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Experimental behaviour of concrete-filled stiffened thin-walled steel tubular columns

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Abstract

An experimental study on the structural behaviour of concrete-filled stiffened thin-walled steel tubular columns is presented in this paper. The stiffening was achieved by welding longitudinal stiffeners on the inner surfaces of the steel tubes. Companion tests were also undertaken on 12 unstiffened concrete-filled steel tubular (CFST) columns, with or without steel fibres in the infill concrete. The test results showed that the local buckling of the tubes was effectively delayed by the stiffeners. The plate buckling initially occurred when the maximum load had almost reached for stiffened specimens, thus they had higher serviceability benefits compared to those of unstiffened ones. Some of the existing design codes were used to predict the load-carrying capacities of the tested composite columns.

Keywords: Concrete-filled steel tube (CFST); Thin walled; Columns; Local buckling; Stiffeners; Steel fibre reinforced concrete (SFRC); Strength; Ductility

1. Introduction

For concrete-filled thin-walled steel tubes, it is well known that local buckling is always a big concern in column design, especially for square or rectangular steel tubes [1–5].

In recent years, in order to improve the performance of such kind of composite columns, three stiffening measures have been proposed and studied in the literature: installing bi-directional binding bars (Fig. 1(a)), welding a set of four steel tie bars (Fig. 1(b)), and welding longitudinal stiffeners on the inner or outer surfaces of a steel tube (Fig. 1(c)). The binding bars or steel tie bars are installed at regular spacing along the tube axis. Recent test results have revealed these measures to be promising in increasing ultimate strength or ductility [6–11]. Reviews of these studies are given in [3,6], which indicates that almost all studies in the literature were performed on stiffened stub columns, while research on stiffened columns was very rare. The lack of information indicates a need for further research in this area.

As far as the welding stiffener method is concerned, the effectiveness of the stiffeners in delaying local buckling of the steel tubes has been demonstrated by stub column tests presented in [8–10]. However, test results reported in [10] have also shown that, the load versus axial strain curves tended to drop quickly after peak loads had been achieved since thin-walled tubes were used, and no obvious ductility improvement was observed with the increase of stiffener rigidity. A further experimental investigation was carried out recently by Tao et al. [11] with an aim to improve the ductile behaviour of stiffened concrete-filled thin-walled steel tubular stub columns with various methods. It was found that welding anchor bars on stiffeners and adding steel fibres in core concrete can effectively enhance the ductility capacity. The research results reported in this paper are part of a wider study on stiffened columns with cross-sections shown in Fig. 1(c).

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Nomenclature

A_{sc}	overall cross-sectional area of composite member ($= B^2$)
$A_{s,s}$	total cross-sectional area of steel stiffeners
B	width of square steel tube
CFST	concrete-filled steel tube
DI	ductility index
e	load eccentricity
e/r	load eccentricity ratio, $r = B/2$
E_c	Concrete modulus of elasticity
E_s	steel modulus of elasticity
f_{cu}	characteristic cube strength of concrete
f_y	yield strength of steel
$f_{y,s}$	yield strength of the stiffener
h_s	height of the steel stiffener
i	radius of gyration of CFST ($= \sqrt{I_{sc}/A_{sc}}$)
I_{sc}	second moment of area for CFST cross-section
L	length of column
N	axial load
N_{ue}	experimental ultimate strength
SFRC	Steel fibre reinforced concrete
t	wall thickness of the steel tube
t_s	thickness of the steel stiffener
u_m	deflection at mid-height
Δ	axial shortening
ε	strain
ε_L	longitudinal strain at extreme fibres in compression at the time of local buckling
λ	slenderness ratio ($= L/i$)

surfaces of the steel tubes. The main experimental parameters considered were load eccentricity and slenderness ratio. For comparison, additional tests were also undertaken on 12 unstiffened concrete-filled steel tubular (CFST) columns. In order to investigate the effect of adding steel fibres in core concrete on specimen behaviour, six of the unstiffened columns were constructed with steel fibre reinforced concrete (SFRC). Existing design codes with minor modifications, were used to predict the load-carrying capacities of the tested composite columns.

2. Experimental program

2.1. General

A total of 18 specimens, including six stiffened columns and 12 unstiffened columns, were tested to failure. In the case of the unstiffened specimens, half of them were filled with normal concrete (NC), and the rest of them filled with steel fibre reinforced concrete. The steel tube cross-sections for stiffened and unstiffened specimens are shown in Fig. 2(a) and (b), respectively.

All specimens were designed to have a same overall width (B) of 200 mm, as well as a same tube thickness (t) of 2.5 mm. Therefore, a width-to-thickness ratio (B/t) of 80 was achieved. According to design code AS 4100 [12], all specimens were considered thin walled since the calculated slenderness limit is 53.3 [10,12]. In determining the slenderness classification of the selected column cross-section, a local buckling coefficient $k = 10$ and an imperfection parameter $\alpha = 0.651$ were incorporated. Details of slenderness calculation of a cross-section can be found in [10,12].

The stiffeners were chosen to have a height (h_s) of 35 mm and a thickness (t_s) of 2.5 mm. The sizes of the stiffeners were so determined to meet the rigidity requirement for stiffeners presented in [10].

The main features of the test specimens are listed in Table 1, where the slenderness ratio (λ) and load eccentricity (e) for each specimen are given. In Table 1, specimen designations starting with a U refer to columns

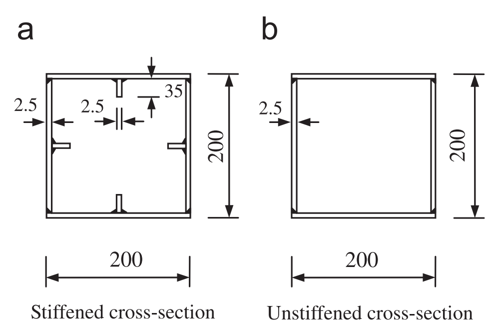

Fig. 2. Cross-sections of test specimens.

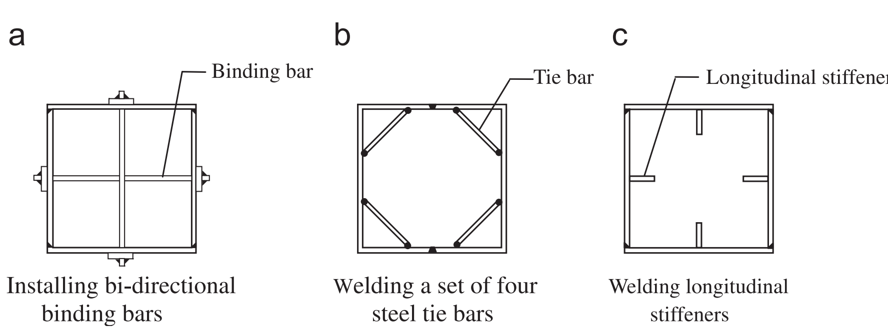

Fig. 1. Three stiffening measures to improve the performance of thin-walled CFST columns with square cross-sections.