Mechanical Behavior of Square CFST Columns with Embedded Steel Plate Reinforcement

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***Abstract*—Concrete filled steel tube (CFST) columns have been gradually adopted in modern civil engineering structures mainly in high-rise buildings and bridges. Past research have shown that circular CFST columns were far more superior to its square or rectangular counterparts. Besides lower confinement effect, square and rectangular steel tubes with large width-to-thickness ratio were prone to suffer from local buckling. In order to improve the ultimate load carrying capacity of the these columns, the CFST columns were reinforced by longitudinal steel plate embedded into the concrete core. The mechanical properties such as ultimate strength, stiffness and ductility of the square CFST columns with and without longitudinal plate reinforcements were compared and studied.**

***Index Terms*—CFST columns, eccentricity, reinforcements, stiffeners, slender**

I. Introduction

Square and rectangular CFST are increasingly used as one of the main structural elements either in resisting vertical or lateral loads in civil engineering structures due to the fact that they have high moment capacities, easy beam-to-column connection and also aesthetic consideration. In order to overcome the low confinement effect and local buckling issue, lots of researches have been done in order to enhance the interaction between the steel tube and concrete core and increase the resistance of square and rectangular CFST columns. The modifications done on square and rectangular CFST columns are by incorporating the use of longitudinal plate stiffeners, reinforcing bars, anchor or binding bars, tensile strips, shear studs and also using steel fiber reinforced concrete.

The use of longitudinal plate stiffeners is the most well known method on improving the resistance of a square or rectangular CFST column. Usually longitudinal plate stiffeners are welded on the inner surface of the steel tubes. Experimental tests [1], [2] have shown that the longitudinal stiffeners can delay local buckling, improves the confinement pressure on the concrete core and thus increasing the resistance and ductility of the CFST columns. The improvement on the ultimate load of square and rectangular CFST columns with one longitudinal stiffeners on each steel tube surface were 9 and 10% higher than unstiffened sections respectively [3].

Hsu and Juang [4] and Cai and He [5] investigated the effect of using binding bars arranged at spacing along the longitudinal axis of the steel tube as stiffening scheme in CFST columns. The use of binding bars was able to improve the confinement of concrete beyond the corner region, delay or even prevent local buckling and hence improve ultimate strength and corresponding strain of square CFST columns when coupled with appropriate spacing and diameter of binding bar. Huang et al. [6] studied the use of inclined steel bar (also known as tie bars) welded at regular spacing along the longitudinal axis of steel tube to strengthen the lateral confining pressure on the concrete core. They conclude that the tie bars help enhancing the behavior of square CFT columns in terms of ultimate strength and ductility. These type of stiffening scheme i.e. binding bars and tie bars make better use of steel tension property and were able to improve the mechanical properties of square CFST column by restraining the plate deformations.

Wang et al. [7] and Yang et al. [8] investigated the possibility of using various configurations of reinforcement-stiffeners and tensile strips on square CFST in order to improve its mechanical behaviors such as resistance and ductility. The introduction of the reinforcement stiffeners was able to delay or prevent local buckling of steel tubes and enhance the constraint effect on the concrete core. Therefore the use of reinforcement stiffeners was able to increase the sectional strength, stiffness and ductility of square CFST columns. While the tensile strips, oblique battlement-shapes reinforcement and welded circular stirrup contribute to little improvement on ultimate load but can contribute significant improvement in ductility. A parametric study based on numerical model [8] showed that the mechanical behaviors of square CFST columns could be enhanced by decreasing the depth-to-thickness ratio, increasing the concrete and steel tube compressive and yield strength respectively,

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decreasing the horizontal and longitudinal spacing of stiffener welds and increasing the tensile strip thickness.

All of these stiffening scheme as discussed previously reveal that the use of stiffeners were able to improve the mechanical properties of the square or rectangular CFST columns. However, the existing stiffeners may have limitations in material efficiency or construction practice, for example longitudinal plate stiffeners need to be weld to the steel tube; oblique tie bars and tension sheets give rise to welding difficulty and stress may concentrate severely at the joins of tie bars and steel plate; tie rods show limitations with more steel consumption, bolt exposure, and concrete leak during casting construction and the welding process required during installation the stiffeners if not done carefully will introduce residual stress and also imperfections to the CFST columns. Hence, in this study we are looking at the possibility to reinforce the concrete core by embedding longitudinal steel plate rather than welding it to the steel tube. Detail of the proposed method will be discussed in the next section.

