Journal of Physics: Conference
Series

Experimental investigation of a hybrid steel truss reinforced concrete beam for aerospace shelters

To cite this article: E A Lofty *et al* 2023 *J. Phys.: Conf. Ser.* **2616** 012049

ASAT-20 IOP Publishing
Journal of Physics: Conference Series **2616** (2023) 012049 doi:10.1088/1742-6596/2616/1/012049

Experimental investigation of a hybrid steel truss reinforced concrete beam for aerospace shelters

E A Lofty [1], I M Kamal [1], M A Hassan [1] and K M Hassan [2].

[1] *Department of Civil Engineering, Military Technical College, Cairo, Egypt*
[2] *Housing and Building National Research center, Cairo, Egypt*

Email: eslam_333@mtc.edu.eg

Abstract. This paper illustrates experimentally the significance of using hybrid steel truss reinforced concrete beam (HSTRCB) in the construction of aerospace shelters. A finite element analysis was carried out in a previous stage to compare the flexural behaviour of HSTRCB with steel truss beams (without concrete casting) and traditional reinforced concrete beams. The Finite element simulations showed a significant improvement in the flexural behaviour of the HSTRCB. In this paper two beams were tested by 4-point bending test. The first is standard reinforced concrete beam. The other is HSTRCB with steel angles as top and bottom reinforcement. Stirrups were replaced by vertical steel plates. Flexural behaviour was represented by the load-deflection curves. Results showed that the adhesion strength between steel truss members and concrete should be enhanced. Failure occurred due to slippage between steel truss elements and concrete. Moreover, HSTRCB showed a noticeable improvement in the ductile behaviour for the zone after the ultimate capacity.

Keywords: Embedded truss, composite beams, steel-angle truss, aerospace shelters.

1. Introduction

Various methods were used over the last decades to improve the flexural behaviour of reinforced concrete beams such as : reinforcing beams with fiber reinforced polymers (FRP) bars and sheets, using high-performance concrete, etc. [1], [2]. Hybrid Steel trussed reinforced concrete beams (HSTRCB) were used for beams improvement. HSTRCB is using steel truss as a reinforcement instead of reinforced concrete bars. Normal Steel trusses are widely used in structures of long-spans due to its high stiffness and strength. However, it has low durability, poor fire resistance and needs regular maintenance routines of high cost. [3] recommended using the advantages of steel truss as a replacement for reinforced bars in reinforced concrete beams to overcome the above mentioned problems.

Ballarini et el numerically validate experimental results from another research. The validation was carried out for a group of trussed beams to analyze the failure mechanisms and ultimate load. The results showed that, beams with small size, under one point load located at the mid span experienced shear failure. While, beams of large size experienced flexural failure[4,5].

Kun wang et el used a steel truss skeleton as a reinforcement in concrete beams, top and bottom reinforcement were replaced the by steel hollow square tubes filled by grouted materials. The web reinforcement were replaced by steel rods. Beams were tested numerically by four-point load test using ABAQUS software. The effect of changing the concrete compressive strength, steel-concrete ratio and the spaces between web rods on the flexural capacity of those beams were examined[3].

Salah et el investigated the effect of changing the web reinforcement configurations on the flexural behaviour of trussed beams. Crack pattern and the growth of cracks through different loading periods were observed. Results showed that, beams with N-shape truss had the best flexural behaviour compared to traditional reinforced beams [6].

In this paper two beams were designed and tested to explore the flexural behaviour of the embedded truss system. The first beam is standard reinforced concrete beam while the second one is embedded hybrid steel truss reinforced concrete beam (HSTRCB).

2. Experimental Work:

Two specimens were tested as shown in Table 1 via 4-point load test to investigate the flexural behaviour of the hybrid steel-angle reinforced concrete beams. The beams were designed such that they have the same ultimate moment capacity not the same steel-concrete ratio. The beams were designed as double reinforced section with compression-tension reinforcement ratio equal 0.64. Preparing the tested specimen was carried out in the lab in two stages: First, arranging the steel parts of the truss and use welded connection to assembly the truss skeleton. Second, preparing and pouring concrete after measuring its compressive strength after 28 days.

Table 1. Specimen Details

Specimen Name	Top Reinforcement	Bottom Reinforcement	Stirrups
SB1	2Ø16	2Ø16+2Ø12	5Ø10/m
V20B5	2L 40 × 40 × 4	2L 50 × 50 × 5	Pl 30 × 4 Vertically placed

Specimen SB1 was designed as a standard beam to compare the results obtained by specimen V20B5. Both specimens were designed to have the same ultimate moment capacity. According to the Egyptian code for design and construction of concrete structures (ECP 201) [7], both beams have a reinforcement ratio less than the maximum of the double reinforced sections. As shown in Figure 1, specimen SB1 has bottom reinforcement 2Ø16 + 2Ø12, top reinforcement 2Ø16, and web reinforcement 5Ø10/m. While, specimen V20B5 has bottom reinforcement 2 angles 50 × 50 × 5, upper reinforcement 2 angles 40 × 40 × 4, and web reinforcement batten plates 30 × 4 mm distributed at distance 200 mm from each other, as shown in Figure 2.

