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# EXPERIMENTAL INVESTIGATION OF CRACK ON A NON-MONOLITHIC EXTERIOR BEAM-COLUMN JOINT OF REINFORCED CONCRETE UNDER STATIC LOAD

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## ABSTRACT

*This study aims to determine the experimental crack propagation pattern on non-monolithic exterior reinforced beam-column joints with strengthening. The strengthening provided is in the form of a pedestal plate installed on the column and notch at the interface between the beam and column. Broken steel pipes used as a sleeve that connects the reinforcement extending from the column to the beam. Four sets of specimens were made to represent each monolithic connection, non-monolithic non-strengthening joints, and non-monolithic joints with strengthening. All specimens tested with a single static load. Monolithic beam-column joints used as control specimens against crack propagation patterns in the non-monolithic beam-column joints. The results showed that the decrease in performance and strength due to the non-monolithic connection in the beam-column joints could improve by giving a pedestal plate and notch. This strengthening can increase peak load capacity to reach 99%. The non-monolithic joint stiffness can also be fixed up to 90% compared to the monolithic beam-column joint, the crack pattern that occurred also improved through of crack width and crack rate.*

**Keywords**: Crack Propagation, Non-Monolithic, Beam-Column Joint, Static Load

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## 1. INTRODUCTION

Natural disasters that often occur cause a lot of damage to buildings. The construction of damaged buildings needs to be rebuilt immediately with a quick and easy method of implementation so that people's lives can return to normal.The method was the precast concrete method. Precast concrete is all concrete products made in the factory and ready for final installation on site. Compared to the construction of conventional concrete structures, the construction of precast concrete structures saves time, reduces labor costs and energy consumption, and makes controlling costs and quality easier [1][2]. However, the method of precast concrete is unfamiliar applied to simple multi-story buildings because it requires special expertise. Therefore, in this study the semi-precast method, which is easy to implement in a simple story building, is presented. Parts of columns and beams are placed with different casting times so that they become non-monolith connections.

The connection of reinforced concrete beam-columns is an important part of the frame structure. Design of connections is one of the most important considerations for the successful construction of reinforced concrete structures. Details of beam-column connections affect strength, stability, ductility, and load redistribution due to loading. A common problem with non-monolithic beam-column connections is the reduced structural stiffness that can lead to decreased strength and performance of reinforced concrete structures. However, this reduction is recommended not to exceed the limit of 20% [3][4][5].

Beam-column joints are structural elements that are most susceptible to failure due to static loads. The failure of this structure usually begins with the occurrence of cracks that continue to propagate. Therefore the propagation of cracks in the beam-column joints must be predictable so that no sudden failure occurs [6]. Failure of the beam-column joints in RC buildings causes the entire structure to collapse.

According to Park and Paulay[7] the principle of connection planning in precast elements can be classified into two categories, namely: (a). Strong Connection, when joints between precast elements still behave elastically during a strong earthquake. This connection system is proven theoretically and experimentally has the strength and hardness as the monolithic concrete structure. (b). Connection ductile, when the connection undergoes inelastic deformation, the system connection must be proven theoretically and experimentally to meet the reliability requirements and stiffness of earthquake resistant structures.

Several studies have been conducted to study the behavior and cracks in reinforced concrete structures with various strengthening[8][9][10]. Strengthening to inhibit the speed of cracks that cause RC structural collapse. In bamboo reinforced concrete beams, *installationof hose clamp pegsincreases thebond slip parameter*[11]. Additional diagonal reinforcement on reinforced concrete column joints can increase load capacity and joint ductility [12]. The addition of anchors to joints has also been done to improve the performance of reinforced concrete column joints. The results obtained show improvements in load capacity parameters and deflection, ductility, stiffness reduction, and better control of cracks[13].

Based on previous research, this paper presents experimental investigation regarding crack propagation patterns in reinforced concrete exterior beam-column joints with static loads. The beam-column joints observed were monolithic and non-monolithic joints with pedestal plate strengthening and notch. This study had the objective to improve the performance of non-monolithic beam-columns joints due to separate casting which is connected with a broken sleeve pipe.

