Failure Mechanism of Cold-Formed Steel Beams Single C-Profile with Intermediate Stiffener

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ABSTRACT
Cold-formed steel is a structural material that enhances building resilience and supports sustainable construction methods. In Indonesia, earthquake-resistant buildings are crucial, and research on its use as the main structure of buildings is essential. This study modeled a beam structure with intermediate stiffeners in ABAQUS using a single channel profile of C 80x30x9x0.75 with G550 grade and a beam length of 1000 mm. Four variations of intermediate stiffener modeling were used, with a concentrated load applied in the middle of the beam span. The analysis revealed that failure of the beam with intermediate stiffeners occurs due to an open cross-section, resulting in a significant stiffness-to-thickness ratio. The failure pattern observed in model 1 was local buckling, while models 2, 3, and 4 showed both local buckling and lateral torsional buckling. Using intermediate stiffeners in the beam structure can enhance its strength and load-carrying capacity, reducing construction costs.

Keywords: *Buckling, Cold-Formed Steel, Intermediate Stiffeners, Load Capacity, Economic Benefits*

1. INTRODUCTION

The UN established the 17 Sustainable Development Goals (SDGs) in 2015, aiming to achieve resilience, sustainable industrialization, and innovation by 2030 [1]. Resilient structure design is crucial in seismic design to minimize damage and minimize consequences of disasters. It enables structures to quickly repair to pre-earthquake functional levels, becoming the core theory of seismic design. Building resilience helps prepare for future earthquakes and mitigate their impact on society and infrastructure. Therefore, high-quality and cost-effective materials that align with sustainable development goals are of crucial importance.

Innovations in the construction industry are enhancing quality, efficiency, and sustainability, with cold-formed steel being a popular choice due to its high yield strength and tensile strength, making it a strong structural component, unlike traditional steel which undergoes yielding before failure. Previous study was done by several researchers related to the topic. This study investigates the utilization of thin-walled cold-formed steel sections as energy dissipative components in earthquake-resistant multi-storey structures, demonstrating significant seismic energy dissipation capability and satisfactory ductility [2]. However, Thin-walled sections and cold-forming manufacturing can create design challenges like buckling strength, web crippling, ductility, plastic design, connections, fire resistance, corrosion, and connection, among others [3][4][5].

In cold-formed steel structures, intermediate stiffeners improve performance, strength, and stability by stopping lateral-torsional buckling, raising flexural strength, and lowering the risk of local buckling. They distribute applied loads efficiently and reduce local buckling risk in elements with slender proportions. Strategic placement of intermediate stiffeners can improve stability and torsional resistance in members prone to instability. Design and placement should be considered based on structure requirements and loading conditions.

Prior research has investigated the conduct of cold-formed steel with intermediate stiffeners, specifically focusing on the flexural strength of gapped built-up channels [6][7][8]. A study on back-to-back gapped built-up channels under four-point bending revealed that design can be conservative by 27% and flexural capacity increases by 10% on

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average [6]. Advanced numerical modeling predicts buckling behavior in cold-formed steel beams with edge and intermediate stiffeners in compression flanges. It also examines flexural behavior of Z sections, examining the impact of intermediate stiffener size, position, and interaction [7]. The study demonstrates that incorporating intermediate web and edge stiffeners improves the behavior and strength of the section, as indicated by comparisons with specifications of the direct strength technique.

The correlation between the structural resilience of cold-formed steel and its economic impact has been studied in several papers. Thiyagu, et al. [9] investigated the ultimate load carrying capacity of cold-formed steel columns and proposed a new innovative and economical column element. Usefi, et al. [10] evaluated hybrid cold-formed steel (HCFS) structures and found that they exhibited better structural performance and could save up to 23% in framing costs compared to conventional systems. In addition, Cucu, et al. [11] focused on the economic impact of using lightweight members in cold-formed steel structures and compared them to classic systems, showing potential savings based on advanced calculations. These studies highlight the potential for cold-formed steel structures to provide both structural resilience and economic benefits.

This research aims to enhance the use of cold-formed steel materials in Indonesia, particularly for the beam elements of main buildings, as they are currently limited in application. The modeling starts by using a C-profile without intermediate stiffeners. The installation of two intermediate stiffeners in the web is next, and then one intermediate stiffener in the middle of the web. while the proposed model is a C profile with 3 intermediate stiffer sections installed on the body as a modification of the previous profile.

1.1. Intermediate Stiffeners

Intermediate stiffeners are additional elements installed at the middle section of steel beams to enhance their rigidity and resist shear stresses in the beams [12]. Intermediate stiffeners serve to prevent the beams from buckling and help strengthen them by resisting lateral loads, as shown in Figure 1.

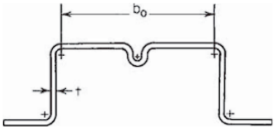


Figure 1 Intermediate Stiffeners [12]

1.2. Failure Mechanism

Previous study related to the failure mechanism of cold-formed steel was studied [9], [11], [13], and [14]. Local buckling is a type of bending that occurs only in certain elements of the cross-section, such as the web or flanges. On the other hand, global buckling is a combination of torsional and lateral bending, resulting in pressure and lateral bending on the wings and twisting of the beam's cross-section. In contrast, distortional buckling takes place within the overall cross-section and affects half of the length of the span. Torsional buckling arises when an open cross-section has its shear center positioned away from the center of gravity of the cross-section.

