

Residual flexural capacity of corroded reinforced concrete beams

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Abstract. Reduction in flexural capacity of reinforced concrete (RC) beams is observed due to the corrosion of reinforcement. Reduction in cross sectional area and continuity of the surface are the consequences of steel corrosion which results in the reduction of the tensile strength of steel and decrease the bond between steel and concrete. In this paper the effects of corrosion on flexural capacity of RC beam are investigated. Results revealed that reinforcement corrosion not only reduced the flexural capacity but also increased the deflections in RC beams. Bond failure at the level of reinforcement was also observed in the beams with reinforcement corrosion.

1. Introduction

Due to numerous advantages, reinforced concrete is the most versatile building material used by construction industry across the globe [1]. Generally, reinforced concrete is known to be very durable, but there are still a large number of failures of RC structures which have been reported due to premature reinforcement corrosion. Ingress of chlorides or carbonation of concrete result in depassivation of the reinforcing steel, resulting in rebar corrosion with significant loss of cross-section [2-5]. The corrosion of rebar in a RC beam is shown in Figure 1. Nearly all the tension in RC flexural member is carried by steel reinforcement; hence the effects of corrosion are more prominent in them [6]. The rebar corrosion reduces its cross-sectional area and produces local discontinuities on the steel surface. The capability of steel to carry tension is reduced in proportion directly to the loss of the steel area. Also, the loss of ribs on the steel surface reduces the bond between the steel and surrounded concrete [2-4]. Because of the above mentioned reasons, loss in ductility, stiffness and the flexural capacity of the beam may be observed.





Fig 1. Corrosion of rebar in a RC beam

2. Experimental program

The experimental program is consisting the following steps which are as follow

2.1 Fabrication and casting of beams

Four beams of 100 mm x 150 mm x 1200 mm size were casted with concrete having 28 day compressive strength of 30 MPa. Two, 8 mm steel bars with yield strength of 500 MPa were used as longitudinal reinforcement on tension as well as compression face. 6 mm stirrups with 100 mm c/c spacing were used as shear reinforcement to ensure flexure failure. After 24 hours of casting, the specimens were demoulded and shifted in curing tank for 28 days.

2.2 Corrosion of beam rebars

After curing, three beams were shifted to accelerate corrosion tank containing 5 % NaCl solution. To simulate corrosion, direct current was supplied to the reinforcement cages. The amount of current was decided through Faraday's law [2] using equation 1.

$$m = \frac{tAM}{nC} \quad (1)$$

Where m = mass loss in grams

t = time in seconds

A = current in amperes

M = molar mass of anode (stainless steel)

n = valancy number of ions of the substance (electrons transferred per ion).

C = Faradays constant = 96485 mol⁻¹

2.3 Testing of beams

Beams were tested in four point bending for the determination of flexural capacity. Load was increased at an interval of 2 kN and the corresponding deflection was measured through a dial gauge placed below the centre of the beam.

2.4 Determination of corrosion

After testing the beams in flexure they were broken and the reinforcing steel was washed using kerosene oil to remove loose rust particles from the steel.

All the three cages used in corrosive environment were weighed in order to calculate the actual mass lost in the corrosion process using equation 2.

$$\text{Corrosion} = \frac{W_1 - W_2}{W_1} \times 100\% \quad (2)$$

Where W_1 and W_2 are Weight of cage before and after corrosion respectively.

3. Results and discussion

3.1 Visual observations

The first indication of corrosion activity in reinforced concrete is staining of the surface (Fig.2), which is caused by water soluble corrosion products as those leach out with water through the capillary pores of the cover concrete. The corrosion products occupy a larger volume and these induce stresses in the cover concrete resulting in cracking, delamination and spalling (Fig.3). The corrosion product (rust) present at the interface between reinforcement and concrete reduces the bond between them; therefore bond failure was also observed (Fig.4).



Fig 2. Stains on the beam surface due to corrosion



Fig 3. Cracking of concrete due to corrosion products (horizontal cracks)



Fig 4. Bond failure due to corrosion

3.2 Flexural capacity of RC beams

Corrosion and ultimate flexural capacity obtained for each beam is given in Table 1. Maximum load was carried by control beam (B1). Corrosion reduced the ultimate load carrying capacity of RC beams. Minimum load carrying capacity was found for the beam with 8.9% corrosion.

Table 1. Corrosion and flexure capacity of beams

Beam	Corrosion (%)	Load (kN)	Reduction in flexural capacity (%)
B1	0	28.5	0
B2	2.4	26.0	8.77
B3	2.75	25.9	9.13
B4	8.9	23.5	17.55

3.3 Load-deflection behaviour of beams

Fig.2 shows the load-deflection curves obtained for different beams. Stiffness of a beam may be defined as the slope of load-deflection curve [7]. For B2 and B3, stiffness was found to be unaffected upto 30% of the flexural capacity of the member. When the load was increased above 30% of the flexural capacity, stiffness for both the beams was found to be reduced by 10%. For B4, stiffness was found to be reduced at initial load levels. At 10% of the flexural capacity, stiffness for B4 was found to be reduced by 25%.

