Performance Evaluation and Crack Repair in Building Infrastructure

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Abstract. The implementation of building infrastructure development to improve people's lives is important. The use of reinforced concrete structures has increased very rapidly. But many buildings are failed and are not safe because of overloading, changes in function and configuration of buildings, poor maintenance, and natural disasters. Many methods developed to reduce the damage caused by earthquakes so that the development of methods to strengthen and repair building structures is needed to anticipate damage to buildings. This study focuses on beam-column joint cracks with simple building characteristics, column size 20/20 and beam 15/20 (monolithic) with concrete quality $f_{c'}^\prime = 21$ MPa, so it is necessary to evaluate and repair beam-column joint cracks in buildings because of overload. The method used was experimental and testing in a laboratory with a single static load and Ultrasonic Pulse Velocity (UPV) test to determine the density after repair. Test specimens are SK (control-specimens) and SK-repairing. The results showed that the beam-column joint performance before and after repairs had relatively the same flexural strength of 1,669 kg and 1,686 kg, while the stiffness was lower at 14.48%. The velocity after repair average is 3,327.5 m/s (medium-category). The elasticity average modulus of the test is 20.43 GPa.

Keywords: buildings, beam-column joints, cracks, repairs, UPV

1. Introduction
Materials that are often used in the world of construction are reinforced concrete due to its good durability, ease of implementation and it has been used for years to build various structures (houses, high-rise buildings, bridges, and dams). As a developing country which is developing massive infrastructure, the use of reinforced concrete structures has also increased very rapidly. The view that concrete is a durable and maintenance-free construction material has changed in recent years. It is possible to achieve the reinforced-concrete performance as good as expected [1]. Thousands of reinforced concrete structures are built every year throughout Indonesia. There are also a large number of poor concrete structures that become unsafe due to inadequate detailed structural design, poor construction and quality of maintenance, overloading, chemical attack, steel reinforcement, foundation, abrasion, fatigue effects, atmospheric effects, abnormal flooding [2], changes in building functions, changes in configuration and natural disasters that will affect the durability of concrete structures.
Many general problems related with repairs emerge along with various solution methods, specifications and regulations. Broken concrete, concrete surface preparation, cleaning and or steel reinforcement replacement, surface inspection, and selection of appropriate repair materials depend on the level of damage and damage conditions. Damage due to debonding too quickly is a significant problem for repairs. Structural failure in building infrastructure occurs due to less efficient bonding or due to the nature of the concrete substrate, and the repair material is not suitable. The better the materials with additives, the higher the strength of the structure [3]. The International Concrete Repair Institute has shown several patterns of premature failure due to the nature of the repair material that does not match and mentioned properties for repair materials [4].

One way to investigate the performance of concrete testing is Non-Destructive Test (NDT) to test the elastic modulus in concrete using the Ultrasonic Pulse Velocity method [5, 6, 7]. The workings of NDT is by calculating the ultrasonic wave velocity needed for propagation in concrete and calculating the elastic modulus. The stiffness of elasticity in concrete affects NDT results. The UPV wave velocity will decrease in concrete which has poor compaction or damage to material grains.

Many research have been carried out on beam-column joint performance [8, 9], and structural performance of reinforced concrete structures using the latest repair materials where the bond between concrete and steel has disappeared, but the use of UPV to check the results of concrete reinforcement repairs has not been studied. Therefore, this study presents a study of the flexural performance of reinforced concrete column beams which are repaired using flowing concrete repair (grout) mortars.

