

Flexural behavior of double straight notch joint beam column exterior due to lateral cyclic load

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Flexural behavior of double straight notch joint beam column exterior due to lateral cyclic load

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Abstract. This study aims to determine and analyze the flexural behavior of the double straight notch joint beam column exterior due to lateral cyclic load. There are 3 (three) scale test specimens, BK monolith, SBK type 1 and SBK type 2. The joint model on the beam is a double straight notch and uses the method of mechanical connection and grouting. Loading with alternating lateral loads assumed as cyclic loads. Testing and analysis using the Displacement Control Method with the standards of the European Convention for Constructional Steelwork (ECCS) 1986. The results showed that the stability of SBK type 1 and type 2 specimens in terms of the characteristics of the hysteresis loop curve had a curve similar to BK monolith. The greatest displacement in compressive conditions occurs in SBK type 2 while drag conditions occur on monolithic BK. From the results of the study, it is also known that lateral loads are directly proportional to displacement, where the higher the lateral load is borne the greater the displacement experienced and vice versa. The displacement ductility that occurs is the partial ductility in type 1 SBK = 0.971 monolithic BK while SBK type 2 = 1.047 monolithic BK. Based on the results of studies of some of these behaviors, type 2 SBK has more advantages than type 1 SBK so that the results of SBK type 2 analysis can then be used as validation of monolithic BK.

1. Introduction

The need for earthquake resistant buildings is a matter that must be fulfilled, especially for areas with high earthquake hazard levels such as in Indonesia. Development is constantly being developed. However, with a lot of construction, the available land becomes increasingly narrow. Therefore, many regions have begun to build high rise buildings to solve the shortages of land. Most of the construction of high rise buildings still uses conventional reinforced concrete methods by using formwork that is casted in places and will be more costly because they required a lot of formwork. However, nowadays there is a new innovation to reduce many formworks by using precast methods made by the factory or at the project site and then assembled. In the structure of a connection building is one element that is very important and requires special treatment. The connection function is to connect the force that works, and also must be the function to unite each component of precast concrete into a monolithic, so the stability of the building structure is maintained. Precast concrete structures are generally planned to assume the structure is like a monolithic structure and cast in place. Based on this, a good planner must be able to show the analysis and



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test results that the structure has behavior, strength, and stiffness that is equivalent to monolithic reinforced concrete. The aim of the study was to find out and analyze the comparison of the normal beam column flexural behavior with straight double-beam notch joint beam columns due to lateral cyclic loads. Elements must be well distributed so the stability of the structure remains stable. According to Widodo (2007), the beam-column joints with static structures are not necessarily very important in gripping so that there is no freedom of rotation on the beam. Gripping occurs when a joint is monolithic and rigid [1].

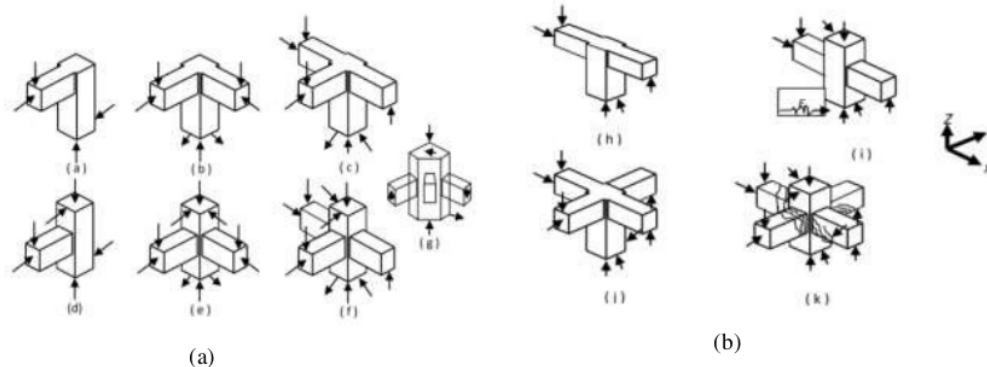


Figure1. Location of exterior joint and interior joint

Explained that joints are critical areas that can respond to inelastic conditions to withstand earthquakes [2]. The joint will work like a horizontal and vertical shear force and has a value of several times the shear forces of adjacent beams and columns. Based on the location of the gathering point, the joint can be divided into two. Outer Joint (exterior Joint) is a meeting of column elements with beam elements located on the outside of the building structure. Figure 1. (a) shows the location of the exterior joint at point a - g. Interior Joint is a meeting of column elements with beam elements located on the inside of the building structure. Figure 1. (b) shows the location of the interior joint at point h, i and j.

