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The Analysis of Beam-Column Joint Reinforced with Cross Bars according to SK SNI T-15-1991-03 on Cyclic Loads

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ABSTRACT The primary structural component supporting the other structural loads in a building is the beam-column joint. It is considered a critical area of a building which needs to be accurately designed to ensure energy is dissipated properly during the occurrence of an earthquake. Beam-column joint has the ability to offer a proper structure required to transform cyclic loads in the inelastic region but also has a direct impact on the components connected to it during the occurrence of any failure. This is one of the reasons the beam-column connection needs to be designed carefully. Therefore, this study focused on designing a beam-column joint with reinforcement according to SK SNI T-15-1991 in order to withstand cyclic loads. The test specimen used was observed to have a concrete compressive strength of 19.17 MPa while the dimension of the beam was 120 x 30 x 40 cm and the column was 30 x 30 x 200 cm, having 8Ø13.4 mm bars with 310.03 MPa yield strength (fy) as well as Ø9.8-100 mm stirrup reinforcement with (fy) 374.59 MPa. The test was initiated through the provision of 0.75 mm, 1.5 mm, 3 mm, 6 mm, 12 mm, 24 mm monotonic cyclic loads at the end of the beam up to the moment the specimen cracked. A maximum load of 68.35 kN for the compression and 49.92 kN for the tension was required to attain the cyclic load capacity. The maximum load was attained at 50.98 mm displacement. Furthermore, beam-column with 23.93 mm displacement caused a reduction in capacity. Meanwhile, the load at 24 mm produced the cycle's highest dissipation energy of 13.25 but this can be increased through the addition of stirrups to provide stiffness in the joint. The stiffness value was also observed to have increased after the structural repairs.

KEYWORDS Beam-Column Joint; Cyclic Load; Ductility; Monotonic Loading; Building Structure.

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1 INTRODUCTION

Indonesia is a country located between three tectonic plates and this increases its vulnerability to natural disasters, specifically earthquakes. Therefore, the buildings in the country require to be earthquake-resistant to prevent any damage during these disasters. This means the beam-column joint also needs to be designed to sustain the building and provide higher strength capability for the other structural components during earthquake occurrence to avoid damages. Therefore, the purpose of this study was to determine the ability of building structures constructed using reinforced beam-column joint according to SK SNI T-15-1991 to withstand cyclic loads.

Previous studies only analyzed the behavior of columns and beams subjected to cyclic loading under ductile conditions and discovered that there are no repairs which conducted on these elements without destroying their structure. Moreover, Abdullah & Takiguchi (2003) examined the behavior and strength of concrete columns reinforced with ferrocement using 6 columns covered with square ferrocement as the test specimen. The result showed that the use of ferrocement along the column was able to increase ductility significantly. Soebandono *et al.*

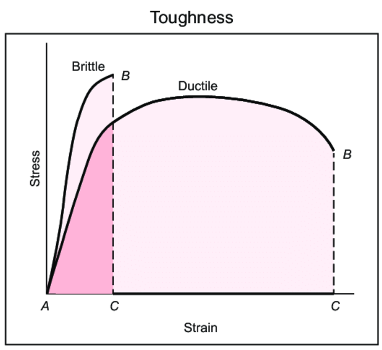
(2011) also showed the improvement made by the ferrocement jacketing method using exterior beams with cyclic loads up to the level of damage caused to the ultimate load. Furthermore, Venkatesan & Ilangovan (2016) also evaluated the ability of retrofitting techniques to strengthen beam-column joints.

Literature studies involve reviewing several books, standardization documents such as SK SNI T-15-1991, and the findings of previous study in order to obtain information required to complete a particular study. This method was applied in this study while data were also collected from the laboratory tests conducted in the Construction and Building Materials Laboratory in Syiah Kuala University. The findings are expected to be applied to old buildings constructed using the SK SNI T-15-1991 standard and which are experiencing damages in their joints to provide the best method to repair these buildings without destroying them.

1.1 Ductility

Rodrigues *et al*. (2010) showed that ductility detailing is very important during the design process of new and existing buildings. Meanwhile, one important topic which was not referenced in the current situation is the impact of the masonry infill panels on the structural response and this has the ability to cause a brittle failure, even in structural design with a higher ductility degree.

