Effect of filling steel tube chords by concrete on the structural behaviour of composite truss girders

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ABSTRACT

In this study, three specimens of Warren truss girders composite with concrete deck slab were tested experimentally under a central monotonic load to study the effect of the existence of concrete inside the chords. The load capacity, deflection, slip between the concrete slab and steel tube, and failure modes were reported. Both chords were filled with concrete to the first specimen, only the lower chord was filled with concrete and the upper chord remained hollow to the second specimen and both chords were kept hollow in the third specimen. The result indicated that the existence of concrete inside the chords has a significant effect on the load capacity, failure pattern, and the slip. The steel tubes of the upper chord filled by concrete prevent surface plasticity failure of the upper chord under loading and increase the ultimate load by 6.68 %. Also, filling the lower chord with concrete prevents the surface plasticity failure in the supports zone and caused an increase in the ultimate load by 39.59 %. The slip at the end of the specimen of two chords filled with concrete is less by 71% than the end slip of specimen of hollow top chord and higher by 46.8 % than the specimen of two hollow chords.

1. Introduction

For several decades, the use of steel in combination with concrete has been a more successful and widely applied structural system. The applications of this type of composite material were extended to numerous structural constructions like multi-story buildings, e.g., concrete slab supported by steel beams. Other applications are the road bridges, e.g., concrete decks supported by steel frame or truss, as well as factories and commercial buildings Johnson et. al. [1]. Steel-concrete composite in the structures aims to preserve the advantages of both materials steel and concrete Nie et. al. [2]. When the concrete exposed to compression, it exhibits significant strength and high rigidity, while when exposed to tension, it has precarious behaviour and with time it is likely to shrink and creep. On the other hand, the steel structures have low fire resistance and it is prone to lateral and local buckling although it has high ductility and significant load capacity Oehlers et. al. [3]. The concrete-filled steel tube (CFST) was used in columns Han et. al. [4], beams [5-7], and truss girders Huang et. al. [8]. The tensile strength is improved by about 11% when using CFST compared to a hollow steel tube Han et. al. [9]. The hollow braces and the chords filled with concrete are the common apparatuses in (CFST) trusses. The tensile strength and the compressive strength of the chords are improved. The steel tube of the upper chord is prevented from buckling inward in compression and the steel tube of the lower chord is avoided from contraction inward in tension. The CFST also improved the whole flexural stiffness of the truss and the strength of the joints [8, 10-12]. Numerous

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Nomenclature			
CFST	concrete filled steel tube.	L.P.	limestone powder
C.A.	coarse aggregate	Pu	The ultimate load
F.A.	fine aggregate	S.P	superplasticizer
Ki	Stiffness	U	Mid-span Deflection

studies have been conducted on the behaviour of CFST truss girders in flexural with different parameters [13-22].

Chan et. al. [13] found that the load capacity of the truss of members filled with concrete is higher by 17.5% than the truss of the hollow members. Machacet et al.[14] studied numerically the warren truss with concrete deck slab and determined the longitudinal shear distribution between the concrete and steel form elastic up to plastic and proved that, the non-linear longitudinal shear distribution, requisite for the design of shear connectors. Huang et al. [15] obtained experimental results agreed with Chan et. al. [13] and Machacet et. al. [14] findings and they found the concrete inside the chords rises the strength and the rigidity of the joint. Xu et al. [16] investigated the influence of the high-to-span ratio and the existence of concrete infill on the flexural behaviour of curved CFST truss girders and straight CFST truss girders. They found that the stiffness and the ultimate load of curved CFST truss girder are higher than the straight CFST truss girders and the curved hollow truss girders. Similar findings were obtained by [17-20]. All the previously mentioned researches were concentrated on CFST truss girders without taking into consideration the existence of the concrete deck slab. Only limited researches investigated the structural behaviour of CFST truss girders with a concrete deck slab.

