Study of RC Beams with Special Reference to Reinforcement Corrosion

Dr. Arvind Dewangan, Er. Rajnish Magotra, Dr. D.P.Gupta

Abstract— 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.

Index Terms— RC, Destructive, Non-Destructive, Concrete,Corrosion
Sub Area: Construction Technology & Mgmt.
Broad Area: Civil Engineering.

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.

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
- 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.

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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. 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 obtain the properties of materials by measuring the time of travel of stress waves through a solid medium. The time of travel of a stress wave can then be used to obtain the speed of sound or acoustic velocity of a given material. The acoustic velocity of the material can enable inspectors to make judgments as to the integrity of a structure.

Corrosion is one of the most, if not the most, pressing durability queries of RC . The following sections report on the fundamentals of some aspects of corrosion, including t he conditions that lead to corrosion and factors that influence the rate of corrosion, with the focus on corrosion initiated by chloride ions, as this was the mechanism used to initiate corrosion for the experimental.

Corrosion Mechanism

Corrosion is the process of the transformation of a metal to its "native" form, which is the natural ore state, often as oxides, chlorides or sulphates. This transformation occurs because the compounds such as the oxides "involve" less energy than pure metals, and hence they are more stable thermodynamically. The corrosion process does not take place directly but rather as a series of electrochemical reactions with the passage of an electric current. Corrosion also depends on the type and nature of the metal, the immediate environment, temperature and other related factors. The corrosion may be defined as the destructive attack of a metal by chemical or electrochemical reaction with its environment. Steel in concrete is normally immune from corrosion because of the high alkalinity of the concrete; the pH of the pore water can be greater than 12.5, which protects the embedded steel against corrosion. This alkalinity of concrete causes passivation of the embedded reinforcing bars. A microscopic oxide layer, which is the “passive” film, forms on the steel surface due to the high pH, which prevents the dissolution of iron. Furthermore, the concretes made using low water-cement ratios and good curing practices have a low permeability, which minimizes the penetration of the corrosion inducing ingredients. In addition, low permeability is believed to increase the electrical resistivity of the concrete to some degree which helps in reducing the rate of corrosion by retarding the flow of electrical currents within the concrete that accompany the electrochemical corrosion. Consequently, corrosion of the embedded steel requires the breakdown of its passivity.

Once the passive layer on the reinforcing steel has been disrupted and corrosion is activated, the chemical reactions are similar whether the corrosion was initiated by chloride attack or by carbonation. The principal cause of steel corrosion is the presence of chlorides during the preparation of the concrete. In several places close to shore, even sea sand is used as an aggregate. Some chemical admixtures, as accelerators, can contain high percentage of chlorides.

Test Program

The test program was planned as below.

1. Determinations of basic properties of constituent materials namely cement, sand, coarse aggregates and steel bars as per relevant Indian standard specifications.
2. Five real size beams (127 x 227 x 4100mm) were casted using M 20 grade concrete.
3. Initially, control beam was tested to failure to determine its P-Δ behavior and subsequently other beams are corroded at different levels.
4. Out of five beams, all the four beams were corroded at different levels using accelerated corrosion technique.
5. After the corrosion process was completed all the four beams were also tested under static loading, to relate the effect of varying corrosion with the load-deflection behavior of RC beams.
6. Levels of corrosion were ascertained b y calculating the mass loss of longitudinal reinforcement.
7. Degradation due to corrosion was also measured by non-destructive technique of ultrasonic’s.

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.

Mass Loss Determination

Following the structural and subsequent destructive tests, the reinforcement was removed from each beam by dismantling the beams using jack-hammer as shown in Fig: 3.9 and the corrosion products were cleaned using a wire brush. The corroded reinforcing bars were characterized by percent mass loss (ML), which was calculated by eq: 3.1 where *m* denotes mass and the subscript “mi” represents the initial or reference mass and“cor” represents the residual mass. The reference mass of reinforcement was measured using healthy bar. For residual mass calculations middle 1.5 m. portion of reinforcement was cut from the cage which was taken out after dismantling of corroded beams.

Visual Observations

Visual inspection refers to evaluation by means of eyesight, either directly or assisted in some way. The visual inspection of a structure is the “first line of defense” and typically involves the search for large-scale deficiencies and deformities.

As discussed earlier, initially one control beam was subjected to the accelerated corrosion until the longitudinal crack spread in the whole length of the beam, this took 28 days. And then the test matrix for the corrosion was further decided. So, rest three beams were subjected to 6 days, 12 days, & 18 days of corrosion representing different levels of corrosion. So results of visual observation are discussed in same order.
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. At the front side face also longitudinal crack was observed throughout the centre 1.5m portion along the tension bar. 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.

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. 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.

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 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.

