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Deform Of RC Beams Due To Reinforcement Corrosion

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Abstract— Reinforced concrete has been used as essential materials in main load-carrying system of various structures in several countries. Reinforced concrete is recognized to be durable and capable of withstanding a variety of environment conditions. Nevertheless, failures of structures still do occur as a result of premature steel reinforcement corrosion. The corrosion of rebar in reinforced concrete, shown in Figure 1.1, deforms/deteriorates the strength of such a structure. The effects of corrosion is even more pronounced in flexural reinforced concrete member as nearly all of tension force is exerted on steel reinforcement.

Index Terms— Reinforced concrete(RC), Beams,Corrosion, Concrete
Sub Area: Construction Tech.& Mgmt.
Broad area: Civil Engineering

I. Introduction

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.

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Nondestructive testing (NDT) of civil engineering structures is a potentially valuable tool for monitoring the performance of new structures or detecting and evaluating deterioration in older structures. The inherent cost savings compared to existing destructive evaluation techniques are considerable. Currently, there are a large number of nondestructive testing techniques available for this monitoring and evaluation, though proper implementation procedures for these techniques must be developed. There is also a need to evaluate the various nondestructive testing techniques available to determine which are best suited for specific types of damage or even the absence of damage. Ultrasonic testing is a NDT method that is used to

It should be emphasized that the reinforcing steel is provided in reinforced concrete to resist the tensile forces, and to produce controlled cracking within that zone. However, corrosion not only deteriorates the steel bar and its function of transferring the tensile stresses, but it deteriorates the concrete by spalling of the cover. Therefore, corrosion of the reinforcement has a strong influence on the bond behavior at the interface between the steel reinforcement and concrete. As corrosion of the reinforcing steel progresses, the bond strength between the reinforcing steel and concrete diminishes progressively, and major repairs or replacement is needed. Reinforcement corrosion reduces the bond strength between steel and concrete, deteriorating the load carrying capacity of RC members. Therefore, it is very important to understand the mechanism of bond deterioration and to estimate the residual load carrying capacity of corroded RC beams.

Most national building codes aimed at ensuring that the structure being designed, constructed and operated would perform satisfactorily at the ultimate and the serviceability limit states. Therefore, a capacity reduction factor is used in the calculation of the resistance of the concrete structure for consideration of the variation of the material properties, member geometry and details, deficiencies in construction practice and quality control, and the normal variation in the applied loads. However, these considerations do not include the time-dependent behavior of loads and resistances of the concrete structures. For example, the load may change (the highway loading has increased significantly over the past several years), also, the resistance of a concrete structure will decrease due to aging of the material and the deterioration because of various environmental influences (such as corrosion of RC).

1.2 Corrosion in RC Structures

Corrosion of steel reinforcement is one of the main causes of deterioration of reinforced concrete structures. It is particularly prevalent in structures consistently exposed to aggressive environments, where deterioration often progresses at a rapid phase, resulting in severe damage to reinforcement and its surrounding concrete. While the most obvious effect of corrosion is a reduction in cross-sectional area of reinforcing bars, there are other associated effects caused by the buildup of corrosion products at the interface between the reinforcing and surrounding concrete. These corrosion products are expansive in nature and so induce radial pressures on the surrounding concrete resulting in cracking and spalling. Furthermore, the buildup of corrosion products affects the bonding between the steel reinforcing and surrounding concrete.

OBJECTIVES AND SCOPE OF WORK

The objective of this thesis is to study how progressive corrosion is detrimental to reinforced concrete beams. Specifically, the aim is to investigate both qualitatively and quantitatively the changes in flexural crack development, mode of failure and change in load-carrying capacity of RC beams under static loading subjected to corrosion at different levels. The deterioration levels are also assessed using non-destructive ultrasonic guided waves.

Parameters Studied

The following parameters are proposed to be measured.

- Deterioration of beams at different levels of corrosion by visual observation
- Static load-deflection behavior would be studied for beams at different levels of corrosion.
- Mass Loss of corroded beams at different levels will be measured.
- NDT of beams corroded to different levels will be studied using ultrasonic guided waves.

