechanical hindrances can be used to quantitatively discover the damage debasement. For the proposed sign of the UMI, the direct connections between recurrence change and disintegration time and root square deviation at the hour of consumption were autonomously summarized. Relative examinations on electromechanical endorsement and joined mechanical obstacles have indicated that a unified mechanical obstruction is strengthening delicate to the location of basic harm brought about by consumption by steel. The outcomes additionally affirmed that changes in accordance with the MI (Mechanical Impedance) of lead zirconate titanate sensors brought about by basic harm to

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electromechanical impedance (EMI) innovation must not be disregarded. In outline, joined mechanical obstructions have demonstrated to be an on a very basic level practical EMI technique for checking the auxiliary soundness of steel F.G. Baptista et al. [39] examined the perfect size of PZT patches for structure prosperity checking reliant on the EMI (Electromechanical Impedance) technique. Theoretical assessment and test outcomes fit well and show that the privilege PZT fix configuration can improve affectability to hurt ID. Contingent upon the outcome, the fix must be little to ensure low static breaking point and more noteworthy sufficiency in the electrical heartbeat to guarantee amazing outcomes for the connection coefficient deviation metric (CCDM) and root mean square deviation (RMSD) records. Regardless, if the mechanical impedance of the host development is high as indicated by the MI (Mechanical Impedance) of the transducer, the expansion in fix mark improves the affectability for hurt area, particularly when the connection coefficient deviation metric file is used. It has been indicated that an equivalent transportation framework improves affectability and keeps up a low static limit. As referenced over, the arranged technique is fitting for materials and structures with short damping where the cross-sectional arrangement can be seen as consistent. At long last, the proposed technique may be useful for the right size of PZT transducers, especially in metal structures with short damping and solid mechanical impedance as for the MI of the transducer.

E. Nakamura et al. [40] revealed that a down to earth program of potential extensions for erosion assessment on a present pre-tensioned solid scaffold near the shore in Japan. As per exploratory perceptions, they presumed that the most harming potential region about the indistinguishable limit map compares with this phase with higher chloride content and confined erosion. They likewise reasoned that the potential slant is an incredible pointer for picking the spot for extra damaging testing when there are no signs of erosion to the solid surface. They likewise found that the deliberate potential benefits varied because of various things, for example, fever, reference anode kind, and pre-wetting second. Then again, the potential slope design remained precisely the same for its structure. Indeed, even the Equipotential Limit outline is a much reliable instrument for finding confines erosion and picking the spot for extra dangerous testing.

S. Bhalla et al. [42] acquainted another technique with assessing the weariness length of shot steel joints utilizing the comparable firmness relying upon piezo-impedance transducers associated with the surface. The equal parameters of this board were related to the acquired

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electromechanical utilization marks. During looking at three parts of metal joints, both observational conditions were made to connect the entire time of remaining exhausted into the proportionate recognized decrease of firmness. The most encouraging element of this recommended approach is the way that it straightforwardly applies the induction of piezoelectric transducer marks associated with the surface, accordingly continuing the finish of the in situ firmness of the joint.

M. Moreno et al [48] researched that the effect of different degrees of carbonation and the closeness of different chloride substances in propagation plans were investigated. The results show the gainful result of high alkalinity on the limited disintegration of steel realized by chloride particles. The results of the potentiodynamic tests evaluated an essential chloride obsession for every arrangement over which the sting could happen. The chloride limits discovered here are in a comparable solicitation as those as of late point by point in the composition without film steel. The result of arrangements recreating carbonated cement showed that nonpassive carbon steel improved at low carbonation conditions, while limited consumption obstruction was improved at high carbonate and bicarbonate focuses.

2.3 Research gaps

- A gap in the writing about constant corrosion observing of RCC structure.
- A large portion of the writing is worried about corrosion detection in RCC structure utilizing a damaging technique.
- Constrained bits of writing are accessible which give utilization of the electrical sensor for ongoing corrosion identification in RCC structures
- There are few looks into on the examination and corrosion checking of various high-grade cement

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2.4 Research objectives

- Investigation of the pressure trial of solid shapes and corrosion test consequences of concrete beams of Grades M40, M50, and M55.
- To propose the best appropriate evaluation of cement among three high evaluations which is less prone to corrosion.
- To discover the pressure test aftereffects of solid blocks of various evaluations relieved at various time range.
- Constant corrosion checking of steel bars installed with piezo-sensor by utilizing the EMI method.

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CHAPTER 3

EXPERIMENTAL INVESTIGATIONS

3.1 General

The reinforcement of concrete takes place with the help of steel. There thermal expansion coefficients are equivalent;a great capacity of forming bond and increase in strength. Corrosion of a steel stand is classified as most familiar reason for failure of RC structures.

This shows new methodology of checking corrosion on exposed steel bars,by the impedance-based procedure. By the surface-connected PZT patch the corrosion-induced damage is evaluated &depends on the equal parameters recognized. Originally, the important concrete properties were identified and the constraints of further cement substances were put. The properties of concrete impacted by elements are discussed so that experimental arrangement could be made.

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3.2 Research methodology

To achieve the research objectives, a successive methodology was suggested.

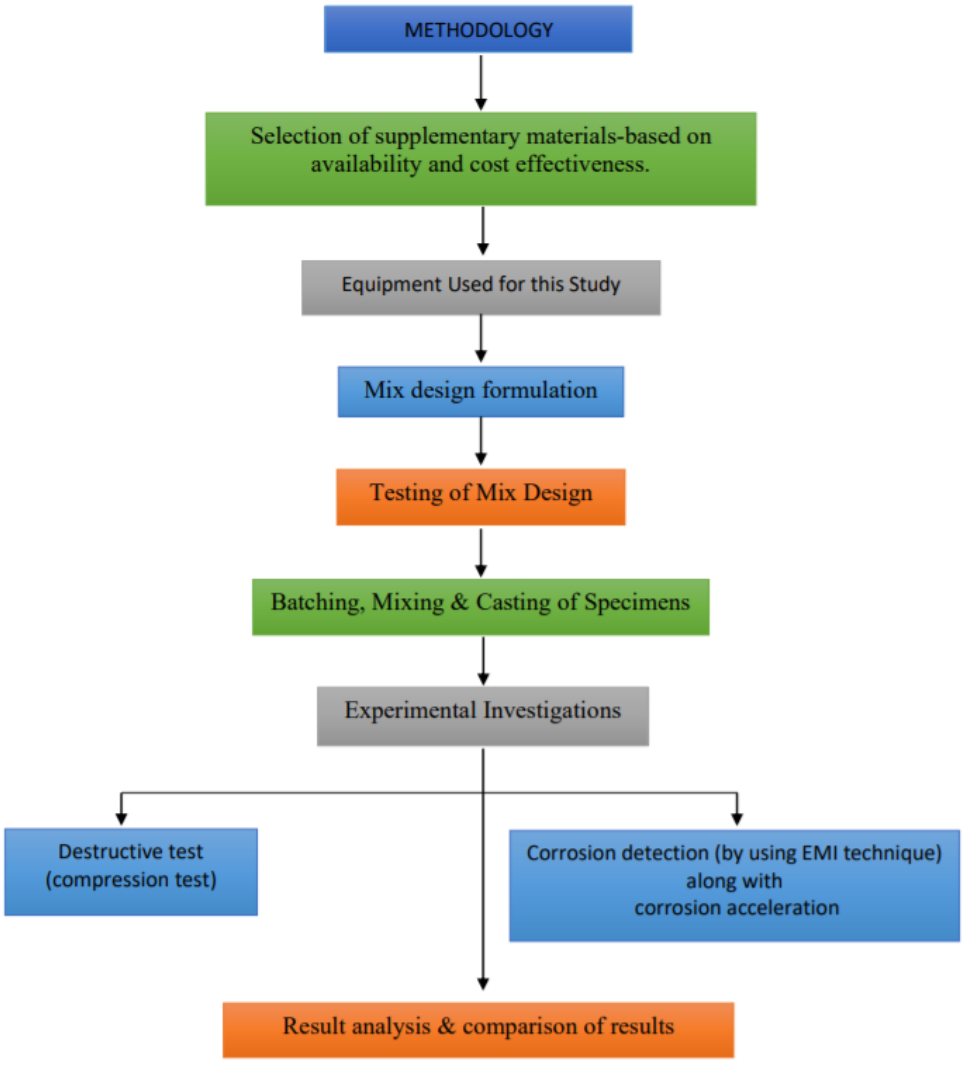

Figure 3.1: Layout of experimental methodology

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Step 1: Material Selection

This can be done by evaluation and usage of OPC with super-plasticizer used for experimental investigation.

