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# Flexural Behavior Of Square CFST Truss Girders Infilled With Light Weight Concrete By Adding Reinforcement

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**Abstract:** The composite CFST truss girders typically consist of a steel tubular filled with concrete in the chords and hollow steel tube braces. This research paper considers the performance of CFST truss girders filled with Lightweight concrete by conducting experimental tests. six specimens of composite truss girders (Warren truss type) were tested. The major parameters investigated were the effect filling of the concrete, influence of the steel ratio and the position reinforcing bars of the bottom chord. one specimens were prepared without reinforcement to act as reference specimens. This paper depicts the load versus deflection curves at mid-span, overall deflections, load-strain curves at mid-span at both chords, the failure modes, and ultimate loads of all the specimens tested. Failure mode was discovered to include the following: the weld fracture, cracking around tubular joints at the upper and lower chords, and local buckling of the vertical and diagonal braces. The results showed that the existence of concrete in the chords increases the strength of the CFST truss girder by about 52.3%, as well as giving them better ductility when compared to hollow truss girders and that adding reinforcing to concrete in the bottom chord increased the strength by about 6.3 % to 21.3 %. The best increase in ultimate load comes from adding reinforcement to the lower of the bottom chord.

**Key words:** Square CFST, Composite Truss Girder, Warren truss type, Lightweight aggregate concrete, Modes of failure, Overall deflection.

## 1. Introduction

Concrete-filled steel tubular (CFST) trusses are commonly composed of CFST chords and hollow steel tube braces. Due to the existence of the concrete infill, they have stronger behavior and strength than hollow steel tube trusses. They have been commonly used in various structures, such as bridges, offshore structures, and high-rise buildings, because of their high structural performance as depicted in Figure 1. They offer desirable features such as high strength capacity, high stiffness capacity, and high ductility, and have superior seismic resistance structural features, including a large capacity to absorb strain energy compared to hollow steel columns and reinforced concrete columns [1–5]. The composite action of steel tube and concrete core is responsible for these excellent structural characteristics. The steel tubular acts as a permanent formwork and carries the load during building before concrete is poured. In exchange, the presence of a concrete core Improves the steel tubular's local buckling and avoids the steel tube from being buckled inward; thus, both construction time and costs are reduced [6–8]. The (CFST) is used in columns [1], beams [9-10], and truss girders[11]. The CFST improves tensile strength by about 11 % more than the (CFST) hollow steel tube. Typically, CFST trusses contain chords infilled with concrete and hollow braces. The (CFST) increases the compressive and tensile strength of the chords.

The first recorded research on the (CFST) truss girders was performed in 2000 by Zhang et al.[12]. They tested a CFST truss girder subjected to in-plane bending in that research. Since then, the behavior of these members has been studied experimentally by many researchers. Chen et al.[13] Experimental investigation on three steel circular hollow tubular truss girders. The trusses were Pratt type, the first specimen was hollow truss, the second truss specimen was filled with concrete in the top chord only, and the third truss specimen was filled with concrete in both the top, and bottom chords. The test results showed that filled concrete in the chord members could improve the strength, and the stiffness of the composite truss girders. Huang et al.[14] Considered experimentally the influence of truss type on the performance of CFST truss girders. three types of concrete-filled steel tubular (CFST) were investigated In this study, the first type of truss was Warren-vertical (has diagonal braces and vertical braces), Pratt truss was the second type of truss., and Warren truss was the third type of truss.. The results demonstrated that the Warren-vertical truss girder had a better performance, next by a truss of Pratt and then a truss of Warren. The mode of joint failure of the Pratt and Warren-vertical Trusses were punched shear failure of chord tube Meanwhile, local buckling was the mode of failure of the Warren truss compression braces. Chan et al.[15] investigated two trusses, experimentally and analytically, One truss was a hollow steel tubes in all members, and the other truss filled with concrete in the compression members. The results showed that when comparing, The strength of the truss filled with concrete is greater by 17.5 % than for the truss with hollow steel tubes. Xu et al.[16] Investigated the performance of curved CFST trusses girders with CFST curved chords and hollow braces. eight specimens were tested (Warren truss), Two of these specimens straight CFST trusses, two specimens hollow curved steel tubular trusses, and four specimens were curved steel tubes filled with concrete trusses. The results demonstrated that the ultimate load and stiffness of the curved CFST trusses was higher than that of the straight CFST trusses and hollow curved steel tube trusses. Chen et al.[17] studied the behavior of concrete filled multi-planar tube trusses. Four types of trusses were tested : triangular, inverse triangular, squares and trapezoidal trusses. Three types of failure modes were observed from the experiments included: the local buckling for the straight brace, the surface plasticity and shear failure of the bottom chord, the weld fracture around the tubular joints of the lower chord, and the failure of the end support for the top chord. Inverse triangular truss demonstrated ideal ductility, flexural rigidity, and in practice efficiency. Fu et al.[18] Tested truss beam filled by lightweight aggregate concrete under bending load, one specimen were tested only by carrying out both experimentally tests and theoretical using finite elements. the main conclusion of this study was that the strain was approximately linear during loading stages this means that the truss beam behavior matched Bernoulli-Euler theory. Zhou et al.[19] studied flexural behavior of the circular stainless steel tubular trusses filled with concrete (Warren truss type). Four specimens were tested, three of them CFST and one hollow steel tube. The test parameter was the infill concrete location, Concrete filled the top chord, concrete filled the bottom chord, and the two chords filled with concrete. The specimens subjected to a two-point static load. The load-carrying capacity, load vs displacement curves, deflections, modes of failure, and load-strain curves of all specimens tested have been recorded. The results indicated that the truss filled with concrete in the two chords have the greatest load-carrying ability, and optimum strength rigidity. Han et al.[20] Experimental tests were conducted on twelve straight specimens, Six trusses from them CFST without slabs, and others four trusses CFST Hybrid with slabs, and two hollow tubular trusses. The type of truss was Warren, with three CFST chords (2 at the top and 1 at the bottom) and hollow diagonal braces. To study the influence of the shear length to depth ratio (1.6, and 3.2), The angle between chords and diagonal braces (45° and 60°), bottom chord diameters (140 mm and 180 mm), the presence of the infill concrete, and the concrete strength of slab. These studies demonstrated that the behavior and strength of CFST trusses are substantially enhanced as compared to trusses of hollow steel tubes, and the CFST truss girders have two kinds of failure modes typically include the bottom chord tensile fracture and failure of shear.


