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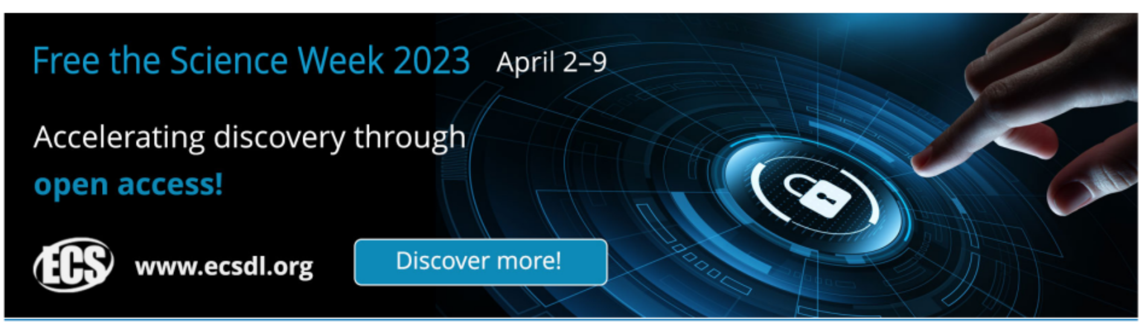

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Load-carrying capacity and failure mode of composite steel-concrete truss element under monotonic loading

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Abstract. Composite steel-concrete trusses are among the most economical systems for building, particularly for greater spans, allowing proper internal space utilization without limiting columns. This paper examines 12 lab tests on two types of composite steel-concrete truss elements compared with the conventional steel truss element as a control specimen. The experiments investigate the load-carrying capacity of the truss element with different configurations under monotonic loading. The study on the specimen's failure modes was based on the welded joints. The obtained results were compared with analytical evaluations of typical resisting mechanisms of steel-concrete composite, reinforced concrete, and steel structures with updated Indonesian design codes. The basic features of the steel-concrete truss elements discussed quantitatively and qualitatively.

1. Introduction

Composite materials are widely used to design truss structures since they have suitable properties [1]. Composite steel-concrete trusses are highly economical for designing structures with spans of up to 20 m [2]. These structural elements are used for longer spans of about 30 m, ensuring effective utilization of internal space with no impact to the columns [2]. Furthermore, the trusses not only facilitate the achievement of the exact limits in building height, but are also useful in managing complex systems involving electricity, heat, ventilation and communication. The filigree steel truss and slim piers are used to support composite steel bridges with carriageway deck to increase their fitness, especially the ordinary concrete bridges. It accounts for the technical and architectural aspects with concession between landscape protection and hard transport basics. Therefore, a composite truss bridge, with a quick engineering assembly is economically and aesthetically appropriate.

Several studies focused on the strategies for designing composite truss structures. For instance, Shütze [3] developed and implemented equilateral triangle composite truss beams with cross-sectional bases by joining individual parts to bonded joints, and supporting them with gusset plates. The structured beams were used in the rigid airship frame. Weaver and Jensen [4] used a braiding machine to create a truss beam by employing IsoTruss®, a concept that is currently under commercial development. This is advantageous because it does not require the designing of separate individual members to be connected. In other studies, internal mandrels have been used to design a similar basic structure [5–7], through winding-based techniques. The mandrel geometries are, therefore, created by strengthening the nodes

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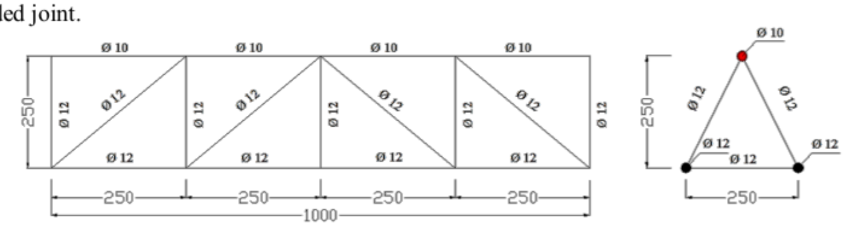
of the non-continuous cross-section. As a result, the complex multi-component solutions are easily dissembled once the composite is cured.

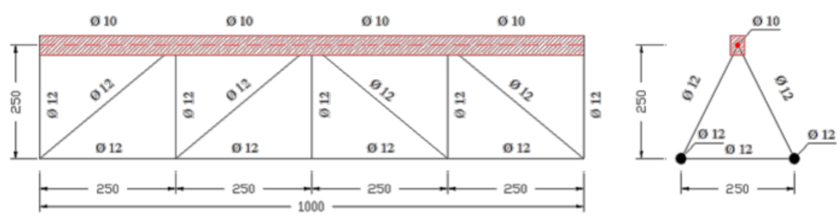
Another studies have examined types of braided truss structures that facilitate geometrical simplification. This is achieved by using a circular cross-sectioned mandrel [8]. The circular cross-sections are flexible and weaker because they function as beams under combined axial and bending loading. Although many studies have examined composite truss elements' structural behavior, accurate knowledge of these elements' behavior is vital. It is also critical to study how different parameters affect the composite truss elements' efficiency. This paper mainly deals with the prime significance for the behavior of composite steel-concrete trusses subjected to monotonic loads. Specifically, the paper primarily addresses the investigation of the load-carrying capacity and failure mode mechanisms in composite steel-concrete trusses in experimental three-point bending tests on specimen representative of the elements stated.

