Effect of Corrosion on Flexural Behaviors Of RC Beam

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Abstract: — **In order to study the flexural behavior of structures exposed to severe environmental condition as like in case of marine structures in corrosive environment, a powerful nondestructive technique as a structural health monitoring tool needed to be employed. Acoustic emission (AE) is one of the most powerful nondestructive technique widely used for corrosion assessment of steel embedded in concrete as well as to study the behavior of RC beams under flexure. The presence of corrosion affects the flexural behavior structural elements. Hence it is necessary to interpret and evaluate the failure mechanism of deteriorated concrete structures with rebar corrosion using suitable non-destructive technique. The present paper investigates monitoring of failure with rebar corrosion by means of acoustic emission technique. From the experimental study it is observed that, AE technique is effective in identifying flexural as well as corrosion behavior of RC specimens.**

Index Terms- **Acoustic emission technique; Corrosion; Flexural behavior; RC element; Rebar**

I. INTRODUCTION

In order to study the flexural behavior of structures exposed to severe environmental condition like marine structures or any other structures in corrosion environment, a powerful nondestructive method of structural health monitoring tool have to be employed. Acoustic emission (AE) is one of the most powerful nondestructive methods available on the market. Structural health monitoring of a particular structure without direct contact upon it and without altering its structural behavior make this method more special. Term "acoustic emission" is commonly used to describe both a technique and the phenomenon upon which the technique is based. The AE monitoring technique uses one or more sensors to 'listen' to a wide range of events that may take place inside a solid material. Examples of AE events related to civil engineering materials include yielding of steel, crack growth in steel and concrete, corrosion of metals, fiber breakage and matrix debonding for composites [1].

In real life structures, especially in marine structures the structural elements are subjected to external loading along with simultaneous corrosion. The presence of corrosion affects the flexural behavior structural elements. Hence it is necessary to interpret and evaluate the failure mechanism of deteriorated concrete structures with rebar corrosion using suitable non-destructive technique.

In real life, corrosion of rebar is one of the serious deterioration phenomena in concrete structures, affecting their safety. It is important to interpret and evaluate the fracture mechanism of deteriorated concrete structures with rebar corrosion. Past reseaRCh works and specifications classify the deterioration processes due to corrosion as dormant stage, initiation stage, accelerated stage and deterioration stage. For maintenance scheme, it is important to identify the deterioration process more specifically. Previous reseaRCh on AE applications to corrosion of reinfoRCed concrete aimed at evaluating the corrosion process of rebar, including cracking of Concrete and corrosion of rebar itself. However, there was little investigation on AE activity of corroded RC members subjected to external loading. Hence the aim of present study is to understand flexural failure behavior of RC beams with uncorroded and corroded rebars.

II. ACOUSTIC EMISSION TECHNIQUE

Acoustic emission testing is a powerful nondestructive testing tool for examining the behavior of materials deforming under stress. By definition, AE is the class of phenomena whereby transient elastic waves are generated by the rapid release of energy from a localized souRCe or souRCes within a material. Thus, the technique can be used to listen to events that lead to failure of a material using sensors that act like the material scientist's stethoscope. The acoustic emission testing technique uses either operational or applied loads to simulate emissions from the material to be tested. A single test system may be used for many different measurement applications by making suitable frequency adjustments. In order to interpret the results obtained from these tests, one should know the underlying physical process involving the propagation of the wave in test materials, techniques and equipment used in measurement, inherent material characteristics, and the possibility of background noises that may interfere in the acquisition of data [2].

A. *Basis of Acoustic emission*

AE sensors consist of piezoelectric crystals which are placed in casing for protection and attached using a simple acoustic coupling. The sensors are highly sensitive, operating in the kHz range, this sensitivity enables the detection of cracks long before they are visible [3]-[4]. The sensitivity of AE sensors along with their wide ranges of operation makes AE an ideal candidate for assessment of in-service structures. Sensors are available with a wide variety of sizes and different operation ranges.

