Structural Behaviour Of Slip-In Gusset Plate Connection For Double Lipped Channel Cold Formed Steel Using Partial Strength Connection

KM Aminuddin, Anis Saggaff, Mahmood Md Tahir

Abstract: Commonly, the cold-formed connection used screwed joint that advantages in simple and fast installation. However, the screw connections should have many problems when it applied for primary structure such as beam and column. To solve this problem, it can be applied the bolted connections using slip in gusset plate as primary structure. The aims of this paper to study the behaviour slip-in gusset plate connection for double lipped channel C20024 using sub-assemblage frame test. The proposed of connections were rectangular gusset plate (RG) and haunched gusset plate (HG). The failure mode, moment resistance, classification connection and discussion will be presented in this paper. The failure mode of bearing bolt CFS was occur for isolated joint test specimens. All of specimens sub-assemblage frame test have similar failure modes where the beam had lateral torsional buckling. The moment resistance of sub-assemblage frame test for RG connection was 13.17 kNm and HG connection was 17.76 kNm. The classification of strength for all sub-assemblage frame test specimens test were classified as partial strength connection.

Index Terms: Connection, gusset plate, cold formed steel, moment resistance, sub-assemblage frame test, partial strength

1 Introduction

Cold-formed steel have been used in the structural frames in roof, storage racks and panel for walls. The cold-formed steel had predominant to local buckling because it has the thinness sections [1] so it would not applied in the primary structure. In recent years, the using of cold-formed steel was high in the construction building [2] because it was easy to install. The connection of cold-formed steel was recommended such as bolts, screws, rivets and spot welds [3]. Commonly, the cold-formed connection used screwed joint that had simple and fast installation. The screwed joint was effective to apply for thin section and did not affect difficulty to the process of drilling [4, 5]. However, the screw connections should have many problems when it applied for primary structure such as beam and column. Since that connection was applied for primary structure, it will be made the steel grade and thickness were increased, so the problem of drilling was happened. to solve this problem, it can be applied the bolted connections using slip in gusset plate as primary structure. The previous research about cold-formed connection were conducted by Ahamed [5], Tan [6, 7], Lee [8], Aminuddin [9] and Bucmys [10, 11]. Ahamed [5] have studied the strength, stiffness and ductility for bolted connection for beam-column cold-formed steel. The result showed all of specimens have efficient moment capacity 70-100% to connection capacity so the connection was classified as partial strength connection. Tan [6, 7] has investigated the slip in rectangular gusset plate 6 mm of thickness for beam-column cold-formed steel with column and beam have the same number of bolts. From Tan's study obtained the ratio between moment connection and moment resistance of beam have increase from 0.46 to 0.70. This result presented the type of connection were classified as partial strength connection by referring to Eurocode 3.

- *KM Aminuddin is PhD. student of Civil Engineering, Faculty of Engineering, Sriwijaya University, Indonesia. Corresponding Email: km_aminuddin@student.pps.unsri.ac.id*
- *Anis Saggaff, Civil Engineering Department, Faculty of Engineering, Sriwijaya University, Indonesia.*
- *Mahmood Md Tahir, Construction Research Centre (CRC), Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor Bahru, Malaysia*

Bucmys [10, 11] explained the connection should be simple and easy to applied. Gusset plate and bolts was the one practical solution to connect cold-formed steel. Bucmys [10, 11] studied the experimental and numerical analysis for rectangular gusset plate 6 mm and 12 mm of thickness. The result showed the ratio of the experimental and numerical analysis differed 11-12%. From literature review above, some of research were used bolted and slip-in gusset plate connection for cold-formed steel. However, the research about slip-in haunched gusset plates for cold-formed steel was very few. In this research will be conducted the haunched gusset plate for slip-in connection for beam-column cold-formed steel. That connection was potential to reduce the larger number of bolts and bolt distance. The haunched gusset plate connection was predicted to increase the strength of connection as partial strength connection that classified by Eurocode 3. By used the partial strength connection will be reduced beam size and saved the overall of frame weight could be acquired [12]. The aims of this paper to study the behavior slip-in gusset plate connection for double lipped channel C20024 using sub-assemblage frame test. This test was to study the behavior of beam that influenced of partial strength connections. The failure mode, moment resistance, classification connection and discussion will be presented in this paper.

