Cold Formed Steel Type C On Beams With Connection Variations

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Abstract. The disadvantages of using cold rolled steel (cold formed steel) include a thin profile and low stiffness of the connecting parts. Stiffness research of various types of joints is needed to study element failure, machine error or connection failure which causes the collapse of cold rolled steel structures. Analysis is needed for cantilever structures, because the maximum deflection that occurs in cantilever structures is greater than that of simply supported beam structures. The shape and type of cold rolled steel joints greatly affect the stiffness and stability of cold rolled steel structures so that the strength of several types of joints must be studied. The purpose of this study was to analyze the stiffness of the test results under the influence of bending loads on each type of cold rolled steel beam-column connection. Cold steel C channel profile with a thickness of 0.75 mm is used as the object in this study. The beam-column structure is assembled with various kinds of connections, including direct screw connections, screw-gusset plates, screw-angle plates, and screw-angle plate-gusset plates. This research shows addition of the elbow plate increases the strength of the test object by means of a screw connection and gusset plate to the load. However, the results of the maximum load in the experiment still have not reached the maximum load of the analysis results. In the screw connection the damage that occurs is tearing in the connecting plate (tear out), in the gusset plate connection the damage that occurs is the collapse of the gusset plate, in the screw-angled plate connection there are 2 damages, where the damage starts with a tear in the connecting plate (tear out) and followed by damage to the screw that is damaged (pull out).

1 Introduction

Use The use of steel in the world of construction is already familiar. Because steel is a material with good properties and strength and is also economical. The use of steel material is quite popular due to its faster fabrication process. However, the use of hot rolled steel has disadvantages such as the limited form of the elements produced and a reduction in strength with respect to temperature [1]. One alternative type of steel coated with aluminum as a conductor is cold-formed steel [2]. Where cold rolled steel has lighter properties than hot rolled steel and can produce a more economical design [3].

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Cold rolled steel (cold formed steel) is very often used in the field of construction in today's era. However, in its use there are several drawbacks in the use of cold-formed steel, including a thin profile and problematic joints [4], light steel roof trusses in Indonesia often experience collapse [5]. The failure is caused by element failure, workmanship error or connection failure, so analysis is needed.

Theoretically a cantilever structure is a structural element in which one side is free or unsupported and the other side is clamped. However, in reality in the field, the supported side cantilever steel structure is not certain to be clamped. It can be joint or roll. The maximum deflection that occurs in the cantilever structure has a greater value than the simple supported beam structure [6]. The large deflection will affect the stiffness value. The stiffness value of the cantilever structure will be smaller than that of a simple supported beam. Where to ensure the stability of the strength and rigidity of the structure, it is necessary to connect a connecting device with a minimum strength and stiffness equal to the main elements/components of the structural system [7]. This explains that connection elements have an important role in the stability and strength of structures, especially cantilever structures.

The shape and type of connection in cold rolled steel contributes greatly to the rigidity and stability of the cold rolled steel structure. Research by [8] explained that there are 4 types of beam-column joints for cold-formed steel, where each type of connection has different properties, functions, and characteristics. Researchers will conduct experimental tests to study the effect of load on deflection in each type of cold rolled steel beam-column connection. So with this research, it is expected to obtain connection strength data for cold rolled steel so that it can be the basis for planning cold rolled steel bars.

2 Methodology

This research was conducted with a quantitative approach using experimental methods by conducting tests in the laboratory and numerical calculation methods using software to compare test results. This study uses 12 cold rolled steel joint test specimens 4 connection variations where the load, deflection and collapse mode obtained are data from readings recorded by data loggers, dial gauges, and visual observations. Then the results obtained are processed to obtain a graph of the load-deflection relationship and an image of the failure mode that occurs.

The test object used in this study is cold rolled steel with a profile used is a double channel back-to-back C (channel) profile. Cold rolled steel in this study is assembled into a beam-column connection system, where there are 4 types of test objects with variations in the connection. Cold rolled steel used in this study is cold rolled steel C75 profile with a thickness of 0.75 mm. The screw used in this test object is a self-driving screw A325 type. The connections used in this study are beam-column connections with screws, screws - gusset plates, screws - angle cleats, and angle cleats - gusset plates. Each type of connection is made as many as 3 test objects, where there are 4 types of connection configurations (Fig.1), so that the test objects in this study amounted to 12 test objects. For screw connections marked with code B, BP gusset screw-plate connections, BS elbow-screw-plate connections, and CBN gusset-plate screw-plate connections. For each type of connection, a strain gauge is attached with an additional strain code (B-strain, BP-strain, etc).