Transient elastic waves emitted from the active souRCe traveling through the solid and those elastic waves are captured using piezoelectric sensors. These piezoelectric sensors coverts mechanical wave into electric signals and gets collected with a dedicated AE acquisition system, which is shown in Fig. 1.

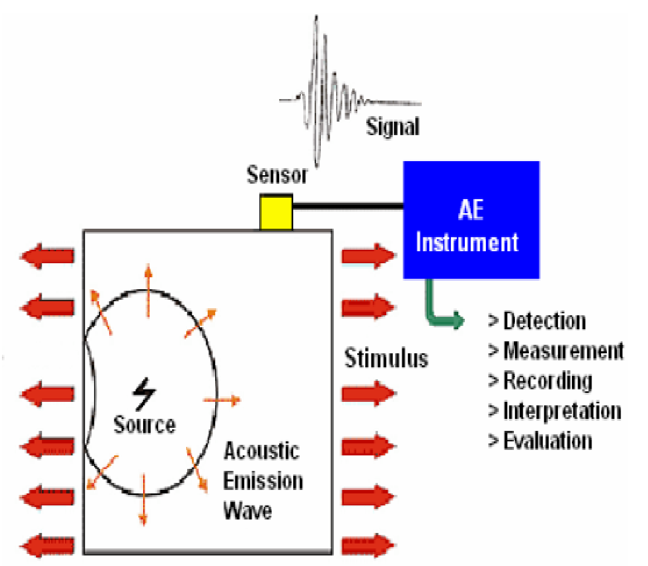

Fig. 1: concept of ae technology [5]

The emitted transient elastic waves are typically short pulses that depend on the dynamics of the souRCe. From sub microscopic dislocations to gross cracking, the energy and amplitude of the emissions change over a wide range.

Advantages of AE over other NDT

- Measurements can be done in real time.
- Use of multiple sensors can aid in finding the location of defect.
- Detailed analysis of signal will brought differentiation between genuine defects and noises.
- AE technique can be used for local, global and continuous monitoring.
- AE technique is less geometric sensitive.

III. AE ANALYSIS TECHNIQUE

a. *Intensity signal analysis*

Intensity signal analysis (isa) is another technique for evaluating the structural implications of damage identified through analysis of AE signals and is used to maintain the integrity of the structure. This technique involves an AE parameter known as signal strength. Mathematically, this is defined as the integral of the rectified voltage signal over the duration of the AE waveform packet [6]. It is an essential parameter in assessing the significance of AE data during the damage process.

Evaluation of isa involves the use of two indices; historical index (hi) and severity index (sr). Historical index is used to determine the change of signal strength rate throughout the test. Particularly, it measures the slope change in cumulative signal strength against time by comparing the signal strength of all hits. The historical index is calculated using the following expressions, equation (1) and (2).

$$HI = \frac{N}{N-K}\left(\frac{\sum_{i-k-1}^{N} Soi}{\sum_{i-1}^{N} Soi}\right) \qquad (1)$$

Where hi: historical index, n: number of hits data, s_{oi}: signal strength of the i^{th} hit, k: empirically derived constant based on the test material.
Severity index (sr) is defined as the average signal strength among the largest numerical value of signals. This is calculated as using the following equation [7].

$$Sr = \frac{1}{J}\left(\sum_{m-1}^{1} Som\right) \qquad (2)$$

Where Sr: Severity Index, J: Empirically Derived Constant Based On Material, S_{om}: Signal Strength Of The M^{th} Hit Where The order of m is based on magnitude of the signal strength. for concrete, k and j values are related to n by the relations: $K = 0, N \leq 50$; $K = N - 30, 51 \leq N \leq 200$; $K = 0.85N, 201 \leq N \leq 500$; $K = N - 75, N \geq 500$; $J = 0, N < 50$; $J = 50, N \geq 50$.