2. METHODS

2.1. Material Specifications

The research utilizes cold-formed steel with a G550 grade. The data parameters for the profile include a modulus of elasticity (E) of 200,000 MPa, a shear modulus (G) of 80,000 MPa, and a Poisson ratio of 0.3. The true stress and true strain inputs utilized are depicted in Figure 2. The profile under analysis in this study is a C-channel profile with the dimensions of C 80x30x9x0.75. The test specimens possess a G550 grade, characterized by a yield strength (f_y) and ultimate tensile strength (f_u) of 552.75 MPa.

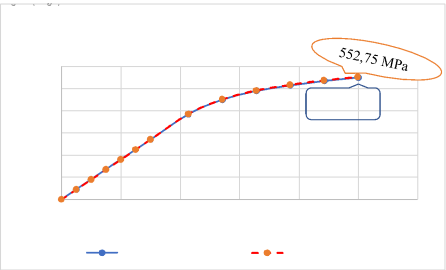
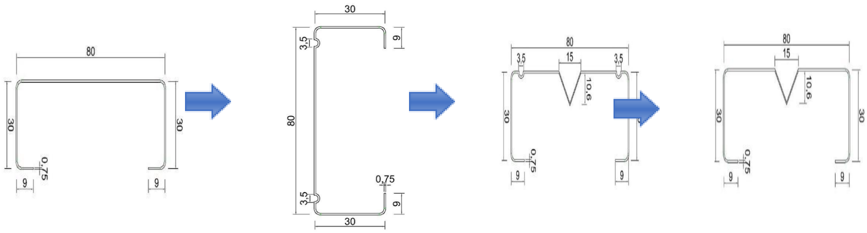


Figure 2 True stress-strain vs Engineering stress-strain

2.2. *Modelling of Test Specimens*

In this model, a concentrated load is applied at the midpoint of the beam span. This load is used to determine the structural response of the beam, including stress-strain analysis and collapse mechanisms. This study, a beam structure with intermediate stiffeners was modeled in ABAQUS [15].

There are 4 profile variation models, namely model 1 (profile without stiffeners), model 2 (profile with edge web stiffeners), model 3 (profile with intermediate stiffeners), and model 4 (proposed model for profile with intermediate stiffeners type 2). The basis for proposing model 4 is model 1, which is without stiffeners, and models 3 and 4, which have been developed in previous research. The profile variations can be observed in Figure 3.



(a) (b) (c) (d)

Figure 3 Profile dimensions C 80x30x9x0,75

3. RESULTS AND DISCUSSIONS

3.1. *Stress-Strain Relationship*

In each variation, stress and strain values will be taken from two points: the point with maximum stress and the point with maximum strain. According to the previous Table 1, the limit value for true stress is 552.75 MPa and the true strain is 0.004987.

The strain values in model 4 are higher than those in models 1, 2, and 3, due to a larger load applied in model 4. The stress-strain curve comparisons show that the addition of intermediate stiffeners significantly increases the buckling strength of the beams, with an increasing load of 16%. Figures 4 and 5 show the comparison results at the maximum stress and strain points.

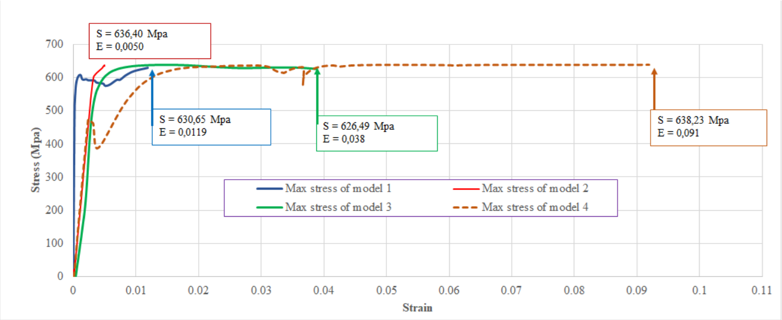


Figure 4 Comparison of stress-strain curves at the point of maximum stress in the structure

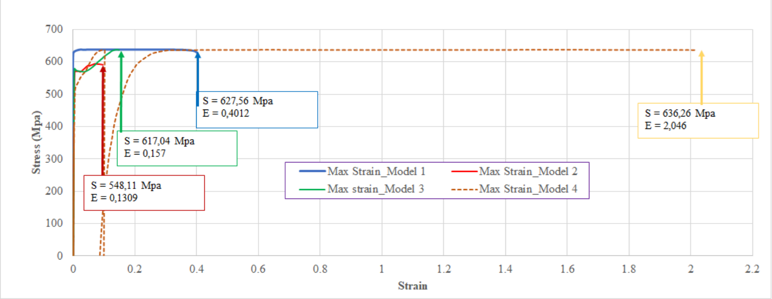
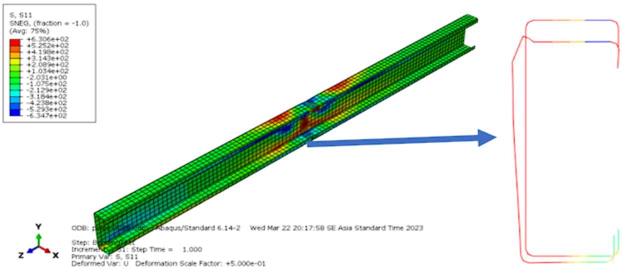