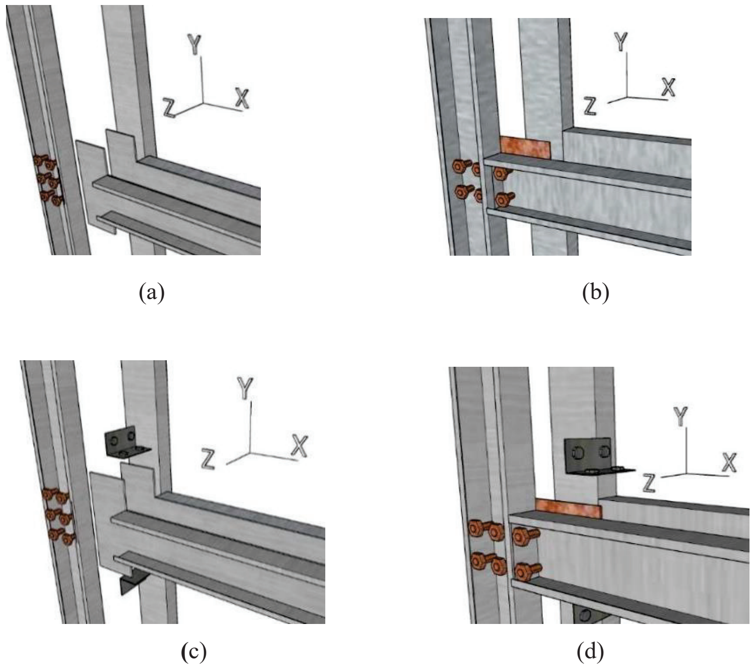

Fig. 1. Illustration of test object, (a) screw connection. (b) screw-gusset plate connection, (c) angle cleats-screw connection, (d) gusset plate-plate joint.

3 Result

Data analysis in this study used quantitative descriptive analysis techniques. The data were obtained based on the results of experimental tests and numerical calculations. The data obtained is data that is in accordance with the research objectives, namely the value of load, deflection, and failure mode, where the data obtained is collected in a table, then the relationship between the data, namely load and deflection, is presented in a graph. The deflection data is obtained by looking at the value on the dial gauge, where in this study the deflection value is seen from the dial gauge at the end of the span (1). 2 is a dial gauge at the end of the beam that serves to see the value of the lateral deviation that occurs in the beam.3 to see the drop in the beam at the joint. 4 and 5 are located at the top and bottom of the column to see if there is a change in the shape of the column where 3 is to see column displacement and 4 is to see column settlement.

3.1 Load and Deflection in Variation of Cold Rolled Steel Connections

The relationship between the load and the deflection at the beam-column connection is obtained from testing at the farthest point on the beam from the cold rolled steel connection by periodically loading the load by the loading jack until the test object reaches its maximum load. The test results of the relationship between load and deflection in this study are shown in the following table 4.1.

Table 1. Load Data and Connection Deflection

Connection Type	Test Object Notation	Compressive Strength (kN)	Deflection (cm)	Average Compressive Strength (kN)	Average Deflection (cm)
Screw	B1	1.17	4.1	1.26	2.9
	B2	1.2	1.6		
	B-STRAIN	1.5	3.0		
Bolt-Plate Screw	BP1	1.56	9.2	1.43	6.0
	BP2	1.21	7.6		
	BP-STRAIN	1.53	3.6		
Screw-Angle cleats	BS1	1.95	1.6	1.92	2.2
	BS2	2.08	1.2		
	BS-STRAIN	1.79	4.0		
Bolt-plate screws, angle - cleatss	CBN1	1.63	6.2	1.60	4.9
	CBN2	1.46	3.7		
	CBN-STRAIN	1.79	4.9		

3.2 Failure Modes That Occur in Variations of Cold Rolled Steel Joints.

When the load reaches its peak, the cold rolled steel column beam structural member will be damaged. Such damage will be observed as a failure mode.