Step 2: Mix Design

The materials are selected than individual mix design of different grade is prepared.

Step 3: Experimental Study

(i) Compressive test

(ii) Detection of corrosion

(i) Destructive test:

Compression test was performed on the cubes. The comparison and result of different grades are carried out.

(ii) Corrosion detection test:

Acceleration of corrosin technique adopted involving NaCl solution alongside monitoring was done by PZT senor..

Step 4: Results comparison

Electromechanical impedance technique used for corrosion results. Instrument used to observe change was oscilloscope. Change in values noted at Specific interval of time and best suitable material find out with is more resistant to corrosion.

3.3 Material used

Fine and coarse aggregates used for the formation of concrete. The compaction provides potential strength and quality of concrete. The inspection of concrete also takes place with time.

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3.3.1 Aggregates

Aggregates are most important building materials used as a base material in foundations, roads and railways. Volume occupied is 75 percent, proves to be important for construction.

Table 3.1: Categorization of ordinary weight aggregates [49]

Natural aggregates	Artificial aggregates
Sand, Gravel, Crushed	Broken Brick
Rock such as Granite	Air-cooled Slag
Quartzite, Basalt	Sintered fly ash
Sandstone	Bloated clay

Categorization of aggregate based on unit weight:

i. normal weight.

ii. light weight.

iii. heavy weight

Classification based on size of aggregates:

1. Fine Aggregate

2. Coarse aggregate

Classification based on shape:

1. Rounded aggregate

2. Irregular aggregate

3. Angular aggregate

(a) Flaky aggregate

(b) Elongated aggregate

Surface texture is a property whose assessment relies upon the quantity of clean, smooth, orrough surfaces of the particles. The consistency of the surface depends upon the hardness, grain size, pore structure, rock structure and degree of smoothness or roughness of the forces following the

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particle limits. As surface perfection increases, the contact surface reductions, so a cleaned molecule will exclusively have a smaller surface area for adhesion to the matrix than a coarse molecule of a comparable volume. The physical properties of the aggregates utilized in thisinvestigation are introduced in Tables 3.2 and 3.3. For workable concrete, size distribution or grading of aggregate plays an important role. The size and shape of the aggregate affect the properties of new concrete more than simply hardenedconcrete. Concrete is more viable when round and smooth aggregate is used rather than rough angular or extended aggregate. Crushed

stone generates more aerodynamic and more elongated aggregates, which include a greater surface-to-volume ratio; greater bond attributes however need more concrete paste to produce a viable mixture. Arrangement of IS Sieve for its analysis is shown in Figure 3.2 [51]. Grading of coarse and fine aggregates are shown in Table 3.4 and Table 3.5 respectively. The grading limits for fine aggregate and coarse are clarified in IS 383-1970 [52]. For the study work, both CA and FA are purchased from locally available suppliers in Chandigarh. This is embedded in the mix ratio process. It is expressed as the sum of the collective %age of the engaged weight in a standard sieve-set divided by 100. Fineness modulus is used to determine the order of fine aggregates & is classified in Table 3.6.

Table 3.2: Physical properties: coarse aggregate (20mm size)

Sr. No.	Type of Test	IS Standard	Results
1	Water absorption	IS-2386-P-3	1.513%
2	Specific Gravity	IS-2386-P-3	2.75
3	Bulk density test	IS-2386-P-3	1436

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Table 3.3: Physical properties of F.A. (Fine Aggregates)

Sr. No.	Type of Test	IS Standard	Results
1	Specific Gravity	IS-2386-P-3	2.67
2	Water absorption	IS-2386-P-3	7%

Table 3.4: Sieve analysis of C.A. (Coarse Aggregate)

Coarse Aggregate = 20mm				
Total Weight of Aggregate =1000g				
IS Sieve Size (mm)	Weight of Aggregate Retained	% age of Total Weight Retained	Cumulative %age of Total Weight Retained	Cumulative %age Passing
20	0	0	0	100%
16	47.3	4.73	4.73	95.27%
12.5	494	49.40	54.13	45.87%
10	347.7	37.47	91.60	8.40%
4.75	76.0	7.60	99.20	0.80%
pan	8.0	0.80	100%	Zero%

`

Table 3.4.1: Specification sieve analysis of C.A. (Coarse Aggregate)

IS Sieve Designation	Specification (IS-383:1970)					
	%age Passing For Single Size Aggregate of Nominal Size (mm)					
	63	**40**	**20**	**16**	**12.5**	**10**
80mm	100	-	-	-	-	-
63mm	85-100	100	-	-	-	-
40mm	0-30	85-100	100	-	-	-
20mm	0-5	0 - 20	85-100	100	-	-
16mm	-	-	-	85-100	100	-
12.5mm	-	-	-	-	85-100	100
10mm	0-5	0-5	0-20	0-30	0-45	85-100
4.75mm	-	-	0-5	0-5	0-10	0-20
2.36mm	-	-	-	-	-	0-5

`

Table 3.5: FA (Fine Aggregates) of sieve analysis

Total weight of fine aggregate = 1000gm					Specification (IS: 383-1970) Percentage Passing For			
IS Sieve Size	Weight Retained	Cumulative Weight Retained	Cumulative %age Retained	Cumulative % age Passing	Zones I	Zones II	Zones III	Zones IV
10mm	0	0	0	100	100	100	100	100
4.75mm	13.3gm	13.3gm	13.3	99.86	90-100	90-100	90-100	95-100
2.36mm	49.1gm	62.4gm	62.4	99.38	60- 95	75-100	85-100	95- 100
1.18mm	118.4gm	180.8gm	1.80	98.2	30-70	55-90	75-100	90- 100
600µ	91.7gm	272.5gm	2.72	97.28	15-34	35-59	60-79	80-100
300µ	174.7gm	446.2gm	44.6	55.4	20-5	30-8	12-40	15-50
150µ	453.7gm	901.1gm	90.1	9.9	0-10	0-10	0-10	0-15
Pan	98.9gm	1000gm	98.9	0				
Total	1000gm	Fineness modulus = 2.46						

`

Figure 3.2: Analysis of sieve

Table 3.6: Fine aggregates on the basis of fineness modulus (F.M.) [50]

Fine	F.M.	2.3-2.6
Medium	F.M.	2.6-2.9
Coarse	F.M.	2.9-3.2

`

3.3.2 Binder

Ordinary Portland cement (OPC)

Cement can be categorized as the cohesive & adhesive properties of bonding material which permits us to join the different building materials. The most generally utilized types of Portland cement is normal Portland cement. Lime, silica, alumina and iron oxide are the main raw materials utilized for cement production. The cement creation process consists of crushing the raw materials, carefully blending them in certain proportions according to their composition and purity, and processing them in a furnace at a temperature somewhere in the range of 1300 and 1500°C, to which the sintered material is formed and, to some extent, fused to form a nodal clinker. The clinker is cooled and milled into fine powder with the accumulation of 3 to 5% gypsum. One component formed by this technique is Portland concrete. Tri-calcium silicate and dialcium silicate are the most significant quality blends.

Figure 3.3: Ordinary Portland cement

The ordinary Portland cement (OPC) has categorized by the bureau of Indian standards (BIS) to three levels so as to create different grades of concrete to fulfill the requirements of the building businesses. This sorting was depending on the 28-day compression force as follows:

1. OPC of Grade 33– IS 269: 1989

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2. OPC of Grade 43– IS 8112: 1989

3. OPC of Grade 53– IS 12269: 1987

Ordinary Portland Cement (OPC) of Grade 43 from single source (Ambuja Cement) is used throughout the research work. The cement properties in current project compliant to IS 8112-1989 are presented below in Table 3.7 [54-53]. OPC 43 grade was purchased by Ltd Darlaghat. Figure 3.3 shows OPC cement.

Table 3.7: Physical properties: Ordinary Portland cement

Property	**Average Value**	**Standard Value as per IS 8112-1989**
Specific gravity	3.129	
Normal Consistency	32%	
Initial setting time	40	>30min
Final setting time	460	<600min
Fineness	5% retained	
Compressive Strength		
3-days	24 N/mm^2	>23
7-days	35N/mm^2	>33
28-days	46N/mm^2	>43

`

3.3.3 Water

Water plays an extremely huge function in the concrete-mix. There are following two main reasons which signifies it's need:

Bonding: Mixing of cement with other ingredients of concrete with water as a binder. And also, to produce unique structures, water can also be responsible for the practice of hydration that contributes to the hardening of concrete.

