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Damage Assessment Study of RC Beams due to Acid Attack Using Surface Bonded Piezoelectric Based Transducer

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ABSTRACT: Sustainability has become one of the most important considerations in building design and construction in recent years. Concrete is susceptible to acid attack because of its alkaline nature. The socioeconomic losses associated with infrastructure deterioration due to acid attack exceed billions of dollars all around the world. This is because concrete is exposed to variety of environments from factories to sea structures. With Pollution in environment increasing every day, the rain has also become more acidic. Hence there is need to expose every kind of concrete to be tested in various percentages of acid solutions, so that the durability and vulnerability aspects of the type of concrete invented is thoroughly studied. Acid is a substance which has sour taste and reacts with alkaline or bases to form salts which may be or may not be soluble in water. Acids are present in rain due to pollution of atmosphere. The acids predominant in the rain are sulphuric and nitric acids. These acids are deleterious to manmade concrete structures. To detect the damages in RC beams due to acid attack, the piezoelectric transducers are surface bonded in all the beams and monitor the cracks on beams by transducer connected with oscilloscope and function generator. The analysis of result done by graph shows the frequency response curve and time response curve plotted in oscilloscope and function generator.

I. INTRODUCTION

Concrete is the most popular man-made material in civil engineering. Many important civil infrastructures, such as bridges, dams, and tunnels, are made of concrete. Concrete structures have a long service life compared to structures made of other artificial materials. However, sometimes this material does not perform well because of the brittle nature of concrete. Since concrete is weak in tension, brittle failure of concrete under tension can occur. Therefore, it is important to ensure the safe operation of concrete structures throughout their operation life.Damage detection and continuous health assessment are necessary for critical concrete structures. In recent years, guided wave (GW) based testing techniques have been found to be very efficient for damage detection and health assessment of various structures.

The critical element of GW based methods is the wave generating transducers. Piezoelectric (PZT—Lead Zirconate Titanate) material is the most commonly used material for ultrasonic transducers. The PZT material can generate ultrasonic waves when an electric voltage is applied to it. It can also convert mechanical stress to electrical voltage when it is struck by ultrasonic waves. Due to this special property, PZT materials can be used to fabricate both actuator (or transmitter) and sensor (or receiver). The piezoceramic-based element, is an innovative multifunctional device. The transducer has been successfully applied to the SHM of concrete structures under both static loading [7, 8] and seismic excitations [9, 10]. In those studies, a number transducer were surface bonded in concrete structures and the health state of the concrete structures was evaluated by monitoring the signals recorded by the transducer.Most tests with transducer are conducted by placing these piezoelectric- based elements on surface of the concrete structures. The combination of piezoceramic patches for SHM of concrete structures has been seldom studied and will be the focus of this paper.

A transducer is bonded in surface of a concrete beam to act as an actuator (or transmitter) and piezoceramic patches are attached to the surface of the concrete beam to act as sensors. The efficiency of this combination of the transducer and

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piezoceramic patches for SHM of concrete structures is investigated here.The elastic wave generated by the transducer can propagate a long distance along the beam as the guided wave for which the beam serves as the waveguide. This guided wave can be sensed by the piezoceramic patches mounted on the beam surface. The advantage of this combination is that since the transducer id surface bonded in concrete it is well protected from the deterioration due to the environmental effect while the smart patches can be attached at various locations of the surface of the structure to monitor different segments of the structure by recording the wave signals coming from the transducer. These patches are expected to monitor not only the surface damage near the patch but also external damage. It is shown in this investigation that it is possible to do it.

II. LITERATURE REVIEW

This chapter presents a review of the related literature on the subject under study presented by various researchers, scholars and authors. It gives an overview of what has been written or researched on different aspects of the subject. It also summarizes selected studies that would be relevant to organization and interpretation of data. Finally, it presents the conceptual framework utilized in this study.

Jinlei Zhao et al.2015 [1] studied a new method combining an embedded smart aggregate and surface mounted piezoceramic patches is introduced for health monitoring of concrete structures. The smart aggregate is embedded in a concrete beam as an actuator (or transmitter), and piezoceramic patches are attached on the surface of the concrete beam as sensors.Two tests using the smart aggregate and the piezoceramic patches are conducted. The first test investigates the sensitivity of the recorded signal amplitude- frequency relation on the piezoceramic patches. To explain the significant amplitude fluctuations in the results, the possibility of resonance occurring in the piezoceramic patches in a certain frequency range is verified through finite element modelling. In the second test, a damage index is proposed to evaluate the health of concrete structures and a three-point bending test is conducted to induce damage in the concrete beam. It is observed that, with increasing severity of damage in the concrete beam, the recorded signal amplitude at the patches decreases gradually while the value of the damage index increases significantly.The experimental results show that the proposed method is an effective tool for health monitoring of concrete structures.