The design of reinforced concrete structures assumed that compressive failure occurs when the strain compression of concrete reaches 0.003. Compression failure followed by the formation of cracks that are parallel to the direction of the load and referred to as splitting failure. The beam will crack due to the load if the tensile stress on the concrete has exceeded the tensile stress on plain concrete. After a crack occurs, steel receives the tensile stress needed due to the load acting. The design procedure assumes that steel has a linear stress-strain relationship until the yield stress, fy, is reached.

Stages of the reinforced concrete beam when receiving bending moments are(a). The beam is uncracked, (b) the beam is cracked, it is still at the elastic limit, and (c) the beam reaches its limit strength.

We can sawthe behavior of reinforced concrete beam with increasing bending moment in the figure 1a, 1b, and 1c[14]

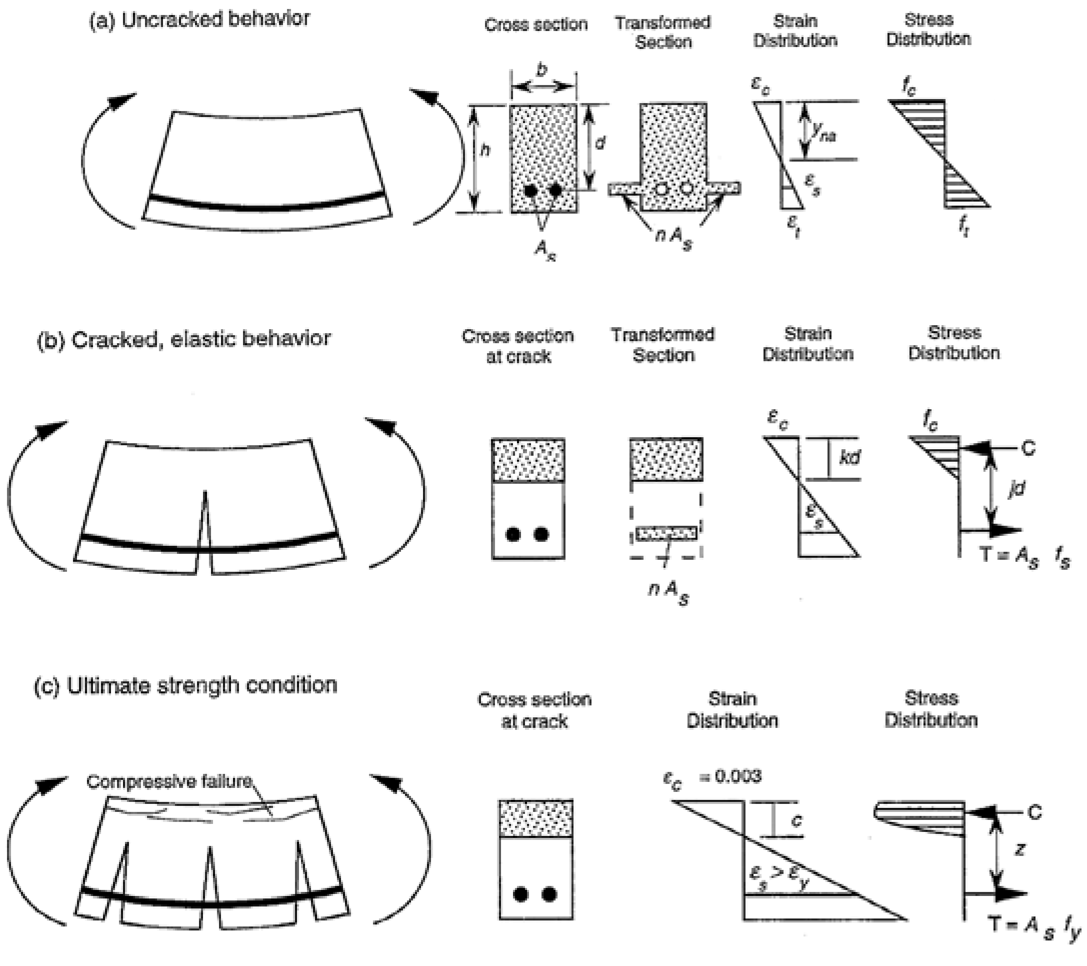



**Figure 1** The behavior of reinforced concrete beam with increasing bending moment

# 2. MATERIAL AND EXPERIMENTAL PROGRAM

## 2.1. Material

The size and description of the specimen beams-column joints seen in Table 1.