Figure 5 Comparison of stress-strain curves at the point of maximum strain in the structure

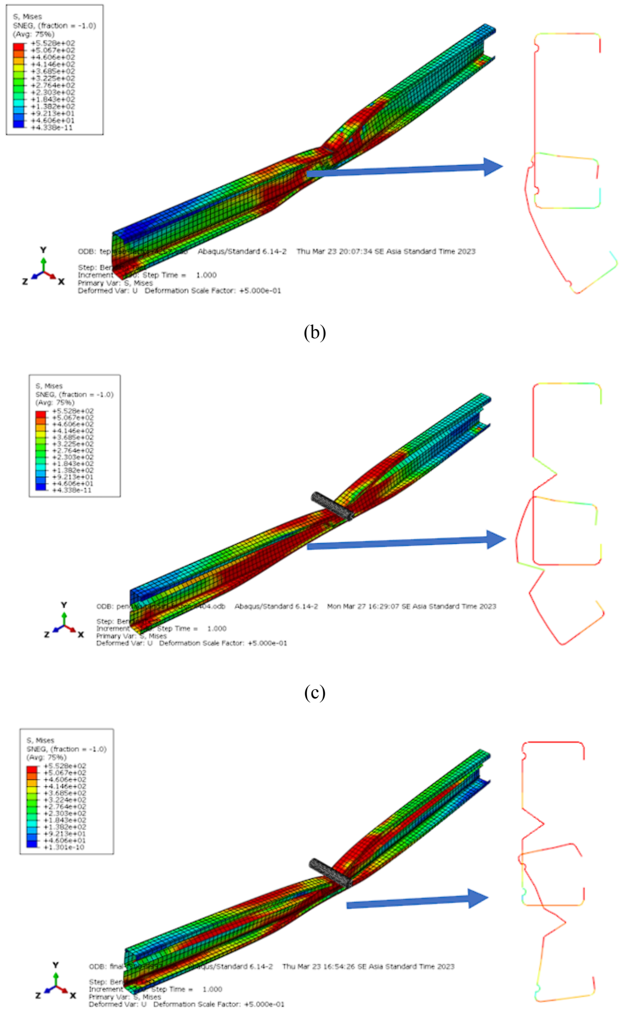
3.2. Failure Mechanism

The failure patterns that occur in each profile, such as local buckling and lateral torsional buckling in cold-formed steel, are due to the profile's very thin thickness. Failure occurs because the profile has an open cross-section, resulting in a stiffness-to-thickness ratio that is significant. When the structure is subjected to continuous maximum loads, it will experience failure.

In the case of beam structure model 1, the failure pattern observed is local buckling. Models 2, 3, and 4 of beam structures show failure patterns due to local and lateral torsional buckling, which significantly affect the performance of cold-formed steel structures. These buckling modes can affect the load-bearing capacity and structural response of the beams, affecting the overall structure's stability and strength.



(a)



(b)

(c)

(d)

Figure 6 Failure patterns in each profile. (a) Model 1; (b) Model 2; (c) Model 3; and (d) Model 4

4. CONCLUSIONS

The research found that Model 4 has a higher maximum load capacity and higher stress and strain in the beam structure compared to Models 1, 2, and 3. In beam structures with cold-formed steel, potential failure modes include local buckling and lateral torsional buckling, with local buckling observed in Model 1, and both in Models 2, 3, and 4.

Applying cold-formed steel with an intermediate stiffener may improve a beam structure's bending capacity. Utilizing this material for constructing structural beams will result in a reduction in construction expenses. Nevertheless, further research is required to determine the efficacy of utilizing connections and the performance of cold-formed steel frames in withstanding both self-load and seismic loads. These studies emphasize the capacity of cold-formed steel constructions to offer both structural durability and financial advantages.

AUTHORS CONTRIBUTIONS

Desy Setyowulan, Lilya Susanti, Indra Waluyohadi, Nuril Charisma, Dhiya Ul Haq Al Hanif Muhsin, Alif Habibi Nur Ilmiawan, and Saker M. I. Mohamed conceived the idea. Desy Setyowulan and Dhiya Ul Haq Al Hanif Muhsin developed the theory and performed the computations. Desy Setyowulan, Lilya Susanti, Nuril Charisma, Dhiya Ul Haq Al Hanif Muhsin, and Saker M. I. Mohamed verified the analytical methods and analyzed and interpreted the results. Desy Setyowulan prepared a draft of the manuscript. The manuscript's final version has been approved by all authors who reviewed the results.

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