Workability: This really is the simplicity of mixing concrete. Additionally, it may be considered the fluidity of the concrete. As a result of Water, concrete could be readily blended to make the desired mix. The function of water is to decrease external friction between the concrete and all those gears used to combine it. It Is due to the workability eased by water which concrete could be moulded into different shapes before it may harden.

For concrete production use of water also depends on the pH value of water. PH in between 6 to 8 is free from organic compound. Water-concrete ratio ensures the strength of concrete. Cement gel hydration is shown in Figure 3.4 with the given ratio of (w/c 0.2, 0.3 and 0.5). A small amount of water can be used to hydrate the cement and to lubricate the mixture extra water is required. Some capillary pores could be formed due to the excess of water& strength of concrete could decrease with excess use of water [49].

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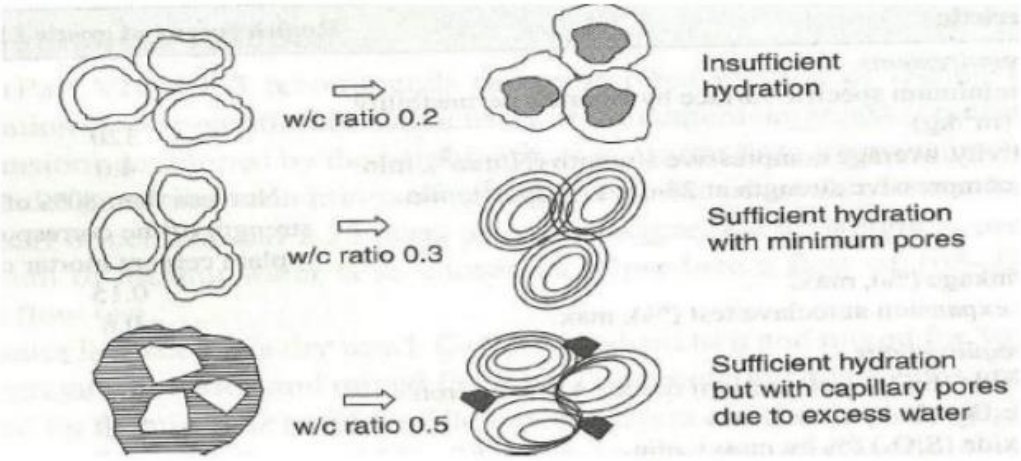

Figure 3.4: Presentation of hydration based on amount of water [49]

3.3.4 Superplasticizers (High Range Water Reducers)

Superplasticizers are a reasonably new class and a better variant of the plasticizer, the utilization of that was made in 1960 and 1970 respectively in Japan and Germany. They are chemically distinct from ordinary plasticizers. The utilization of superplasticizer reduces water by around 30 percent without diminishing functioning capability, when compared with a reduction of around 15 percent for plasticizers. This raises the workability at a specified w/c ratio, generally increasing the slump from 75 mm to 200mm. The principal issue is these superplasticizers is as strong as a dispersant and therefore are high-end water reducers. They're known as High Range Water Reducers in American literature. It's the potential of superplasticizer which has allowed to use w/c as low as 0.25 or lower and to create flowing concrete to find the strength of this sequence 120 MPa or more. The properties of superplasticizer were referenced in the IS: 9103- 1999 [55].

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3.3.5 Equipment utilized

a) Piezo -electric Sensor

The word ‘piezo’ originates from Greek words that mean pressure. The phenomenon of piezoelectricity was found in 1880 by Pierre and Paul-Jacques Curie. It is found in balanced noncentral crystals, such as quartz (SiO_2), Liithium Niobate ($LiNbO_3$) and lead zirconate titanated [PZT, Pb (Zr1-xTix) O_3], where electric dipoles (surface charges) is generated when the crystal is exposed to mechanical stress [57].Piezoelectric materials have an exceptional property of producing electrical dipoles (reverse surface fees) when subjected to mechanical pressure (see Figure. 3.5 a) and they endure mechanical deformations when subjected to electrical fields as revealed in Figure 3.5 (b). A piezoelectric sensor is a device that utilizes the piezoelectric effect, to quantify changes in pressure, acceleration, temperature, stress or force by changing them into an electric charge. The piezoelectric material as a PZT patch is probably the best material for structural health monitoring (SHM) and damage detection in the civil, mechanical and aerospace installations [56]. Apart from its unique properties, its low cost, size and easy installation have been the key factors for being most preferred material for continuous monitoring of engineering amenities.

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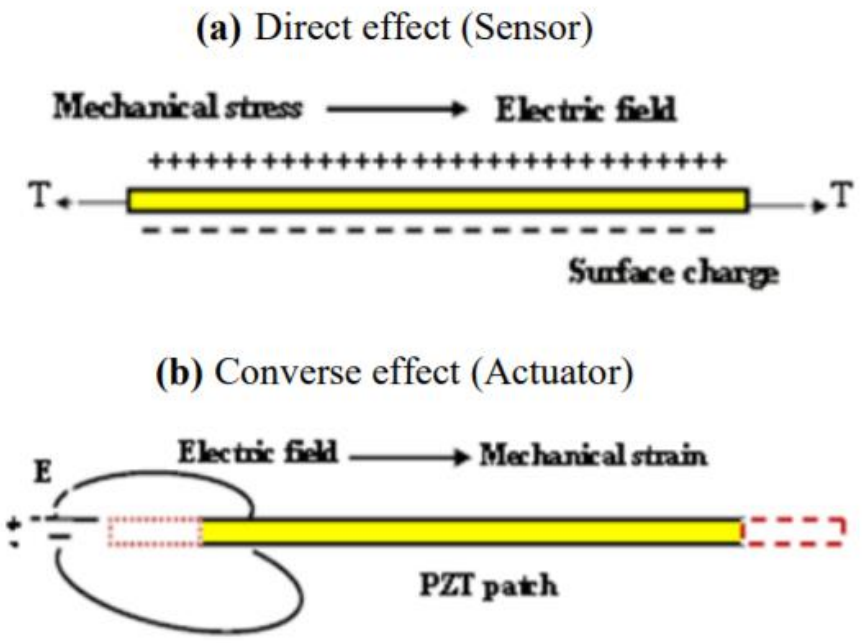

Figure 3.5: Direct and converse effect of piezoelectric materials [56]

Figure 3.6: Lead Zirconate Titanate-Piezoelectric ceramic sensor

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The PZT round sensor is used in this project for structural health monitoring. The lead zirconate titanate piezoelectric ceramic sensor is use in this project for structural health monitoring (as shown in Figure 3.6). A set of sensors was ordered using online internet platform (amazon.in website).These are 27mm diameter gold color Piezo Discs made by Prielsys Enterprises.

b) Oscilloscope

An oscilloscope is a device for measuring electronic signals and is found in several scientific laboratories (as shown in Figure 3.7). It is operated to watch variable sign voltages on a two- 46 dimensional system that represents time [57]. When the oscilloscope is connected to an energy source via a probe, it immediately displays the corresponding waveform in real time. Although they are mainly used in science and technology, they are also used in other areas such as telecommunications and medicine.

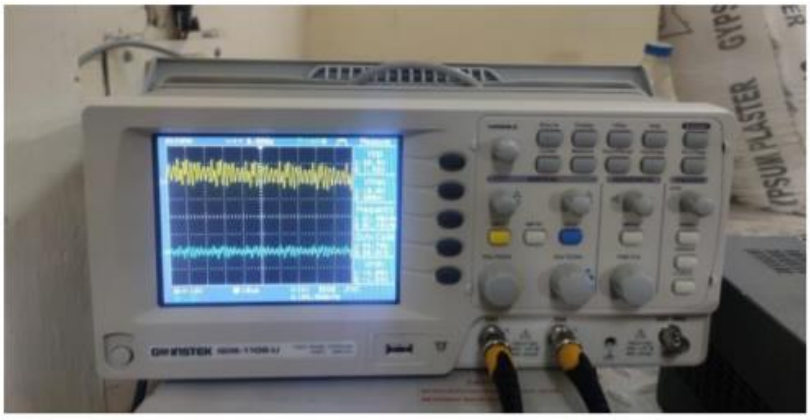

Figure 3.7: Oscilloscope

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3.4 Mix design

In concrete mix design cement sand and aggregate are mixed in accurate proportion to achieve desired strength. The concrete mix design entails various measures, calculations and lab testing 47 to discover appropriate mix proportions. This process is usually adopted for structures that require higher levels of concrete like the M25 and over and big construction jobs where the quantity of concrete ingestion is enormous. An advantage of concrete mix design is that it supplies the ideal proportions of substances, thus creating the concrete construction cheap in attaining required power of structural members. As, the number of concrete necessary for big constructions are tremendous, economy in volume of materials like cement makes the job construction cheap. Mixed design can be characterized as the best approach to pick reasonable concrete components [49]. The inspiration behind the planning, as found in the definitions above, is two-fold. The fundamental objective is to accomplish the lowest durability & strength.

