Journal of Constructional Steel Research 90 (2013) 1–12

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Nonlinear behaviour of eccentrically loaded FR concrete-filled stainless steel tubular columns

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ARTICLE INFO

Article history:
Received 18 March 2013
Accepted 11 July 2013
Available online 15 August 2013

Keywords:
Composite columns
Eccentrically loaded
FR concrete
Finite element
Modelling
Stainless steel
Structural steel design

ABSTRACT

This paper investigates the nonlinear behaviour of eccentrically loaded fibre reinforced (FR) concrete-filled stainless steel tubular composite columns. A nonlinear 3-D finite element model for the axially loaded composite columns, recently reported by the author, was extended to study the structural performance of the eccentrically loaded composite columns. The columns were pin-ended subjected to an eccentric load acting along one axis. The model accounted for the inelastic behaviour of the composite column components, effect of FR concrete confinement and interface between the stainless steel section and concrete. The measured initial local and overall geometric imperfections were carefully incorporated in the model. The finite element model has been validated against tests previously reported by the author. Furthermore, the variables that influence the eccentrically loaded composite column behaviour and strength comprising different eccentricities, different column slenderness and different concrete strengths were investigated in an extensive parametric study comprising 72 columns. The composite column strengths and moment resistances predicted from the finite element analysis were compared with the design composite column strengths and moment resistances calculated using the Eurocode 4. The study has shown that finite element modelling could effectively assess the accuracy of the design rules in current codes of practice.

1. Introduction

Numerous experimental and numerical investigations were presented in the literature highlighting the advantages, behaviour and design of concrete-filled carbon steel tubular columns, as detailed for example in References [1–15]. With growing use of stainless steel as an efficient structural material compared to traditional carbon steel, the aforementioned investigations were extended to study the performance and design of concrete-filled stainless steel tubular columns as presented in References [16–20]. The presented studies [16–20] highlighted the structural performance of axially loaded concrete-filled stainless steel tubular short and long columns having circular, square and rectangular cross-sections. However, test data highlighting the structural performance of eccentrically loaded concrete-filled stainless steel tubular long columns, see Fig. 1, are rarely found in the literature, leading to the current investigation.

Fibre reinforced (FR) concrete has many advantages including elimination of micro cracks at early age of concrete, enhanced mix cohesion, improved resistance to explosive spalling in case of a severe fire, improved impact resistance, reduction of plastic cracking of concrete and particularly greater flexural and tensile strengths compared to plain concrete. The greater flexural and tensile strengths is attributed to the fact that the presence of fibres in plain concrete results in post-elastic property enhancement that ranges from subtle to substantial, depending upon a number of factors, including matrix strength, fibre type, fibre Young's modulus, fibre volume, fibre strength, fibre surface bonding characteristics, fibre content, fibre orientation, and aggregate size effects. Fig. 2 shows a comparison between a stress–strain curve of plain concrete against that of FR concrete with low and high fibre volumes. It can be seen that the presence of fibres has resulted in a considerable improvement on the stress–strain curve of concrete. Although, the concrete first-crack strength is not increased, a significant enhancement from the fibres is clear in the post-cracking response, which improves long-term serviceability of the structure. Gopal and Manoharan [21] carried out twelve tests on eccentrically loaded slender carbon steel tubular circular columns filled with both plain and steel FR concrete. The study [21] has shown that the use of FR concrete as infill material has a considerable effect on the strength and behaviour of slender composite columns. Tokgoz and Dundar [22] have investigated experimentally the structural behaviour of plain and fibre reinforced concrete-filled steel tubular columns subjected to biaxial bending and short-term axial load. The authors have concluded that the addition of steel fibres in core concrete has a considerable effect on the behaviour of concrete-filled steel tube columns. However, experimental investigations highlighting the performance of eccentrically loaded FR concrete-filled stainless steel tubular columns are rarely found in the literature, leading to the current study.

Recently, Ellobody and Ghazy [23,24] have carried out an experimental investigation on pin-ended axially and eccentrically loaded FR

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http://dx.doi.org/10.1016/j.jcsr.2013.07.018