2 Experimental Procedures

2.1 Preparation of specimens

This paper used double lipped channel C-section that connected back-to-back to avoid local, distortional buckling [13]. The column was used only one profile C30024 that has 3 m of height and the beam was 4 m of length. The profiles of cross section (see Table 1) were used C20024 grade 350 N/mm^2. The connectors of joint were used hot rolled steel which have 10 mm of thickness. The connectors named rectangular gusset-plate (RG) and haunched gusset plate (HG). The configuration of bolts were required by range validity that refer to EC 3 [14] (Table 3, Fig 1, Fig 2). The specimen test label can be seen in Table 2 with BGJ-1 was RG connection and BGJ-7 was HG connections which used C20024 of beam.

Table 1. *Dimension of cross section*

Profile	Dimension (mm)				
	Web	Flange	Lip	Thickness	Radius
C20024	200	75	16	2.4	5
C30024	300	100	25	2.4	5

Table 2. *Specimens label*

Label	Beam	Column	Number of Bolt
RG-BGJ-1	C20024	C30024	8
HG-BGJ-7	C20024		12

Table 3. *Detail of connection*

Label	Configuration of specimen (mm)							
	t_g	h_g	L_g	e_1	e_2	p_1	p_2	p_3
RG-BGJ-1	10	200	600	75	50	150	100	150
HG-BGJ-7	10	200	600	75	50	150	100	150

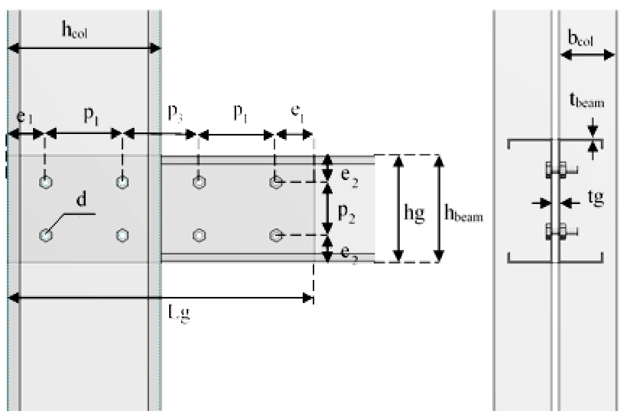

***Fig. 1**. Configuration of RG Connection*

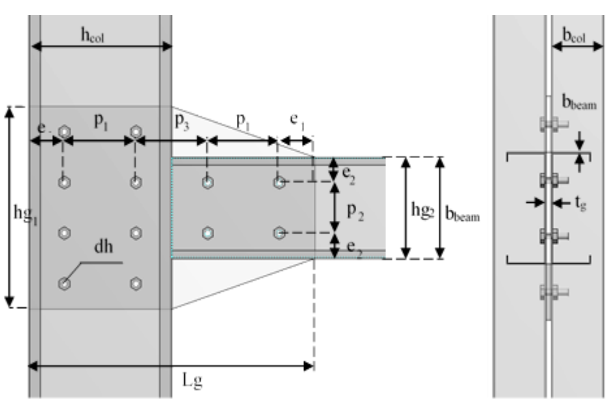

Fig. 2. *Configuration of HG connection*

The dimension of rectangular gusset plate presented in Figure 3 where L_g = 600 mm and H_g = 200 mm for RG-BGJ-1 specimen.

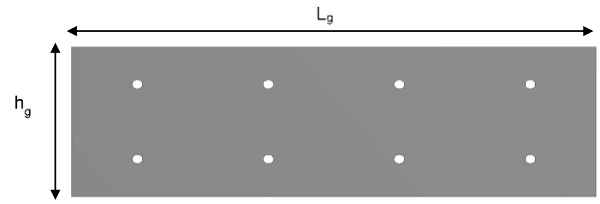

Fig. 3. *Detail of RG plate*

The HG plate dimension showed in Figure 4 which length of gusset plate (L_g) = 600 mm, the length of gusset plate to column (L_{gc})= 300 mm, the length of gusset plate to beam (L_{gb}) = 300 mm, height of gusset plate (h_{gc}) = 400 mm, height of gusset plate to beam (h_{gb})= 200 mm and h_{gb1} = 100 mm.

