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Application of AE Based Mathematical Procedure for Identification of Corrosion in Reinforced Concrete Element

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***Abstract:* -- Corrosion is a major cause of degradation of reinforced concrete (RC) structures. Corrosion of steel rebar in concrete is an electrochemical process and it has been widely studied using various non-destructive techniques such as Half-cell potential, linear polarization resistance, electrochemical impedance spectroscopy etc. All these techniques cannot be called truly non-destructive technique as the instruments require physical and electrical contact with steel embedded in concrete. To overcome this difficulty, the research for finding the applicability of other non-destructive techniques such as ultrasonic pulse velocity, acoustic emission (AE) technique etc. for quantification of corrosion is going on. From the literature, it is found that AE technique is a powerful technique for identification as well as quantification of corrosion without having any physical or electrical contact with the reinforced steel. For corrosion quantification AE based mathematical model has been developed which can quantify the corrosion in small scale cylindrical RC specimens. Thus for commercial use of the developed mathematical model, it is necessary to check its applicability for the changed geometry of specimens. The present paper focuses on checking the applicability of developed mathematical model for a rectangular geometry of specimens. For the experimental work, RC slabs of dimensions 500 mm x 300 mm x 60 mm with single reinforcing steel bar were cast and subjected to accelerated corrosion. From the experimental results, it was found that the predicted mass loss values of corroded rebar using developed mathematical model are in agreement with that of the actual mass loss which indicated that AE based mathematical model can be successfully used for rectangular specimens.**

***Keywords*:- Corrosion, AE technique, RC Slab, Mathematical Model, CSS.**

I. INTRODUCTION

Reinforced Concrete structures are generally durable under moderate environmental conditions. However, failures in the reinforced concrete structures do still occur due to adverse effects of external as well as internal factors causing deterioration and subsequent loss in service life. One of the most important causes for deterioration of reinforced concrete structure is corrosion of steel reinforcement.[1] In tropical country like India, that has more than 3000km of coastline where approximately 80% of the annual rainfall takes place in the two monsoon months, corrosion related problems are alarming. The corrosion of steel reinforcement is an electrochemical process that requires a flow of electric current and several chemical reactions forming a galvanic corrosion and it is manifested by loss of structural serviceability characterized by concrete cracking and delamination.

Thus corrosion is of great importance while considering the safety and durability of reinforced concrete structures. This problem has reached alarming proportions in the past three decades, leading to very high repair costs, sometimes above the initial construction cost or in extreme situations leading to the final collapse of the structure. Therefore for the early detection, the corrosion analysis by qualitatively as well as quantitatively is important.[2] In previous research works[3] researcher taken a cylindrical specimen with single rebar to develop AE based mathematical model for corrosion assessment as follows: Gravimetric mass loss = (1.407 x ln CSS) – 19.49 This mathematical model is applicable for fixed location of sensor on periphery of cylindrical specimen and concluded most effective. When we tried to apply mathematical model for assessment of corrosion practically it should be applicable for any geometry. Present work deals with the application of developed mathematical model for the assessment of corrosion in changed geometry of the RC element like single bar embedded in Rectangular specimen (i.e RC Slab specimen) and checking applicability of mathematical model.

Acoustic Emission Technique

Acoustic emission (AE) is the phenomenon of radiation of acoustic (elastic) waves in solids that occurs when a material undergoes irreversible changes in its internal structure, for example as a result of crack formation or plastic deformation due to aging, temperature gradients or external mechanical forces. In particular, AE is occurring during the processes of mechanical loading of materials and structures accompanied by structural changes that generate local sources of elastic waves. This result in small surface displacements of a material produced by elastic or stress waves generated when the accumulated elastic energy in a material or on its surface is released rapidly. The waves generated by sources of AE are of practical interest in the field of structural health monitoring (SHM), quality control, system feedback, process monitoring and others. In SHM applications,[4] AE is typically used to detect, locate and characterize damage. The mechanical waves generated by the defect structure detected by the key instrument i.e sensor (Piezoelectric Resonant Sensor) and convert them into electrical AE signals. The preamplifier filters the AE signals from external noise area outside the sensor operating range. Modem AE systems use computers and appropriate software for data acquiring.[5] All the AE signals received at sensor end are acquired and stored in acquisition system as shown in fig.1 below:

