Journal of Constructional Steel Research 102 (2014) 256–265

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Numerical modelling of concrete-filled steel box columns incorporating high strength materials

Huu-Tai Thai [a,*], Brian Uy [a], Mahbub Khan [a], Zhong Tao [b], Fidelis Mashiri [c]

[a] Centre for Infrastructure Engineering and Safety, School of Civil and Environmental Engineering, The University of New South Wales, Sydney, NSW 2052, Australia
[b] Institute for Infrastructure Engineering, University of Western Sydney, Penrith, NSW 2751, Australia
[c] School of Computing, Engineering and Mathematics, University of Western Sydney, Penrith, NSW 2751, Australia

ARTICLE INFO

Article history:
Received 30 December 2013
Accepted 15 July 2014
Available online 12 August 2014

Keywords:
Finite element model
High strength concrete
High strength steel
Confining stress
Concrete-filled steel columns

ABSTRACT

In this paper, an accurate finite element model which accounts for the effects of initial local imperfections and residual stresses is developed for the nonlinear analysis of high strength steel box columns infilled with high strength concrete. The inelastic behaviour of the steel box and the concrete core is modelled using an elastic–plastic model with linear hardening and a concrete damaged plasticity model, respectively. In addition, an extensive numerical analysis based on a wide range of width-to-thickness ratios, yield stresses of steel tubes and compressive strengths of concrete core was also carried out to propose a new empirical equation for estimating the confining pressure on the concrete. The predictions of ultimate strengths, behaviour and failure modes are compared with experimental results to verify the accuracy of the present model. Parameter studies indicate that both the Eurocode EC4 and Australian Standard AS 5100 approaches can be safely extended to predict the ultimate strength of concrete-filled steel columns with high strength materials.

1. Introduction

Concrete-filled steel tubular (CFST) structures have been increasingly used in high-rise buildings, bridges and other industrial structures because of their excellent seismic performance such as high strength, high ductility and large energy absorption capability. Compared with normal strength CFST columns, high strength CFST columns have been found to be more attractive due to benefits from reducing materials and the impact of construction materials on carbon emissions [1]. Although extensive theoretical and experimental studies on CFST columns have been carried out, studies on CFST columns fabricated by high strength materials are still limited.

Experimental and analytical studies on high strength steel box columns infilled with normal strength concrete have been conducted by Uy [2,3]. The obtained results were compared with the Eurocode 4 (EC4) approach which limits the maximum yield stress of steels to 460 MPa and compressive strengths of concrete to 60 MPa. It was shown that EC4 overestimated the ultimate strength of cross-sections. Sakino et al. [4] carried out a comprehensive experimental investigation on composite columns fabricated from both normal strength and high strength materials. The yield stress of steel tubes ranged from 262 MPa to 835 MPa, whilst the compressive strength of the concrete ranged from 41 MPa to 80 MPa. Design formulas to estimate the ultimate strength of composite columns were also proposed based on test results. Liu and his colleagues [5–7] presented some tests on rectangular steel tube columns infilled with high strength concrete of cylinder compressive strengths from 55 MPa to 106 MPa. The experimental results were used to calibrate the specifications in EC4. It was found that EC4 gave a close and conservative prediction of the ultimate strength of the specimens fabricated by high strength steel, but it overestimated the ultimate strength of the specimens fabricated by mild steel [6]. Experimental studies on circular steel tubular columns infilled with ultra-high strength concrete of compressive strength close to 200 MPa were conducted by Liew and Xiong [8,9]. It was revealed that EC4 provided reasonable estimation of the ultimate strength of composite columns if the confinement effect was considered. Recently, Liew et al. [10] and Uy et al. [1] presented experimental studies on square composite columns fabricated from both high strength steels and high strength concrete.

In order for the widespread applicability of high strength CFST columns, further research on these structures is necessary. Although experimental approaches provide reliable results, it is highly expensive and time-consuming. Therefore, numerical methods, such as finite element models and beam-column models, offer an effective way to investigate the behaviour of CFST structures considering a wide variety of parameters. Although the finite element (FE) models [11–17] are more computationally intensive than the beam-column ones [18,19], they can provide highly accurate predictions due to the explicit modelling

* Corresponding author. Tel.: +61 2 9385 5029; fax: +61 2 9385 6139.
E-mail address: t.thai@unsw.edu.au (H.-T. Thai).

http://dx.doi.org/10.1016/j.jcsr.2014.07.014

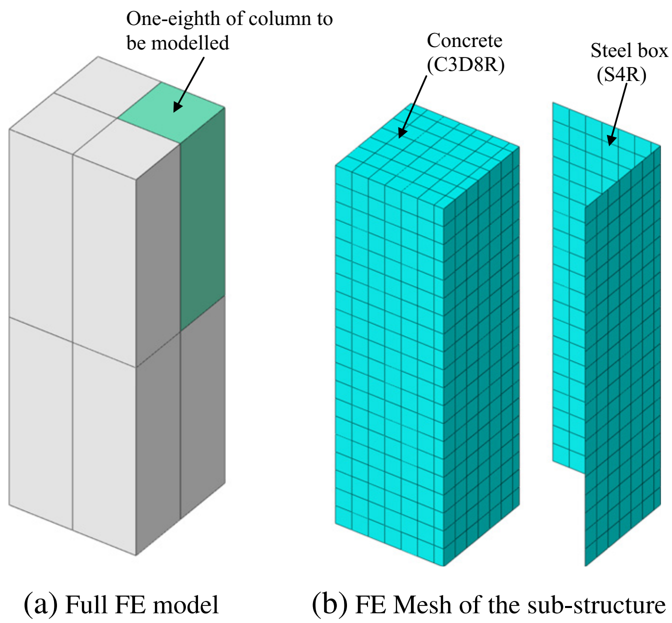

Fig. 1. Modelling of CFST columns.