Developing of concrete is the second objective. All concretes that are noticeable depend mainly on two variables; equipment-specific costs and labour costs. For a good concrete, the labour costs of formworks, bunching, mixing, transport and hardening are almost. The expense of the various elements is less than the cost of concrete; the emphasis is on utilizing less concrete, if necessary, compatible with quality and durability. From this point of view, the main consideration is the expenditure of materials [58]. Specifications and data used for Mix proportioning for concrete of M40, M50 and M55 grade are accounted below:

a) Mix proportioning for a concrete of M40 grade:

1. Design Specifications [59]

a) Designation of grade = M40

b) Cement used = OPC 43grade (IS 8112: 1989)

c) Aggregate Size (Max.) = Below 20mm angular

d) Supervision Mark = Good

e) Exposure condition = Severe (meant for reinforced concrete)

2. Test data for materials

a) Cement used = OPC 43grade (IS 8112:1989)

b) SG of cement = 3.129

`

c) SG of CA = 2.75

d) SG of FA = 2.67

e) Water absorption of CA =1.513%

Table 3.8: Mix design proportions of M40

Water to cement ratio : 0.45			
Water	Cement	Fine aggregate	Coarse aggregate
190kg/m^3	399kg/m^3	632kg/m^3	1129kg/m^3

Final mix design – 1:1.58:2.8

b) Mix proportioning for a concrete of M50 grade:

1. Design Specifications

a) Designation of grade = M50

b) Cement used = OPC 43grade (IS 8112: 1989)

c) Aggregate Size (Max.) = Below 20mm angular

d) Supervision Mark = Good

e) Exposure condition = Severe (meant for reinforced concrete)

2. Test data for materials

a) Cement used = OPC 43grade (IS 8112:1989)

b) SG of cement = 3.129

c) Chemical admixture = superplasticizer

d) SG of CA = 2.75

e) SG of CA = 2.67

f) Water absorption of CA =1.513%

`

Table 3.9: Mix design proportions of M50

Water to cement ratio : 0.35			
Water	Cement	Fine aggregate	Coarse aggregate
190kg/m^3	399kg/m^3	632kg/m^3	1129kg/m^3

Final mix design – 1:1.58:2.8

c) Mix proportioning for a concrete of M55 grade:

1. Design Specifications

a) Designation of grade = M55

b) Cement used = OPC 43grade (IS 8112:1989)

c) Aggregate Size (Max.) = Below 20mm angular

d) Supervision Mark = Good

e) Type of exposure condition = Severe (meant for reinforced concrete)

2. Test data for materials

a) Cement used = OPC 43grade (IS 8112:1989)

b) SG of cement = 3.129

c) Chemical admixture = Superplasticizer

d) SG of CA = 2.75

e) SG of FA = 2.67

f) Water absorption of CA =1.513%

Table 3.10: Mix design proportions of M55

Water to cement ratio : 0.32			
Water	Cement	Fine aggregate	Coarse aggregate
143.8kg/m^3	410.85kg/m^3	752kg/m^3	1227.38kg/m^3

Final mix design – 1:1.83:2

`

3.5 Material's testing

3.5.1 OPC Cement

a) Normal Consistency

It's defined as the percentage of water from weight of cement that generates a consistency that lets a plunger of 10mm diameter to penetrate to a thickness of 5mm to 7mm over the base of vicat's mold. The Vicat device was utilized from IS: 4031 Part 4:1988 [60]. In OPC cement the normal consistency is 35.5%

Figure 3.8: Normal consistency

b) Initial setting time

First setting time of cement would be your lapse between the inclusions of water along with the instantaneous cement paste begins to shed its plasticity without sacrificing its potency. It's the period when water has been added to the cement and also the time in that needle of 1mm2

`

segments neglects to penetrate the thickness of the block into a thickness of 5 to 7mm in the Vicat mold. The IST is 40 minutes.

c) Final setting time

Final setting time is the time lapse between the addition of water to the instant the cement paste completely loses its plasticity. It is the time when water is added to the cement and the time when the 1 mm needle establishes an impression on the dough in mold, however the 5mm accessory doesn't make an impression. The FST is 460 minutes.

d) Specific gravity

Specific gravity, also referred to as relative density, is that the portion of the density of a substance to the density of a reference substance; equates with the portion of the mass of a substance into the mass using a reference substance for the same specified quantity. The apparent specific gravity is the ratio of the burden of some of this substance to the weight of an equivalent quantity of the reference substance. The density jar procedure is used for calculating the specific gravity of this cement.

Figure 3.9: Specific gravity of cement

`

We have used water to calculate the specific gravity of this substance. However, we usedkerosene in cement to come across gravity. This is only because cement is sterile and creates calcium when answered with water. The cement indicates no response when mixed with kerosene. In lab SG is 3.129 (see Figure 3.9).

e) Compressive strength

In the mortar cubes, folding resistance of the cement is considered by a compression resistance. For cement mortar production normal sand is utilized. Compression test machine was utilized for compression tests with cube volume70.6mm3.

Figure 3.10: Cubes preparation for compression test

Results of compressive strength (CS) are:

- After 3 days of curing(CS) – 24 N/mm^2
- After 7 days of curing(CS)– 35 N/mm^2
- After 28 days of curing(CS)– 46 N/mm^2

`

3.5.2 Sand

a) Specific gravity (SG)

Density bottle dictated the specific gravity of sand. Sand particles made out of quartz have a SG from 2.65 to 2.80. Weights are given below

Empty bottle (W1) = 694gm

Bottle + sand (W2) =850.2gm

Bottle + sand + water (W3) =1551.1gm

Bottle + water (W4) = 1420.2gm

SG of sand =W2 – W1÷ (W4 –W1) – (W3 – W4)

SG of sand using density bottle = 2.67

3.5.3 Coarse Aggregates

a) Water absorption

In the concrete mixture, coarse aggregate tends to absorb water. Incomplete hydration of the cement may occur if there is decrease in water content& if not taken into account. From range 0.1-2.0% water absorption takes place. In research facility tests, the absorption of water from coarse aggregates is 1.513%

Absorption of water = (A−B)

B × 100

b) SG (Specific gravity)

From the outcome of the water absorption test the specific gravity of the aggregates was considered as follows:

Weight of, Saturated Aggregate (SA) on hold with container in water (W1) = 1.75kg