According to Elghazouli (2017), ductility is the capability to resist large deformations of a structure beyond its yield point without causing any lead on the fracture. In earthquake engineering, the term is normally used to define a building's capability to endure large lateral displacements imposed by ground shaking. Some of the advantages of a ductile-reinforced concrete structure include: (1) the ability to resist overloads, reversals of the load, and the differential foundations settlement caused by the impact and secondary stresses in the ground, (2) provision of enough time for the occupants to vacate the structure by indicating large deformations before the final collapse, and (3) the ductility property of the material allows the absorption of dynamic loads, thereby reducing the failure risk during an earthquake (Raghucharan & Prasad, 2015). Ductility has also been defined as the ability of a structure or sub-structure to hold the response provided by a dominant inelastic structure in carrying a load to prevent it from collapsing.



Toughness = the ability to absorb energy up to fracture
= the total area under the strain-stress curve up to fracture

Figure 1. Typical stress versus strain curves for brittle and ductile materials
Source: (Sudha *et al.*, 2015)

Mathematically, the ductility value (μ) of a structure is defined as the ratio between the structure deformation parameter (δ_u) and the deformation at the time of the first meeting in the structure under review (δ_y). Figure 1 shows the common deformation parameters include curvature, rotational angle, strain, and displacement. Moreover, the amount of ductility is usually represented as a displacement ductility factor μ which was calculated using the Equation (1).

$$\mu = \frac{\delta_u}{\delta_y} \tag{1}$$

1.2 Design Planning for Beams-Column Shear Reinforcement According to SK-SNI-T15-1991

Design planning, according to Schodek (1998), uses the ultimate strength design method and this involves planning the cross-section of the structure by considering the condition of the inelastic strain when it reaches its boundary conditions (the condition of the stable structure before collapse). In this plan, the workload was multiplied by a load factor called the factor load and this was further used to plan the structural dimensions to ensure a smaller size of collapsed cross-section compared to the actual collapse strength. It is also important to note that the strength at the time of collapse is normally called a strong ultimate limit while the load that is occurring, is known as an ultimate load. Moreover, the strength of the cross-sectional plane is usually calculated by multiplying the nominal/theoretical strength with a capacity factor.

1.2.1 Beam Shear Reinforcement Design

According to SK-SNI-T15-1991-03 (1991), shear reinforcement is designed to prevent failure in shear, increase beam ductility, and subsequently reduce the likelihood of sudden failure. The ability of the concrete produced with shear-resisting structural components to withstand shear forces can be calculated using the Equation (2).

$$V_c = \left(\frac{1}{6}\sqrt{f_c{}'}\right).\ b_w\ .\ d \quad (2)$$

The multiplier limit and V_c can be calculated as describe in Equation (3).

$$V_c \leq \left(0.30\sqrt{f_c{}'}\right).\ b_w\ .\ d \quad (3)$$

The shear strength provided by the shear stress can be using the Equation (4) and (5).

$$V_s \leq \frac{A_v.\ f_y.\ d}{s} \quad (4)$$

$$V_s \leq\ 0.66\sqrt{f_c{}'}.b_w\ .\ d \quad (5)$$

The basics of shear reinforcement planning are as described in Equation (6), (7), and (8).

$$V_u \leq\ \phi\, V_n \quad (6)$$

$$V_n =\ V_c +\ V_s \quad (7)$$

$$V_u \leq\ \phi\,(V_c +\ V_s) \quad (8)$$

The distance of the shear reinforcement can be calculated as describes in Equation (9) and (10).

For vertical cross bar

$$S_{req} = \frac{A_v.f_y.d}{V_s} \quad (9)$$

For horizontal cross bar

$$S_{req} = (1.414)\ \frac{A_v.f_y.d}{V_s} \quad (10)$$

Where V_c is the nominal shear strength, $f_c{}'$ is the compressive strength of concrete (MPa), b_w is the beam width (mm), d is the distance from the outer compression part to the center of gravity of the longitudinal tension reinforcement and it is expected not to be less than 0.80h for practical elements (mm), A_v is the area of shear reinforcement in the range s or area of vertical shear reinforcement perpendicular to the tensile flexural reinforcement in a region with a distance s in the component for the high bending structure (mm^2), V_u is the shear force with a factor on the cross-section, V_n is nominal shear strength, V_s is nominal shear strength provided by shear reinforcement, f_y is yield point (MPa), and s is transversal reinforcement spacing measured along the longitudinal axis of the structural member (mm).