1.3.2 Equipments used

The equipment to be used for carrying out tests includes the following:

- Universal testing machine
- Loading frame
- LVDT for measuring deflections
- DPR 300 Pulser/Receiver for ultrasonic investigations
- PZT Cylindrical Transducers (12mm with frequency of 1MHz)
- PC with Aquiris DAC
- Constant Voltage Supply

1.3.3 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 **Effect of Corrosion on Structural Capacity**

There are three broad types of corrosion experienced by reinforcing bars namely, **Pitting**, **General** and **Macro-cell** corrosion. The factors governing these types of corrosion are discussed below.

- **Pitting corrosion**

Pitting corrosion is most likely to occur in concrete with good conductivity, a high content of alkali (i.e. non-carbonated) and a moderate level of chloride (or chloride reaching only isolated areas of the reinforcement). The chloride ion breaks down the passive film locally in those areas where the concentration is high or the passive film is weak. A localized corrosion cell is formed with adjacent areas of passive steel acting as a cathode, where oxygen is reduced, and the anodic dissolution of iron taking place only at the small central anode. Several factors then maintain or aggravate the development of the existing pit rather than to spread the corrosion or nucleate new pits. Acid is produced at the anode (pit site) due to hydrolysis reactions and alkali at the cathode due to the reduction of oxygen. Under the acid conditions present, the corrosion products formed 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. are soluble. Therefore, considerable amounts of corrosion can occur without spalling of the concrete. In pitting corrosion access of oxygen is the major factor in determining the total amount of corrosion. However, with the large cathode/anode area ratio, intense pitting can result even with limited oxygen supply.

Effectiveness of Impressed Current Technique to Simulate Corrosion of Steel Reinforcement in Concrete

Accelerated corrosion by means of the impressed current technique is widely used in concrete durability tests. The impressed current technique in accelerated corrosion studies is used so that tests can be completed within a reasonable amount of time. Corrosion is induced by applying an electrochemical potential between the reinforcing steel anode and cathode. The potential applied is varied, in order to achieve a constant applied current density. The majority of previous studies have used current densities that are from 3 to 100 times greater than the maximum current densities reported from field studies (Andrade et al. 1990, 1993; Broomfield 1997). The applied impressed current densities have typically ranged from 200 to 3,000 mA/cm2, with a maximum of 10,400 mA/cm2 (Almusallam et al. 1996b0 and a minimum of 45 mA/cm2 (Bonacci et al., 1998). A summary of some of the previous accelerated corrosion tests on reinforced-concrete members is presented in Table2.2. Although accelerated corrosion using an impressed current is typically used, there is little information in the literature on the influence of varying the current density level on the effects of reinforcement corrosion in concrete structures.

Table 3.2: Sieve analysis of fine aggregate

S. No.	Sieve No.	Mass Retained (g)	Percentage Retained	Percentage passing	Cumulative %age retained
1.	4.75 mm	1	.1	99.9	.1
2.	2.36 mm	21.5	2.15	97.75	2.25
3.	1.18 mm	204	20.4	77.35	22.65
4.	600 µm	190.5	19.05	58.3	41.7
5.	300 µm	298	29.8	28.5	71.5
6.	150 µm	225	22.5	6	94
7.	Pan	60	6	ΣF	**232**

Table 3.4: Sieve analysis of 10mm aggregates

S. No.	Sieve No.	Mass retained (kg)	Percentage retained	Percentage passing	Cumulative %age retained
1.	80 mm	-	0.00	100	0.00
2.	40 mm	-	0.00	100	0.00
3.	20 mm	-	0 .00	100	0.00
4.	10 mm	1.005	33.5	66.5	33.5
5.	4.75 mm	1.572	52.4	14.10	85.9
6.	Pan	0.423	14.1	ΣC	**119.4**

Fineness Modulus of Coarse aggregate (10 mm) = ΣC+500/100 = (119.4+500)/100 = 6.194

Physical Properties of Steel Bars

Sr. No.	Diameter Of bars/ mesh wire	Yield-strength (N/mm^2)	Ultimate strength	Percentage Elongation
1.	10mm	440.55	515.2	14.9
2.	8mm	555.5	638.23	22.5
3.	6mm	459.2	614.8	31.5

Concrete Mix

It was decided to use ***M20*** grade concrete mix design as per IS code method using the properties of materials as discussed above i.e. Table 3.1 to Table 3.6 the water-cement ratio used in the design is ***0.5***. The mix proportion of the concrete to be designed was calculated as***1:1.8:3.3*** (cement: sand: aggregate). Total six cubes of size (150 x 150) mm were casted for the compressive strength test of designed concrete mix. Three cubes very tested after seven days of curing and rest after 28 days and the average values were recorded at which concrete cubes break and compressive strength of materials after 7 days and 28 days comes out to be 16 and 28.5 KN/mm² respectively.