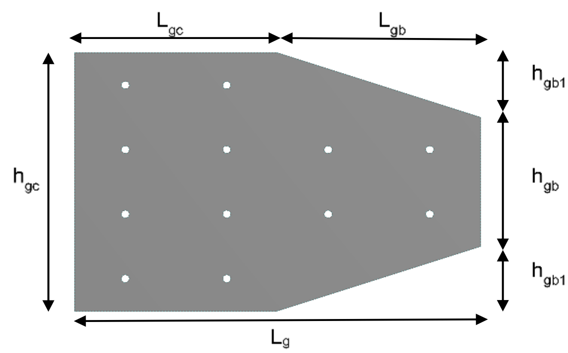

Fig. 4. *Detail of HG* plate

2.2 Method

The specimens were tested on Constructions Research Center (CRC) Universiti Teknologi Malaysia (UTM) using full scale test. The experimental tests were divided into two group test. The first group was full-scale isolated joint test (IJT) and the second group was sub-assemblage frame test (SAFT).

2.3 Isolated Joint Test (IJT)

The The aims of IJT test was to determine the characteristic of connection. IJT layout's was mounted on the Magnus frame and the configuration is cantilever beam with sub portal frame (Fig 5). The testing tool, hydraulic jack was installed at the end of the beam with load cell that located on distance of 100 cm. Each specimen will be loaded gradually about 0.2 – 0.5kN. The inclinometer provided the rotational of the beam, located about 100 mm from flange column. For identifaction of deflection using linear variable displacement transducer (LVDT) that recorded via data logger. The number of LVDTs were used 5 units. The LVDT-1 located in the 1 m from the face flange column. LVDT-2 was placed in the mid-span 0.5 m away from the face flange column. The LVDT-3 located on a beam flange 0.1 m away from the face flange column and the LVDT-4 and LVDT-5 located on the flange column with place in upper the web beam. All the specimens were tested until the failure mode is indicated such as: Failure mode or yield mode at flange column. Buckling behavior at flange column. There is an indication of large rotation on the beam or column due to bearing failure on the bolt hole.

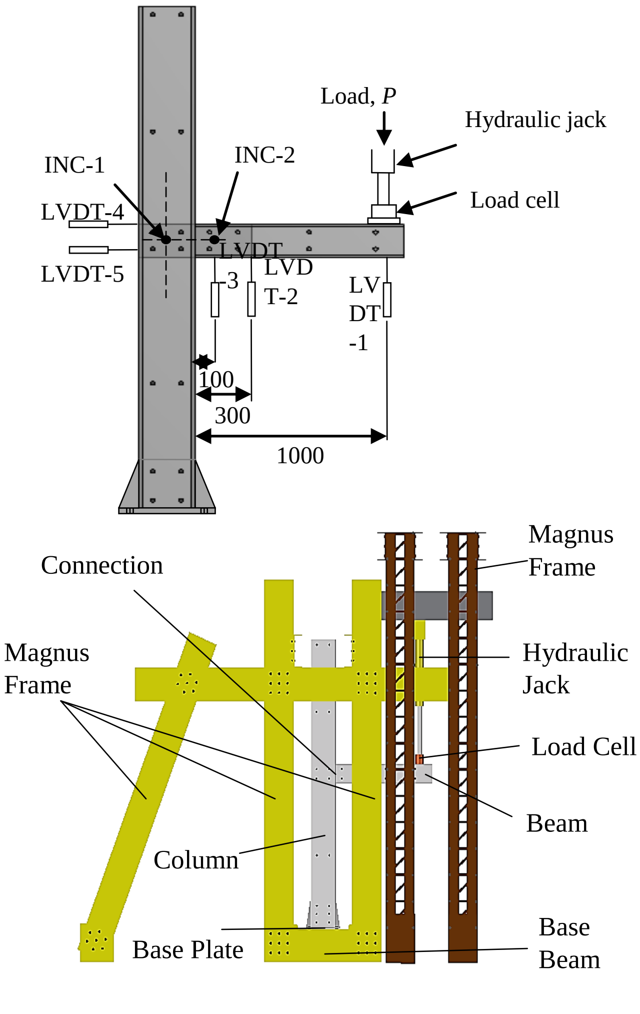

Fig. 5. The layout for IJT testing

2.4 Sub-assemblage Frame Test (SAFT)

The SAFT is a test used full-scale structure with two cantilever restraint that connected to the beam. The load was applied regularly using the load cell and hydraulic jack pump. The load cell was installed in the center of spreader beam which had 2 m of span (Fig 6).