TABLE I : SIGNIFICANCE OF INTENSITY LEVELS [8]

Intensity levels	Recommended action
A	Insignificant acoustic emission. (No damage).
B	Note for reference in future tests. Typically minor surface defects such as corrosion, pitting, gouges or crack attachments. (damage detected)
C	Defects require evaluation. Evaluation may be based on further data analysis or complementary nondestructive examination. (minor damage)
D	Significant defect requires follow-up inspection. It consider as major damage. (major damage)
E	Major defect requires immediate shut-down and follow-up inspection. (severe damage)

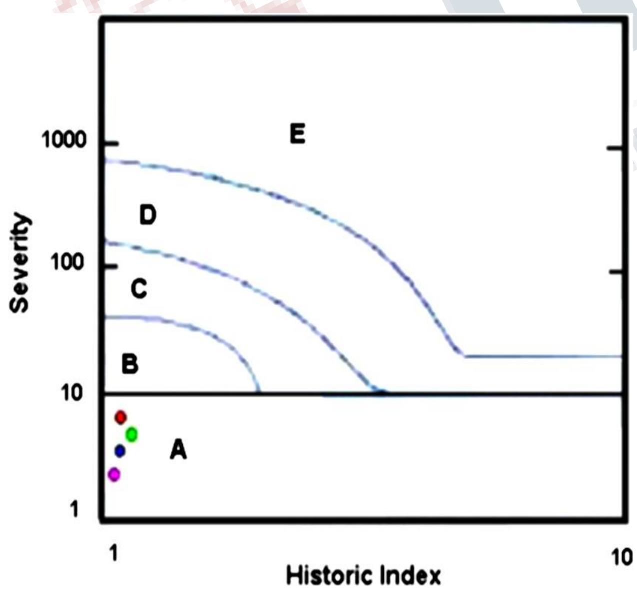

Fig. 2: example of intensity analysis chart [8]

This method is evaluated from the AE signal strength data which is collected by AE win software. Normally the isa method is based on the channel basis, however in this reseaRCh the data was collected from the critical area of the beams under test.

The severity and maximum historical index are plotted on the intensity chart as presented in fig. 2. The chart is divided into intensity zones which indicate the structural significance of the emission. The description of zones is presented in table I.

IV. METHODOLOGY

Tests were carried out on reinfoRCed concrete (RC) beams of dimension 150x250x800mm and designed in accordance with Indian standard (IS 456:2000) code for grade M35. The mix design used for M35 grade concrete was 1: 1.654: 2.870 with water cement ratio 0.58. The beams are reinfoRCed with two 16 mm diameter high yield strength steel bars of grade Fe 500 with 50 mm cover from the both sides as well as from bottom.

The compressive strength of the cubes at 7 and 28 days of age was found to be 25.6 MPA and 36 MPA respectively. Three specimens were casted with uncorroded and corroded REBARS for each set. After demolding at the age of 1 day, specimens were cured for 7 days.

V. EXPERIMENTAL SETUP

a. *Accelerated corrosion set up*

In order to provide relevant results within a realistic period of time, corrosion process is being accelerated using an electrolytic cell. The electrolyte used is 5% NaCl solution, which represents marine environmental condition. The reinfoRCed bar is used as anode and mild steel mesh is used as cathode. MS mesh is placed below the RCC beam and a wick is sandwiched in between RCC beam and MS steel mesh, which facilitates sufficient contact of electrolyte with the specimen throughout the experiment. The external driven voltage (10 V) is applied using a direct current (DC) power supply. A PVC tank is used as the container for the electrolysis cell setup, as it is neutral to redox reactions. To prevent the corrosion of the protruded parts of rebar, exposed portions were coated with an epoxy resin. Accelerated corrosion process is controlled according to the level of corrosion with help of half-cell potential reading taken periodically throughout the experiment. Single AE sensor was mounted on the top of the beam as shown in the Fig. 7.1 using a clamp mechanism. High performance grease is used as the coupling agent in between sensor and aluminum sheet, and aluminum sheet with RCC beam. Aluminum sheet below sensor is used to avoid wear and tear of face material of sensor as the concrete surface generally appears to be rough. The AE threshold was set to 45 dB, which is to eliminate pore water peRColation noises and record only emissions due to corrosion activity and cracking of concrete. Sensor was calibrated before the test by employing lead breaking test (BS EN 1339). The exact location of sensors and experimental set up is shown in Fig. 3.