**Figure-1.** CFST applications [1].

Wenjin and Bruno[21] carried experimental study the behavior of Simply supported of welded joints of hollow circular steel tube and CFST truss girder. The presence of infill concrete in the upper and lower chords raised the strength and joint rigidity of the truss, Punching shear failure was the principal failure mode. Huang et al.[11] Studied the performance of concrete-filled steel tubular CFST ( Warren vertical truss type ) experimentally and analytically. three specimens were examined experimental to investigate the influence of the concrete grade. The results show that the rising of the infill concrete grade produces a slight increase in both the strength and stiffness of the whole truss. The parameters of analysis were, (i) brace to chord stiffens ratio (ii) shear length to depth ratio (iii), and infill concrete grade. The parametric studies showed that the CFST truss girder has two fail shapes, bottom chord tensile fracture (flexural dominated, more ductile) or joint shear failure (shear dominated, less ductile). It is found when the brace to the chord stiffens ratio ≥ 0.8, and the shear length to the depth ratio ≥ 4.8, bottom chord tensile fracture is the controlling failure shape, Meanwhile, in the other status, joint failure is the controlling the shape of failure.

The load-carrying capacity of the truss depends primarily on the strength of the lower chord, due to the lack of concrete influence in the tensile region compared to the compression zone. therefore, Many researchers have attempted to reinforce the tensile characteristics. So in this research, we aim to improve the lower chord by adding a steel reinforcement (one bar with a diameter 10 mm, and two bars with a diameter 10 mm) embedded in the concrete for the lower chord, where the concrete used was lightweight concrete to reduce the weight for such types of buildings. This paper chiefly investigates the flexural performance of square steel trusses. Experiments were conducted on five CFST truss girders. The test parameters involved the steel ratio of the bottom chord and the location of reinforcing bars. The failure modes, overall deflection, load-strain curves, load versus deflection curves, and load-carrying capacity of all the specimens, are offered in this paper.

**2. Experimental study**

six CFST truss girders (Warren-Vertical truss) subjected to one-point loading in the middle of the span were tested in this research. The test parameters involved the effect of filling, steel ratio, and the position of reinforcing bars in concrete at the bottom chord, as depicted in Table 1. The initial letter "S" denotes the square section. The second notation denotes the number of reinforcing bars. R0 means there is no reinforcement in the bottom chord, "R1" indicates the bottom chord reinforced by one steel bars with a nominal diameter Ø10 mm, "R2" denotes that the bottom chord reinforced by two steel bars with a diameter Ø10 mm, and the last part M or L means the location of steel bar in the bottom chord, M means there are steel bars at the middle of the bottom chord, L means there are steel bars at the lower of the bottom chord, while the part H means Hollow steel tube. The geometric properties for all specimens were the same: the overall length was 1840 mm (length of the span between supports was 1640 mm), the overall height of the truss was 500 mm, The dimensions of steel tubes for the chords are 100 *100*4 mm, while the dimensions of steel tubes for the vertical and diagonal braces are 80*80*3 mm, and the angle between the chord and diagonal brace was 52° as shown in Figure 2. To prevent local buckling due to concentrated reaction from the supports, the width and thickness of the vertical braces above the supports were increased to 100 mm, and 4 mm, respectively. The top and bottom chords were spaced to achieve the desired truss height during specimen fabrication. After that, as shown in Figure 3, The top and bottom chords were spaced to achieve the desired truss height during specimen fabrication. After that, as shown in Figure 4, the chords and braces were welded together. The specimens were then placed vertically and packed with lightweight concrete before being examined after 28 days.

