International Journal of Scientific & Engineering Research, Volume 4, Issue 5, May 2013
ISSN 2229-5518

Effect of Corrosion on Load Deflection Behaviour of OPC concrete in NBS Beam

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Abstract— Problems of corrosion have always been a matter of serious concern for structural engineers. The problems of corrosion are widespread all over the globe. Expansive corrosion products provoke cracks along the reinforcement, and subsequently, spalling of the concrete cover occurs. loss of bond-strength may lead to reduction in load bearing capacity.This paper aims to quantify the experimental investigation on load carrying capacity and center deflection behavior under different degree of corrosion levels on Ordinary Portland Cement (OPC) in NBS beam specimen.

Index Terms—Bond Strength, Corrosion, Deflection, Flexural Behavior, Load, OPC, Reinforcement Bar.

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1 INTRODUCTION

FLEXURAL strength is a measure of resistance against failure in bending. Although the probability of structures being flexure deficient is low, one of the factors by which failure can occur due to reduction or total loss of rebar area causing the corrosion in service environments.

Quality concrete is an utmost environment for embedded rebars, but the increased use of chlorides and carbon dioxide are result into corrosion of rebar. Corrosion is one of the important factors that reduces the cross-sectional area of the steel, thereby reducing the load carrying capacity, bond strength and spalling of concrete and induces brittle failure of structure without prior warning. Hence, these effects of corrosion need to be studied for better performance of structures.

When steel corrosion develops, the corrosion products first accumulate at the bar surface and try to fill the closest voids. Then they spread throughout the material and mix with the hydrated products of cement [1], [2], [3]. Once the threshold value of chloride content at the reinforcement reaches, then accumulates in the concrete –steel interfacial zone, generate unrestrained pressure on the surrounding concrete, and cause crack initiation and propagation [4]. Longitudinal cracks may affect the load bearing capacity of the structural elements presenting this distress, and in consequence may shorten their service life, in addition to opening a path for a quicker arrival of aggressive elements to the environment [5].

1.1 Time-Dependent States of Reinforcement Corrosion

The status of corrosion of steel in concrete may be predictable to change as a function of time. Corrosion process has three distinct stages, namely; depassivation, propagation, and final state, as shown in Fig. 1. Depassivation is the loss of thin film passive layer over the rebar, which is initially formed due to the high alkalinity of concrete. The process of depassivation takes an initiation period, t_p, which is the time from construction to the time of initiation of corrosion (depassivation). It had been noted that the initiation and propagation of corrosion in the specimens depend on many factors; the important among them are given below [6]:

i. Permeability of the concrete matrix;
ii. Cover thickness;
iii. The electric current applied;
iv. Density of the solution used;
v. The environmental temperature.

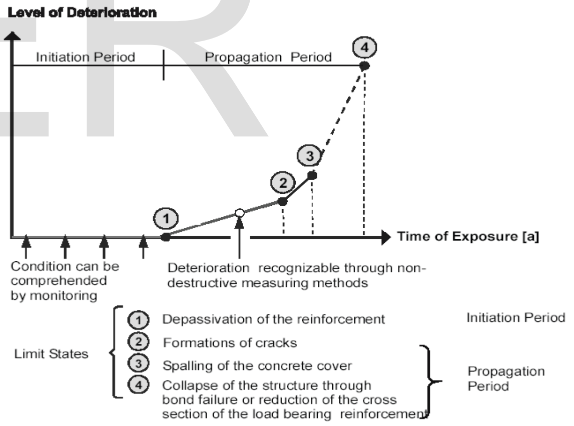

Fig. 1: Typical deterioration levels for a steel reinforced concrete structure suffering from corrosion [7].

The propagation phase starts from the time of depassivation, t_p, to the final state, is reached at a critical time, t_{cr}, at which corrosion would produce spalling of concrete cover or cracking through the whole of concrete cover.

During the propagation period, i.e. corrosion period, t_{cor}, which begins at the moment of depassivation, the rebar corrosion is usually assumed to be in a steady state, as indicated by a straight line in Fig. 1. The critical time, t_{cr}, as defined above can be expressed as:

$$t_{cr} = t_p + t_{cor} \qquad (1)$$

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For reinforced concrete, it has been assumed reasonable to equate the unacceptable corrosion damage to the onset of spalling of concrete cover. Therefore, the service life can be equated to the critical time, as given by equation (1). The depassivation time, t_p, can be assumed to be zero when the quantity of free chloride ions, introduced in concrete at the time of construction itself by any means, is found to be more than the rebar corrosion threshold value.

