Structural Behaviour of Reinforced Concrete Corroded Column

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Abstract. Worldwide in the construction industry uses reinforced cement concrete. The different types of structures which were built using reinforced cement concrete served for long period. But due to faulty design, improper quality control and corrosion of reinforcement there are notable premature failure and subsequently sudden collapse of the structure occurs. The presence of aggressive medium such as moisture and chloride ions are the main factors which are induces the steel corrosion. The cost involves for repairing the corroded structure escalate very rapidly which leads property loss to the people, if the problem is not corrected. Columns are the main structural members of R.C bridges when exposed to de-icing salt they are more vulnerable to steel reinforcement corrosion. The thorough knowledge about the corrosion can get only by proper investigation. This experimental work mainly focuses on structural behaviour R.C columns subjected to steel corrosion. Columns with two different size were cast and accelerated corrosion was induced. Structural behaviour of the columns were studied with axial load test and compared with conventional specimen. The ultimate load carrying capacity, axial strain, energy absorption capacity were reduced in all the corroded columns

Keywords: Corrosion, Column, Axial load, Energy absorption capacity, Strain

1. Introduction
In reinforced concrete structures corrosion of steel is the major causes of deterioration. The concrete around the steel has high pH in normal environment thus the steel does not corrode. The changes in the composition of pore solution present in the concrete is due to outside environment which leads to corrosion. The changes in the pH of pore solution takes place due to permeability of concrete. Cracks and pores are formed through which aggressive chloride ions moisture and oxygen enter into concrete thus lower the pH. The passive film around the steel destroys by lowering of pH. The corrosion of steel takes by the two mechanism. Carbonation and chloride induced corrosion. The pH of concrete surrounding the steel is lowered when the depth of carbonation reaches the reinforcement level and thereby corrosion starts. The corrosion product exert pressure and this exceed the tensile strength of the concrete. Thus cracks are formed and this affect the structural stiffness and structural integrity and the structure becomes unfit to serve the purpose for safety reasons. Cui et al. [1] investigated the seismic performance, fragility, and the life cycle cost analysis of the Corrosion affected bridges and Structures. Finite element programs were used for the analysis. From their study it was concluded that further research is required due to uncertainties in numerical models. Mushtaq et al., [2] carriedout investigation on Reinforced concrete columns of diameter 150mm and height 300mm were subjected to accelerated corrosion process combined with wetting and drying cycles. Axial load was carried out after the corrosion process. It was concluded that there was reduction in the load in the range of 19% to 40% for the mass loss of in the range of 10 % to
30%. Revathy et.al, [3], Studied the experimental investigation on reinforced concrete column of diameter and 900 were cast and subjected to accelerated corrosion process to the corrosion level of 10% and 25%. The structural behaviour of R.C.Columns were tested in the laboratory using axial load test. It was noted that the ultimate load, axial strain and Energy absorption capacity was reduced due to corrosion. Altoubat et al, [4] Investigated experimental study on Reinforced concrete column of size of diameter 208 mm and height of 666mm. The specimens were subjected to accelerated corrosion process by two sets. One set consist of maintaining constant current and other set consist of constant voltage. The specimens were tested under load test. From the experimental investigation it was concluded that constant current specimens obtained less load than constant voltage specimens. Jin Xia et.al, [5] studied the performance of reinforced concrete corroded column. The reinforcement in the steel were subjected to corrosion by using combined electro chemical process and wet – dry cycles. Eccentric – compressive loading were applied to column to determine the ultimate strength, area loss of the steel bars, maximum width of concrete cover. Mathematical model is also predicted to quantify the residual compressive strength of corroded column.

2. Experimental Investigations

2.1 Material Properties

The properties of materials used for preparing concrete as cement, fine aggregate, coarse aggregate and water are tested in the laboratory. Cement of type 53 grade from a single source was used. River sand which is available locally was tested and used, found to be falls in zone II of IS 383-1970. With the tested material property concrete mix design was carried out using IS method. The fresh properties of the concrete mix such as workability was tested which gave satisfactory result of 80 mm to 150mm. The design mix proportion is presented in Table 1.

Table 1. Concrete Mix Ratio

| Constituent          | kg/m³ | Ratio       |
|----------------------|-------|-------------|
| Portland Cement      | 450   | 1:1.12:2.69 |
| Water                | 191.6 |             |
| Fine Aggregate       | 504   |             |
| Coarse Aggregate     | 1209  |             |

2.2 Details of specimen

Totally twelve specimens, Six numbers of column size 150x150 mm designated as S1 and six numbers of column size 125 x125mm designated as S2 were cast. From each size, three numbers used as uncorroded (UC) and three numbers used as corroded (C) specimens. The reinforcement details are shown in Table 2. Figure 1 shows specimens after 28 days curing.