In 2019 Taheri Shima [2] investigated a multitude of structural health monitoring options are currently being investigated to address the reliability of concrete infrastructures at different stages of their service life. This review presents the recent achievements in the field of sensors developed for monitoring the health of concrete infrastructures. The focus of this review is on sensors developed for monitoring parameters including temperature, humidity, pH, corrosion rate, and stress/strain and the sensors particularly fabricated based on fibre optic, Bragg grating, piezoelectric, electrochemical, wireless and self-sensing technologies. Several examples of developed concrete monitoring sensors (from laboratory concepts to commercialized products) together with their various benefits and drawbacks as well as open research problems will be discussed in this paper.

Demi ai et al 2022 [3], dealt with the paper performed a numerical simulation on corrosion damage identification using embedded piezoceramic (PZT) transducers.Three-dimensional finite element (FE) model of a full-scaled RC beam was generated with experimental validation, where three groups of PZT sensors in depth, width and longitudinal directions of the beam were simulated to evaluate corrosion damage rate correlated to concrete/rebar parameters including mass loss, cross-section loss, elastic modulus, strength and bond-slip relationship at steel–concrete interface.

Demi Ai et al 2024 [4], Simulation and experimental results indicated that corrosion severity was well reflected in resonance characteristics of PZT admittance and its derived root mean square deviation (RMSD) as well as mechanical impedance. Based on the results, a new sensitivity index was proposed for evaluating corrosion evolution, which suggested that the optimal sensor location was in the depth direction of the beam within a scope of 400 mm, and corrosion evolution as corrosion initiation and crack propagation stages could be effectively identified.

Dhinesh T, Prakash and S. Gnana, 2019 [5] dealt with the study of identifying the possibilities of utilizing the quarry dust in concrete to obtain the improved strength and durability properties of concrete during sulphate attack by using smart piezoelectric sensor. In this study the addition of quarry dust as alternative for natural sand and partial replacement for cement with GGBS has been investigated for the durability properties of concrete.Mechanical

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properties of conventional concrete and partially replaced GGBS concrete were evaluated. The GGBS incorporated concrete strength was evaluated and the comparison between mechanical properties of GGBS incorporated concrete and ordinary Portland cement concrete was made. Sensors were used for monitoring corrosion of reinforcement during sulphate attack in both cases.

Arash Arjomandi , Reza Mousavi and Morteza, 2023 [6] studied about the Replacing of natural aggregate with recycled plastic has been a strategy to reduce pollution associated with conventional concrete production and disposal of plastic materials. Due to the possibility of structures subject to acid attacks, it is of value to check the resistance of concrete against these attacks. The present study evaluates the behavior of concrete containing steel fibers and nylon granules under sulfuric acid attack. 9 batches of concrete containing 0, 10, and 20% (by volume) of nylon granules, replacing natural sand and three volume percentage of steel fibers (0, 0.75, and 1.25%) were prepared. First, concretes were placed in a 5% sulfuric acid solution for 0, 45, and 90 days, and then their ultrasonic pulse velocity (UPV) and compressive capacity were evaluated.

III. METHODOLOGY

This study is mainly focused on the damage detection of reinforced concrete beam due acid attack. Test were performed in the 1 reinforced concrete beam (acid attack) and one conventional concrete beam of size 0.15m X 0.25m X 2m.Grade of concrete is M25 and steel is Fe500. All beams are reinforced with main rods of 12mm and 10mm dia and stirrups of 8mm dia @ 150mm C/C spacing. The piezoelectric smart aggregate are embedded in the both supports and middle of a beam and monitor the cracks on beams by smart aggregate connected with oscilloscope and function generator. The analysis of result done by graph shows the frequency response curve and time response curve noted in oscilloscope and function generator.

Casting And Curing Process of Beam

The reinforcement for beams are prepared at equal spacing and the mould is cleaned properly and then grease is applied inside the mould. reinforcement bars are placed inside the mould with a cover block of 30mm. After proper tamping and placing of smart aggregates , beam casting is done successfully. After 24 hours , beam is demoulded and subjected to curing process.

