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EFFECT OF SCREW ON THE AXIAL PERFORMANCE OF COLD-FORMED STEEL

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ABSTRACT: Along with the development of the construction world in Indonesia, the use of cold-formed steel (CFS) as a construction material is also increasing. The connection is an important element that must be considered in this type of material. Structural elements that are joined experience stress concentration around the hole resulting in a change of the behavior of structure that becomes more complex. To predict the failure mode of the connection section, this study conducted an experimental test to study the capacity of cold-formed steel against tensile loads. The test specimens used in this study are canal type, which is usually used as material construction, with three different configurations of screw positions. The effect of the screw will be compared with an original model without a screw. In addition, numerical simulation by ABAQUS Student Edition and analytical studies by SNI 7971:2013 which referred to AS/NZS 4600:2005 have been conducted to investigate the axial capacity of the CFS element. From the experimental results, the main failure modes for all types of screw connections are categorized by tilting and pull-out failure. Increasing space between screws will also increase the maximum load by 6.67% and 10.81% for connection with three and four screws, respectively. In addition, the specimens with one and four screw connections have an average extension which was 300% larger than that of without screw.

Keywords: Axial Performance, Cold Formed Steel, Connection, Screw, Failure model

1. INTRODUCTION

Nowadays, steel has become one of the most widely used construction materials around the world. The use of steel material will be effective in reducing the consumption of cement as the main binder of concrete. It means that the air pollution due to CO2 emissions will be reduced to realize the concept of green building and sustainable construction in Indonesia. Structural engineering applications of cold-formed steel are increasing steadily. Many advantages can be achieved by using this material in building construction, such as being easily assembled into a wide range of structural and architectural forms, easily assembled and modified on site, Efficient use of material leads to competitive construction and to save in material costs, etc. However, the use of thin-walled sections and cold-forming manufacturing effects can result in special design problems, such as buckling strength (including local, global, distortional, shear), torsional rigidity, web crippling, ductility and plastic design, connections, fire resistance, and corrosion [1].

Many studies have been undertaken related to the behavior of cold-rolled steel to improve its design problems, such as numerical and experimental studies related to the axial capacity, flexural capacity, and connection [2, 3, 4].

Connections are the critical components in cold-formed steel structures. A review of cold-formed steel connections is investigated [5]. The performance of screw connections, storage crack connections, welded connections, and bolted connections were discussed. From this review, it was concluded that screw is a common type of connection that is used due to the thinness of CFS sections. In addition, a review on CFS frame connection was also studied previously [6]. Based on the review assessment, the results highlighted that all types of connections except adhesive connections have shown the proper behavior that can trigger the change of any design codes.

The failure modes of connections were investigated by researchers. The results have shown that screwed CFS connections can be subjected to similar fracture and different moment–rotation capacities under loading [7]. An experimental investigation and FEA of CFS bolted connections with single and multiple bolts under shear loading were investigated [8]. The comparison results show that current AISI (2012) design provisions for the CFS provide the safe bearing resistances for the bolted connections with washers on oversized holes in single bolted, double bolted and quadruple bolted connections.

This study conducted an experimental test to study the axial performance of cold-formed steel connections with different screw configurations, including the capacity and failure modes of each model test. The results of this study will be used as the basis for analyzing whether the formulations in the Indonesian Standard of 7971: 2013 are by the real conditions of using cold-formed steel profiles in the market.

2. RESEARCH SIGNIFICANCE

The significance of this study is related to the analytical results, which will be used as the basic formulation for the axial performance of the cold-formed steel structure in real conditions. The steel profiles were generally used in the Indonesian market. The axial capacity of the structure will be compared between experimental and analytical calculation by the formula derived in Indonesian Standard 7971:2013, which is referred to as AS/NZS 4600:2005. The result will be used as the basis to modify the formula inappropriate with the real condition.