Container suspended in water (W2) = 0.49kg

SSD (saturated surface dry) aggregate in air (W3) = 1.955kg

OD (ovendried) aggregate = 1.925kg

SGofaggregates = 2.75

`

3.6 OPC specimens: casting, mixing & batching

To conduct the experiments, High yield deformed (HYD) steelbarsofgradeFe415 (IS:1786, 1985) of 450 mm length and different diameters of 8mm, 12mm and16mm were selected. To Get a smooth surface in the middle section all bars were machined to bond the patch (seeFig.3.11).thilayeroftwo-piece epoxy adhesive was applied to the machined surface and 27mm diameter PZT patch and grade PIC151 (PI Ceramics, 2012) were applied (seeFigure3.12). A smallweight isused to apply light pressure over the complete surface.To allow the complete curing of bonded material, complete setup was left intact at room temperature for 1 day. For the determination of corrosion test, concrete specimens were prepared by using rectangular moulds of size (100mmx100mmx150mm). And also, to measure the compressive strength of concrete cubicalmouldsofsize150mmx150mmx150mmwereprepared. The preparation of mould sis shown in Figure3.13. All specimens are ready inaccording to the Indian Standard Specifications IS: 516-1959 [62]. A total of 27 cubes and 9 beams are prepared. In this experiment we provide clear cover of 45 mm. Fortheen tire process Ordinary Portland cement of grade-43from single source was used.After preparing the concrete of the cement, sand and aggregate mixture (as shown in Figure3.14), three mixture designs M40, M50, M55 were used to cast a total of 9 beams (3of M40, 3 of M50 and 3of M55) and 27cubes (9 of M40 , 9 of M50 and 9 M55). Admixture was only used for the M50and M55design. Steel rebar of diameter 12mm, 16mm, 20mm with concrete of M40 grade were used, samples were designated as OX1, OX2, OX3and with M50 grade is also prepared with similar diameter sizes and samples were designated as OY1, OY2, OY3. Also, with M55 grade and samples were designated as OZ1, OZ2 and OZ3. Specimens of different grades are shown in Table3.11. In the reinforcing projecting side, a woodenend of size (100mm x100mm) was utilized to provide backing. Before starting the casting process, all molds were oiled after cleaning properly. Specific consideration was reduced for keeping the oil from penetrating the reinforcing steel, because this might be injurious to the force of this ray due to the lack of durability of this joint which wouldn't be identified in to years of corrosion. Predicated on the reinforced spansgot, the most bizarre surfaces were selected to use from the tests.

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Figure 3.11: Rebar specimen prepared For bonding

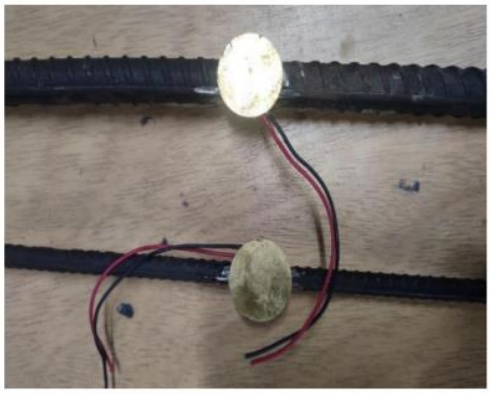

Figure 3.12: PZT on surface of rebars

Figure 3.13: Mould preparation

Figure 3.14: Preparation of concrete mix

Figure 3.15: Samples Casted

Figure 3.16: Cured Samples

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All these are rigorously substituted to fix the size prior casting. Consideration was paid in to the molds in order there are not any spaces left at which there's a prospect of plastic concrete blockage. Careful strategies are embraced in batch processing, mixing and casting surgeries (Figure3.15). From there forward, rough aggregates were inserted. Subsequently the water along with superplasticizer was carefully inserted so no liquid was leaking through out the mix. The concrete mix was prepared by the cement mixer and also with manual blending. It was initially cleaned out of the water and following that dried to ensure that impurities do not stick to the surface from before usage. All samples were abandoned in the steel mould for the initial 24 hours beneath ecological conditions. From there forward, they had been closely de-moulded from the aging requirements that no border shave been broken & established in the aging tank in room temperature for aging was 27 ± 20 as per IS: 10262-1982 (Figure3.16) [59]. Concrete should be suitably considered to develop it perfect properties. The illustrations have been immediately immersed into the water to prevent water fromevaporating out of hydrated concrete

Table 3.11: Specimen categorization

Grade	Specimen Name	Dia. of Steel Bar (mm)	Cover Depth(mm)
M40	OX_1	8	45
M40	OX_2	12	45
M40	OX_3	16	45
M50	OY_1	8	45
M50	OY_2	12	45
M50	OY_3	16	45
M55	OZ_1	8	45
M55	OZ_2	12	45
M55	OZ_3	16	45

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3.7 Impressed current technique

Impressed current technique isused to accelerate the corrosion of reinforcing steel. The current technique, more over referred to as galvanostatic technique, in which Dc power source is 56 utilized to supply constant current flow to steel embedded into the concrete to organize to cause substantial corrosion in a quick moment. After employing the current for a certain period of time, the amount of induced corrosion may be determined by the law of electromagnetism, or the percentage of the actual amount of steel dropped in corrosion could be determined with the Aid of a gravimetric test conducted on the bars extracted resulting accelerated corrosion [65].

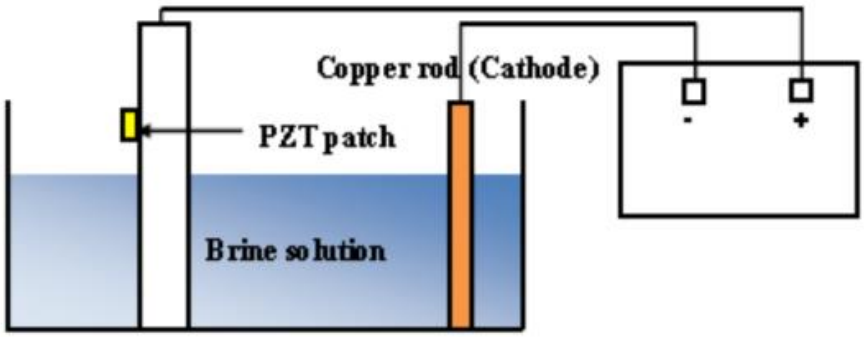

Figure 3.17: Accelerating corrosion setup [65]

The current is impressed by the counter electrotroding of the reinforcement by the concrete with the electrolyte (usually the sodium chloride solution). To get adesirable out come with in less time period, impressed current technique to accelerate the corrosion was conducted. In this study we utilized 3.5% NaCl solution

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CHAPTER 4
RESULTS & DISCUSSION

4.1 General

In this chapter, final outcomes of the compression test and accelerated corrosion tests carried out concrete cubes and beams. After that corrosion test results of concrete beams of all three grades (M40, M50, M55) was compared. The evaluation of corrosion has been done with the PZT patches bonded on the surface of particular rebars, using the impedance technique. The corrosion evaluation models are developed based on the analyzed data. While all of the previous research has concentrated upon metal parts plus employed the raw conductance signature with regard to corrosion monitoring as discussed in chapter 2, the research covered in this chapter focuses on corrosion in RC constructions utilizing the equivalent structural parameters extracted through the mechanical impedance, after filtering away the PZT guidelines. The next part of the chapter works with the comprehensive experimental study, data acquisition, analysis, plus the progress of the corrosion assessment model dependent on the comparative parameters.

Also, this chapter presents all of the compression test outcomes on the 27 concrete cubes of three grades (i.e., M40, M50, M55). Experimental results of a new corrosion measurement approach with regard to bare steel bars using the EMI technique through the use of the application of surface-bonded PZT patches based on the extracted structural parameters from the impedance spectrum. This chapter extends the suggested method to the rebars embedded inside the concrete and presents corrosion assessment comparison versions that can work extremely well in real-life corrosion monitoring of structures

4.2 Tests conducted

4.2.1 Compressive strength test

Proportioning of concrete is used to control the strength of concrete, rough and fine aggregates, water, and assorted admixtures. To determining power of concrete, proportion of the water into

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cement is the main factor. The compressive strength is more when there is low water-cement ratio is used. The capacity of concrete is currently stated as MPa - mega pascals in SI units and psi - lbs per sq. inch in US units. This is usually caused due to the compressive strength characteristic of real fc/fck. Concrete having strength strength ranges from 10 MPa to 60 MPa can be ideal for normal field applications For certain applications & designs high compressive strengths concrete in the range of 500 MPa, are produced, commonly referred to as ultra-high strength concrete or chemically active concrete powder.