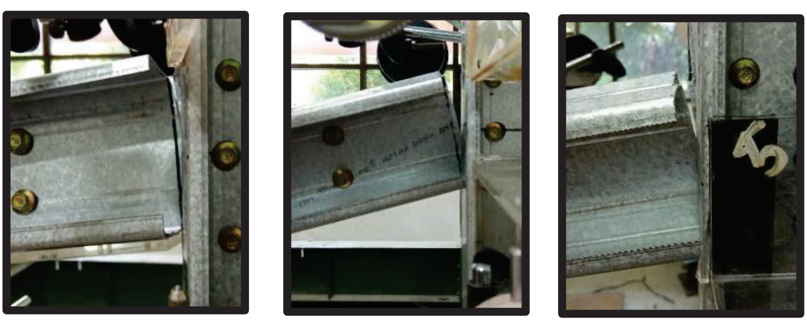

Fig. 2. Failure at the screw joint.

In the screw connection, the damage that occurred in the three test specimens was similar, namely the damage started with flexural buckling in the cold rolled steel beam. Furthermore, the cold rolled steel connection plate is torn from the top to the bottom of the profile (Fig 2).

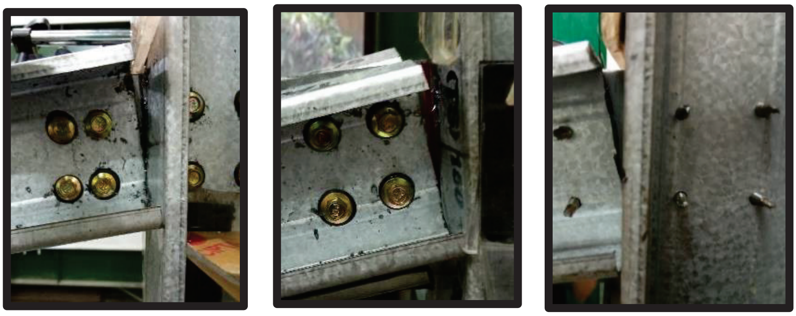

Fig. 3. Failure of the gusset-plate screw connection.

For the screw-plate gusset connection, the damage begins with flexural buckling in the cold rolled steel beam. Then the gusset plate collapses so that it is no longer able to withstand flexural buckling due to axial loads on the cold rolled steel beam (Fig.3).

Fig. 4. Failure at the angle-cleats-screw joint.

Damage to the screw-plate elbow joint begins with flexural buckling of the cold rolled steel beam. Then the angle cleats that holds the beam on the column is damaged and is followed by a tear in the connecting plate (Fig.4).

Fig. 5. Failure in the screw-tush-plate joint-angle cleats.

Damage to the screw-gusset plate-angle cleats connection is a large flexural buckling of the cold-rolled steel beam, due to the gusset plate being damaged by the load. So that due to the bending of the beam that is too large, the angle cleats that holds the beam is damaged (Fig.5).

4 Discussion

4.1 Maximum Load that the Beam can Bear with Variation of Connections

The maximum load that the beam can withstand at each connection variation has a different value. In this study, the experimental load bearing is located at the end of the beam. This is because in the cantilever structure the maximum load is at the end of the rod. From the results of testing the strength of the cold rolled steel column beam connection, it can be seen that the connection that can withstand the largest to the smallest load is the screw-angle cleats connection with an average of 1.92 kN, the screw-gusset plate-angle cleats connection with an average of 1.60 kN, screw-plate gusset connections averaged 1.43 kN, and screw connections averaged 1.26 kN. From the results of testing the strength of the cold rolled steel column beam connection described above, it can be concluded that the connection that can withstand the smallest load is the screw connection with an average of 1.26 kN.
Research results by [9] explains that the addition of a gusset plate to a cold rolled steel screw connection increases the strength of the joint. This is in line with the results of the study that there is an increase in the flexural strength of the screw-gusset plate connection compared to the screw connection. In research by [3] stated that the addition of an angle cleats to the joint increases the joint capacity. This is also in line with the results of the study that the elbow screw-plate connection experienced an increase in strength compared to the screw connection.

