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2 Structural ductility of RBS on castellated beam subjected to cyclic loading

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Abstract. RBS placement on a castellated beam on exterior connection structure with RBS position from column face refers to Prequalified Connection for Special and Intermediate Moment Frames for Seismic Application AISC 358-10, Article 5.8. The column beam test aims to evaluate structural ductility of the RBS on the castellated beam flange from the column face. The study was expected to explain the effect on column beam joints to provide input for planning earthquake-resistant building structures. The results show that the castellated test beam with RBS could withstand a load of 12.05 kN with a value of 4.2 structural ductilities.

1. Introduction

The earthquake design is essential for structures to remain elastic during an earthquake, as was the case at the Northridge earthquake in 1994, where failures were found in the connection, which should be addressed because it causes a global collapse of a structure.

Explains that the ultimate condition occurs when the peak load is reached. In this condition, cracks occur in the wing in the support part. At this time, the strain on the crack location has reached strain hardening. Therefore, the ultimate deviation is more precisely observed when the maximum load is achieved because of the structural collapse that occurs in testing due to cracks in the wing in the support area [1].

Conducted a test on RBS where he found that the connection showed significant ductility to maintain the desired inelastic deformation, and showed no signs of brittle fracture. In the test, the three specimens showed damage to the beam flanges while the RBS area did not show faults on the welded joints on the column beams [2].

The solid steel profile that can be converted into a castellated steel profile is the I, H, or U with holes steel profile. The results of the study show that there was buckling on the RBS area, which ensures the stress concentration in the RBS area [3].

Analyzed the ability of castellated beams with RBS. The results show that the maximum lateral load capacity of each drift ratio along the collapse phase was 12.05 kN, which means that the structure meets earthquake design requirements with a drift ratio of 3.2%. The decrease in power that occurred due to the addition of loads to reach necking in the drift ratio of 17% was 12.25%. This means that the RBS on castellated beams shows ductility before the collapse [4].



The study aims to determine the strength and deformation of the structure to obtain the RBS ductility value of the castellated beam from the face of the column. The exterior connection of the castellated column was tested with cyclic loading.

The study was expected to obtain the analysis and behavior of castellated beams with opening distance from the column face, as well as investigate the performance of castellated beams whether the openings can provide reinforcement in the column. We also analyze the experimental results of the load and deflection, strength and ductility of the structure to determine the performance of the RBS castellated beam.

2. Scope and limitation

This study used castellated beams with an exterior connection model. Experimental studies produced structural data from the experimental tests of pillar structures (columns) clamped with beams that were considered rigid at the connection, creating a strong column-weak beam behavior. This study used an experimental study to analyze the deflection and some forces due to the cyclic loading. The test used a cyclic loading, and it was limited by the placement of joints with a moment value equal to zero.

The study only focused on the beam without discussing the column. Moreover, the identified parameters were deflection, load, and type of damage to the beam only on the exterior connection. The condition of the Castellated beam was also examined.

3. Experimental materials

3.1 Specimen

The properties of the material used in the cyclic behavior test is shown in table 1. The specimen was a type H 25 x 25 column and a castellated beam type IWF 225 x75. Figure 1 shows the dimensions of the RBS on the castellated beam.

Table 1. Properties of the specimen.

Model	Member	Size	Grade (Indonesian standard)	Steel stress	
				Yield Stress (N/mm ²)	Ultimate Stress (N/mm ²)
RBSC-1	Castellated Column	W225 75 5 7	BJ 37 SNI 03-1729-2002	366.17	433.76
		H250x250	BJ 41 SNI 03-1729-2002	410.11	487.36

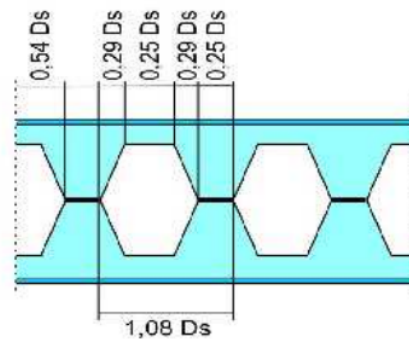


Figure 1. Standard of the castellated beam.

The detailed dimension used in the cyclic behaviour test beam is shown in figure 2. The beam was a solid type IWF 150 x75 mm and converted into 225 x75 mm castellated beam with a distance of 22.5 cm from the face of the column.

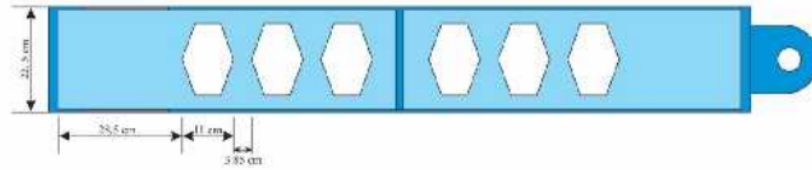


Figure 2. Location of castellated beam opening distance.