Han et al. [21] constructed a CFST truss girder specimen consists of two upper cords and a lower chord as well as a deck slab and compared the results with CFST truss girders without deck slab. The top and bottom chords were filled with concrete. They concluded that the ultimate load of the CFST truss with a concrete slab is higher than the ultimate load of CFST truss girders only, and a hollow steel tube truss girder.

Hu et al. [22] studied the flexural behaviour of two concrete filled steel tube truss composite beams experimentally and analytically. One of the specimens has transverse braces and the other has diagonal and transverse braces. The load capacities, the deflection shapes, the failure modes, the strain responses were evaluated. It was found that the failure mode of the specimen which has diagonal braces was surface plasticity at the lower chord and the failure mode of another specimen was surface plasticity at the top chords, local buckling, and weld cracks. The specimen of diagonal braces can develop a shear transmute mechanism between the upper and the lower chords, this led to larger load capacity, stiffness, and ductility than the other specimen.

This study extended the knowledge on the flexural behaviour of CFST truss girders with a reinforced concrete deck slab. The experiments were carried out on three truss girders. The test parameter was the location of the concrete-filled tube and its existence. The deflection, load capacity, failure modes, and slip between the concrete slab and steel tube were reported.
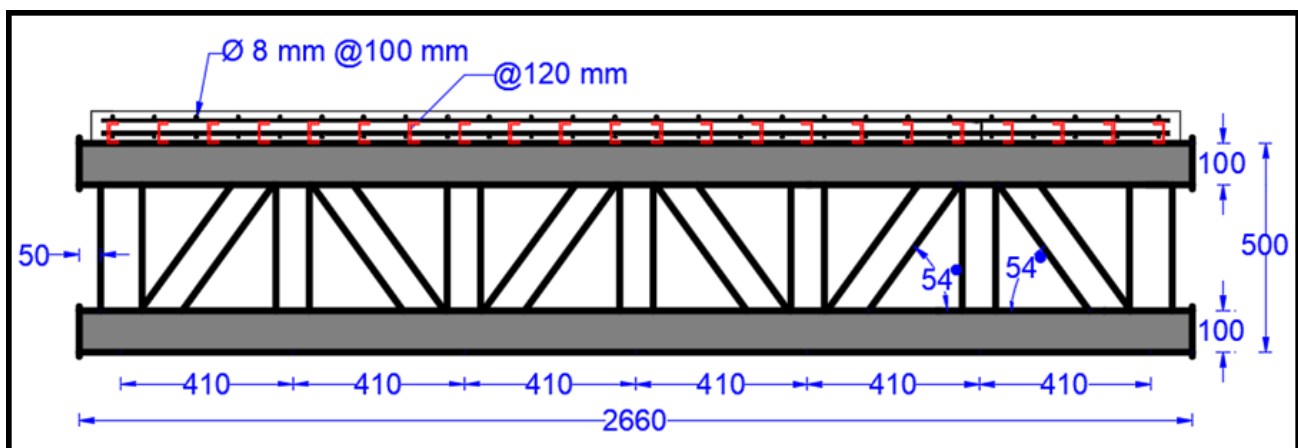

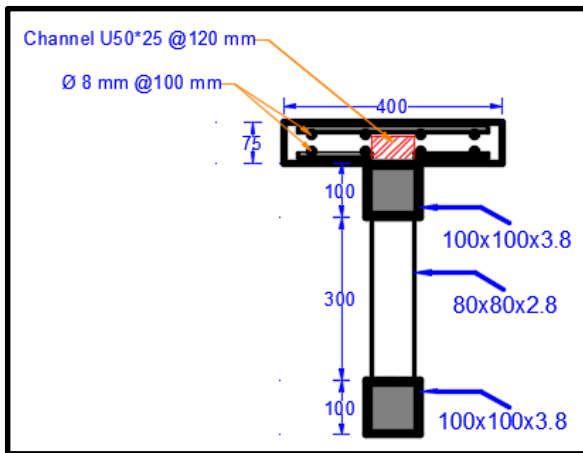**Figure 1 Details of the test specimens.**

Figure 2 Cross-section of the test specimens.

