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Concrete-filled steel tube (CFT) truss girders: Experimental tests, analysis, and design

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ABSTRACT

This paper investigates the behavior of Warren-vertical CFT truss girders by conducting both experimental tests and finite element analyses. Experimental tests on three CFT truss girders are first conducted. The test parameter is the compressive strength of the concrete infill. Finite element models, which were developed and benchmarked previously by the authors, are then used to further investigate the behavior of CFT truss girders and the influence of parameters such as the brace-to-chord strength ratio, shear span-to-depth ratio, and concrete compressive strength. Results from the parametric studies indicate that CFT truss girders are flexure dominated if (i) the brace-to-chord strength ratio ≥ 0.8 and (ii) the shear span-to-depth ratio ≥ 4.8. Both the experimental tests and FEM analyses indicate that the concrete compressive strength has negligible effects on the failure mode of CFT truss girders. Based on results from the experimental tests and FEM analyses, design equations are also proposed for estimating the flexural strength of Warren-vertical CFT truss girders.

1. Introduction

Concrete-filled steel tube (CFT) trusses usually consist of CFT chords and hollow steel tube braces, as shown in Fig. 1. The concrete infill increases the compressive strength of the top chord and the tensile strength of the bottom chord. It prevents the steel tube of the top chord from buckling inward and restrains the steel tube of the bottom chord from pinching (inward contraction due to Poisson's effect). The concrete infill also increases the strength of brace-to-chord joints and the overall flexural stiffness of the truss. Moreover, the steel tube serves as formwork for placing the concrete, which facilitates and expedites construction while reducing labor costs [1–3].

As an innovative and efficient structural system, CFT trusses have been widely used around the world in various types of structures. For example, they have been used as girders in roof systems [4]. They have also been used as main girders in cable-stayed bridges or continuous truss bridges, as shown in Fig. 2. In Wanzhou Bridge as shown in Fig. 2(a), CFT Warren truss girders were used; while in the other three bridges as shown in Fig. 2b-d, CFT Pratt truss girders were used.

The first documented research on CFT truss girders was conducted by Zhang et al. [5] in 2000. In that research, they tested a CFT truss girder subjected to in-plane bending. Since then, several researchers have experimentally investigated the behavior of these members. Fong et al. [6] conducted two experimental tests to compare the behavior of a CFT truss (Warren truss) and a hollow steel tube truss. Xu et al. [7] tested eight spatial curved CFT truss girders (Warren truss) to investigate their flexural behavior, including effects of the rise-to-span ratio (0, 0.1 and 0.2) and the presence of concrete infill. The spatial truss girders consisted of two CFT top chords spacing 432 mm apart, a CFT bottom chord locating 375 mm below the top chords, and hollow steel tube braces connecting the chords. Han et al. [8] tested 10 spatial CFT truss girders (Warren truss) to evaluate effects of the shear span-to-depth ratio (1.6 and 3.2), concrete infill, concrete slab, and the angle between diagonal braces and chords (45° and 60°). These experimental studies indicate that: (i) the behavior and strength of CFT trusses are significantly improved as compared to hollow steel tube trusses, and (ii) the failure modes of CFT truss girders usually include the tensile fracture of the bottom chord and shear failure (e.g., weld fracture and local buckling of braces).

The authors have also conducted a series of experimental tests on CFT truss girders using a four-point bending loading scheme. In the first series [9], three truss girders (Pratt truss) were tested to evaluate the effects of concrete infill. The first specimen was a hollow steel tube truss. The second specimen had concrete-filled top chord, hollow bottom chord, and hollow braces. The third specimen had concrete-filled top and bottom chords and hollow braces. The shear-span-to-

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Nomenclature

A	cross-section area of the chord
A_b	cross-section area of the brace wall
A_c	cross-section area of the concrete infill
A_s	cross-section area of the chord wall
A_{st}	cross-section area of the steel tube
D	diameter of chords
D_b	diameter of braces
F_y	yield stress of the chord wall
F_{yb}	yield stress of the brace wall
N_{tu}	tensile strength of CFT members
H	height of truss girders (centroidal distance between the top and bottom chords)
M_u	flexural strength of CFT truss girders
P_u	peak load obtained from experiments
$P_{u,est}$	peak load estimated from preliminary finite element analysis
a	shear span
t	chord wall thickness
t_b	brace wall thickness
f_{cu}	concrete cube compressive strength
$f_{cu,k}$	nominal 28-day concrete cube compressive strength
f_p	steel proportional limit, see Eq. (1)
f_u	steel tensile strength
f_y	steel yield stress
α	steel ratio, $\alpha = A_s/A$
β	force transfer coefficient for vertical braces
κ	brace-to-chord strength ratio
ξ	confinement factor, see Eqs. (2) and (3)
θ	angle between the diagonal brace and the chord