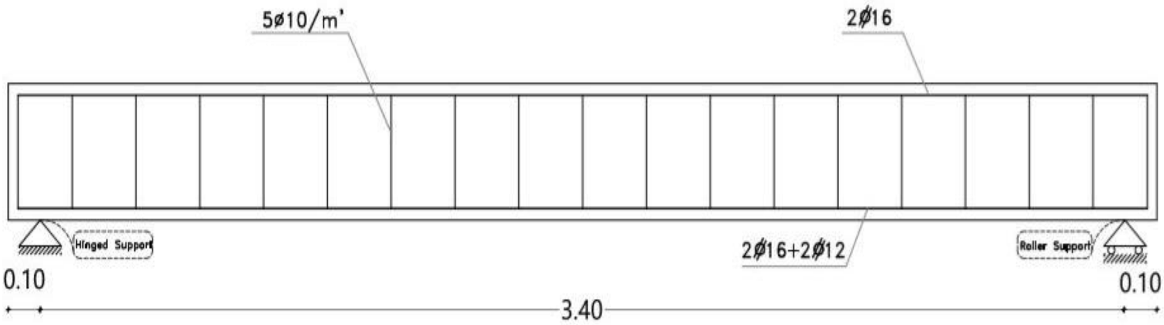
The concrete was mixed according to the ECP 201[7], as shown in Table 2. The average of three cubes were considered to calculate the compressive strength of the designed mixture after 28 days curing in the lab. A calibrated tensile testing machine was used to measure the yield strength of the steel bars, angles and plates tested in the current research. The material properties for the used concrete, steel bars, steel angles, and steel plates are shown in Table 3.

Table 2. The Concrete Mix Design

	Cement	Coarse Aggregates	Fine Aggregates	Water	Super plasticizer	Slump
For 1m^3 of concrete	400 kg	1086 kg	724 kg	188 litres	6 litres	12-15 cm

Table 3. Material Properties of Concrete and steel Parts

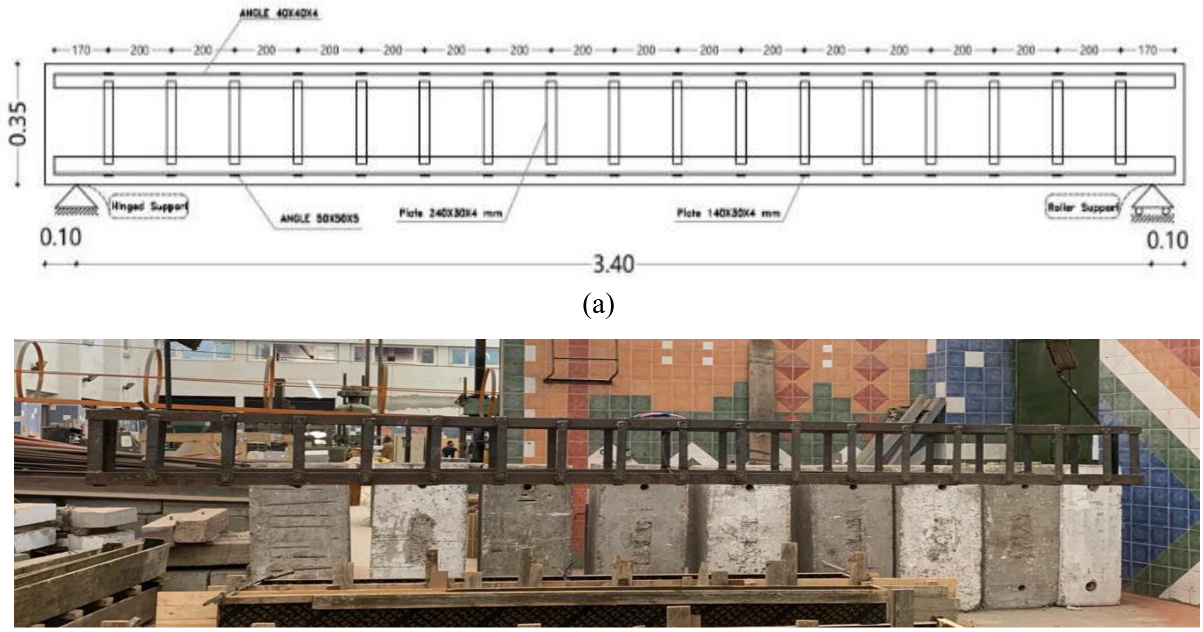
Type	Compressive Strength	Yield Strength	Modulus of Elasticity	Poisson Ratio
Concrete	32 MPa	----	21 MPa	0.3
Bars Ø 16	---	500 MPa	210 MPa	0.2
Bars Ø 12	----	500 MPa	210 MPa	0.2
Bars Ø 10	----	500 MPa	210 MPa	0.2
Angles 50x5	----	360 MPa	210 MPa	0.2
Angles 40x4	----	360 MPa	210 MPa	0.2
Steel Plates	----	360 MPa	210 MPa	0.2



