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The behavior of self-compacting concrete (SCC) infilled steel tube Warren-vertical truss girders

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Abstract: investigated the behavior of self-compacting concrete (SCC) infilled steel tube Warren-vertical truss girders in this paper. Ten simply supported truss girders including eight CFST truss girders and two hollow tube trusses were tested under one-point loading. The test parameters were the existence of concrete in the steel tube, the addition of reinforcing steel to the concrete core in the lower chord, and the type of steel tube (square and circular). Peak loads, the load-displacement curves at the mid-span, flexural strength, deflections along the span, and failure forms are all depicted in this study. The test results indicated the CFST truss girders had higher ultimate load capabilities than their hollow truss girder counterparts by about (49.59% -117.31%), also the square type truss had higher in the ultimate load compared to the circular type section of CFST truss girders, while the best rise in ultimate load comes from adding a circular tube to lower chord by about (14.67% - 26.57%).

Key words: self-compacting concrete(SCC)**,** Warren-vertical truss girders**,** CFST truss girders**,** filled steel tube, failure shapes

1. Introduction

The concrete-filled steel tube (CFST) truss is a type of composite structure with concrete filled upper and lower chords and the braces are hollow tubes. In steel tube filled with concrete (CFST) has the advantage of both steel and concrete as the infill concrete prevents local buckling inward of the steel tube, Meanwhile, the steel tube confines the concrete, causing triaxial compression stress in the concrete, which improves the structure's strength, stiffness, load-carrying capacity, and flexibility [1]. Steel tubes serve as concrete formwork, resulting in fewer working hands, lower construction costs, and shorter building times [2,3]. Vibrations affected concrete-filled parts less than hollow sections [4, 5]. Because of these advantages, CFST structures are now widely used in civil engineering structures.

The CFST trusses are currently widely utilized in large-scale structures, particularly in bridges used as bending girders, compression piers, and arch ribs in combined bending and compression [6]. Fig. 1 depicts the use of CFST trusses on the Ganhaizi Bridge in China.

Zhang Li and Cheng [7] performed the first recorded study on CFT truss girders in 2000. They investigated a CFT truss girder subjected to in-plane bending in that study. Ever after, the behavior of these members has been studied by many researchers. Huang et al. (2012) [8] investigated the influence of simply welded joints of CFST truss girder and circular hollow steel. Six truss specimens were examined. The result of this research was that the concrete-filled in the upper and lower chords raised rigidity and strength of the joint and prevented plastic failure of the chord surface. Augmented Warren-type truss girders behaved better with greater overall strength and flexural rigidity than other types of truss girders. Xu et al. (2014) [9]: the behavior of a curved concrete-filled steel tube CCFST truss subjected to bending was investigated in this study. Eight specimens were tested, including two CFST trusses that are straight, four CCFST trusses, and two empty curved steel tube trusses. The test parameters were the type of chords and the height to span ratio. The experimental outcome showed CCFST trusses were higher in stiffness and load-bearing capability than CFST trusses. Chen et al. (2015) [10] investigated the performance of concrete-filled multi-planar tube trusses in this study. Four kinds of multi-planar tube trusses constructed of circular hollow section(CHS) members that are filled with concrete including triangular, Inverse Triangular, Square, and Trapezoid were tested. The tests result showed that the failure shape of multiplanar trusses involves local buckling of straight brace members, the lower chord's shear failure and surface plasticity, weld failure around the bottom chord tube joints, and top chord end support failure. Perfect ductility was shown by the inverse triangular truss. Huang et al. (2017) [11] studied the influence of interfacial imperfections on the performance of CFST trusses. Four CFST trusses with various degrees and kinds of separation between the steel and concrete are carried out experimentally and analytically. The results of the testing indicated that specimens having 100 percent interfacial separation, 10% depth separation, and 20% depth separation had lower strength relative to specimen without interfacial imperfections by 9.2%, 18%, and 37.3% respectively. Zhou et al. (2017) [12] circular CFST truss girders' flexural performance was evaluated. Four specimens were evaluated in this study where three circular CFST truss girders and one empty circular steel tube truss. The main parameter was the infill concrete location. The test result show that the specimen filled with concrete in the upper and lower chord have the best ductility and load carrying capacity. Huang et al. (2017) [13] studied the performance of pre-stressed CFST truss girder experimentally and analytically. Five specimens were examined. The shear span-depth ratio, as well as the prestress level, were used as test parameters. The experimental results indicated that with rising shear span to depth ratios or prestress levels, the stiffness and strength of prestressed CFST truss girders increased. Also, the modes of failure rely on these ratios, when these ratios rise, the bottom chord tensile break of them becomes the failure mode, while the others fail due to joint shear failure. Hu et al. (2017) [14] Experimentally and analytically, the flexural performance of a concrete-filled steel tube truss composite (CFSTTC) beam with a concrete slab was examined. Two CFSTCC beams were tested. The results of the experiment indicated that the bottom chord surface plasticity failed in the first specimen T2. The second sample T1 failed because of the top chords' surface plasticity Specimen T1 had more severe local buckling and weld cracks than specimen T2. In specimen

T2, the diagonal braces will enhance the shear transformation mechanism between the upper and lower chords, stiffness, ductility, and load-carrying ability compared to specimen T1. Huang et al. (2018) [15] Experiments and numerical analysis were used to investigate the performance of Warren-vertical truss girders. Three specimens were evaluated for experimental testing. Concrete compressive strength was the test parameter. The results of the experiments show that rising the compressive strength of the concrete results in a small rise in stiffness and strength while numerical analysis results showed that when the shear length to depth ratio is less than 4.8 and the brace to chord stiffens ratio ≥ 0.8, tensile fracture at the Bottom chord is the controlling failure form. Joint failure is the controlling failure form in the other situation.