2. Methods
The building samples for this study are simple buildings (2 levels) with 20/20 size columns and 15/20 size of beams with concrete quality of fc'= 21 Mpa. The laboratory specimens use a beam-column joint that has a rectangular cross-section with a column size of 200x200 mm with a length of 1,000 mm, and a 150x200 beam with a length of 1,000 mm. Concrete cover of 25 mm, column and beam has longitudinal reinforcement of 4 D13. The size of beam stirrups is Ø8 - 100 mm in mid-span and Ø8 - 50 mm in edge span, column stirrups are Ø10 - 100 mm in edge span and Ø10 - 50 mm in mid-span. The procedure for casting monolithic specimens, loading specimens until they reach the yielding point and repairing test specimens is based on ACI 224-07 criteria [12], and according to the requirements we then use SikagROUT 215 New which has a compressive strength of 65 N/mm² (28 days), flexural strength > 6 N/mm², expansion 0.3-1.4%, adhesion strength > 1.5 N/mm² and elastic modulus of 2600 N/mm² and SikaBond NV for connecting old and new concrete.

Materials for reinforced concrete include portland cement ex. Gresik cement, Lumajang sand and broken stone with a maximum aggregate size of 20 mm with a cement water factor (FAS) of 0.65 to produce the desired concrete quality of 21 MPa. The use of standard cylindrical samples to determine the compressive strength of concrete and Young's modulus of elasticity at 28 days. The test on specimen based on design criteria according to ACI 318-14 and ACI 352R-02 [10, 11]. The testing of each sample uses a static load with a 50 kg load interval until it reached collapse. The measurement of deflection on the beam uses LVDT (Linear Variable Displacement Transducer). Illustration of the experimental set up beam-column joint test specimens can be seen in Figure 1.
UPV (Ultrasonic Pulse Velocity) testing of structures is used to determine concrete density quality and how deep the crack based on wave propagation speed. The working principle of the UPV test equipment is to produce and deliver ultrasonic waves in the form of pulses/pulses into concrete, and the average travel time of the wave from the starting point to the end point through concrete. Waves will take longer if there is an air cavity inside the concrete. UPV consists of two transducers and a Pundit Touchscreen which function to operate the transducers function.

The concrete quality category with UPV is based on the wave velocity because the principle of the UPV test is to determine the time of propagation of ultrasonic waves in concrete. The better the concrete density, the shorter the time needed by the wave to propagate from the transmitter to the receiver. If the concrete has a lot of delimitation (cavity), then the waves will require a longer propagation time.

| Wave propagation speed | Concrete Quality |
|------------------------|-----------------|
| > 4500 m/s             | Excellent       |
| 3500 – 4500 m/s        | Good            |
| 3000 – 3500 m/s        | Medium          |
| < 3000 m/s             | Doubtful        |
3. Results and Discussions

3.1. SK Specimen

The specimen control (SK) is a column of monolithic specimens before repair. From the results of a single static load, it can be seen that horizontal bending occurs when the load is 1,150 kg with a deflection of 1.98 mm on the beam on the four grid. The results of the stiffness values in the first crack in the beam-column joint are 581 kg/mm. At a load of 1,200 kilograms with a deflection of 2.18 mm, horizontal bending slits occur in the four and six lattices spaced 20 cm and 30 cm from the beam-column joints. Cracks increase in length at a load of 1,400 kg and produce a deflection of 3.38 mm. Then flexural shear cracks are started at 1,450 kilograms with a deflection of 3.74 mm. At 1,500 kilograms, crack openings occur in the meeting area of the beam and column joints, but cracks in other areas are no longer increasing. The crack opening in the beam-column joint increases in length and width until the peak load reaches 1,686 kg and the deflection is 6.08 mm. The concrete spalling enlarges towards the compression area until the test stops when the load drops to 33% of the peak load. The results of the crack pattern in the SK specimens is shown in Figure 2.

