Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 54(5) (2022) 367-370
DOI: 10.22060/ceej.2021.19919.7290

Compressive strengthening of steel columns with local corrosion using CFRP

O. Yousefi[1], A. A. Hedayat[1,2*] , K. Narmashiri[3], A. Karbakhsh[1]
[1]Department of Civil Engineering, Sirjan Branch, Islamic Azad University, Sirjan, Iran
[2]Department of Civil Engineering, Kerman Branch, Islamic Azad University, Kerman, Iran
[3]Department of Civil Engineering, Zahedan Branch, Islamic Azad University, Zahedan, Iran

ABSTRACT: Steel structures are damaged for a variety of reasons including accidental loads, corrosion and reduced strength which need to be repaired and improved. In this investigation, local corrosion was applied to the steel circular columns and the effects of Carbon Fiber Reinforced Polymer (CFRP) for strengthening have been studied. 19 specimens of steel Circular Hollow Section (CHS) column with the same height and damage dimensions under compressive load were analyzed by ABAQUS software which six cases of them were performed experimentally. In laboratory cases, progressive corrosion was used to create damage to the specimens. In order to improve the accuracy of the analysis, a combined method was used to study the post-buckling of the plastic zone. For this purpose, the specimens were first subjected to elastic buckling analysis and then Riks non-linear analysis with global and local imperfections was conducted. The results showed that the corrosion reduces the bearing capacity and rigidity of the steel columns and complete destruction of the corroded area reduced the load bearing capacity by 40% for the column with corrosion in the middle and by 21% for the damage close to the base, which shows the former is more critical. Strengthening of columns retrofitted with carbon fibers restored ultimate load reduction by 33% and had a positive effect on controlling fractures and reducing stresses in the damaged area

Review History:

Received: Apr. 25, 2021
Revised: Jul. 08, 2021
Accepted: Jul. 28, 2021
Available Online: Aug. 05, 2021

Keywords:

Strengthening
Corrosion
Steel column
Column buckling
CFRP

1- Introduction

Most structural members that have lost their useful life due to corrosion or other factors need repair. Much research has been done on retrofitting with new materials and methods. Fiber Reinforced Polymer (FRP) is relatively new and not yet widely used; however, extensive research has been conducted on them. Tao et al. [1] strengthened nine short concrete-filled square and circular columns with CFRP jackets to experimentally study how CFRP fibers increased the bearing capacity and found out that an increase in the number of layers will increase the ultimate load more in circular columns than in square ones. Haider and Zhao [2] retrofitted short columns with CFRP fibers transversely and longitudinally and observed that the fiber direction affected the yielding capacity and the onset of buckling. Sivasankar et al. [3] studied the fracture modes, stress-strain behavior and ultimate bearing capacity of short CFRP-reinforced steel columns and showed that an increase in load could tear the CFRP fibers. Ghaemdoust et al. [4] studied short square damaged steel columns with horizontal and vertical defects located at the corner and center of the column, Karimian et al. [5] investigated short circular defective steel columns strengthened with CFRP. These studies showed that defects reduced the bearing capacity and increased the axial deformation and local buckling in steel columns. As mentioned before, most previous works have studied the behavior of short columns strengthened with the CFRP; the behavior of corroded slender steel columns, where global buckling is quite vital, has been less attended to. Hence, 19 defective slender columns were prepared with and without CFRP strengthening and subjected to corrosion at different locations, and the effects of such parameters as the location, defect severity and CFRP wrapping on their behavior were investigated both experimentally and numerically.

2- Materials and Method

To study the effects of corrosion and strengthening techniques on the behavior of corroded columns, this research did experimental tests and numerical analyses on 19 slender steel column specimens, which one was undamaged for controlling purposes. The geometrical and material properties of the selected steel column are listed in Table 1.

This study has used four CFRP layers (SikaWrap®230-C) with elasticity modulus, Poisson ratio and thickness

*Corresponding author's email: Amirahmad1356@yahoo.com

Table 1. Properties of the CHS steel column

D (mm)	t (mm)	f_y (N/mm^2)	f_u (N/mm^2)	ε %
88	2.06	265	325	11

equal to 230000 MPa, 1.7 and 0.129 mm, respectively, to strengthen the corroded columns.

The Sikadur®330- epoxy used in this study is recommended by the CFRP producer and has an elasticity modulus and tensile strength equal to 4300 and 30 MPa, respectively. It is commonly used for SikaWrap®230-C CFRP where the mixing ratio of the resin and harder parts is 1:4.

Corrosion was applied to the different locations of the column height. A 12-v, 30-amp, regulated DC power supply transmitted a constant 5-amp current to each phase wire by putting a resistor in its path, and the current was applied to four 5-mm thick rods installed with a weak weld at the same distance from the center of the damage to create a constant phase current for uniform damage around the desired area. The zero wire was attached to a stainless screw inside a 5% sodium chloride solution, the percent concentration of which was adopted from Malumbela et al. [6].