Based on the deformation area, the joint can be divided as follows:

- Elastic joint is where inelastic joint deformation does not occur in beams and columns bordering the joint panel because it has strong reinforcement.
- Inelastic joints are where plastic joints occur on the beam in the face of the column after several cycles of inelastic deformation occur on the joint panel.

According to the connection method can be divided into 3 (three) the casting method (wet connection) is the connection using a casting system, the mechanical connection method is the connection method used on reinforcement with a welding system or connection bolt and the connection method that uses a combination of wet connection and mechanical connection. Terms of connection planning in precast that must be fulfilled

Connections are able to translation to a certain extent at the point, generally significant shear deformations and crack.

- Connections are able to withstand loads according to planning both as a whole system and as individual members.
- Connections have sufficient strength and stiffness to be able to behave in a stable manner in holding loads.

- There are deviations both in terms of the installation and size of each precast element with the tolerance limit is 3mm on the joint.

The most important thing is that the connection must be proven theoretically and experimentally to have the reliability requirements of the structure to withstand internal and external forces, especially when an earthquake. The beam-column joint is an important part of the structure of a high rise building. The beam-column connection area is a critical area of a reinforced concrete frame structure, which must be specifically designed for the inelastic deformation event of a strong earthquake. The effect of the column moment in above and below, and the moments of the beam when carrying the earthquake load, the beam-column connection area will have a large horizontal and vertical shear force. The shear force that magnitude will be several times higher than the shear forces arising on the beam and column connected. As a result, if the beam-column connection area is not designed properly, it will cause a shear failure which is brittle and endanger the building user [3].

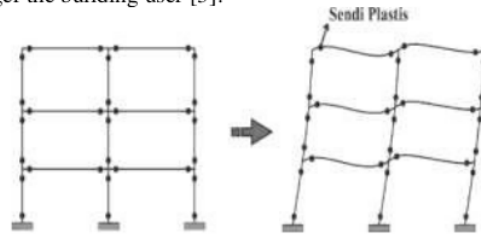


Figure 2. Location of Plastic Joint

2. Research Methods

2.1. Tools and Materials of Research

Research Tools: *Cyclic Actuator Lateral Load, Supporter, Hydraulic Power Supply, Data Logger, Universal Testing Machine (UTM) capacity 1000 kN, Concrete Vibrator, Linear Variable Displacement Transducer (LVDT), Concrete Mix, Strong Wall, Personal computer, Multipleks, wood beam, dan nails for formwork.*

Research materials: Bolt, Nut, Steel (reinforcement) plain Ø10 and screw D13, *Strain Gauge Steel and Strain Gauge concrete, CN Adhesive, Cement Portland Type I, Fine Aggregate and Coarse Aggregat, Water, Sikadur732 dan Sika Grout 215 (new).*

2.2. Column Beam Joint test Object

Column beam joint test specimens were made of 3 (type) pieces, one for monolithic connections and two for precast joint notch models. Followed by the rules of SNI 1726-2012, Procedures for Resilience planning for structures of buildings and non-buildings, and SNI 2847-2013 concerning Requirements for Structural Concrete for Buildings, Specifically the Special Moment Resisting Frame System.

