Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 52(2) (2020) 135-138
DOI: 10.22060/ceej.2018.14560.5684

Strengthening of Deficient Mortar Filled Steel Columns using CFRP

I. Badih Damghani, K. Narmashiri*
Department of Civil Engineering, Zahedan Branch, Ialamic Azad University, Zahedan, Iran

ABSTRACT: Recently, the application of concrete-filled steel tubes (CFST) columns has been widely trended due to their several advantages. Some of the CFST columns may be damaged due to different problems and need to be strengthened. One of the methods which can be applied to improve the efficiency of the damaged columns is the strengthening using fiber reinforced polymers (FRP). The present research investigates the effects of strengthening deficient columns through numerical and experimental studies. The numerical simulation has been adopted using ABAQUS software in 3D simulation method, and the experimental test has been done using steady pressure test machine. The defects created horizontally and vertically at the center of the columns. The specimens include one control and four deficient specimens, which two of them were strengthened using four carbon fiber reinforced polymers (CFRP) layers. The results showed that the horizontal deficiencies in columns resulted the most reduction in load-bearing capacity in comparison with Control (-46%). Strengthening using four CFRP layers (two-transverse and two-longitudinal) resulted in improving load bearing capacity appropriately (approximately %27 increment in comparison by the deficient column). The application of CFRP improved confinement strength and controlled the local failures.

Review History:

Received: 2018-06-25
Revised: 2018-07-07
Accepted: 2018-08-06
Available Online: 2018-09-25

Keywords:

Deficiency
steel column
mortar filled
CFST
CFRP

1- INTRODUCTION

Concrete Filled Steel Tubes (CFST) are one of the special composite sections that are widely used as compressive members. In recent decades, these kinds of sections are mostly attracted by engineers due to high flexibility and axial strength. Different reasons such as corrosion, deterioration, and fire may cause problems for CFST columns and influence their ordinary behaviors. Strengthening using Fiber Reinforced Polymer (FRP) materials is one of the advanced methods that can be used for such structures. FRP materials have several advantages such as high tensile strength, efficient durability and stability, high flexibility, and capable bonding with concrete and steel. In recent years, a wide range of research has investigated the strengthening of concrete members such as beams, columns, slabs, etc., but less research examined the strengthening of deficient CFST members.

Teng et al. reviewed the strengthening of steel structures using Carbon Fiber Reinforced Polymer (CFRP). They investigated the selection of appropriate adhesive and surface preparation [1]. Batikha et al. presented an analytical method on buckling behavior of thin-walled cylinders under axial compression using FRP [2]. Teng and Hu researched the structural behavior of steel pipes strengthened using CFRP [3]. Haedir and Zhao investigated the effects of strengthening ten short steel columns using CFRP. They concluded that application of longitudinal and transverse layers showed better performance in delaying buckling [4]. Kalavagunta et al. studied the strengthening of cold-formed lipped steel columns using CFRP [5].

Devi and Amanat researched on strengthening steel Square Hollow Section (SHS) numerically. Application of CFRP layers increased load-bearing capacity between (10-90%) [6]. Sundarraja and Sivasankar investigated strengthening of 12 short steel columns using CFRP. They found that parameters such as numbers of layers and distances of CFRP layers influenced the load-bearing capacity significantly [7]. Shaat and Fam concluded that numbers of CFRP layers affected the local buckling of steel short columns [8]. Bambach et al. researched CFRP strengthening of steel tubes under static and dynamic impacts. They found that CFRP strengthening increased energy absorption of columns [9]. He et al. investigated the structural behavior of CFRP strengthened concrete-filled steel cylindrical columns. Increasing number of CFRP layers improved the columns bearing capacity [10]. Sundarraja and Prabhu investigated the structural behavior of CFRP strengthened CFST under axial compressive. They concluded that in the non-strengthened area, the local buckling occurred due to high stress and strain intensity [11]. Dang et al. researched on CFRP strengthening CFST columns. Twenty-two columns were investigated. It was shown that cylindrical columns indicated better behavior than square ones [12]. Feng et al. investigated FRP strengthening of mortar filled steel tubes. They concluded that for shorter columns, the failure occurred firstly at the end of the columns (local buckling), but for the longer columns, the failure happened

