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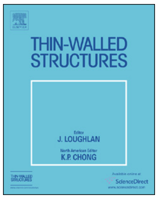

Experimental study of concrete-filled multiplanar circular hollow section tubular trusses

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ABSTRACT

This paper presents an experimental study on concrete-filled multiplanar tubular trusses made of circular hollow section (CHS) members. A total of four types of concrete-filled multiplanar tubular trusses including Triangular truss (TT), Inverse-Triangular truss (IT), Square truss (ST) and Trapezoid truss (TZ) were tested under static loading. The failure mode, load carrying capacity, overall deflection and strain intensity of all specimens are reported. The effects of top and bottom chord members, straight and diagonal brace members and lateral bracings on the load carrying capacity, flexural rigidity and ductility of all specimens were also investigated. The typical failure modes observed from the tests include the local buckling of straight brace members, the surface plasticity and shear failure of the bottom chord members, the weld fracture around tubular joints at the bottom chord members, and the end support failure of the top chord member. The load carrying capacity, flexural rigidity and ductility of different types of multiplanar tubular trusses made of identical CHS members are quite different due to the remarkable changes of the mechanical behaviour of CHS members. On the other hand, the lateral bracings play different roles under different load levels in enhancing the load carrying capacity of different types of multiplanar tubular trusses. It is demonstrated from the comparison that the Inverse-Triangular truss (IT) has optimum flexural rigidity, ductility and efficiency in practice.

1. Introduction

Multiplanar tubular truss is nowadays increasingly used in stadium, exhibition hall, bridge and pipeline structure due to its aesthetic appearance and excellent structural performance. However, the load carrying capacity and flexural stiffness of tubular truss made of hollow section members are rather limited compared to the rapid development of super long-span structures and increase of all types of loads. One of the commonly used reinforcing methods is to fill the chord members with concrete or grout. The behaviour of the resulting structure which is the so called concrete-filled multiplanar tubular truss is significantly improved by enhancing the concrete strength with the confinement of the steel tube and preventing the inward buckling of steel tube with the help of the infilled concrete.

Extensive research studies have been conducted in recent years on concrete-filled tubular trusses made of circular hollow section (CHS), square hollow section (SHS) and rectangular hollow section (RHS) members. A parametric study was performed by Kozy et al. [1] on the bearing capacity of long-span tubular truss. The effects of the geometry of bearing connection, the nature of loading and material properties on the bearing capacity of tubular truss were evaluated. The failure mechanism was analyzed and the design equations were proposed. Kawano et al. [2] studied the deformation capacity of tubular trusses with concrete filled in the chord members. This type of reinforced tubular trusses provided excellent deformation capacity under both monotonic and cyclic loading. Mujagic et al. [3] present the analytical and experimental findings pertaining to the design and behaviour of composite truss members with standoff screws as shear connectors. An experimental and analytical investigation of buckling behaviour of bare steel and concrete-filled steel (CFS) tubes used as columns and as members of trusses was done by Fong et al. [4]. Test results were used to validate the proposed second-order analysis, which skip the assumption of effective length, for accurate and reliable design of composite members. Distribution of longitudinal shear along an interface between steel and concrete parts of various composite truss bridges from elastic phase up to plastic collapse was investigated by Machacek et al. [5]. Some recommendations for practical design of the composite truss were suggested. Tesser et al. [6] conducted a set of 24 lab tests on 12 composite steel truss and concrete beams with inferior precast concrete base completed

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Notation

TT	Triangular truss
IT	Inverse-Triangular truss
ST	Square truss
TZ	Trapezoid truss
d_0	Chord outer diameter
t_0	Chord wall thickness
d_i	brace outer diameter
t_i	brace wall thickness
2γ	chord diameter to wall thickness ratio (d_0/t_0)
β_i	brace to chord diameter ratio (d_i/d_0)
τ_i	brace to chord wall thickness ratio (t_i/t_0)
w	weld sizes
f_y	yield stress
f_u	ultimate tensile stress
f_{cu}	concrete cube strength
E	elastic modulus
F	load carrying capacity
F_y	yield loads
F_p	peak loads
U	vertical deflection
U_m	midspan deflection
U_y	midspan deflection corresponding to the yield load
U_p	midspan deflection corresponding to the peak load

by second phase concrete cast. The experiments investigated the shear and flexural strengths of the beams with different depths, widths and transverse reinforcement inclinations. Composite beams constituted by a concrete-encased steel truss welded to a continuous steel plate were analyzed using a nonlinear finite element formulation based on Newmark's classical model by Tullini et al. [7]. A series of tests were conducted on curved concrete filled steel tubular (CCFST) trusses with curved CFST chords and hollow braces subjected to bending by Xu et al. [8]. A simplified model was proposed to predict the elastic stiffness considering both the flexural and the shear deformation. The load-carrying capacity of the CFST structure was also discussed. The seismic performance of an innovative lightweight bridge with CFST composite truss girder and lattice pier was studied experimentally and numerically by Huang et al. [9]. The lightweight bridge with CFST composite truss girder and lattice pier has a favourable seismic performance.

