

## EXPERIMENTAL STUDY OF SHEAR BEHAVIOR OF REINFORCED CONCRETE BEAM-COLUMN JOINTS

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### Abstract

Beam-column joints must be designed to be sufficiently strong and capable of withstanding shear forces (horizontal) and factored vertical forces resulting from the formation of plastic hinges at the beam ends when seismic forces act. The use of stirrups as reinforcement between columns and beams aims to ensure effective force transfer and prevent cracking or structural damage. However, in practice, several challenges are often encountered that may hinder the implementation process. This study employs an experimental method, where direct testing of specimens is conducted to analyze their behavior. The experimental results, including cracking, load, and Deformation, are analyzed to obtain values for strength, ductility, energy dissipation, and joint capacity. Based on the test results, specimen BJ-2 demonstrated a 51.30% increase in capacity compared to specimen BJ-1. However, in terms of ductility, BJ-1 had a higher average value of 3.59, while BJ-2 had a value of 2.8. Regarding energy dissipation, BJ-1 had a lower value of 0.12831 compared to BJ-2, which reached 0.15069. Both specimens experienced initial cracking, first yielding, and ultimate conditions. Additionally, the joint capacity of specimen BJ-2 was 1.7 times greater than that of specimen BJ-1.

**Keywords:** *Beam-Column Joint Without Stirrups; Deformation; First Crack; Ultimate; Dissipation Energy; Joint Shear Capacity.*

## 1. INTRODUCTION

Designing earthquake-resistant reinforced concrete building structures involves critical beam-column connection areas, requiring precise design and the ability to effectively dissipate energy during an earthquake. This is because numerous forces and moments from beam and column elements interact with their respective capacities during an earthquake. Beams are structural components that transmit moments to the columns. Beams are also known as flexible structural elements, capable of supporting dominant internal forces in the form of bending moments and shear forces. Columns, on the other hand, are vertical structural components that support axial loads from gravity, and their height should not exceed three times the smallest lateral dimension.

## 2. LITERATURE REVIEW

### 2.1 Beam Column-Joint

Joints between beams and columns must be carefully planned, taking into account potential forces such as axial forces, bending moments, torsion, shear, and the effects of the frame, temperature losses, or support settlement. The ability of the beam-column connection to deform in the inelastic region provides the structure with good ductility, thus minimizing damage caused by earthquake shaking and preventing sudden (brittle) collapse. Instead, the structure will experience several phases gradually until it collapses [1]. In the analysis carried out, the shear force at the beam-column connection joint is greater than the shear force at the beam and column. Therefore, shear reinforcement is required between these joints. From the existing review, the size of the column and beam is sufficient to carry the shear force that occurs [2].

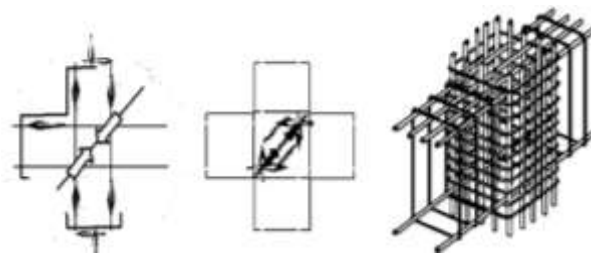


Figure 1. Illustration of cracks in beam-column joints

Based on Figure 1, it is explained that the cracking pattern in the specimen begins with fine cracks in the concrete, then shear cracks begin to work on the connection so that shear failure occurs at the connection [3]. Therefore, it is necessary to design shear or restraining reinforcement in the joint area with calculations based on SNI 2847-2019. Joints in beams and columns must be planned carefully by paying attention to possible forces such as axial forces, bending moments, torque, shear and also the influence of the frame, temperature shrinkage or support reduction.

