An Experimental Research on the Effect of Connection Types on Frame using Cold-Formed Steel

Indra Waluyohadi, Ananda Insan Firdausy, Bhondana Bayu B.K.

Abstract*: *The growth of construction technology, innovations using cold-formed steel materials have begun to be developed in ordinary earthquake resistant buildings. In addition, those materials lighter and cheaper instead use conventional steel material. In building construction, the weakest part of the structure is the connections. Many cases of building failures occur due to collapse in the connection of structures. In this research an experimental study was carried out on frame structure using cold-formed steel with variations in the connection of beam-column given lateral loads as a representation of earthquake loads to determine the type of effective connection on the structural performance. Specimens in this study are one bay two stories frame with variations used are the type of connection of bolt-nut and self-drilling screw. Loading test is performed by giving lateral load at the upper end of one of the frame sides with a four steps cyclic load. From experimental test results found that in the push cycle, frame with bolt-nut connection has greater lateral load than model with self-drilling screw connection. In contrast to the pull cycle of model with bolt-nut connection has smaller lateral load compared to model with self-drilling screw connection. Frames with bolt-nut connections have better ability to dissipate energy compared to models with self-drilling screw connections. Compared to initial stiffness, the model with bolt-nut connection has greater decrease than model of self-drilling screw connection. However, in term of stiffness behavior, model with bolt-nut connection is more rigid compared to the model with self-drilling screw connection.

Keywords* : *Cold formed steel, earthquake resistant building, structural connection.

I. INTRODUCTION

The growth of construction technology, innovations using cold formed steel materials have begun to be developed in ordinary earthquake resistant buildings. In addition, those materials lighter and cheaper instead use conventional steel material [1]. In building construction, the weakest part of the structure is the connections. Many cases of building failures occur due to collapse in the connection of structures. Connecting tools that are often used in cold-formed steel structures are bolts-nut and self-drilling screws. There are five types of failures in structure joints, especially using self-drilling screws that are pull-out failure, tilting failure, pull-through failure, shear failure, and tear-out failure [2].

In this research an experimental study was carried out on the frame structure of buildings using cold formed steel with variations in the connection of beam-column given lateral cyclic loads as a representation of earthquake loads to determine the type of effective connection on the structural performance. Cyclic load is a lateral load that is applied to the structure repeatedly. Failures that generally occur due to cyclic loads are fatigue failures.

II. MATERIALS AND METHODS

A. Specimens

Two types of specimens used in this study, that are specimens for materials testing and specimens for frames testing. Material testing is carried out by tensile testing based on the ASTM E-8 standard [4] to determine the yield strength (fy) and ultimate strength (fu). A total of three specimens were made consisting of beam structure component plate and two of column structure component plates. The shape of the test specimen for material testing is shown in Fig. 1.

Fig. 1. Specimen for material testing

Specimen for frames testing uses six models with a variety of connecting tools, which consist of three models of bolt-nut connection and three models of self-drilling screw connection. Table 1 shows the test object along with the variation of the connection used. The frame used is a two-storey with a height of 500 mm in each floor and a width of 500 mm. Column and beam profiles used are rectangular hollow 40x40x0.4 and 20x40x0.4. Fig 2 demonstrates the frame test object to be cyclic loaded. The connection plate used is angle shape with 0.4 mm thickness. The diameter of the connecting tool used is either bolt or screw that is 8 mm. The connection tool details can be seen in Fig. 3.

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Table- I: Specimen for frames testing

Model	Connection	Plate Connection Shape	Connection Distance
B1	Bolt	Angle	12 mm
B2	Bolt	Angle	12 mm
B3	Bolt	Angle	12 mm
S1	SDS	Angle	12 mm
S2	SDS	Angle	12 mm
S3	SDS	Angle	12 mm

Fig. 2. Frame model specimens

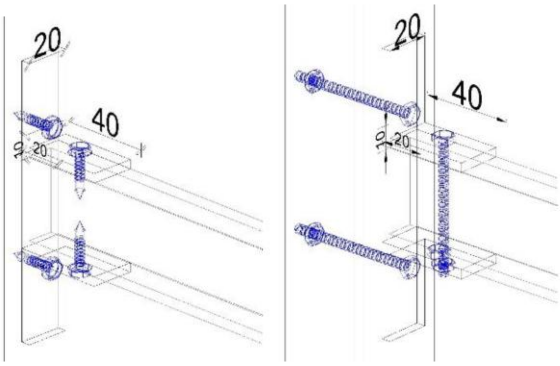


Fig. 3. Connection details (a) screw, (b) bolt-nut

B. Tensile Strength Test

Tensile testing is carried out using a universal testing machine to determine the yield strength (*fy*) and ultimate strength (*fu*). Fig. 4 demonstrates tensile testing of cold-formed material using a universal testing machine.