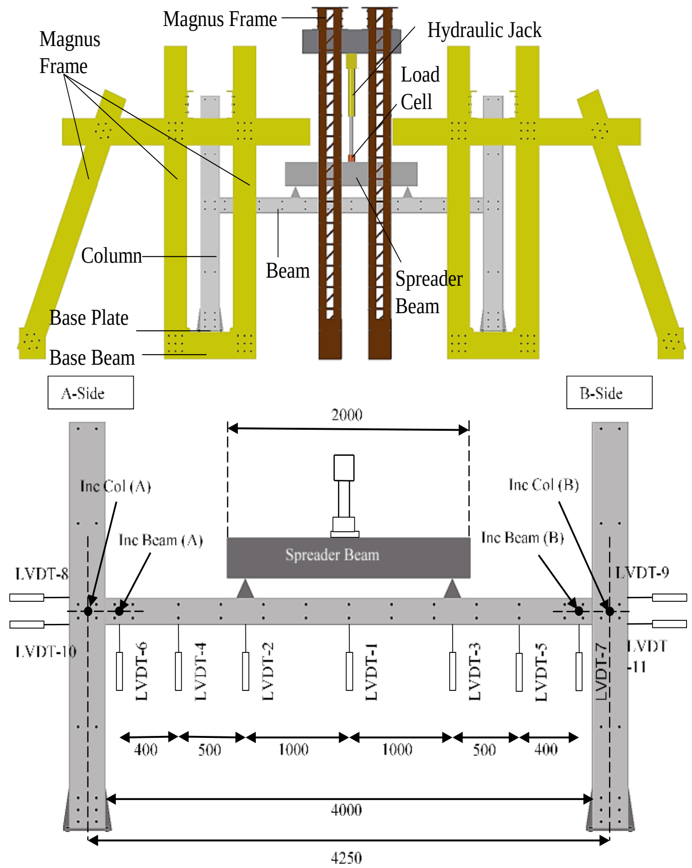

Fig. 6. Schematic diagram of the SAFT

The position of the inclinometer have the same location of the Isolated Joint Test (IJT) but the LVDTs were used 10 units. The LVDT-1 until LVDT-3 were located in the mid-span of the beam where this point was the maximum bending moment. While the LVDT-8 to LVDT-11 were placed horizontally in both web columns and the LVDT-4 until LVDT-7 were installed to obtain more information test results (Fig 6). The purpose of SAFT test was to obtain the maximum load and moment joint of beam.

3 Results and Discussion

3.1 Modes of Failure of Isolated Joint Test (IJT)

The RG-BGJ-1 specimen was rotated by load and made compressive (at bottom of beam) and tensile (at upper of beam) conditions in the column section (Fig 7). The beam had rotated and pressed the column so the failure mode occurred. The failure mode was occurred in the compression zone that showed the buckling failure of flange column and the lower flange of the beam (Fig.8).

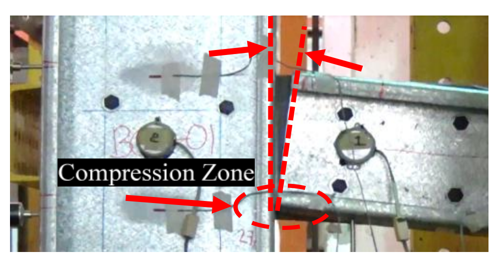

Fig. 7. Deformation of specimen RG-BGJ-1

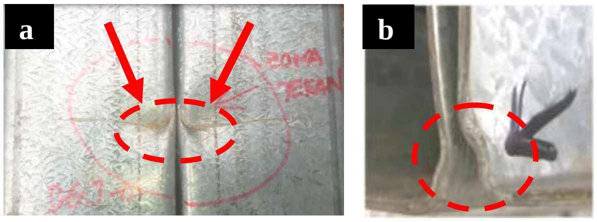

Fig. 8. *The column (a) and beam (b) failure modes at compression zone (RG-BGJ-1)*