2. Experimental work

2.1. Specimens and materials details

Three specimens of composite concrete-steel truss girders were designed as shown in **Figs. 1** and **2** and tested experimentally. Square steel tubes with dimensions of (100×100×3.8) mm were used to construct the chords as well as the first and the last braces of the truss specimens while the diagonal and vertical braces were constructed by using square steel tubes with dimensions of (80×80×2.8) mm. The braces and the chords were welded (electrode-welding type E6013) together in a manner illustrated in **Fig. 1**.

The upper chord of the three trusses was composite with concrete deck slabs 2600 mm long and 400 mm wide. All the slabs were constructed with a (75) mm thickness and reinforced by ϕ8 mm steel bars. Shear connector channels (U50x25) with a length of 80 mm and 5 mm in thickness were used to connect the slabs with the chords distributed at a distance of (120) mm centre to the centre along the slab length. The properties of the steel types used in this study are shown in **Table 1**.

Table 1 Steel sections and bars properties [23].

Steel section	Yield Stress (fy) (MPa)	Ultimate Stress (fu) (MPa)
Tube (100*100*3.8)	328.2	372
Tube (80*80*2.8)	382.9	435.4
Channel (U50x25)	344.4	487
Bar (Φ 8 mm)	401.5	598.8

Self-compacting concrete (SCC) was utilized to fill the tubes and to cast the deck slabs to avoid the difficulty of the compaction when using normal concrete. The production of such concrete was according to the requirements of the European Federation of Specialist Construction and Concrete (EFNARC) specifications Bibm et. al. [24]. The tests performed for this purpose are showing in **Table 2**.

The steel tubes were filled by SCC with a (50 MPa) strength grade while the deck slabs were cast by using SCC with a strength grade of (60 MPa). The concrete mix proportions of the SCC used are shown in **Table 3**.

Table 2 Results of the test of fresh concrete

Method		Mix Symbol		Limitations [24]
		M50	M60	
Slump Flow	(D) mm	674	665	650 – 800
	(T50 cm) sec.	3.5	4.4	2 – 5
V-Funnel	(Tv) sec.	8.4	9.2	6 – 12
L-Box (BR)		0.82	0.86	0.8 – 1.0

Table 3 Concrete mixes proportions

Mix	Cement (kg/m³)	F.A. (kg/m³)	C.A. (kg/m³)	L.P. (kg/m³)	S.P (kg/m³)	Water/Cement (kg/m³)
M50	328.7	489.4	533.2	65.7	(1.5%)	0.42
M60	336.3	500.8	545.6	67.3	(1.75%)	0.36

As shown in **Table 4**, in the (D60T50B50S12) truss, both chords were filled with concrete. For the (D60T0B50 S12) truss, only the lower chord was filled with concrete while the upper chord remained hollow. In the case of the (D60T0B0 S12) truss, both chords were kept hollow.

Table 4 Parameters of the test specimens

ID	Specimen	Compressive strength fcu (MPa)			
		Deck slab	CFT chord	Top	CFT bottom chord
1	D60T50B50S12	60	50		50
2	D60T0B50S12	60	0		50
3	D60T0B0S12	60	0		0

2.2. Manufacturing process

The manufacturing process of the specimens is shown in Fig. 3, which can be summarized as follows:

i.   Closing the first end of chords by welding a 4 mm thick steel plate, while the other end was covered to prevent the evaporation of the water from the fresh concrete.

ii. The concrete was poured into the chords while the trusses were placed vertically as shown in **Fig. 4.** The CFST specimens were then left for 10 days to harden the filling concrete

iii. To cast the deck slab, the moulds were cleaned and oiled first then, the steel reinforcement was placed inside the moulds and the concrete was poured and levelled. This stage was demonstrated in **Fig. 5**.

Figure 3 Manufacturing proses.

