Analysis of reinforced concrete beam-column joint structures retrofitting

Z Araby¹, A Abdullah¹ and M Affifuddin¹

¹ Department of Civil Engineering, Universitas Syiah Kuala, Banda Aceh, Indonesia

Corresponding e-mail: zardan_araby@unsyiah.ac.id

Abstract. There are many earthquake-related damages among Indonesian buildings, especially old buildings constructed based on SNI T-15-1993 standard. This research aims to study the comparison of the reinforced concrete beam-column joint structures' ability in resisting cyclic loads according to SNI T-15-1991-03 and SNI T-15-1991 codes to the ability of the joint structure that had been improved to the newer SNI 2847-2013 code. The beam-column joints structures designed by SNI T-15-1991-03 then retrofitted according to newer SNI 2847-2013 code in real-life situations refers to the damaged old building structures that fixed without the need to construct new buildings thus this will impact to budget efficiency. The joint specimens were made into three types of variation, which are the specimen with the reinforcement distribution not following the SNI T-15-1991-03 (BBK-1), retrofitting the specimen with the addition of woven wire (BBK-2), and the specimen with the reinforcement detailing according to SNI 2847-2013 (BBK-3). The beam dimension is 30 × 40 × 120 cm, and the column dimension is 30 × 30 × 200 cm. A test was carried out by applying a cyclic load in stages to a specimen through a hydraulic jack connected to a portable data logger for load recording. The specimen was equipped with strain gauges installed on steel reinforcements to detect strains that occur. The expected results in this study are to find out the most efficient and effective method used to reinforce the beam-column joints in resisting cyclic loads, both in the construction of new or old buildings.

1. Introduction

Indonesia is one of the countries where earthquakes frequently happen. Until now, there is not much that can be done to prevent earthquakes, which also directly cause damage to buildings. However, governments continue to update the codes regarding the structure of earthquake-resistant buildings to prevent damage to building structures so that there are no fatalities and material losses due to the impact of the earthquake [1].

Currently, the building structure failures related to the earthquake are caused by the design that does not follow the standard or by the design that refers to the older standard. The structure that frequently fail is the beam-column joint. Beam-column joint in buildings is one of the essential parts to receive loads; however the joint also has limited capacity. When an earthquake hits the structure, there will be a very large shear force at the beam-column joint; this shear force results in collapsing the beam-column joint because of the over shear-capacity force, the bonding breakdown, or the result of both [2].

The strength of the joint must not be less than the maximum requirement, which the strength can enlarge the mechanism of the plastic joint of the structure. The well design joint can relatively reduce the need for repairing the joint and the energy in a joint decreases when repetitive loads hit it in the
elastic phase and the capacity of the column should not be affected by the possibility of a strength decreased in the joint (SK SNI T-15-1991). The joint area must be calculated accurately as part of the column. So that during an earthquake, a joint is expected in a plastic phase, and joint deformation may not increase the occurrence of a joint. Strengthening the joints needed to increase the capacity should not cause difficulties in the construction process. This research aims to find out and to study the comparison of the strength ability of beam-column joint designed according to SNI T-15-1991-03 and SNI 2847-2013 codes to resist shear forces from cyclic loads and also capability of the beam-column joint designed according to SNI T-15-1991-03 code which then the joint strengthened by wiremesh to resist shear force from cyclic loads [3].

The compressive strength of concrete is the ability of concrete to accept the compressive force of broad unity. Concrete compressive strength identifies the quality of a structural plan, where the higher the level of strength of the desired structure, the higher the quality of the concrete was produced. Factors that influence the compressive strength of concrete include the proportion of constituent materials, methods of implementation, maintenance, and circumstances at the time of casting [4].

The value of compressive strength of concrete is obtained through standard testing using a compressive testing machine with a loading speed of 0.15 MPa / second up to 0.34 MPa / second until the concrete cylinder specimen is destroyed [5]. The commonly used test procedure is the American Society for Testing and Materials (ASTM) C39 standard. Compressive strength testing of each specimen done at 7, 28, and 56 days.