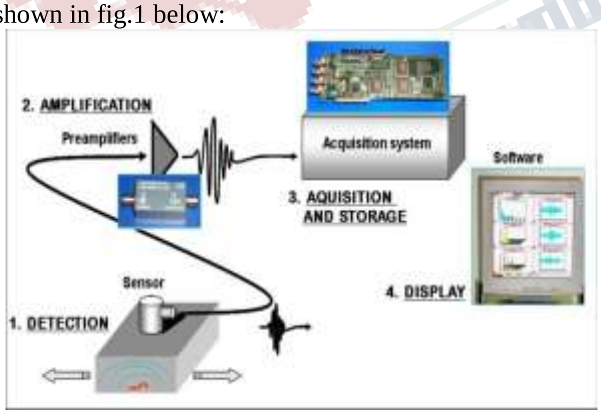

Fig.1: Acoustic Emission Data Acquisition System.[6]

A typical AE-signal (or wave) which includes AE duration, rise time, AE amplitude, AE energy, counts, hit etc are shown in Fig. 2.

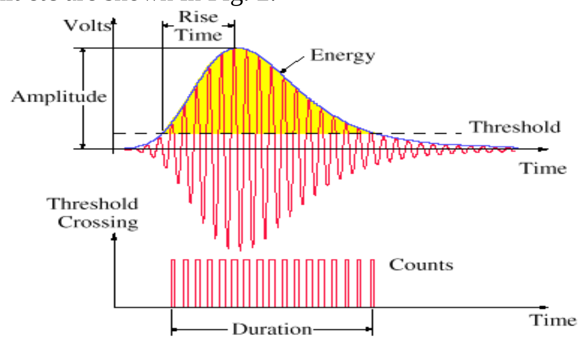

Fig.2: AE Signal Parameter [7]

In this work main focus is on the parameter Cumulative of Signal Strength (CSS) which is defined as the measured area of the rectified AE signal with units proportional to volt-sec.

II. METHODOLOGY

Materials and Mix Proportion:

For the present work the material of M20 grade of concrete was prepared using 53 grade Ordinary Portland Cement (OPC), natural river sand confirming to zone II as per IS:383-2002 as fine aggregates and coarse aggregate of nominal size 10mm. The specific gravity of fine and coarse aggregates were 2.67 and 2.46 respectively. The water absorption for coarse aggregate was 2.15% while moisture content for fine aggregate was 1.9%. The ratio of cement: sand: coarse aggregate was 1:2.59:2.1 with water-cement ratio of 0.5. 150mm size cubes were cast to measure the compressive strength of the mix designed. The cubes were cured for a period of 28 days at the temperature of 27±2ºC and relative humidity 100%. The average compressive strength of the cubes at 28 days of curing was measured on 2000 KN capacity compression testing machine and was obtained to be 22Mpa.

Preparation of specimen and Casting: Rectangular Slab specimen with dimensions of 300mm X 500mm X 60mm were cast with single bar of diameter of 20mm embedded in it with clear cover of 20mm at both direction as shown in fig.3 as below:

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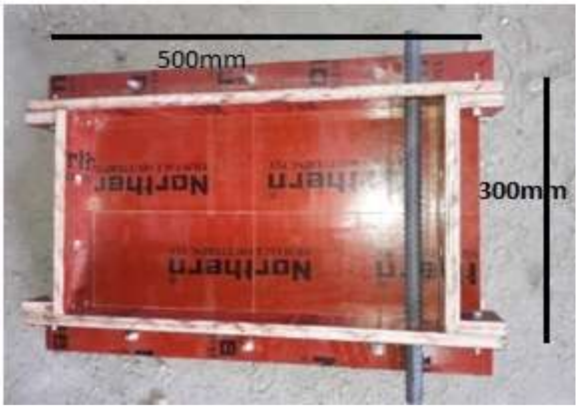