*Corresponding author's email: narmashiri@iauzah.ac.ir

Table 1. Specimens' specifications and results

Specimen	Deficiencies' dimensions (mm)		CFRP	Experimental		Numerical	
	Hor.	Ver.		Load bearing capacity (kN)	Increment/ decrement (%)	Load bearing capacity (kN)	Increment/ decrement (%)
Control	N/A	N/A	N/A	456	-	445	-
MVD400-60	N/A	400×60	N/A	242	-45.61	235	**-48.08**
MHD60-60	60×60	N/A	N/A	240	-46.06	233	**-46.74**
MVD400-60-2T2L	N/A	400×60	2T2L	367	-17.52	356	**-20**
MHD60-60-2T2L	60×60	N/A	2T2L	353	-20.67	364	**-18.20**

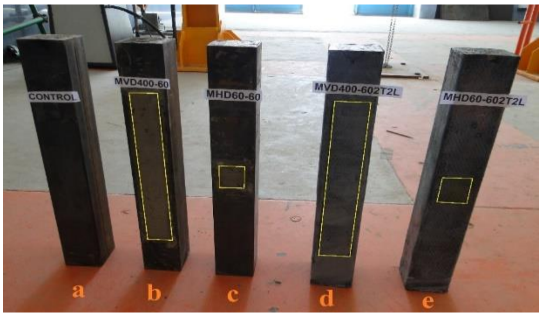

Fig. 1. The experimental specimens before test

Table 2. Comparison of modeling verification with experimental test [14]

Specimen	Load bearing capacity (kN)		Difference
	Experimental [14]	Numerical	
Control	928	916	**-1.29**
CFRP Strengthened	1001	1044	**4.29**

mostly as the overall buckling [13]. Prabhu and Sundarraja used different CFRP distances for strengthening CFST columns. They found that the application of sufficient CFRP layers and distances caused overcoming lateral deformation [14]. Recently, CFRP strengthening of deficient steel short columns were researched. The results indicate the feasibility of CFRP for overcoming strength lost due to deficiencies [15-19].

As abovementioned, most of researches investigated FRP strengthening of hollow and CFST columns without deficiency. This research aims to investigate the effects of CFRP strengthening deficient mortar filled steel square short columns. The horizontal and vertical deficiencies were made at the middle of the columns' height. Both numerical and experimental investigations were employed.

2- MATERIALS AND METHODS

The investigated specimens in this research include 5 square steel short columns having dimensions of 90×90 mm^2 with a height of 600 mm and a thickness of 2 mm. The dimensions of the columns were selected based on the requirements of the Iranian National Building Code Part 10: Design and Construction of Steel Structures [20]. The vertical and horizontal deficiencies were created at the middle of the height. All columns were filled using Grout Mortar. Some of the specimens were strengthened using CFRP layers. For experimental test, before installing CFRP, the surfaces were sandblasted, then adhesive was used to past CFRP sheets to steel surfaces. The specimens' specifications and results are shown in Table 1. The experimental specimens before the test are indicated in Figure 1.

All specimens were simulated using ABAQUS software. All parts of the specimens were modeled using three dimensional (3D) Solid elements. Axial load as static gradual loading was applied, and nonlinear analysis was used. To verify the simulation method, the experimental works were used [14]. The investigated specimens were the control, and CFRP strengthened CFST columns with the dimensions of 91.5×91.5×3.5mm and the height of 600mm. As shown in Table 2, the results confirmed each other appropriately.

