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Experimental investigation of thin-walled concrete-filled steel tube columns with reinforced lattice angle

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ABSTRACT

Experimental investigation of thin-walled concrete-filled steel tube columns with reinforced lattice angle was conducted in this study. The lattice angle was designed to reinforce the concrete-filled steel tube columns by increasing the percentage of steel cross-sectional area. Column specimens having different lengths ranged from 500 mm to 3500 mm were tested. The behavior and strengths of concrete-filled steel tube columns with lattice angle were investigated. In addition, concrete-filled steel tube columns having the same size but without reinforced lattice angle were also tested for comparison. Material properties of the concrete and steel used in the test specimens were measured. The test strengths are compared with the design strengths calculated using the AISC Specification and Eurocode for the design of composite structural members. A new design method was also proposed for the concrete-filled steel tube columns with reinforced lattice angle. It is shown that the design predictions from the proposed method agree with test results well.

1. Introduction

Tubular structures have been widely used for their pleasing appearance, light weight, easy fabrication and rapid erection. Recently, concrete-filled steel tubes (CFST) are used in the main members of steel tubular structures due to the advantages of high strength, high ductility, high stiffness and full usage of construction materials [1–6]. Filled concrete composite members also provide a solution to those members having large diameter to thickness ratio since the filled concrete could effectively enhance the local buckling resistance of the thin-walled steel tube. However, the requirement of steel to concrete cross-sectional area ratio may not be satisfied for such thin-walled concrete-filled steel tubes. I section or crossed I-section steel member has been used to reinforce the concrete filled steel tube by increasing the percentage of steel cross-sectional area [7–8]. However, I section or crossed I-section steel bone was difficult to be erected in some structures such as an electric transmission line tower.

In this study, a lattice angle structure has been used to reinforce the concrete-filled steel tube. This kind of structural members has the engineering application in a 370 m electric transmission line tower in Zhejiang province, China. The four main columns of the electric transmission line tower are concrete-filled steel tubes with reinforced lattice angle, as shown in Fig. 1. The maximum diameter of the main columns is 2500 mm with the thickness of 25 mm. Steel tubes with large thickness are difficult to be fabricated and erected. Using of lattice angles provide an economic solution to the 370 m electric transmission line tower. Compared with those I section or crossed I-section steel members, the lattice angle has these advantages: 1) the angle could be connected to the inner wall of steel tube by short steel bars at spacing of meters so it is easy to be positioned; 2) the lattice angle could be used as scaffolding during the process of construction. Worker could climb inside the steel tube with the support from the lattice angle during the constructional process; 3) the steel cross-sectional area of lattice angle is far from the central axis of the column so that the moment of inertia could be maximized. However, the behavior and strength of this kind of composite member have not been studied. There is also a lack of knowledge about its structural behavior and corresponding design rules. Therefore, a test program on the thin-walled concrete-filled steel tube columns with reinforced lattice angle was conducted in this study.

2. Test program

2.1. Test specimen

For casting the test specimens, the ends of the steel tubes were cut to specified lengths of 500 mm, 1500 mm, 2500 mm and 3500 mm. The insides surface of the tubes was wire brushed to

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Nomenclature

A_c	concrete cross section area;
A_g	gross area of lattice angle cross section;
A_s	steel tube cross section area;
A_{sr}	lattice angle cross section area;
b_a	angle width;
E_c	elastic modulus of concrete;
E_s	elastic modulus of steel;
$E_{s\text{-}sr}$	elastic modulus of steel angle;
$E_{s\text{-}st}$	elastic modulus of steel tube;
EI_{eff}	effective stiffness of specimen;
f_c	compressive strength of concrete;
F_e	elastic buckling stress of steel lattice angle;
F_y	yield stress of steel;
$F_{y\text{-}sr}$	yield stress of steel angles;
$F_{y\text{-}st}$	yield stress of steel tubes;
F_u	ultimate strength of steel;
I_c	moment of inertia of concrete cross section about the elastic neutral axis of the composite section;
$I_{s\text{-}st}$	moment of inertia of steel tube about the elastic neutral axis of the composite section;
$I_{s\text{-}sr}$	moment of inertia of lattice angle cross section about the elastic neutral axis of the composite section;
L	specimen length;
L_a	angle length;
L_0	calculated length of specimen;
P_e	elastic critical buckling load of specimen;
$P_{pl,Rd}$	plastic resistance of the composite section;
$P_{pl,Rk}$	the characteristic value of the plastic resistance of the composite section;
$P_{u\text{-}test}$	tested compressive strength of specimen;
P_u	compressive strength of specimen calculated using a proposed method;
$P_{u\text{-}AISC}$	compressive strength of specimen calculated using AISC Standard;
$P_{u\text{-}EC4}$	compressive strength of specimen calculated using EC4 standard;
P_{u-CFT}	compressive strength of a concrete-filled steel tube calculated using AISC Standard;
P_{u-sr}	compressive strength of steel angle lattice;
r_{sr}	minimum radius of gyration of built-up steel angle acting as a unit in buckling direction;
S_a	interval distance between connected plates of built-up angles;
t	thickness of steel tube;
t_a	thickness of angle;
α	an imperfection factor, in this paper $\alpha = L/200$;
ρ	$A_{sr}F_{y-sr}/(A_c f_c)$;
ϕ	$A_s F_{y-st}/(A_c f_c)$;
λ	slenderness ratio of composite column, $\lambda = 4L_0/D$;
$\bar{\lambda}$	the relative slenderness for plane of bending;
χ	the reduction factor for the relevant buckling mode;
Φ_{sr}	coefficient associated with steel section reinforced ratio and slenderness ratio.

remove any rust and loose debris present. The self-compacting concrete was cured without any vibration. During curing, a very small amount of longitudinal shrinkage occurred at the top of the column. High strength cement was used to fill this longitudinal gap before the welding of the top steel end plate.

A total of 14 concrete-filled steel tube specimens were tested. Due to the computer's error, the displacement and strain data of specimen series having the diameter of 400 mm were lost. Only the ultimate strengths and failure modes were recorded for specimen series having the diameter of 400 mm. The measured cross-section dimensions and specimen length for each test specimen are shown in Table 1. Fig. 2 shows the details of reinforced lattice angle. L—500 mm columns (columns having the length of 500 mm) were design to study the local buckling of the single

Fig. 1. An electric transmission line tower in Zhejiang Province.