The main goal of this research was to improve the load-carrying capacity of CFST truss using reinforcing the self-compacting concrete at the lower chord on two different steel tube sections (square and circular steel tube section). The investigated specimens included eight CFST truss girder specimens and two hollow tubular trusses specimens. The test parameters were the existence of concrete in the steel tube, the addition of reinforcing steel to the concrete core in the lower chord, and the type of steel tube (square and circular).

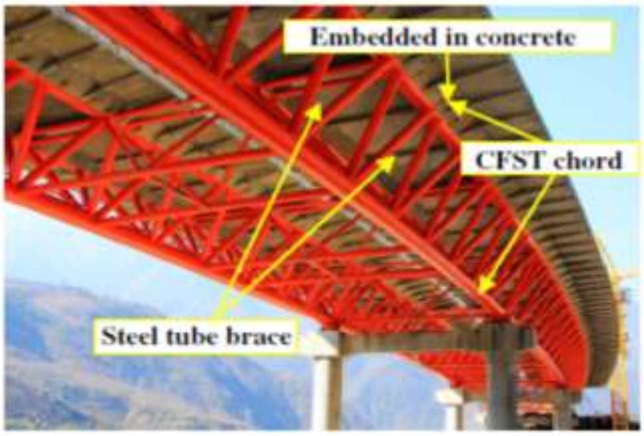

Fig. 1 The Ganhaizi Bridge in China uses CFST trusses

2. Experimental Work

Ten simply supported truss girders including eight CFST truss girders and two hollow tube trusses were tested under one-point loading. The test parameters were the existence of concrete in the steel tube, the addition of reinforcing steel to the concrete core in the lower chord, and the type of steel tube (square and circular) as shown in Table 1.

The specimen's nomenclature is divided into two parts. The first is S or C, which refers to the section type (the character S means square section and C is a circular section). The last part is HS, or R0, or R1, or R2, or RΦ. "HS" stands for hollow section without concrete filling, "R0" indicates that the bottom chord is unreinforced, " R2" means is reinforced with (2Ø10mm) steel bars in the lower chord, "R1" denotes is reinforced with (1Ø10mm) steel bar in the lower chord, "RΦ" indicates circular tube with diameter 55 mm and wall thickness 1.0 mm reinforcement the bottom chord. The gross length of the truss (1840 mm), the effective length of 1640 mm (from support to support), and the height of the truss (500 mm) were applied for all the specimens in the experiment. The main chord dimensions of square steel tube specimens are (100*100*4) mm, brace dimensions are (80*80*3) mm, while the main chord dimensions of circular steel tube specimens are (Φ100*4) mm and brace dimensions are (Φ80*3) mm. The angle between the inclined brace and main chords is 54º, the dimensions of vertical brace above the supports are (100*100*4) mm for square section and (Φ100*4) mm for circular section, this brace's dimensions have been increased to avoid local buckling caused by stress concentration at the supports, as shown in fig. 2.