Fig 1:Casting Of Specimen

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Fig.2 curing of beams into water

Both concentrated sulphuric acid and Nitric Acid (each 100 ml) is diluted with water, upto it reaches the Ph range of 4-4.5 and it is checked periodically using ph meter. After dilution, acid curing tank is sealed to avoid contact with the environment and for a safety purpose.

Fig.3 checking of PH values

Placing of Transducer

Soldering is a joining process used to join different types of metals together by melting solder. Solder is a metal alloy usually made of tin and lead which is melted using a hot iron. After preparing the surface of the beam the transducers are placing on the beams by using strong glue.

Fig. 4 Placing of transducer

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Test set up and Instrumentation:

Tests were carried out on one reinforced concrete beams under acidic condition and one conventional concrete beam, intended to initiate failure in the flexure zone. The beams of 150mm x 200mm cross-section with a length of 2000mm were cast as a singly reinforced rectangular section under bending, tested under a two point load configuration. Both the beams the transducer are surface bonded and provided a reinforcement of 12mm and 10mm dia bars with 8mm stirrups @150mm c/c spacing. The experimental setup is shown below.

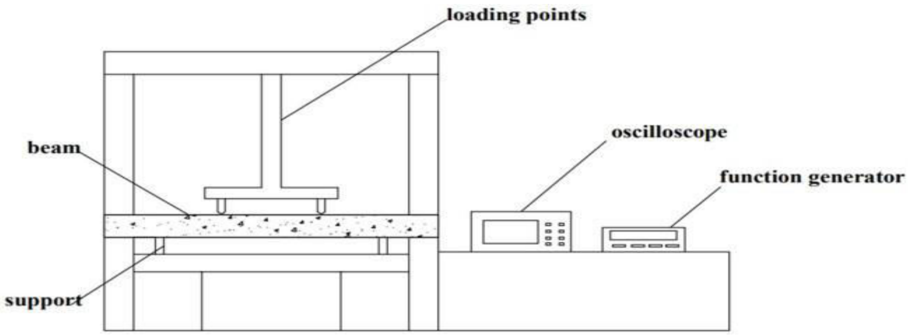

Fig. 5 test setup cross section

Six PZT patches of 3cm thickness and 6cm diameter in dimension (PZT1, PZT2, PZT3 , PZT4 PZT5 , PZT6) were surface bonded in conventional concrete and concrete under acid attack as shown in Figure 4.2(b). PZT were placed at the both supports and in the middle of the beam in the form of transducer. After loading, the initiation of crack and its propagation was observed and traced on the surface of the beam to identify the type of failure. The deflections at the centre of the span were measured using deflectometer. Measurements of load and deflection were observed and recorded continuously throughout the tests. The signals were generated by function generators and recorded by a mixed-signal oscilloscope in the time response. The PZT 1 and PZT 2 were actuated simultaneously by generating electric signals of 5V magnitude in the form of sine waves. The elastic waves originating from the PZT 1 and PZT 2 were transmitted and received by the PZT 3. Further, measurements of the electric signals in terms of volts were recorded.PZT at the supports were connected to the digital storage oscilloscope and the PZT in the middle were connected to the function generator.

IV. RESULTS AND DISCUSSION

In a conventional beam, there is no different colour formation and inflorescence. There is less pores and comparatively more stronger than the beam exposed to acid. But in a beam under acid attack, there is reddish brown colour formation due to corrosion and marks the presence of inflorescence. Beam become comparatively more porous and weaker than the conventional beam. The corners of the beam became very thin.

Fig 6 beam under acid attack

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The figure 5.4 sighted below depicts the deflection and other strain due to the application of load.It helps to understand the behaviour of a beam under the application of load. with the gradual increase in application of constant load of 10 kN at a particular interval of time, the deflection of the beam increases and the maximum deflection of the beam is towards the centre of the beam. The constant load of 10 kN is applied to the beam under acid attack at the time interval of o.5s and readings were obtained for 10kN load. The figure 5.6 represents the behaviour like extent of deflection on position of maximum deflection and other strain of a beam under acid attack. With the gradual increase in the application of constant load of 10 kN load at regular interval of time, the extent of deflection is plotted and it is observed to be centre of beam prone to maximum deflection.From this analysis, it is observed to be slight reduction of compressive strength upto 22% in a beam under acid attack for the period of 14 days (ph4). In the conventional beam, the maximum deflection is 13mm and the maximum deflection is towards the centre of the beam. The figure 5.7 sighted below depicts the deflection of conventional beam. From these observations , the conventional beam exhibit the maximum deflection the beam under acid attack comparatively exhibit less deflection and cracks and fails before the conventional beam. The conventional beam exhibit the more strength compared to beam under acid attack.in the conventional beam , small cracks first propagates through the centre and the corners of the beam is slightly stronger than the beam under acid attack. the figure 5.9 below displays the initiation of crack in conventional beam.