1.2.2 Column Shear Reinforcement Plan

Schodek (1998) showed that the spacing of the stirrup reinforcement is not more than 16 times the length of the reinforcement base lengthwise, 48 times the diameter of the stirrup reinforcement, and the smallest dimension of the column. Moreover, the stirrup bar is required to be installed and arranged to ensure the angles do not bend at a value greater than 135° while the minimum shear reinforcement diameter is usually 10 mm.

1.2.3 Bond Requirement

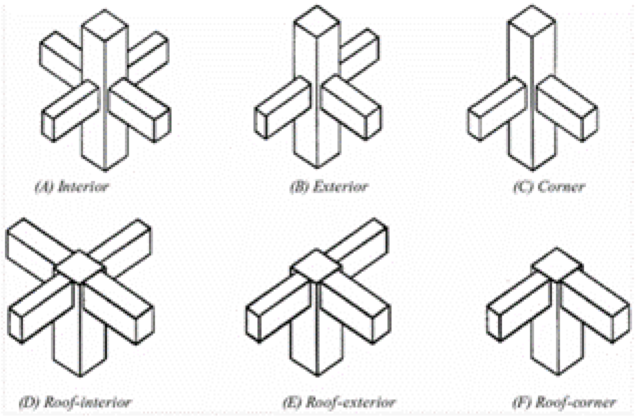
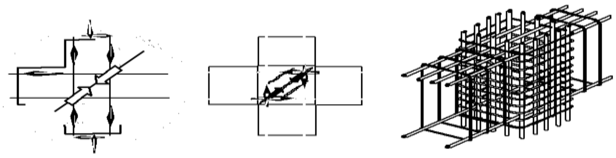


Figure 2. Beam-Column Joint Connection Types
Source: (Elmasry *et al.*, 2017)

Flexural forces in beams and columns cause tension or compressive forces on the longitudinal reinforcement through the joint. Moreover, the magnitude of the tensile force at the plastic joint is transmitted through bonds. It is important to note that the types of connection or bond between columns and beams can be described as indicated in Figure 2.

1.2.4 Beam-Column Joint Failure

The first crack of the beam-column joint usually occurs when the concrete has exceeded its maximum tensile strain due to loading and this usually reduces the concrete tensile and shear strength to zero, thereby allowing the longitudinal and stirrup reinforcement to take over the concrete's ability to withstand tensile and shear forces. Therefore, the failure pattern of the beam-column connection is presented in the Figure 3.



a) b) c)

Figure 3. Beam-Column Connections Pattern: a). Forces to Joint, b). Crack on Joint , c). Shear Reinforcement Joint
Source: (Wang and Salmon, 1991)

Figure 3 shows that the initial crack pattern in the concrete beam-column joint specimen starts with hair fracture in the joint followed by the shear crack attacking the joint. This has the tendency of causing damage in the joint, thereby leading to its structural failure. Therefore, it is necessary to have appropriate restraints in the joint area of the connection.

2 STUDY METHOD

2.2 Details of Beam-Column Joint Specimen

The specimens tested were reinforced concrete beams and columns designed based on SK SNI T-15-1991 with the dimension of the column designed to be 300 x 300 x 2000 mm while the beam was 300 x 400 x 1200 mm. Moreover, the cyclic load capacity testing required reinforced concrete column joints and this led to the use of 8Ø14 mm primary reinforcement and Ø10-100 mm stirrup as indicated in the detailed beam-column joint shape presented in Figure 4.

2.3 The Process of Making and Maintaining Specimens

The maximum aggregate used was 19.1 mm in diameter as indicated by the physical property tests conducted on filter analysis, specific gravity, volume weight, and water absorption. The process involved connecting the test object to an iron plate measuring 300 x 300 x 15 mm which was fastened to the frame beam and other supporting loads with bolts. The assembled specimens were placed on the three cylindrical formworks prepared for casting to ensure quality. Moreover, during the process of casting, fresh concrete was poured into the formwork and vibrated to ensure it is evenly distributed and solid. After 24 hours of casting, the formwork was opened and treated with wet burlap up to the moment the concrete was 28 days old.