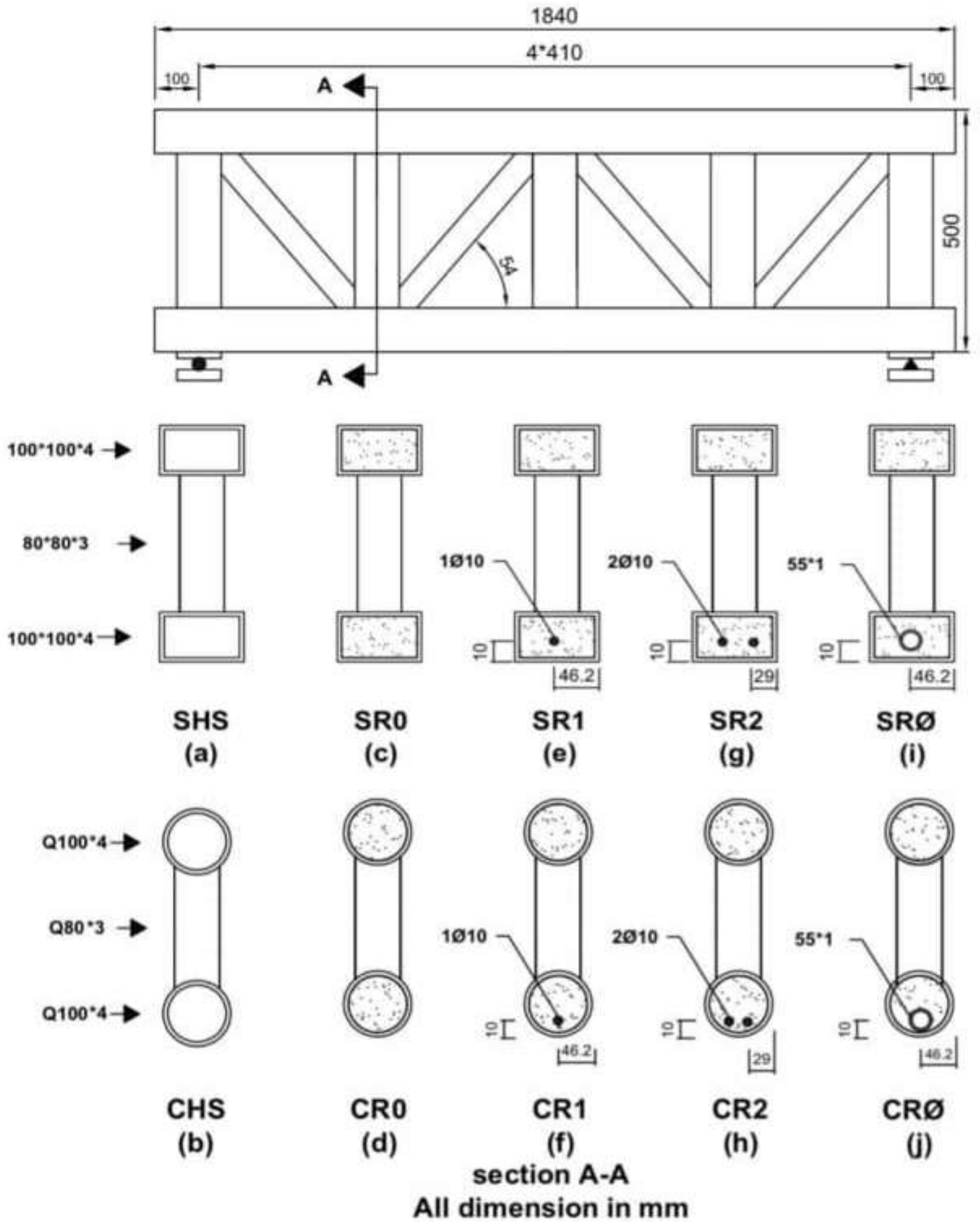

Fig. 2 Detail of specimens

The specimens were manufactured by spacing the two chords to achieve the truss's necessary height (see Fig. 3a). The braces were then welded to the main chords (see Fig. 3b). Then the specimens were coated in white color (see Fig. 3c). After the CFST specimens were fabricated, they were put vertically and self-compacting concrete was filled in the upper and lower chords (see Fig. 3d), the specimens were tested after 28 days.

The concrete grade of (SCC) that filled the chords of CFST specimens was 50 MPa. Table 2 shows the mixed proportions of the SCC. Table 3 indicated the results of the fresh concrete tests. The characteristics of the concrete were measured in accordance with European Guidelines [16].

Table 3. shown the yield and ultimate stresses of the various steel sections utilized in the specimens in accordance with ASTM 370-05a [17].

f_u (MPa)	f_y (MPa)	Steel
446.89	398	Circular tube Ø100 mm
342.51	331	Square tube 100 mm
389.71	303	Circular tube Ø80 mm
331.52	340	Square tube 80 mm
462.21	365	Circular tube Ø55 mm
599.67	462.11	Steel bar Ø10 mm

Table 1. Parameters of the test specimens.

NO.	Specimen	Section type	reinforcement at the core of the lower chord
1	SHS	Square	Non
2	CHS	Circular	Non
3	SR0	Square	Non
4	CR0	Circular	Non
5	SR1	Square	1Ø 10
6	CR1	Circular	1Ø 10
7	SR2	Square	2Ø 10
8	CR2	Circular	2Ø 10
9	SRΦ	Square	Circular tube D=55mm, t=1.0mm
10	CRΦ	Circular	Circular tube D=55mm, t=1.0mm

Table 2. SCC mix proportion.

Mix	Cement (kg/m^3)	F.A. (kg/m^3)	C.A (kg/m^3)	L.P. (kg/m^3)	S.P%	W/C ratio	f_{cu} at 28 (MPa)
C50	490	735	800	98	1.5%	0.42	49.34

Table 3. Fresh concrete testing results.

Test	result	Specification[38]
Slump (mm)	670	(600– 800)mm
T50 Slump (Sec)	4	(2 – 5) Sec

Table 4. Steel test results

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(a)Position chords

(b)welding the braces

(c)paint the specimens

(d)cast concrete

Fig.3 fabricated and casting of specimens.

Fig.4 indicated the test setup, the specimens were simply supported, and a hydraulic jack applied a concentrated load at the mid-span, which was then calculated by a load cell with a capacity machine of 1000 kN. To ensure the specimen's stability, four lateral supports were provided, two on each side. Two linear variable differential transformers (LVDT) were used to calculate the vertical deflection. Fig.6 shows the testing machine used in the test of the truss specimens.