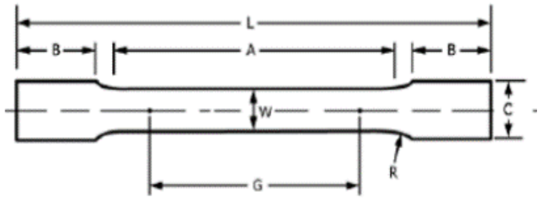
3. METHODS

3.1 Experimental Model

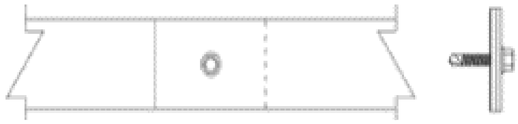
An experimental model of CFS connection with screw configurations is shown in Fig. 1. In this analysis, we used three different screw configurations. The block shear behaviors of double-shear screw connections fabricated with CFS were planned to be investigated.

The common dimension for specimens is in the following: screw diameter *d* was 4 mm, thickness for each specimen of 0.6 mm, and space between each screw was determined by 4*d* and 5*d*. Each configuration has three specimens. The total length for specimen without connection as shown in Figure 1(a) was 200 mm, and for other specimens were 250 mm, as shown in Figure 1(b, c, d). The detail dimension for specimens without connection was 50 mm, 12.7 mm, 12.5 mm, 200 mm, 57 mm, 60 mm, and 20 mm for G, W, R, L, A, B, C, respectively. As shown in the configuration and assembly of the test specimen of Figure 1, the specimen consist of two coupling CFS plate in the connection with length is adjusted to the space used between the plate.

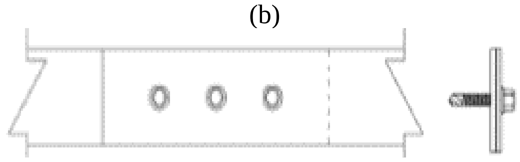
The tensile strength test procedure was determined based on Indonesian National Standard (SNI 7971:2013). The external tensile load was produced by the Universal Testing Machine, which increased gradually until the failure of each specimen. It indicated that the specimens cannot withstand the external load.



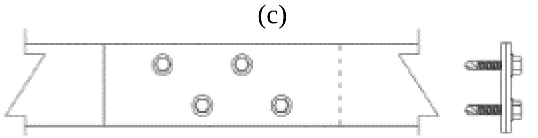
(a)



(b)



(c)



(d)

Fig. 1. Configuration and assembly of test specimen; (a) without connection, (b) 1 screw, (c) 3 screws, and (d) 4 screws.
Source: an experimental model

3.2 Numerical Model

The finite element program ABAQUS Student Edition was used to simulate the behavior of the connection in the CFS element [9]. The beam was developed by shell element with properties of G550 [10], with the thickness of 0,75 mm and model shown in Fig. 1(a). The tensile load was applied axially at the center of the element beam by using Universal Testing Machine. It increased gradually until collapse occurred.

The measured stress-strain curves were incorporated in the finite element model. The elastic-plastic material model provided by ABAQUS [9] allows for a nonlinear stress curve to be used, with the Young's modulus (*Eo*) of 200.000 MPa, and Poisson's ratio υ of 0.3. The engineering static stress-strain curve was converted to a true stress and logarithmic plastic strain curve. The true stress σ_{true} and plastic true strain ε_{true}^{pl} were calculated using Eqs. (1) and (2):

$$\sigma_{true} = \sigma_{eng}\left(1 + \varepsilon_{eng}\right) \quad (1)$$

$$\varepsilon_{true}^{pl} = ln\left(1 + \varepsilon_{eng}\right) - \frac{\sigma_{eng}}{E} \quad (2)$$

It was defined by the S4R shell element, which has six degrees of freedom per node and provides an accurate solution for most applications [11]. Fig. 2 show the meshing size of the specimen, for element without screw. The tensile test specimens with one screw are modeled with two types: plate element and C profile as shown in Fig. 3.