### 2.2 Crack Pattern Yielding Point Value and Ultimate Value

The ultimate load  $P_u$  is chosen as the maximum load, and the failure Deformation  $\Delta_f$  is defined as the maximum Deformation corresponding to a load not less than  $0.85P_u$  according to the characteristic load and Deformation derived from the skeleton curve as shown in Figure 2.

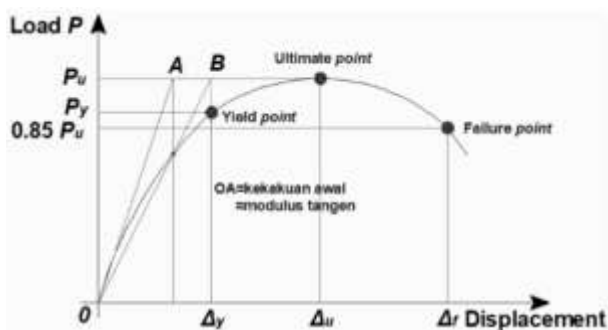


Figure 2. Load-Deformation curve yielding

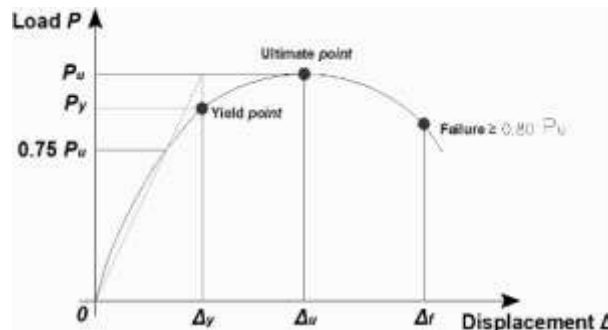


Figure 3. Load-Deformation curve yielding

Then the yield point is based on the reduction of the elastoplastic yield equivalent stiffness, as shown in Figure 3. The yield Deformation is defined using the stiffness of the secant connecting the source and 75% of the ultimate load. The maximum Deformation  $\Delta_f$  is defined as the Deformation corresponding to 80% of the ultimate load.

### 2.3 Energy Dissipation

One form of energy an object can possess is energy associated with motion. Energy can be defined as the work done by a force to move an object a certain distance. Energy dissipation can be seen by comparing the area of the hysteresis loop for the cycle to the area of the circumscribing parallelogram, defined by the initial stiffness during the first cycle and the peak resistance during the cycle. The energy dissipation calculation in this study, using ACI 374.1-05, provides a concept for energy dissipation, as shown in Figure 4. In the cycle under consideration, the relative energy dissipation ratio ( $\beta$ ) is expressed in the following equation:

$$\beta = \frac{Ah}{(E_1 + E_2)(\theta_1' + \theta_2')} \quad (1)$$

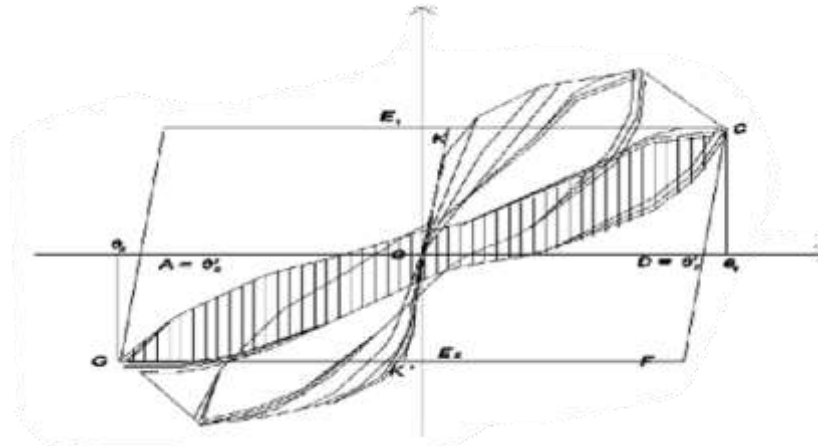


Figure 4. Definition of Relative Energy Dissipation Ratio [ACI 374.1,2019]

### 3. EXPERIMENTAL PROGRAM

#### 3.1 Research Analysis Stages

The structure analyzed was a reinforced concrete beam-column connection without stirrups at the joint area. Based on the results of the numerical analysis stage, validation was conducted using experimental methods. Testing was conducted using reinforced concrete beam-column connections without stirrups at the joint area, and reinforced concrete beam-column connections in accordance with SNI 2847-2019 and SNI 1726-2019 standards, as well as reinforced concrete beam-column connections.