Fig. 4. Tensile strength testing with universal testing machine

C. Cyclic Loading Test

Cyclic loading test was carried out on cold-formed frame specimens in four alternating cycles using deformation control. Push and pull loads are given each cycle at the top end of frame by measuring the deformation that occurs using LVDT at the top end of frame which is conducted on the loading frame as shown as Fig. 5. The cyclic load pattern using drift ratio with deformation control is shown in Fig. 6.

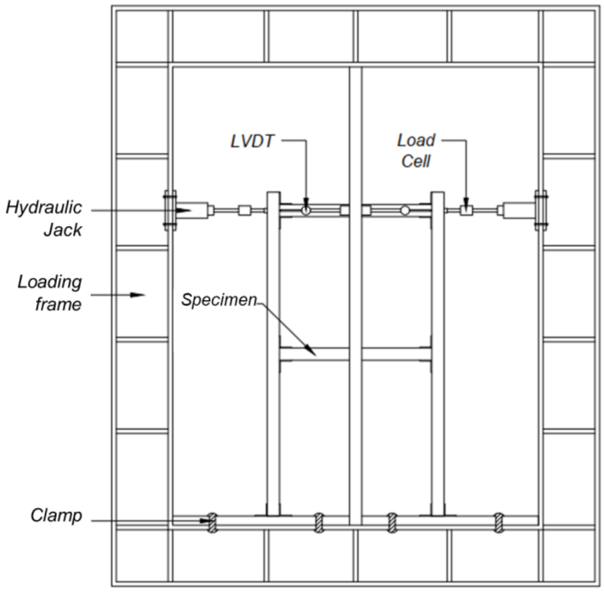


Fig. 5. Cyclic loading test

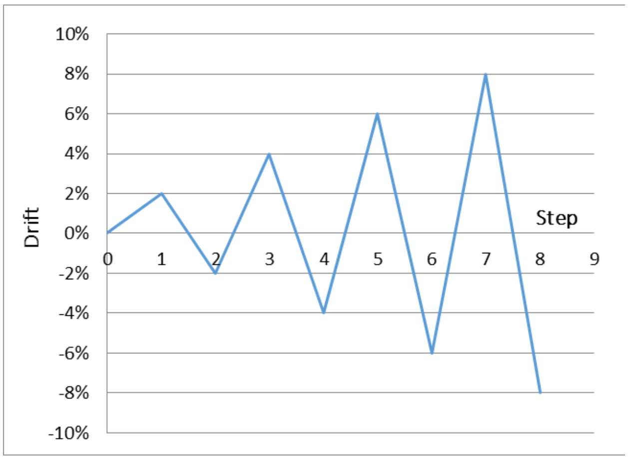


Fig. 6. Cyclic loading test

III. RESULT AND DISCUSSION

Cold-formed material testing is carried out with a tensile test based on ASTM E8 standards [4] to determine the yield strength and ultimate strength. The following Table-II shows the results of the material testing. It was found that fy and fu averaged 531.33 MPa. These results are close to the fy and fu values on the AISI S100-07 Standard [5]

Table-II: Cold-formed material test results

#	Model	P (kN)	A (mm^2)	Fy (Mpa)	Fu (Mpa)
1	B	2.72	5	544.00	544.00
2	K1	2.59	5	518.00	518.00
3	K2	2.66	5	532.00	532.00
			Average	**531.33**	**531.33**

Table-III and Figure 8 show the lateral load of the cyclic testing results in the fourth cycle separately for the push cycle and pull cycle. In the push cycle, the test object with bolt-nut connection has a lateral load of 29.1% greater than the specimen with self-drilling screw connection, but for the pull cycle the model with bolt-nut connection has a lateral load of 8.4% smaller than the self-drilling screw specimen. There is a decrease in lateral load strength in the pull cycle because the test object is given a push load at the first. A drastic decrease occurred in model with bolt-nut connection by 49.74%, while a slow decline occurred in the self-drilling screw connection model by 7.02%.