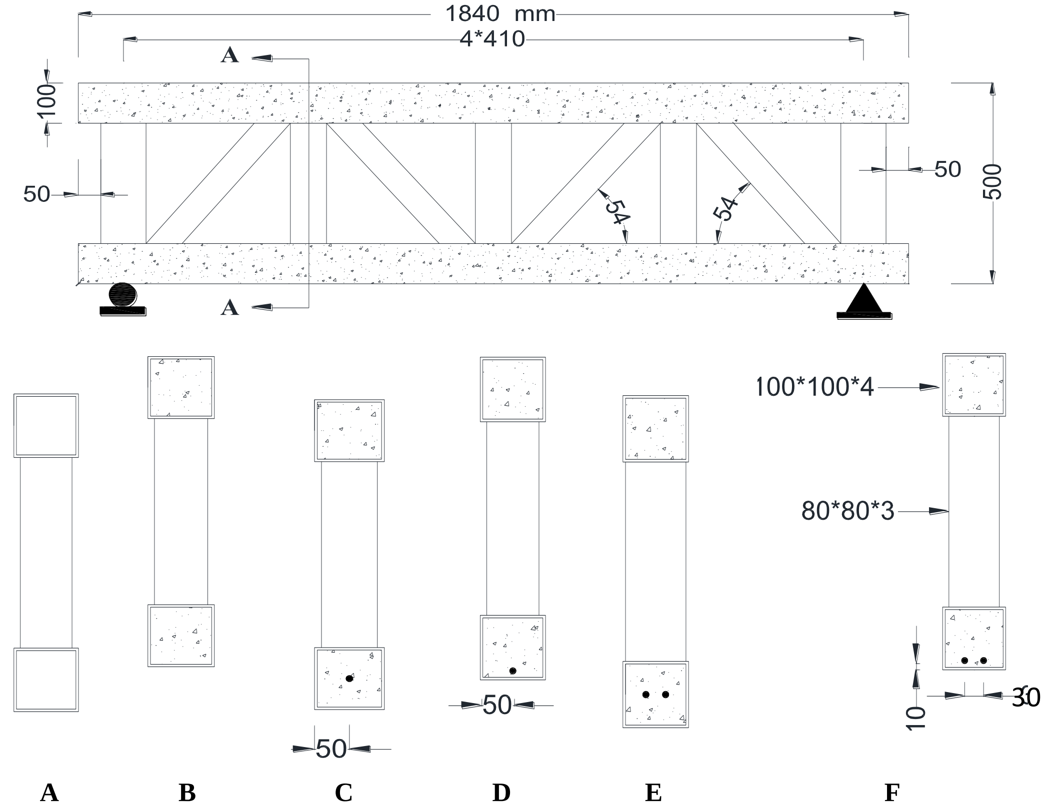



**Figure -2** Specimen details, (A) Hollow specimens ,(B) without any reinforcement (C) reinforced by 1Ø10mm at middle (D) reinforced by 1Ø10mm at lower (E) ) reinforced by 2Ø10mm at middle (F) ) reinforced by 2Ø10mm at lower.

The concrete that was used in this project was a lightweight concrete with a clay aggregate size of no more than 10 mm (LECA). The lightweight concrete (20 MPa) mix proportions were as follows: cement 500 kg/m3 ,sand 872 kg/m3, (LECA) 250 kg/m3, water 150 kg/m3, and superplasticizer 5 kg/m3. The measured cubic compressive strength was 21.16, and the slump flow was 950 mm.The values of yield stress, and ultimate tensile strength of the steel tubes, and steel reinforcement are summarized in Table 2.