3- RESULTS AND DISCUSSION

3-1- Load bearing capacity

As mentioned in Table 1, the deficiencies caused decreasing in the load-bearing capacity of the columns significantly (up to %46). Strengthening the specimens using four CFRP layers caused increasing the bearing capacity of the deficient specimens up to %20 in comparison by the deficient specimens.

3-2- Failure modes

All specimens were tested until failure. In the control specimen, the elephant-foot failure occurred at the top of the specimen (Figure 2). In the deficient specimens, local buckling on steel and concrete (mortar) cracking (Figure 3) around the deficiency region were happened.

The application of CFRP on the columns caused prevention on local buckling around the deficiency regions appropriately. This resulted in improving load-bearing capacity of the specimens.

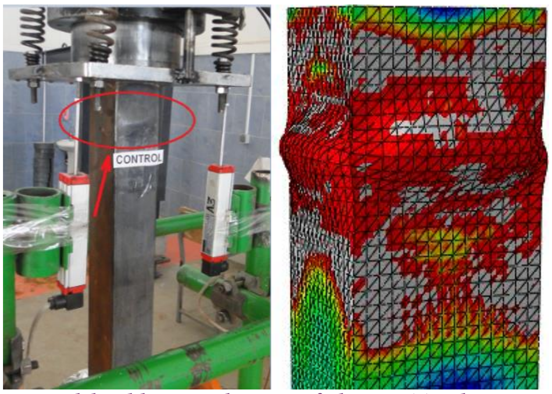

Fig. 2. Local buckling at the top of the CFST column without deficiency

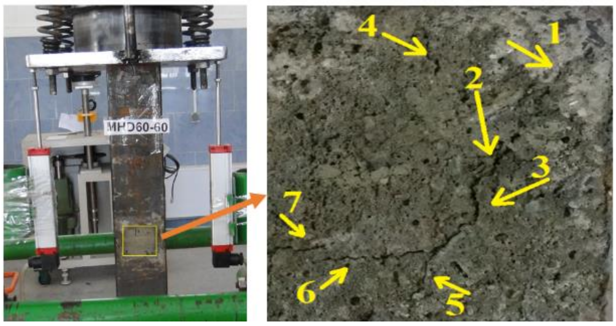

Fig. 3. Concrete (mortar) cracking in CFST column having horizontal deficiency

4- CONCLUSIONS

In this research, numerical study using ABAQUS software and experimental test using axial pressure test on CFRP strengthening CFST columns having horizontal or vertical deficiencies were investigated. Four CFRP layers, including two transverse and two longitudinal layers were wrapped on columns. The results indicated that horizontal deficiency caused more reduction in load-bearing capacity in comparison with vertical ones. Application of CFRP caused increasing the load-bearing reduction, retarding the local buckling, and controlling the failures in the deficiencies area. The failure mode for the control specimen was the elephant-foot failure at the top of the column. For the specimens having deficiencies, local buckling and failure around the deficiency region in steel columns and crack propagation in mortar were observed. Mortal filling the columns caused increase in load-bearing capacity and controlling the failure of thin-walled steel columns appropriately. The increment reason is due to the high compressive strength of the mortar and its appropriate bonding to the steel walls.

REFERENCES

[1] Teng, J.G., Yu, T., and Fernando, D., 2012. "Strengthening of steel structures with fiber-reinforced polymer composites". *Journal of Constructional Steel Research*, 78, pp. 131-143.

[2] Batikha, M., Chen, J., Rotter, J., and Teng, J., 2009. "Strengthening metallic cylindrical shells against elephant's foot buckling with FRP". *Thin-Walled Structures*, 47, pp. 1078–1091.

[3] Teng, J.G., and Hu, Y.M., 2007. "Behaviour of FRP-jacketed circular steel tubes and cylindrical shells under axial compression". *Construction and Building Materials*, 21(4), pp. 827–838.

[4] Haedir, J., and Zhao, X.L., 2011. "Design of short CFRP-reinforced steel tubular columns". *Journal of Constructional Steel Research*, 67, pp. 497–509.