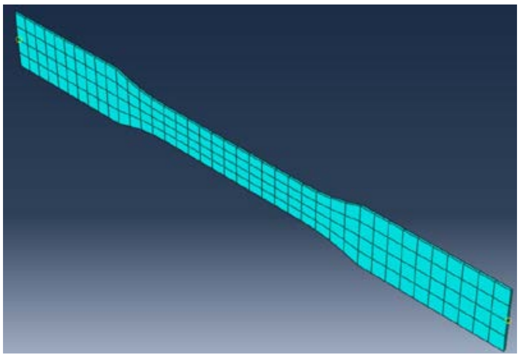


Fig. 2. Meshing size of the tensile testing element
Source: numerical model

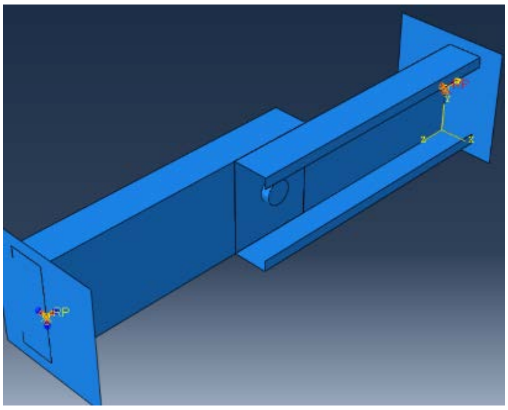


Figure 3. Modeling of tensile test for C profile
Source: numerical model

4. RESULTS AND DISCUSSIONS

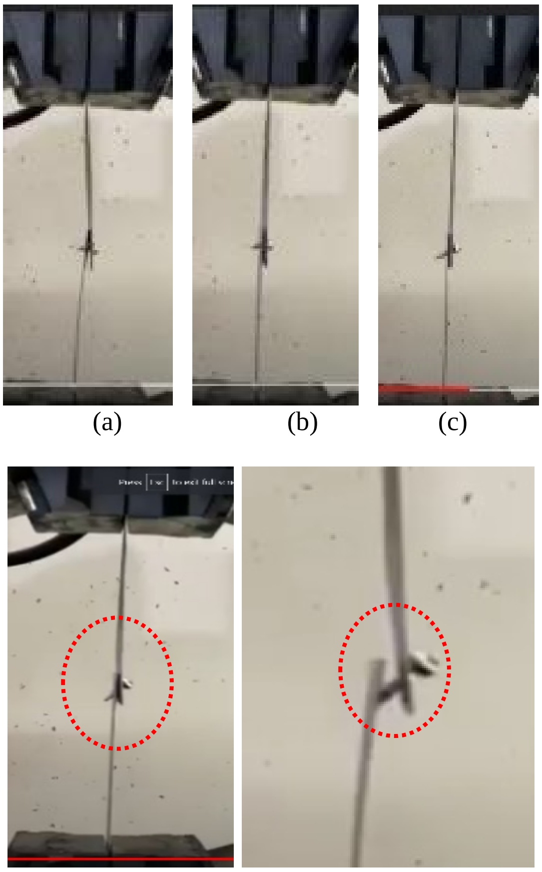
4.1 Tensile Testing Stage

The tensile testing stage for CFS with a screw connection is shown in Fig. 4. According to this figure, the tensile testing stage can be seen clearly. These stages include the initial condition, balanced level before loading, tilting failure, and pull-out failure. When two materials of the same thickness are screwed together, or when the thicker material is against the screw head, tilting failure occurs [12]. Hancook [13] illustrates this shortcoming in Fig. 5.

Furthermore, the collapse modeling of the screw connection which is tilting failure is shown in Fig. 6(a) and Fig. 6(b), and the stress-strain curve in Fig. 7(a) and 7(b) for plate and C-profile element, respectively. The following curve for plate element in Fig. 7(a) shows the maximum stress of 572.74 MPa, which exceed the maximum plastic limit of 552.75 MPa. In addition, the maximum strain of 0.011 mm also surpasses the maximum plastic strain limit of 0.0045 mm.

Moreover, the following curve in Fig. 7(b) shows the maximum stress of 587.07 MPa which is beyond the plastic stress of 552.75 MPa. The maximum strain also exceeds the plastic strain. So, it can be concluded that the collapse of the tensile test object with a screw connection at the maximum load occurs and reach its plasticity.