**Table -1** Specimen properties.

| Specimen | reinforcement details at the bottom chord |
|---|---|
| SH | Non. |
| SR0 | Non. |
| SR1M | 1Ø10 at the middle |
| SR1L | 1Ø10 at the lower |
| SR2M | 2Ø10 at the middle |
| SR2L | 2Ø10 at the lower |

**Table -2** steel Properties

| *Steel tube* | $F_y$ *(MPa)* | $F_u$ *(MPa)* |
|---|---|---|
| Square tube 100 mm | 331 | 342.51 |
| Square tube 80 mm | 310 | 331.52 |
| Steel bar Ø10 mm | 462.11 | 599.67 |


**Figure -3.** Fabrication of specimens and casting.

The test setup is shown in Figure 4. The specimens were simply supported. A hydraulic jack was utilized to apply a concentrated load at the mid-span by a load cell. To provide lateral stability, four supports were installed along the span, two on either side. The vertical deflections were measured using two linear variable displacement transducers (LVDTs) installed along the span. Strain gauges were used to test the steel strains in the chords at mid-span.

**3. Test results**

Table 3 shows that the experimental load-midspan deflection responses, stiffness strength, and the displacement ductility index of the test specimens. To see the effect of filling concrete for the CFST truss, It is shown from the comparison of the ultimate load for specimens SR0 with SH. The ultimate load for SR0 was 381.65 kN, while for SH it was 181.9 kN, an increase of 52.3%, which means, the specimen SR0 has a greater safety margin. the ultimate load of the specimens SR1M, SR1L, SR2M, and SR2L were 407.33, 463.14, 428.94, and 484.89 kN, respactively. As shown, changing the steel ratio and the position of reinforcing bars in the bottom chord of specimens SR1M, SR1L, SR2M, and SR2L increased the ultimate load by around 6.3 %, 17.6 %, 11 %, and 21.3 %, respectively, as compared to SR0. Because of the position effect In comparison to the other steel bar additions to the bottom chord, it can be determined that the addition of two steel bars in the lower is the greatest choice for adding to the concrete. The slope of the elastic zone was used to calculate the specimen stiffness. The ductility index for displacement is computed by dividing the displacement that corresponding to 85% of the maximum load of the curve's post-peak area by the displacement that corresponding to the specimen's initial yield displacement. [22]. indicate results that the stiffness strength, ductility, and modes of failure of CFST truss girders are affected by changing the steel ratio and the position of reinforcing bars in the bottom chord.

Figure 5, Figure 6, and Figure 7 show the load midspan deflection of the specimens affected by filling of concrete, changing the steel ratio, and affected by changing the location of reinforcing bars, respectively. As shown in all figures, the responses of all specimens are almost similar and are summarized as the following. Early in the loading process, the concrete in the bottom chord cracked, while mine, The mid-span deflection response of the load stayed almost linear. The steel tubular at the bottom chord yielded about 70% of the maximum load when incrementally loaded. After then, the steel tubular in the bottom chord started to strain hardening, and the steel tubular in the top chord started to yield. At about 97% of the maximum load, the bottom chord cracking.

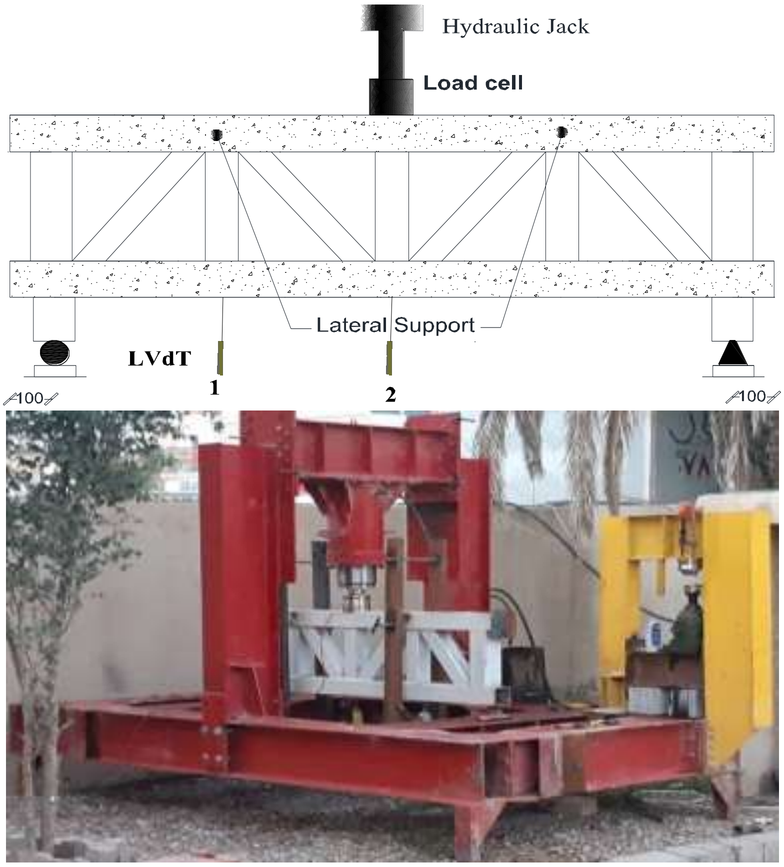
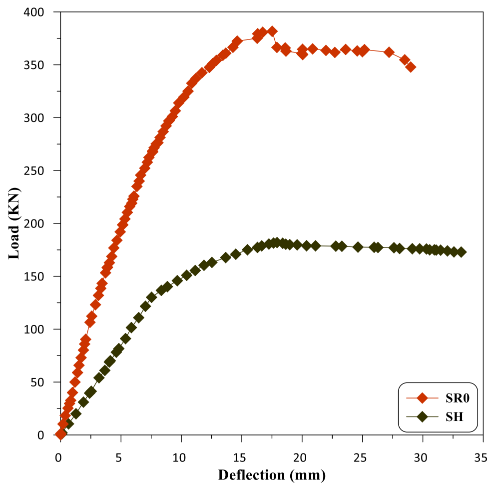