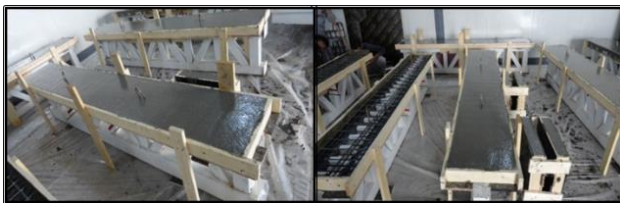**Figure 4 Cast of CFST truss girder.**

Figure 5 Cast of the concrete deck slab.

2.3. Testing procedure

The specimens were tested under a monotonic load, by utilizing a hydraulic machine, to test the flexural response of this type of composite trusses. The load was placed in the mid-span and the girders were simply supported in addition to the lateral support to prevent the specimen from twisting as shown in **Fig. 6**. To measure the vertical deflection and the slip between the concrete deck slab and the steel tube of truss girder, four linear variable differential transformer (LVDT) were utilized. For vertical deflection measurement, one of the LVDTs was placed at the mid-span and the other one was at the third of the span attaching the bottom face of the bottom chord. The remaining two were used to measure the slip of the deck slab at the end and one-third of the specimen slab as shown in **Fig. 6**.
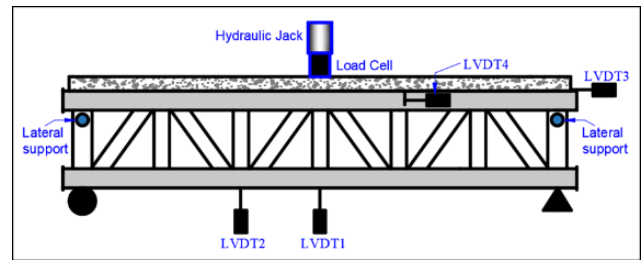

Figure 6 Testing of CFST composite with a concrete deck slab.

3. Results and Discussions

3.1. Load-Deflection Relationship

The deflections were recorded at mid-span and one-third of the span for every loading increment of the three tested specimens. The results illustrated in **Fig. 7** and **Table 5** revealed that there is a reduction in the ultimate load of the tested specimens D60T0B50S12 and D60T0B0S12 compared to that of D60T50B50S12 by 6.68% and 39.59% respectively. The reason behind this reduction is the existence of the hollow tubes in these trusses. The buckling of the bottom chord's steel tube at the supports was observed in the tested specimen (D60T0B0S12) resulted in a significant decrease in the ultimate load. While the specimen (D60T0B50S12) showed buckling of the top chord's steel tube at the mid-span. The resistance to the compressive and the tensile forces of the top and the bottom chords increases when the tube was filled with the concrete. This prevents the buckling inward in the top chord and restrains the pinching in the bottom chord Huang et. al. [8]. It was previously agreed that the strength of CFST exceeds that of the hollow tube Chan et. al. [13].

Fig. 8 shows the deflection shape of the specimens at a different load level (0.25Pu, 0.5Pu, 0.75Pu, 0.9Pu, and Pu). This figure indicated that the deflection increases with the progress of loading stages, especially in the final stages, as the relationship is approximately linear until the yield load is reached, then it becomes nonlinear. The lowest value of the stiffness was observed at the D60T0B0S12 specimen and the highest value was at D60T50B50S12 as shown in **Table 5**.

Table 5 Load capacity and deflection for the tested specimens.