Figure 3. Location of the RBS on the flange from the column face.

3.2 Ductility

The ability of a structure or structural component to avoid a sudden collapse (brittle) but still able to experience considerable deformation when the maximum load is reached before the structure has collapsed is called the ductility factor [5]. The structural ductility factor is the ratio between the maximum deviation/strain of the structure due to the influence of the earthquake when it reaches the collapse threshold condition (Δ_u) and the deviation/strain during the first yield point (Δ_y) as formulated in equation 1.

$$\mu = \frac{\Delta_u}{\Delta_y} \tag{1}$$

where

μ : ductility

Δ_u : displacement at the maximum load (mm)

Δ_y : displacement at the first yield point (mm)

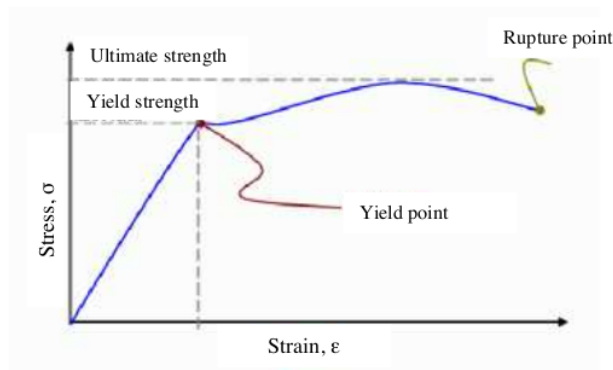


Figure 4. The relationship between stress and strain.

If a load (P) reaches the yield point or yield strength and then passed over the linear line, then it is called the elastic boundary. When the force is continued, the strain increases to the boundary strength i.e. the ductility value of a beam. Then the strength decreases while strain continues to increase as shown in figure 4. (Phase values are elastic/linear and inelastic/collapse).

4. Experimental method

In the experiment, it was assumed that the lateral force was very dominant compared to the gravity load for which the test method was presented with cyclic loading given in displacement-controlled form (P) Actuator (horizontal jack) that moved back and forth with an LVDT (Linear Variable Displacement Transducer) with 0.01 accuracy as the control of displacement value at the upper end of the beam. The amount of deformation and the number of cycles were adjusted with the pretest analysis results to determine the yield displacement, then it was connected to the computer data logger and switching box to record data measured by a strain gauge, LVDT, and load cell simultaneously and automatically. The data were also collected by visual observation of test beam failures such as welding damage, flange bending, web bending, and observing the types of failures that determined the failure of beam structural elements. Loading basis used the ATC-24 loading cycle [6]. Figure 5 displays the actuator test equipment and castellated column beam specimen.

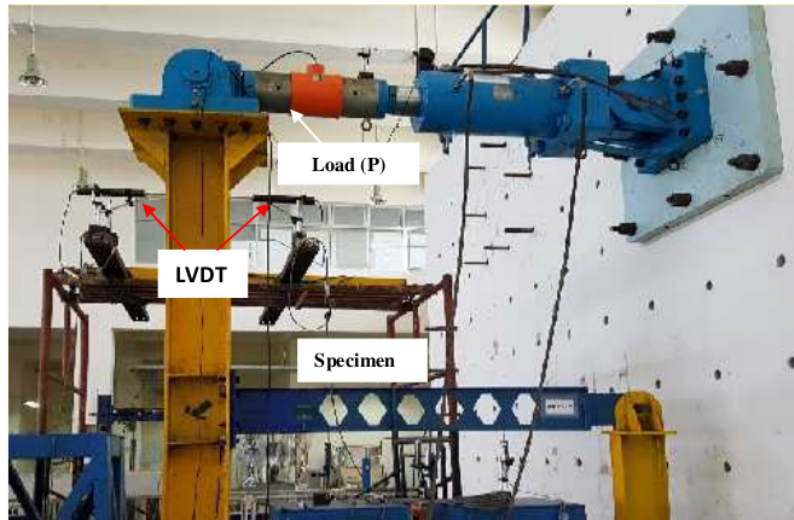


Figure 5. The instrument of the castellated beam-column testing.

