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Finite element analysis of square concrete-filled steel tube (CFST) columns under axial compressive load

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ABSTRACT

The confinement provided in concrete-filled steel tube (CFST) columns can significantly increase the strength and ductility of the concrete columns. However, in non-circular CSFT, the confining stresses are non-uniform and anisotropic, making their incorporation in structural analysis and design fairly difficult. Herein, a novel finite element (FE) model, which takes into account the lateral expansion and triaxial behaviour of the confined concrete, plastic behaviour of the steel tube and interaction at the concrete-steel tube interface in the evaluation of the confining stress field, is developed. It is applied to analyse a total of 92 axially loaded square CFST specimens published in the literature with concrete cylinder strength ranging from 24 to 110 MPa, steel yield strength from 262 to 835 MPa and steel tube depth-to-thickness ratio from 18 to 102. Overall, the FE analysis yielded full-range load-strain curves in good agreement with the experimental results. Using the new FE model, parametric studies on the effects of corner radius have been conducted and it is found that increasing the corner radius would produce better confinement at post-peak stage and thus would improve the post-peak behaviour of square CFST columns.

1. Introduction

Concrete-filled steel tubes (CFST) have several benefits in terms of structural performance and constructability. Firstly, the concrete infill can increase the effective stiffness of the steel tube and reduce the risks of global and local buckling. Secondly, when under compression, the restraint of the steel tube against lateral dilation of the concrete can provide confinement to improve the strength and ductility of the concrete. Thirdly, the steel tube can be used as a permanent formwork for concrete casting to save construction time and cost. Because of these benefits, this structural form is rapidly gaining popularity. For instance, in China, there are already many arch bridges (e.g. Shuibai Railway Beipan River Bridge) and tied-arch bridges (e.g. Dongguan Shuidao Bridge) constructed of CFST [1].

It is well recognized that the confinement effect in CFST is dependent on the shape of section. Generally, a circular CFST under axial compression will have the ideal confinement effect because the confining stresses in the concrete are always uniform across the section and isotropic. For a non-circular CFST, however, the confining stresses in the concrete are non-uniform and anisotropic, and in general would produce a smaller increase in axial compressive capacity. Nevertheless, for architectural and functional reasons, the CSFT often has to be non-circular in shape. It is, therefore, important to study the structural performance in terms of both strength and ductility of non-circular CFST and produce design guidelines for such CFST, especially square CFST, which are quite common.

Schneider [2] had tested axially loaded CFST columns with steel tubes of varying depth-to-thickness ratios and found that the ductility of a CFST column would increase as the depth-to-thickness ratio of the steel tube decreases and that at the same depth-to-thickness ratio, a square CFST column would have lower ductility than a circular CFST column. Uy [3] carried out experimental studies on square CFST beam-columns under axial load, eccentric load and 4-point bending to investigate the strength-interaction relation of square CFST. He observed separation between the steel tube and the infilled concrete prior to reaching the peak load and thus inferred that the steel tube confinement may not be effective. However, he had not extended his study to further investigate the effectiveness of the steel tube confinement at the post-peak stage. Uy [4] also performed experimental and numerical studies on square CFST beam-columns made of high-strength steel with strength up to 750 MPa. He discovered that the design guidelines in Eurocode 4-1994 [5] was unable to give conservative strength estimates for square CFST made of high-strength steel and thus proposed some modifications to the Eurocode to cater for such CFST.

Varma et al. [6] had tested square CFST beam-columns made of high-strength concrete with cylinder strength up to 110 MPa by