The compressive strength that arises according to the American Society of Testing Materials (ASTM) C-39 was calculated using the equation (1):

\[ f'\text{c} = \frac{P}{A} \]  

Annotation:
- \( f'\text{c} \) = Concrete cylinder compressive strength (MPa);
- \( P \) = Maximum press load/ press (Newton); and
- \( A \) = Cross-sectional area of the specimen (mm\(^2\)).

1.1. Beam-column joint

1.1.1. Beam-column joint according to SNI T-15-1991-03 Code. The force in the reinforcement of the longitudinal beam on the surface side of the joint must be determined by assuming that the tension inside the flexural tensile reinforcement is 1.25 \( f_y \). Flexural moments and column shear forces, as well as horizontal shear and vertical forces passing through the joint, must be evaluated with rational analysis,
which will count all the forces forming a balance on the joint column reviewed (6). The nominal horizontal shear force in the beam-column joint is given by the following equation:

$$V_c = \left(\frac{\sqrt{f_c}}{6}\right) \cdot b_w \cdot d$$  \hspace{1cm} (2)

Annotation:
- $b_w =$ board width, or circle cross-section diameter (mm);
- $d =$ effective cross-section; and

The shear strength provided by the shear tension is given by the following equation.

$$V_s = \frac{A_v \cdot f_y \cdot d}{S}$$  \hspace{1cm} (3)

Annotation:
- $A_v =$ Total cross-sectional area of shear reinforcement (mm$^2$);
- $f_y =$ Steel yield tension (MPa);
- $d =$ Distance from the outer press fiber to the tensile reinforcement (mm); and
- $S =$ Reinforcement space distance (mm).

The requirements for shear reinforcement planning are as follows:

$$V_u \leq \phi V_n$$  \hspace{1cm} (4)

$$V_n = V_c + V_s$$  \hspace{1cm} (5)

$$V_u \leq \phi (V_c + V_s)$$  \hspace{1cm} (6)

Figure 2. Beam-column joint according to SNI-T-15-1991 code.

1.1.2. Beam-column joint according to SNI 2847-2013 Code. SNI 2847:2013 explains that the shear force design ($V_e$) must be determined from an observation of the static force on the joint component structure of the joint. It must be assumed that torques with opposite signs are related to the strength of
the bending torque (Mpr) that might be working on the surfaces of the joint and that the structural components which deducted with factored gravity loads along the beam [7]. The picture of the beam-column joint, according to SNI 2847: 2013, can be seen in figure 3 below:

Figure 3. Illustration of beam-column joints from SNI 2847: 2013 code.

There are two types of factored shear forces that work on beam-column relations (Vu), i.e., for interior joints in equations (7) and exterior joints in equations (8) and (9). For the exterior joint, the biggest value is taken from those two equations.

\[ Vu = 1.25(As + As)fy - V_{kol} \]  \hspace{1cm} (7)

\[ Vu = 1.25 \cdot As \cdot fy - V_{kol} \] \hspace{1cm} (8)

\[ Vu = 1.25 \cdot As \cdot fy' - V_{kol} \] \hspace{1cm} (9)

The shear force in the column can be calculated based on the values of Mpr- and Mpr+ divided by half of the upper column height (h1), plus the lower half of the column height (h2). The equation is shown below:

\[ V_{kol} = \frac{Mpr^- + Mpr^+}{h_1 + h_2} \] \hspace{1cm} (10)

Nominal shear tension (Vn) in beam-column joints can be seen from the equation below:

\[ V_n = \frac{V_u}{bj \cdot hc} \] \hspace{1cm} (11)

Annotation:
\[ V_n = \text{Nominal shear tension joint;} \]
\[ V_u = \text{Factored shear force;} \]
\[ bj = \text{Effective width of beam-column relations;} \]
\[ hc = \text{Effective height in beam-column relations.} \]

The value of the shear force (Vn), for the confined beam-column relationship, can be seen from the following equation:
\[ V_n \leq 1.7 \sqrt{f'_c \cdot A_j} \]  

(12)

The shear tension borne by concrete is calculated from the following equation:

\[ V_c = \frac{2}{3} \sqrt{\left( \frac{N_{n,k}}{A_g} \right) - 0.1f'_c} \]  

(13)

Annotation:

- \( V_c \) = Shear stress borne by concrete;
- \( N_{n,k} \) = Axial force column;
- \( A_g \) = Cross-sectional area of the column; and
- \( f'_c \) = Concrete compressive strength.