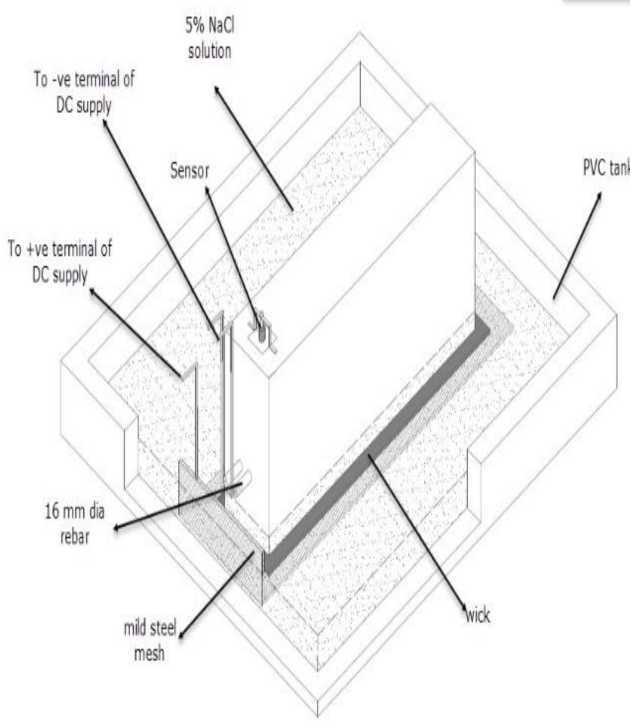

Fig. 3: accelerated corrosion set up

b. External loading set up

All the beams were tested under three point loading to examine the flexural behavior and level of damage using AE technique as shown in Fig. 4. Tests were conducted on universal testing machine having capacity of 1000 kN.

During the test the beams were simply supported with a span of 600mm. Single point load is applied at the center of the beam at a loading rate of 2 kN per minute. Beam is loaded up to failure and entire test is being monitored continuously with a dedicated AE acquisition system. Two sensors of type R3α were mounted on the top of the beam as shown in the Fig. 4 using a clamp mechanism with same procedure as explained in section V. The experimental set up is shown in Fig. 4.

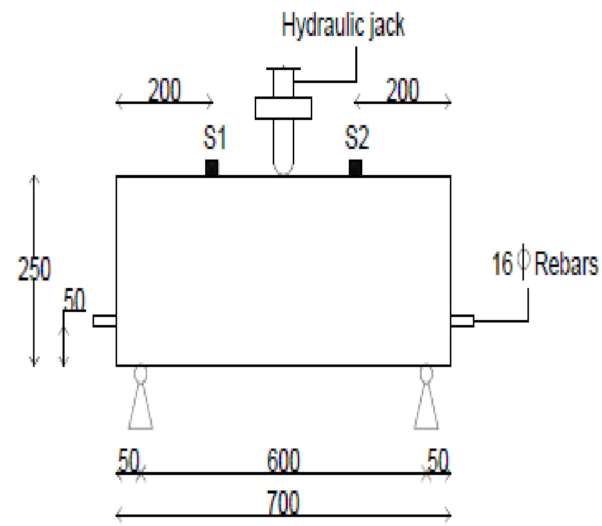

Fig. 4: external loading set up

VI. RESULTS AND DISCUSSIONS

Here experiments are done on two beams, one directly subjected to external loading and the other first subjected to accelerated corrosion to the severe level of corrosion and then subjected to external loading. On both cases AE activity is monitored continuously as explained on above section vii**.**

Signal strength is defined as the measured area of the rectified AE signal with units proportional to volt seconds (the proportionality constant is specified by the AE instrument manufacturer) [9]. AE amplitude is the highest peak captured from a particular wavelet captured by the instrument due to any sort of activity. This two parameters represents intensity of failure from AE perspective. Plot between AE parameters like signal strength and amplitude with respect to time for the beam with uncorroded and corroded rebars, during external loading is showed in Fig. 5 and 6 below.