The tensile capacity for CFS specimens from the calculation based on SNI 7971:2013 shows that with the thickness of 0,75 mm and yielding strength of 550 MPa is 5,156 kN. The result is found from the calculation of $N_t = A_g f_y$.



(a) (b) (c)

(d) (e)

Fig. 4. The tensile testing stage for CFS using screw connections, including (a) initial condition, (b) balanced level, (c) and (d) tilting failure, (e) pull out failure
Source: experimental data

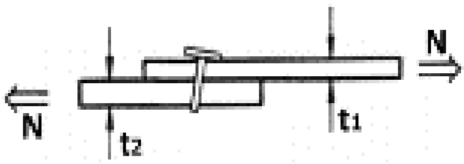
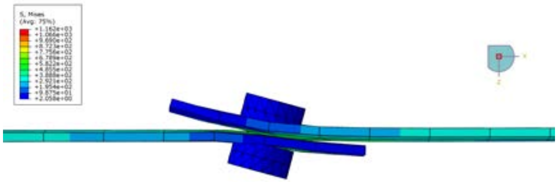
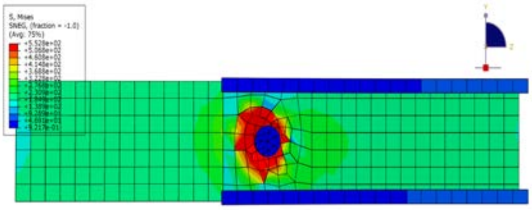


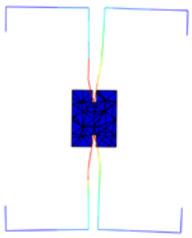
Fig. 5. Tilting failure of screwed connections [13]



(a) Plate element

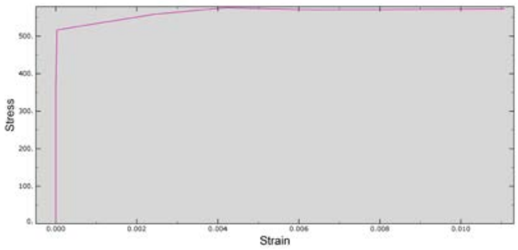


(b) Side view of the connection in C-profile

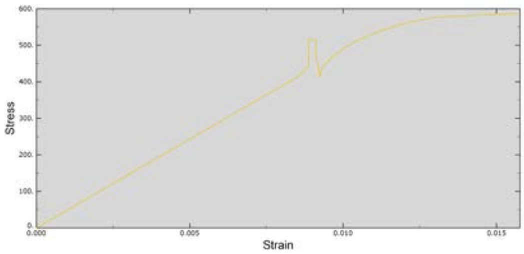


(c) Detailed connection in C-profile

Fig. 6. The collapse of the screw connection
Source: numerical data



(a) Plate element



(b) C-profile element

Fig. 7. Stress-strain curve for an element with one screw connection
Source: numerical data

4.2 Failure Modes

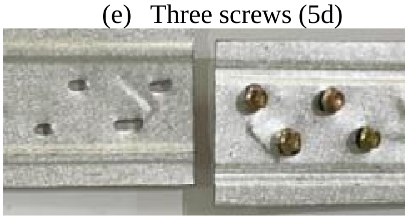
Previous research has shown that the end distance of 3d is enough to avoid the tear-out failure for the stainless-steel bolted connections [14]. In this study, we used the space of 4d and 5d by SNI 7971:2013 with the minimum spacing should be ≥ 3d.

(a) Without connection

(b) One screw (4d) (c) One screw (5d)

(d) Three screws (4d)

(e) Three screws (5d)



(f) Four screws (4d)

(g) Four screws (5d)

Fig. 7. Failure modes for tensile specimens without a connection
Source: experimental data

The effect of edge distance and screw spacing on the failure modes of CFS connection was investigated, as shown in Fig. 7. From the experimental results, the main failure modes for all types of screw connections are categorized by tilting and pull-out failure.

For the specimen without connection, fracture occurs. This type of failure produces stretching of the hole on one side of the screw, while the plate is bunched together on the other side of the screw. Because of the common thickness of CFS, Rogers, and Hancook [15] demonstrated that using washers under the bolt head and nut can considerably boost a connection's resilience to bearing failure. Block shear failure of the element with 3 and 4 screws does not occur in the test object, due to the high tensile strength of CFS.

