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Ultimate resistance behavior of rectangular concrete-filled tubular beam-columns made of high-strength steel

Yansheng Du [b], Zhihua Chen [a,b,*], Yan-Bo Wang [c], J.Y. Richard Liew [c]

[a] State Key Laboratory of Hydraulic Engineering Simulation and Safety, Tianjin 300072, China
[b] Department of Civil Engineering, Tianjin University, Tianjin 300072, China
[c] Department of Civil & Environmental Engineering, National University of Singapore, 117576, Singapore

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ABSTRACT

High-strength steel is permitted in steel structures, whereas, further studies are needed to allow the use of high-strength steel in concrete-filled tubular (CFT) structures. In this study, twelve rectangular CFT columns using Q460-grade steel were tested under eccentric load and the test results were discussed. A nonlinear finite element model (FEM) was developed to predict the load-displacement and ultimate resistance behaviors of the test columns. Parametric studies were conducted using the verified FEM to investigate the influence of aspect ratios, steel strength, and width-to-thickness (h/t) ratio of steel plate. The ultimate resistance calculated by European Code (EC4), American Code (AISC 360) and Chinese Code (CECS 159) is compared with the FEM predictions to evaluate their feasibility in the use of higher aspect ratios, high-strength steel, and various h/t ratios. The results indicate that the three design codes are safe in the design of columns with higher aspect ratios. EC4 is conservative in the design of rectangular CFT columns with high-strength steel up to 690 MPa under its h/t ratio limitation. AISC 360 method can accurately predict the maximum resistance of rectangular CFT columns with steel strength 550 MPa. CECS 159 method is highly conservative and can be safely extended to the use of steel strength up to 690 MPa and plate slenderness ratio $85\sqrt{235/f_y}$.

1. Introduction

Concrete-filled steel tubular (CFT) columns have been increasingly used in high-rise buildings, bridge piers and the other industrial structures [1]. The compressive resistance of the concrete core can be increased by the lateral confinement from the external steel tube and the local buckling of steel tube can be delayed by the concrete core. The concrete and steel materials complement each other to offer excellent performance in resisting high compression load. It is more convenient for the design of connections with rectangular CFT columns which can reduce the steel dosage in the construction. Hence, the rectangular CFT columns have a promising future in the application of constructions.

The effectiveness of rectangular CFT members in resisting axial force and moments can be enhanced in two ways: 1) use optimum section aspect ratio ($\alpha = h/b \geq 1$) and plate width-to-thickness (h/t) ratio; 2) use high-strength materials. Rectangular CFT columns show advantages to be utilized as edge and corner columns of a frame structures as shown in Fig. 1(a). Rectangular CFT columns with different aspect ratios can resist higher major-axis moment in the YOZ plane and the minor moment in the XOZ plane whose cross sections are shown in Fig. 1(b). With the improvement of manufacturing and welding technology, high-strength steel plates can be produced and used in rectangular CFT columns with reasonable quality and cost. The cross-sectional area may become smaller as the Q235 (nominal steel strength 235 MPa) steel tube is replaced by Q460 (nominal steel strength 460 MPa) steel tube in rectangular CFT columns, see Fig. 1(c).

High-strength steel is susceptible to local buckling which has to be treated carefully in constructions. The behaviors of square CFT columns using high-strength steel have been investigated by some researchers. Sakino [2], Uy [3,4], Liu [5,6,7], Liew [8], and Aslani [9] reported the experimental programs on rectangular CFT stub columns using high-strength steel under axial load, respectively. Liew [8], Fujimoto [10], Chung [11], and Kim [12] conducted tests on square CFT stub beam-columns made of high-strength steel. Varma [13] conducted the experiments on square CFT slender columns with steel strength up to 600 MPa under combined constant axial load and increasing bending moment. Mursi [14] tested four square CFT short columns and four square CFT slender columns made of 761 MPa steel and normal strength concrete. The tests on rectangular sections are relatively less than that of square CFT columns. Qu [15] and Guo [16] conducted the rectangular

* Corresponding author.
E-mail address: zhchen@tju.edu.cn (Z. Chen).