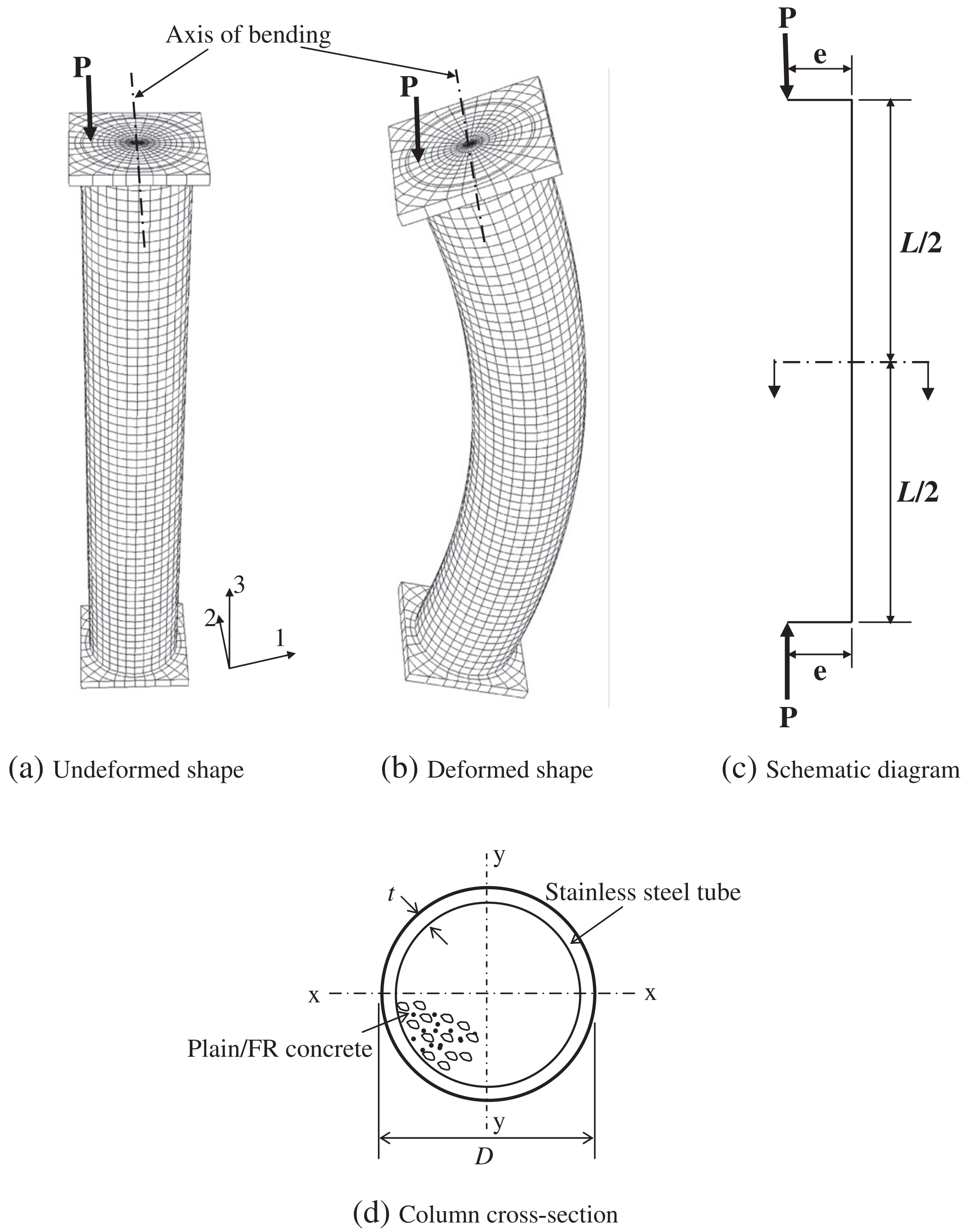

Fig. 1. Eccentrically loaded plain/FR concrete-filled stainless steel circular tubular columns.

concrete-filled stainless steel circular tubular columns. The investigation augmented available tests published in the literature on concrete-filled stainless steel composite columns [16–20]. The columns tested in References [23,24] had different lengths equal to 3*D* of short columns, 6*D* of relatively long columns and 12*D* of long columns, where *D* is the external diameter of the stainless steel circular tubes. The test ultimate loads [23,24] were compared with the design ultimate loads calculated using the European Code for composite columns. Generally, it was shown that the code accurately predicted the ultimate loads of axially loaded concrete-filled stainless steel circular tubular columns, but was quite conservative for predicting the ultimate loads of the eccentrically loaded columns. It was also shown that the conservatism of the code predictions were increased as the eccentricity was increased. However, the test results were limited to concrete cube strengths of around 40 MPa (cylinder strengths of around 30 MPa). Based on the test results [23,24], Ellobody [25] has recently developed a nonlinear 3-D finite element model for analysing axially loaded FR concrete-filled stainless steel tubular composite columns. However, up-to-date, the nonlinear behaviour of eccentrically loaded FR concrete-filled stainless steel tubular long columns remains not fully understood, which is addressed in this study.

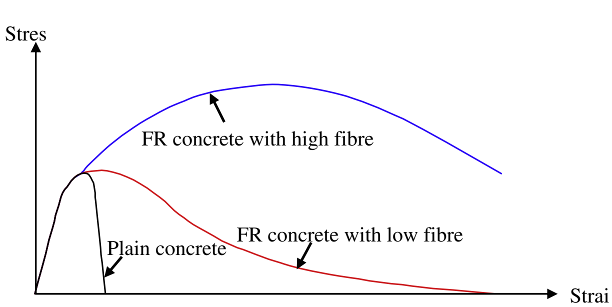

Fig. 2. Comparison of stress–strain curves of plain and FR concrete.