The Performance between Two Long-span Roof Trusses of Cold Formed Steel with Back to Back Channel Section

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Abstract. Cold formed steel (CFS) is mostly used for short span structures in Indonesia because its advantages in cost and time efficiency. However, there is still limited number of long-span construction using cold formed steel because its buckling issue. Throughout the time, there are many researches that revealed the buckling issues can be prevented; one of them is combining their section. Then, CFS structure should give full structural performance. This research aims to analyze the performance of long-span roof truss, 24 m, using CFS back to back channel section. Two types of roof trusses, model 1 and model 2, are compared to get better configuration for long-span roof truss. Analysis is conducted by 2D model and analytically calculated based on SNI 7971:2013. The results are the maximum axial tensile force and axial compressive force, and also deflection. They will be compared to CFS back to back channel section capacity. This analysis obtained the stress ratio and deflection of both configurations. Based on analysis results, CFS back to back channel section safely withstands resisting axial forces by giving compressive ratio number around 0.54-0.72. Then, model 2 has given better structural performance, stress ratio and deflection, than model 1.

1. Introduction

In this recent time, demanding of cold-formed steel (CFS) increases for roof structure construction, whether for simple residential houses or medium-rise buildings. There are many advantages can be obtained using cold-formed steel structure, such as time and cost efficiency as well as getting strong structure through its properties [1,9]. Compared to hot rolled steel, the construction of cold-formed steel causes the mass of the building can be lighter. It means the effect of the earthquake also can be minimized [5,6]. However, cold-formed steel (CFS) structure still has the stability issue where buckling occurs due to the ratio of width-thickness [9,12]. Local buckling, one of major buckling, commonly occurs in the elastic zone when the axial-compression subjected to compression members [2,3].

Many kinds of research have been conducted to find the proper methods to prevent buckling in cold-formed steel structure; one of them is combining a single section into double sections such as the back-to-back section [7, 8,10]. This method has been studied analytically and experimentally to prove that CFS stiffness and capacity can be increased to 50%. Furthermore, the ductility of this section also increased to 70%. According to these researches, it can be determined that the cold-formed steel structure can be enhanced for not the only short-span structure but also the long-span structure, specifically for roof structure. This type of structure should be applied for plant, factory storage, sports
hall, market, and hangar [7]. However, the study for long-span truss of cold-formed steel is slightly conducted to obtain appropriate analysis and design.

This paper aims to analyze the optimum configuration for long-span roof truss using cold-formed steel back-to-back section. The main configuration that is analytically studied in this paper is Howe Slope Parallel Chord where it can be modified based on force ratio concept and structure deflection which are obtained from the two-dimensional analysis. Fitrah [7] has concluded that howe slope parallel chord must be continuously developed to get better configuration. The comparison of these results will determine which one of the configuration that might be good for long-span roof truss.

2. Methodology

The two types of howe slope parallel chord roof truss 24 m long-span were analyzed to obtain comparison of each structural performance such as deflection and stress ratio. This span was taken as common span for long-span constructions such as sport hall, plant, hangar, etc. They were constructed using the same CFS section of back to back channel. Both trusses, named model 1 and model 2, have the same span and height, as shown in Figure 1(a) and 1(b). Model 2 has modification that 6 m span of bottom chord is straight.

![Figure 1. (a) Model 1 (b) Model 2](image)

Model 1 and Model 2 were constructed by using CFS back to back channel with double section of 150.75.0.8 for top and bottom chords and single section of 75.35.0.75 for web members, as shown in Figure 2. The length of each chord is specifically illustrated in Table 1.

Analysis of both trusses was assumed that they are connected to the supporting column using a few bolts and it does not permit to any lateral movement. It means that both trusses used pin supports and most of truss members are subjected to compressive load. However, the connection designs for support and truss members are not presented in this paper.

Material properties of CFS were obtained from previous research conducted by Fitrah [7]. The average yield stress and average elastic modulus of CFS are 495 MPa and 200,000 MPa respectively.
### Table 1. The length of tensile and compressive member

| Model | Member Code | Length (m) |
|-------|-------------|------------|
| 1     | T-8 – T-9 ; B-8 – B-9 | 1.6       |
|       | B-8 – H     | 1.69      |
| 2     | T-8 – T-9   | 1.6       |
|       | B-1 – A     | 1.69      |
|       | B-7 – G     | 1.69      |
|       | B-8 – H     | 2.07      |
|       | B-8 – B-9   | 1.54      |

#### Figure 2. (a) The cross section for top chord and bottom chord (b) The cross section for web

The analysis was conducted by modeled both trusses using SAP2000. Truss connection in each node was assumed as the rigid connection. According to the Indonesian Code, 4 type loads were determined such as the dead load (D), live load (L), wind load (W), and rain load (R). However, the earthquake load (E) was simply calculated by distributing 10% of the dead load for each node. These loads were calculated to obtain the load distribution between two adjacent trusses where 1.5 m distance was used in this design. Furthermore, the dead loads (D) were generally determined based on material type and CFS section used in truss design. CFS purlin (0.01 kN/m) and metal roof (0.18 kN/m²) were also defined as point load in each node that is subjected to truss.