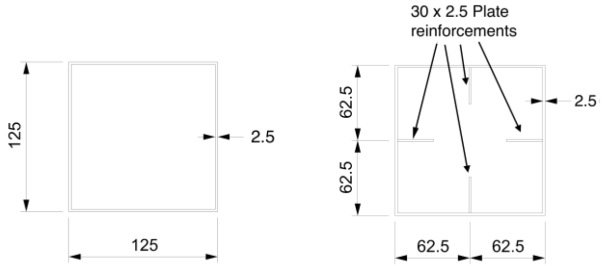
II. Experimental Study

A. Details of the Specimens

Two slender CFST columns were tested, one specimen without reinforcements compared against specimen with reinforcements. All columns were 2.26m high and were designed as square section of 125 x 125 mm. The basic geometric properties of the specimens are listed in Table 1. Column A was the reference specimen as shown in Fig. 1(a). Column B was the specimen with longitudinal plate reinforcements (Fig. 1(b)). The wall thickness of 2.5mm was adopted for both columns. Comparison will be done between Column A and Column B to determine the effect of reinforcements on the strength, stiffness and ductility of the columns.

TABLE I. Dimensions of Columns

Column	Dimensions B x D (mm)	Height (mm)	Wall thickness (mm)	Width-to-thickness ratio
A	125 x 125	2260	2.5	48
B	125 x 125	2260	2.5	48



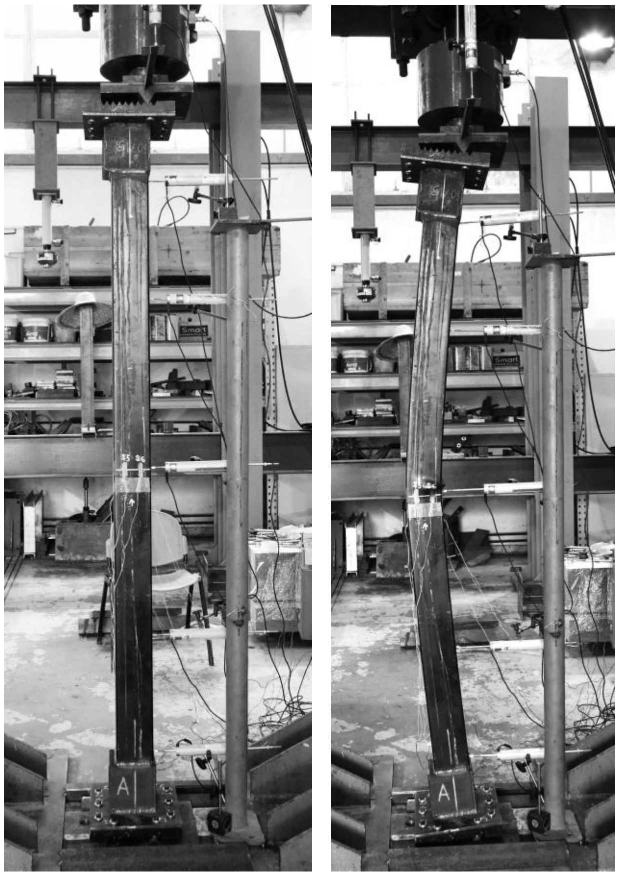
(a) (b)

Figure 1. Cross-sections of the column.

B. Material Properties

The steel tubes and longitudinal plate reinforcements were fabricated with mild steel sheet. Standard coupon tests were conducted to measure the steel properties. The tested steel properties are: elastic modulus E_s =203.6 GPa; yield strength f_y = 364.5 MPa; yield strain ε_y = 1790 $\mu\varepsilon$; ultimate strength f_u =441.9 MPa; and ultimate strain ε_u = 0.145.

The concrete used in the experiment was made with ordinary Portland cement with water-to-cement ratio of 0.5. The mix proportions for the normal concrete were as follows: cement = 440 kg/m^3; water = 233 kg/m^3; fine aggregate = 747 kg/m^3; and course aggregate = 895 kg/m^3. The course aggregate was well graded with a maximum size of 20 mm. In order to determine the compressive strength of concrete, three 150 mm cubes were cast for each batch of concrete and cured in similar conditions to the columns. The average cube strengths (f_{cu}) at the time of tests were found to be 30 MPa.



(a) (b)

Figure 2. Typical test setup: (a) Prior to testing; (b) At failure load

C. Specimens Preparation and Experimental Setup

The steel tubes were a square hot rolled sections and made of mild steel. The longitudinal plate reinforcements were tack welded at each ends to the inner surface of the steel tube to ensure that the reinforcements are in place during concreting. End plate with a thickness of 10 mm was welded to one end of each steel tube before filling the concrete into the tube. The concrete mix was poured into the steel tube layer by layer and was vibrated using a poker vibrator.