#### 3.1 Test Specimen Method

The interior reinforced concrete beam-column connection test specimen modeling used a beam model with dimensions of 150 mm x 300 mm with a length of 3100 mm and a column with dimensions of 250 mm x 300 mm with a height of 2100 mm.

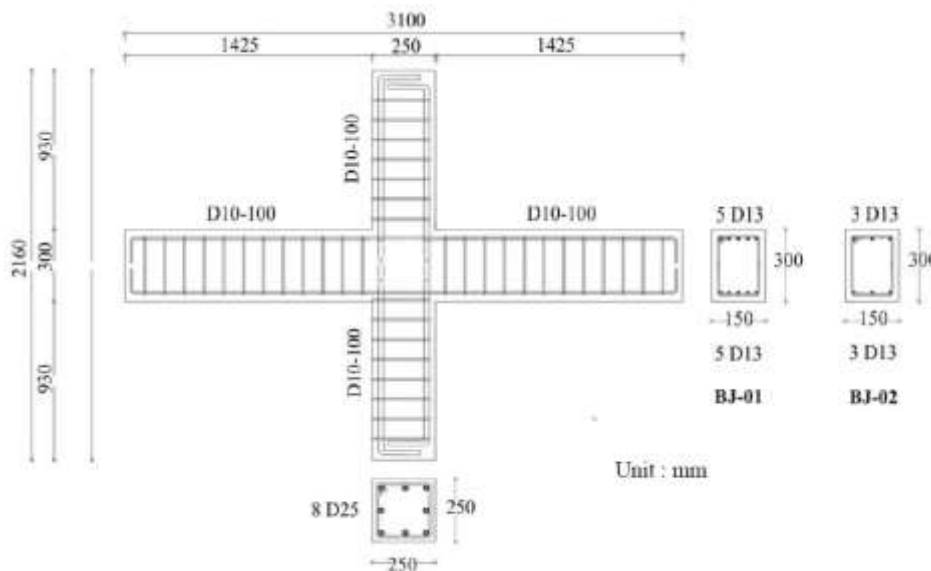


Figure 5. Test Specimen Model Without Stirrups

The test specimens used in this experimental test were differentiated using variables such as the number of longitudinal reinforcements in the beam, stirrup reinforcements in the joint area, and without reinforcement. The test specimens made in Phase I of this research were 2 test specimens first as control specimens without stirrup reinforcements in the joint area according to SNI.

#### 4. RESULTS AND DISCUSSION

##### 4.1 Load-Deformation Relationship

Test Specimen with Longitudinal Reinforcement: 3D13 Beam (BJ-1) with a flexural reinforcement-to-beam ratio of 0.98%. The loads and Deformations obtained from the BJ-1 test specimen were used to construct a hysteresis curve. This hysteresis curve represents the structural response of the test specimen to alternating loading cycles, reflecting the characteristics of the test specimen material due to the loading cycles.