Table-III: Lateral load peak for positive and negative curve

Model	Lateral Load (N)			
	Positive Curve	Average	Negative Curve	Average
B1	58.5	58.4	36.8	39.0
B2	62.8		28.7	
B3	53.9		51.5	
S1	43.0	45.2	41.9	42.3
S2	45.2		43.1	
S3	47.5		41.8	

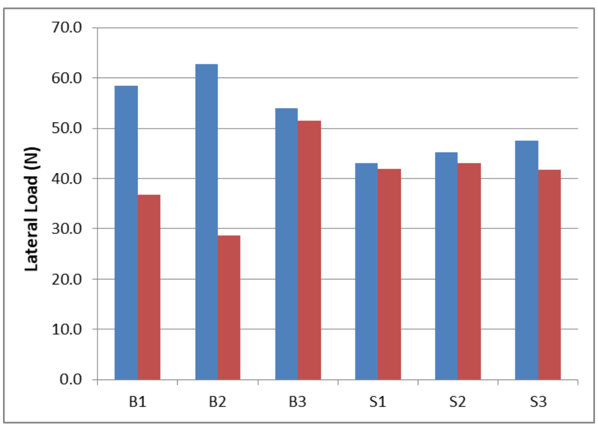
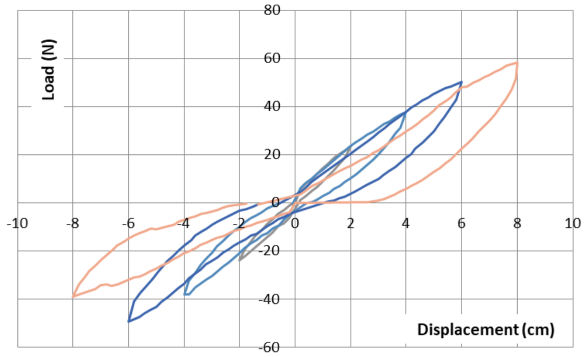
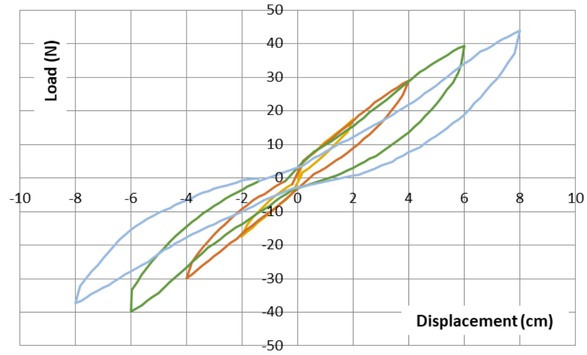


Fig. 7. Comparison of peak lateral load

Energy dissipation is calculated from the amount of input energy minus elastic energy. Dissipation energy is the area of the area covered on the hysteresis curve from the cyclic loading of four alternating loading cycles. The results of the hysteresis curve from cyclic loading for frame testing with bolt-nut connection and self-drilling screw connection can be seen in Fig. 8.



(a)



(b)

Fig. 8. The cyclic loading hysteresis curve (a) bolt-nut, (b) self-drilling screw

Table-IV shows the calculation of energy dissipation for the bolt-nut and self-drilling screw connection model. From the calculation of energy dissipation, it is obtained that the frame model with bolt-nut connection has better capability than the model with self-drilling screw connection. This is indicated by the bolt connection model that consistently has greater dissipation energy for all cyclic loading cycles compared to the framed model using self-drilling screw connections as shown in Fig.9. The ratio of cumulative energy dissipation in the final cycle is 44.9%

Table-IV Energy dissipation of bolt-nut and self-drilling screw model

	Model	Bolt	SDS
Energy Dissipation (N.mm)	Drift 2%	129.6	88.2
	Drift -2%	279.0	157.2
	Drift 4%	749.0	420.5
	Drift -4%	1166.8	651.5
	Drift 6%	2126.8	1280.7
	Drift -6%	2940.0	1797.0
	Drift 8%	5054.8	2783.6
	Drift -8%	6108.3	3665.1

Lateral stiffness is analyzed using the method of peak to peak stiffness by calculating the slope of the line from the positive peak to the negative peak. Stiffness calculations are performed for each cyclic load testing cycle. Table-V shows the calculation of lateral stiffness for models with bolt-nut and self-drilling screw joint variations. From the table it was found that at each drift ratio testing, the frame model with the bolt-nut connection has a greater lateral stiffness compared to the stiffness of the frame model with self-drilling screw connection.

Ratio of lateral stiffness to initial stiffness for each cyclic loading cycle in the model with a variety of bolt-nut and self-drilling screw connections shows at Fig. 10. From the figure it was found that generally there was a decrease in lateral stiffness in the cyclic load testing cycle, both the frames with bolt-nut connection and self-drilling screw connection. In the first cycle with a drift ratio of 2%, there was not very noticeable difference in stiffness, whereas in the next cycle the decrease in stiffness was clearly seen.

The specimens with bolt-nut connections sustained a greater decrease compared to frames with self-drilling screw connections, although numerically the model of bolt-nut connection stiffness value was greater than the model of self-drilling screw connection lateral stiffness. The decrease that occurred until the final cycle obtained a difference of 12.01%.

