Recent Trends in Civil Engineering and Built Environment Vol. 3 No. 1 (2022) 1136-1142
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RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

Effect of Stiffener Properties on Built-up CFS Column: Numerical Modelling using Finite Element Method

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DOI: https://doi.org/10.30880/rtcebe.2022.03.01.129
Received 4 July 2021; Accepted 13 December 2021; Available online 15 July 2022

Abstract: A cold-formed steel (CFS) column has become very common in low-rise building and portal steel frame system. However, built-up CFS column tendency to experiences buckling that directly affecting strength and displacement. Thus, the main objective of this study is to investigate the strength and displacement of built-up CFS column at different stiffener properties using finite element method (FEM) called WELSIM. The depth and thickness of stiffener was simulated to obtain various result. From the numerical modelling, it was observed that by increasing the stiffener properties, the ultimate strength eventually increases. For failure mode, lobe buckling, and flexural buckling occurs when the high force applied on the column. Therefore, the present of higher stiffener properties shows good result with the simulation result.

Keywords: Cold-Formed Steel Column, Ultimate Strength, WELSIM

1. Introduction

Cold-formed steel (CFS) column is produced from plates and strips in rolling machine or by press brake operation. It provides many benefits in term of lightweight material and environmental safeguard. Built-up member is the perfect option to be used in multi-storey, cold-formed thin-walled steel structures, high axial or bending load. In addition, built-up CFS column have higher strength, symmetric cross and resistant to out-of-plane movement. However, built-up CFS column easily failure in overall buckling unless they have been laterally supported. This unfavourable condition makes it instable to be applied as column. Hence, the load carrying capacity can be enhanced by the presence of stiffeners. An experimental study was conducted has be shown that the impact of using stiffener on the built-up CFS column can reduce lateral buckling and increase load carrying capacity [1]. Other than that, built-up column based on CFS closed section with battens or stiffeners shows stronger buckling resistance under axial compression [2]. Finite element method (FEM) is most commonly used because it can provide strong prediction for both failure mode and ultimate strength of the specimens [3]. In order to minimize the number of physical prototypes and testing, FEM software optimize component in their design process to produce a better product and cut costs.

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The study focuses on the numerical modelling of built-up CFS column that has been conducted using finite element method called WELSIM. The proper selection of stiffeners is paramount in which controlled by its depth and thickness. As the aim and goal for reaching the desired outcomes, this study contributes three objectives. However, the main objective of this study was to investigate the performance of built-up CFS column with different stiffener properties. Variable depth and thickness of stiffener was simulated to obtain the stress, strain, force and displacement, hence can be evaluated to understand its effect on the load carrying and failure mode.

2. Materials and Methods

This numerical modelling was conducted using finite element method to carry out the failure under buckling and impact on strength and displacement of built-up CFS column. This study involves four stages which is design and specification, pre-processing, appraisal and validation and lastly is three-dimensional was determined by variables. By followed the programme flow to conduct the experiment, fifteen models were designed using WELSIM software.

2.1 Geometry and stiffener properties

The built-up CFS column was modeled in three-dimensional which can be seen in Figure 1. The model of sample will be used in WELSIM simulation by using different stiffener properties which are three depth and five thickness of stiffener that can be seen in Table 1. Testing designation are following original designation made by original author [4].

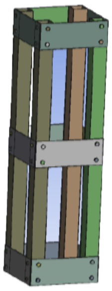


Figure 1: 3D-Model of the specimen

Table 1: Cross-sectional properties of stiffener

Code	Depth, H (mm)	Thickness, t (mm)
D1T1	25	0.72
D1T2		1.0
D1T3		1.2
D1T4		1.9
D1T5		2.2
D2T1	50	0.72
D2T2		1.0
D2T3		1.2
D2T4		1.9
D2T5		2.2
D3T1	75	0.72
D3T2		1.0
D3T3		1.2
D3T4		1.9
D3T5		2.2

2.1 FEM simulation

In the numerical modelling, the constraint is used to control the translational and present the support. Using WELSIM software, the bottom part of built-up CFS column was described as fixed exactly to the actual condition as experiment. The constraint thus become applicable in all direction (x, y, and z axes). The loading that shall be imposed on the built-up CFS column is in difference value with 15 sub steps within a second. Mesh the specimen to regular because the successful meshing would give the better solution and efficiently converge. The numerical modelling completed by running the study and obtain the results. The steps for simulation are same and were done for each model.