**Figure -4** Test setup.

**Table -3** Results of Specimens.

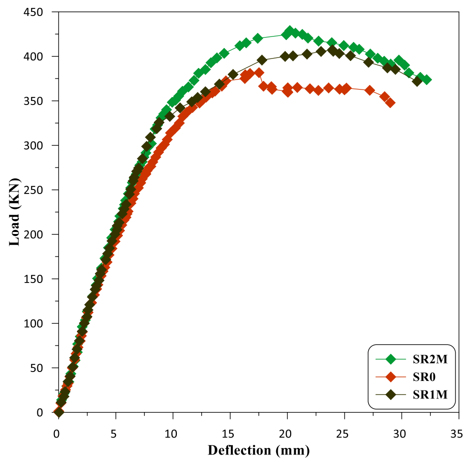
| Specimen name | Ultimate load (Pu) (KN) | Deflection at (Pu) (mm) | Stiffness (KN/mm) | Ductility ratio |
|---|---|---|---|---|
| SH | 181.9 | 17.32 | 17.65 | 1.43 |
| SR0 | 381.65 | 17.52 | 34.77 | 1.68 |
| SR1M | 407.33 | 23.94 | 38.52 | 1.75 |
| SR1L | 463.14 | 19.76 | 38.86 | 1.87 |
| SR2M | 428.94 | 17.81 | 37.31 | 1.92 |
| SR2L | 484.89 | 21.84 | 39.99 | 2.18 |

Figure 8 shows the longitudinal strain of the chords at mid-span in the top and bottom chords, Which was measured by strain gauges are fixed on the upper and lower chords. This figure also includes the chord yield strain in both compressive (0.0017) and tension (- 0.0017) for reference (the vertical bold line). The yield strain for chords was determined as as Fy/Es (Fy = 331 MPa, Es = 200 GPa. The top chord is the compressive strains (positive), while the bottom chord is the tensile strains (negative). This figure shows that the steel tubes were in the elastic state when a load of less than 0.7 Pu (Pu is the maximum load). The steel tube at the bottom chord yielded as the load increased from (0.7 to 0.9) Pu, while the steel tube at the top chord remained relatively elastic. At this applied load level, the compressive strains at the top chord are less than the tensile strains at the bottom chord. This is because the steel tube primarily supported the tensile force in the bottom chord, while the steel tube and concrete infill in the top chord carried the compressive force. The steel tube at the bottom chord cracked after yielding as the load raised from (0.9 to 1.0) Pu. The top chord then yielded after this crack.

