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Bond strength between steel and self-compacting lower expansion concrete in composite columns

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A B S T R A C T

In order to study the bond behavior between the steel tube and the concrete infill, a total of 17 self-compacting lower expansion CFST columns were prepared and tested. Cross-sectional dimension, dosage of concrete expansive agent, concrete compressive strength, steel tube fabrication method and interface condition were varied to assess their effect on the ultimate average bond strength. The push-out load-slip curves for each specimen are obtained and the distribution of the interface bond stress along the member axial direction and around the cross-section for various load levels are reported. The test results indicate that the steel tube interface roughness, influenced by both the steel tube fabrication method and the interface condition, the maximum flat width-to-thickness ratio (D/t), the concrete compressive strength, and the dosage of expansion agent are the main influence factors for interface bond strength. Then, regression analysis was performed to examine the bond strength of the test results of 19 square and 13 rectangular CFST columns with cold-formed steel tubes from this investigation and other additional references. Considering the influences of the dosage of concrete expansion agent, concrete cube compressive strength and D/t ratio to the bond stress, two empirical equations have been proposed for predicting the ultimate average bond strength for square and rectangular self-compacting lower expansion CFST columns with cold-formed steel tube respectively. Finally, by the analysis of the test data and the previous four segments bond stress-slip curve model, a new bond strength-slip model fitting equation has been proposed to predict the bond stress development.

1. Introduction

CFST columns are gaining rapidly developing, which has many advantages in terms of higher carrying capacity, better ductility performance and greater energy absorption. They have been increasingly used in industrial plants, high-rise and super high-rise buildings, bridges and underground structures, etc. And CFST columns have achieved good economic benefits and building effects in practical engineering [1–6]. The constraint function of the steel tube to the concrete infill changes with the changing of the cross-section shape: the constraint stress along the radial direction in tube wall is relatively evenly distributed for circular CFST columns; while the constraint stress distribution of rectangular CFST columns is not uniform, and the stress value is larger around the corner (Fig. 1). In addition, the constraint mechanism is very complex and it is also affected by both the material property and the length-width ratio of cross-section.

By adding expansive agent in self-compacting concrete can make the concrete have the abilities of self-compacting and self-stressing [7]. The advantages of both steel and concrete can be made full use of by this kind of high performance rectangular CFST columns, and the difficult problem for concrete vibration after pouring can be solved. Besides, due to the existence of expansive agent, the concrete infill will produce pre-stress on the steel tube. Therefore, the interface bonding performance between steel and concrete for self-compacting lower expansion CFST columns will be more complex.

Researches on the interface bond strength was begun in 1975, 88 circular CFST columns push-out tests were carried out by Virdi [8] and the research results showed that the interface bond strength of circular CFST columns was not changed obviously with the concrete strength. After that, the researches of interface bond strength in circular, square and rectangular CFST columns have been carried out by domestic and foreign researchers [9–31,33]. And qualitative analyses of the influence of concrete strength, interface length, cross section shape and other factors on interface bond properties were discussed from macro perspectives. Recommended values or related calculation formulas for interface bond strength have been proposed by different researchers through experimental studies. In the British standard BS5400 [32], the design value of the interface bond strength was recommended as 0.4 MPa for CFST columns used in composite bridges, while the influence of the hollow section to the bond strength was not considered. A study for push-out tests of 64 circle and square CFST columns was

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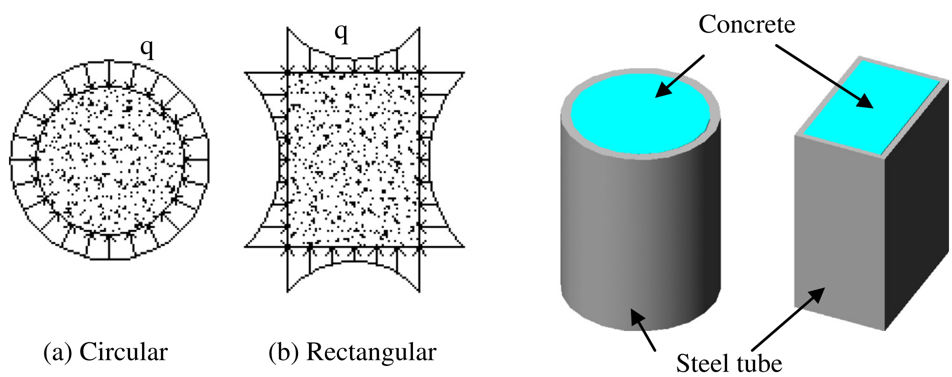