Transverse reinforcement in beam-column joints is needed to provide sufficient restraints on the concrete, so it is capable of showing the ductile behavior and of carrying vertical gravity due to exfoliation on the concrete covers. Planning a shear reinforcement must meet the requirements as follows:

1. If \( V_n \leq V_c \), the minimum shear reinforcement will be used, and
2. If \( V_n > V_c \), it will need shear reinforcement.

1.2. Retrofitting on reinforced concrete

According to [8], damage to unstable structures may be caused by external forces such as earthquakes, wind loads, and vibrations. Earthquakes can cause buildings to sway and cause the structure to crack where the damage level of building structures is based on the width of the cracks. Building damages that often occur are cracks, faults, debris, arches, and deflections. As a result of the damage to the structure, there is a need for improvements in the structure of the building. Durable building retrofitting requires the selection of suitable materials, including the retrofitting that require chemical resistance. The selection of retrofitting materials must be based on low-cost ease, the availability of skilled workers, and the work equipment needed.

1.3. Ferrocement

According to [9], ferrocement itself is a composite material with materials made from a mixture of sand and cement using mesh wires that can form a unified whole and form a strong construction. Generally, ferrocement thickness ranges from 10 mm to 50 mm, with reinforcement volumes ranging from 6% to 8% of all construction contents.

According to [10], the shear strength of ferrocement's contribution can be calculated by the following equation:

\[ V_j = \frac{0.125 \pi^2 d_w^2 f_{yj} n D_r}{8w} \]  

(14)

Meanwhile, to calculate the number of wire mesh layers needed for shear reinforcement, it is calculated by equation (15) for round columns and equation (16) for square columns.

\[ n = \frac{0.8158 w V_j}{d_w^2 f_{yj} D_r} \]  

(15)

\[ n = \frac{0.7858 w V_j}{d_w^2 f_{yj} D_r} \]  

(16)

Annotation:

- \( V_j \) = Jacket slide strength / ferrocement (kg/cm²);
\( n \) = The amount of wiremesh layers (unit);
\( g_w \) = Distance/space wiremesh (mm);
\( f_{yj} \) = Jacket pull strength/ferrocement (kg/cm²);
\( d_w \) = Wiremesh diameter (mm); and
\( D' \) = Column diameter (mm).

2. Methodology
To achieve good research results, it must be done with a good and correct method and procedure. The stages of this research began with a literature study, followed by preparation of equipment and materials, materials testing, concrete mixture proportions planning, specimen preparation and maintenance, specimen testing, and data analysis.

2.1. Study Objectives
The specimens were varied into three types, the specimens with the length of the reinforcement distribution were not in accordance with the SNI T-15-1991 code (BBK-1), the retrofitting specimens with the addition of woven wire (BBK-2), and the specimens with reinforcement length according to SNI 2847-2013 code (BBK-3), with the quality of concrete for each specimen is 18.68 MPa and the steel quality is 240 MPa. The dimensions of beams were 30 x 40 x 120 cm, and the dimension of columns were 30 x 30 x 200 cm, both beams and columns used 8Ø14 mm for main reinforcement and Ø10-100 mm for stirrup reinforcement with yield strength (fy) 240 MPa and tested at 28 days. Cylindrical specimens were also prepared in size of 15 x 30 cm. The mix design was obtained by the trial method based on the concrete volume weight. The specimen is made for testing the cyclic load capacity in reinforced concrete beam-column joints. The planned specimen consists of normal reinforced concrete with smooth aggregates, coarse aggregates, reinforcing iron, and water. In this research, planning for reinforced concrete will use normal aggregates such as gravel, sand, and water. The plan and dimensions of the specimen can be seen in table 1 and table 2 below.