The figure of reinforcement test object:

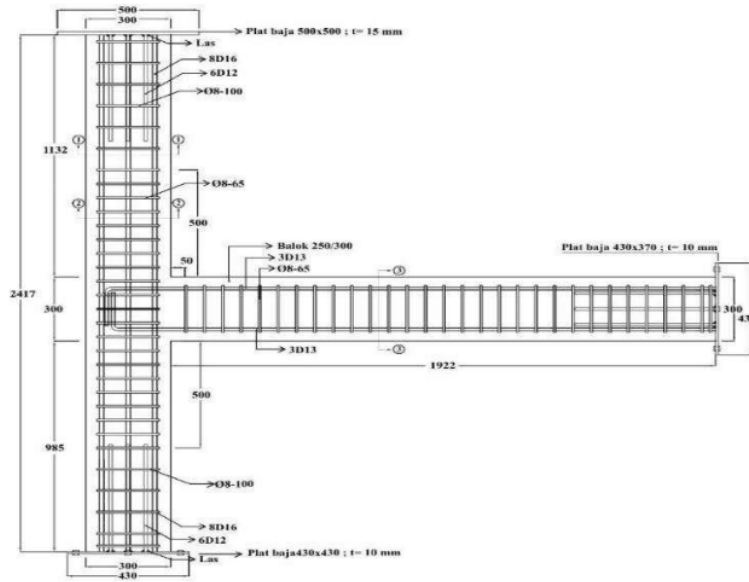


Figure 3. Reinforcement of BK Monolithic

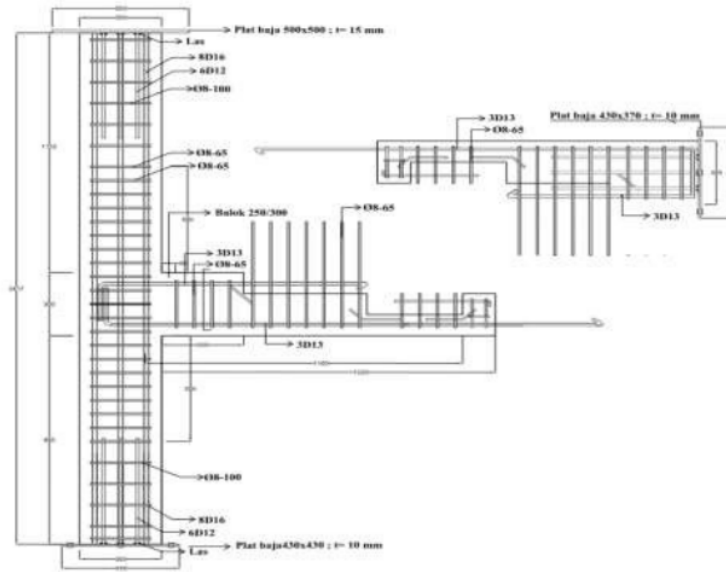


Figure 4. Reinforcement of SBK Type 1

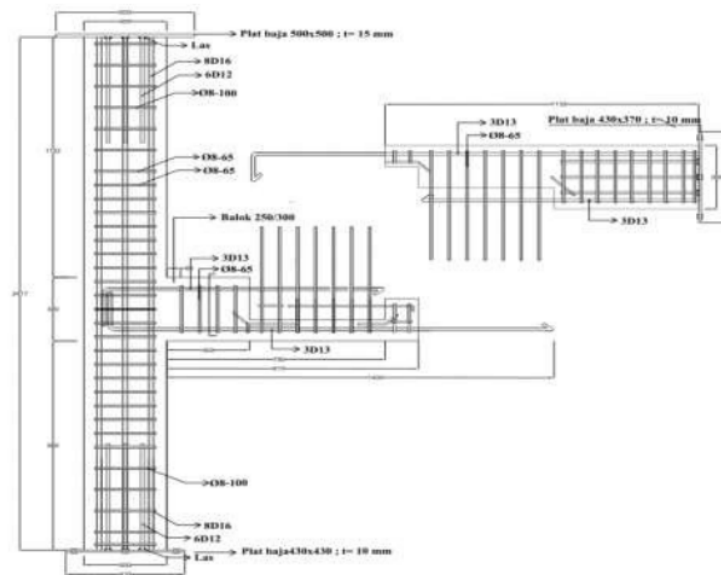


Figure 5. Reinforcement of SBK Type 2

2.3. Research Steps

The research was conducted by experimental methods and quantitative. This study expected to provide a description of precast beam-column joints that use notch joints due to alternating loads in order to determine the behavior, structural stability, and exterior joint behavior models.