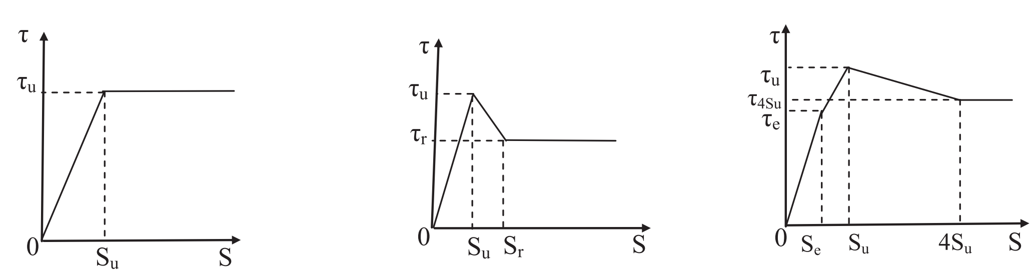
Fig. 1. The effect of different cross-section shape on concrete infill.

reported by Tao [14] in 2011, and the results of interface bond strength in circle and square CFST columns (the range of concrete strength is 46.1–72.3 MPa, the range of steel strength is 297–427 MPa) were recommended as 0.4 MPa and 0.15 MPa, respectively. In addition, the conclusion of interface bond strength in circle CFST column is mainly as follows: Chang [25] proposed an empirical equation based on the effects of pre-stress due to the use of expansive cement and compressive strength. The range of pre-stress in the formula is 0–6 MPa and the range of concrete strength is 35–50 MPa. When the pre-stress is 0, the formula is similar to the existing equation proposed by Cai [33]. Moreover, a formula with five influencing factors (slenderness ratio, D/t ratio, concrete strength, steel ratio, and constraining effect) was put forward by Kang [26]. However, the equation has a complicated form, and it is not convenient for engineering practice. For formula of interface bond strength for the rectangle CFST columns, the main factors determined by experimental study by Qu [27,28] were the width of the cross section and the concrete compressive strength, and an empirical equation for determining the rectangle CFST column interface bond strength (the range of concrete strength is 29–49 MPa, the range of steel strength is 242–336 MPa) was proposed.

Conclusions on about interface bond strength-slip curve models are mainly reflected as following: Xue [22] proposed a simplified elastic-plastic model by load-reversed push-out tests on 32 circle CFST columns carried out in wax sealing condition in 1996 (shown in Fig. 2(a)). Then, based on the analyses of push-out tests on square CFST columns, a three segments bond strength-slip model was proposed by Liu [24] in 2006 (Shown in Fig. 2(b)). After that, a four segments bond strength-slip model was proposed by Qu [29] by the analyses of push-out tests on 18 rectangle CFST columns (shown in Fig. 2(c)). Although the four segments bond strength-slip model can predict the bond-slip curve more accurate, the key points of the curve are determined by the measure data. The fitting equation for the four segments bond strength-slip model was not given. Therefore, it is not convenient for predicting the bond strength-slip curves of other CFST columns.

At present, the design of concrete filled steel tubular structure and the bearing capacity calculation theory have been gradually improved. Summarizing all the existing design codes [34–40], three different bearing capacity calculation theories are used for determining the bearing capacity of CFST columns. All the calculation formulas are different in the bearing capacity prediction accuracy, and the key reason for the difference among all the calculation theoretical assumptions is the different determination on how the steel and the concrete core work together. It should be noted that the value of the interface bond strength is the key point to ensure the two materials resist loading coordinately. Besides, the demand for the bond stress in the region of the beam-column connection is always greatest, because the vertical component of brace force is normally designed to transfer to CFST columns. Moreover, the existing calculation theories are based on the experimental research and theoretical derivation of the bearing capacity of the conventional CFST columns, and their prediction accuracy for self-compacting lower expansion CFST columns bearing capacity is still needed to be improved.

Therefore, a series of push-out tests were carried out to study the bond strength of self-compacting lower expansion CFST columns. Concrete properties (self-compacting concrete with different compressive strength and different dosages of expansive agent), cross-sectional dimension, interface condition (with and without shear studs), and steel tube fabrication method (welded steel tube and cold-formed steel tube) were designed as the main experimental parameters. The distribution of the interface bond stress along the member axial direction and around the cross-section for various load levels is reported. And the changing law of the interface bond strength with the influence factors was discussed. Besides, two new experimental bond strength equations for predicting the ultimate average bond strength of square and rectangular self-compacting lower expansion CFST columns with cold-formed steel tube were derived, respectively. And finally, based on the proposed ultimate average bond strength equations and the existing four segment bond strength-slip model, a new bond strength-slip model fitting equation was proposed.



a. Bond strength- slip elastic-plastic model[22] b. Three segment bond strength- slip model[24] c. Four segment bond strength- slip model[29]

Fig. 2. Interface bond strength-slip models.