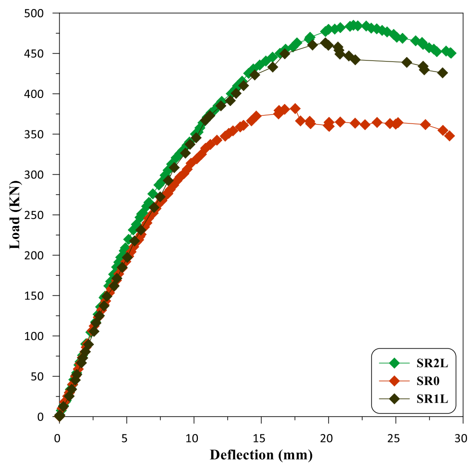



Specimens SR0 and SH

**Figure -5** Effect filling of concrete on the load-deflection curves.

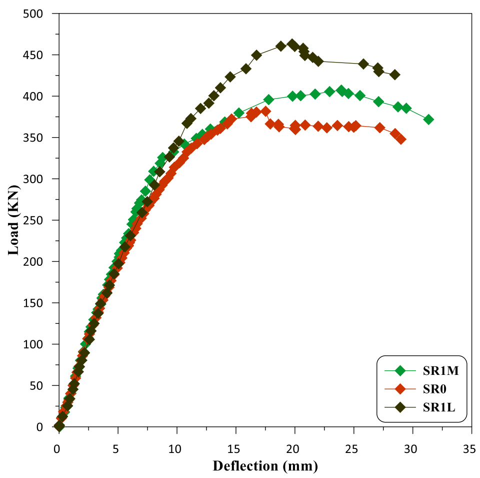



(A) Specimens SR1M,SR2M and SR0

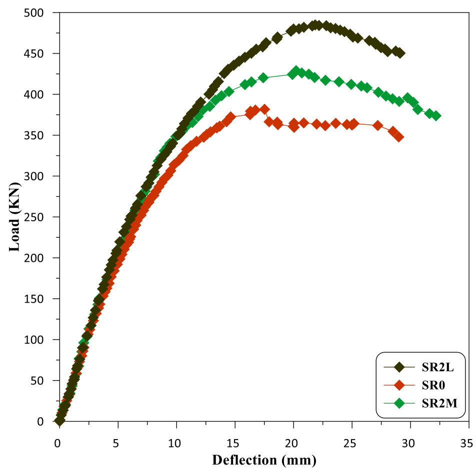



(B) Specimens SR1L,SR2L and SR0

**Figure -6** Affect of steel ratio on the load-deflection curves.

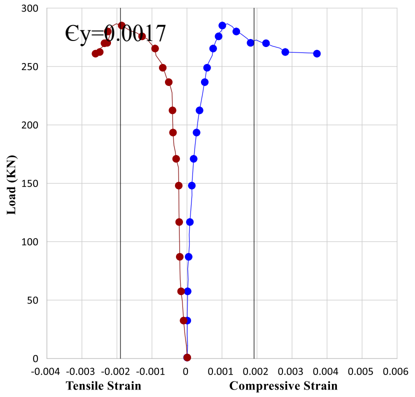



(A) Specimens SR1M,SR1L and SR0

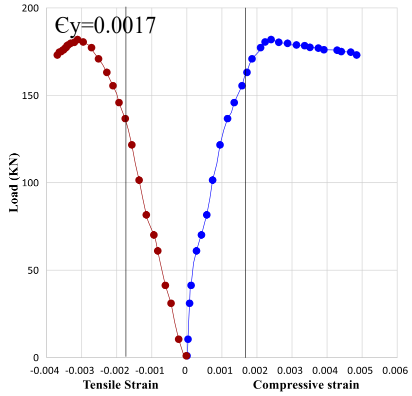



(B) Specimens SR2M,SR2L and SR0

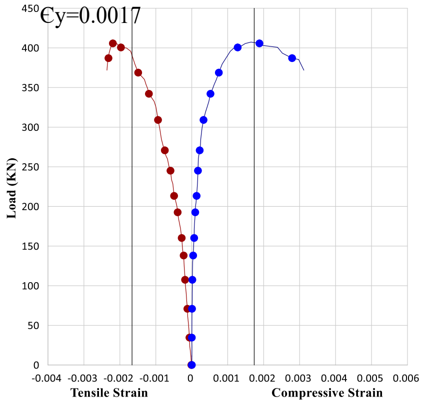
**Figure -7** Affect position of reinforcing bars on the load-deflection curves.