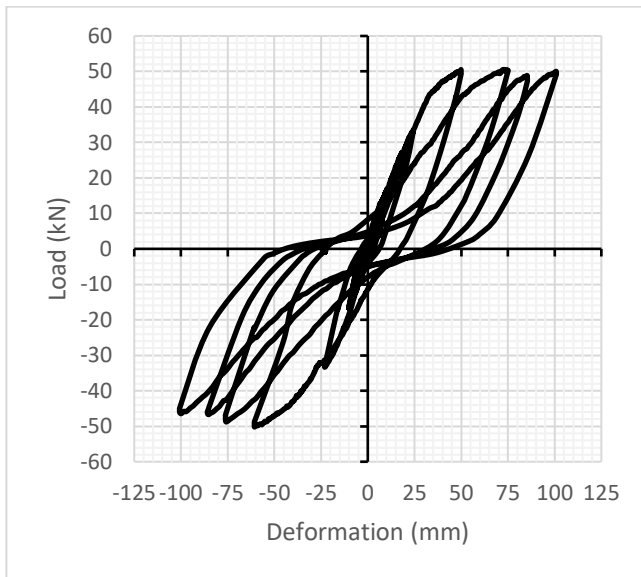


Figure 6. Hysteresis Curve of Load vs. Deformation of Test Specimen BJ-1

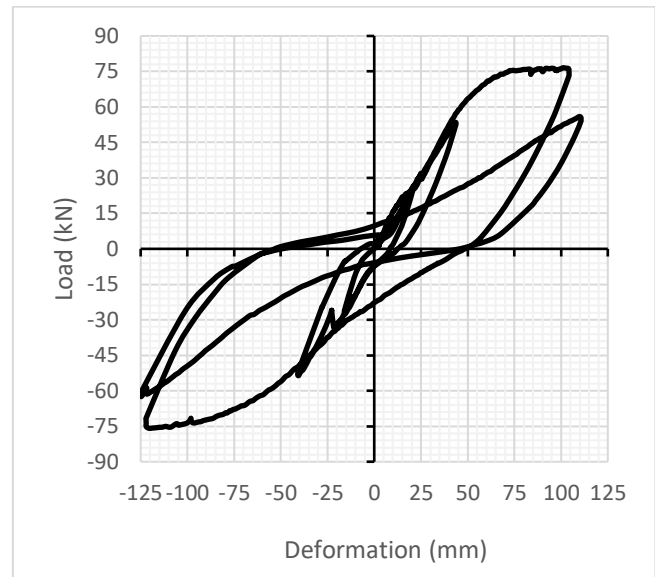


Figure 7. Hysteresis Curve of Load vs. Deformation of Test Specimen BJ-1

##### 4.2 Test Specimen Crack Analysis

During testing, the test specimen will experience damage and even collapse, indicated by cracks. This can be analyzed visually. For test specimens without stirrups at the joint area, the beam is the first part of the test specimen to experience cracks. This can be seen in Figure 6 and Table 1:

Table 1. First Crack of Test Specimen Without Stirrups in the Joint Area BJ-1

Load (kN)	Drift Ratio	Deformation (mm)	Loc.
13,20	0,30	5,13	Beam

Table 2. Yielding and Ultimate Conditions of BJ-1

	Load(kN)	Drift Ratio	Deformation (mm)
First Crack	33,33	1,43	24,33
Ultimate	48,66	5,00	85,00