3. Result and discussion

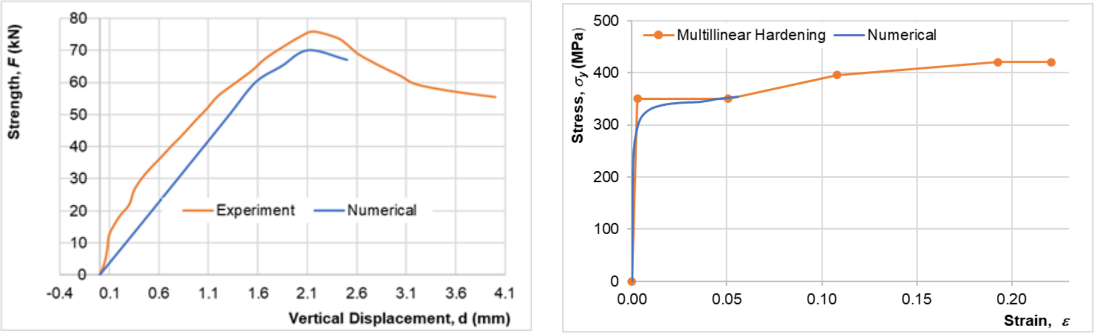
This study was carried out to deeply understand the performance of built-up CFS column with stiffener in term of failure mode and load carrying capacity from simulation and experimental compression test. The comparison of results is done to determine the differences of simulation in the strength and displacement of each model. The findings are summarised as easy to understand tables and graphs.

3.1 Validation and Appraisal

Validation is a method that aid in ensuring the accuracy and dependability of models and simulations [5]. Choosing the right constitutive model for the material is one of the important things in FEM [6]. The results are compared in term of force-displacement and stress-strain curve from each hardening properties used in WELSIM. The conclusion was reached that multilinear kinematic hardening should be chosen since the force-displacement and stress-stain curve is similar to the experimental study. Table 2 highlights the percentage difference between numerical modelling and experimental study, meanwhile Figure 2 present the force-displacement and stress-strain curve.

Table 2: Percentage difference between numerical modelling and experimental study

Hardening Properties	**Force, F (kN)**		**Displacement, d (mm)**		**Percentage different (%)**	
	Num. model	Exp. study	Num. model	Exp. study	Force	Displacement
Trilinear isotropic	70	75.88	2.07	2.16	7.75	4.37
Trilinear kinematic	70	75.88	2.33	2.16	7.75	7.34
Multilinear isotropic	70	75.88	2.35	2.16	7.75	8.12
Multilinear kinematic	70	75.88	2.11	2.16	7.75	2.71



(a) (b)

Figure 2: Multilinear kinematic hardening, (a) Strength-displacement curve, and (b) Stress-strain curve

3.2 Force-Displacement Profile

The variable of thickness and depth of stiffener were proposed in this numerical modelling to evaluate the force-displacement curve. Table 3 highlights the maximum force and displacement obtained from numerical. Meanwhile Figure 3 to Figure 5 shows the graph and pattern of force-displacement curve for different thicknesses and depths of stiffener.

Table 3: Maximum force and displacement

Code	**Cross sectional properties**		**Maximum force, F (kN)**	**Displacement, d (mm)**
	Depth, H (mm)	Thickness, t (mm)		
D1T1	25	0.72	84.93	1.99
D1T2		1.0	84.93	1.95
D1T3		1.2	84.93	1.94
D1T4		1.9	84.93	1.90
D1T5		2.2	84.93	1.86
D2T1	50	0.72	84	1.83
D2T2		1.0	84.45	2.22
D2T3		1.2	84.47	1.63
D2T4		1.9	84.47	2.27
D2T5		2.2	84.93	1.67
D3T1	75	0.72	86.8	2.26
D3T2		1.0	86.8	2.23
D3T3		1.2	82.33	2.20
D3T4		1.9	82.33	1.85
D3T5		2.2	69.67	1.68