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.

Figure:

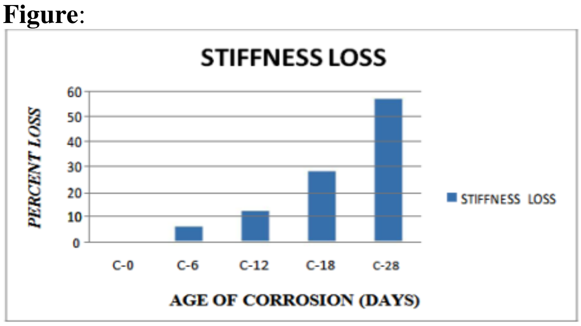

Fig: 4.33 % Loss of Stiffness Vs Age of corrosion

REFERENCES:

[1] Andrade, C., Alonso, M. C., and Gonzalez, J. A.,(1990). An initial effort to use the corrosion rate measurements for estimating rebar durability. *Corrosion rates of steel in concrete*, ASTM, West Conshohocken, Pa., 29–37.

[2] Almusallam, A. A., Al- Gahtani, A. S., Abdur Rauf Aziz, and Rasheeduz zafar. (1996b). Effect of reinforcement corrosion on bond strength. *Constr. Build. Mat.,* 10(2), 123– 129.

[3] Andrade C, Garcés P, Martínez I., (2008). Galvanic currents and corrosion rates of reinforcements measured in cells simulating different pitting areas caused bychloride attack in sodium hydroxide. Corrosion Sci;50:2959-64.

[4] A.A. Torres-Acosta, M.J. Fabela-Gallegos, A. Muñoz-Noval,D. Vázquez-Vega,J.R. Hernandez-Jimenez,and M. Martínez-Madrid., (2004). Influence of Corrosion on the Structural Stiffness of Reinforced Concrete Beams. Nace International.

[5] Aal H, Assem Adel A., (2003). Bond of reinforcement in concrete with different types of corroded bars. Theses and dissertations. Paper 133.

[6] Abdullah A. Almusallam., (2000). Effect of degree of corrosion on the properties of reinforcing steel bars. Department of Civil Engineering, King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia.

[7] Bonacci, J., et al.,(1998). Laboratory simulation of corrosion in reinforced concrete and repair with CFRP wraps. *Proc., Canadian Society of Civil Engineering Annual Conf.,* Canadian Society of Civil Engineering, Ottawa, IIIb, 653–662.

[8] Broomfield, J. P., (1997). Corrosion of steel in concrete: understanding, investigation, and repair, E&FN Spon, London.

[9] Ballim, Y., J.C. Reid., (2003). Reinforcement corrosion and the deflection of RC beams—an experimental critique of current test methods . School of Civil and Environmental Engineering, University of the Witwatersrand, Private Bag 3, WITS, 2050 Johannesburg, South Africa.

[10] El Maaddaway T, Soudki K., (2003). Effectiveness of impressed current technique to simulate corrosion of steel reinforcement in concrete . J Mater Civil Eng 2003; 15(1):41-7.

[11] G. Malumbela, Mark Alexander, Pilate Moyo., (2009). Steel corrosion on RC structures under sustained service loads -A critical review. Department of Civil Eng., University of Cape Town, Private Bag X3, Rondebosch, 7700, South Africa.

[12] G. Malumbela, P. Moyo & M. Alexander., (2009). Structural behaviour of beams under simultaneous load and steel corrosion. University of Cape Town, South Africa.

[13] Iyer, S., (2002). Evaluation of ultrasonic C-scan imaging to detect corrosion and voids in post-tensioning tendons. M.S. Thesis, The Pennsylvania State University.

[14] Joyce, T. A. (2008). The Effects of Steel Reinforcement Corrosion on The Flexural Capacity and Stiffness of Reinforced Concrete Beams. MASc Thesis, Ryerson University, Toronto.

[15] Jones, R., S. Pitt, M. Tan, C. Wallbrink, W.K. Chiu., (2006). Interaction of ultrasonic waves with structural damage: A diffraction analogy.

[16] Kivell, A. Palermo and A. Scott., (2011). Effects of Bond Deterioration due to Corrosion in Reinforced Concrete. Department of Civil and Natural Resources Engineering, University of Canterbury, Christchurch, 8140, New Zealand.

[17] Smith, Roger W., (2007). The effects of corrosion on the performance of reinforced concrete beams. Master Thesis. Toronto, Canada, Paper 149.
[18] Torres-Acost, A. A., Navarro-Gutierrez, S., and Terán-Guillén, J. (2007). Residual flexure capacity of corroded reinforced concrete beams. Engineering Structures, Vol. 29, No. 6, pp. 1145-1152.
(www.googleimages.com)

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