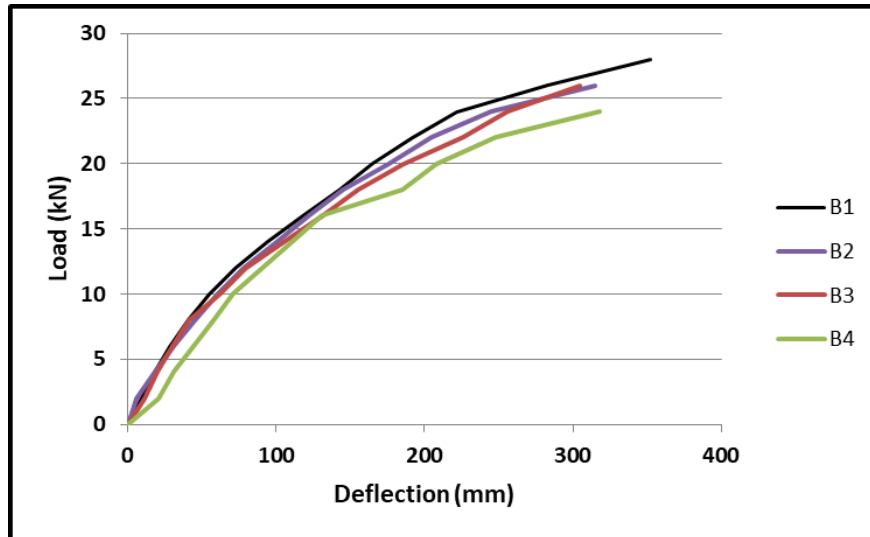


Fig 5. Load-deflection curves for beams

4. Analytical Results

Ultimate moment capacities of the tested beams were calculate using the provisions of IS: 456-2000 [8]. For corroded beams residual yield strength was calculated by using the model (equation 3) given by Lee and Cho, 2009 [9].

$$f_{yr} = (1 - 1.98 \times \Delta w) \times f_y \quad (3)$$

Where, f_{yr} = residual tensile strength of steel after Δw corrosion

Moment capacity = $T \times z$

For B1, Ultimate load carrying capacity = 28 kN (using $f_y = 500$ MPa)

For B2, i.e. $\Delta w = 2.4\%$, $f_{yr} = 475$ MPa, Ultimate load carrying capacity = 26.8 kN

For B3, i.e. $\Delta w = 2.75\%$, $f_{yr} = 475$ MPa, Ultimate load carrying capacity = 26.5 kN

For B4, i.e. $\Delta w = 8.9\%$, $f_{yr} = 411.9$ MPa, Ultimate load carrying capacity = 23.18 kN

Experimental and analytical results of the ultimate load capacity of the beams are plotted in Fig.6. All the experimental results are in good agreement with the analytical results when calculated by using the provisions of IS: 45-2000 and residual yield strength of bars calculate by using the model of Lee and Cho [9].

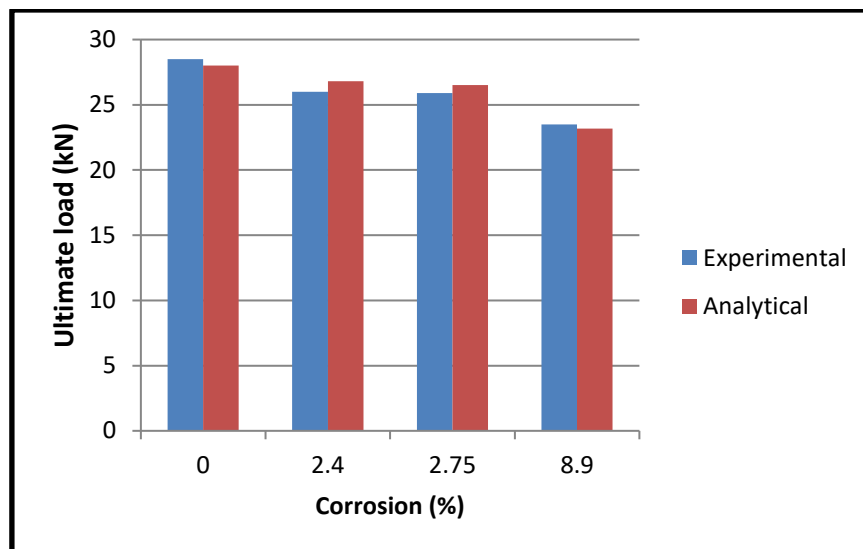


Fig 6. Ultimate load carried by beams at different corrosion level

5. Conclusions

From the present study, the following conclusion are drawn

1. Corrosion activity in a reinforced concrete member can be identified by visual observations like staining of concrete surface, cracks running parallel to the reinforcement.
2. Small amount of corrosion (upto 2.75%) did not reduce the stiffness of the member upto 30% of the ultimate load carrying capacity. Reduction in stiffness was found beyond this limit.
3. Stiffness of the member was found to be reduced at all the stages for 8.9% of corrosion.
4. Flexural capacity of the members was found to be reduced after corrosion.
5. Flexural capacity of corroded reinforced concrete beams can be precisely calculated by the provisions of IS: 456-2000.

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