Casting of Composite Beams

The casting of beams was done in single stage. The beams were cast in mould of size 127 x 227 x 4100 mm. Entire beam mould is first oiled so that the beam can be easily removed from the mould after 24 hours. Spacers of size 25mm are used to provide uniform cover to the reinforcement. When the bars have been placed in position as per design, concrete mix is poured in the mould and the beam is vibrated using a needle vibrator, to ensure the proper compaction. The vibration is done until the mould is completely filled and there is no gap left. The beams are then removed from the mould after 48 hours. After demoulding the beams are cured for 28days using jute bags. Fig. 3.2 shows the beams before and after casting.

Fig. 3.2 Beams Before and After Casting

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.

- *eq. 4.1*

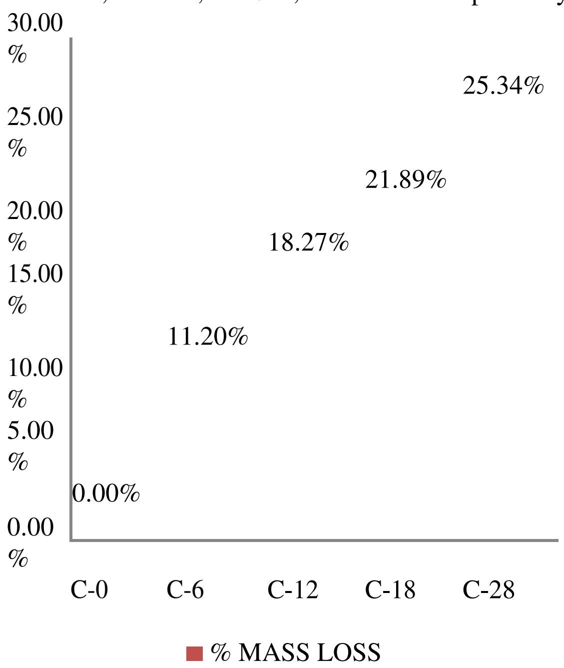
$$ML = \frac{mi - mcor}{mi} X 100$$

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.



Pe rcent Mass Loss in Bars corroded at different level

Ultrasonic Testing Results

After finding the percent mass loss of centre 1.5m portion of corroded area, the tension and compression bars were extracted from the corroded portion and trimmed to equal length of 500mm for ultrasonic testing. Extracted bars were visually observed for deterioration due to corrosion, and it was found that with the increase in exposure time of the beams to corrosion, damage to the bars increases, comparison of healthy bar with corroded bar is shown in Fig: 4.34 & 4.35. The extracted bars from the beam subjected to 28 days corrosion shows huge pits on its surface as shown in Fig: 4.36. The type of corrosion found in the more severely corroded bars can be classified as pitting.

After the visual observations of the extracted bars, they were tested both in pulse echo (P/E) and pulse transmission (P/T). As discussed earlier in P/E single transducers is used to send the pulse in the testing bar and same is used for receiving. And in P/T two transducers are used, one act as transmitter to send the pulse wave and other act as receiver. Both the transducers are used on the opposite ends of the bar which is to be tested.

CONCLUSIONS

- rom the reinforced concrete beams subjected to accelerated corrosion at different levels i.e. 6 days, 12 days, 18 days, & 28 days, all beams were visually inspected and it was observed that as exposure time of the beams to corrosion increases deterioration increases. Following results are observed:
- For C-6 Beam shows only reddish brown corrosion patches on the centre 1.5 m portion of beam which was intentionally corroded and which act as a cathode. No cracks were developed on the surface of the beam.
- For C-12 beam small cracks were seen on the surface of beam of smaller length and width and increase in volume of corrosion product was noticed.
- For C-18 beam, increase in length and width of crack was noticed and corrosion liquid of reddish brown colour was seen oozing out from the cracks.
- For C-28 beams, it was observed that the cracks has covered full longitudinal length at middle 1.5m portion of RC beam and corrosion products generated were of dark reddish brown colour of increased volume that other beam with lot of corrosion liquid oozes out from the cracks.

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