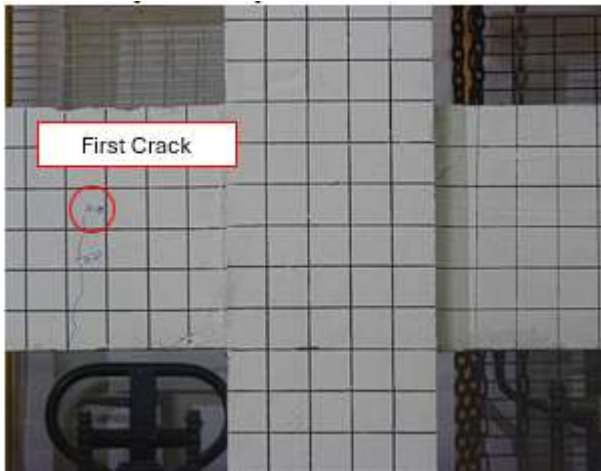


Figure 6. Test Specimen Model without Stirrups BJ-1

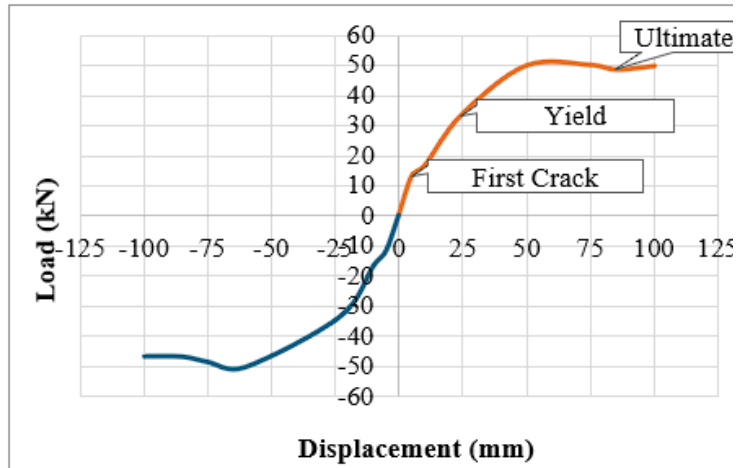


Figure 7. Yielding Point and Ultimate BJ-1

From Table 2, it can be seen that the BJ-1 specimen experienced its first yield when given a load of 33.33kN with a drift ratio of 1.43% and a Deformation of 24.33mm. Then, BJ-1 experienced its ultimate yield when given a load of 48.66kN with a drift ratio of 5.00% and experienced a Deformation of 85mm.

In the test specimen (BJ-2) without stirrups in the joint area, the first part of the test specimen to experience cracking was the beam. This can be seen in Figure 8 and Table 3:

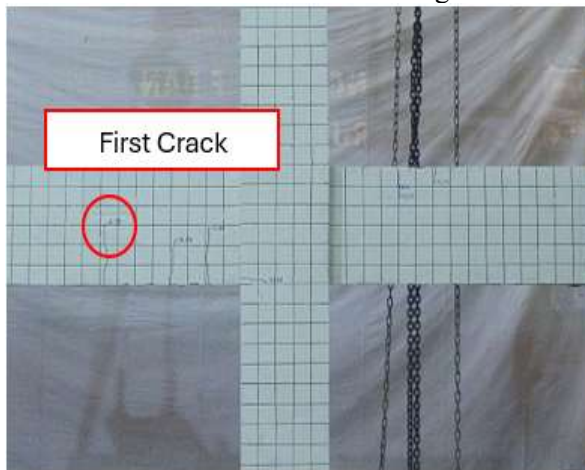


Figure 8. Test Specimen Model without Stirrups BJ-2

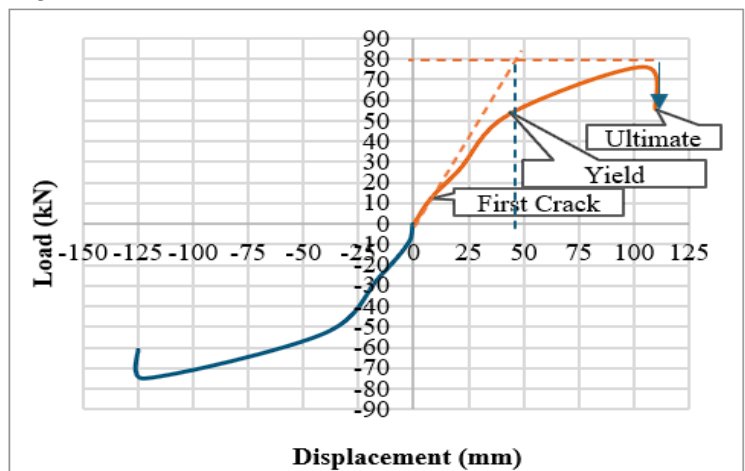


Figure 9. Yielding Point and Ultimate BJ-2

Table 3. First Crack of Test Specimen Without Stirrups in the Joint Area BJ-2

Load (kN)	Drift Ratio	Deformation (mm)	Loc.
26,67	1,24	21,00	Beam

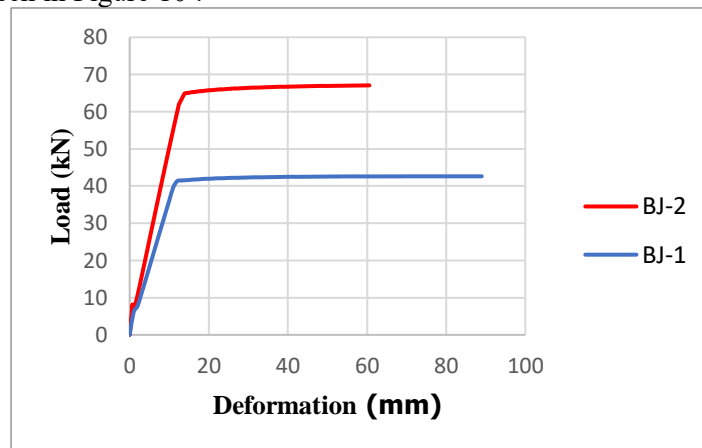
Table 4. Yielding and Ultimate Conditions of BJ-2

	Beban (kN)	Drift Ratio	Perpindahan (mm)
First Crack	53,33	2,57	43,68
Ultimate	55,60	4,50	110,00

From Table 4, it can be seen that the BJ-2 specimen experienced its first yield when given a load of 53.33kN with a drift ratio of 2.57% and a Deformation of 43.68mm. Furthermore, BJ-2 experienced ultimate yield when given a load of 55.60kN with a drift ratio of 4.50% and experienced a Deformation of 110mm.

#### 4.3. Capacity

The strength of a test specimen is the maximum ultimate shear value that can be sustained during loading, obtained from the maximum value of each loading cycle. For a clearer analysis, this comparison is presented in a graph, making it easier to visualize the increase in ultimate shear value and the comparison of strength between test specimens, which can be seen in Figure 10 :



**Figure 10.** Increase in the ultimate shear value of the test specimen

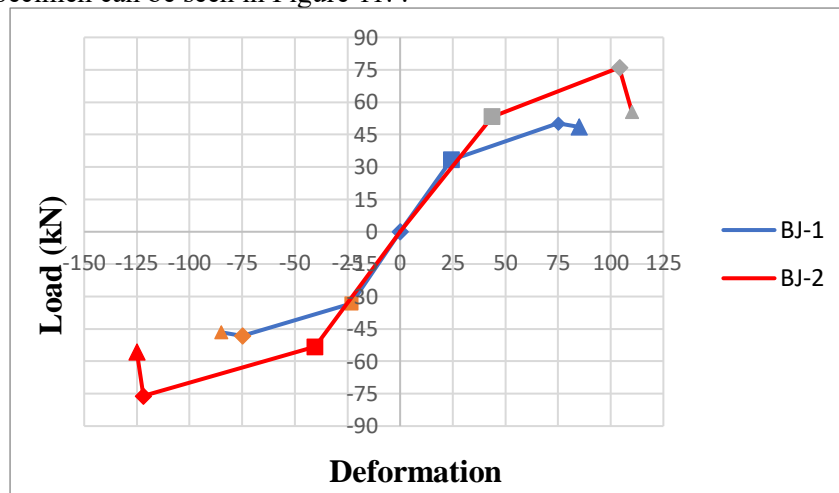
**Table 5.** Increase in the ultimate shear value of the test specimen

Specimen	Load (kN)	Specimen	Load (kN)	Increase
BJ-1	50.23	BCJ-2	76.00	51.30%

Based on Figure 10 and Table 5, a comparison was obtained which showed that the BJ-2 specimen had a greater ultimate shear value than BJ-1. This was caused by the difference in the ratio of flexural reinforcement to the beam.

