Experiment Study of Ultrasonic Pulse Velocity Test of R/C Column Under Axial Load Variation

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Abstract. This study presents a simple NDT method with Ultrasonic Pulse Velocity (UPV) to detect repair of R/C columns by injection and grouting. In this paper, the technique applied is mainly based on the use of epoxy under pressure into the R/C column crack system for lightly damage, whereas grouting used for repair of medium and heavy damaged R/C columns. The specimen is initially charged to increase axial loads up to 0.1P0, 0.3P0 and 0.5P0. After repair, all specimens were retested with the same method. The test results show that the repair technique is in a good category with a pulse velocity value of 4.21km/s. Pulse velocity transmitter analysis provides conceptual support to increase column capacity through repair methods. Direct methods can be recommended for post-repair structural strength with high accuracy. This method is a potential candidate for future development, especially to predict the level of damage and building rehabilitation after an earthquake.

Keywords: Axial load, NDT, UPV, R/C column

1. Introduction

Based on the current seismic building design methodology, earthquake damage cannot be concentrated at the lower end of the column or plastic joint, because it will cause the building to collapse. During strong earthquakes, R/C columns structures suffer damage such as concrete crushing and sloughing [1], withdrawing longitudinal steel rods, and bending or fracturing longitudinal or transverse steel bars.

The study of repairing concrete columns damaged by lateral forces has been widely developed by [1-4]. For damaged RC columns without cracked or cracked iron bars, repair techniques include loose concrete removal, cracked epoxy injection [5-6], grouting or an external jacket [1-2]. In this case, the use of injection and grouting for column repair is reported to improve the performance of the post-damaged structure as reported [7]. This is confirmed from the results of the test before and after repairing the column structure.

In recent years, Non Destructive Test (NDT) was quite popular among researchers. The use of NDT that is able to predict material behavior such as compressive strength [8-9], concrete homogeneity [10-12], crack prediction [13-14], is very helpful in the process of evaluating work in the field of civil
engineering. In addition, in reality the evaluation of structural work installed in the field with the NDT method can provide significant benefits such as labor and time.

In this paper, the work was focused on direct NDT testing using Ultrasonic Pulse Velocity (UPV). NDT method using direct test supported by statistical analysis can provide valuable conceptual justification for knowing the quality of structures installed in the field. R/C column was chosen because it is a vital object in a building that forwards the load from the beam and plate to the ground through the foundation, the reliability of the column structure will be tested when an earthquake occurs, especially in the plastic hinge area. Therefore, the structural model developed in this paper simultaneously simulates the effects of earthquake forces that occur in the structure column, with a special review of the plastic hinge area (soft story effect). The type of damage that occurs is limited to lightly damaged with a crack width less than 1mm and is moderately damaged with a crack width of more than 1mm, whereas being severely damaged with a crack width of > 2mm.

The injection repair method was chosen because it is a modern technique that is used to increase the strength of concrete structures, has a very fast setting (5-15 minutes), this material is also capable of penetrating cracks with a width of up to 0.1mm. The use of this method can conquer problems such as non-structural cracks, and voids. Epoxy injection has been successfully used in the repair of cracks in buildings, bridges, dams, and other types of concrete structures [15]. The use of injection and grouting for reinforced concrete structures has been studied by many researchers [5-7]. However, the author has not found a previous study in detail revealing the success of this method which is actually unless the cause of the cracking has been corrected, it will probably recur near the original crack. If the cause of the cracks cannot be removed, then two options are available [15].

Finally, the process of modeling, analysis parameters and options needed related to the repair method are explained. The existence of changes in geometry and material at the time of testing can be considered as a potential source for revealing structural failure behavior. In addition, the crack patterns obtained at various stages of loading are very significant to identify the repair methods that need to be carried out. The accuracy of the test using the direct method for predicting post-repair strength was reported in this paper.

2. Materials and Methods

2.1. Materials

2.1.1 Before repaired
The production of the test material before repaired using ready mix concrete, with a concrete compressive strength of $f_{c'} = 25$ MPa, which is considered that the strength of the concrete was relatively the same for all materials because it was stirred in one ready mix and worked in almost the same time.

2.1.2 After repaired
The material used after repaired of R/C column such as nipple, Epoxy materials and hardener and Mortar. Ultrasonic pulse velocity testing schemes using the direct method have been reported by [8,10], with a distance of 100mm each test point [8,10,12], the test schematic is presented in Figure 1 below.

2.2. Ultrasonic Pulse Velocity
The UPV equipment (e.g. PUNDIT) includes a transducer, a receiver and an indicator for showing the time of travel from the transducer to the receiver [16]. The pulses go through the concrete and reach the receiver [17]. The test equipment must provide a means of generating a pulse, transmitting this to the concrete, receiving and amplifying the pulse and measuring and displaying the time taken [18]. UPV tests are also performed to predict strength of early age concrete [19], homogeneity materials [10,12], compressive strength [8-9,20], indicate the presence of voids and cracks, and to evaluate the effectiveness of crack repairs [17].
Ultrasonic pulse velocity testing schemes using the direct method have been reported by [8,10,12] with a distance of 100 mm at each test point [8-9,20]. The Ultrasonic pulse velocity test as shown in Figure 1.

![Figure 1. Schematic of Pulse Velocity test on R/C column specimen](image)

To calculate the pulse velocity as follows ASTM C 597-02 [17]:

\[
V = \frac{L}{T}
\]

Where:
- \( V \) = pulse velocity, m/s,
- \( L \) = distance between centers of transducer faces, m,
- \( T \) = transit time, s.