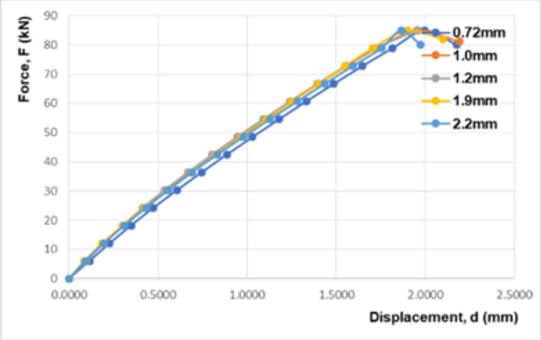


Figure 3: Force-displacement curve for depth 25mm

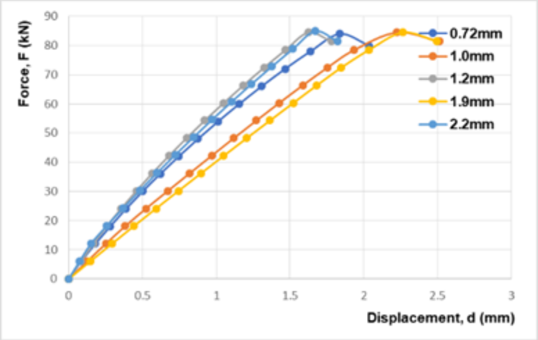


Figure 4: Force-displacement curve for depth 50mm

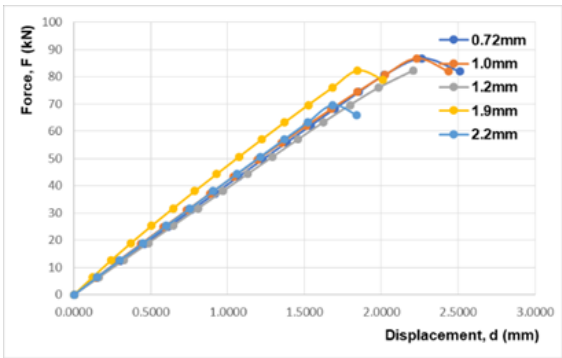


Figure 5: Force-displacement curve for depth 75mm

From the Table 3, it is noticeable that both force and displacement keep decrease steady under the applied load until the built-up CFS column experiences yielding. The maximum force achieved by built-up CFS column indicate the ultimate strength, while the displacement at the peak curve can be considered as maximum displacement.

The comparison of force-displacement graph gives an overall simulation of maximum force from WELSIM software. From the graph 5 shows that the maximum force for stiffener with depth 70mm can be reaches a value from 69.67 kN to 86.80 kN compares to models of stiffener with depth 25mm and 50mm which can be reaches 84.93 kN and 85 kN respectively. The displacement of stiffener with depth 75mm is almost same with models of stiffener 50mm. It can be seen here that although the force-displacement curve shows an increment pattern for all models but the value of maximum force and displacement show decrement pattern in correspond to the thickness of stiffener.

3.3 Effect of Stiffener

Table 4 shows a comparison Euler's load and ultimate strength that was obtained from numerical modelling. It was found that Euler's load estimates higher value of ultimate strength compared to numerical modelling. The discrepancy is clearly contested by 4.36% to 13.69% for stiffener with depth 25mm, 31.7% to 64.01% for stiffener with depth 50mm and 65.83% for stiffener with depth 75mm. The percentage was significant because the Euler's load indicates the critical value for a single segment of column. Since built-up CFS column has a difference characteristic, the prediction of ultimate strength using Euler's load is found misleading. In Euler's load, the presence of stiffeners was included in the moment inertia that directly contributes to the higher value of ultimate strength.

Table 4: Comparison Euler's load and ultimate strength

Code	**Cross sectional properties**		**Euler's load, P_{cr} (kN)**	**Maximum load, P_{fem} (kN)**	**Percentage difference (%)**
	Depth, H (mm)	Thickness, t (mm)			
D1T1	25	0.72	74.7	84.93	13.69
D1T2		1.0	77.4	84.93	9.73
D1T3		1.2	79.3	84.93	7.10
D1T4		1.9	86	84.93	1.24
D1T5		2.2	88.8	84.93	4.36
D2T1	50	0.72	123	84	31.70
D2T2		1.0	144	84.45	41.35
D2T3		1.2	160	84.47	47.20
D2T4		1.9	213	84.47	60.34
D2T5		2.2	236	84.93	64.01
D3T1	75	0.72	254	86.8	65.83
D3T2		1.0	326	86.8	73.37
D3T3		1.2	378	82.33	78.22
D3T4		1.9	558	82.33	85.25
D3T5		2.2	636	69.67	89.05