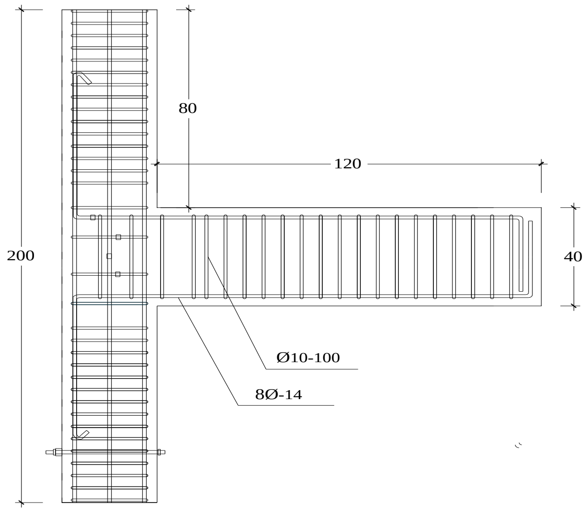


Figure 4. Specimen Shape

2.4 Procedure of Beam-Column Joint Test Objects

The test was conducted on the 28 days old test specimens using both the beam-column and cylindrical specimens with the focus on the compressive strength of the load which is part of the cyclic load capacity. Moreover, the surface of the cylindrical specimen was painted white before the test and placed on the grid to ensure a clearer crack pattern after which it was firmly installed on the frame beam. A two-way steel plate was attached to the surface of the beam connected to a bolt while the plate to the load cell was fastened as the desired cyclic load was provided. It is also important to note that the load was applied horizontally on the end of the beam through the hydraulic jack connected to the load cell and transferred to the beam-column specimen. Furthermore, the load provided was controlled by reading the dial in the data logger to determine the cycle and associated crack patterns. The load was provided continuously up to the moment the specimen was destroyed. A transducer was also installed to measure the deflection in the lateral direction on the side of the beam. These configurations and procedures are presented in the test kits series and specimen installation on steel frames presented in the Figure 5.

A Portable Data Logger was used to measure the strain in the beam-column joint connected to the strain gauge. It was discovered that the loading value also stopped when the load stopped increasing and this is associated with the inability of the specimens to receive more loads, thereby leading to cracking and failure. The crack development pattern observed on the image of the column is related to the load provided over time as indicated in the Figure 6.

2.5 Data Processing

The data obtained from the cyclic load test of reinforced beam-column joints include the beam-column joint crack pattern, beam-column joint cyclic load capacity, concrete strain and displacement, primary reinforcement strain in the stirrups, and the beam-column joint area were processed. The results presented in the form of tables and graphs showed the capacity of the beam-column joint under cyclic load and it was discovered that the repair efforts can be planned for the joint without having to knock down the building in case of insufficient capacity or occurrence of any damage.