[5] Kalavagunta, S., Naganathan, S., and BinMustapha, K.N., 2013. "Proposal for design rules of axially loaded CFRP strengthened cold formed lipped channel steel sections". *Thin Walled Structures*, 72, pp. 14–19.

[6] Devi, U., and Amanat, K.M., 2015. "Non-linear finite element investigation on the behavior of CFRP strengthened steel square HSS columns under compression". *International Journal of Steel Structures*, 15(3), pp. 671–680.

[7] Sundarraja, M.C., and Sivasankar, S., 2013. "Behaviour of CFRP jacketed HSS tubular columns under compression an experimental investigation". *Journal of Structural Engineering*, 39(5), pp. 574–582.

[8] Shaat, A., and Fam, A., 2006. "Axial loading tests on CFRP–retrofitted short and long HSS steel columns". *Canadian Journal of Civil Engineering*, 33(4), pp. 458-470.

[9] Bambach, M.R., Lama, H.H., and Elchalakani, M., 2009. "Static and dynamic axial crushing of spotwelded thin-walled composite steel-CFRP square tubes". *International Journal of Impact Engineering*, 36, pp. 1083-1093.

[10] He, D., Dong, J., Wang, Q., and Chen, X., 2011. "Mechanical behaviour of recycled concrete filled steel tube columns strengthened by CFRP". International Conference on Multimedia Technology (ICMT), 26-28 July (2011), pp. 1110-1113.

[11] Sundarraja, M.C., and Prabhu, G.G., 2012. "Experimental study on CFST columns strengthened by CFRP composites under compression". *Journal of Constructional Steel Research*, 72, pp. 75–83.

[12] Dong, J.F., Wang, Q.Y., and Guan, Z.W., 2013. "Structural behaviour of recycled aggregate concrete filled steel tube columns strengthened by CFRP". *Engineering Structures*, 48, pp. 532-542.

[13] Feng, P., Zhang, Y., Bai, Y., and Ye, L., 2013. "Strengthening of steel columns in compression by mortar-filled FRP tubes". *Thin Walled Structures*, 64, pp. 1–12.

[14] Prabhu, G.G., and Sundarraja, M.C., 2013. "Behaviour of concrete filled steel tubular (CFST) short columns externally reinforced using CFRP strips composite". *Construction and Building Materials*, 47, pp. 1362–1371.

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

[16] Karimian, M., Narmashiri, K., Shahraki, M., and Yousefi, O., 2017. "Structural behaviors of deficient steel CHS short columns strengthened using CFRP", *Journal of Constructional Steel Research*, 138, pp. 555-564.

[17] Yousefi, O., Narmashiri, K., and Ghaemdoust, M.R., 2017. "Structural behaviors of notched steel beams strengthened using CFRP strips". *Steel and Composite Structures: An International Journal*, 25(1), pp. 35-43.

[18] Shahraki, M., Sohrabi, M.R., Azizyan, G.R., and Narmashiri, K., 2018. "Experimental and numerical investigation of strengthened deficient steel SHS columns under axial compressive loads". *Structural Engineering and Mechanics: An International Journal*, 67(2), pp. 207-217.

[19] Shahabi, R., and Narmashiri, K., 2018. "Effects of deficiency location on CFRP strengthening of steel CHS short columns". *Steel and Composite Structures: An International Journal*, 28(3) 267-278.

[20] Ministry of Housing and Urban Development, 2013. Iranian National Building Code Part 10: *Design and Construction of Steel Structures*, Tehran, Iran (in Persian).

HOW TO CITE THIS ARTICLE

I. Badih Damghani, K. Narmashiri, Strengthening of Deficient Mortar Filled Steel Columns using CFRP, Amirkabir J. Civil Eng., 52(2) (2020) 135-138.

DOI: 10.22060/ceej.2018.14560.5684