2. Material and methods

Tests were conducted on a series of composite steel-concrete truss elements in Howe and Waren configuration. The top chord was integrated with a concrete material (figure 1 and figure 2). The total length of the element and span between support axes was 1000 mm, while the height and width were 250 mm. The concrete material was designed to have 50 mm wide and 70 mm thick. The average compressive strength of used concrete determined on the cubic samples was 14.19 MPa and 17.15 MPa for Howe and Waren configuration specimens. The bottom chords and webs were made of steel bars with 12 mm diameter having a yield strength of 300 MPa, while a 10 mm diameter steel bars with a yield strength of 353 MPa were used as the top chords. Finally, all the members were connected using a welded joint.

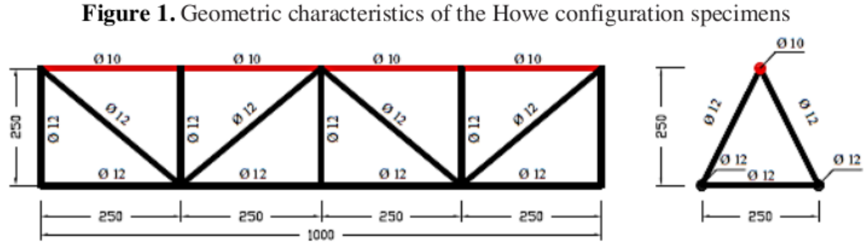


(a) TH-S specimen

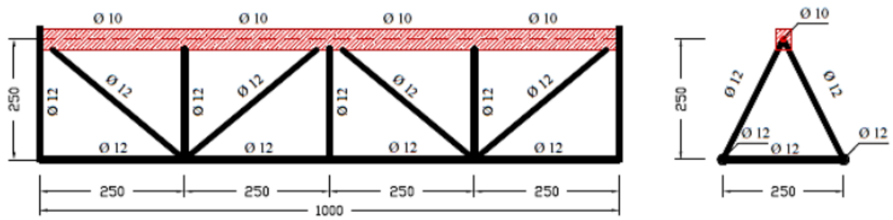


(b) TH-C specimen

Figure 1. Geometric characteristics of the Howe configuration specimens



(a) TW-S specimen



(b) TW-C specimen

Figure 2. Geometric characteristics of the Waren configuration specimens

The first letter of the specimen code indicates it is a truss element while the type of configuration is shown by the second letter, followed by whether it is a conventional steel truss element or composite steel-concrete truss element shown by the last letter of the specimen code. During the tests, the specimens were under a monotonic load with a scheme analogical to three-point bending a freely supported beam, as shown in figure 3. The load from Universal Testing Machine (UTM) was applied to the upper concrete part over the central node of the steel-concrete truss element. The experiments we performed at the Jenderal Soedirman University, Indonesia, as a research program to validate methods and criteria for element typology's structural design.

Figure 3. The scheme of test

3. Result and discussion

3.1. Load-carrying capacity

At the time of failure of the specimen, the load level was the final loading level, taken as the ultimate load-carrying capacity. The ultimate load-carrying capacity of each specimen is presented in table 1, where the average load-carrying capacity of the conventional steel truss element with Howe configuration (TH-S) could reach 43.43 kN, while the average value for the composite steel-concrete truss element with Howe configuration (TH-C) was 58.43 kN. The measured value for the TW-C specimen was 34.54% higher than the TW-S specimen. The average load-carrying capacity of the composite steel-concrete truss element with Waren configuration (TW-C) was improved by about 56.66% compared to the conventional steel truss element with Waren configuration (TW-S). This was mainly caused by the placement of concrete material in the top chords of the truss elements that enhanced the members' compression resistance.

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Table 1. The ultimate load-carrying capacity

No.	Specimen code	Load-carrying capacity (kN)	Average value (kN)
1.	TH-S-01	39.50	
2.	TH-S-02	45.50	43.43
3.	TH-S-03	45.30	
4.	TH-C-01	65.50	
5.	TH-C-02	54.60	58.43
6.	TH-C-03	55.20	
7.	TW-S-01	34.40	
8.	TW-S-02	36.30	35.33
9.	TW-S-03	35.30	
10.	TW-C-01	59.50	
11.	TW-C-02	59.10	55.33
12.	TW-C-03	47.40	

3.2. Mode of failure

The specimens were designed for compression failure. For this reason, the welded joint was strengthened in the best way to avoid tension failure. The welding process was conducted two times because, during the preliminary test, there was a tension failure on the welded joint. The welding process had to be strengthened again (re-welding). When the final tests were performed, all the truss elements failed on the compression chords. The failure mode was the compression chords experiencing buckling, as shown in figure 4 and figure 5.