Figure 4.1: Compression testing machine

On hardened concrete, compression evaluation is the most common test that could be conducted, partially as it is a simple test to do, and compressive strength test can provide more practical usable properties of concrete. The compressive strength of concrete is given concerning the characteristic compressive strength of 150-millimeter size cubes tested at 28 days (fck) (as shown in Figure 4.1). The strength of concrete must figure out the strength of their members. Concrete

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specimens have been casted and analyzed under the act of compressive loads to ascertain the strength of concrete [62]. 59 Within this study work concrete with quality control was prepared under restrained exposure state. To avoid any effect on the compressive strength, they are poured into cubical molds and put on a table to lessen air entrapped inside the molds. Removed of molds after1 day the molds the specimens were retained for healing at room temperature before testing. For the Compressive evaluation, we've ready 9 cubes of every grade. i.e, total 27 cubes were tested (as shown in Figure 4.2)

Figure 4.2: Concrete cubes of different grades used for compression test

For the purpose of compressive strength, these specimens were analyzed at several ages i.e., they are cured for 7 days, 14 days and 28 days. The load of roughly 140 kg/sq cm/min has been implemented without any jolt and load was improved continuously at a speed of before rising load breaks it down, without an increased load could be sustained. We noted down the maximum load applied to the specimen. The equal strength of this specimen was calculated by dividing the maximum load by tile region of contact of the bearing plates and has been stated to the nearest kg/sq cm. Typical of 3 values is accepted as the agent of this batch supplied the individual variation isn't greater than ± 15% of their typical. If not, replicate evaluations are taken. For every grade, 3-3 cubes were divided into three batches (i.e., Batch1, Batch2 & Batch3). For M40 grade, total 9 cubes were divided into three batches designated as C401, C402, C403, C404, C405, C406, C407, C408 and C409.

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Figure 4.3.1: M40 Grade Cubes

For Grade M40, compression test results of batch 1 were taken after 7 Days of curing. Which have the minimum average compressive strength of 28.69 Mpa. Cubes of Batch 2 were cured for 14 days. Average compressive strength of batch 2 was 42.57 Mpa. Maximum compressive strength of 46.83 Mpa was obtained after 28 days of curing for batch 3. Compression test results of M40 are given in following Table 4.1.

Table 4.1: Compressive strength (N/mm^2) of Grade-M40

Batch 1			**Batch 2**			**Batch 3**		
Day 7			Day 14			Day 28		
Compressive Strength (MPa)								
$C40_1$	**$C40_2$**	**$C40_3$**	**$C40_4$**	**$C40_5$**	**$C40_6$**	**$C40_7$**	**$C40_8$**	**$C40_9$**
28.10	29.89	28.10	42.89	42.41	42.41	46.34	46.34	47.89
Average compressive Strength(MPa)								
28.69			42.57			46.83		

`

For M50 grade, 3-3 cubes were divided into three batches (Batch1, Batch2 & Batch3) designated as C501, C502, C503, C504, C505, C506, C507, C508, C509

Figure 4.3.2: M50 Grade Cubes

For Grade M50, compression test results of batch 1 were taken after 7 Days of curing. Which have the minimum average compressive strength of 36.63 Mpa. Cubes of Batch 2 were cured for 14 days. Average compressive strength of batch 2 was 49.97 Mpa. Maximum compressive strength of 54.383 Mpa was obtained after 28 days of curing for batch 3. A compression test result of M50 is given in following Table 4.2.

`

Table 4.2: Compressive strength (N/mm^2) of Grade-M50

Batch 1			**Batch 2**			**Batch 3**		
Day 7			Day 14			Day 28		
Compressive strength(MPa)								
$C50_1$	**$C50_2$**	**$C50_3$**	**$C50_4$**	**$C50_5$**	**$C50_6$**	**$C50_7$**	**$C50_8$**	**$C50_9$**
36.40	36.40	37.10	50.64	48.63	50.64	52.76	52.76	57.63
Average compressive Strength(MPa)								
36.63			49.97			54.383		

For M55 grade, 3-3 cubes were divided into three batches (Batch1, Batch2 & Batch3) designated as C551, C552, C553, C554, C555, C556, C557, C558, C559. A compression test result of M55 is given in following Table 4.3.

Figure 4.3.3: M55 Grade Cubes

For Grade M55, compression test results of batch 1 were taken after 7 Days of curing. Which have the minimum average compressive strength of 39.16 Mpa. Cubes of Batch 2 were cured for 14

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days. Average compressive strength of batch 2 was 54.49 Mpa. Maximum compressive strength of 58.57 Mpa was obtained after 28 days of curing for batch 3. A compression test result of M50 is given in following Table 4.3.

Table 4.3: Compressive strength (N/mm^2) of Grade-M55

Batch 1			**Batch 2**			**Batch 3**		
Day 7			Day 14			Day 28		
Compressive strength (MPa)								
$C55_1$	**$C55_2$**	**$C55_3$**	**$C55_4$**	**$C55_5$**	**$C55_6$**	**$C55_7$**	**$C55_8$**	**$C55_9$**
40.01	38.73	38.75	53.45	55.02	55.02	57.13	57.13	61.45
Average compressive Strength(MPa)								
39.16			54.49			58.57		

Batch1, Batch2 & Batch3 of all three grades were tested after 7 days, 14 days and 28 days. Averages of every batch of all three grades were taken for research reference. The compression test results are tabulated in the above tables. We get maximum average compressive strength of 58.57Mpa for grade M55 which is cured for 28 days, followed by average Compressive strength of 54.383 Mpa for grade M50 and 46.83 Mpa for grade M40 both were also cured for 28 Days.

4.2.2 Corrosion detection test

It is known that different types of oxidation products are formed during corrosion process. Due to the different material properties of corrosion products, volume of corroded part of a steel bar may increase. The Ultrasonic wave are guided through the steel bar as they are designed to do so. The wave energy would transmit to the part of concrete when the sensor was embedded into concrete

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[57]. Less wave energy would release to the concrete when the corrosion products were gathered. Thus, wave amplitude would change during the corrosion.

4.3 Experimental setup

The piezo sensor bonded with the concrete specimen was placed in the solution of 5% NaCl. The DC power has been connected with the corrosion circuit. The anode was connected with embedded reinforcement bar and cathode was connected with the copper rod of their direct-64 current power. Both ends of metal rods were connected using a oscilloscope and signal generator (as shown in given Figure 4.4).

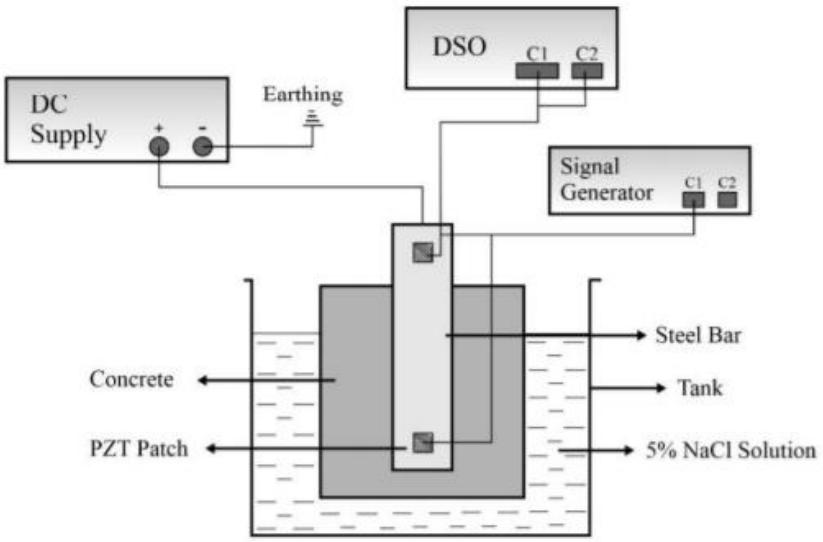

Figure 4.4: Corrosion monitoring setup

An electric pulse from a signal generator (SFG 1030) was stimulated with one piezoelectric component by along with another piezoelectric element. And this was utilized to get the ultrasonic wave that had been captured by an oscilloscope (GDS-1102-U). The input pulse was a step function of ±10V. Using a cover depth of 10 mm, sensor was then casted into the concrete beam. Wave amplitude was listed for all of the concrete grades. It may be noticed that the detector could respond to the changes in its surrounding. Then, to track corrosion monitoring the utilized sensor was shown in Figure 4.5.

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Figure 4.5: Test instruments used in corrosion monitoring

The 5 volts of potential was used in the acceleration test. The ultrasonic wave signals were measured at particular interval of time. The amplitude of wave detects the initiation of the corrosion in the OPC concrete beam.We have taken total 3-3 concrete beams of all three grades i.e., M40, M50 and M55. So total 9 concrete beams were monitored. Ultrasonic waves were recorded at 10hr, 30hr and 50hr for all three grades. During the initiation period the wave signals first measured at 10h were shown in the Figure 4.6.

