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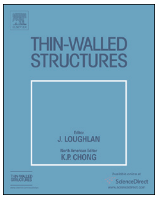

Axial strengthening of thin-walled concrete-filled-steel-tube columns by circular steel jackets

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A B S T R A C T

External confinement in the form of steel rings, tie bars, spirals and FRP wraps has been widely adopted for strengthening concrete-filled-steel-tube (CFST) columns. Previous experimental and theoretical studies have proved that it can improve the strength, elastic stiffness, ductility and interface bonding of CFST columns. However, in real engineering practise, CFST columns need to be strengthened are usually under pre-compressed axial load. The stress-lagging effect between the CFST columns and external confinement due to pre-loading has not yet been justified. In this paper, external confinement in the form of circular steel jacket is proposed to improve the uni-axial behaviour of CFST columns with and without pre-compressed axial load. An experimental study, consisting of 5 hollow-steel-tubes and 10 thin-walled CFST columns was conducted to examine the effectiveness of the proposed strengthening scheme. The main parameters were the concrete cylinder strength, jacket spacing and pre-compressed axial load level. Test results revealed that the steel jacket could improve the uni-axial behaviour of CFST columns and the stress-lagging could degrade this beneficial effect. In addition, a theoretical model developed by the authors previously was adopted to predict the uni-axial behaviour of the strengthening columns. Very good agreement has been obtained between the theoretical and experimental results.

1. Introduction

Concrete-filled-steel-tube (CFST) column, which consists of a hollow-steel-tube (HST) column filled with concrete, is widely adopted in many structures nowadays attributed to the superior behaviour by the composite action [1–4]. However, during the initial elastic stage under compression, due to the different dilation properties between steel tube and concrete [5,6], the corresponding confining stress may become negative (i.e. hoop compressive stress). This will reduce the strength, elastic stiffness and ductility of CFST columns [7,8]. On the other hand, degradation of confining stress, strength and ductility would occur in the post-elastic stage owing to the inelastic outward buckling of steel tube. To overcome the deficiencies and fully utilise the composite action of CFST columns, various approaches were proposed, which included internal stiffeners [9,10], tie bars [7], spirals [11], rings [5,8] and FRP wraps [12,13]. A brief review of these approaches has been conducted by the authors [11] and it has been concluded that among these approaches, external confinement in the form of steel rings proposed by the authors [5,8,14] is one of the best methods to improve the uni-axial behaviour of CFST columns.

However, the installation of external rings requires welding onto steel tube, which increases the surface imperfections, making the steel tube more sensitive to local buckling and the welding of rings is difficult if the tube wall is thin (diameter-to-thickness ratio over 100). Besides, none of the previous research studies have investigated the effects of pre-existing loads on stress-lagging effect between the original CFST column and the external confinement, although it was reported by Su and Wang [15] that pre-loading would degrade the effectiveness of strengthening scheme on the reinforced concrete (RC) columns seriously. (The stress-lagging effect in CFST columns is referring to the slower development of confining stress with pre-load condition.) Thus, to address the above shortcomings, a simple and novel approach, using circular steel jacket is proposed in this paper. In this approach, circular steel jacket in the form of screw clamp, which consists of a stainless steel band and a pressed screw thread pattern, is installed at different spacing against the steel tube. Fig. 1 shows that the steel band contains a captive screw at one end. When the screw is turned clockwise, the band will tighten against the external surface of the steel tube and vice versa. Thus, a perfect contact between the steel jackets and the steel tube can be produced.