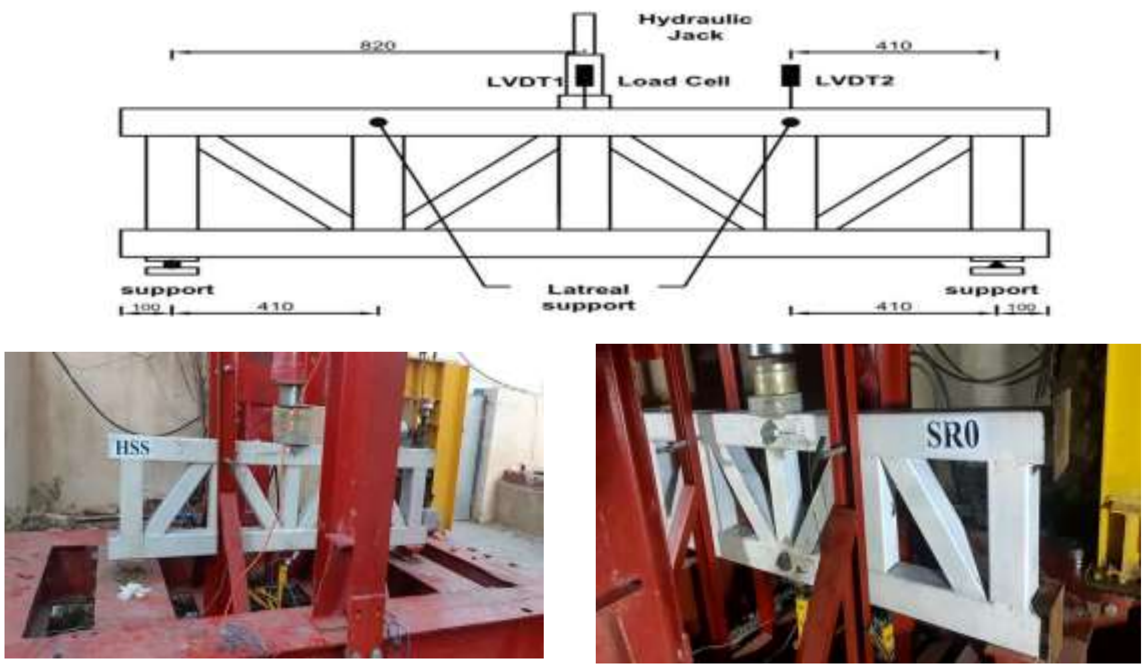


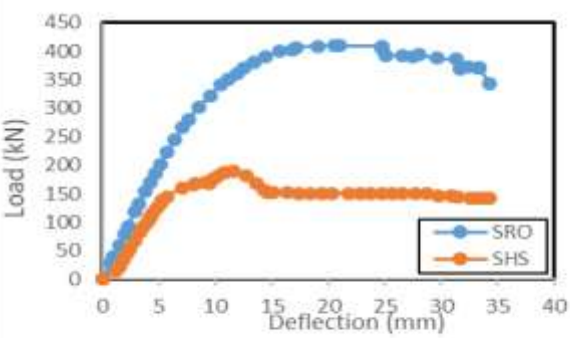
Fig. 4 Test setup (unit in mm)

3. Results of the test

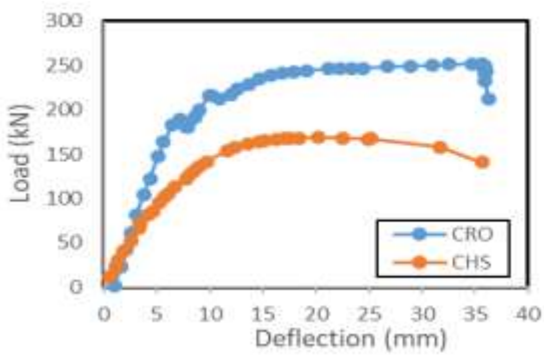
Table 5. indicates the results of specimens tested. When the concrete strength is identical to the specimens the ultimate load of SHS, SR0, SR1, SR2, and SRΦ specimens were 188.90, 410.53, 433.54, 448.33 and 470.56 kN, respectively. While the ultimate load of CHS, CR0, CR1, CR2 and CRΦ specimens were 168.05, 252.10, 270.20, 283.54, and 319.10 kN, respectively. As indicated, the ultimate load is influenced by filled chords with concrete of SR0 and CR0 specimens when comparing with SHS and CHS specimens, it can be noted that the ultimate load of the specimen's SRO and CRO is higher than that of specimens SHS and CHS by 117.31 % and 49.59 %, respectively. Due to the different in the section type of steel tube, the ultimate load is affected by this change of specimen's SRO, SR1, SR2 and SRΦ as compared to CR0, CR1, CR2 and CRΦ were increased by about 62.82%, 60.06%, 58.12% and 47.53% respectively. Meanwhile adding circular steel tube or steel bars to the lower chord of CFST truss girder specimens increased the strength of the CFST truss girder. When comparing SR1, SR2 and SRΦ specimens to SR0 specimen, we can note that the strength was increased by about 5.6%, 9.21%, and 14.67%, respectively, and increased by about 7.42%, 12.46% and 26.57% when comparing CR1, CR2 and CRΦ specimens to CR0 specimen. Based on the results, circular tube adding to concrete on the lower chord is a better option than steel bars adding. This due to the confinement between the concrete and circular tube. Fig. 5, Fig. 6, and Fig. 7 indicate the load midspan deflection of the specimens influenced by filled chords with concrete, the different in the section type of steel tube, and influenced by adding circular steel tube or steel bars to the lower chord of CFST truss girder specimens respectively. The response of specimens is almost same and enable be summed up in the following: when the load applied was less than 0.75Pu, the curve stayed roughly linear, while the applied force was between (0.75 Pu) and (0.9Pu), lower chord steel tube began to yield, however, the upper chord steel tube remained rather elastic. The specimens failed when load applied attained the ultimate load.