**Table. 1.** Description of beam-column connection specimens.

| Description | Beam | Column |
|---|---|---|
| Dimensions (mm) | 150 x 200 x 1000 | 200 x 200 x 750 |
| f'c (MPa) | 21 | 21 |
| Longitudinal reinforcement | 4 Ø 13 | 4 Ø 13 |
| Fy (MPa) | 580 | 580 |
| Stirrup | Ø 8 – 100 | Ø 10 – 100 |
| | Ø 8 – 50 | Ø 10 – 50 |
| Fy (MPa) | 440 | 440 |

We can see the classification of beam-column connection specimens intable 2.

**Table 2**.classification of beam-column connection specimens.

| No. | Specimen | Number of specimens | Code of specimens |
|---|---|---|---|
| 1 | Monolithic | 3 | SK-A0 |
| 2 | Non-monolithic no notches | 3 | A0-B0 |
| 3 | Non-monolithic with notches | 3 | A0-B1 |
| 4 | Non-monolithic with notches and support-plate | 3 | A1-B1 |

## 2.2. Experimental Program

The experimental program includes a total of four sets of specimens of RC beam-column connection. The test specimen based on design criteria according to ACI 318-14 dan ACI352R-02 [15][16]. Each specimen tested by providing a static load with a 50 kg load interval until it reached collapse. The deflection occurring on the beam is measured by installing LVDT. Illustration of making non-monolith beam-column joint test specimens seen in Figure 2.