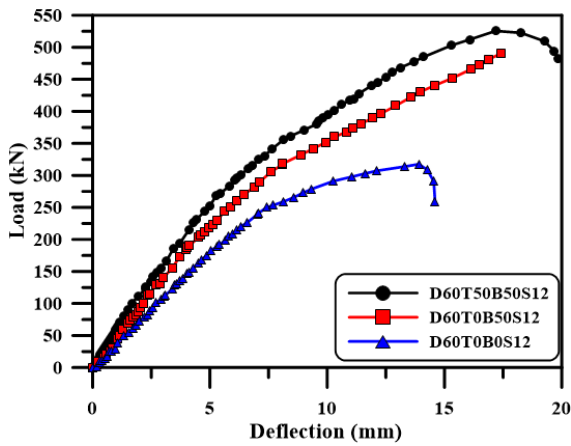| Specimen	Pu (kN)	Δ (mm)	Ki (kN/mm)
D60T50B50S12	525.6	17.19	60.2
D60T0B50S12	490.5	17.42	46.3
D60T0B0S12	317.5	13.92	37.3

Figure 7 Load-deflection relationship of specimens D60T50B50S12, D60T0B50S12 and D60T0B0S12 at the mid-span.

3.2. The failure pattern

It was found that the failure mode was dominated by the tensile fracture of the lower chord when the ratio of the brace to the strength of the chord is exceeding or equivalent to 0.8 and the span/depth ratio of the shear is exceeding or equivalent to 4.8. On the other hand, for the other cases, the dominated failure mode was the joint failure according to Xu et al. [16].

Fig. 9 shows that, for the specimen D60T50B50S12, the failure mode was the joint shear failure (weld fracture) where the ratio of the shear span to depth was (3.075). This result agreed with that obtained by Huang et al. [8]. In the case of the specimen D60T0B50S12, the failure mode was surface plasticity failure as shown in **Fig. 10**. This attributed to the absence of the concrete in the top chord (hollow). **Fig. 11** indicated that D60T0B0S12 shows a plasticity failure at the supports as the bottom chord was hollow.
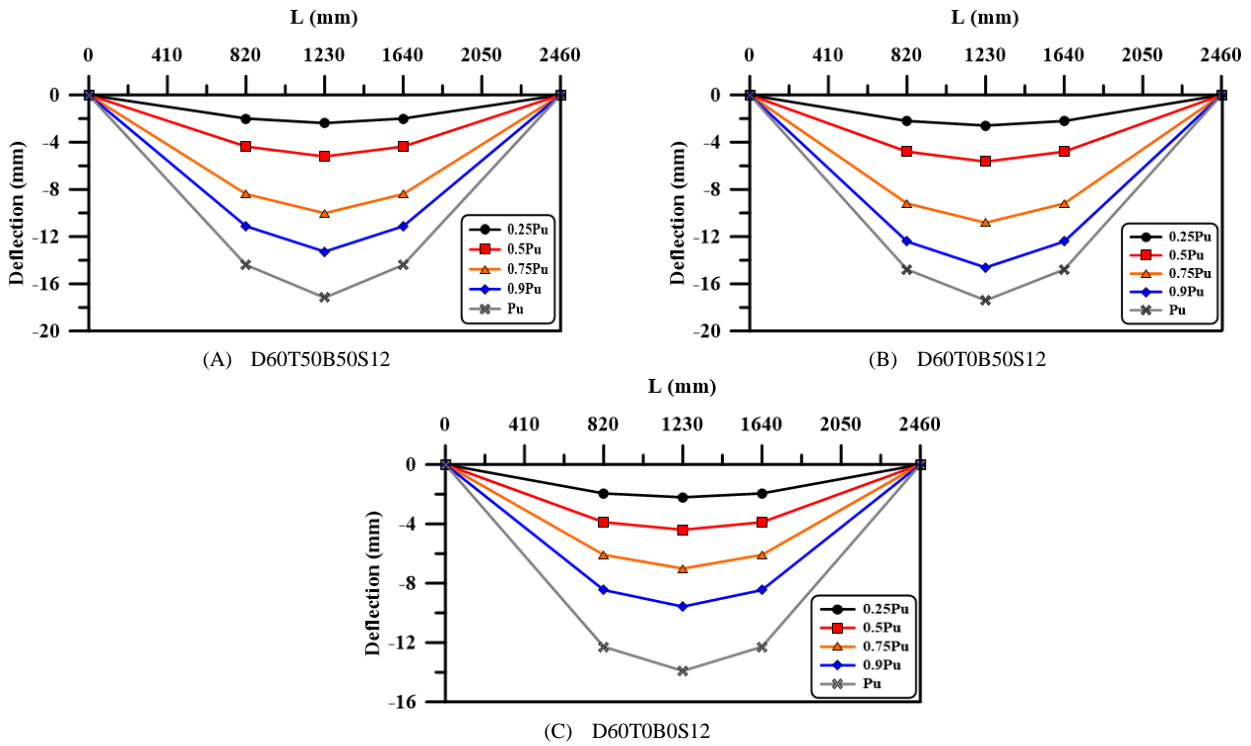