Fig.3: Mould for RC Slab Specimen

Before casting of the RC slab specimen, weight of the steel bar is taken for the further calculation of Actual Gravimetric mass loss and then after the steel bar is coated with Epoxy resin on the exposed portion of steel bar which is not embedded in the concrete to avoid direct corrosion. Application of Epoxy resin is done at both end of the steel bar. At one end of the bar, 20mm length is kept without application of epoxy for achieving electrical connections and then next 130mm length of bar is coated with epoxy. At other end epoxy coating for 150 mm was provided from the end of the bar. Finally again the weight of the steel bar with epoxy coating is taken for the further calculation.

Accelerated corrosion Technique:

The objective of inducing corrosion to the reinforcing bar is to simulate the corrosion damaged concrete. The quickest method of inducing corrosion is by impressing anodic current.[8] In this method, the specimen is immersed in 5% NaCl solution and direct current of 6V is passed making the reinforcement bar as an anode and another metal i.e. stainless steel mesh as cathode which is placed below the RC slab specimen in the NaCl solution.

Experimental Setup:

For the entire experimental work, the other parameters like method of accelerated corrosion, test period etc. are kept same as that of the previous research work [Patil et al. 2014].The details of experimental parameters of previous research work and present work are as shown in table 1

Table 1: Experimental parameters used in Previous and Present Research Work

Sr. No	Parameter and condition	Previous Research Work	Present work
1	Specimen geometry	Cylindrical (RC cylinders)	Rectangular (RC slabs)
2	Size of RC specimen	Diameter and height of cylinder 60 mm & 100 mm resp.	Slab dimensions 500 mm x 300 mm x 60 mm
3	No. of bars reinforced in concrete	1	1
4	Diameter and length of reinforced steel bar	20 mm and 105 mm resp.	20 mm and 500 mm resp.
5	Period of curing and NaCl saturation of specimens	28 days of Curing and one day for NaCl saturation	28 days of Curing and one day for NaCl saturation
6	Technique used for accelerated corrosion	Impressed current technique	Impressed current technique
7	Testing period	15 days	15 days
8	Current applied by impressed current technique	3 volts	6 volts (for maintaining test period of 15 days as specimen size is large)

All the RC slab (i.e. 9 specimens) specimens were tested by using AE technique to check the applicability of developed mathematical model (for cylindrical specimen) for the corrosion assessment to changed geometry of RC element i.e. RC slab specimen. The key instrument i.e. sensor S1 is placed on the bar at 20mm cover on both the direction and another sensor S2 is placed at the centre point of the slab specimen as shown in the fig.4 below.

The experimental setup for AE testing of RC slab specimen is as follows:

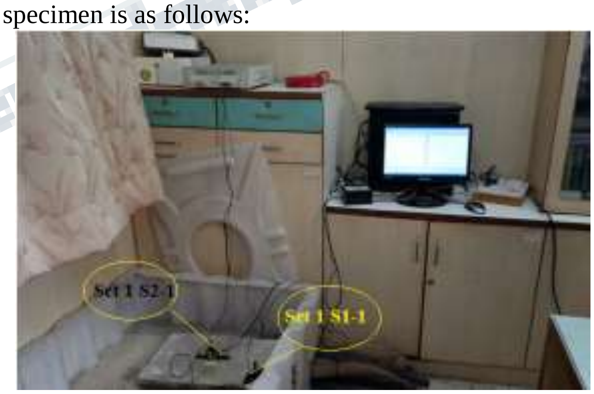

Fig.4: Experimental setup

III. RESULTS AND DISCUSSION

A). Actual Gravimetric mass loss:

For the calculation of actual gravimetric mass loss the weight of the corroded bar was taken after the all test is completed.