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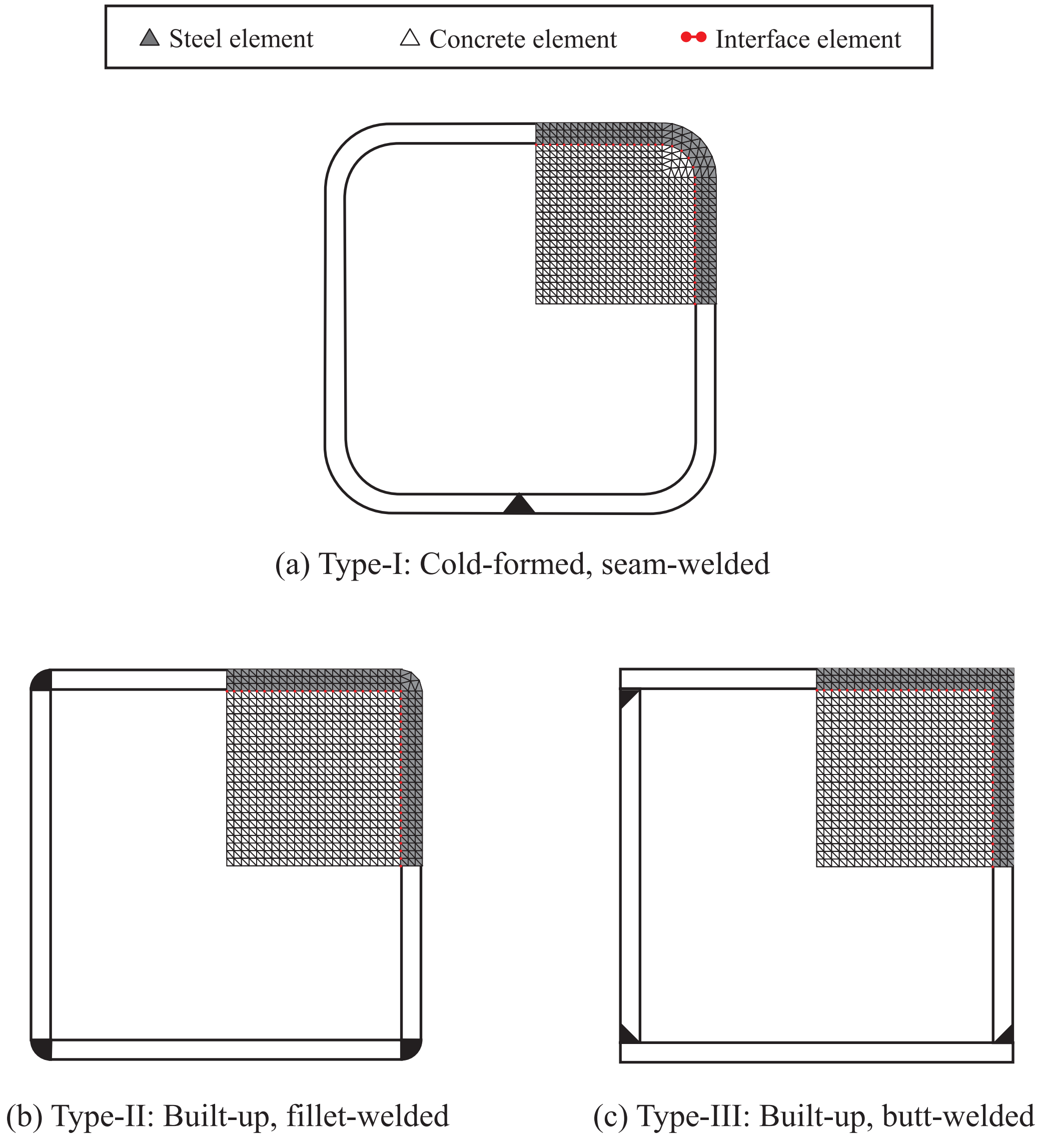

Fig. 1. Steel tube types and corresponding FE meshes.

applying combined axial load and bending moment. They concluded that the American Code ACI 318-99 [7] can give reasonably accurate predictions of the axial load-bending moment interactive strengths of such CFST. However, it should be noted that although the interactive strengths of CFST up to fairly high concrete strength can be accurately predicted because the confinement effects are actually quite small before the peak loads are reached, the post-peak behaviour, which governs the ductility, is not easy to predict due to larger and more complicated confinement effect at the post-peak stage.

Sakino et al. [8] made use of the experimental results of axially loaded CFST columns with circular or square sections to develop a unified axial stress-strain model for the two types of sections. Somehow, the confinement effects in the two different types of sections have not been explicitly considered in the mathematical formulation of these models. Likewise, Liu and Gho [9] also utilized experimental results to develop an empirical axial stress-strain model for the infilled concrete in square CFST. This model also has not explicitly considered the confinement effects, which could vary during loading. Overall, such empirical models [8,9], which were derived without the confining stresses explicitly evaluated from the strain compatibility condition, are of limited applicability to only CFST with similar structural parameters to those used in the calibration process of the model development.

Recently, Yu et al. [10,11] analysed FRP (fibre-reinforced polymer) jacketed concrete columns by the finite element (FE) method with the confinement effect of the FRP jacket fully considered. In the FE analysis, they simulated the lateral expansion of the concrete under triaxial compression by making solution-dependent adjustments to the dilation angle of the plastic flow potential. However, the required solution-dependent adjustments to the dilation angle are fairly complicated. Instead of making such complicated adjustments, Lo et al. [12] and Ouyang et al. [13] decided to directly compute the inelastic lateral strains of the concrete from the axial strain and lateral stresses, and hence developed a new and novel FE model, which does not require any complicated adjustments to the dilation angle.

In this research, the authors have extended the previously developed FE model [12,13], which is an open framework capable of incorporating any user-specified lateral strain-axial strain relation, triaxial failure surface and axial stress-strain relation of confined concrete in the analysis, to axially loaded square CFST columns. The extended model was applied to analyse square CFST specimens tested by others for verification. In each case, the analysis was continued beyond peak load to obtain the post-peak load-strain curve for ductility evaluation. Lastly, two parametric studies were conducted to investigate the effects of corner radius.