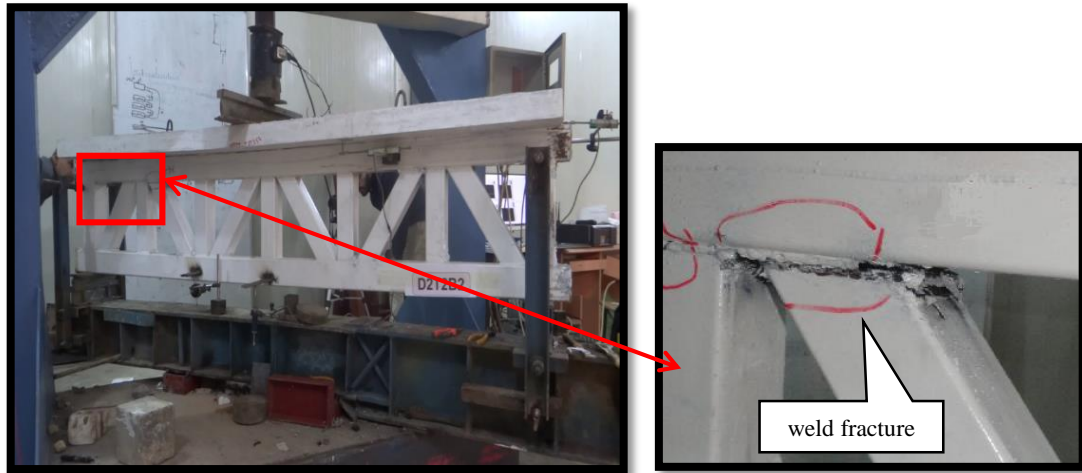**Figure 8 Deflected shape of the tested specimens.**
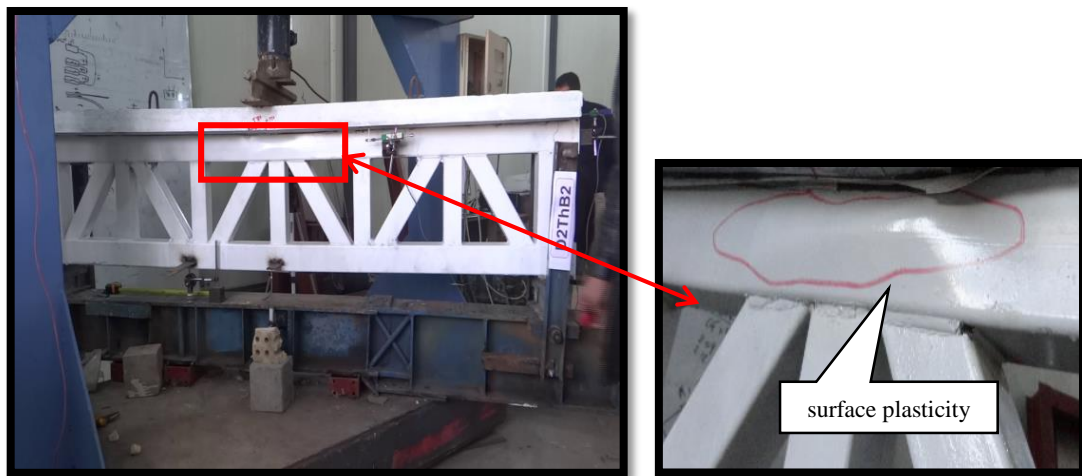
Figure 9 Failure mode of specimen D60T50B50S12.