B) Gravimetric mass Loss by mathematical model

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Results of RC slab specimen having dimension of 300mm X 500mm X 60mm with single bar of 20mm diameter embedded in it is analyzed. From the AE data obtained, amplitude until failure (i.e. on 15th day of Testing) was recorded. From the output file of the data the signal strength at every time period among the sensor readings were chosen for the analysis and its cumulative value is taken for the calculation of corrosion rate by developed mathematical model as mentioned above. The cracks on the RC slab specimen are observed along the steel bar embedded in concrete on the above surface of slab specimen. Hence mass loss is calculated by mathematical model given in table 2 below for all specimens:

Gravimetric mass loss = (1.407 x ln CSS) – 19.49

Table 2: Results of AE testing of all specimens

Specimen No	CSS		Mass loss by mathematical model (gm)		Actual mass loss (gm)
	S1 (CH1)	S2 (CH2)	S1 (CH1)	S2 (CH2)	
Set 1					
1	$7.56*10^6$	$1.02*10^6$	2.4576	-0.2156	4
2	$5.28*10^6$	$2.71*10^7$	5.5292	4.5908	6
3	$3.73*10^6$	$1.09*10^7$	5.0403	3.3093	5
Set 2					
1	$1.53*10^7$	$1.35*10^7$	3.7864	3.6104	4
2	$2.18*10^7$	$1.74*10^7$	4.2846	3.9674	5
3	$9.08*10^6$	$5.36*10^7$	3.0523	2.3107	4
Set 3					
1	$8.95*10^7$	$5.00*10^7$	6.2717	5.4525	7
2	$3.85*10^7$	$1.69*10^7$	5.0848	3.9264	6
3	$6.33*10^7$	$5.68*10^6$	2.5447	2.3923	3

Graphs

After completion of testing, from the output data file of AE acquisition, the graph of Cumulative signal strength versus Time for both the sensor i.e. S1 and S2 is plotted as shown in fig.6 and 7.

From the graph of S1 and S2 it is observed that there is sudden increase in the value of CSS after 1st day of testing, it indicates that there is initiation of micro-crack in the RC slab specimen due to initiation of Corrosion in the RC slab specimen. The pattern of the graph is same as the pattern of graph in previous research work which is shown in fig.8. Simultaneously at the time of AE testing of RC slab specimen, on every day was taken the half cell potential readings at the center point of the specimen along the bar concrete surface of the slab for the result comparison of AE testing with electrochemical technique i.e. half cell potential technique.