To achieve a good column-fiber bond, the specimens were sand blasted on the outer surface to eliminate the corrosion, then acetone was used to clean all the contamination from the steel and CFRP surfaces and, finally, CFRP sheets were wrapped around the specimens and kept at room temperature for seven days (as the fiber manufacturer had recommended). To measure the axial deformation, an LVDT was installed under the hydraulic jack and some more were placed around mid-height to measure the deformation because slender circular columns have large global buckling. Since the buckling direction is not predictable, all the specimens were tested for vertical displacements and a 16-channel Data logger system was used to store the data. The column base was fixed by a 30 mm wide, 10 mm thick plate welded to the bottom steel plate to keep column ends unwelded and prevent the laboratory system from destructive displacements; a similar system with no loading disruption was also used to restrain the column loading edge.

To study the structural behavior and Von-Mises stresses at the CHS thickness, especially at the damaged zone, all the specimens were numerically modeled by the finite element (FE) method (with both non-linear geometric and material analyses) where each model was created with reduced integration using 10-node solid elements (C3D10R); all models were first imperfected and then subjected to non-linear analyses. Imperfections were both local and global; for the former, the columns were first analyzed for elastic buckling and then the first two modes with imperfection values of t/10 and t/100 (t = section thickness) were combined to create the imperfect model.

3- Results and Discussion

Load-displacement curves of the specimens were investigated and results showed that for corrosion with 50% damage (lost 1 mm of its thickness), load bearing capacity was reduced by 13.7 and 6.22% for the mid-height and near-the-support damage, respectively, which indicates that the corrosion is more critical in the middle. For 100% damage, the surface of the damaged area was completely destroyed, thus reducing the ultimate load for damage in the middle was 40% and for the damage close to the supports was 21%. To compensate for this reduction, CFRP sheets (2 transverse and 2 longitudinal layers) increased the load bearing capacity up to 45% compared to the non-strengthened corroded specimen. The initial failure in the control column was global buckling with significant mid-height local deformations; as loading continued to enter the plastic area, the column experienced a mid-height local buckling and a secondary failure. For 50% damage, the stress increased in the vicinity of the corrosion zone and local buckling emerged. For 100% corrosion, since corrosion destroys the damaged area, failure occurs more quickly and the area shrinks. It is noteworthy that the global buckling occurs in all columns. For columns wrapped with CFRP sheets, compressive loading led to concentrate stresses in CFRP fibers. Rapture failure occurred in CFRP sheets after stresses exceeded their elastic limit. They reduced the mid-height column stresses significantly and delayed the local buckling at the damage zone.

4- Conclusions

The results showed columns with mid-height defects experienced significantly lower load bearing capacity than others. Results concluded that a reason for this greater reduction could be the concentration of the column’s global and local buckling in the same area.

For the control column, global buckling (with emphasis on the mid-height damage) was the failure mode, but for non-strengthened damaged specimens, it was both global and local buckling (in the form of overlapped notch edges). It is worth noting that slenderness was the reason for the global buckling of all the columns. The global buckling failure of near-the-support damage was in the direction of the damage location, but for the mid-height damage, it was in the opposite direction. CFRP strengthening postponed the local buckling and reduced the stress intensity in the damage location. In strengthened specimens, stress concentration was around the damaged area leading, finally, to a rupture failure due to the damage deflection gained by continued loading.

References

[1] Z. Tao, L.-H. Han, J.-P. Zhuang, Using CFRP to strengthen concrete-filled steel tubular columns: stub column tests, in: Fourth International Conference on Advances in Steel Structures, Elsevier, 2005, pp. 701-706.

[2] J. Haedir, X.-L. Zhao, Design of short CFRP-reinforced steel tubular columns, Journal of Constructional Steel Research, 67(3) (2011) 497-509.

[3] S. Sivasankar, T. Thilakranjith, M. Sundarraja, Axial Behavior of CFRP Jacketed HSS Tubular Members-An Experimental Investigation, International Journal of Earth Sciences and Engineering, 61(413) (2012) 1729-1737.

[4] M.R. Ghaemdoust, K. Narmashiri, O. Yousefi, Structural behaviors of deficient steel SHS short columns strengthened using CFRP, Construction and Building Materials, 126 (2016) 1002-1011.

[5] M. Karimian, K. Narmashiri, M. Shahraki, O. Yousefi, Structural behaviors of deficient steel CHS short columns strengthened using CFRP, Journal of Constructional Steel Research, 138 (2017) 555-564.

[6] G. Malumbela, M. Alexander, P. Moyo, Variation of steel loss and its effect on the ultimate flexural capacity of RC beams corroded and repaired under load, Construction and Building Materials, 24(6) (2010) 1051-1059.

HOW TO CITE THIS ARTICLE

O. Yousefi, A. A. Hedayat, K. Narmashiri, A. Karbakhsh, Compressive strengthening of steel columns with local corrosion using CFRP, Amirkabir J. Civil Eng., 54(5) (2022) 367-370.

DOI: 10.22060/ceej.2021.19919.7290