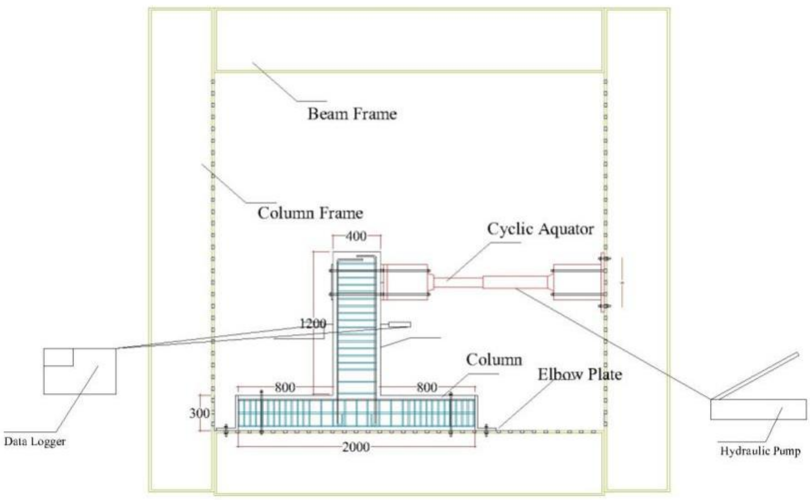


Figure 5. Set-Up for the Beam-Column Joint Test

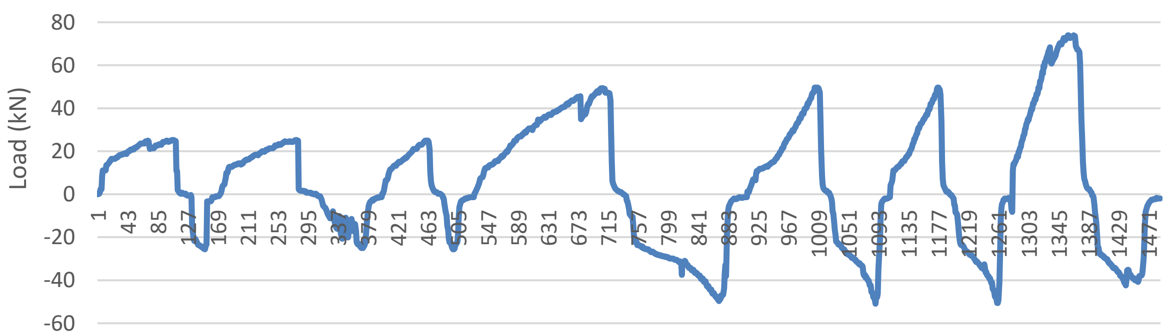


Figure 6. Load Cycle Pattern

3 RESULTS AND DISCUSSION

3.2 Cyclic Load

The maximum load achieved by the beam-column joint specimen was found to be 68.35 kN, the compressive load was discovered to have occurred at 24 mm displacement, and the tensile load was recorded to be 49.92 kN as presented in the graph of the cyclic load placed on the test object at 24 mm, 12 mm, 6 mm, 3 mm, 1.5 mm, and 0.75 mm. Figure 6 shows that the load continues to increase as the displacement increased, and the joint area was observed to have broken and cracked at the maximum conditions, thereby leading to a reduction of the load during the displacement. Moreover, the beam-column joint specimens showed a relatively horizontal crack pattern on the pedestal as indicated in Figures 7 and 8.

Figure 7. Crack Pattern of the Compressive Load (-), 24 mm

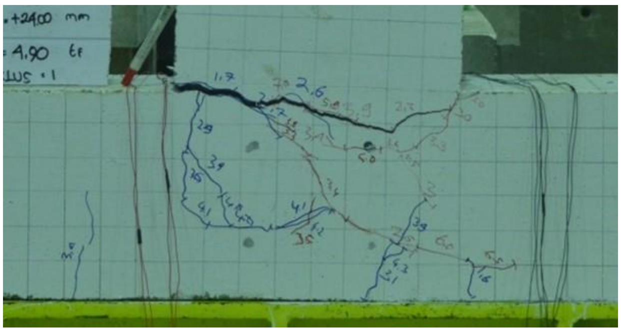


Figure 8. Crack Pattern of the Tensile Load (+), 24 mm

3.3 Monotonic Loading

The cracking discovered to be occurring continuously and widening in the beam-column joint was due to monotonic loading. The most significant crack in the connected beams became wider as the load increased, and the different kinds of patterns observed due to the monotonic loading are indicated in the Figure 9.