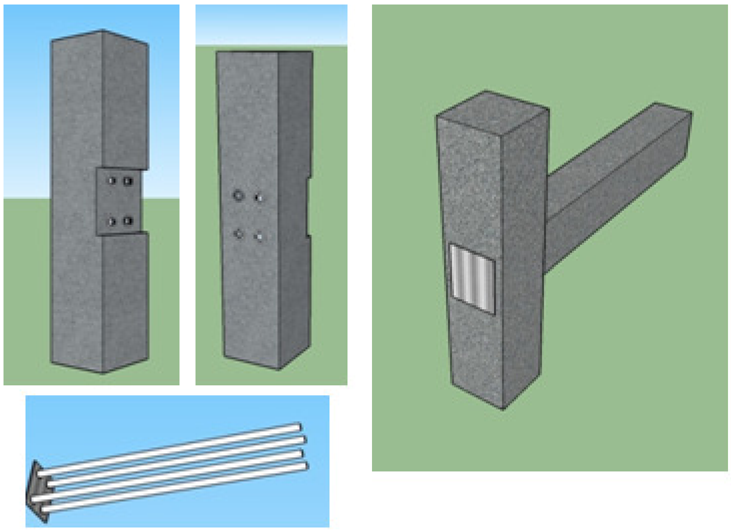


**Figure2**.Illustration of making non-monolith beam-column joint test specimens

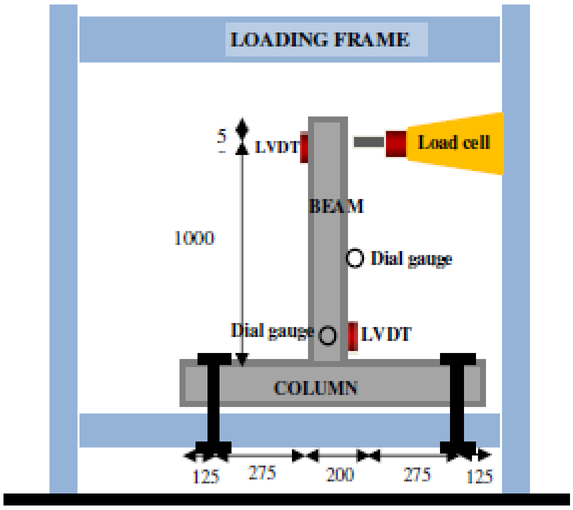



**Figure3**.Experimental Test Set up

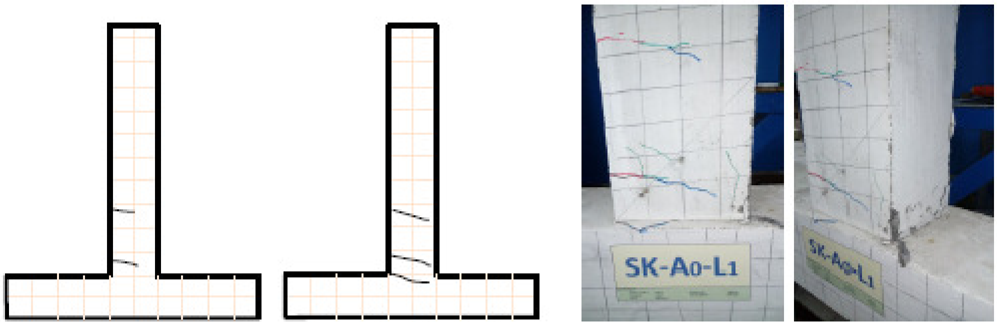
## 3. RESULTS AND DISCUSSION

During testing, crack propagation which is a weakening sign of beam-column joint of reinforced concrete was observed and recorded. Behavior and crack patterns differ in each specimen. In each specimen 5x5 cm grid lines were made to facilitate the observation of crack propagation

• SK Specimen

The SK specimen is a control specimen beam-column joint that made monolithically.

Horizontal bending cracks began to be seen in the beam on the grid two with a deflection of 1.98 mm when the load was 1150 kg. The stiffness value when the first crack occurs is 581 kg/mm. At a load of 1200 kg with a deflection of 2.18 mm, horizontal bending cracks occurred on the grid four and six a distance of 20 cm and 30 cm from the beam-column joint. At a load of 1400 kg with a deflection of 3.38 mm the crack on grid two increases in length and width, the cracks in the grid four and six increase in length and spalling begins on the compressed zone of the beam. The flexural-shear crack began when the load was 1450 kg with a deflection of 3.74 mm. At a load of 1500 kg openings occur in the meeting area of the beam and column. When these openings occur, cracks in other areas no longer develop. The openings at this beam-column intersection increase in length and width until the peak load is 1686 kg with a deflection of 6.08 mm. Concretespalling extends to the compression area until the observation stopped when the load has dropped to 33% of the peak load. The crack pattern on the SK specimen as shown in figure 4



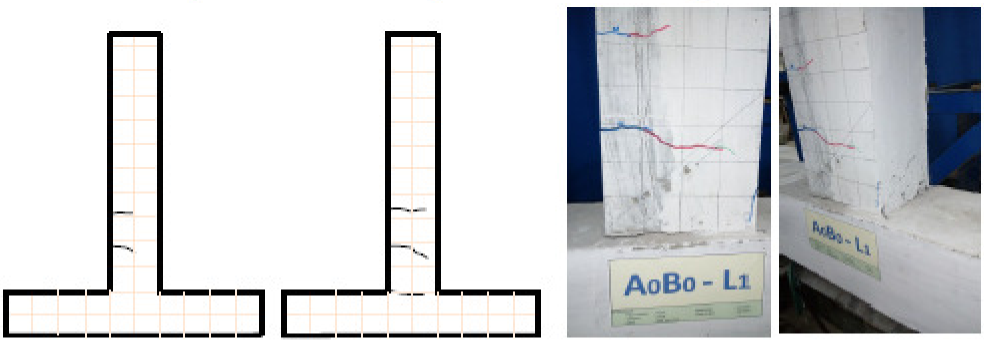

(c) When the first (b) During peak load (c) Final Condition

**Figure 4.** Crack propagation on the SK specimen

A0B0 Specimen

The A0B0 specimen is a specimen beam-column joint that madenon-monolithically without strengthening.