2.3.1. Preparation Steps.

This step is a literature review on the basic theory of previous studies related, preparation of tools and materials, and mixed design calculations for planned concrete quality.

2.3.2. Steps of Making Test Materials

Making the test object is divided into 2 parts as follows:

1. The specimens used for testing concrete and reinforcement materials. Test pieces of size 150 mm x 300 mm, 50 mm x 50 mm, specimens beam column 400 mm x 100 mm x 100 mm and Reinforcement tested D16, D13 and $\phi 10$.

2. Column beam joint test specimen

The making of column beam joint test specimens consists of two steps the first casting includes casting parts of precast concrete in the form of column sections and beam sections. The concrete quality of the plan is $f'c$ 25 MPa and the second casting involves connecting the parts of precast concrete use the grouting method and sikagrout 215 (new).

2.3.3. Testing Steps

This test is divided into 5 parts:

1. The testing of reinforcement tensile strength is based on ASTM E8 / E8M-09 (Standard Test Methods for Tension Testing of Metallic Materials).
2. The testing of cylinder concrete compressive strength is based on ASTM C39 / C39M-01 (Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens).
3. The concrete flexural strength test is based on ASTM C78 / 78M-16 (Standard Test Method for Flexural Strength of Concrete, Using Simple Beam with Third Point Loading).
4. Testing of mortar compressive strength grouting is based on ASTM C109 / C109M-07 (Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. Or [50-mm] Cube Specimens)
5. Testing of beam-column joint structure and full-scale monolithic structure referring to SNI 7834: 2012 (Test method and acceptance criteria of a precast reinforced concrete moment frame structure for building).

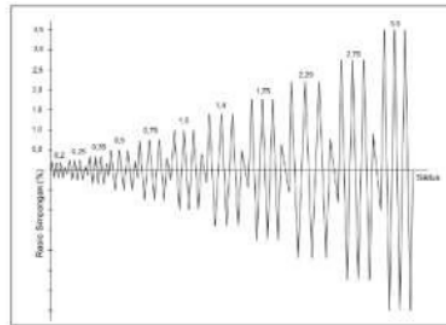


Figure 6. Loading Cycle Program

The test is done by giving a cyclic load at the end of the beam which is simulated by a tool consisting of a hydraulic actuator equipped with a load cell, 4 (four) LVDTs to measure displacement and strain gauge mounted on reinforcing steel and concrete to determine the strain. The loading system is done by the displacement control method with the gradual type of loading starting from the smallest displacement gradually until the largest displacement that can be achieved. The testing model can be seen in figure 6. The testing of beam-column joints is assuming the support of the roller-joint structure. The test object is after 28 days or more. The test object is placed on a steel loading frame with the column in a horizontal position above the placement. While the installation of joint-column after that joint specimens is installed as shown in figure 7.

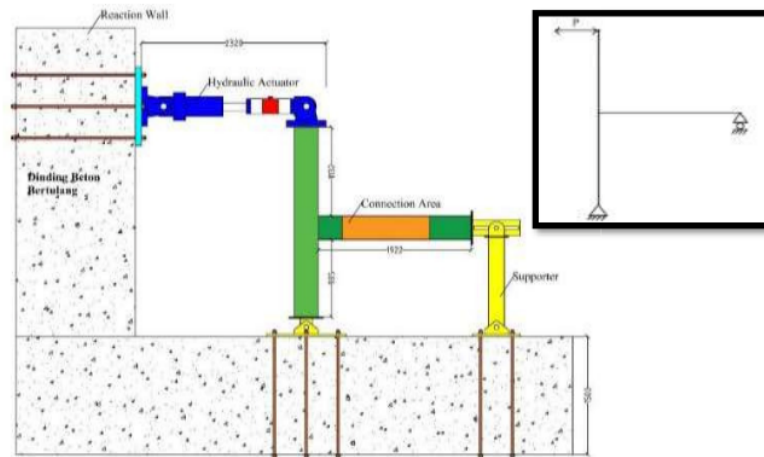


Figure 7. Testing model

3. Analysis

3.1. Material characteristics

3.1.1. *Press Strength Testing.* The test of cylinder concrete compressive strength is shown in Figure 8. (a).