Load combinations subjected to each model were determined based on SNI 1727-2013 verse 2.3.2 [11] below:

1. 1,4 D               (1)
2. 1,2 D + 1,6 L + 0,5 W (2)
3. 1,2 D + 1,6 R + 0,5 W (3)
4. 1,2 D + 1,6 R + 1,0 L (4)
5. 1,2 D + 1,0 W + 1,0 L + 0,5 R (5)
6. 0,9 D + 1,0 W       (6)
7. 0,9 D + 1,0 E       (7)

#### 3. Result and Discussion

The axial tensile capacity of back to back channel is calculated based on SNI 7971:2013 verse 3.2.1 (Equation 8,9) where $N_t$ is the nominal tensile capacity, $\phi_e$ is the reduction factor for tension element where 0.9 is taken for the calculation. $k_e$ is the correction factor for the force distribution where 0.85 and 1.0 are taken for the calculation because the section is single and double channel [4]. $A_g$ is the gross cross-sectional area, $A_n$ is the net cross-sectional area, and $f_u$ is the tensile strength of CFS based on aforementioned data.
The axial compressive capacity calculation is also based on SNI 7971:2013 verse 3.4.1 (Equation 10,11) where \( N_c \) is the nominal compressive capacity, \( \varnothing_c \) is the reduction factor for compressive element where 0,85 is taken for the calculation. \( A_e \) is the effective cross-sectional area when \( f_n \) occurred. \( f_n \) is critical strength based on non-dimensional buckling strength [4].

\[
N_c = \varnothing_c A_e f_y
\]  
(8)

\[
N_c = \varnothing_c 0.85 k_t A_n f_u
\]  
(9)

\[
N_c = \varnothing_c A_e f_y
\]  
(10)

\[
N_c = \varnothing_c A_e f_n
\]  
(11)

Based on the calculation results, the axial tensile and compressive for section double back to back channel and single channel can be seen in Table 2. Based on analysis, all top and bottom chord of both model occurred the compressive force. Then, the capacity is presented for top and bottom chord are compressive capacity, \( N_c \), only. Meanwhile, the tensile and compressive force occurred in web.

Top chord (T-8 – T-9) of model 1 and model 2 has the same section and length. Then, the compressive capacity of both also has same result. It can be seen that for straight chord in bottom chord (B-8– B-9) of model 2, the compressive capacity is slightly higher than model 1.

Table 2. The axial tensile and compressive capacity for member

| Model | Member     | \( N_c \) (kN) | Member     | \( N_c \) (kN) | \( N_c \) (kN) |
|-------|------------|----------------|------------|----------------|----------------|
| 1     | T-8 – T-9  | 39.76          | B-8 - H    | 20.7           | 17.75          |
|       | B-8– B-9   | 39.76          |            |                |                |
| 2     | T-8 – T-9  | 39.76          | B-8 - H    | 22.3           | 16.51          |
|       | B-8– B-9   | 41.33          | B-7– G     | 20.7           | 17.75          |

According to structural analysis result, the maximum axial compressive for model 1 is 28,7 kN and for model 2 is 25,43 kN. It is occurred at each bottom chord (T-8 – T-9). Axial tensile and compressive are occurred in their webs. Table 3 showed the comparison between axial tensile and compressive force that is occurred for each truss and axial tensile and compressive capacity of CFS section. Truss performance is determined by compressive and tensile ratio, and structure deflection. The compressive ratio is obtained by dividing the required capacity (\( N^* \)) and axial compressive capacity (\( N_c \)). Then, the tensile ratio is obtained by dividing the required capacity (\( N^* \)) and axial tensile capacity (\( N_t \)).

Table 3. Ratio and deflection results

| Model | Member | Required Capacity, \( N^* \) (kN) | Axial Compressive Capacity, \( N_c \) (kN) | Axial Tensile Capacity, \( N_t \) (kN) | Compressive Ratio | Tensile Ratio | Deflection (mm) |
|-------|--------|----------------------------------|-------------------------------------------|------------------------------------------|------------------|---------------|-----------------|
| 1     | T-8 - T-9 | 27.23                              | 39.76                                    |                                          | 0.68             |               |                 |
|       | B-8 - B-9 | 28.7                                | 39.76                                    |                                          | 0.72             |               |                 |
|       | B-8 - H   | 13.4                                |                                          |                                          |                  | 12.7          |                 |
| 2     | T-8 - T-9 | 21.66                              | 39.76                                    |                                          | 0.54             |               |                 |
|       | B-8 - B-9 | 25.43                              | 41.33                                    |                                          | 0.62             |               | 6.2             |
|       | B-8 - H   | 12.8                                |                                          |                                          | 0.57             |               |                 |
|       | B-7– G    | 10.1                                |                                          |                                          | 0.49             |               |                 |
Based on calculation, Compressive ratios for top and bottom chord in model 1 are 0.68 and 0.72 respectively. In the other hand, model 2 has smaller compressive ratios than model 1, they are 0.54 and 0.62. It means both trusses have well performance and safely withstand for maximum tensile and compressive force by using CFS back to back channel section in the chord. Deflection that occurred in model 1 and model 2 is 12.7 mm and 6.2 mm respectively. It also showed that maximum deflection of both trusses is lower than the allowable maximum deflection for 24 m span, 200 mm. Besides that, CFS back to back channel already proved can increase the stiffness of trusses as well.

4. Conclusions
This research aimed to analytically conduct the comparison of two types of CFS roof trusses for long-span 24 m. conclusions on this research can be listed as follows:
1. Analysis showed that CFS back to back channel section can safely construct for long-span roof truss because it can withstand the maximum forces in the truss whether axial tensile and axial compressive. It also increases the stiffness of trusses.
2. Based on the performance of roof trusses, model 2 has given well performance compared to model 1. It clearly seen that both stress ratio and deflection in model 2 is smaller than model 1.

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