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Analytical behaviour of tapered CFDST stub columns under axially partial compression

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ABSTRACT

This paper conducts a numerical investigation on the behaviour of tapered concrete-filled double skin steel tubular (CFDST) stub columns subjected to axially partial compression. A finite element analysis (FEA) model is developed to investigate the partial compressive behaviour of the CFDST column. The full-range load versus deformation relations of tapered CFDST columns under partial and overall compression are both analyzed using the verified FEA model. A parametric study is then conducted to investigate the ultimate strength of the column with various geometric and material parameters. Finally, a simplified model is proposed based on the parametric analysis, which could predict the ultimate strength under partial compression with generally good accuracy.

1. Introduction

In the past decades, the concrete-filled double skin steel tubular (CFDST) member has attracted attentions from researchers and engineers all over the world. Numerous experimental and theoretical investigations have been done on CFDST members under various loading conditions, such as static loading (Wei et al. [1], Zhao et al. [2], Han et al. [3], Pagoulatou et al. [4], Liang [5], Uenaka et al. [6], Huang et al. [7], Hu et al. [8]), long-term sustained loading (Han et al. [9]), cyclic loading (Zhou et al. [10]), fire (Shekastehband et al. [11], Imani et al. [12]), lateral impact loading(Aghdamy et al. [13]), partial loading (Yang et al. [14]), joint connection (Chen et al. [15], Hou et al. [16]) and preloading on steel tubes (Li et al. [17]), etc. It was found that CFDST members inherited similar behaviour from conventional concrete-filled steel tubular (CFST) members with high bearing capacity, large stiffness, good ductility, favorable energy dissipation ability and reasonably good fire resistance. Moreover, the CFDST member is characterized by a lighter self-weight when compared with the solid CFST one, which might make it a better solution when designing the member of large cross-sectional profile.

The tapered columns with varied cross sections along the longitudinal direction may be a more economical choice in some particular cases such as station platforms, transmission tower, exhibition halls and bridges, for the lighter self-weight when compared with that of the straight ones. Furthermore, it might also have better architectural appearance. Fig. 1 shows an application of tapered CFST columns in a spacious structure in China. The outer diameter of the cross-section of the tapered CFST columns changes from 2100 mm to 1300 mm along the longitudinal direction. It can be seen from Fig. 1 that the axial load is transferred to the top end of the tapered CFST column through a rigid block and an endplate. In fact, the top section of the tapered CFST column is subjected to axially partial compression rather than compression on the entire cross section (overall compression in short). It was found from previous studies that the behaviour of CFST columns under partial compression is different from those of the members under overall compression, and it is significantly influenced by the thickness of the top endplate (t_a) and the partial compression area ratio (β) [18], of which the partial compression area ratio is given by $\beta = A_c / A_p$, A_c is the cross-sectional area of the concrete, A_p is the partial bearing area of the axial load.

Recently, tapered CFDST columns have been used in structures such as electricity transmission towers in China. It is believed that the tapered CFDST columns may also be subjected to axially partial loading conditions when the tapered CFDST columns are served as the loading-carrying members in practice. Fig. 2 shows a schematic view of a tapered CFDST member under axially partial compression. Moreover, based on their unique cross-sectional profiles, it is expected that the mechanism of tapered CFDST members under axially partial compression is different from that of the corresponding tapered CFST ones. However, there is a lack of understanding of the behaviour of tapered CFDST members subjected to axially partial compression.

In previous studies, Li et al. [19,20] have conducted both experimental and numerical investigations on the behaviour of tapered CFDST columns under concentric axial compression and eccentric compression,