![Figure 2](image)

Figure 2. The final results of crack propagation on the SK specimen (front, back, and side view)

3.2. SK-R Specimen

The SK-R specimen is a specimen beam-column that is repaired after being damaged by grouting (Sikagrout 215 New). The cracks of horizontal bending began in the beam on the grid seven with a deflection of 0.66 mm when the load was 700 kg. The value of stiffness when the first crack occurs is 1,063.8 kg/mm. At a load of 1,200 kilograms with a deflection of 1.59 mm, there is horizontal bending crack of one and two grid with distances from 5 cm and 10 cm from the beam-column joint. At a load of 1,500 kg with a deflection of 2.91 mm the two grid cracks increase in length and width, the crack six grid increases in length and the spalling of concrete begins on the compressed of the beam zone. The flexural shear crack started when the load was 1,550 kg with a deflection of 4.08 mm at a capacity of 1,600 kg the area of the beam and column. When these openings occur, crack in other areas no longer develop. The beam column intersection opening increases in length and width until the peak load is 1,686 kg with a deflection of 8.07 mm. Concrete spalling extends to the compression area has dropped to 38% of the peak load. The crack pattern beam-column joint on the SK-R specimen are shown in Figure 3.

![Figure 3](image)

Figure 3. The final results of crack propagation on the SK specimen (front, back, and side view)
3.3. The results test of a single static load and discussion

The results of testing a single static load on SK specimen and SK-R specimens are shown in Figures 5 and Figure 6:

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

**Figure 5.** The relationship between deflection and load (a) $X = 100$ cm (deflection 100 cm from the column); (b) $X = 10$ cm (deflection measurement of 10 cm from the column)

**Figure 6.** The behavior of beam-column joint stiffness (a) $X = 10$ cm; (b) $X = 100$ cm
Figure 5 (a) shows the results of the behavior comparison between load and deflection for deflection measurement of 100 cm from the column, X = 100 cm before 1,669 kg and 6.83 mm; after 1,686 kg and 8.07 mm. Meanwhile, Figure 5 (b) shows a comparison of the behavior between the load and the deflection for a deflection measurement of 10 cm from the column, X = 10 cm before 1,669 kg and 2.89 mm; after 1,686 kg and 0.56 mm. Figure 5(a) and 5(b) aim to see deflection in plastic joints.

Figure 6 (a) shows the stiffness behavior of the higher / more rigid beam connection with the first stiffness of 577.50 kg/mm and the end of 2,763.9 kg/mm with a difference of 79.11% (measurement of deflection 10 cm from the column, X = 10 cm). Figure 6 (b) shows the result of the beam-column joint behavior for deflection measurement of 100 cm from the column (X = 100 cm) which decreases the first stiffness of 244.36 kg/mm and the tip of 208.81 kg/mm with a difference of 14.48%.

3.4. The result of the UPV test

The results of UPV testing on SK-R specimens are shown in Figures 7 and Figure 8:

Table 2. Recapitulation of UPV testing

| No | Number       | Date & time    | Distance (m) | Total velocity (m/s) | Correction | Average quality |
|----|--------------|----------------|--------------|----------------------|------------|-----------------|
| 1  | SK-A0-L2-R   | 12/06/2018 12.34 PM | 0.200        | 3080                 | 1.30       | Good            |
| 2  | SK-A0-L2-R   | 12/06/2018 12.27 PM | 0.150        | 3575                 | 1.30       | Medium          |

From Figure 7, 8 and Table 2, it can be seen that the concrete quality in the beam-column joint structure has an average wave velocity of 3,327.5 m/s (medium category).
Figure 8 shows the results of the average modulus of elasticity of the test are 20.43 GPa.

4. Conclusion

The test results show that the repair on a joint column can restore the beam-column joint performance but it decreases stiffness performance. This performance improvement is a good bond between old concrete and concrete grouting repairs. The beam-column joint performance before and after repairs have relatively the same flexural strength of 1,669 kg and 1,686 kg, while the stiffness increases/more rigid at 79.11% (X = 10 cm). The result of the beam-column joint behavior for deflection measurement of 100 cm from the column (X = 100 cm) decreases the first stiffness of 244.36 kg/mm and the tip of 208.81 kg/mm with a difference of 14.48%. The UPV test which obtained wave propagation speed on the beam-column joint structure after retrofitting has an average velocity of 3,327.5 m/s (medium category), and the average modulus of elasticity of the test was 20.43 GPa. Repairing damage to building infrastructure must be done immediately so as not to increase the level of damage to be fatal and require a significant cost.

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