Structural Health Monitoring of Acid Attacked Beams

piezoelectric sensors are embedded in the beam in the form of smart aggregates are very helpful to monitor the beam in the healthy state and during load application by connecting the sensors to function generators and digital storage oscilloscope. for every application of constant load of 10 kN ,the results have been obtained and waves can be generated from that result and it can be stored for future use. Thus, piezoelectric transducers are very helpful in structural health monitoring.

Fig 7 deflection of beam under acid attack

Table 1 table for volt and second of conventional beam at healthy state

Source	**PEZ 1**	**PEZ 2**
Second	Volt	Volt
-0.0008	-300	-0.4
-0.0008	-300	-0.2
-0.0008	-300	-0.4
-0.0008	-400	-0.2
-0.0008	-400	-0.2
-0.0008	-400	-0.4

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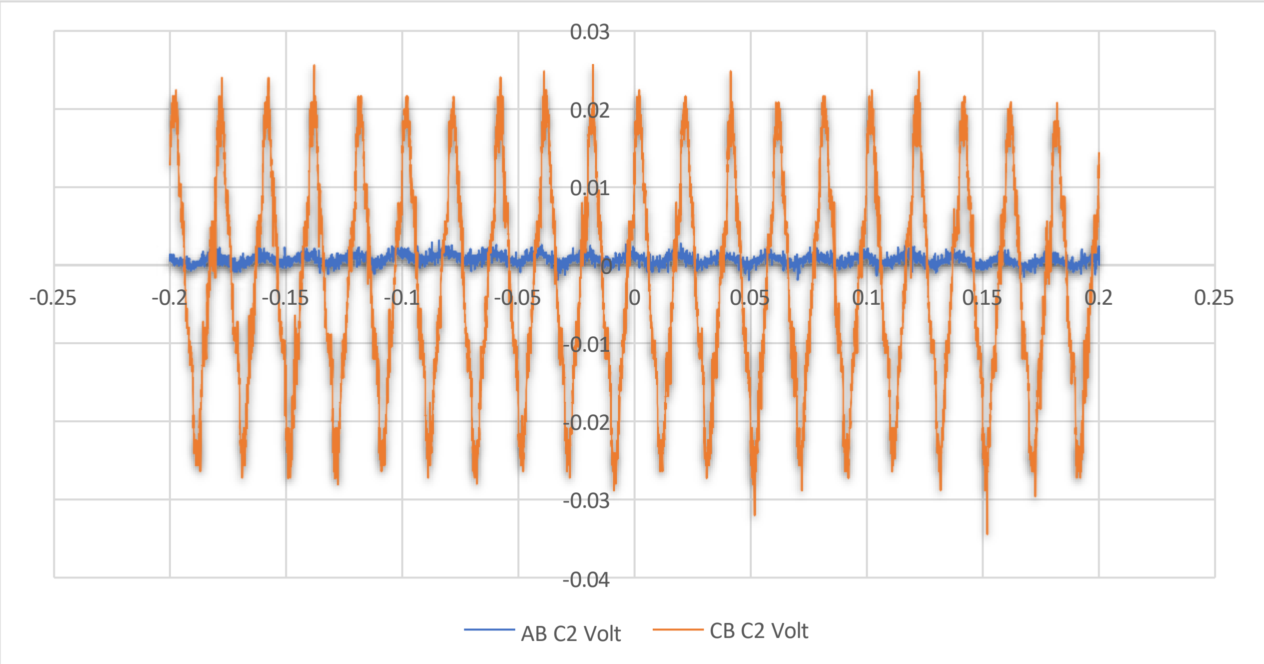
Table 2 table of seconds and volt for acid attack beam at 20 Kn

Source	**PEZ 1**	**PEZ 2**
Second	Volt	Volt
-0.2	-84	0.128
-0.2	-84	0.136
-0.2	-84	0.136
-0.2	-84	0.136
-0.2	-84	0.136
-0.2	-84	0.136
-0.2	-84	0.136
-0.2	-84	0.136
-0.2	-80	0.136
-0.2	F-82	0.128

