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Effect of Corrosion Damage on the Ductility Performance of Concrete Columns

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Abstract: Problem statement: An experimental investigation was carried out on reinforced concrete columns with corroding reinforcement to assess the residual strength and ductility performance of columns. **Approach:** An accelerated corrosion regime of different degrees of corrosion damage of 10 and 25% were induced in the steel reinforcement of concrete columns. The columns were then tested under uni-axial compression until failure. **Results:** The results showed a marked reduction in axial strength and ductility of the corroded concrete columns. **Conclusion/Recommendations:** The increase in corrosion intensity decreased the axial load carrying capacity of the columns and hence reduction in ductility of the corroded columns.

Key words: Axial loads, corrosion, ductility, RC columns, residual strength

INTRODUCTION

Corrosion of reinforcing steel is widely accepted as the primary cause of premature deterioration in Reinforced Concrete (RC) structures. Predominantly, with the extensive use of de-icing salt in cold weather regions, bridge decks and bridge piers are vulnerable to corrosion of steel reinforcement[3]. The high alkaline environment of good quality concrete forms a passive film on the surface of the embedded steel that normally prevents the steel from further corroding. However, under the influence of chloride and carbonation, the passive film is disrupted or destroyed and the steel corrodes. The corrosion products occupy a larger volume and these induce stresses in the cover concrete resulting in cracking, delamination and spalling. In addition to loss of cover concrete, a RC member may undergo structural damage due to loss of bond between steel and concrete and loss of rebar cross-sectional area. To plan repair strategy for damaged structures, the strength of the existing structures needs to be estimated. The past research addressed on the flexural behavior of corrosion damaged concrete members[5,7,8]. They indicated that load carrying capacity and ductility decreased as the reinforcing steel bars were corroded. Relatively limited literature exists on the axial behavior of corrosion damaged reinforced concrete columns. Uornoto[12] studied the effects of corrosion damage on the load bearing capacity of reinforced concrete columns. He reported that the bearing capacities of corroded columns was not simply caused by reductions in strength or effective areas of the reinforcing bars but also by cracks formed during the corrosion process. Tapan[1] proposed a bridge pier column strength evaluation method that can be adapted into a currently used bridge condition evaluation method. The proposed evaluation method provided a good estimate of the condition and load-carrying capacity of bridge piers that currently cannot be obtained by normal visual surveys. The research studies[2,4,6,9,11] also showed the influence of corrosion on bond characteristics between steel and concrete. They demonstrated that loss of bond increased with sectional loss.

Research significance: For assessing the condition of corrosion-damaged structures, the remaining service life of such structures is to be estimated. For this purpose, the effects of maintenance and repair options on their service life are to be determined. To meet this objective, the present study is focused on the residual strength and ductility of reinforced concrete columns that were subjected to different degrees of corrosion damage.

Experimental studies:

Test specimen: The specimens considered in this test program were subjected to 10 and 25% degrees of corrosion damage. The specimens used in this study were the control specimen (NC CON) and corrosion-damaged specimens (CD 10 CON and CD 25 CON). All the specimens were then tested for their behavior under uni-axial compression test.

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MATERIALS AND METHODS

Concrete, Steel: The specimens were 150 mm in diameter and 900 mm in height. The specimens were cast with a concrete of strength 63.24 MPa. The material properties of concrete mixture are shown in Table 1.

The specimens were provided with six bars of 8 mm diameter as longitudinal reinforcement. Each specimen also contained 6 mm diameter stirrups with a spacing of 115 mm c/c. The specimens were cast in an asbestos pipe mould of internal diameter 150 mm as shown in Fig. 1. The longitudinal bars were kept protruded from the column face to accommodate the electrical connections for accelerated corrosion.

Accelerated corrosion testing: Column specimens (except control column NC CON) were subjected to accelerated corrosion condition.