Table 5. Results of the specimens.

Specimen	Ultimate load Pu (kN)	Deflection at Ultimate load (mm)	Stiffness (kN/mm)	Ductility ratio
SHS	188.90	11.61	25.63	1.98
SRO	410.53	20.57	37.27	3.14
SR1	433.54	23.94	38.85	2.88
SR2	448.33	21.05	45.78	3.87
SRΦ	470.56	19.76	49.71	2.71
CHS	168.05	17.11	18.75	2.19
CRO	252.10	34.75	29.10	4.44
CR1	270.20	11.81	35.32	2.83
CR2	283.54	7.92	39.12	2.45
CRΦ	319.10	11.86	41.40	4.81

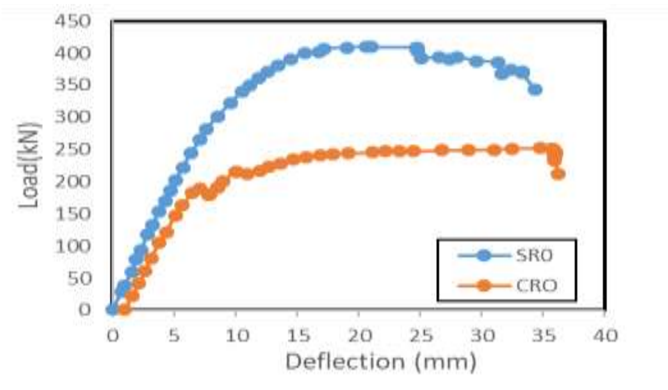


(a) SR0 and SHS specimens

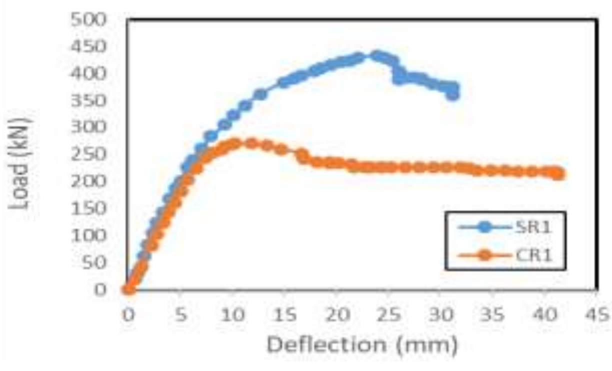


(b) CR0 and CHS specimens

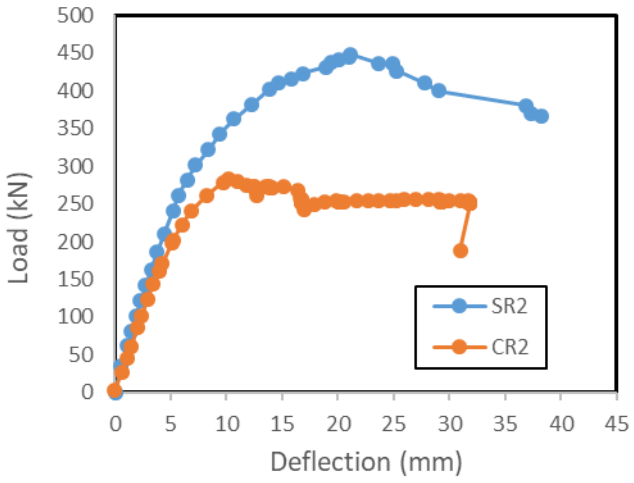
Fig. 5 Influence of filled chords with concrete on the load-deflection curves.