#### 4.4 Ductility

The ductility of the test specimen is evaluated based on the structure's ability to undergo plastic deformation before reaching failure. This is analyzed by comparing the displacement at yielding and ultimate conditions, which reflects the structure's ultimate shear value in absorbing energy without experiencing a significant decrease in strength. The ductility of the test specimen can be seen in Figure 11. :



**Figure 11.** Comparison of Ductility of Test Specimens

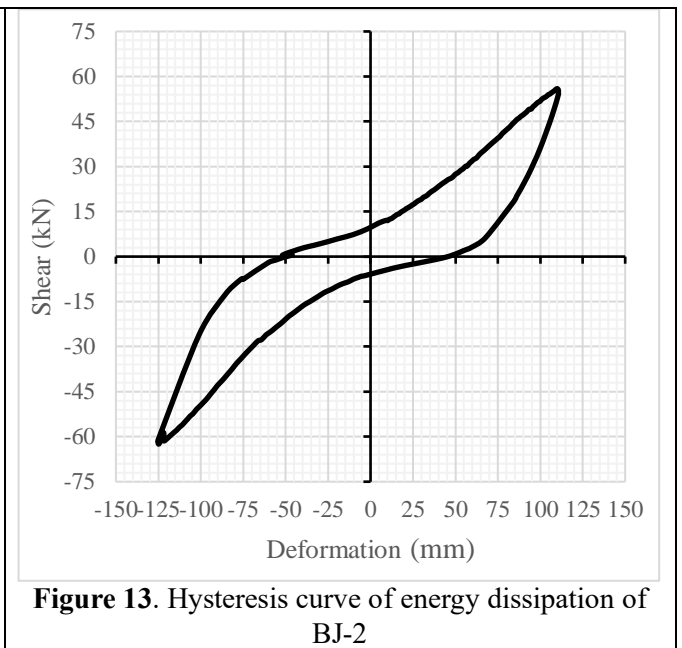
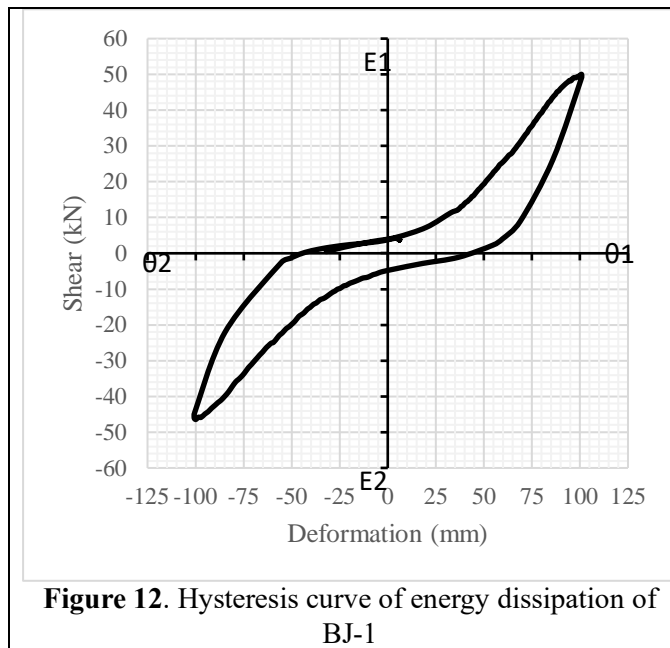
**Table 6.** Comparison of Ductility Values of Test Specimens

Benda Uji	Daktilitas (+)	Daktilitas(-)	rata-rata
BJ-1	3.49	3.68	3.59
BJ-2	2.52	3.09	2.80

Based on Figure 11 and Table 6, it can be seen that specimen BJ-1 has a higher ductility value compared to BJ-2.