Through the calculation of the flexural capacity of the beam, it can be seen that the experimental test results of the flexural strength of the cold rolled steel connection variations did not reach the analytical value of the flexural capacity of the beam. The percentages of experimental results on the analysis of screw connections, gusset screws, angle cleats-screws, and gusset screws and angle cleats respectively were 31%, 35%, 47%, 39%.

4.2 Deflection Produced by Beams with Various Types of Cold Rolled Steel Connections

The value of the deflection of the beam at the maximum load for each variation of the connection has a different value that the average deflection that occurs in the screw connection is 2.9 cm, for the screw-gusset plate connection the average is 6.0 cm, the screw-angle cleats connection is 2.2 cm, and the screw-gusset plate-angle cleats connection is 4.9 cm then the smallest average deflection is at the screw-angle connection.

The deflection value at the elbow screw-plate connection is the smallest with an average of 2.2 cm. Connections with gusset plates which are expected to increase the capacity of screw connections actually have the largest deflection with an average deflection of 6.0 cm. this is due to the difference in the material of the connecting plate between the screw connection and the screw-gusset plate connection. The use of gusset plates as connecting elements of beams and columns increases the ductility of the structure [10]. The bending that occurs at the gusset plate connection is due to the difference in yield stress between the gusset plate used and the cold rolled steel [8], the tensile strength of mild steel and ordinary steel and obtained the yield stress of mild steel is 330 MPa and ordinary steel is 410 MPa. So that the ability of the gusset plate connection to experience post-elastic deviation is greater than that of the screw connection. This is what causes the deflection that occurs before the structure is damaged at the screw-plate gusset connection which is greater than the screw connection.

The addition of angle-cleats in cold rolled steel joints to prevent premature failure due to bending and torsion [11]. This is in line with the results of this study where the value of deflection at the screw connection and screw-gusset plate connection becomes smaller when the angle cleats is added, where there is 27% reinforcement in the screw connection and 21.75% reinforcement at the gusset plate connection after adding the angle cleats.

4.3 Relationship Between Load and Deflection in Variation of Cold Rolled Steel Connections.

In SNI 1729 of 2002, it is written that the allowable deflection for ordinary steel beams is L/240. Then the allowable deflection for cold rolled steel with a beam length of 500 mm is 2.08 mm. After that the allowable deflection value is entered on the load and deflection graph using the Microsoft Excel application, it is found that all test objects have passed the allowable deflection value. From the load and deflection relationship, it can be seen that the elbow screw-plate connection has the highest average load resistance and the lowest deflection value, while the connection with the lowest load resistance and deflection value is the screw-plate gusset connection. It can also be seen that the entire connection has passed the allowable deflection value, where in the screw connection, the load on the allowable deflection is 0.7 kN, 0.9 kN, and 0.39 kN. In 0.13 kN, 0.2 kN, gusset plate screw connections, and 0.59 kN. In the 1.2 kN, 1.56 kN and 0.36 kN elbow-plate screw connections. At the screw-plate-gusset-elbow joints, 0.42 kN, 0.2 kN, 0.52 kN.

4.4 Types of Failure That Occur in Variations of Cold Rolled Steel Joints.

The initial failure that occurs in each type of connection is almost the same, which is caused by large flexural buckling. Then followed by damage to the connection. In 4 types of connection, the damage occurred to the connection plate, while the screw was not damaged. The structural components of all test objects have not melted, as indicated by the results of test data using a strain gauge.

In the screw connection, the result of flexural buckling causes the plate connecting the beam to the joint to tear. This damage was explained in research by [4] which states that this condition is called tear out, where the condition of the joint plate support is tearing when the plate support area is unable to withstand the tensile load due to the lack of quality of the connection plate. The tear starting at the tensile part of the connection proves that the connection plate is not strong enough to withstand the bending that occurs.