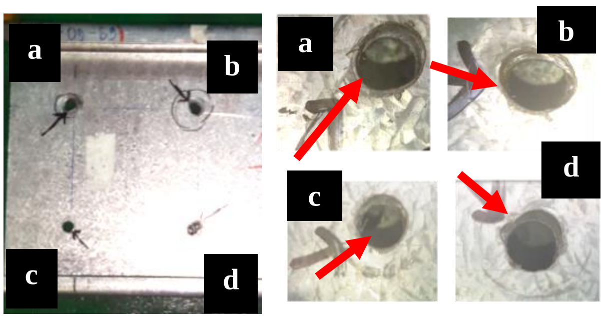

Fig. 9. *Beam bolt holes failure (RG-BGJ-1)*

When the load was applied, the beam has rotated and the bottom of flange beam pushed the flange column thus the flange column had buckling at the compression zone (Fig 10). The column flange and beam flange were buckling in compression zone because the beam push the flange column due to the rotation of beam. The beam bolt holes have wider elongation than the column bolt holes (Fig 11) because the column bolt was more than beam, so the resistance of column bolt was more than beam than beam.

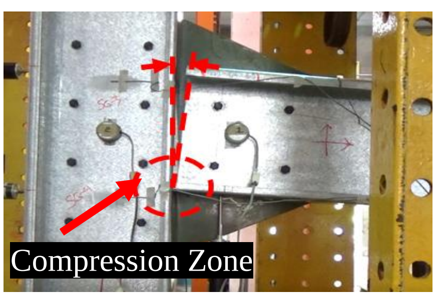

Fig. 10. *Deformation of HG-BGJ-7 specimen*

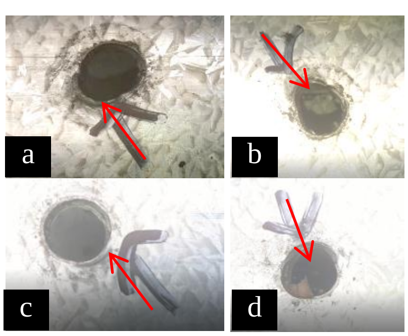

Fig. 11. *Beam bolt holes failure mode for HG-BGJ-7*

3.2 Moment vs Rotation of Isolated Joint Test (IJT)

The aims of moment and rotation curve was to obtain the characteristic of connection i.e. rotational stiffness and moment resistance. The rotational of specimen were recorded from inclinometer that located on beam and column.

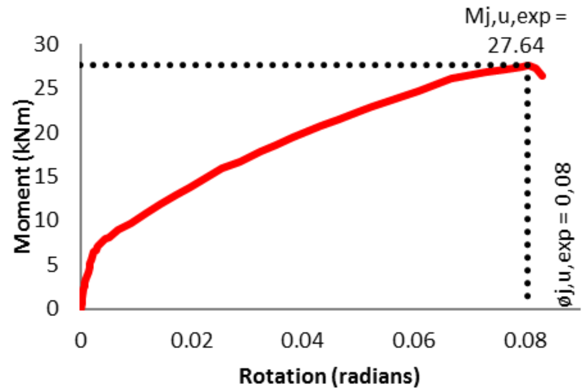

Fig.12. *Moment-rotation curve RG-BGJ-1*

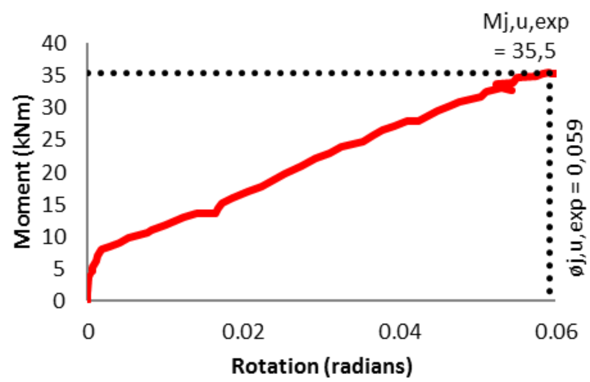

Fig. 13. *Moment-rotation curve HG-BGJ-7*

Fig 12 was the moment-rotation curve RG-BGJ-1 where the maximum moment was 27.64 kNm at 0.08 radian of rotation. Fig 12 was the HG-BGJ-7 moment-rotation curve. This figure presented the maximum moment was 35.5 kNm at 0.059 radian of rotation.