The flexural crack first appeared in the beam section on grids 3 and 6 with a deflection of 4.76 mm when the load was 950 kg.The stiffness value when the first crack occurs is 200 kg/mm. Flexural cracks in the fifth grid do not develop further. Horizontal bending cracks in the third grid are the main cracks that are getting longer and wider as the load increases to 1100 kg. At the load of 1250 kg, spalling began to occur in the beam compression area and crack at the beam-column intersection. There was no development of other cracks in the beam, both flexural and shear, until the peak load occurred at 1394 kg. The test terminated when the load cannot increase with a load capacity that has dropped to 30% peak load capacity. There is no major damage due to spalling in the beam compression area.The crack pattern on the A0B0 specimen as shown in figure 5



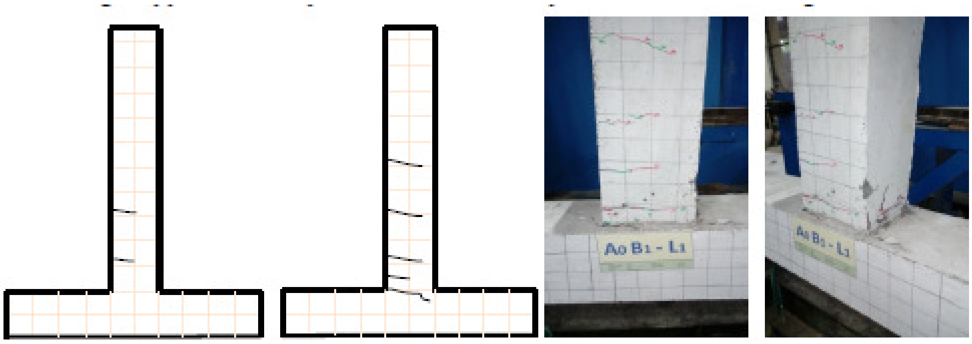

(b) When the first (a) During peak load (c) Final Condition

**Figure 5.** Crack propagation on the A0B0 specimen

A0B1 Specimen

The A0B1 specimen is a specimen beam-column joint that made non-monolithically and notch strengthening.

The flexural crack first appears in the beam section on first and third grids with a deflection of 2.26 mm when the load was 1000 kg.The stiffness value when the first crack occurs is 442 kg/mm. The flexural cracks in the first grid began to develop into shear cracks at the load of 1350 kg and the deflection of 7.58 mm that followed by another crack in the beam. At the load of 1400 kg, spalling began to occur in the beam compression area and crack at the beam-column intersection. Cracks on the beam do not develop until the peak load reaches 1447 kg and the deflection is 10.92 mm.Load capacity had dropped to 76% when testing stopped. A crackpattern on the A0B1 specimen as shown in figure 6.



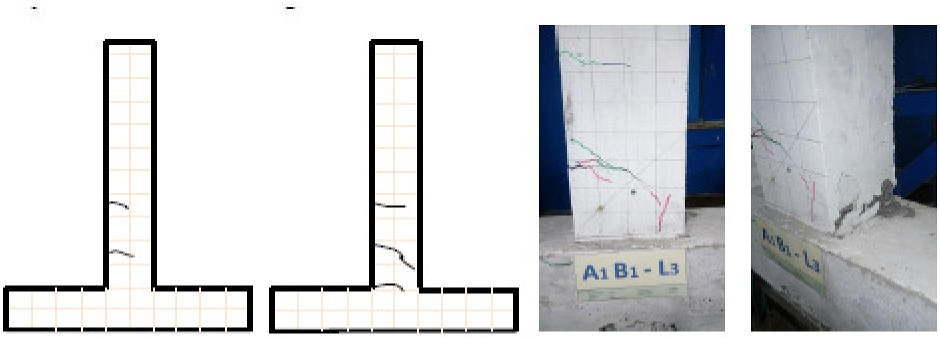
(a) When the first (b) During peak load (c) Final Condition

**Figure 6.** Crack propagation on the A0B1 specimen

A1B1 specimen

The A1B1 specimen is a specimen beam-column joint that made non-monolithically andnotch and pedestal plate strengthening.