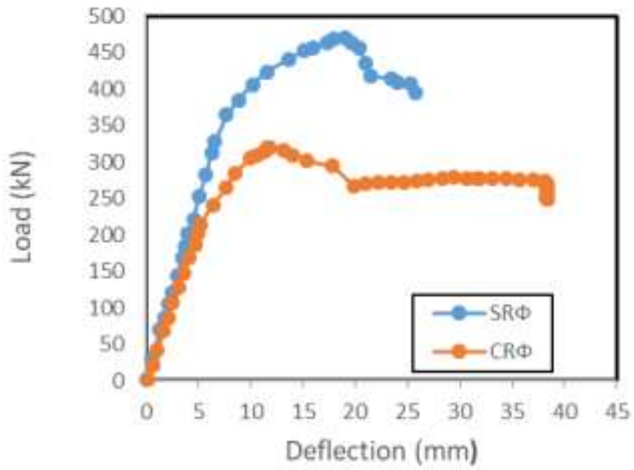
(a) SR0 and CR0 Specimens



(b) SR1 and CR1 specimens

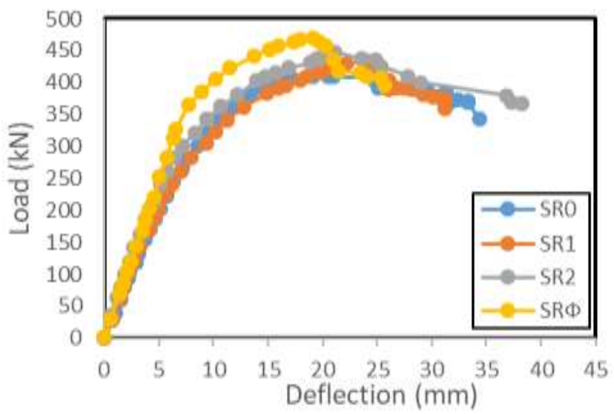


(c) SR2 and CR2 specimens

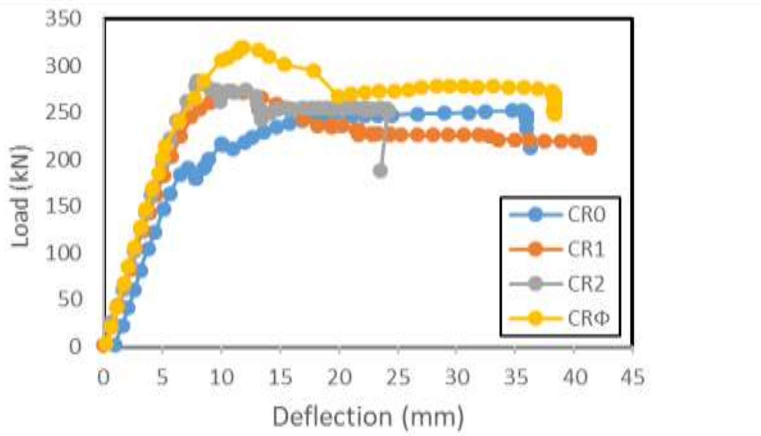


(d) SRΦ and CRΦ specimens

Fig.6 Effect of tube section type on the load deflection curve.



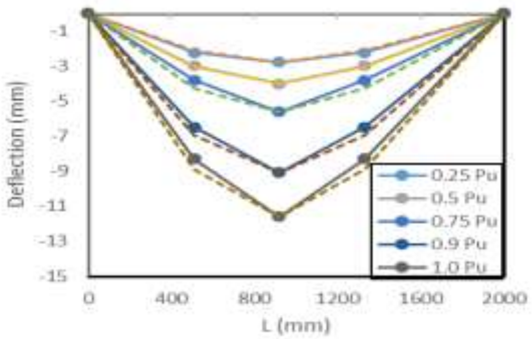
(a) Specimens SR0, SR1, SR2 and SRΦ



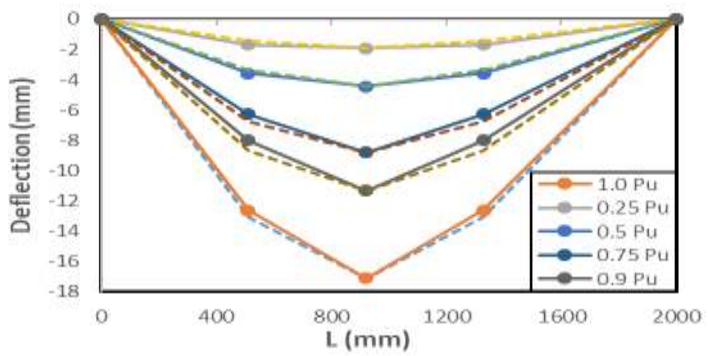
(b) Specimens CR0, CR1, CR2 and CRΦ

Fig. 7 Influence of adding circular steel tube or steel bars on the load deflection curve.

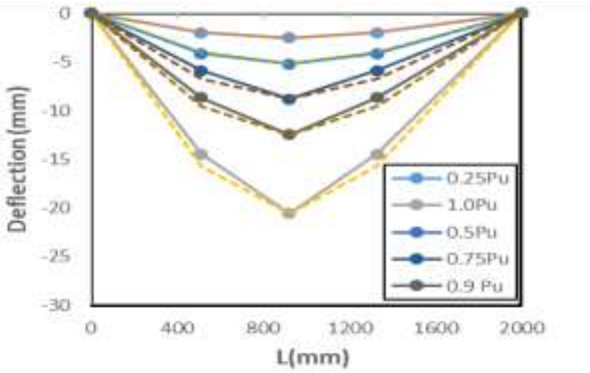
The deflections of each specimen were measured in two places (third and a half span). Second half-span deflections are assumed to be equal to those in the first half span. The experimental deflections along the specimen's span were compared to the dished line's half-sine curve at various load levels, as shown in Fig.11. Generally, the deflections of half-sine and test specimens are approximately identical when the load applied is less than 50% of the ultimate load, but , when the load applied was greater than 50% of the ultimate load the specimen's deflections are less than half-sine excepting for the mid-span deflection because the curve of half-sine was dependent on the mid-span deflection value.