The corrosion of rebar in concrete is generally considered as an electrochemical process [8], [9], [10], [11]. With attention of researchers focusing towards the prediction of the residual life of reinforced concrete structures affected by reinforcement corrosion, the use of electrochemical techniques for the determination of relevant parameters in this regard becomes a major area of durability study. Therefore nowadays the electrochemical techniques are widely used for the study of rebar corrosion in laboratories together with their application to real life structures [12].

1.2 Effects of corrosion on the structural behavior

It has been already accentuate that corrosion of reinforcing bars produces effects on the structural behavior of RC members. This phenomenon involves due to the reduction in the bond strength of two composite materials i.e. steel and concrete. The effects of steel corrosion are mainly distinguishing between the "local" effects, i.e. at the RC member level, and the "global" effects, i.e. at the RC structure level. It is worth noting that, among the global consequences of corrosion on the structural performance, together with the decline of load carrying capacity and ductility, also the shift of the failure mechanism and detrimental torsion effects may occur [13].

2 EXPERIMENTAL PROCEDURES

2.1 Preparation of NBS Specimens

National bureau of Standard (NBS) beam specimens of size 2.15mx0.457mx0.203m were designed as an under reinforced section as per IS 456-2000 [14] for the present study. A total fifteen number of specimens were cast and a mass concreting was adopted for the huge specimens. TMT rebar of 25mm diameter bar was placed at a cover depth of 50mm from bottom and 12mm hanger rebar was provided at top and Side bars of 12mm with a stirrups of 8mm diameter as in Fig. 2.

Concrete mix for M_{30} Grade was prepared using Ordinary Portland cement concrete (OPC), fine sand and aggregate (20 & 12.5mm) as per IS 10262:2009 [15]. Mix proportion of 1: 1.77: 2.87 was used for the present study. Water cement ratio of 0.45, with an addition of 2ml/kg of a commercially available chemical admixture was used to get desired. Slump obtained was 58mm. Specimens were kept in water for 28 days of curing. Compressive strength of 34.44N/mm^2 achieved at the end of 28days.

2.2 Accelerated Corrosion Technique

The electrochemical corrosion technique was used to accelerate the corrosion of steel bars embedded in the beam specimens. Electrical wires were connected to the rebar at both the ends and it was left outside to impress current, at one end and monitoring of specimen at the other end. Specimens were immersed in a 5% NaC1 solution for 8 days. Current required to achieve different corrosion levels can be obtained using Faraday's law. The amount of current to be applied to obtain required corrosion levels of 2.5%, 5% and 7.5% and 10% are respectively 2.5A, 5A, 7.5A and 10A. For each trial, three specimens were considered. A photo of accelerated corrosion of beam specimen is shown in Fig. 3. After completion of accelerated corrosion the corrosion rate is monitored with applied corrosion monitoring instrument as in Fig. 4, based on Linear Polarization Resistance (LPR) method.

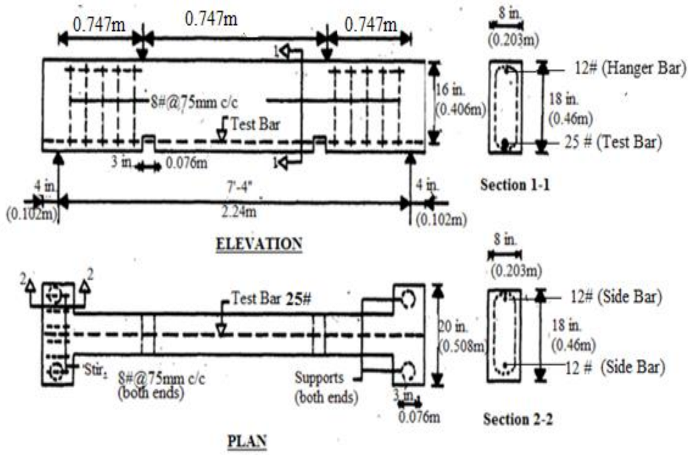

Fig. 2: Reinforcement details of beam specimen (NBS beam)

Fig. 3: A Photo of accelerated corrosion of beam specimen

The corrosion current density was calculated by using the Stern-Geary formula.

$$i_{corr} = \frac{B}{R_p} \tag{1}$$

where,

i_{corr} = corrosion current density (μA/cm^2)

R_p = polarization resistance (kΩ cm^2).

B = 26 mV (for steel in active condition this value is normally used).

Using Faraday's law, the corrosion rate in mm/year obtained from gravimetric measurement was converted to corrosion current density (μA/cm^2) by assuming uniform corrosion over the rebar surface by the following equation [16], [17], [18]:

$$Corrosion\ rate\ (mm/year) = \frac{0.0327 \times a \times i_{corr}}{n \times D} \qquad (2)$$

where,

a =atomic weight of iron, i.e. 55.84 amu

n = no. of electrons exchanged in corrosion reaction, i.e. 2 for iron and D =density of rebar (7.85g/cm^3).

