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Deterioration of RC Beams Due To Reinforcement Corrosion

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Abstract— **Reinforced concrete structures have not been immune to the ravages of corrosion despite the protection that concrete provides to embedded steel. Since steel corrosion remains unnoticed inside the concrete, it further accelerates and can cause loss of life and property. This report discusses the results on deterioration caused to reinforced beams due to corrosion at different levels. Five RC beams (127 x 227 x 4100) mm were casted, four of which were corroded to different levels i.e. (6 days, 12 days,18 days & 28 days) by impressed current technique, while one remain as control beam. All four beams were visually inspected at the end of their respective corrosion period for the extent of damage in the RC beams, with the increase in age of corrosion. Each beam was tested under static four-point loading and corresponding loads and deflections were recorded. The results of this experiment clearly show that there is a decrease in load carrying capacity, deflection capacity and stiffness with the increase in age of corrosion. Most importantly it was noticed that as corrosion increased the failure mode of beams shifts from predictable ductile failure to brittle failure. After the destructive testing, reinforcement was retrieved from the beams by dismantling and then cleaned to find the mass loss. The results show that there was an increase in mass loss in the reinforcement with the increase in corrosion level.**

Index Terms— **Reinforced concrete, Corrosion, RC Beams, Concrete**
Sub Area : RCC
Broad Area : Civil Engineering

INTRODUCTION

Corrosion of reinforced concrete was first recognized early in the twentieth century, but it has become worse in recent years with the widespread use of de-icing salts on highways and bridge decks. The corrosion of steel reinforcement in concrete greatly reduces the loading carrying capacity, shortens the service life and increases the maintenance cost of the structure. Therefore, designing against corrosion of reinforcement in concrete should be of a great concern for materials and bridge engineers, reinforced concrete corrosion specialists and those concerned with the performance of reinforced and pre-stressed concrete bridges. It is known that the load-carrying capacity of reinforced concrete (RC) beams is reduced with increasing corrosion. As was mentioned earlier, the degree to which performance of reinforced concrete is damaged as a result of reinforcement corrosion is a matter of great concern to those responsible for assessing and maintaining the corroded RC structures. While considerable research effort has been dedicated to the mechanisms and causes of reinforcement corrosion and to researching the durability of repair materials, considerably lower attention has been dedicated to the problem of assessing the residual strength of the corroded structure. A detailed guidance on assessment of residual strength of corrosion-damaged RC structures will be of a great importance to number of practicing and practitioners. Therefore, comprehensive knowledge (that understands and quantifies the effect of reinforcement corrosion on structural behaviour) on the effect of corrosion on structural capacity and integrity is essential for the development of effective tools for the prediction of residual service life and for the development of cost effective repair strategies. This chapter will discuss the available information on the factors that cause and control corrosion of steel in concrete, as several metals will corrode under certain conditions when embedded in concrete. Factors influencing the electrochemical process are also discussed. Hence it is very important to detect the damages in the steel caused due to corrosion. So this chapter further includes information on ultrasonic technique as non-destructive technique to detect damages in the structures.

Experimental methodology

Five experimental beams of size (127 x 227 x 4100) mm were casted using M 20 grade concrete. Out of these five beams one was kept as control beam and other four beams were corroded at different levels (i.e. 6 days, 12 days, 18 days, and 28 days) using an accelerated technique. It was done by means of the impressed current technique. The successive deterioration in beams corroded to different levels was investigated using destructive (static four point loading) and non-destructive methods.

Beam corroded to 28 Days (C-28)

Beams undergoing corrosion for 28 days shows dark reddish brown corrosion products with reddish brown liquid oozes out from the cracks on all faces of the beam at centre 1.5m portion. Corrosion products formed in C-28 beam was in large volume than in other cases. At the top surface of C-28 beam continuous longitudinal crack was observed throughout the centre 1.5m portion of the beam as shown in Fig: 4.1. At the front side face also longitudinal crack was observed throughout the centre 1.5m portion along the tension bar as shown in Fig: 4.2. At the back side face small vertical and horizontal cracks were observed as shown in Fig: 4.3. At the bottom face of beam large corrosion products were noticed but no crack generated. It was noted that deterioration of C-28 beam due to corrosion was more than the other beams.

In this work, deterioration in RC beams subjected to varying degree of corrosion was studied by measuring the effect on load carrying capacity of beams, variation in crack pattern and effect on deflections under static four point loading. The different levels of corrosion were related to percent mass loss and change in ultrasonic signals with varying corrosion.

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Beam Corroded to 6 Days (C-6)

A beam undergoing accelerated corrosion for 6 days shows reddish brown patches of corrosion product on the all four sides of beam at centre 1.5m portion of beam as shown in Fig: 4.5 to 4.7. It was noted that no cracks was generated on surface of beam after 6 days corrosion. It was observed that 6 days corroded beam shows small corrosion products and no cracks as compared to other beams.

Beams corroded to 18 days (C-18)

Beam undergoing corrosion for 18 days shows reddish brown patches on four sides at centre 1.5m portion of the beam along with cracks on top and side faces. At the top of the C-18 beam longitudinal crack was observed with increased length and width than C-12 beam at centre as shown in Fig: 4.11. At the front side face of the beam vertical cracks were observed originating from tension face towards compression face as shown in Fig: 4.12. At the back side face of the beam it was observed that full centre 1.5m portion of the beam was covered with reddish brown patches, an increase in volume of corrosion product was observed in C-18 beam than in C-6 and C-12 beams and longitudinal crack was observed on the surface throughout the centre 1.5m portion of the beam as shown in Fig: 4.13. A reddish brown liquid oozes out from cracks on the back side face of the beam as shown in Fig: 4.14

Variations in Potential

The fluctuations in the voltage of the corrosion cell can be useful when comparing the corrosion of individual specimens. After 28 days of curing, each specimen (except for the control) was subjected to accelerated corrosion. The current and voltage that was supplied was monitored on a daily basis. Since the current was constant, the voltage was continuously regulated to compensate for the changing resistance. It was notice that the voltage had undergone an initial increase -within the first 24 hours, which was followed by a gradual decrease. Given that voltage is directly proportional to resistance -when current is constant (ie. a decrease in resistance would require a reduction in voltage), it can be concluded that there was mounting electrical resistance initially, followed by a progressive reduction. The average voltages during the accelerated corrosion for the beams connected in series were approximately 9.5volts during corrosion period and at initial stage voltage was 15.5 volts at constant current of 0.8A.