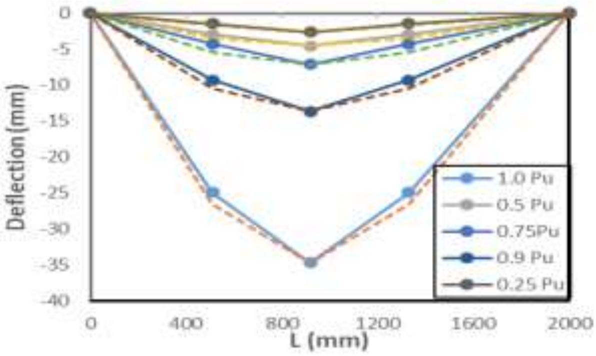
(a) SHS specimen



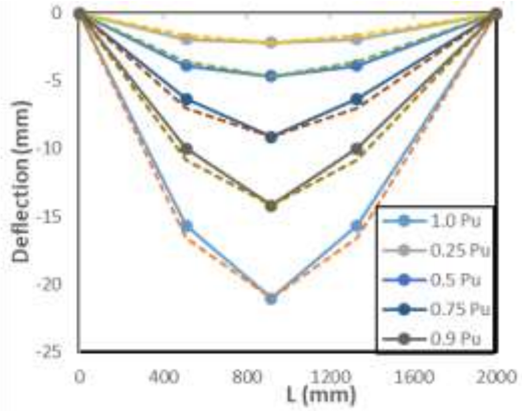
(b) CHS specimen



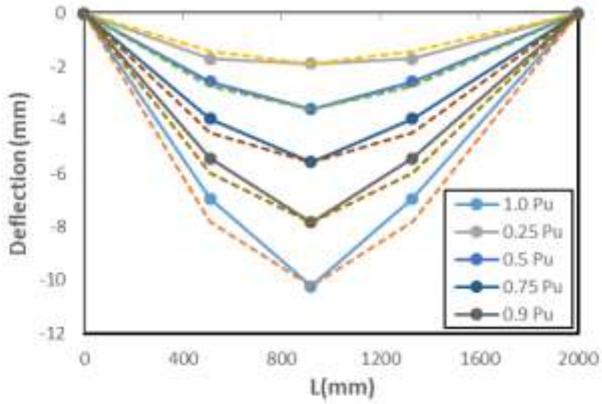
(e) SR1 specimen



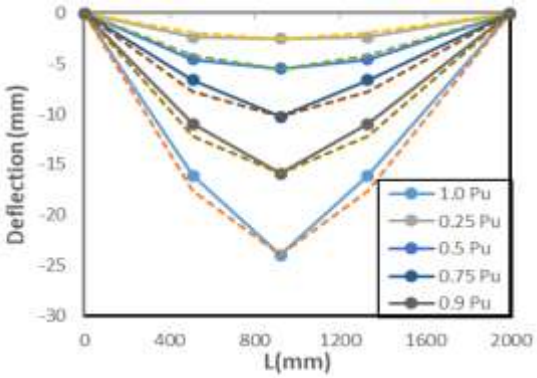
(f) CR1specimen

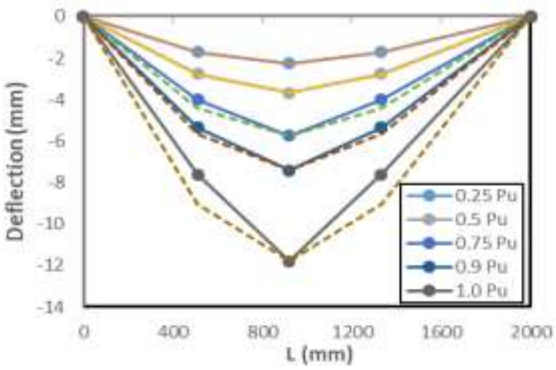


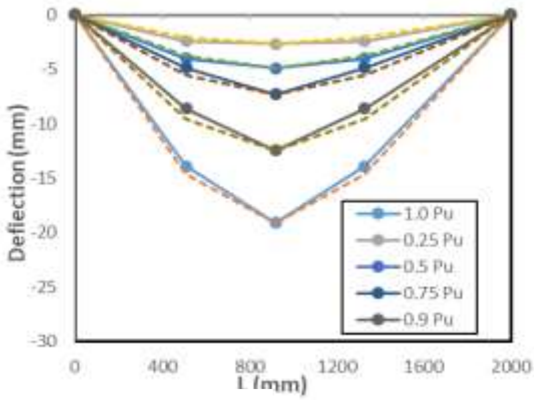
(g) SR2 specimen



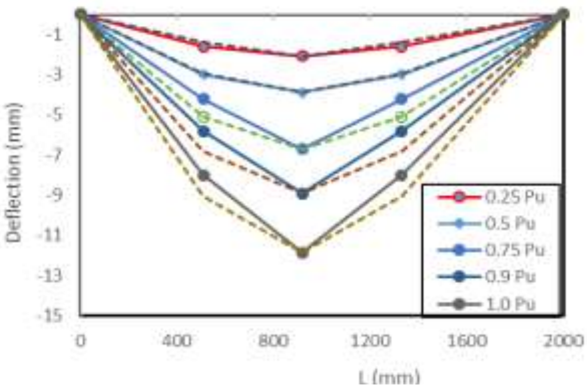
(h) CR2 specimen







(i) SRΦ specimen.



(j) CRΦ specimen

Fig. 8 Deflection along the span for specimens

After exceeding the ultimate load, deformations increased significantly, affecting the joints. Several of these joints entirely failed at the welding zone because of tension loads, and others buckled because of compression loads. Fig. 9 shows failure shapes, the failure shape in Fig.9-a was a partial welding fracture at the inclined braces on the upper side, as shown. Fig.9-b shows failed in the upper side of the inclined brace's joints, cracked in the lower side of the vertical brace, and buckled in the other inclined brace. Fig. 9-c shows failed at the joint at the vertical brace in the support on the lower interior side, with buckling at the upper side of the inclined braces, while Fig. 9-d shows failed in the joint at the vertical brace in the support at the lower side and welding fracture at the inclined and vertical brace in the upper side.