Figure 10 Failure mode of specimen D60T0B50S12.
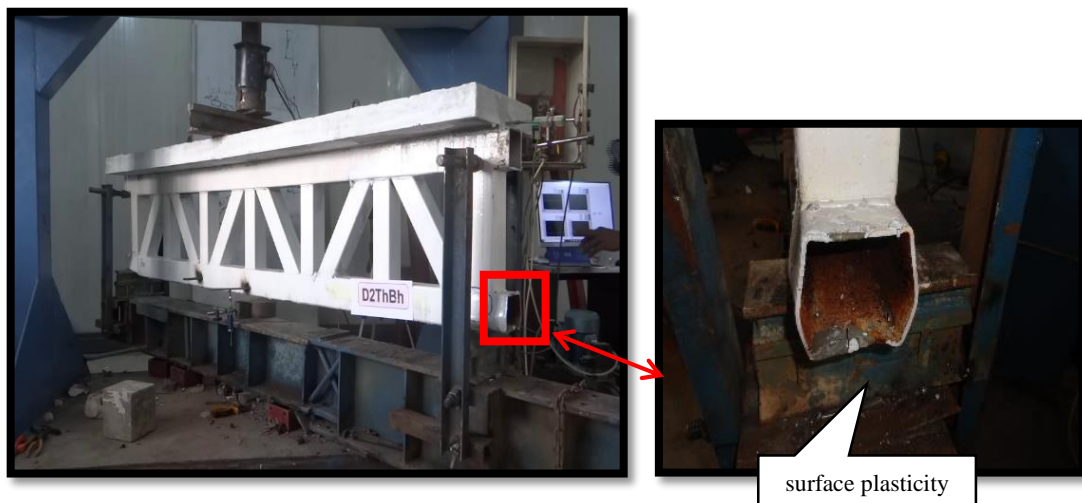

Figure 11 Failure mode of specimen D60T0B0S12.
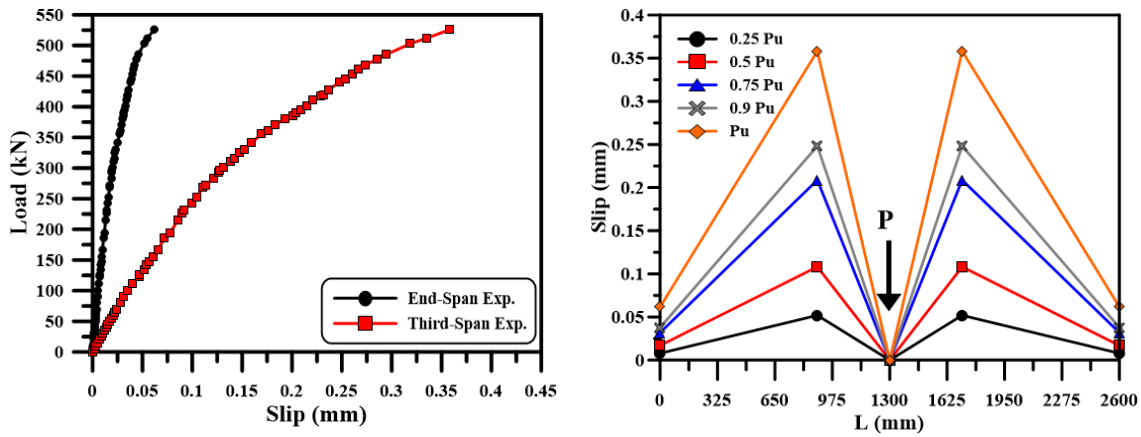
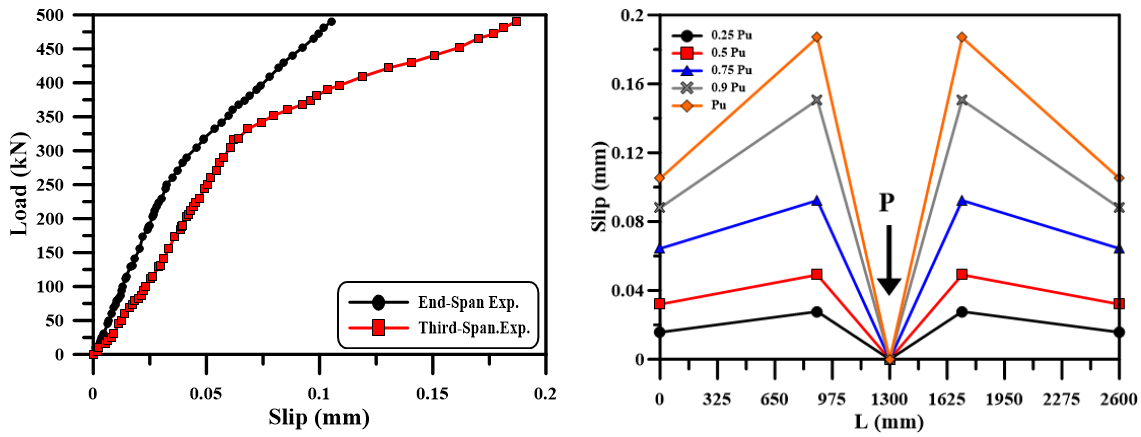**Figure 12 Load-slip and longitudinal slip of specimen D60T50B50S12.**