The columns were kept immersed in 3.5% NaCl solution in a high-density polyethylene tank. The columns were immersed for a day to ensure full saturation condition. The direction of the current was arranged so that the reinforcement cage served as the anode while a stainless steel perforated cylinders acted as counter electrode. The accelerated corrosion process was achieved by applying a power supply with an output of 32 V and 11 amps. High voltage was used to accelerate the corrosion and shorten the test period.

Table 1: Concrete ingredients

Material	Quantity in Kg m^{-3}
Cement	450
Coarse (20 mm)	680
Aggregate (10 mm)	450
River sand	780
Super plasticizer-glenium B233	0.8% by weight of binder
Silica fume	25
Water	160

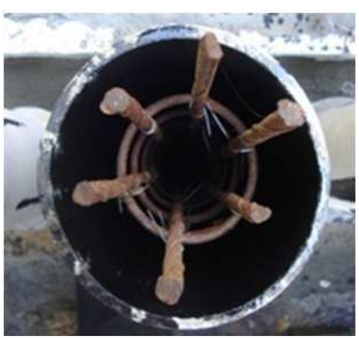

Fig. 1: Reinforcement cage in formwork

A schematic drawing of the corrosion testing is shown in Fig. 2 Two different degrees of corrosion damage of 10 and 25% were induced in this research study. The time for corrosion can be estimated by the Faraday's equation:

$$\Delta w = \frac{A_m.I.t}{Z.F}$$

Where:
Δw = Mass loss due to corrosion
A_m = Atomic mass of iron (55.85 g)
I = Corrosion current in amps
t = Time since corrosion initiation (sec)
Z = Valency (assuming that most of rust product is due to $Fe(OH)_2$, Z is taken as 2)
F = Faraday's constant [96487 coulombs (g/equivalent)]

The corrosion activity was monitored for the columns by measuring the corrosion potential in accordance with the ASTM[10] procedure. The probability of corrosion is based on specific ranges of potential of steel reinforcement with respect to standard reference electrode.

Axial compression testing: After inducing different degrees of accelerated corrosion, the control column and corrosion- damaged columns were tested under uni-axial compression in a testing machine of capacity 2000 kN. Figure 3 shows the test set up and instrumentation for a column specimen. The load was applied monotonically with uniform increments of load.

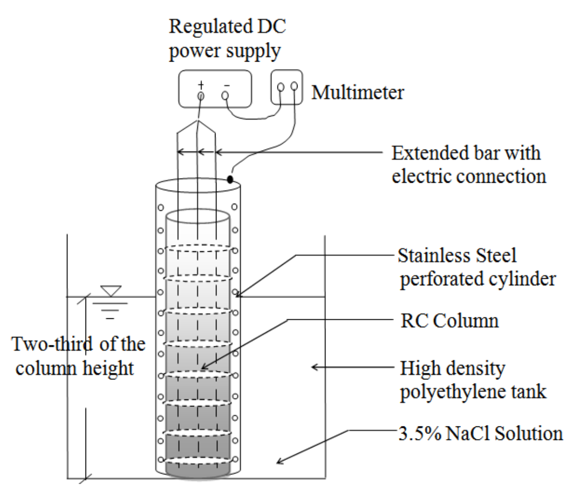

Fig. 2: Accelerated corrosion testing

Fig. 3: Column test setup and instrumentation

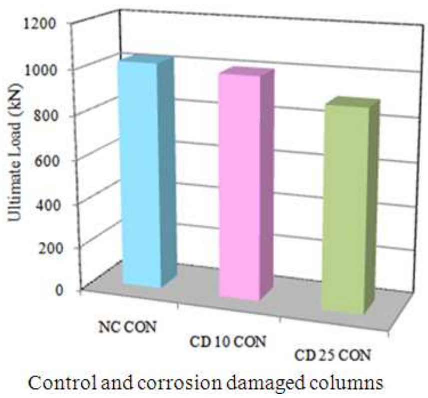

Fig. 4: Ultimate loads of columns

In order to observe the axial compression of the column two deflectometers were placed at top and bottom of the specimen. At mid-height of the specimen, a lateral extensometer was provided to measure the lateral strain of the specimen.