Table 2. Details of the Specimen

| SL.No | Specimen | No of Specimen | Size of the Column | Cover in mm | Main reinforcement | Lateral ties       |
|-------|----------|----------------|--------------------|-------------|--------------------|--------------------|
| 1     | S1UC     | 3              | 150x150x500        | 25          | 4 Nos 10mm diameter | 6mm dia at 150 mm c/c |
| 2     | S1C      | 3              |                    |             |                    |                    |
| 3     | S2UC     | 3              | 125x125x500        | 20          | 4Nos 10mm diameter  | 6mm dia at 125 mm c/c |
| 4     | S2C      | 3              |                    |             |                    |                    |
2.3 Method of Accelerating Reinforcement Corrosion

In the laboratory the column specimens were subjected to accelerated corrosion process. The Direct current power supply unit was used. A small hole of 3mm was drilled in the main reinforcement of the column specimen and the electrical wire was held, which was connected to the positive terminal of DC source act as anode.[6][7] The stainless steel plate act as cathode, placed in the fibre reinforced plastic tank filled with salt solution. The specimens were placed in the tank and maintains 5V voltage current. Figure 2. Shows specimens subjected to accelerated corrosion process.

3. Results and Discussion

After the corrosion process of thirty days all the specimens were subjected to axial load test. This was conducted by using a load frame. The load is applied uniformly by placing the steel box of column size at the top. Demountable mechanical strain gauge having a least count of 0.002 mm were used with gauge length of 150 mm. The strain are measured at every 100kN increment by fixing the pellets on the concrete surface. This arrangement is shown in Figure 3. Ultimate load, axial strain and energy absorption capacity of corroded and conventional column were studied. The first set includes S1UC, and S1C, S1UC served as control columns. The conventional column specimen are
failed due to shear by formation of inclined cracks on the sides. The ultimate load carrying capacity of all the specimens are compared and shown in Figure 4. The ultimate load taken by specimen SIUC is 825 kN, whereas specimen S1C reached an ultimate load of 747 kN which is 10% less than SIUC. The cross sectional area of the steel is reduced in the corroded column specimen, so that the bond between steel and concrete is reduced. Specimen S2UC reached an ultimate strength of 734 kN, whereas the same observed in corroded specimen as 640 kN which is 1.14 times less than the conventional column. The column of size 150mm x 150 mm has taken increase in load than 125 mm x 125 mm size due to increased cross sectional area. The load taken by S1UC as 12 times higher than S2UC, whereas 16% increase in the load was noted in the corroded specimen.

Figure 3. Test Set up for the Column

![Figure 3. Test Set up for the Column](image)

Figure 4. Comparison of ultimate loads for each specimens

![Figure 4. Comparison of ultimate loads for each specimens](chart)
3.2 Stress-Strain Response and energy absorption capacity

From the experimental observation of corroded and conventional specimen a graph is plotted between stress versus strain as shown in Figure 5. The axial strain were noted at eighty percentage of loading and energy absorption capacity was calculated for area under stress-strain curve[8][9]. The axial strain taken by specimen SIUC is 1310 micro strain, whereas the specimen S1C is if 1000 micro strain which is 24 % less than SIUC. The cross sectional area of the steel is reduced in the corroded column specimen, so that the bond between steel and concrete is reduced. Specimen S2UC reached an axial strain of 1260 micro strain, whereas the same observed in corroded specimen as 947 which is 25 times less than the conventional column. The column of size 150mm x 150 mm has taken decrease in strain than 125 mm x 125 mm size due to increased cross sectional area. The strain taken by S1UC as 4% times higher than S2UC, whereas 5 % increase was noted in the corroded specimen. The energy absorption capacity of the specimen SIUC is 0.03, whereas specimen S1C is 0.0255 re which is 15 % less than SIUC. Specimen S2UC reached an ultimate strength of 0.0287, whereas the same observed in corroded specimen as 0.0211 which is 27 times less than the conventional column. The column of size 150mm x 150 mm has decrease in energy absorption capacity than 125 mm x 125 mm size due to increased cross sectional area. The load taken by S1UC as 4% higher than S2UC, whereas 17 % increase in the energy absorption was noted in the corroded specimen.

![Figure 5. Comparison of Axial strains for each specimens](image)

3.2 Failure Mode of Column

The failure behaviour gives a strong message for the assessment of reinforced concrete columns as displays in the figure. There is difference in the mode of failure was noted in the corroded and conventional concrete columns. The conventional column is experienced the shear failure that happened instantly afterward the stress attained its ultimate strength. This failure was attended by abrupt fracture with a high pitch sound. The corroded columns subjected to splitting and debonding failure due to high level of corrosion. This trend is due to the loss of bond between steel reinforcement and concrete Column and the formation of existing cracks after the corrosion process. Figure 6 and Figure 7 shows the mode of failure of the conventional and corroded column.
The ultimate load carrying capacity of the corroded column was decreased due to the loss of cross sectional area of steel reinforcement caused due to corrosion. The axial strain of corroded column was reduced due increased level of corrosion damage. The energy absorption capacity of the corroded column was reduced compared to conventional column. The structural behaviour of conventional and corroded column with increased cross section and increased cover performed well in column with reduced cross-section and reduced cover.

4. Conclusions

Figure 6. Failure of Conventional Column

Figure 7. Failure of Conventional Column
5. References

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