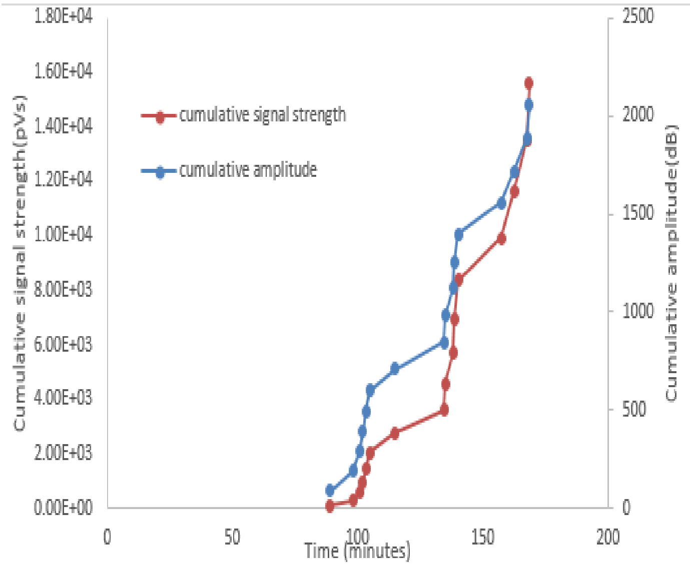

Fig. 5: plot of AE activity with time for beam with un corroded rebar during external loading.

From the fig. 5 it is clear that, for the beams with uncorroded rebar, AE activity is only observed at after some period of time. Once micro cracking starts in beam AE activity also initiates and start increasing with increase in load.

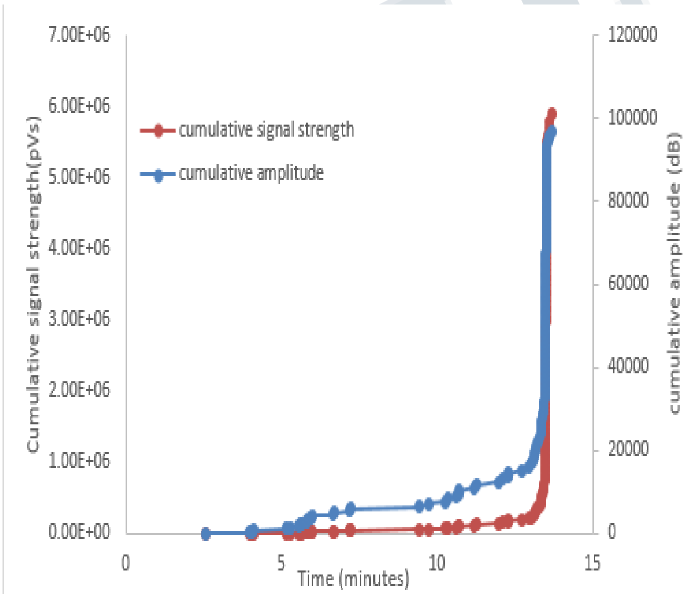

Fig. 6: plot of AE activity with time for beam with corroded rebar during external loading

For the beams with corroded rebar, micro cracks are already present in beam and these cracks propagates further with the increase in load. This phenomenal is captured on AE device as evident from fig. 6. AE activity increase as the load increases as shown in the fig. 6. Sudden increase in the AE activity indicates the failure of the beam.

VII. CONCLUSIONS

- For the beams with no corrosion AE activity only starts when the beam starts micro cracking, and as the cracking propagates AE activity also increase.
- For the beams with corrosion, AE activity starts with external loading because of the presence of micro cracks due to corrosion.
- Increase in the AE activity with respect to load represents crack propagation.
- Sudden increase in AE activity represents failure of the specimen.

Thus from the present study it can be concluded that, AE technique is effective in identifying flexural as well as corrosion behavior of RC specimens.

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