Figure 13 Load-slip and longitudinal slip of specimen D60T0B50S12.
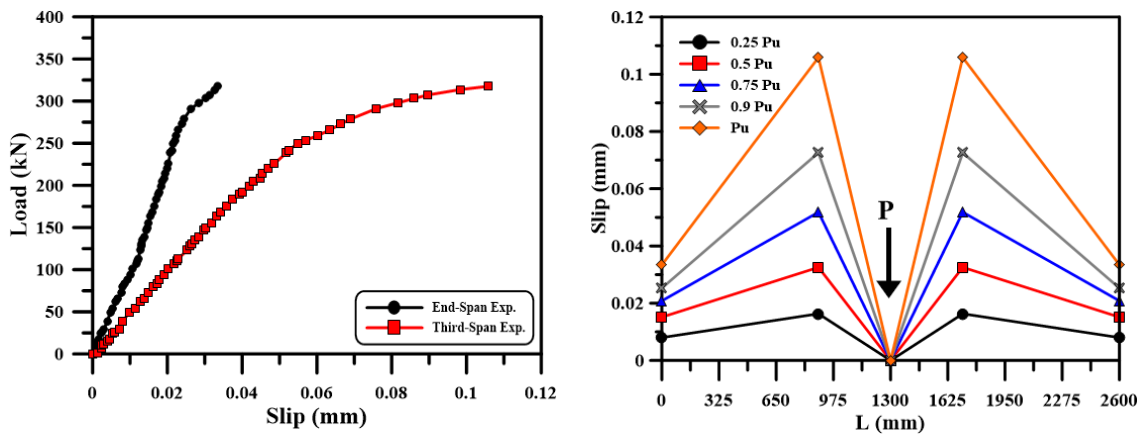

Figure 14 Load-slip and longitudinal slip of specimen D60T0B0S12.

4. Conclusions

From this study, the following conclusions can be reported as:

1. The steel tubes of the upper chord filled by concrete prevent surface plasticity failure of the upper chord under loading and increase the ultimate load by 6.68 %. Also, filling the lower chord with concrete prevents the surface plasticity failure in the supports zone and caused an increase in the ultimate load by 39.59 %.

2. The slip at the end of the specimen of two chords filled with concrete is less by 71% than the end slip of specimen of hollow top chord and higher by 46.8 % than the specimen of two hollow chords.

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