(a)

(b)

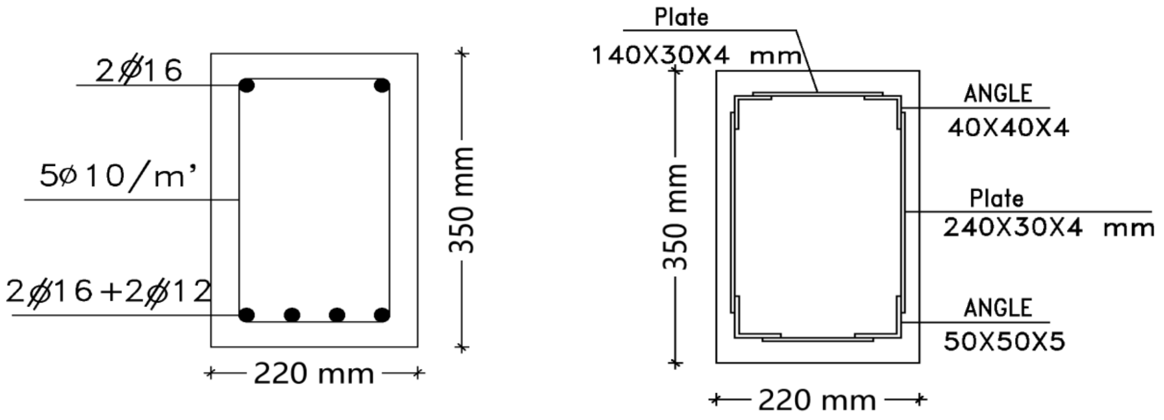
Figure 1. The longitudinal Section of Specimen SB1: (a) shop drawing (b) in lab



(a)

(b)

Figure 2. The longitudinal Section of Specimen V20B5: (a) shop drawing (b) in lab (All The Dimensions in mm)



(a) (b)

Figure 3. The Cross Sections of: (a) SB1 (b) V20B5

3. Test Setup:

Flexural testing was carried out using 4-point load test. Beams were supported as a simple beams with hinged and roller support with clear span of 3400 mm. A calibrated compression load cell of 2000 KN was applied on the top of the beam, over two loading points, 1000 mm distance apart each other, with 500 mm distance from the centre of the beam. Test setup was placed on a fixed steel frame in the lab. The compression load cell was force controlled by an acquisition system and load was applied at constant rate. Three calibrated LVDTs (linear carriable differential transformer) were used: one under the bottom of the mid span of the beam. The other two LVDTs were located under the extension of the two loading points, at the bottom of the beam. The three LVDTs were connected to the acquisition system to collect data trough out the test as shown in Figure 4.

Figure 4. The Test Setup

4. The Experimental Results:

As shown in Figure 5, load-deflection curve of the specimens were plotted from the data collected by the acquisition system, recorded by LVDT no. 1. Initially the HSTRCB showed a better behavior in the initial stiffness. First crack at the mid span was formed at the same stress for both beams, when the tensile stress exceeded the concrete tensile strength. The more the stress exceeding the tensile strength of concrete the more of the flexural cracks were developed for the two beams . Figure 5 shows a sudden drop in the strength of V20B5, at a displacement of 6 cm. Then, strain hardening resumes. This sudden drop was a result of the slippage between the steel angles of the truss and concrete at the compression zone (Top of the beam). As the load increases cracks in the mid-span of the tension zone started to become wider due to the weak adhesion stress between the concrete and the smooth surface of the angles of the truss as shown in Figure 6. The ultimate load reached by SB1 was 18 ton at 12.5 mm displacement while the ultimate load for V20B5 was 17 ton at 20 cm displacement. The ductile behavior of the trussed beams as the V20B5 did not show load decaying as in SB1. Figure 6 and figure 7 shows the failure in specimens V20B5 and SB1 respectively.

The strain recorded by the strain gauges attached to the lower reinforcement (steel angles) in specimen V20B5 is shown in Figure 8. It shows that when the steel angles started to yield the specimen reached its ultimate strength which means that the steel skeleton embedded in the concrete is responsible of the ultimate strength of concrete.