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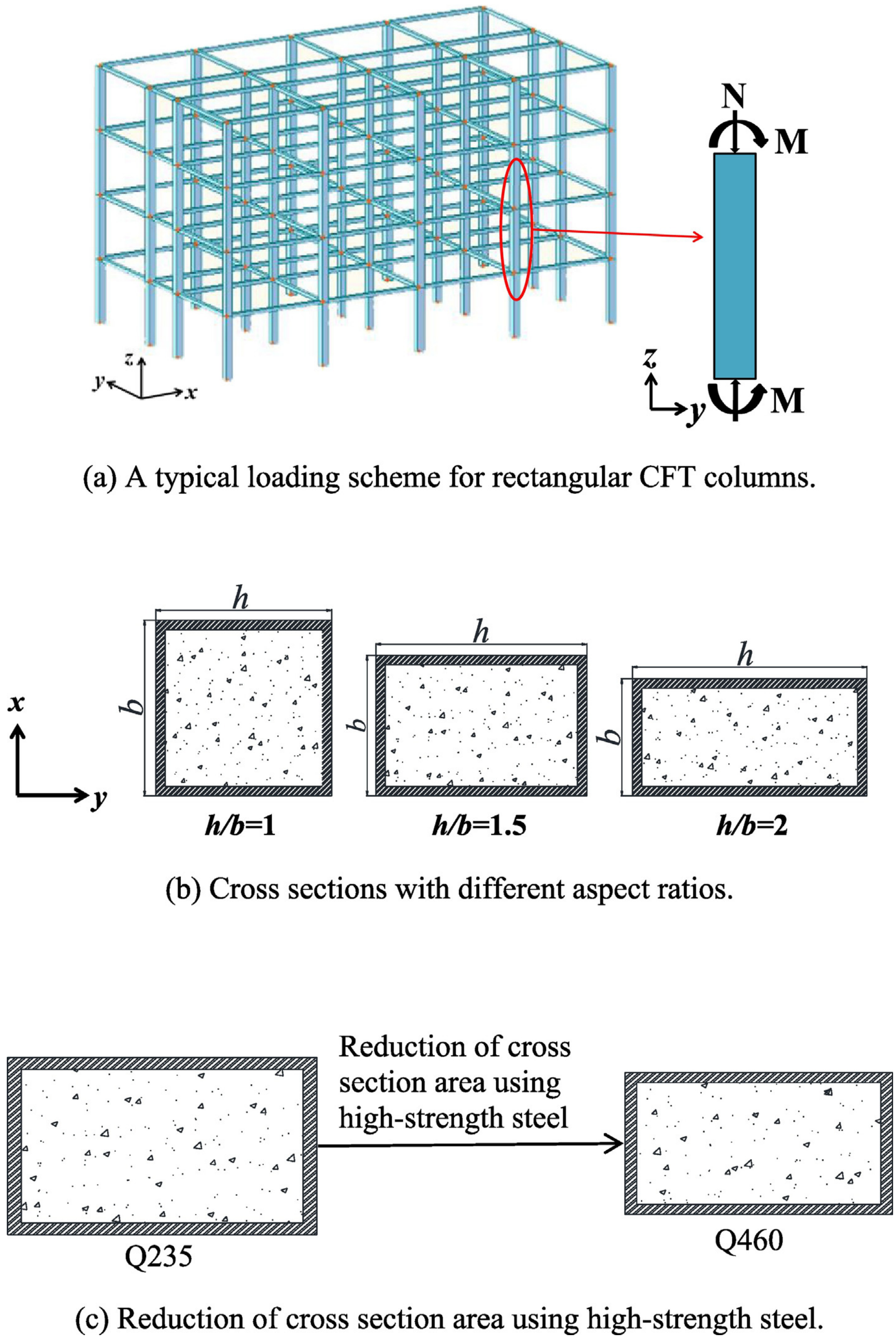

Fig. 1. Effectiveness of rectangular CFT column subject to compression and bending.

CFT columns made of normal strength steel under eccentric load. Liu [17,18] presented the test on rectangular CFT stub and slender columns made of 550 MPa steel under eccentric load. Liu [6] pointed out that the behavior of rectangular CFT columns differs from that of square CFT columns owing to the different degree of concrete confinement although he did not evaluate the differences between them. The previous research mainly focused on the square CFT columns, and the effect of aspect ratios on the rectangular CFT columns using high-strength steel has not been investigated thoroughly.

European and American specifications (EC3 [19] and AISC 360 [20]) for steel structures allow the use of high-strength steel up to yield strength of approximately 700 MPa. However, the application of high-strength steel in CFT structures has been limited by the corresponding codes. EC4 [21] specifies that the steel strength should be lower than 460 MPa, and the h/t ratios to be less than $52\sqrt{235/f_y}$ (Class 3), where f_y is the yield strength in MPa. The upper limitation of steel strength is 525 MPa for CFT columns specified in AISC 360. In the Chinese national specifications GB50936 [22], it allows only steel with $f_y \le 420$ MPa. With respect to the influence of aspect ratios, EC4 and AISC 360 take the rectangular CFT columns the same as square CFT columns. GB 50936 does not cover the design of rectangular CFT columns, so the rectangular CFT columns have to be converted to square CFT columns with the same cross-sectional area. Chinese design code CECS 159 [23] specifies that the aspect ratios should not be >2. GB 50936 and