In the screw-gusset plate connection, damage occurs to the gusset plate, where the gusset plate fails to withstand the axial load. The bending that occurs at the connection of the gusset plate is due to the difference in yield modulus between the gusset plate used and the cold rolled steel [8]. So that the ability of the gusset plate connection to experience post-elastic deviation is greater than that of the screw connection. So that at the screw-gusset plate connection, the greatest deflection occurs as a result of the failure of the gusset plate to withstand the load. This was added by [12] stated that the failure of the gusset plate was caused by a thin plate and errors during installation so that the plate position was not right. Also holes in the plate due to the screws used and the wrong position of the screws can weaken the connection [13]. So with the method of implementing the gusset plate connection in this study, it was concluded that the failure of the gusset plate was caused by a thin plate, and the installation of screws on the gusset plate was not perfect.

There are 2 damage to the screw-angle cleats connection, which occurs on the angle cleats that holds the beam on the column and on the connecting plate. The damage starts at the joint plate due to bending which is tearing out due to bending. Furthermore, damage to the angle cleats occurs because the angle cleats can no longer withstand bending due to the load so that the screw on the upper angle cleats is unable to withstand the pull that occurs so that it is pulled out. However, the use of angle-cleats as joint components has proven to be successful in providing effective reinforcement for cold rolled steel joint components. This is evidenced where there is reinforcement to withstand the load on the screw connection by 52%, and the reinforcement to withstand deflection of the screw connection is equal to27% and reinforcement of 21.75% at the gusset plate connection.

In the screw-gusset plate-angle cleats connection, the initial damage occurs due to the gusset plate not being able to withstand bending flexure so that the deflection that occurs is large enough. Then followed by damage to the angle cleats on the tensile area beam which was unable to withstand the large bending of the beam so that it experienced a pull out.

In general, the damage to the variations of cold rolled steel joints in this study occurred due to structural instability due to the applied axial load. The instability that occurs due to axial loads is the occurrence of large flexural and lateral deformations.

5 Conclusion

1. The average maximum load that can be endured at the screw connection variations is 1.26 kN, the screw-gusset plate connection is 1.43 kN, the screw-angle cleats connection is 1.92 kN, and the screw-gusset plate-angle cleats connection is 1.60 kN . The results of the maximum load in the experiment still have not reached the maximum load of the analysis results, where the results of the analysis show that the maximum load is 4.02 kN.
2. The average value of the deflection that occurs at the maximum load on the screw connection is 28.67 mm, at the gusset plate screw connection is 58.99 mm, the deflection at the screw-angle cleats connection is 22.44 mm, and the deflection at the screw-gusset plate-angle cleats connection is 48.95 mm. The experimental deflection value exceeds the analyzed deflection value and the allowable deflection value, where the analyzed deflection value is 6.43 mm and the allowable deflection is 2.08 mm.
3. From the graph of the load-deflection relationship, a comparison can be obtained between the results of the experimental test and the analysis. Where it can be seen that the value of the load and deflection of the experimental results does not reach the value of the load and deflection of the analysis results. The experimental test results on the analysis results on the value of the load on the screw connection, gusset screws, elbow screws, and successive gusset plates-angle cleats each only reached31%, 35%, 47%, 39%. From the results of the analysis, so that from this value, the reduction factor for the analysis calculation is 0.38. For the experimental test results on the results of the analysis on the value of deflection at the screw connection, gusset screws, elbow screws, and successive gusset plates, the angle cleats exceeded the analytical values of 446%, 942%, 349%, and respectively. 773%. So from this value, the reduction value for deflection analysis is 6.1. From the graph it can also be seen that the deflection has passed the allowable deflection, where at the screw connection, each test object passes the allowable deflection value when the load reaches 0.7 kN, 0.9 kN, and 0.39 kN. In screw-plate gusset connections 0.13 kN, 0.2 kN, and 0.59 kN. In the 1.2 kN, 1.56 kN and 0.36 kN elbow-plate screw connections. At the screw-plate-gusset-elbow joints, 0.42 kN, 0.2 kN, 0.52 kN.
4. At the screw connection the damage that occurs is a tear in the connection plate (tear out), at the gusset plate connection the damage that occurs is the collapse of the gusset plate, at the screw-angle cleats connection the damage that occurs is 2, where the damage starts with a tear in the connection plate (tear out) and followed by damage to the screw that suffered pull out damage, and at the connection of the screw-gusset plate-angle cleats there were 2 damage, the first was the collapse of the gusset plate due to flexural buckling and lateral buckling and continued with damage pull out the screw (pull out).

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