It should be noted that the aforementioned studies were mainly performed on concrete-filled uniplanar tubular trusses or multiplanar rectangular tubular trusses. There is little research being carried out on the behaviour of other types of concrete-filled multiplanar tubular trusses. Therefore, an experimental work was conducted in this study on four types of concrete-filled multiplanar CHS tubular trusses. The failure mode, load carrying capacity, flexural rigidity, overall deflection and strain intensity of all specimens were investigated.

2. Experimental study

2.1. Test specimens

A total of four types of concrete-filled multiplanar CHS tubular trusses including Triangular truss (TT), Inverse-Triangular truss (IT), Square truss (ST) and Trapezoid truss (TZ) were designed according to the design guidelines given in the CIDECT code [10] and Chinese code (GB 50017-2003) [11]. All specimens were fabricated by filling the concrete in the compression top chord members only to optimize the structural performance with slight increase of extra efforts since the concrete is much more efficient in compression. The truss configuration of all specimens is Pratt truss with symmetric geometry, loading application and boundary conditions. Hence, the internal forces of straight and diagonal brace members along the truss span are also in symmetry, in which the straight brace members are in compression and the diagonal brace members are in tension.

The nominal dimensions of CHS members including chord members, brace members and lateral bracings of all types of multiplanar tubular trusses are identical for comparison, in which the overall length, width and height are 3130 mm, 400 mm and 400 mm, respectively. The effective span between the end supports of the top chord members is 3000 mm. Hence, the height-to-span ratio and height-to-width ratio are 1:7.5 and 1:1, respectively. The tubular joints are equally spaced in 500 mm along the truss span. The top and bottom chord members of all specimens are CHS of $\varnothing 89 \times 2.5$ with outer diameter (d_0) of 89 mm and wall thickness (t_0) of 2.5 mm. The corresponding chord diameter-to-chord thickness ratio ($2\gamma = d_0/t_0$) is equal to 17.8. The straight and diagonal brace members of all specimens are CHS of $\varnothing 50 \times 2.0$ with outer diameter (d_1) of 50 mm and wall thickness (t_1) of 2.0 mm. The corresponding brace diameter-to-chord diameter ratio ($\beta_1 = d_1/d_0$) and brace thickness-to-chord thickness ratio ($\tau_1 = t_1/t_0$) are equal to 0.56 and 0.80, respectively. The lateral bracings of all specimens are CHS of $\varnothing 40 \times 1.8$ with outer diameter (d_2) of 40 mm and wall thickness (t_2) of 1.8 mm. The corresponding lateral bracing diameter-to-chord diameter ratio ($\beta_2 = d_2/d_0$) and lateral bracing thickness-to-chord thickness ratio ($\tau_2 = t_2/t_0$) are equal to 0.45 and 0.72, respectively. The dimensions of all types of concrete-filled multiplanar CHS tubular trusses including chord members, brace members and lateral bracings are detailed in Fig. 1.

The welds connecting brace and chord members, plate and SHS tube member were designed according to the American Welding Society (AWS D1.1/1.1M) Specification [12] and laid using shielded metal arc welding. The weld sizes (w) in the test specimens are all greater than the larger value of 1.5t and 3 mm, where t is the thickness of thinner part between brace and chord members or plate and SHS tube member. The 3.0 mm and 3.5 mm electrodes of type E4303 with nominal 0.2% proof stress, tensile strength, and elongation of 355 MPa, 447 MPa, and 38%, respectively, were used for welding low carbon steel (Q345) specimens. All welds consisted of 2–3 runs of welding to guarantee that failure of specimens occurred in the brace or chord members rather than the welds. As shown in Fig. 2, the brace is profiled around the intersection before it is welded onto the chord surface.

2.2. Material properties

All specimens were fabricated by using Chinese Standard Q345 steel (nominal yield stress $f_y = 345$ MPa). Tensile coupon tests were conducted according to the test procedures given in the Chinese Standard of Metallic Materials (GB/T 228-2002) [13] to determine the mechanical properties of carbon steel CHS tubes. The material properties obtained from the tensile coupon tests are the elastic modulus (E) of 206 GPa, tensile yield stress (f_y) of 428 MPa and ultimate tensile stress (f_u) of 507 MPa. The welds connecting brace and chord members as well as lateral bracings and chord members were laid using shielded metal arc welding with electrodes type of E4303.