Table 4. *Comparison of moment capacity*

Label	Beam	Type of connection	Moment capacity (kNm)
RG-BGJ-1	C20024	Rectangular gusset plate	27.64
HG-BGJ-7		Haunched gusset plate	35.5
Ratio			27.73%

The comparison moment capacity from isolated joint test (IJT) for RG-BGJ-1 and HG-BGJ-7 show the good agreement. Table 4 presented the HG connection have the largest moment capacity than the RG connection. The ratio of both connections showed the ratio up to 27.73% where the RG connections was the datum. The HG connections have more number of bolt so it can raise the moment capacity of connection.

3.3 Failure Modes of Sub-assemblage Frame Test (SAFT)

The failure mode was presented only one specimen because the failure mode of other specimens have the same. The RG-BGJ-1 failure mode (Fig 14) did not collapse at the connection between column and beam. Fig 15 presented the failure mode of the web beam that occur the bending under the point load. The top of flange and web were crushing that caused by lateral torsional buckling of the beam.

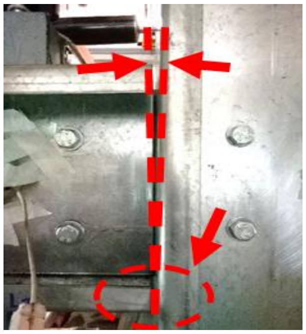

Fig. 14. *Deformation SAFT for RG-BGJ-1*

Fig. 15. *The web beam was buckling*

Fig. 16*. Lateral torsional buckling*

The mid-span of the beam had lateral torsional buckling and made the top flange of beam was crushed too (Fig 16 and Fig 17). This indicated the presence of thin-walled behavior. The test was stopped until lateral torsional buckling occurs. Fig 17 presented that the top and bottom of beam flange crushed because of the flexural of beam and the load was applied until a deformation of beam occur.

Fig. 17. *Beam flange have crushed*

3.4 Load vs Deflection Curve of Sub-assemblage Frame Test (SAFT)

The load and deflection curve was taken from the deflection on mid-span (LVDT-1) when the specimen was deformation. The deformation begin occurred when the limit of the mid-span have been reached. According to Tan [6] the first allowable limit:

$$\delta_{360} = \frac{L}{360} = \frac{4000+300}{360} = 11.94\ mm$$

for beams carrying plaster or other brittle finish The second allowable limit of deflection for all other beams was taken:

$$\delta_{200} = \frac{L}{200} = \frac{4000+300}{200} = 21.5\ mm$$

The limit was used to obtain the allowable of deflection and load. Where L is the distance between centre of two column.