of initial imperfections, residual stresses and steel–concrete interaction. A literature survey reveals that existing FE models [11–17] are applicable for composite columns fabricated from normal strength materials. This paper therefore aims to develop an accurate FE model to predict the ultimate strength and behaviour of composite columns fabricated by high strength materials. In the present model, the steel tubes and concrete infill are modelled using 4-node reduced integration shell elements (S4R) and 8-node reduced integration brick elements (C3D8R) available in the ABAQUS element library [20], respectively. The effects of initial local imperfections and residual stresses of steel tubes are also incorporated in the present model. Inelastic behaviour of steel tubes and concrete infill is modelled using elastic–plastic with linear hardening and concrete damaged plasticity models, respectively. A new equation for estimating the confining pressure on concrete is proposed based on an extensive numerical analysis of CFST columns. The validity of the present model is verified by test data. Parameter studies are carried out to evaluate the extendable application of EC4 and AS 5100 approaches for CFST columns with high strength materials.

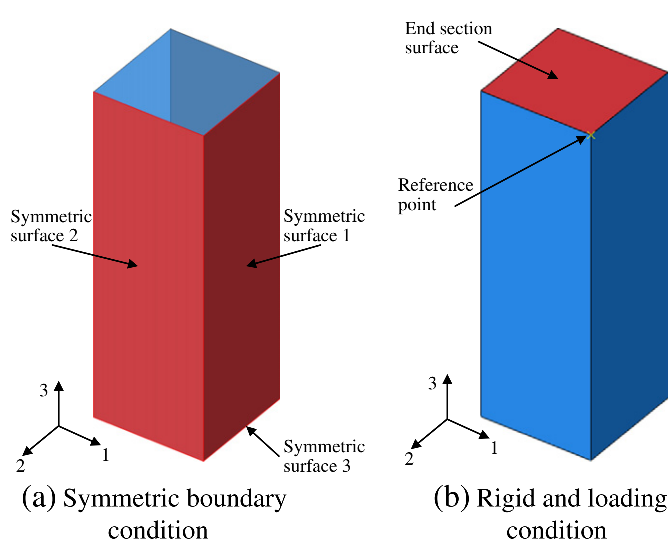

Fig. 2. Boundary and loading conditions.

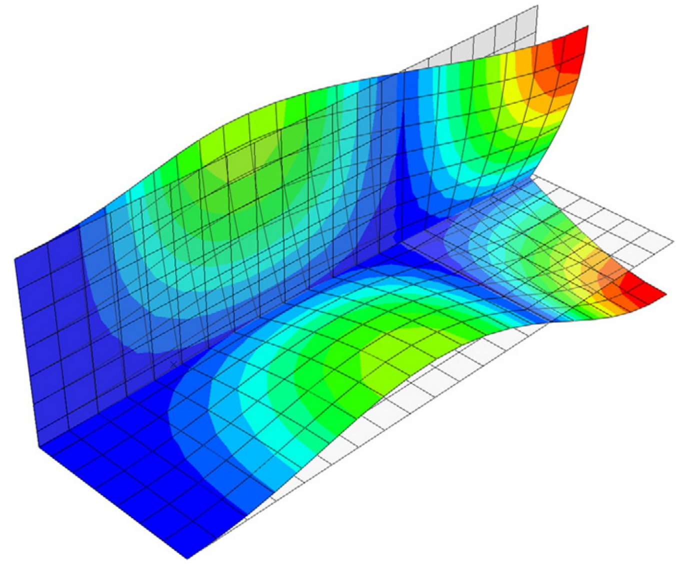

Fig. 3. First buckling mode shape.

2. Finite element modelling

2.1. General description

In this study, the finite element programme ABAQUS [20] is employed to develop an accurate FE model for predicting the ultimate strength and behaviour of high strength CFST columns under axial compression. Due to the symmetrical nature of the specimens, only one-eighth of the column is modelled as shown in Fig. 1. Since initial imperfections are taken into account in the present model, an eigenvalue buckling analysis is first carried out to provide the lowest buckling mode to be used as the shape of the initial imperfection in subsequent load–deflection nonlinear analysis. The ultimate strength and post-buckling behaviour of CFST columns are then obtained from the load–deflection nonlinear analysis.

2.2. Element type and mesh

The steel box of CFST columns was modelled using 4-node reduced integration shell elements (S4R). The S4R element has six degrees of freedom per node and provides an accurate solution to most applications [20]. Meanwhile, the concrete infill was modelled using 8-node reduced integration brick elements with three degrees of freedom per node (C3D8R). Mesh convergence studies were also conducted to obtain a reasonable mesh which provided reliable results with less computational time. Based on the mesh convergence studies, the smallest

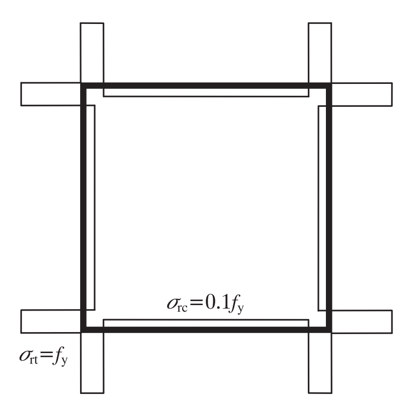

Fig. 4. Idealised residual stress distributions of steel box.