5. Analysis and discussion

The results show that the peak load of the RBSC-1 specimen was in a positive direction of 12.0 kN with displacement value of 97.5 mm while the peak load was in a negative direction of 12.57 kN and displacement of 66.8 mm, which was resulted in ductility resistance of the steel frame structure of 4.2 in both directions. This shows that the beam can withstand partial ductility. The yield point was reached at 8.0 kN load in both positive and negative points. [4] reported that an experiment of the castellated beam with an opening distance of 15 cm from the column face without RBS can deform to 100 mm deflection and withstand a load of 12.5 kN. When to loading was continued, the specimen had a 12.8% decrease of strength, with deflection reached 136.5 mm. With a load of 10.9 kN, the obtained ductility value was 4.1, which means that the castellated beam with RBS had a partial ductility.

Table 2. Experiment results.

Result	RBSC-1
The first yield push load (P_y^+), kN	8.0
Displacement caused by the first yield push load, Δ_y^+ (mm)	31.6
The first yield pull load (P_y^-), kN	8.0
Displacement caused by the first yield pull load, Δ_y^- (mm)	32.5
Maximum push load (P_u^+), kN	12.0
Displacement caused by the maximum push load, Δ_u^+ (mm)	97.5
Maximum pull load (P_u^-), kN	12.57
Displacement caused by the maximum pull load, Δ_u^- (mm)	66.80
Ductility (μ^+)	3.1
Ductility (μ^-)	2.1
Average ductility (μ)	4.2

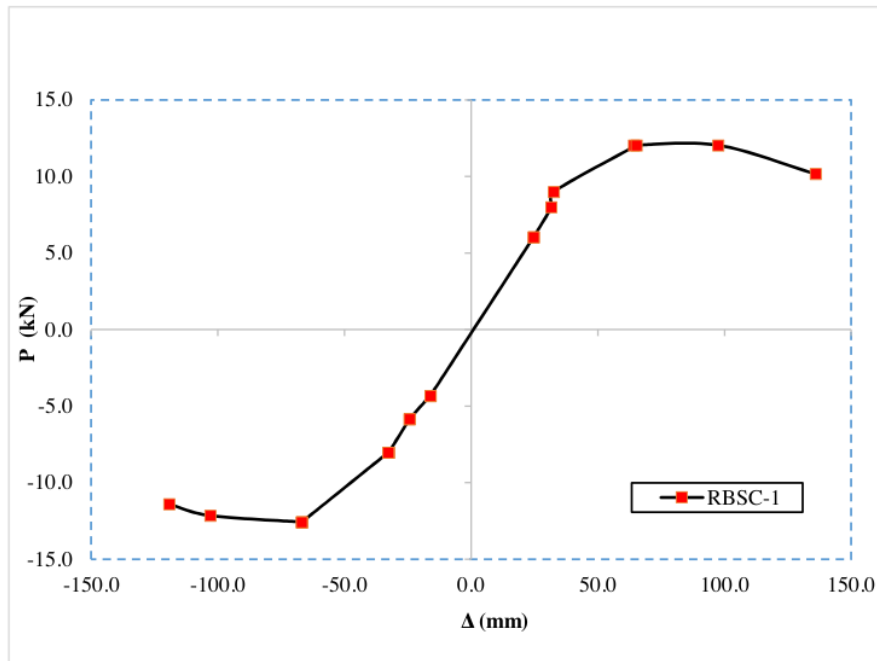
**Figure 6.** Backbone curve of the relationship between lateral loads and displacement.

Figure 6 shows that the structure achieved ductility, where it was deformed during loading until it reached the ultimate boundary. Furthermore, the steel beam reached 97.5 mm deflection at peak load. When the loading was continued until it reached the plastic limit, the ductility reached 4.2-4.3 with strength decreased to 10.9 kN and deflection increased to 136.5 mm.

Figure 7 shows that the failure occurred due to the bending of the beam. The flange area experienced buckling with no visible fracture at the weld meeting between the endplate and the beam. During the cyclic loading, the loss of lateral capacity was followed by a slight reduction in the strength of the specimen resulting in the curve decreased at 10.9 kN load. The first yield moment (yield) occurred in the outermost fiber that reached the yield stress at 8 kN load on the upper flange, then it continued to the lower flange. When the load reached a value of 12.05 kN (maximum) while the loading was

continued, the lateral strength continued to decrease creating the reaction to deviate from linearity, which is commonly known as the ductility property of the steel. The ductility property decreases as the load increases until the specimen was collapsed.



Figure 7. Damage on the specimen that was subjected to cyclic loading.

6. Conclusion

Based on the experiments that have been done, we can conclude that the ductility occurred at the peak of partial ductility loads until full ductility breaking stress. Meanwhile, the results showed that structural ductility due to the cyclic loading on the castellated beam with RBS reached 4.2, which was a partial ductility. The tested beam achieved partial ductility at a maximum load of 12.0 kN with a strain value of 97.5.

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