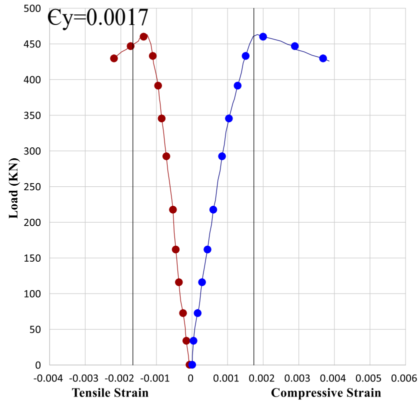

**(A)** SH



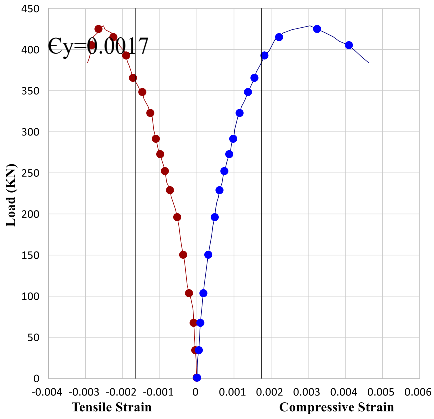

**(B)** SR0



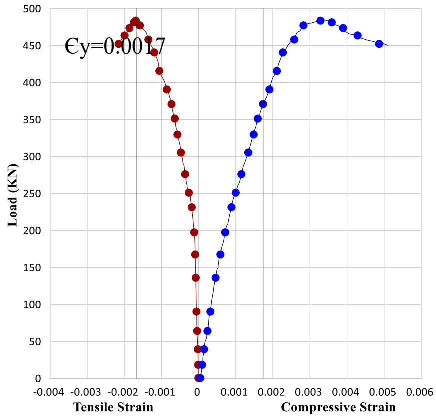

**(C)** SR1M




**(D)** SR1L




**(E)** SR2M




**(F)** SR2L

**Figure -8** distributions of the longitudinal strain for the chords at the midspan for all specimens.

The deflections of each specimen were measured in two locations (mid, and quarter) of the span, the first half span deflections are assumed to be equal to the second half span deflections. Figure 9 displays the deflections along the span about different loading levels of the specimen and comparison with the half-sine curve (the dashed black lines). deflections of the CFST truss girder are almost identical to half-sine curves when the load is less than 0.5 Pu, as shown. When the applied load exceeds 0.5 Pu, the deflections of the CFST truss girders are less than those anticipated by the half-sine curve, except for the midspan deflection, which is because the half-sine curve was dependent on the value of the midspan deflection. These findings approximate those of Huang et al.[11] and Xu et al. [16]. The deformations became clearly apparent after the ultimate load was exceeded, and this had an effect on the joints; Some of these joints had partially failed to owe tension loads in the welding zone, while others suffered buckled due to compression