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List of notations

ε_{cc}	Strain corresponding to confined peak concrete strength
ε_{co}	Strain corresponding to unconfined peak concrete strength
$\varepsilon_{s\theta}$	Hoop strain of the steel tube
ε_{sr}	Radial strain of the steel tube
ε_{ssE}	Hoop strain of external confinement
ε_{sz}	Axial strain of the steel tube
σ_E	Stress provided by external confinement (steel jacket)
$\sigma_{s\theta}$	Hoop stress provided by the steel tube
σ_{sr}	Radial stress provided by the steel tube
σ_{sut}	Ultimate tensile stress of the steel tube
σ_{ssE}	Yield stress of external confinement (steel jacket)
σ_{sy}	Uni-axial yield stress of the steel tube
$\sigma_{sy,b}$	Elastic buckling stress of steel tube
σ_{syc}	Compressive yield stress of the steel tube
σ_{syt}	Tensile yield stress of the steel tube
σ_{sz}	Axial stress of the steel tube
ν_s	Poisson's ratio of steel tube
ω	Hardening parameter
A_c	Contact concrete area
A_s	Contact steel area
CFST	Concrete-filled-steel tube
d	Nominal width of the steel jacket
D_o	Outer diameter of the steel tubes
E_c	Elastic modulus of concrete
E_s	Elastic modulus of steel tubes
E_{ssE}	Elastic modulus of external confinement (steel jacket)
f_c'	Unconfined concrete cylinder strength
f_{cc}	Confined concrete stress
f_{ccp}	Confined peak concrete stress
f_{cu}	Unconfined concrete cube strength
f_r	Total confining stress
f_{rE}	Confining stress of external confinement (steel jacket)
f_{rS}	Confining stress of steel tubes
F_c	Axial load of confined concrete
F_s	Axial load of steel tube
F_t	Axial load of CFST column
G	Shear modulus of steel tube
H	Height of the steel tube
HSC	High-strength concrete
HSCFST	High-strength concrete-filled-steel-tube
HST	Hollow steel tube
I	Increment number
K	Bulk modulus of steel tube
LS	Parameter reflecting the effect of external confinement
LVDT	Linear variable differential transducer
m	Parameter considering the effect of concrete grade
n	Number of steel jackets
N_{cal}	Maximum calculated strength
N_{exp}	Maximum experimental strength
$N_{exp\text{-}c}$	Maximum experimental strength for confined specimens
$N_{exp\text{-}u}$	Maximum experimental strength for unconfined specimens
NSC	Normal-strength concrete
NSCFST	Normal-strength concrete-filled-steel-tube
S	Centre-to-centre pacing of the steel jacket
S_θ	Deviatoric stress in hoop direction
S_r	Deviatoric stress in radial direction
S_z	Deviatoric stress in axial direction
t	Thickness of the steel tube
t_{sj}	Nominal thickness of the steel jacket

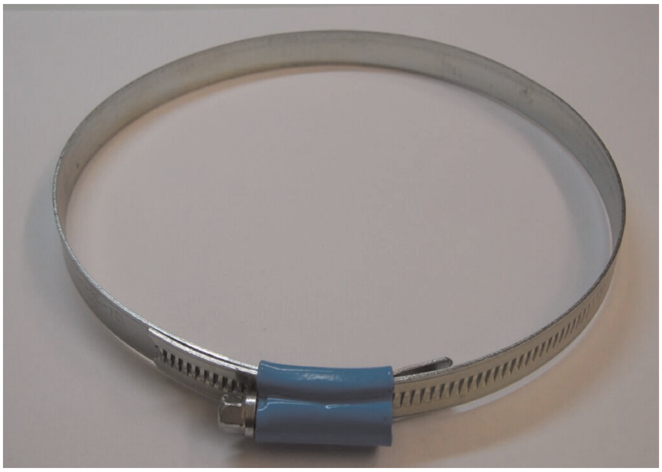

Fig. 1. Details of steel jackets.

In this paper, a total of 5 HST and 10 thin-walled CFST columns were fabricated and tested under uni-axial compression (All with diameter-to-thickness ratio over 100). The main parameters were the concrete cylinder strength, jacket spacing and pre-compressed axial load level. From the experiment, it can be concluded that the proposed circular steel jacket is effective in improving the strength and ductility of the HST and CFST columns. The stress-lagging effect between the original CFST columns and the new jackets degrades this improvement slightly. Finally, a theoretical model previously developed by the authors [16] based on: (1) an accurate hoop strain Eq.; (2) an actively confined concrete model by Attard and Setunge [17]; (3) a comprehensive steel model by Prandtl–Reuss theory; (4) Interaction of core concrete, steel tube and external confinement has been adopted to predict the uni-axial behaviour of the tested specimens. For the unconfined and confined CFST columns without any pre-compressed loads, this model can be used directly; Otherwise, this model needs minor modification (i.e. the steel jackets would be effective only after the pre-compressed axial load). The validity of the proposed model is verified by comparing with the test results in this paper.

2. Experimental Program

2.1. Specimens

A total of 5 HST and 10 thin-walled CFST columns were fabricated and tested under uni-axial compressive load. Material properties of the specimens are tabulated in Tables 1 and 2. For the CFST columns, specimens were divided into two groups depending on the concrete cylinder strength, f_c': (1) 5 CFST columns with f_c' of 30 MPa; (2) 5 CFST columns with f_c' of 80 MPa. Each group consisted of one unconfined CFST columns and four confined CFST columns. The nominal outer diameter and thickness of all the specimens were 114.3 mm and 1 mm, resulting in diameter-to-thickness ratio over 100. The measured outer diameter (D_o) and thickness (t) of steel tube were summarised in Table 1. To reduce the end effects and minimise the slenderness ratio [11,18,19], the specimens were fabricated to be exactly 350 mm in height (H),