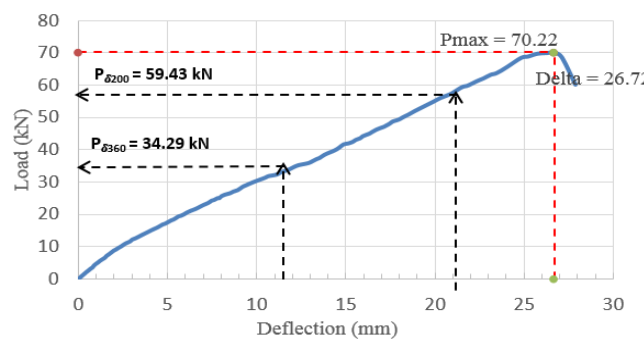

Fig. 18. *Load vs deflection curve RG-BGJ-1*

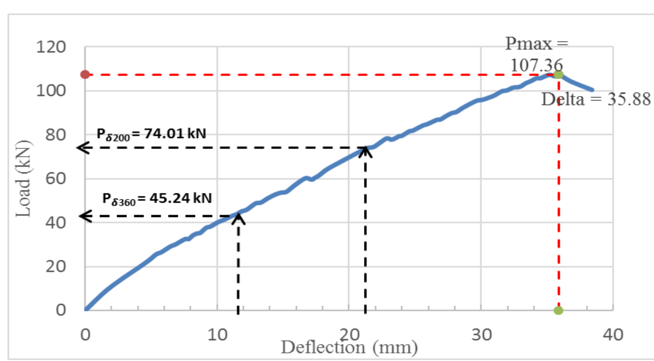

Fig. 19. *Load vs deflection curve HG-BGJ-7*

Fig 18 showed the maximum load for RG-BGJ-1 was 70.22kN where this load made the buckling on beam. The deflection maximum was 26.72 mm. The allowable limit load when 360 mm of deflection ($P\delta_{360}$) was 34.29kN and when 200 mm of deflection ($P\delta_{200}$) was 59.43kN. Fig 19 presented the load vs deflection curve for HG-BGJ-7 where the maximum load was 107.36kN and the deflection was 35.88 mm. The limit load $P\delta_{360}$ was 45.24kN and $P\delta_{200}$ was 74.01kN.

3.5 Load vs Rotation Curve of Sub-assemblage Frame Test (SAFT)

Fig 20 and Fig 21 presented the relationship between load and rotation where the RG-BGJ-1 have rotation maximum 0.018 radian while the HG-BGJ-7 have rotation maximum 0.022 radian. The rotation maximum was needed to obtain the moment of SAFT [12].

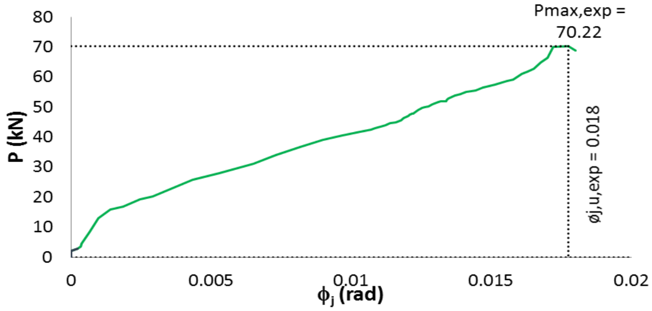

Fig. 20. *P-rotation curve RG-BGJ-1*

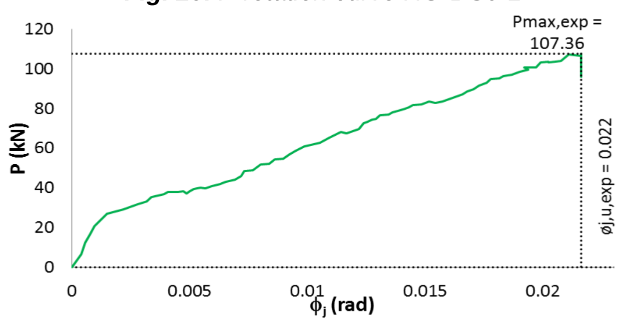

Fig. 21. *P-rotation curve HG-BGJ-7*

3.6 Load vs Rotation Curve of Sub-assemblage Frame Test (SAFT)

Refer to Tan [6], the moment resistance of joint (Mj) can be determined from the load-rotation curve from SAFT and moment-rotation curve from IJT.