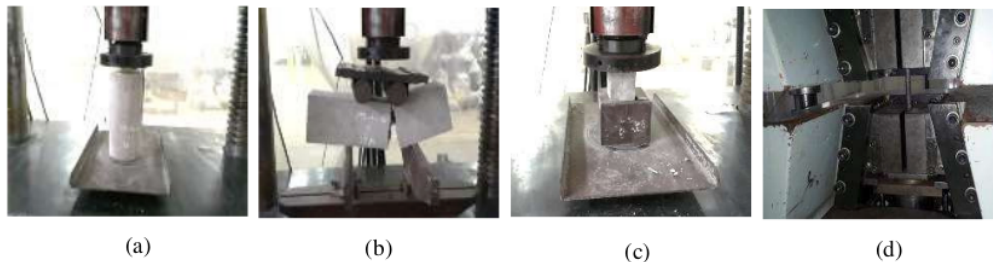


Figure 8. Testing (a) BN Press Strength, (b) BN Flexibility, (c) Mortar Compressive Strength and (d) Reinforcement Pull Strength

Compressive strength testing when 28 days old concrete and from the results of testing the normal concrete compressive strength showed that the overall quality of the concrete was higher than the concrete quality of the plan

3.1.2. *Testing of Bending Strength Concrete.* The samples tested were beam concrete shown in Figure 8. (b). shows that the overall flexural strength of the test is higher than the flexural strength of the plan.

3.1.3. *Mortar Press Strength.* The testing of the mortar compressive strength of the cube is shown in Figure 8. (c). From the results of testing the mortar grouting compressive strength shows the quality of the mortar used for overall grouting has met the planned quality of the mortar 50 MPa.

3.1.4. *Tensile Strength of Reinforced Steel.* There are 3 types of reinforcing steel which was tested for tensile strength in this test Ø8 plain reinforcement steel, D13 and, D16 threaded steel each of 3 pieces. The testing of reinforcement strength can be seen in Figure 8. (d). Reinforcement tensile strength testing before making exterior beam-column joints. From the results of testing the tensile strength of steel, it can be seen that the quality of steel test results is higher than the steel quality plan. The results of testing the tensile strength of steel Ø8, D13 and D16 are used to evaluate the results of testing of beam-column joint test objects.

3.2. *Bending Column Beam Capacity*

Testing the column beam which is laterally loaded aims to determine the ability of the column beam to carry the load. The results of testing the load capacity and deflection of the three test objects can be seen in table 1.

Table 1. Tables of specimens, loads, and Displacement

| Specimen | Press strength (+) | Displacement | Pullstrength(-) | Displacement |
|------------|--------------------|--------------|-----------------|--------------|
| | (kN) | (mm) | (KN) | (mm) |
| BK Monolit | 14.37 | 147.35 | 21.54 | 158.45 |
| SBK Type 1 | 15.71 | 156.85 | 18.3 | 141.05 |
| SBK Type 2 | 15.87 | 162.21 | 19.4 | 156.34 |

Based on the data in table 1, the test results obtained showed that the maximum load obtained for the monolithic sample was 14.37 KN for press and for the attraction of 21.54 KN. The maximum press and pull each at the displacement of 147.35 mm and 158.45mm. While for type 1 column beam connection (SBK Type 1) the maximum press is 15.71 KN and 156.85 mm displacement and for maximum tensile conditions of 18.3 KN and 141.05 displacements. For the maximum press SBK type 2 15.87 KN and the maximum tensile 19.4 KN. The maximum press for SBK type 2 a 162.21 mm displacement and for maximum drag 156.34 mm. From the description above it is known that the maximum compressive load type 2 column beam connection but the differences type 1 and monolith SBK are not too significant. Based on the data the location of the maximum displacement in SBK Type 2 shows a tendency to continue to experience an increase in compressive load that can be borne but due to the limitations of the testing tool, where it is only capable of 162.21 mm deviation, then the load readings for subsequent displacement cannot be obtained. Different results tensile loads where the greatest load can be borne by monolithic BK but the difference is not too significant with SBK Type 1 and SBK type 2.