During initiation of corrosion monitoring test amplitude was started recording at 10hr, maximum amplitude 69.6 was recorded for grade M40 and minimum amplitude of 67.3 was recorded for grade M55. Amplitude on M50 was 68.0. The initiation of corrosion was first started on grade M40 later on M50 & M55. Thus, Grade M40 shows maximum deflection during starting hours of examination. Initially, there was small deflection in the recorded wave, but through corrosion that the amplitude of the wave improved. The motive was it improved since with the increase in the corrosion period, the amplitude of the frequency peak declines gradually. Since the corrosion product layer decreases the transmitted wave energy and of those new appeared peaks rises.Therefore, amplitude increases. The next values of amplitude were taken after a gap of 20-20hr. The waves recorded at 30hr and 50hr are shown in the Figure 4.7 and Figure 4.8.

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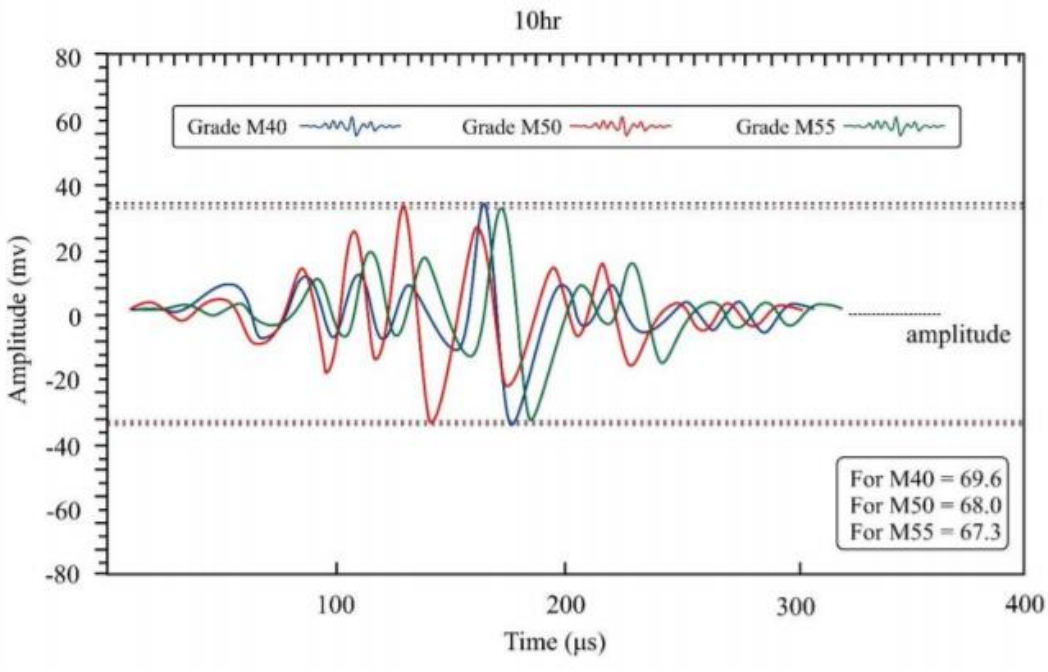

Figure 4.6: Ultrasonic waves recorded at 10hr

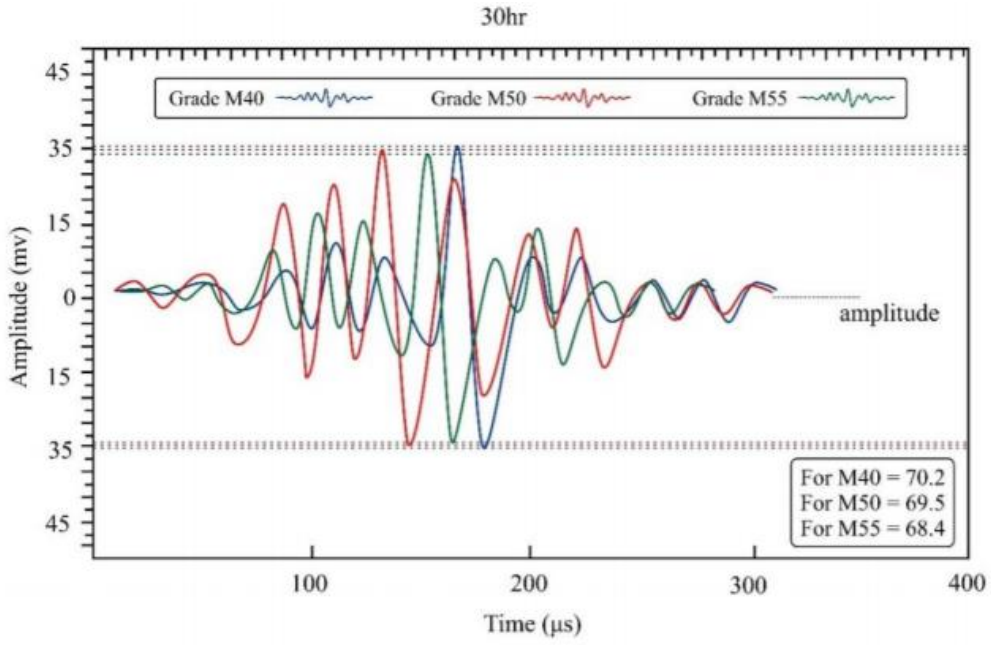

Figure 4.7: Waves recorded at 30hr

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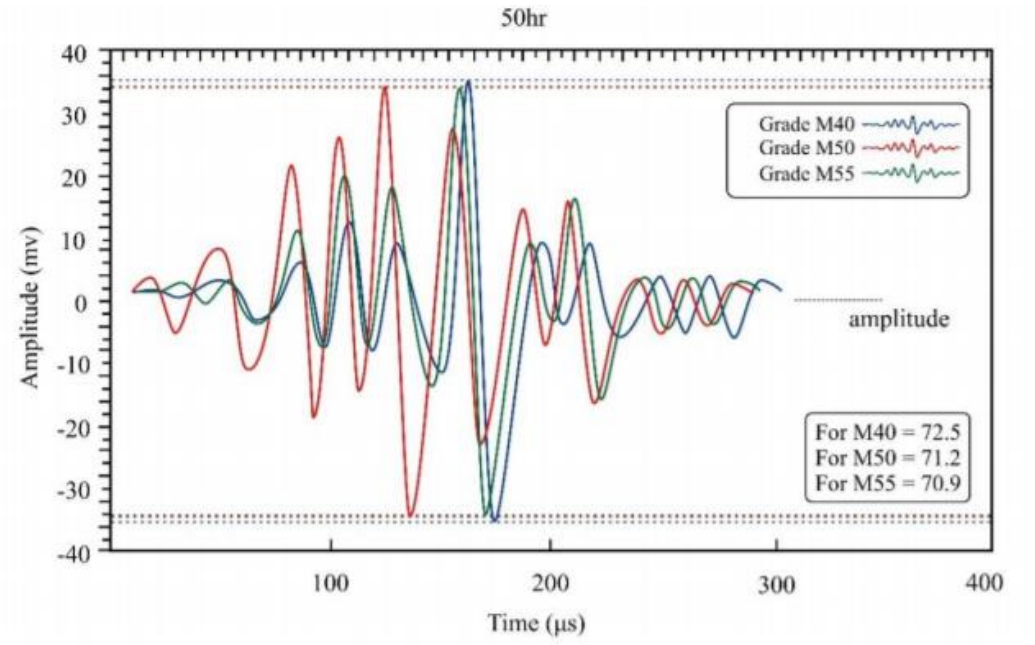

Figure 4.8: Waves recorded at 50hr

At 50hr, maximum amplitude 72.5 was recorded for grade M40 and minimum amplitude of 70.9 was recorded for grade M55. Amplitude recorded on M50 was 71.2. Grade M40 showed unproductive results among three grades. And from the amplitude data it can be conclude that Grade M50 showed the minimum deflection throughout the monitoring because of its better material composition, because of which it leads to a surpassing performance during corrosion acceleration period among the tested grades. Increase of amplitude versus time for M40, M50 and M55 grades are shown in the Figure 4.9.