| Specimens Production | Total of Specimens | Reinforcement |
|----------------------|--------------------|---------------|
|                      |                    |               |
|                      |                    |               |
| SNI T-15-1991 Code   | 1                  | BBK-1         |
|                      | 4                  | 8 Ø 14        |
|                      |                    | Ø 10 – 100    |
| Retrofitting SNI T-15-1991 Code | 1 | BBK-2 |
|                      | 4                  | 8 Ø 14        |
|                      |                    | Ø 10 – 100    |
| SNI 2847-2013 Code   | 1                  | BBK-3         |
|                      | 4                  | 8 Ø 14        |
|                      |                    | Ø 10 – 100    |

| Specimens Production | Specimens Code | Specimen Dimensions (cm) |
|----------------------|----------------|--------------------------|
|                      |                | Beams                    |
| SNI T-15-1991 Code   | BBK-1          | 30 x 40 x 120            |
|                      |                | 30 x 30 x 200            |
| Retrofitting SNI T-15-1991 Code | BBK-2 | 30 x 40 x 120 |
|                      |                | 30 x 30 x 200            |
| SNI 2847-2013 Code   | BBK-3          | 30 x 40 x 120            |
|                      |                | 30 x 30 x 200            |

The details of the planning and cross-section of the specimens can be seen in figure 4 below.
3. Results and discussion

3.1. Concrete compressive strength testing
The method used for the concrete press test is the ASTM C39-86 method. A concrete cylinder compressive strength test is done to determine the desired compressive strength of the concrete. A compressive strength test carried out when the specimen is at 28 days old. Concrete cylinder compressive strength test was used to represent beam casting as a control specimen. The set up of the compressive strength of cylindrical specimens test can be seen in figure 5. This compressive strength test was also carried out according to SNI 03-1974-1990, which concerns the concrete press strength testing method by placing the specimen on a press machine centrically. Then, the press machine was run with constant loading (ranging from 2-4 kg/cm² per second) until the specimen was destroyed. The maximum load was recorded.

![Figure 5. Concrete compressive strength test set up](image-url)
3.2. Beam-column joint specimens test

The test will be carried out when the specimen is at 28 days old. The beam-column specimen test was carried out together with a cylindrical specimen. The cyclic load capacity that will be counted is the compressive strength resulting from the compressive strength test of the cylindrical specimen. Before testing, the surface of the specimen was painted in white and the grid is drawn first in order to make it easier to draw the resulting crack pattern. The specimen is rigidly mounted on the beam frame. On the surface of the end of the beam area, the steel plate was placed as the foundation for the load cell in applying the compression load. The load was given horizontally at the end of the beam. The horizontal load was given by a hydraulic jack connected to the load cell and forwarded to the specimen. The load given was controlled by reading the dial on the hydrant jack. Loading was carried out in stages, and at each step, the load was read and the crack pattern that arises was illustrated. The load was given until the specimen was destroyed. On all sides of the joint, a transducer was installed to read the deflection.

![Figure 6. Beam-column joint specimens set up](image)

Strains that occur in beam-column joints are read by a Portable Data Logger that has been connected to a strain gauge. Loading is stopped when the load is no longer increases due to the specimen being unable to accept the load so that the specimen is cracked and destroyed. The pattern of crack development is monitored at all times by making a crack image that occurs in the column according to the amount of load given.

3.3. Specimens Retrofitting

After the experiment was carried out with a cyclic load on the beam, the failure that occurred will be cleaned and then repaired by coating the failed area, which is in the column joint and beams. The reinforced layer material to be used is a layer made of ferrocement. The number of layers and the length of the layer to be used are calculated by equations 15 and 16.

4. Conclusion

After the test completed in the laboratory, it is expected that the conclusions can be drawn regarding the cyclic load capacity of beam-column joint specimen designed according to SNI T-15-1991 code, the
joint designed according to SNI T-15-1991 code retrofitting with woven wire, and the joint designed according to SNI-2847-2013.

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