3.3. Column Beam Bending Behavior

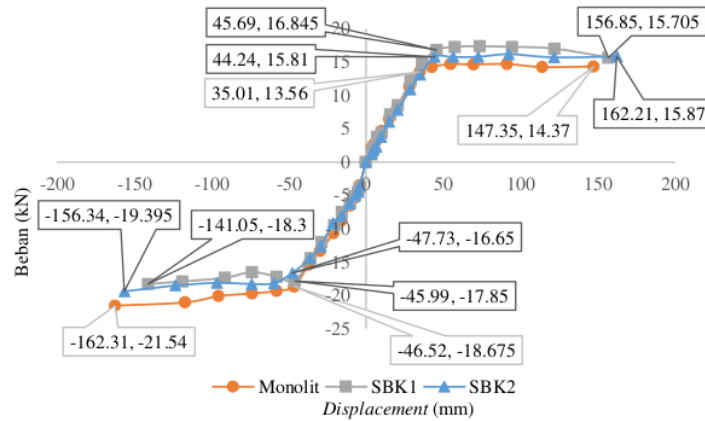


Figure 9. Hysteresis Loop Monolithic Column, SBK Type 1 and SBK Type 2

Figure Hysteresis Loop Monolithic Is a monolithic column beam hysteresis curve (Monolithic BK) when giving thrust and tensile loads. In the melting condition, the force of the thrust direction (Py +) is 13.56 kN and the tensile direction strength (Py-) is 18.675 kN. Displacement of thrust direction is 35.01 mm and the Displacement Pull direction is 46.522 mm. When the specimen is in the ultimate condition the force of the thrust direction is 14.37 kN and the tensile strength is 21.54 kN. Displacement direction displacement is 147.35 mm and Displacement pulls direction is 158.45 mm. Hysteresis Loop SBK Type 1 Hysteresis of Beam Connection Loops The Type 1 column shows that in the melting condition the force of the thrust direction (Py +) is 16.845 kN and the tensile direction strength (Py-) is 17.85 kN. Displacement of the thrust direction of the melting condition is 45.69 mm and the displacement Pull direction is 45.99 mm. When the specimen is in the ultimate condition the force of the thrust direction is 15.71 kN and the tensile direction strength is 18.30 kN. The thrust displacement direction is 156.85 mm and the displacement direction displacement is 141.05 mm. Hysteresis Loop SBK Type 2 Hysteresis of Beam Connection Loops Type 2 column shows that in the melting condition the force of the thrust direction (Py +) is 15.81 kN and displacement is 44.24 mm. while the tensile strength for the melting condition (Py-) is 16.65 mm. for maximum conditions the thrust direction strength is 15.87 kN and the tensile direction is 19.40 kN. Displacement direction of thrust is 162, 21 mm and Displacement of tensile direction is 156.34 mm.

3.4. Ductility

The structural behavior that is important to review is the ductility value of a structure. The ductility is the ability of structures or structural elements to undergo inelastic deformation back and forth repeatedly after experiencing first melting so that even though it has been damaged and is in a state of collapse the structure can still maintain sufficient strength and stiffness to support its load and stand. The equation for calculating the displacement ductility is as follows:

$$\mu_{\Delta} = \frac{\Delta_u}{\Delta_y} \tag{1}$$

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Where (P_{cr}) first crack (kN), (P_y) yield load (kN), (P_u) Ultimate load (kN), (Δ_{cr}) Displacement first crack (mm), (Δ_y) Displacement Yield (mm), (Δ_u) Ultimate Displacement (mm), ($\mu\Delta$) Transfer ductility.

