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Biaxially loaded high-strength concrete-filled steel tubular slender beam-columns, Part I: Multiscale simulation

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ABSTRACT

The steel tube walls of a biaxially loaded thin-walled rectangular concrete-filled steel tubular (CFST) slender beam-column may be subjected to compressive stress gradients. Local buckling of the steel tube walls under stress gradients, which significantly reduces the stiffness and strength of a CFST beam-column, needs to be considered in the inelastic analysis of the slender beam-column. Existing numerical models that do not consider local buckling effects may overestimate the ultimate strengths of thin-walled CFST slender beam-columns under biaxial loads. This paper presents a new multiscale numerical model for simulating the structural performance of biaxially loaded high-strength rectangular CFST slender beam-columns accounting for progressive local buckling, initial geometric imperfections, high strength materials and second order effects. The inelastic behavior of column cross-sections is modeled at the mesoscale level using the accurate fiber element method. Macroscale models are developed to simulate the load-deflection responses and strength envelopes of thin-walled CFST slender beam-columns. New computational algorithms based on the Müller's method are developed to iteratively adjust the depth and orientation of the neutral axis and the curvature at the column's ends to obtain nonlinear solutions. Steel and concrete contribution ratios and strength reduction factor are proposed for evaluating the performance of CFST slender beam-columns. Computational algorithms developed are shown to be an accurate and efficient computer simulation and design tool for biaxially loaded high-strength thin-walled CFST slender beam-columns. The verification of the multiscale numerical model and parametric study are presented in a companion paper.

1. Introduction

High strength thin-walled rectangular concrete-filled steel tubular (CFST) slender beam-columns in composite frames may be subjected to axial load and biaxial bending. Biaxially loaded thin-walled CFST slender beam-columns with large depth-to-thickness ratios are vulnerable to local and global buckling. No numerical models have been developed for the multiscale inelastic stability analysis of biaxially loaded high strength thin-walled CFST slender beam-columns accounting for the effects of progressive local buckling of the steel tube walls under stress gradients. The difficulty is caused by the interaction between local and global buckling and biaxial bending. However, it is important to accurately predict the ultimate strength of a thin-walled CFST slender beam-column under biaxial loads because this strength is needed in the practical design. This paper addresses the important issue of multiscale simulation of high strength thin-walled rectangular CFST slender beam-columns under combined axial load and biaxial bending.

Extensive experimental investigations have been undertaken to determine the ultimate strengths of short and slender CFST columns under axial load or combined axial load and uniaxial bending [1–9]. Test results indicated that the confinement provided by the rectangular steel tube had little effect on the compressive strength of the concrete core but considerably improved its ductility. In addition, local buckling of the steel tubes was found to remarkably reduce the ultimate strength and stiffness of thin-walled CFST short columns as reported by Ge and Usami [10], Bridge and O'Shea [11], Uy [12] and Han [13]. As a result, the ultimate strengths of rectangular CFST short columns can be determined by summation of the capacities of the steel tube and concrete core, providing that local buckling effects are taken into account as shown by Liang et al. [14]. Moreover, experimental results demonstrated that the confinement effect significantly increased the compressive strength and ductility of the concrete core in circular CFST short columns. However, this confinement effect was found to reduce with increasing the column slenderness as illustrated by Knowles and Park [2] and Liang [15]. In comparisons with researches on CFST columns under axial load and uniaxial bending, experimental investigations on biaxially loaded rectangular thin-walled CFST slender beam-columns have received little attention [16–18].

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