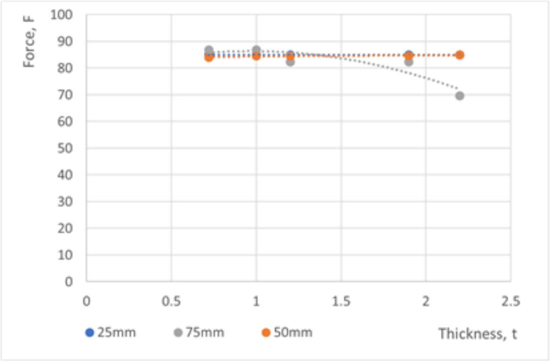


Figure 6: Force against thickness

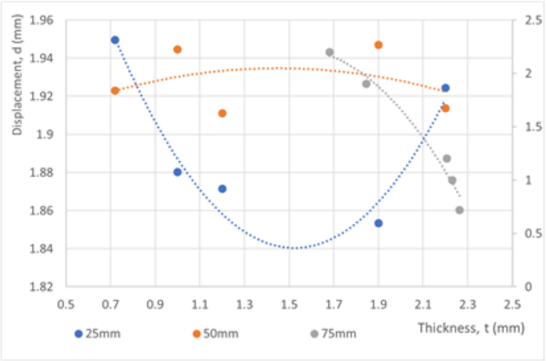
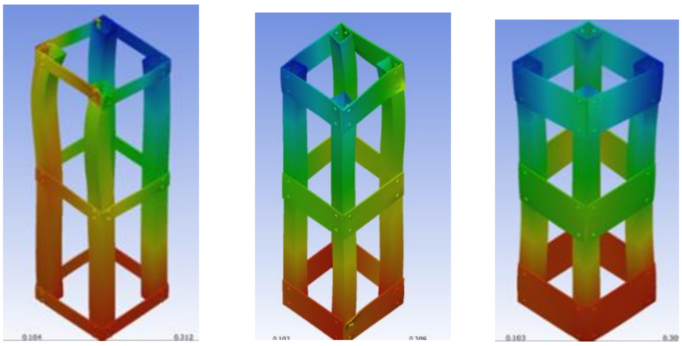


Figure 7: Displacement against thickness

Figure 6 shows a relation of maximum force against thickness of stiffener. Regardless the depth of stiffness, it can be clearly observed that the thickness of stiffener has just small effect on the maximum force of built-up CFS column. For stiffener with depth 75mm, the maximum force decreases when the thickness of stiffener become thicker. The increment of maximum force due to the depth of stiffener also insignificant. This can be said that neither depth or thickness of stiffener will be affecting the maximum load of built-up CFS column. On the other hand, Figure 7 shows a relation of displacement against thickness of stiffener. It can be found that the effect of thickness is a bit abstruse, especially for stiffener with depth 25mm and 50mm. For stiffener with depth 75 mm, the displacement decreases as the thickness of stiffener become thicker. This implies the effect of stiffener on the vertical deformation of built-up CFS column.

3.4 Failure mode

Failure mode refers to the plastic deformation of structures that can be observed at the yielding. Figure 8 illustrate the failure mode of built-up CFS column. It was found that all models display similar behaviour. It can be observed that built-up CFS column experiences local buckling at the top part. The presence of stiffener at the intermediate height able to prevent flexural buckling. On the other hand, stiffener failure also occurs at the rivet’s joint due to the stress accumulation and the slip mechanism. Stiffener with depth 25mm shows an onset of lope buckling at the flange of square hollow section that connected to stiffener. Similar behaviour can also be observed happen to stiffener with depth 50mm. For stiffener with depth 75mm, lobe buckling is invisible. This suggests that stiffener become a factor that govern the failure mode of built-up CFS column.



(a) (b) (c)

Figure 8: Failure mode of stiffener on thickness 2.2mm with depth (a) 25mm, (b) 50mm and (c) 75mm

4. Conclusion

In this study, finite element modelling was used to construct a CFS column. Based on numerical modelling, numerous parametric studies have been carried out to investigate the effects of stiffener properties in terms of depth and thickness on load carrying capacity and failure mode of built-up CFS column. The built-up CFS column with stiffener 25mm able to sustain the maximum force attains at 84.96 kN and experiences displacement varied from 1.86mm to 1.99mm. The performance for stiffener 50mm is similar with stiffener 25mm with maximum force can be achieved below 85 kN. Meanwhile, the displacement shows a typical trend around 1.63mm to 2. 27mm.The performance for built-up CFS column with stiffener 75mm show a better performance in maximum force compared to stiffener 25mm and stiffener 50mm where it can be seen reaches until 86.80 kN. This were proven by the result failure mode where stiffener with depth 75mm experiences local buckling at the top part of built-up CFS column. Besides, it can be concluded that stiffener become a major effect on the incidence of any failure mode on the built-up CFS column.

Acknowledgement

The authors would also like to thank the Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia for its support.

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