It is clear from these observations that there is an initial increase of resistance within the system, which is followed by a decreasing trend. This phenomenon can be attributed to the initial build up of corrosion products that occupy the pores of the concrete, thus blocking the movement of ions and increasing the electrical resistance. Eventually, the tensile stresses developed within the concrete caused by the expanding corrosion products crack the concrete, making a corridor for the transport of ions and escaping corrosion products, which results in the subsiding of resistance.

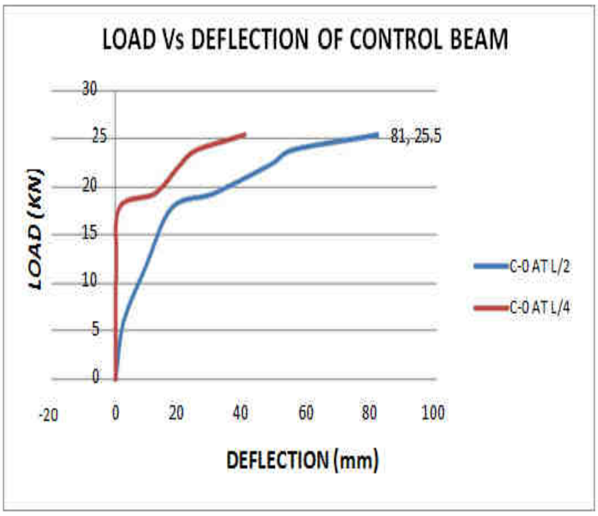

Fig: 4.16 Load-Deflection Curves of C-0 beam

Mass Loss Determination

Following the mechanical testing, the beams were dismantled with a jackhammer to retrieve the reinforcing steel. Once obtained, centre 1.5m corroded portion of cage was trimmed, cleaned to remove all corrosion products and concrete, and then weighed. The mass loss was then calculated relative to a predetermined benchmark called the control mass. Control mass was calculated for fresh uncorroded bars. The corroded reinforcing bars were characterized by percent mass loss (ML), which was calculated by **eq: 4.1** where *m* denotes mass and the subscript "i" represents the initial or reference mass and "cor" represents the residual mass.

$$ML = \frac{mi - mcor}{mi} X\ 100 \qquad \text{- eq. 4.1}$$

Where,

mi = Initial or Reference Mass
mcor = Residual mass

Fig: 4.34 clearly show that mass loss increases with the increases in corrosion level. It was noticed that beams corroded for 6 days, 12 days 18 days and 28 days has percent mass 11.20%, 18.27%, 21.89%, and 25.34% respectively.

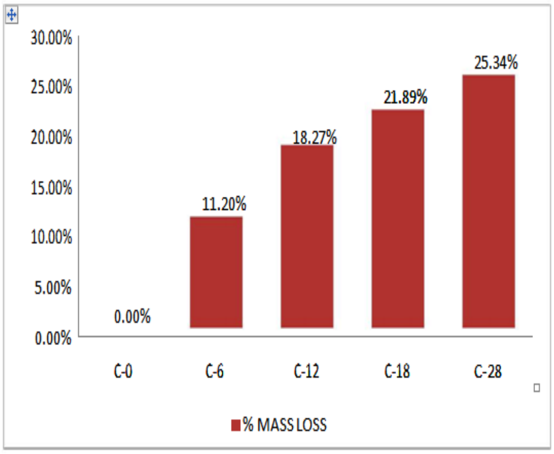

Fig: 4.34 Pe rcent Mass Loss in Bars corroded at different level

CONCLUSIONS

It was observed during ultrasonic testing on bars in air, that recorded signatures for pulse echo and pulse transmission shows a decrease in amplitude with the increase in age of corrosion. By studying the relative change in amplitude of the input pulse and transmitted pulse severity of damage can be calibrated.

By observing the peak to peak voltage trend of transmitted peak as shown in Fig: 4.41 to 4.42, it can be said that by increasing the age of corrosion from 0-days to 28-days, the magnitude of transmitted peak decreases. For the bars which are exposed to 28 days of corrosion, while taking P/E signatures and P/T, peak was observed but of very small. This is because as the damage in bars increased, more energy is reflected back and less of it travels through the bar to reach the other end. Hence, relative signal attenuation of the transmitted pulse can relate to the extent of the damage in the bar. Thus, peak-to-peak voltage amplitudes of reflected and transmitted peaks in pulse echo and transmission methods closely relate to the extent of damage.

This Experiments highlights the results obtained from the experiments done during the thesis work. It shows results of visual observations of RC beams subjected to different levels of corrosion and its effect on load deflection behavior when the RC beams were tested under static four point loading. From the results it was observed that there is decrease in ultimate load, deflection capacity, stiffness as the corrosion level increases. Mass loss determination was also done which show that percent mass loss increases with increase in corrosion level. Further ultrasonic testing on bars shows decrease in voltage amplitude with increase in age of corrosion. It shows that even 6-days corrosion can cause severe damages to the bars in RC structures.

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