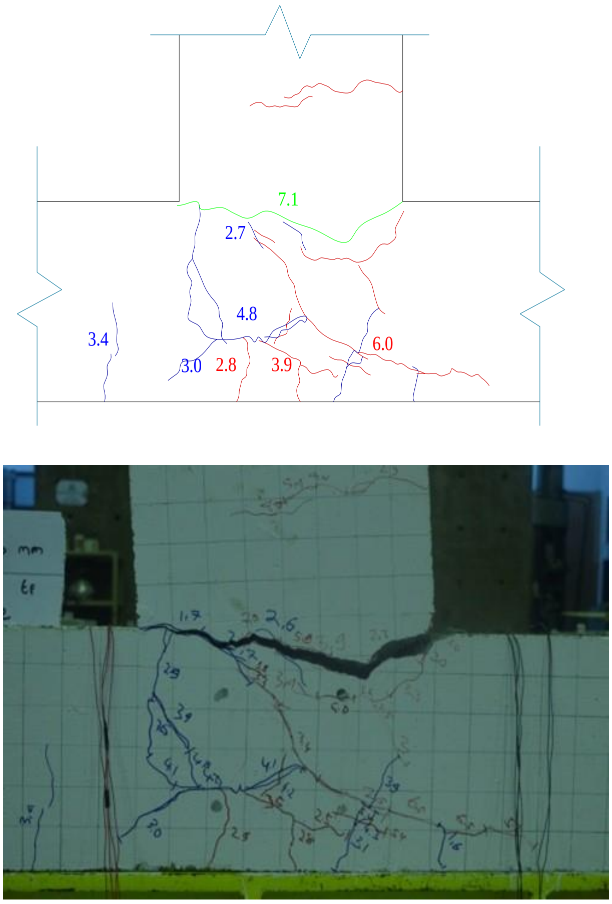


Figure 9. Monotonic Loading Crack Patterns

Larger cracks were observed to have occurred at the connection point of the beam-column. This was associated with the sliding capacity of the column beam and the reinforcement provided for the connection through the stirrup which led to a reduction in the flexural capacity and serves as the weak point.

3.4 Load and Lateral Displacement of the Beams and Columns Specimens

The load and displacement relationship graphs were obtained from the results of the cyclic lateral test conducted on the joint. The maximum lateral displacement value was found to be 50.98 mm which was recorded from the LVDT 1 located at the middle of the beam's left side. Moreover, the graph of the structural behavior towards the cyclic load is presented in Figure 10.