4.3 Maximum Load

Different variation for screw configuration number gives an impact on the maximum axial load, as shown in Fig. 8. From these results, it could be depicted that the average maximum load for the tensile test without connections is similar to a connection in one screw, shown as 6 kN. Increasing space between screws will also increase the maximum load by 6.67% and 10.81% for connection with four screws, respectively. However, connection with three screws for all spaces has a smaller load compared to another screw variation.

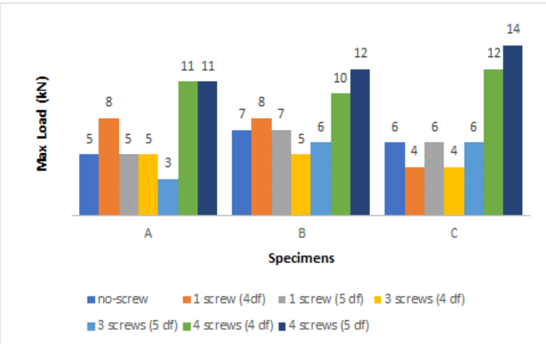


Fig. 8. Maximum load for each specimen
Source: experimental data

4.4 Load-Extension Curve

Fig. 9 depicted the extension for each specimen. According to this data, connection with one screw and 4 screws have a similar result of 21 mm. Furthermore, minimum result occurs for specimen control without a connection of 5 mm. The specimens with one and four screw connections have an average extension which was 300% larger than that of without screw. This capacity was limited by the sheer capacity of the screw.

A load-extension curve for one screw connection is illustrated in Fig. 10. The larger space (5d) shows a less ductile failure compared to the smaller space (4d).

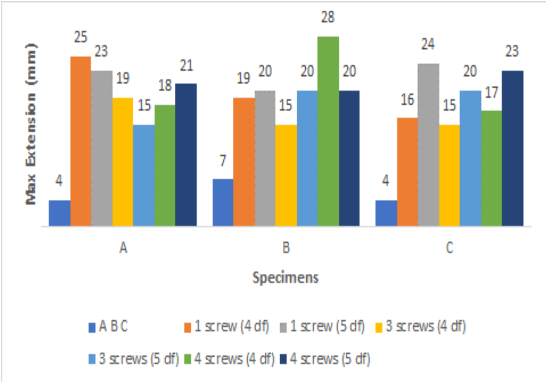


Fig. 9. The maximum extension for specimens
Source: experimental data

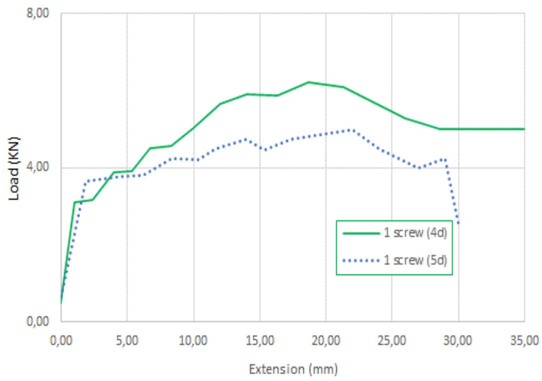


Fig. 10. Load-extension data for CFS element with 1 screw connection
Source: experimental data

5. CONCLUSION

This study used an experimental test to determine the capacity of cold-formed steel against tensile loads to anticipate the failure mechanism of the connection section. The test specimens in this study were canal type, which is commonly utilized as a material construction, and had three distinct screw configurations. The screw's effect will be compared to the original model without the screw.

The following conclusions can be drawn from this research:

1. Tilting and pull-out failure are the most common failure modes for all types of screw connections.
2. For connections with three and four screws, increasing the spacing between screws increases the maximum load by 6.67% and 10.81%, respectively.
3. The specimens with one and four screws have an average extension that is 300 percent greater than the ones without screws.

6. ACKNOWLEDGMENTS

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