#### 4.5 Energy Dissipation

The dissipated energy produced by the specimen is obtained by calculating the area of the hysteresis curve resulting from cyclic loading. The following is the amount of dissipated energy in Figure 12 and 13.



**Tabel 7.** Relative dissipation energy ratio

Specimen	Curve Area kN-mm	Area Bounded by $E_1E_2\theta_1\theta_2$ kN-mm	Relative Energy Dissipation Ratio $\beta$
BJ-1	2430,4986	18942,725	0,128307761
BJ-2	4112,9616	27294,696	0,15068721

From Table 7. it can be concluded that the BJ-1 specimen at the joint experienced a dissipation energy of 0.12831 and the BJ-2 specimen at the joint experienced a dissipation energy of 0.15069. Based on ACI 374.1 regulation article 9.1.3, the relative dissipation energy ratio when the load reaches a drift of 3.5% must not be less than 0.125.

#### 4.6 Ultimate Shear and Ultimate Shear Value of Joint

The ultimate shear force of the joint was calculated by adjusting the force equilibrium at the joint, resulting in the ultimate shear value of the joint without stirrups as shown in Table 8. The joint shear capacity can be calculated by multiplying the joint area by  $1.7\sqrt{f'c}$ .

**Table 8.** Ultimate shear value of test joining with test specimen BJ-1

Specimen		Ultimate Shear Force of Join (kN)		Ultimate shear value	Joint (kN)
		Experimental	Theoretical	Shear	Shear All.
BJ-1	3D13	332,91	338,82	578.06	462.45

**Table 9.** Ultimate shear value of test joining with test specimen BJ-2

Specimen		Ultimate Shear Force of Join (kN)		Ultimate shear value	Joint (kN)
		Experimental	Theoretical	Shear	Shear All.
BJ-2	5D13	567.38	573.12	578.06	462.45

The test results show that the experimental ultimate shear value of the joint is close to the theoretical ultimate shear value, indicating that the test specimen reaches the ultimate shear value in the joint area.

In this condition, the concrete in the joint area works optimally until it reaches failure. The failure of the test specimen joint can be seen in Figure 14 and 15:



Figure 14. Collapse of Joint BJ-1



Figure 15. Collapse of Joint BJ-2

## CONCLUSION

- (a) BJ-2 has a higher ultimate shear value than the BJ-1 specimen.  
(b) In terms of ductility, the BJ-1 specimen has a higher ductility value than the BJ-2 specimen.  
(c) The BJ-1 specimen experiences a dissipation energy of 0.12831, while the BJ-2 specimen experiences a dissipation energy of 0.15069.
- The first crack in test specimen BJ-1 occurred in the beam when a load of 13.20 kN was applied, with a drift ratio of 0.30% and a displacement of 5.13 mm. First yielding occurred when a load of 33.33 kN was applied, with a drift ratio of 1.43%, and a displacement of 24.33 mm. BJ-1 then experienced ultimate yielding when a load of 48.66 kN was applied, with a drift ratio of 5.00%, and a displacement of 85 mm.
- The first crack in test specimen BJ-2 occurred in the beam when a load of 26.67 kN was applied, with a drift ratio of 1.24%, and a displacement of 21 mm. First yielding occurred when a load of 53.33 kN was applied, with a drift ratio of 2.57%, and a displacement of 43.68 mm. BJ-2 then experienced ultimate shear when given a load of 55.60 kN with a drift ratio of 4.50% and experienced a displacement of 110 mm.
- The BJ-1 test specimen's ultimate shear value at the joint area was 332.91 kN, while the BJ-2 test specimen achieved an ultimate shear value of 567.38 kN. The increase in the ultimate shear value in the BJ-2 test specimen was recorded as 1.7 times greater than that of BJ-1, indicating that the increase in the ratio of flexural reinforcement to longitudinal beams contributed to the increase in the ultimate shear value at the joint area.

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