(a) TH-S specimen

(b) TH-C specimen

Figure 4. Failure mode of Howe configuration specimen

(a) TW-S specimen

(b) TW-C specimen

Figure 5. Failure mode of Waren configuration specimen

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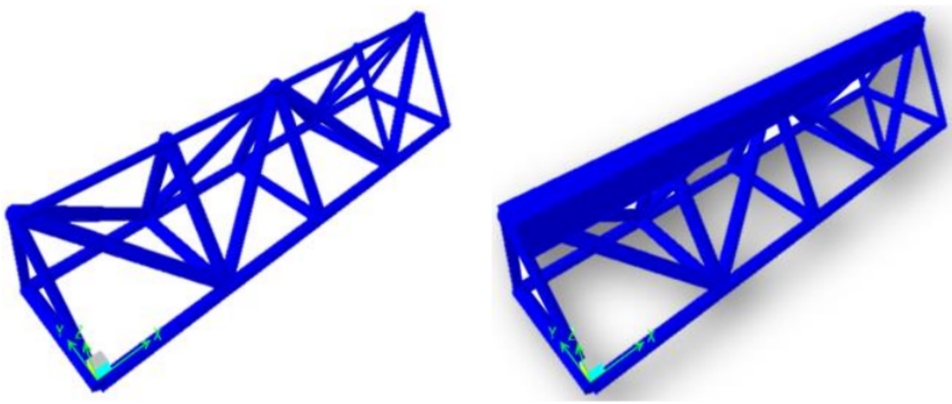
3.3. Comparison with analytical modeling

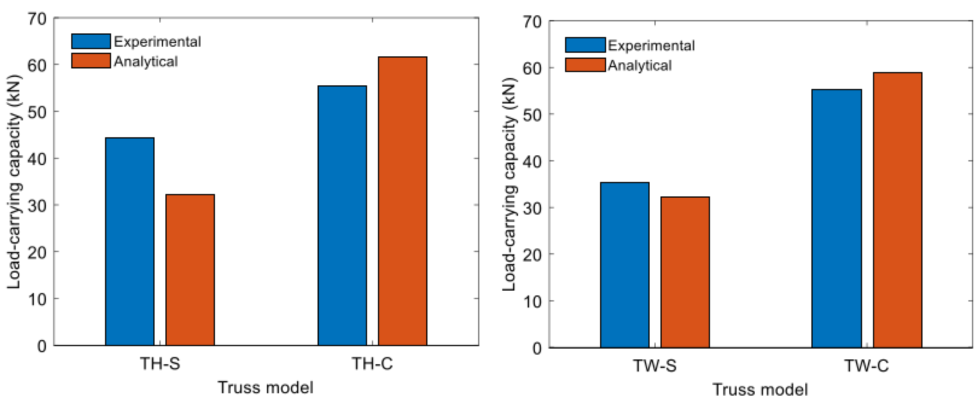
The experimental results were compared with the analytical modeling of typical resisting mechanisms of steel-concrete composite, reinforced concrete, and steel structures. They were then updated based on Indonesian design codes, developed using ETABS, as shown in figure 6.



(a) Convensional steel truss model (b) Composite steel-concrete truss model

Figure 6. Analytical modeling

The analytical evaluation showed that the TH-S and TW-S model's load-carrying capacity was 27.13% and 8.36% lower than the average experimental results. However, there was an increase in the TH-C and TW-C model's load-carrying capacity by about 10.95% and 6.42% compared to the average value of the experimental results. This is because the material properties were homogeneous in all chords in the developed analytical models. The graphical comparison of the load-carrying capacity for all models is shown in figure 7.



(a) Howe configuration (b) Waren configuration

Figure 7. Comparison of load-carrying capacity

4. Conclusions

This study tested 12 specimens on two type configurations of composite steel-concrete truss structures under monotonic loading. Furthermore, it examined the load capacity of the failure modes. The results were compared with the analytical modeling of the steel structures. The study made the following conclusions:

- The average load-carrying capacity was 34.54% and 56.66% higher due to the placement of concrete material in the truss elements' top chords for Howe and Waren configurations, respectively.
- The compression chords experienced buckling, leading to compression failure in all specimens.
- There was a reasonable difference between the analytical evaluation and experimental test results due to the homogeneous material properties for all chords in the models.

Acknowledgments
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