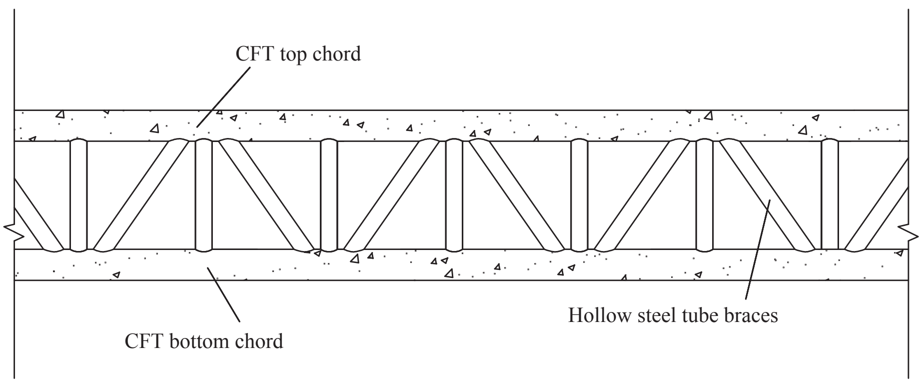

Fig. 1. Typical CFT truss girders (Warren-vertical truss).

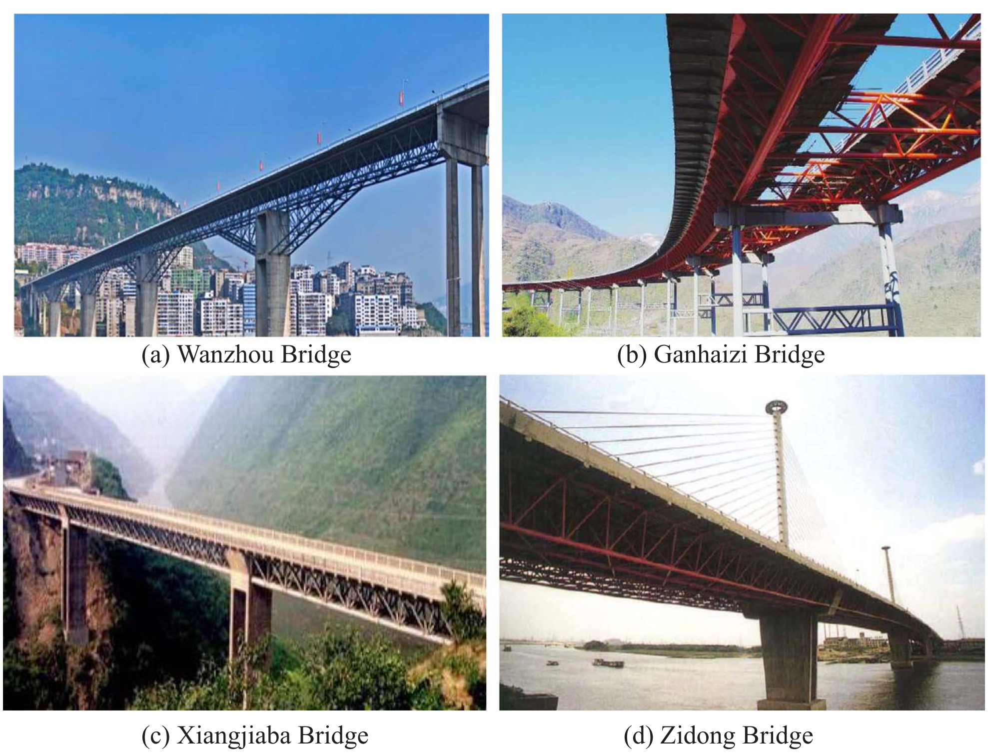

Fig. 2. Typical applications of CFT truss girders in bridges.

depth ratio was 1.8 for all three specimens. The tests indicated that filling concrete in the chord significantly changed the failure mode and increased the stiffness and strength of CFT truss girders. The first two specimens failed by the plastification of the bottom chord at the chord-to-brace joint region, while the third specimen failed by the punching shear failure of the braces. The flexural stiffness ratio of these three specimens was 1.0:1.37:1.67, and the flexural strength ratio was 1.0:1.16:1.59.