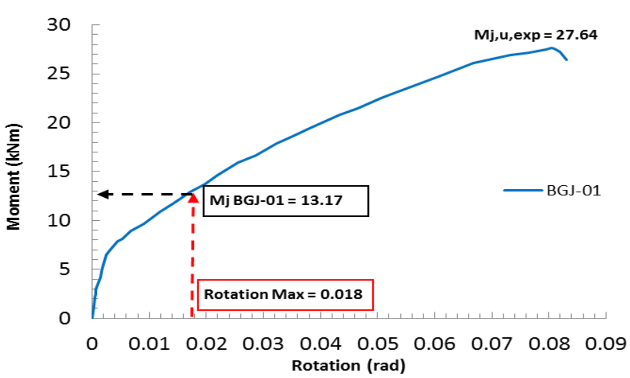

Fig. 22. *Determination of Mj for RG-BGJ-1*

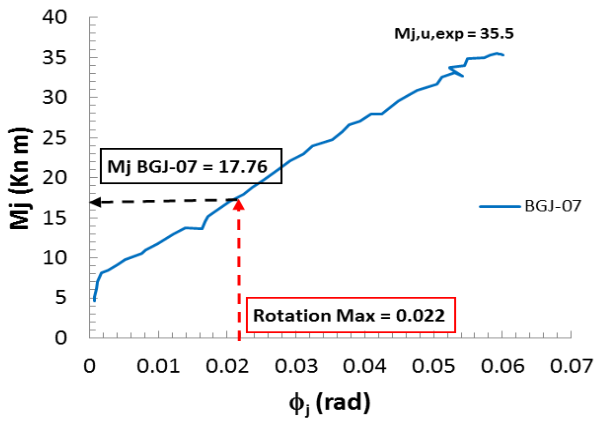

Fig. 23. *Determination of Mj for HG-BGJ-7*

From that curve, will be obtained the beam rotation maximum. This rotation will be plotted in the moment-rotation curve from IJT. Fig 22 and Fig 23 represented the plotting curve for determining the moment joint SAFT (Mj). The RG-BGJ-1 have Mj = 13.17 kNm while the HG-BGJ-7 have Mj = 17.76 kNm. The moment of SAFT was presented by Fig 24 namely moment joint (Mj) and moment of beam (Mbeam) by specific beam span.

Table 5. *Test result of SAFT*

Label	Mj (kNm)	Mbeam (kNm)	Mmax (kNm)	Mj/Mmax
RG-BGJ-1	13.17	21.94	35.11	0.38
HG-BGJ-7	17.76	35.92	53.68	0.33

The HG-BGJ-7 has the highest Mj than the RG-BGJ-1 because the HG connection resist the highest loading than RG connection so that influence the Mj (Table 5). Ratio of Mj/Mmax for RG-BGJ-1 and HG-BGJ-7 have decrease from 0.38 to 0.33 because the different of type connections that resist the moment. The moment joint (Mj) for each specimen can be classified based on strength refer to EN 1993-1-8: 2005 (E) clause 5.2.3 with the following conditions: a. Pinned if Mj < 0.25 Md b. Rigid if Mj > Md, c. Otherwise : partial strength where Md is bending moment resistance of beam, in this study use C20024 beam so the Md = 36.61 kNm.

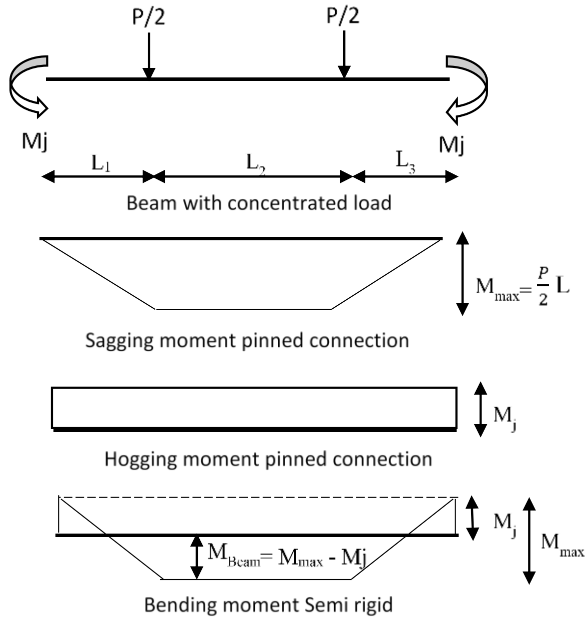

Fig. 24. *The moment of SAFT*

Table 6. *Classification of Strength*

Label	Mj (kNm)	Pinned (kNm)	Rigid (kNm)	Classification
RG-BGJ-1	13.17	9.15	36.611	Partial strength
HG-BGJ-7	17.76	9.15	36.611	Partial strength

Table 6. show the classification strength for specimens of SAFT. According to Table 6, all of specimens were classified as the partial strength by range 9.15 - 36,611 kNm of Mj.

3 Conclusion

The isolated joint test and sub-assemblage frame test were carried out successfully. The results of the experiment produced load, deflection, rotation and moment. From this paper allows us to make the following conclusions : The failure mode of bearing bolt CFS was occur for IJT specimens. All of specimens SAFT have similar failure modes where the beam had lateral torsional buckling. The ratio moment resistance from IJT for RG connections and HG connection were increase 27.73%. The moment joint of SAFT for RG connection was 13.17 kNm and HG connection was 17.76 kNm. The classification of strength for all SAFT specimens test were classified as partial strength connection.

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