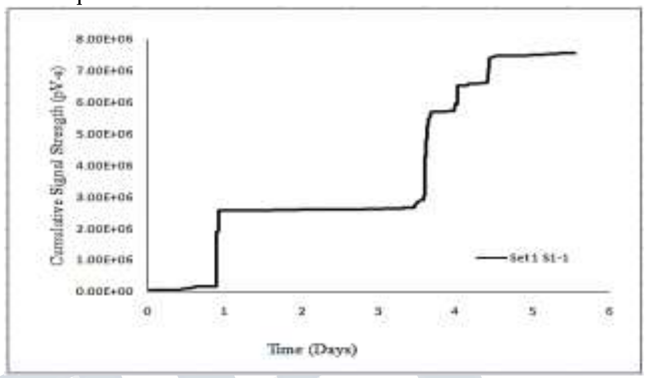

Fig.6: Variation of CSS with time for specimen Set 1-S1-1

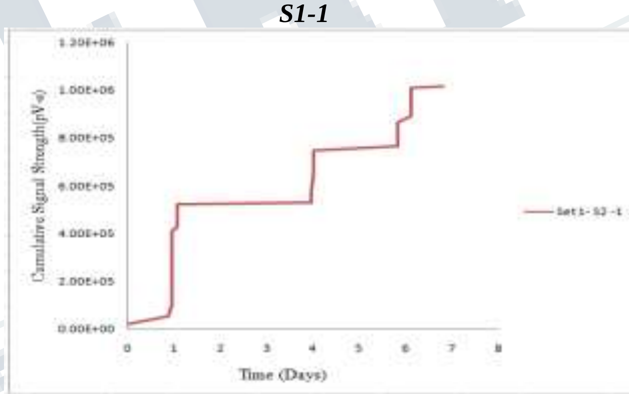

Fig.7: Variation of CSS with time for specimen Set 1-S2-1

Fig 8: Variation of CSS with time for cylindrical specimen used in previous research work

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The graph of half cell potential v/s time is plotted and it is compared with the graph of AE technique i.e. CSS v/s Time which is shown below in the fig.9 and fig.10

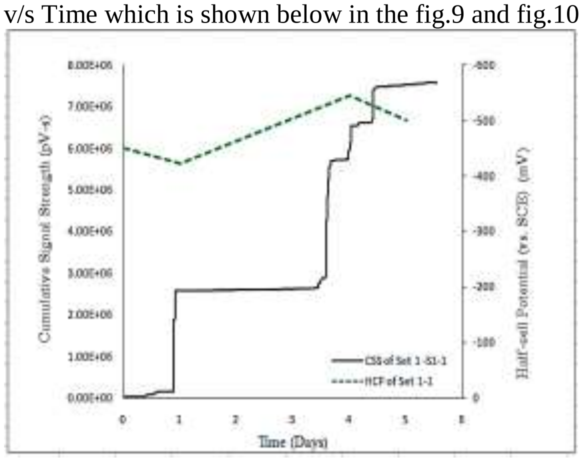

Fig.9: Variation of Half-Cell Potential and CSS with Time for Set 1-S1-1 recorded by Sensor 1

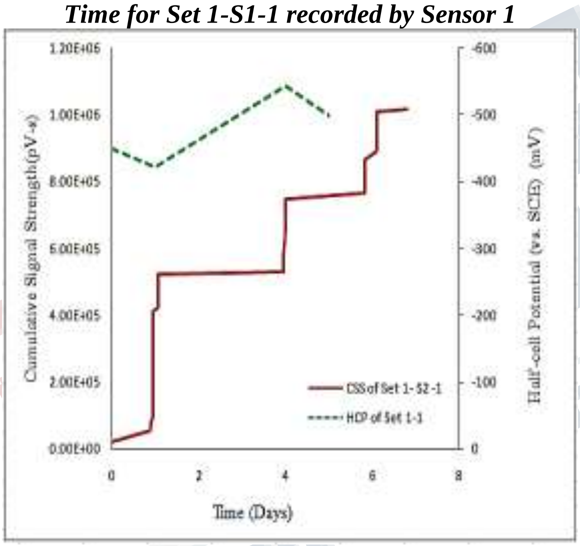

Fig.10: Variation of Half-Cell Potential and CSS with Time for Set 1-S2-1 recorded by Sensor 2

From the above graph it is observed that after 1st day of testing there is intermediate corrosion of steel rebar in the RC slab specimen which indicates the results are near about same as obtained by AE technique.

C). Visual observation

After1st day, oozing of corrosion products on the surface of slab in the form of brown stains were observed. Thus the results obtained from HCP and AE technique are in agreement with visual observation

IV. CONCLUSION

From the above results it can be seen that the results from HCP and AE technique are in agreement with visual observation and concluded that

1. The pattern of graph of CSS vs. Time for RC slab specimen is same as to the graph of CSS vs. Time in previous research work for RC cylindrical specimen i.e. CSS pattern can be applied for slab specimen.

2. Mass loss predicted by sensor one which is close to bar are in agreement with actual mass loss even after changing the geometry, thus mathematical model is applicable for slab specimen

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