Fig 8 Overlapping Signal Response of Channel -2



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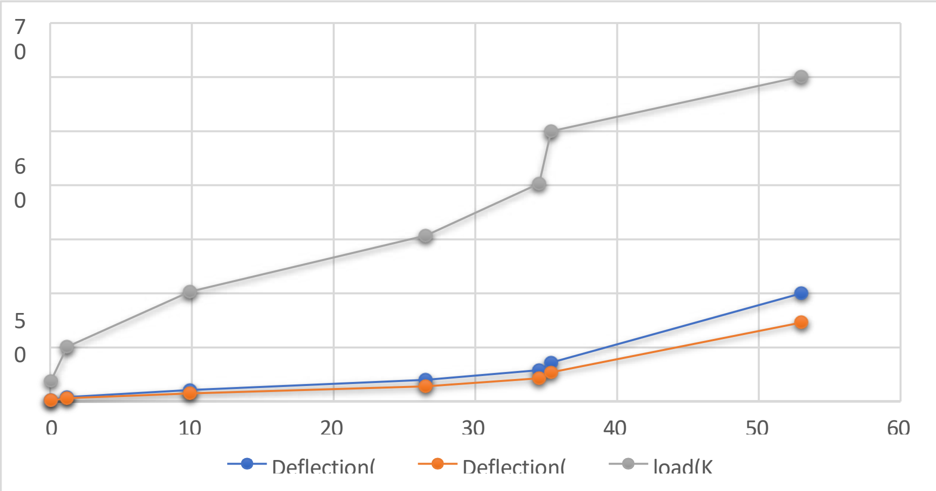
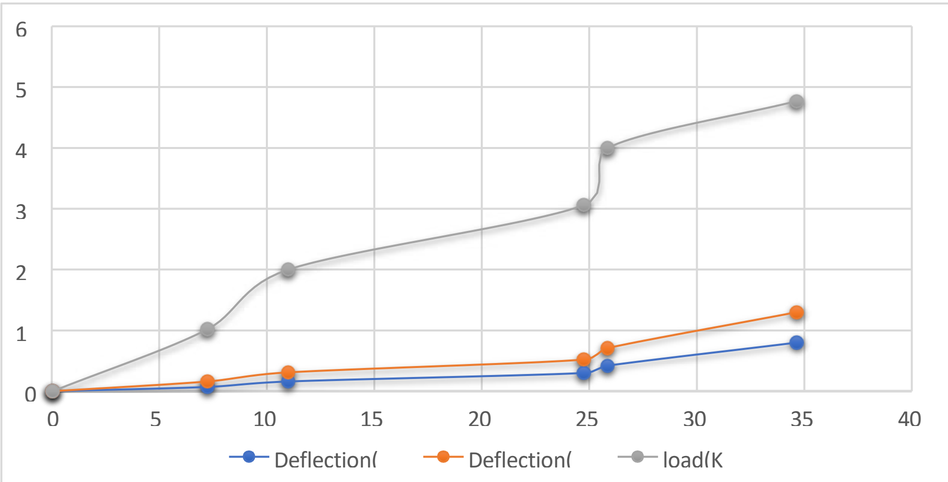


Fig 9 Experimental flexural response of the conventional tested beam

Fig 10 Experimental flexural response of the acid attack tested beam



From the result analysis, conventional beam is comparatively stronger than the beam under acid attack and it can be effectively monitored using piezoelectric sensors. The experimentally measured time histories of the intensity of the current passing through PZT of conventional RC beam is compared with the RC beam under acid attack. the comparisons of these diagrams point out that there are some deflections easily detected between the response of the beam with various loads. Tested RC beam exhibited typical flexural response, as it have been designed and expected. first, flexural cracks formed in, midspan in conventional beam and corners gets damaged in the beam under acid attack. The increase in applied load causes flexural cracks area to spread and inevitability tensional longitudinal bars to yield. Finally, piezoelectric sensors in the surface of beams are very helpful in structural health monitoring even under a acidic condition.

V.CONCLUSION AND FUTURE WORK

Experimentally measured time histories of the signals in volts transmitted through PZT1 and received at PZT2 were recorded simultaneously in both the beam. The comparisons of these time response curves of different reinforced

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concrete beams under acidic condition with conventional concrete beam gives the amount of cracks formed in beam under static loading. This shows that the reinforced concrete beam under acidic condition is slightly affected by both concentrated sulphuric acid and nitric acid. This could include measurements of the beam's strength and stiffness before and after the attack, as well as observations of any visible damage to the surface of the beam. The project was intended to explore the potential applications of piezoelectric transducers in structural health monitoring. Hence, it is concluded that addition of sensors in huge structure is effectively usefull for monitoring of structure in daily routine and easily identify the defects occurred in structure.

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