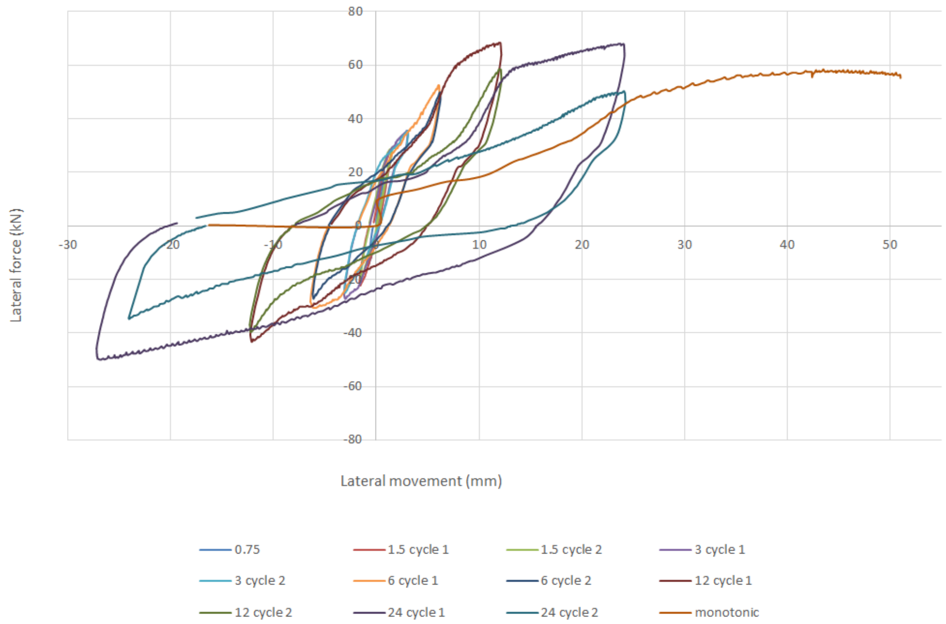


Figure 10. Hysterical Curves of Structural Behavior Against Cyclic Load

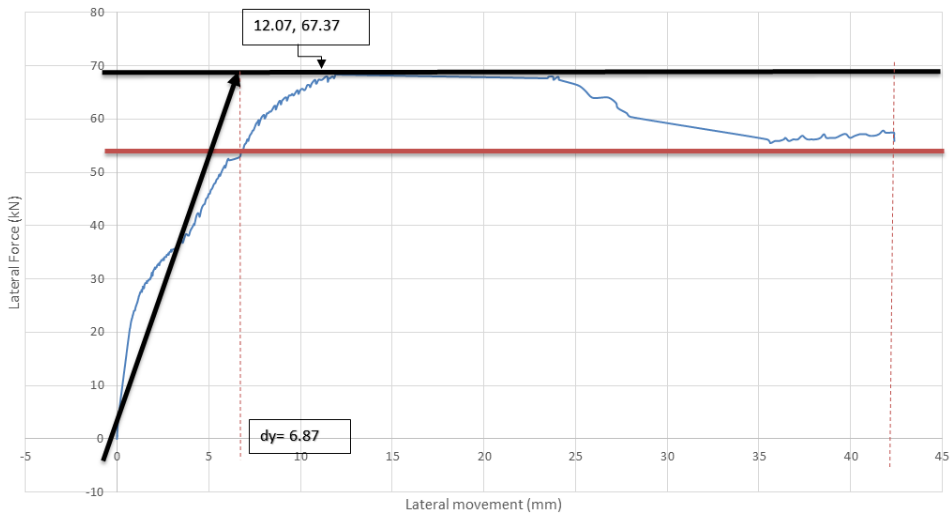


Figure 11. Graph of load and displacement envelopes

3.5 Structural Ductility

Structural ductility was obtained from the graph of envelope load and displacement as shown in Figure 11. It was used to determine the ability of the whole structure or a structural member to resist large deformations after exceeding the yield point without having any fracture. The term is normally used in earthquake engineering to designate the capacity of a building to resist large lateral displacements imposed by ground movement. The load envelope and displacement graph can be seen in Figure 11. The graph showed the ultimate displacement (d_u) was obtained at 50.99 mm, the yield displacement (d_y) value was 6.87 mm, and the ductility values of the test objects are presented in the Table 1.

Table 1. Ductility Value on the Specimens

Specimen	Max. Displacement	Ultimate Displacement	Yield Displacement	Ductility
	d_{maks}(mm)	d_u (mm)	d_y (mm)	d_u / d_y
SNI91	50.99	50.99	12.07	4.22

4 CONCLUSIONS AND RECOMENDATION

The seismic design focuses on the resilience of a framework, which serves as the main structure, to resist lateral forces using some structural elements such as beams and columns. This means there is a need for the connection between the elements to be ductile until they reach their load capacity. Therefore, this study discovered that the capacity of cyclic load value increased by the beam-column joint area of the reinforcement of stirrup replenishment. A maximum load of 68.35 kN for the compression and 49.92 kN for the tension was required to attain the cyclic load capacity. The maximum load was attained at 50.98 mm displacement.

Furthermore, beam-column with 0.09 secant stiffness and 23.93 mm displacement caused a reduction in capacity. Meanwhile, the load at 24 mm produced the cycle's highest dissipation energy of 13.25 but this can be increased through the addition of stirrups to provide stiffness in the joint. The stiffness value was also observed to have increased after the structural repairs.

Hence, it is important to increase the load capacity that can be carried by SNI 1991 test objects through structural repairs as indicated in the background information and problem formulated in the introductory section of this study. Some types of structural repair materials observed to be efficient and can be used as an easy alternative were discovered in this study. Cyclic load is a repetitive loading such as the exertion of regular repetitive pressure on a part which sometimes causes fatigue fractures. Therefore, it is possible to conduct a refinement effort through treatments such as reinforcement or additive materials. This study is recommended to be further developed by analyzing the treatment of beam-column joints based on the reinforcement channel length for failed specimens. In this regard, there is a need to repair the damaged part of the beam-column joints and to ensure proper application of the data obtained from these studies in order to provide better results.

DISCLAIMER

The authors declare no conflict of interest.

AVAILABILITY OF DATA AND MATERIALS

All data are available from the authors.

AUTHOR CONTRIBUTION STATEMENTS

Zardan A conducted data testing in the laboratory and processed the test results data. Samsul R observed and supervised the data processing process. Abdullah A and Affifuddin helped supervise the testing in the laboratory. All authors took a substantial contribution in discussing the result and drafting the manuscript.

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