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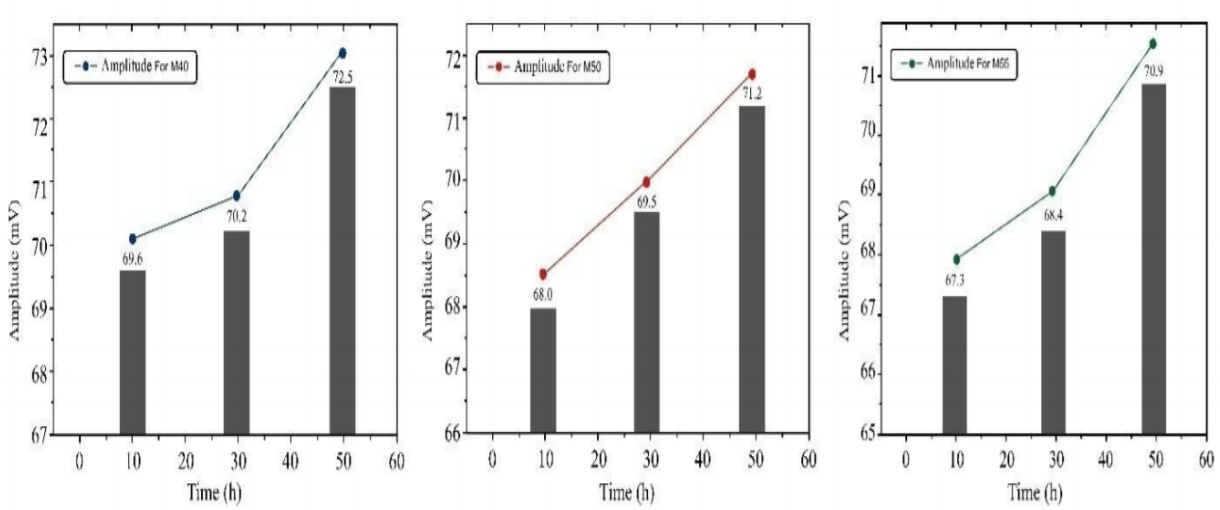

Figure 4.9: Increase of amplitude versus time

At about approximate 50-60hr, the amplitude stopped increasing and the wave propagation from steel bar to concrete gave similar results (as shown in Figure 4.10). Thus, the amplitude of the wave that we got at 50h showed the initiation of corrosion. Thus, the initiation of the corrosion and the cracking of the concrete could detect through amplitude of the wave. It should also be noted that the conducted experiments had very good repeatability.

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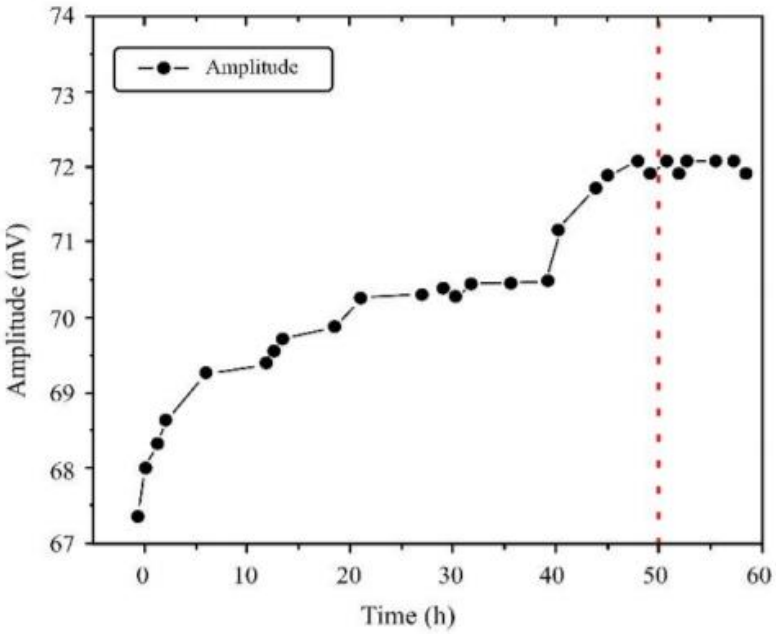

Figure 4.10: Increase of amplitude versus time for all grades

4.4 Comparison results

4.4.1 Compression Test Comparison

From compression test it can be concluded that Grade M55 showed better compression strength after curing of 28 days. Hence M55 grade can preferred over other two grades.

Table 4.4 Compression Test Comparison

Day 28		
M40	**M50**	**M55**
46.83 Mpa	54.38Mpa	58.57Mpa

4.4.2 Corrosion Test Comparison

From corrosion monitoring test it can be concluded that Grade M55 is more ideal for work under in corroded scenario. Hence M55 grade can preferred over M40 & M55 grades.

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Table 4.5: Corrosion Test Comparison

50 hr		
M40	**M50**	**M55**
72.5 mV	71.2 mV	70.2 mV

4.5 Concluding remarks

This chapter has introduced a new and easy approach for tracking the practice of corrosion in RC structures directly from initiation into rebar corrosion extracted from the admittance signatures of PZT patches surface-bonded into the years. The admittance worth of three distinct ranges was compared. The suggested strategy is non-destructive in character and entirely autonomous. The impedance-based method of corrosion tracking by using the PZT patch can be used in corrosion of rebars in real-life RC constructions, where they aren't subjected to a direct visual analysis. To validate the nature of changes emphasized by the amplitude signature information, corrosion tracking results using the electromechanical impedance procedure, representative samples of each grade were compared. The amplitude values for every single concrete column of different levels were analyzed to discover the best appropriate work samples in actual scenarios. From the tests, Grade M55 is more practically suitable for both compression wise and applications which are more prone to corrosion.

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CHAPTER 5
CONCLUSIONS AND FUTURE SCOPE

5.1 General

The main objective of this research was to monitor the corrosion expansion in the steel rebar from RC structures by using electro mechanical technique (with the help of PZT sensors). The piezoelectric sensor includes two conductive piezoelectric components that are employed for producing and receiving ultrasonic waves along with steel bar. The growth of these corrosion products altered the wave amplitude. Also, the wave propagation from steel bar of concrete gave similar results as the amplitude keeps increasing. The uniqueness at this thesis is the very first time an inclusive study on the use of their comparable structural parameters such as corrosion monitoring in concrete structures of different grades are researched and related corrosion assessment models are developed. This chapter provides ideas about future work which will match the material and draws conclusions.

5.2 Research outcomes

The final research results of the thesis mainly include the creation of a comparative data of compression test results and corrosion detection results of different grades. And to compare them for future reference for better implementation in real structural applications. Important results and outcomes of research are outlined as follows:

- In this research work we have used Grade-43 cement and M40, M50 and M55 grade of concrete for compression test and corrosion monitoring test.
- To find out the compressive strength of grades (M40, M50 and M55) total 9 cubes of each grade were casted i.e., total 27 cubes were casted. Samples were cured at different time period i.e., 7days, 14 days &28 days. Compressive strength of M40 (46.83 MPa), M50 (54.38 Mpa) and M55 (58.57) was obtained after 28 days of curing.

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- For non-destructive corrosion test total 3-3 beam i.e. total 9 beams were casted of all three grades (M40, M50 and M55). In research work, the corrosion rates in high grades of concrete were detected and also which grade is corrosive easily with the help PZT sensor. These sensors include two piezo-sensors which were utilized for producing and receiving amplitude values. Transmission of waves changes due to the growth of corrosion products.
- Throughout initiation of corrosion monitoring test amplitude was started recording at 10hr maximum amplitude 69.6 was listed for grade M40 and minimum amplitude of 67.3 was listed for grade M55. The initiation of corrosion was initially began on grade M40 then in M50 & M55. Therefore, Grade M40 shows maximum deflection during beginning hours of evaluation. The upcoming values of amplitude were taken following a difference of 20-20hr. The corrosion was distributing more quickly on grade M40 compared to other two grades. In 50hr, maximum amplitude 72.5 was listed for grade M40 and minimum amplitude of 70.9 was listed for grade M55. Grade M40 revealed undesirable consequences among three grades. This implies lower grade concrete is far more vulnerable to corrosion.

5.3 Future recommendations

In future researches, following points can be considered for more flexible outcomes in the corrosion monitor study:

- The current study was carried out on only three higher grades of concrete. In future, same research can also be done by using different strength of concrete and by using different grades of steel.

- In this work we have used PZT sensor for corrosion detection but same can be extend with new wireless sensors.

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• The corrosion rate model could be used by using other damage identification methods, corrosion for real time structure to could be find to check the long-term effect.

• In future work OPC 43 grade of cement can be replaced with Geopolymer concrete.

From this study and literature reviews, this non-destructive technique, electro mechanical impedance technique by using piezoelectric sensor for corrosion evaluation of different cement grades of concrete has a vast possibility in future. So, at the end we can conclude that this could be a better assessment conventional electrochemical technique.

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