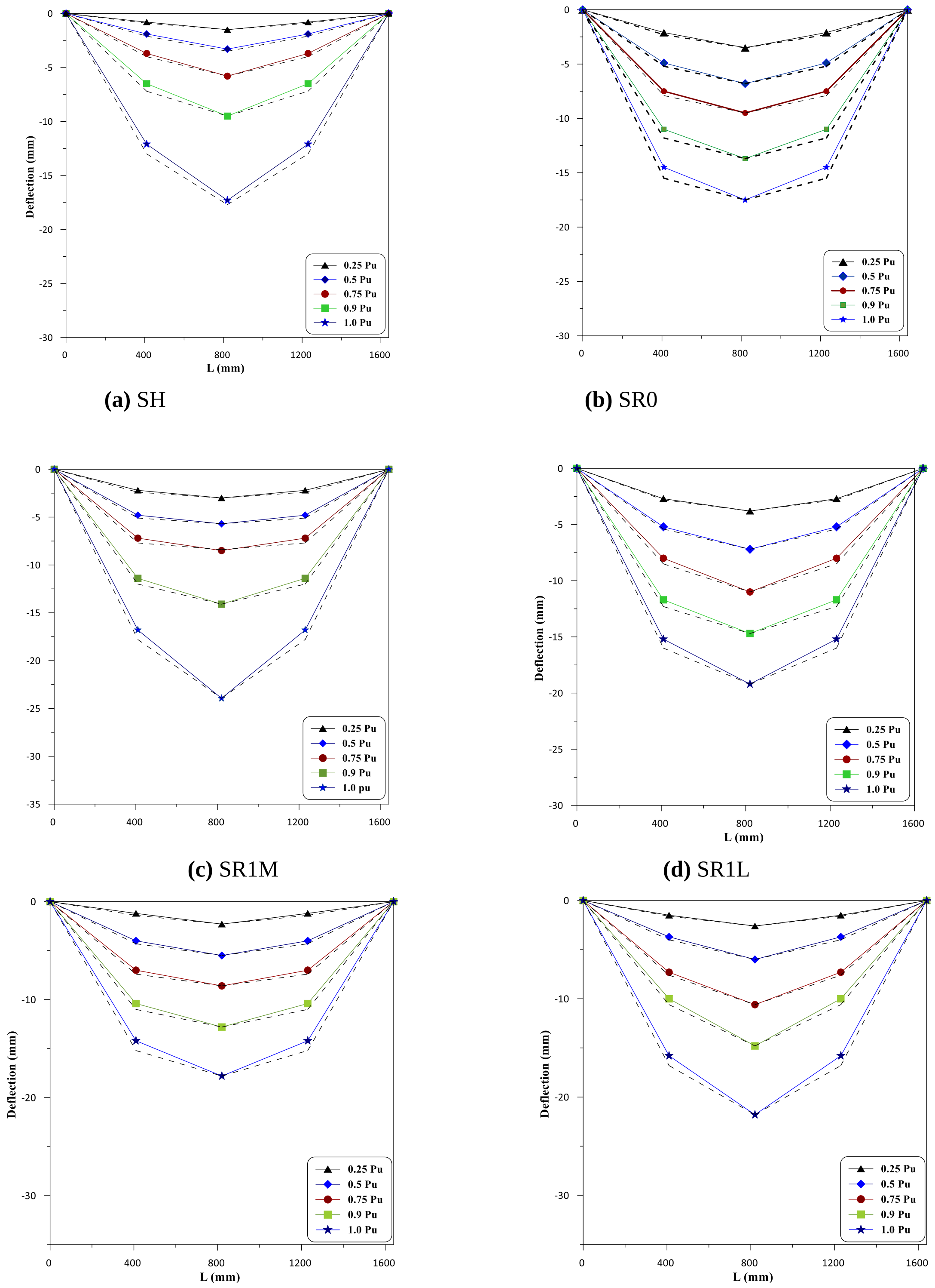



**Figure -9** Deflections along span about different loading levels.

loads. Figure 10 demonstrates the shapes of failure, the failure mode as shown in Figure 10-A the failure resulted from the surface plasticity of the top chord at the loading point, Figure 10-B as shown this specimen failed due to a weld fracture on the bottom side of the inclined brace., Figure 10-C the failure was crack of weld in the upper ,and lower side of the vertical brace at support and buckling in the other inclined brace, Figure 10-D shows a crack in the upper side of the inclined braces in the joint, Figure 9-E shows local buckling on the bottom side of the inclined braces, which caused them to fail, while Figure 9-F shows local buckling on the upper side caused the inclined braces to fail for the specimen.

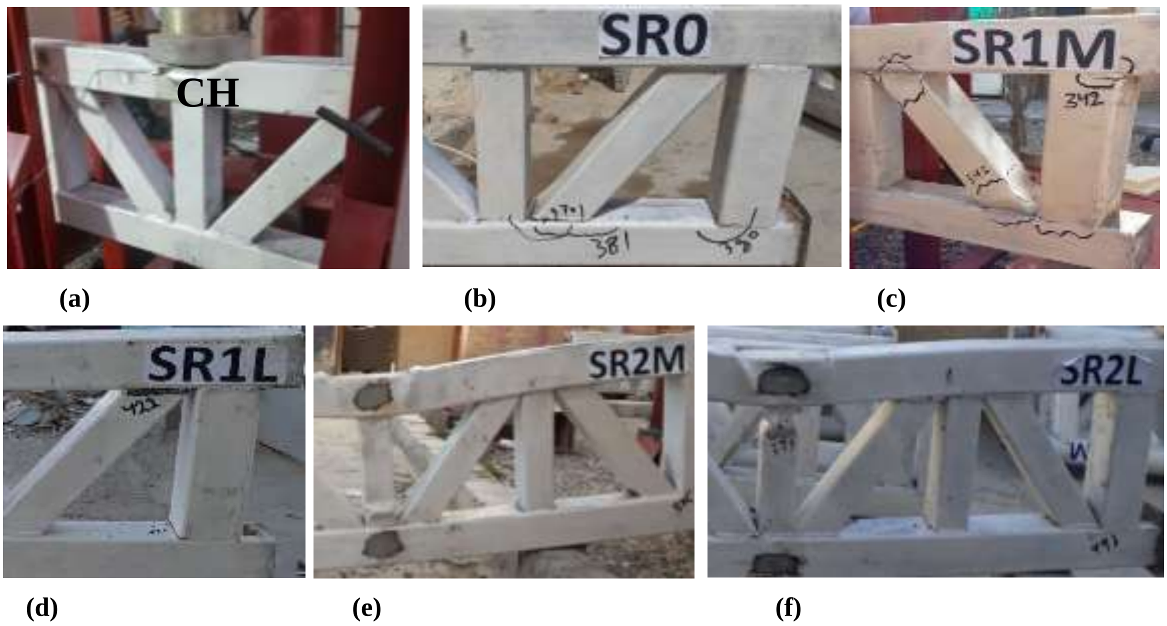



**Figure-10** Modes of failure.

**4. Summary and conclusions**

The flexural behavior of square concrete-filled steel tubular trusses was studied experimentally in this paper. The ultimate load capacity, longitudinal strains for chords, ductility, stiffness, and the modes of failure for all specimens were examined. The main conclusions can be summarized as follows based on the experimental results of this study:

1- The ultimate load capacity for the empty steel tube truss decreased by 52.3% compared with the reference truss. Similarly, the stiffness of this truss was lower than that of the reference truss by 49.2%.

2- The increase in the steel ratio of steel tubes in the bottom chord of the square CFST truss girder does not give the desired benefit when comparing the percentages of increases in the ultimate load, whilst changing the position of reinforcing bars in the bottom chord gives a good increase in the ultimate load.

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