Table 2. Calculation of ductility values

| Type | Load (P) | | | | Displacement (Δ) | | | | Displacement ductility | | (μ) Average | Result |
|---------|------------|------|------------|------|---------------------------|------|-----------------|------|------------------------|------|-----------------|-------------------|
| | P_y (kN) | | P_u (kN) | | Δ_y (mm) | | Δ_u (mm) | | $(\mu\Delta)$ | | | |
| | + | - | + | - | + | - | + | - | + | - | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Monolit | 13.5 | 18.6 | 14.3 | 21.5 | 35.0 | 46.5 | 147. | 158. | 4.21 | 3.41 | 3.81 | Partial ductility |
| SBK | 16.8 | 17.8 | 15.7 | 18.3 | 36.2 | 45.9 | 156. | 141. | 4.32 | 3.07 | 3.70 | Partial ductility |
| Type 1 | 5 | 5 | 1 | 0 | 8 | 9 | 8 | 0 | | | | |
| SBK | 15.8 | 16.6 | 15.8 | 19.4 | 44.2 | 36.2 | 162. | 156. | 3.67 | 4.31 | 3.99 | Partial ductility |
| Type 2 | 1 | 5 | 7 | 0 | 4 | 8 | 2 | 3 | | | | |

Based on the calculation of the result of the ductile value review on the beam it shows that the average ductility value for each specimen is at a partial ductile level according to SNI - 1726 - 2002 with μ values between 1.5 to 5. This indicates that each specimen is in ductile condition. From table 2 it can be seen that the highest ductility value is in type 2 beam joints (SBK Type 2) with an average value of 3.99. SBK type 1 has a ductility value of an average of 3.70 and a monolithic column beam has an average ductility value of 3.81. This shows that SBK type 2 is better than monolithic BK, but SBK type 1 is no better than monolithic connections.

4. Conclusion and recommendation

4.1. Conclusion

The conclusions from the results of the study are as follows:

1. The maximum displacement achieved by SBK type 1 compressive conditions ($\Delta +$) is 156.85 mm and Pull ($\Delta -$) is 141.05 mm while SBK type 2 has the maximum displacement of press conditions ($\Delta +$) of 162.21 mm and in the Pull condition ($\Delta -$) of 156.34 mm. The maximum load for SBK type 1 press conditions (P +) is 15.71 kN and Pull (P-) is 18.30 kN. The maximum load for SBK type 2 press conditions (P +) is 15.87 kN and Pull (P-) is 19.40 kN. For maximum displacement monolith column beam press conditions ($\Delta +$) of 147.35 mm and (P +) of 14.36 kN while Pull conditions 158.45 mm compressive load (P-) of 21.54 kN. The structural performance level for the double straight double beam joint notch connection is at the level of partial ductility with the displacement ductility value for SBK type 1 of ($\mu\Delta$) 3.70 while SBK type 2 is ($\mu\Delta$) 3.99. Monolithic column beams are also at a level of partial ductility with a mean displacement ductility ($\mu\Delta$) 3.81.

2. The stability of the test material in terms of the characteristics of loop hysteresis on precast BK joint due to cyclic load shows a curve similar to that of BK monolith joint. The curve increases with increasing load. Comparison of the results of research between BK monolith SBK type 1 and SBK type 2 the greatest

displacement in press conditions occurs in SBK type 2 while the greatest displacement for Pull conditions occurs on monolithic BK. From the description of the data in point 1, it can be seen that the lateral load is directly proportional to the displacement, where the higher the lateral load is borne the greater the displacement experienced and vice versa. The displacement ductility that occurred in SBK type 1 = 0.971 monolithic BK while SBK type 2 = 1.047 monolithic BK. Based on the results of studies of some of these behaviors type 2 SBK has more advantages than type 1 SBK so that the results of SBK type 2 analysis can then be used as validation of monolithic BK.

4.2. Recommendation

Based on the results of the research for consideration, some suggestions are proposed as follows:

1. Need more in depth research by using more variations of notch modeling so that can add and continue to develop references related to connection modeling.
2. Further research needs to be done in double straight notch modeling so that innovation and research can be obtained about the model.
3. Need further research on double straight notch modeling to obtain innovation and research on the model.
4. It is necessary to continually improve innovation regarding the connection to column beams to find the most ideal connection model.

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