Horizontal bending cracks began to be seen in the beam when the load was 1100 kg with a deflection of 2.11 mm. The stiffness value when the first crack occurs is 521 kg/mm. At a load of 1350 kg with a deflection of 3.92 mm the crack increases in length and width, spalling begins on the compressed zone of the beam. The flexural-shear crack began when the load was 1450 kg with a deflection of 4.82 mm. At a load of 1500 kg openings occur in the meeting area of the beam and column. When these openings occur, cracks in other areas no longer develop. The openings at this beam-column intersection increase in length and width until the peak load is 1622 kg with a deflection of 7.24 mm. Concretespalling extends to the compression area until the observation stopped when the load has dropped to 30% of the peak load. The crack pattern on the SK specimen as shown in figure 7



(a) When the first (b) During peak (c) Final Condition

**Figure 7.** Crack propagation on the A1B1 specimen

Figure 8 shows the behavior of the relationship between load and deflection during loading and Figure 9 shows column beam joint stiffness in all types of specimens.

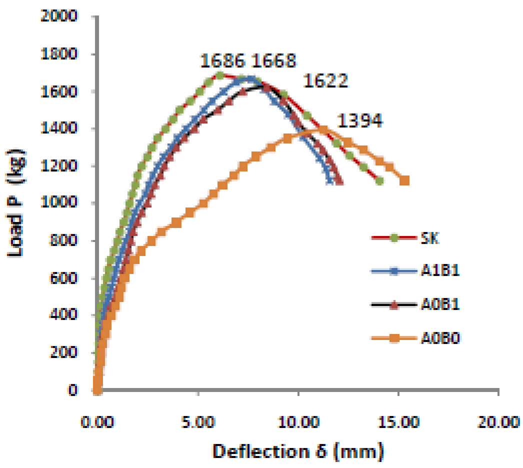



**Figure 8.** The behavior of the relationship between load and deflection

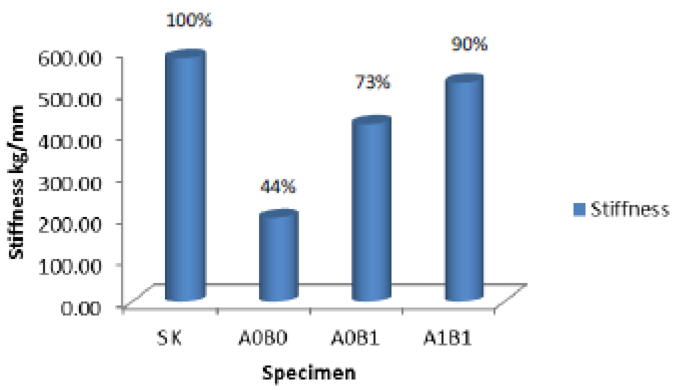



**Figure 9.** Beam-column joint stiffness

The test results show that due to the non-monolithicconnection it causes a decrease in beam-column joint performance: this decrease in performance as shown from reduced load capacity, a decrease in the value of stiffness, and cracks that occur. Strengthening the pedestal plate and notch affects the improvement of beam-column joint performance. This performance improvement is caused by good bonded between reinforcement and grouting in the coarse sleeve pipe. The notch provides additional shear fields thus increasing the rigidity of column beam joints.

## 4. CONCLUSION

The results showed that the decrease in performance and strength due to the non-monolithic connection in the beam-column joints could improve by giving a pedestal plate and notch. This strengthening can increase peak load capacity to reach 99%. The non-monolithic joint stiffness can also be fixed up to 96% compared to the monolithic beam-column joint, the crack pattern that occurred also improved through of crack width and crack rate.Strengthening the pedestal plate and notch affects the improvement of beam-column joint performance. This performance improvement is caused by good bonded between reinforcement and grouting in the coarse sleeve pipe. The notch provides additional shear fields thus increasing the rigidity of column beam joints.

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