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Nomenclature

A_c	Cross-sectional area of sandwiched concrete
A_{so}	Cross-sectional area of outer steel tube
A_{si}	Cross-sectional area of inner steel tube
A_p	Partial bearing area of the axial load
A_{sc}	Cross-sectional area of CFDST$(=A_{so}+A_c+A_{si})$
A_{ce}	Nominal cross-sectional area of concrete $(=\pi(D-2t_o)^2/4)$
	$d_{\text{top or bottom}}$ Outer diameter of top or bottom cross-section of inner circular steel tube
	$D_{\text{top or bottom}}$ Outer diameter of top or bottom cross-section of outer circular steel tube
E	Equivalent axial compression elastic modulus
E_c	Elastic modulus of concrete
E_s	Elastic modulus of steel
E_{so}	Elastic modulus of outer steel tube
E_{si}	Elastic modulus of inner steel tube
f_{ck}	Characteristic strength of concrete $(=0.67f_{cu}$ for normal strength concrete)
f_{cu}	Cube strength of concrete
f_c'	Cylinder strength of concrete
f_y	Yield stress of steel
f_{yo}	Yield stress of outer steel tube
f_{yi}	Yield stress of inner steel tube
H	Total height of the stub column
h	Height to the bottom section of the stub column
N	Axial load
N_L	Bearing capacity of partially loaded composite sections
N_u	Bearing capacity of overall loaded composite sections
$N_{L,test}$	Measured ultimate strength of partially loaded composite sections
$N_{L,FEA}$	Predicted ultimate strength of partially loaded composite sections by FEA
$N_{L,Prop}$	Predicted ultimate strength of partially loaded composite sections by simplified formulae
K_{LC}	Strength index
dr	Outer diameter of ring bearing plate
t_r	Thickness of ring bearing plate
t_a	Top endplate thickness
n_r	Relative rigidity radius
t_i	Wall thickness of inner steel tube
t_o	Wall thickness of outer steel tube
β	Partial compression area ratio $(=A_c\,/\,A_p)$
Δ	Axial deformation
σ	Nominal longitudinal stress
ε_a	Average strain of CFDST
χ	Hollow ratio $(=d\,/\,(D-2t_o))$
θ	Tapered angle$(=\arctan[(D_{bottom}-D_{top})\,/\,(2H)])$
α_n	Nominal steel ratio of outer tube$(=A_{so}\,/\,A_{ce})$
ξ	Nominal confinement factor$(=\alpha_n f_{yo}\,/\,f_{ck})$

Fig. 1. Tapered CFST columns used in a spacious structure.

respectively. Simplified design formulae for the calculation of the ultimate strength of tapered CFDST have been proposed. Ren et al. [21] carried out experimental investigations on tapered CFDST stub columns under axially partial compression. The test parameters included the tapered angle (θ), top endplate thickness (t_a) and partial compression area ratio (β). It was found that the axially partial compressive behaviour and failure modes of the tapered CFDST stub columns were significantly affected by the parameters investigated.

The behaviour of tapered CFDST stub columns subjected to axially partial compression is investigated by nonlinear finite element analysis in this paper. The main objectives are threefold: first, to develop a finite element analysis (FEA) model which could predict the behaviour of tapered CFDST stub columns under axially partial compression; second, to perform the full-range analysis for tapered CFDST columns under both partial compression and overall compression using the verified FEA model; and third, to develop equations which can predict the ultimate strength of axially partially loaded tapered CFDST columns based on parametric study.

2. Finite element analysis (FEA) model

2.1. General description of the FEA model

Previously, Huang et al. [7] established an FEA model to study the behaviour of circular CFDST stub columns; Li et al. [19,20] conducted numerical investigation on the tapered CFDST columns under overall compression. In this study, an FEA model referencing previous studies (Huang et al. [7] and Li et al. [19]) is developed to simulate the behaviour of the tapered CFDST columns under axially partial compression.

2.2. Material models

An elastic-plastic stress-strain relation, consisting of five stages (i.e. elastic, elastic-plastic, plastic, hardening and fracture) for structural steel, is used to represent the uniaxial stress-strain relation of steel. The Mises yield function with associated plastic flow is used in the multiaxial stress states. The steel is assumed to have isotropic hardening behaviour, which means that the yield surface changes size uniformly in

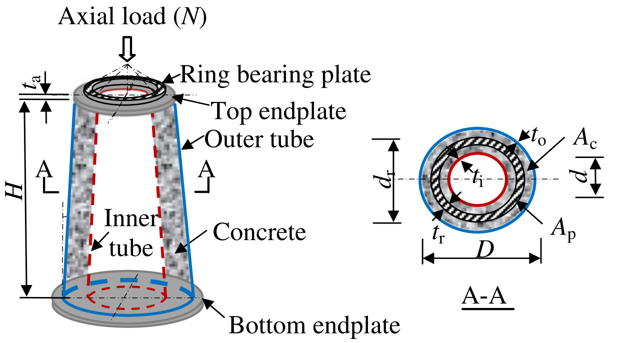

Fig. 2. Schematic view of a tapered CFDST member under axially partial compression.