RESULTS

The load carrying capacity of tested columns is shown in Fig. 4. The reduction in ultimate capacity with increasing levels of corrosion damage was obvious. The stress-strain response of corrosion-damaged columns is shown in Fig. 5 in which the ultimate axial stress decreased with increase in levels of corrosion damage. The deflection ductility is defined by ultimate deflection to deflection at kink point (abrupt change in slope of the curves represents the onset of unstable crack propagation). At higher degrees of corrosion-damage, the deflection ductility also got reduced as shown in Fig. 6.

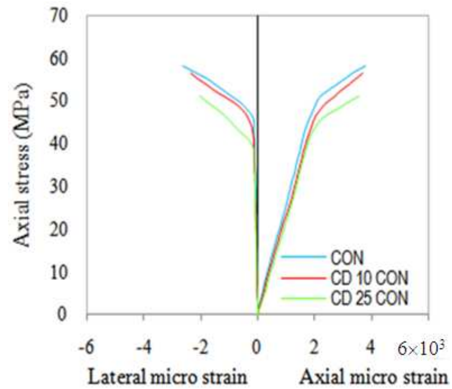

Fig. 5: Stress-strain response of columns

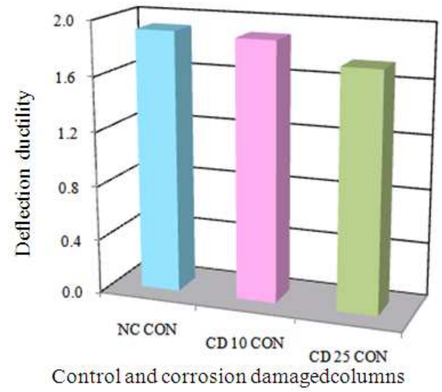

Fig. 6: Ductility of columns

DISSCUSSION

The ultimate strength was reduced by 3% for 10% of corrosion-damaged column. The column with 25% degree of corrosion damage showed a marked reduction in load capacity by 12%.

It can also be explained further that the slope of the stress-strain curve decreased with increasing degrees of corrosion damage level. Thereby it indicated the gradual reduction in the stiffness of the corroded columns. The ultimate axial stresses for the corrosion damaged columns also decreased sharply with increasing corrosion damage level.

The area under the load-deflection curve indicates the energy absorption. The energy absorption for corroded columns decreased as the level of corrosion damage was increased. This indicated that the failure of columns was brittle in nature at higher degrees of corrosion.

The ultimate axial strain also decreased with increasing degree of corrosion levels. For columns with

10%, level of corrosion damage showed a reduction of 2% in ultimate axial strain. The reduction in strain was found to be 5% for columns with 25% degree of corrosion damage level.

The corroded columns exhibited smaller lateral strain to their corresponding stress levels. This may be due to the reduction in cross-sectional area of steel reinforcement. The specimens with 10% level of corrosion damage showed reduction in lateral strain by 10%. For specimens subjected to 25% corrosion damage level, the lateral strain was reduced by 22%.

The ultimate deflection of the columns, decreased with increasing reinforcement corrosion level, leading to a reduction in ductility of the columns. The decrease in ductility was found to be 1.5 and 9% respectively for columns subjected to 10 and 25% corrosion damage level.

CONCLUSION

Based on the results presented, the following conclusions are drawn:

- The reduction in ultimate axial loads was attributed to the loss of cross-sectional area of steel reinforcement due to corrosion
- The ultimate axial strain of the columns decreased with increasing level of corrosion damage, leading to a reduction in the ductility of the columns
- The increase in corrosion intensity decreased the absorbed energy and hence the ductility of the columns
- The corrosion damaged concrete columns failed in brittle manner at higher levels of corrosion

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