The columns were tested as pin-ended supported and subjected to single-curvature bending. Axial loading was applied through knife-edges supports, which were bolted using ten M10 bolts to both ends of the columns before testing. Fig. 2 shows the test setup used during the experiment. All the columns were subjected to eccentricity of 60 mm. Six strain gauges were mounted on the steel tube surface to measure the axial strain at the mid-height of the column. Five linear variable displacement transducers (LVDT) were used along the height of the column to record the deflections. One LVDT was installed at the actuator to measured vertical deflection of the column. Displacement controlled loading of 18mm/hr was used during the testing.

III. Experimental Results and Discussion

Fig. 3 shows the axial load-lateral deflection relationships of the columns. The lateral deflection was taken at the mid-height of the columns. Apparently, the local buckling for all columns only occur after the ultimate load was achieved even though the cross-sections were classified as slender. In EC4 [9], the effect of local buckling in CFST sections may be neglected when the width-to-thickness ratio is lower than $52\sqrt{(235/f_y)}$.

The ultimate strength for Column A was attained at the mid-height deflection, δ_c = 34.20 mm, and Column B with reinforcements attained the ultimate strength at δ_c = 43.97 mm. In term of strength, the ultimate load of Column B was 10% higher than Column A. The test results are summarized in Table II. The test result indicates that embedding plate reinforcements into the concrete core increases the ultimate load of a square CFST column.

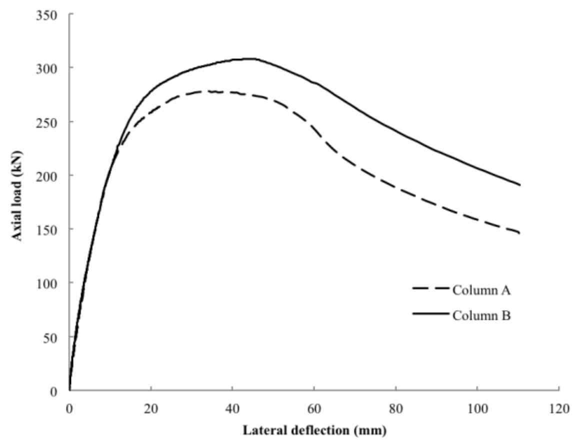


Figure 3. Axial load versus lateral deflection relationship

The stiffness, K_e decreases from 20.45 for Column A to 18.72 for Column B. This was mainly due to the cross-sectional area of the concrete is lower in Column B with the use of plate reinforcements.

Ductility, μ was defined as division of the maximum deflection, δ_{max} over the yield deflection, δ_y [10]. The δ_y was defined by the secant stiffness connecting the origin and 75% ultimate load. While, the δ_{max} was defined as the post ultimate load deflection corresponding to 85% of the ultimate strength. With addition of the plate reinforcements, the ductility was decreases slightly from 4.40 to 4.27 for Column A and B respectively.

TABLE II: Summary of Test Results

Column	Strength		Stiffness		Ductility	
	δ_c (mm)	P_{ult} (kN)	δ_y (mm)	K_e (kN/mm)	δ_{max} (mm)	μ
A	34.20	281	13.75	20.45	60.44	4.40
B	43.97	308	16.47	18.73	70.28	4.27

IV. Conclusions

Square or rectangular CFST columns are known to be less superior to its circular counterpart. There were a lot of researches have been done previously in order to improve the mechanical properties of a square or rectangular CFST columns This entire stiffening schemes were proven to be able to enhance the mechanical properties of the square or rectangular CFST columns. Though, most of the existing methods may have limitations in material efficiency or construction practice as discussed earlier. Hence, another method to improve the mechanical properties of square CFST column was introduce in this study. In this method, the square CFST columns were reinforced by the longitudinal steel plate reinforcements embedded into the concrete core rather than welding it to the steel tube. The test results revealed that the proposed method was able to improve the ultimate strength of the columns. The improvement in the ultimate strength was similar to using longitudinal plate stiffeners welded to the steel tube. Also, it can be concluded that the stiffness and ductility decreases with addition of steel plate reinforcements. However, this study is limited to slender square CFST columns and subjected to single-curvature bending through eccentricity. Further research is required to examine performance of this method on improving the mechanical properties of axially loaded stub square CFST stub columns.

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