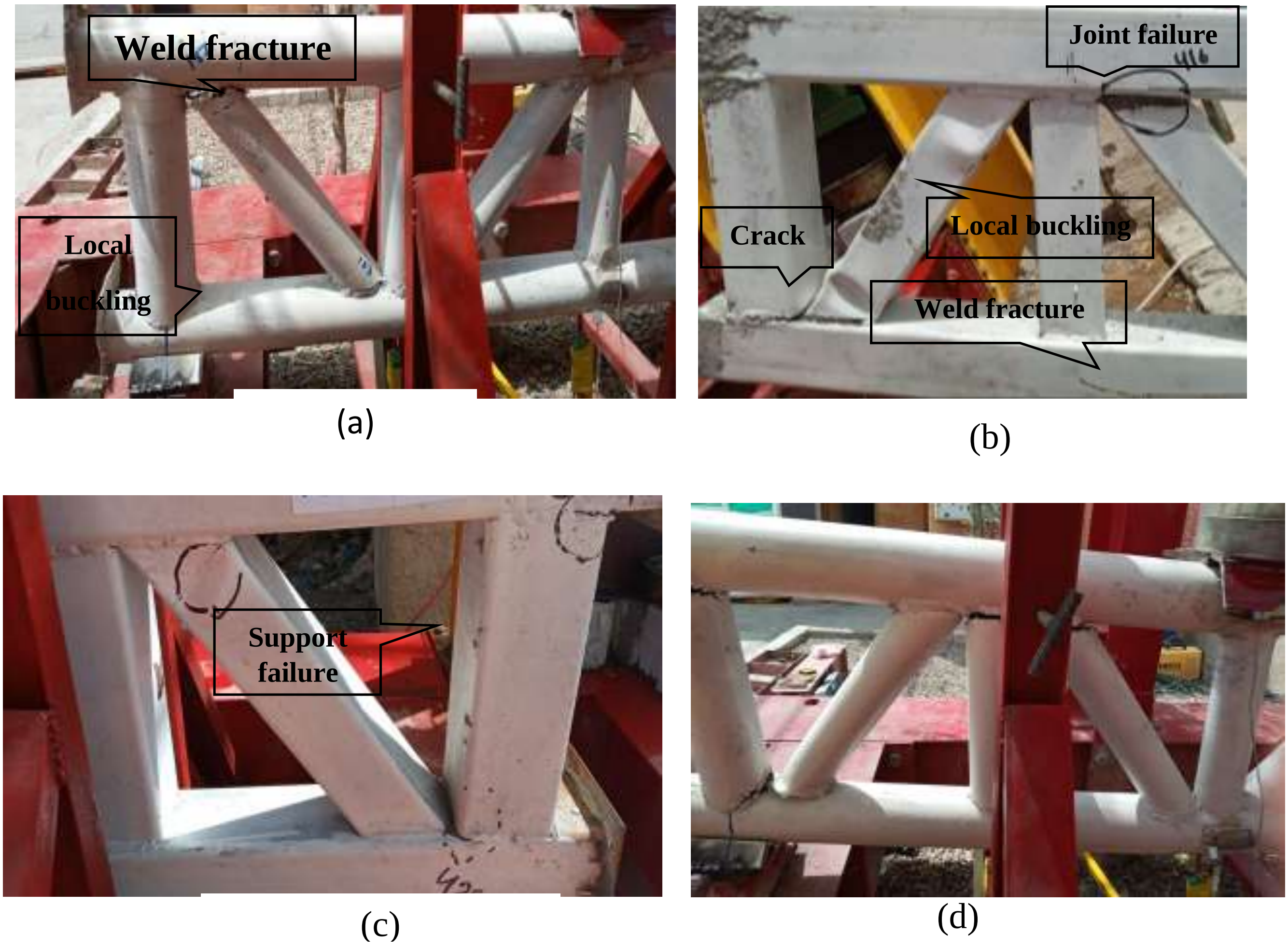


Fig. 9 Shapes of failure.

4. Conclusion

The behavior of self-compacting concrete (SCC) filled steel tube Warren-vertical truss girders is investigated in this study. The following are the study's main findings:

1. The CFST truss girders had higher ultimate load capabilities than their hollow truss girder counterparts. The ultimate load capacities increase ranged from 49.59% to 117.31%.

2. Comparing the CFST truss girders square type section with the CFST truss girders circular type section having identical reinforcement, the square type truss had higher in the ultimate load. Load capacity increased by about 62.82 percent, 60.06 percent, 58.12 percent, and 47.53 percent, respectively.

3. adding reinforced to the lower chord increased the strength of the specimens SR1, SR2 and SRΦ comparing to SR0 specimen by about 5.6%, 9.21%, and 14.67%, respectively, and increased by about 7.42%, 12.46% and 26.57% when comparing CR1, CR2 and CRΦ specimens to CR0 specimen.

4. the adding of a circular steel tube gives a good rise in the ultimate load, while the addition of reinforcing steel bars does not give the desired benefit.

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