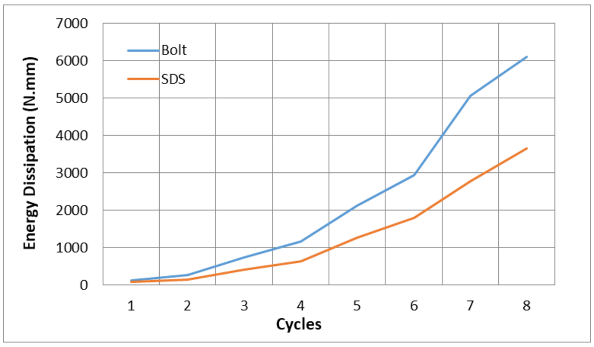


Fig. 9. The cyclic loading hysteresis curve

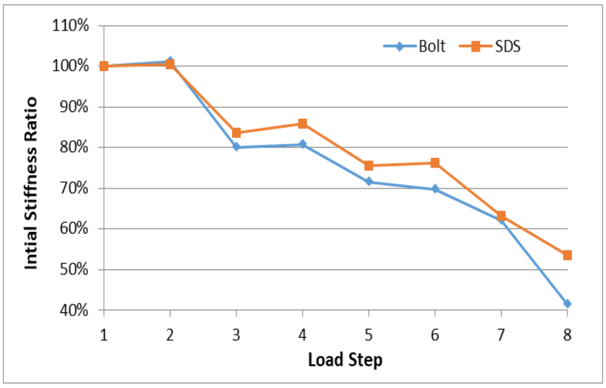


Fig. 10. Trend of decreasing stiffness

IV. CONCLUSION

From the research that has been done, the following conclusions can be drawn:

1) The results of cold-formed material testing obtained by yield strength (f_y) and ultimate strength (f_u) of 531.33 MPa. This value is close to the value on AISI S100-07 Standard.
2) In the push cycle, frame with bolt-nut connection has a greater lateral load than a model with self-drilling screw connection. In contrast to the pull cycle of model with bolt-nut connection has smaller lateral load compared to the model with self-drilling screw connection.
3) Frames with bolt-nut connections have better ability to dissipate energy compared to models with self-drilling screw connections.
4) Compared to the initial stiffness value, the model with the bolt-nut connection has a greater decrease than model of self-drilling screw connection. However, in terms of stiffness value, the model with bolt-nut connection has lateral stiffness which is more rigid compared to the model with self-drilling screw connection.

Table-V. Lateral stiffness of bolt-nut connection model

Drift Ratio	Bolt-Nut Connection			Self-Drilling Screw		
	Peak Load (N)	Deformation (cm)	Stiffness (N/cm)	Peak Load (N)	Deformation (cm)	Stiffness (N/cm)
2%	23.50	2.0	11.75	17.40	2.0	8.70
-2%	-23.77	-2.0	11.88	-17.50	-2.0	8.75
4%	37.67	4.0	9.42	29.10	4.0	7.28
-4%	-37.97	-4.0	9.49	-29.92	-4.0	7.48
6%	50.43	6.0	8.41	39.41	6.0	6.57
-6%	-49.07	-6.0	8.18	-39.78	-6.0	6.63
8%	58.40	8.0	7.30	43.92	8.0	5.49
-8%	-39.00	-8.0	4.88	-37.23	-8.0	4.65

REFERENCES

1. Yu, W.W., LaBoube, R.A., (2010). *Cold-Formed Steel Structures* 4th Edition, 425, John Wiley & Sons, Inc.
2. Zeynalian, M., Shelley, A., Ronagh, H.P., (2016). An experimental study into the capacity of cold-formed steel truss connections. Journal of Constructional Steel Research. 127, 176–186.
3. Watanabe, K., et all., (2004). Experimental Study on Stress-Strain Curve of Concrete Considering Localized Failure in Compression. Journal of Advanced Concrete Technology Vol. 2, No. 3, 395-407.
4. ASTM E-8., (2013). Standard test methods for tension testing of metallic materials. American Society for Testing and Materials.
5. AISI S100-07., (2002) AISI manual cold-formed steel design. Canada: American Iron and Steel Institute.
6. McCrum, D,P., et all., (2019). Experimental cyclic performance of cold-formed steel bolted moment resisting frames. Engineering Structures. 181, 1–14.
7. Wang, L., Young, B., (2018). Behaviour and design of cold-formed steel built-up section beams with different screw arrangements. Thin-Walled Structures. 131, 16–32.
8. Wanniarachchi, K. S., Mahendran, M., (2017). Experimental study of the section moment capacity of cold-formed and screw-fastened rectangular

hollow flange beams. Thin-Walled Structures. 119, 499-509.

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