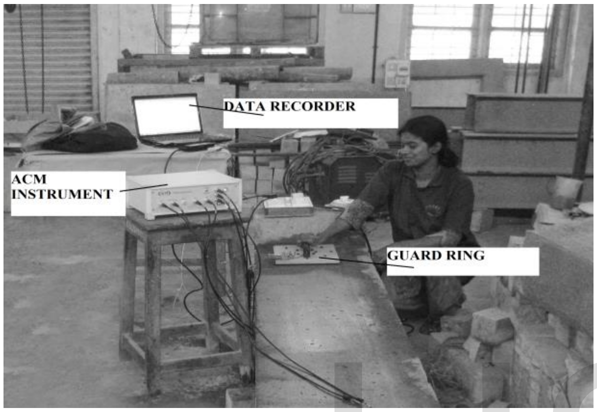

Fig. 4: Monitoring of Test Specimen

3 Test Setup

The beam specimens were tested under four point bending to determine load and deflection measurements. Dial gauges were fixed at the top side (two at load points and one at centre) to measure the deflection at each load increment. Proving ring of 50 tonnes capacity was used to note the applied load (Fig. 5 and Fig. 6). Pump of the hydraulic jack (50 tonne capacity) was operated by a hand lever.

In the present paper only central deflection behaviour with increase in the load for different degree of corrosion levels is calculated. Effect of corrosion on load -deflection curve is shown in Fig. 7.

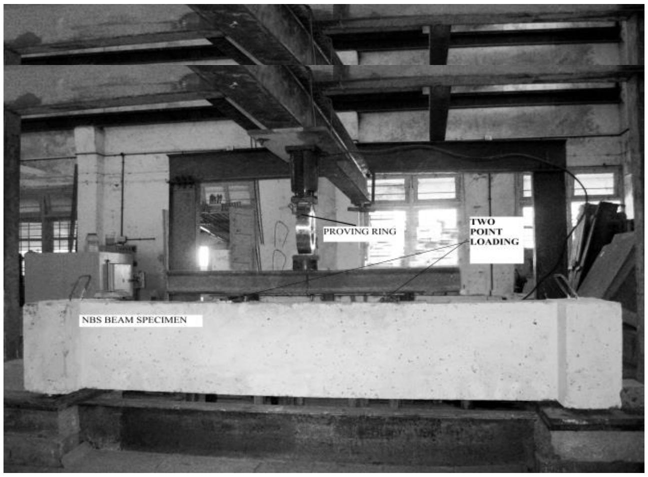

Fig. 5: Test set up of NBS beam Specimen

Fig. 6: Position of Dial gauges at centre and load points

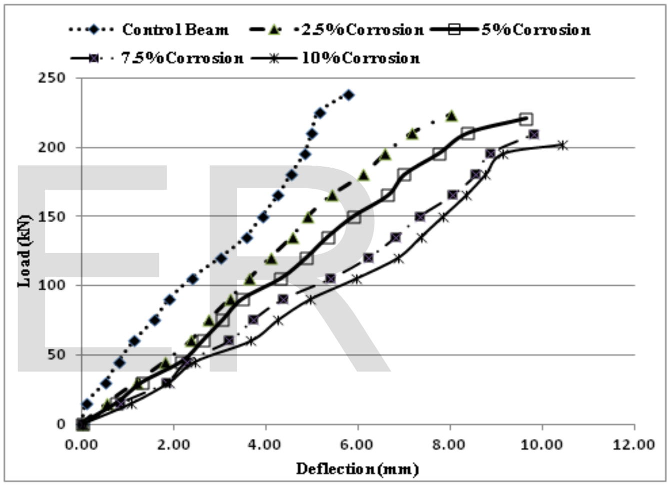

Fig.7: Effect of corrosion on load with central deflection curve

4 CONCLUSIONS

Beam specimens of different degree of corrosion levels such as 2.5%, 5% 7.5% and 10% beam respectively failed at 0.94, 0.92, 0.88 and 0.85 times than that of the control specimens. It is observed that as the corrosion level increases load carrying capacity decreases as well as the deflection increases. The explanation for this may be that, as steel reinforcement yielded, bond between reinforcement steel and concrete failed, and the deflection increased with higher corrosion percentage.

5. ACKNOWLEDGMENT

This research has been funded by the Board of Research in Nuclear Science (BRNS), Government of India.

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