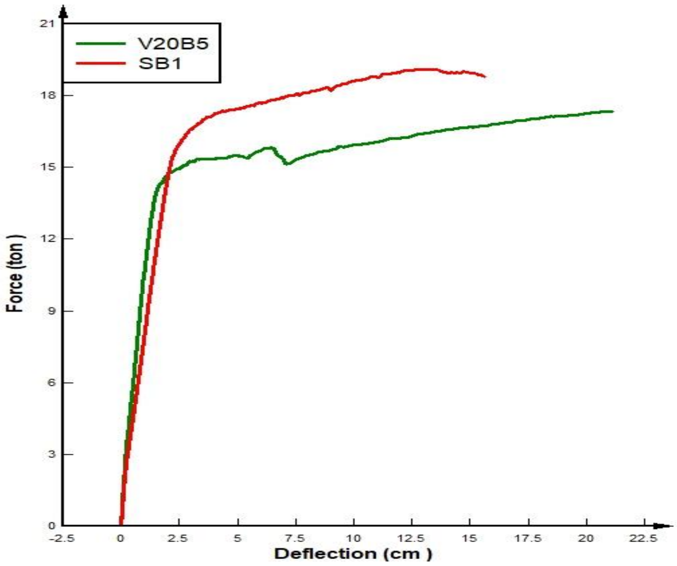


Figure 5. The Load-Deflection Curve of Specimens: SB1 and V20B5

Figure 6. The Concrete Slippage in V20B5

Figure 7. The Failure in SB1

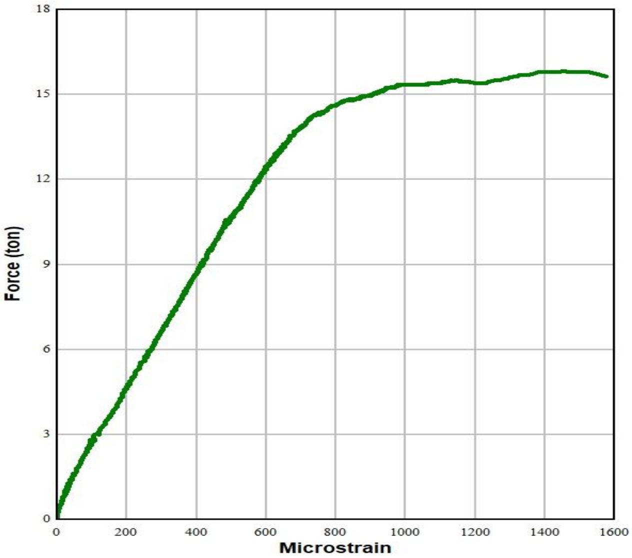


Figure 8. The Strain Curve of Lower Steel Angles in Specimen V20B5

6. Conclusions

In this paper two beams were tested by 4-point bending test. The first is standard reinforced concrete beam. The other is HSTRCB with steel angles as top and bottom reinforcement and vertical steel plates as stirrups. Flexural behaviour was represented by the load-deflection curves. Results showed that the weak bond strength between concrete and steel angles was responsible for the beam failure. The smooth surface of steel angles and plates should be modified to improve the bond strength. Moreover, hybrid steel truss reinforced concrete beam showed better ductility than ordinary reinforced concrete beam. This was noticed as the load did not decrease after reaching 20 cm deflection.

The crack propagation and the number of cracks formed in the trussed beam were better relative to the standard reinforced beam.

Further investigations are needed to increase the bond strength between steel angles and concrete eliminate failure due to slippage.

References

[1] El-Ghandour A A 2011 Experimental and analytical investigation of CFRP flexural and shear strengthening efficiencies of RC beams *Construction and building materials* **25**,1419–1429.

[2] Chalioris C E and Sfiri E F 2011 Shear performance of steel fibrous concrete beams *Procedia engineering***.** **14**, 2064–2068.

[3] Wang K, Zhu Z, Luo H, and Omar A A 2021 Analysis on flexural capacity of square steel tube truss concrete beams with grouted chords *Advances in materials science and engineering* **2021**, 1-13.

[4] Zhang N, Fu C,Chen L and He l 2016 Experimental studies of reinforced concrete beams using embedded steel trusses *ACI structural journal* **113**, 701-710.

[5] Ballarini R, La Mendola L, and Monaco A 2017 Computational study of failure of hybrid steel trussed concrete beams *Journal structural engineering* **143**,04017060.

[6] Afefy H, Taher S, Fawzy O, and Salem S 2022 Numerical simulation of RC beams reinforced with internal steel trusses *International journal advanced structures and geotechnical engineering* **03,** 38–51.

[7] ECP 201 The Egyptian code for calculating loads and forces in structural work and masonry .2022 National research center for housing and building.