### 3. Results and Discussion

#### 3.1. Direct test methods

##### 3.1.1. Direct test methods of R/C before crack

Direct test method for concrete before cracking is carried out at 72 reading points. The test results are presented in Table 1.

**Table 1. UPV test of R/C column before crack**

| Ref | Specimen | Left side | Top Velocity | Bottom Velocity | Standard of Deviation | Coef. of Variants | Right Side | Pulse Velocity Average of Concrete R/C Column Before Repaired | Standard of Deviation | Coef. of Variants |
|-----|----------|-----------|--------------|----------------|----------------------|------------------|------------|---------------------------------------------------------------|----------------------|------------------|
|     |          |           | Top Velocity | Bottom Velocity | Standard of Deviation | Coef. of Variants | Top Velocity | Bottom Velocity | Pulse Velocity Average of Concrete R/C Column Before Repaired | Standard of Deviation | Coef. of Variants |
|     |          |           | (km/s)       | (km/s)         | (sd)                 | (%)              | (km/s)     | (km/s)         | Pulse Velocity Average of Concrete R/C Column Before Repaired | (sd)                 | (%)              |
| 1   | Reference | C         | 3.69         | 3.69           | 0.074                | 0.546            | 3.68       | 3.61           | 3.63             | 0.0002               | 0.362            |
|     | Reference | D         | 3.69         | 3.69           | 0.074                | 0.546            | 3.68       | 3.61           | 3.63             | 0.0002               | 0.362            |
| 2   | Reference | C         | 3.62         | 3.69           | 0.013                | 0.018            | 3.79       | 3.63           | 3.78             | 0.0125               | 1.573            |
|     | Reference | D         | 3.69         | 3.66           | 0.013                | 0.018            | 3.79       | 3.63           | 3.78             | 0.0125               | 1.573            |
| 3   | Reference | C         | 3.71         | 3.69           | 0.034                | 0.115            | 3.76       | 3.63           | 3.77             | 0.034                | 1.483            |
|     | Reference | D         | 3.71         | 3.69           | 0.034                | 0.115            | 3.76       | 3.63           | 3.77             | 0.034                | 1.483            |
3.1.2. Direct test method of R/C column after repaired

Direct test method during post-repair concrete is carried out at 72 reading points. The test results are presented in Table 2.

### Table 2. UPV test of R/C column after repaired

| No   | Reference column | Specimen | Left Side | Bottom Side | Top Right | Bottom Right | Standard of Deviation | Coef. of Variants | Standard of Deviation | Coef. of Variants |
|------|------------------|----------|----------|------------|-----------|--------------|-----------------------|-------------------|-----------------------|-------------------|
|      |                  |          | Pulse Velocity Average | Standard of Deviation | Coef. of Variants | Pulse Velocity Average | Standard of Deviation | Coef. of Variants |
|      |                  |          | (km/s)   | (km/s)     | (km/s)    | (km/s)       | (%)                   | (%)               | (%)                   | (%)               |
| 1    |                  |          | 3.53     | 3.79       | 3.66      | 3.68         | 3.70                 | 3.69              |                       |                   |
|      |                  |          | 3.54     | 3.79       | 3.65      | 3.64         | 3.62                 | 3.63              | 0.0741                | 0.549             |
|      |                  |          | 3.50     | 3.72       | 3.61      | 3.57         | 3.69                 | 3.63              |                       |                   |
|      |                  |          | 3.58     | 3.83       | 3.71      | 3.72         | 3.64                 | 3.68              |                       |                   |
|      |                  |          | 3.53     | 3.81       | 3.68      | 3.68         | 3.66                 | 3.66              |                       |                   |

Table 2 shows that the values of standard deviations and variance coefficients vary. The accuracy of direct method testing is very good indicated by a small standard deviation value [3] [12]. This is supported by the data from the calculation of variant coefficients which means that the results of the test by direct method can be accepted with the value of the coefficient of variance less than 10% [3].

### 3.2. Statistical test

The first step carried out in statistical analysis is the normality of data testing [3] [13]. ANOVA test results on KR-1 show that the level of significant 0.041 with a probability value of 0.00 <0.05, which means that the sample has a different variance. Furthermore, the results of the independent samples t-test analysis also shows that the level of significance is 0.370> 0.05, which means that Ho is accepted. The interpretation of the test results is that there is no difference in the test results either before or after repaired, in other words the improvement in the KR-1 column by injection has no effect on the strength of the R/C concrete column. In KR-2 specimens tested using Kolmogorov smirnov obtained Asym sig
(2-tailed)> a, which means the data is normally distributed. A t-test is conducted to show the effect of injection material and grouting on the repaired column and before cracking occurs. The test results show that t\text{value} 1.758 < t\text{table} 2.447 which means the injection process was successful.

Whereas with the same step has been obtained the value of KR-3 with t\text{value} < t\text{table} which means the repair process is successful [8-9,12].

3.3. Categories of R/C Column based on pulse velocity transmitter test
The UPV test results for various categories are presented in Table 3.

| Specimen | Axial Load of R/C Column | Pulse Velocity Average Using Direct Method | After Repairing |
|----------|--------------------------|--------------------------------------------|-----------------|
|          |                          | Without Axial Load | Axial Load | Crack of R/C |                  |
| KR-1     | 0.1P₀                    | 4.17               | 4.21       | 3.88        | 4.02             |
| KR-2     | 0.3P₀                    | 4.24               | 4.01       | 3.98        | 3.86             |
| KR-3     | 0.5P₀                    | 4.24               | 4.00       | 3.74        | 3.95             |

In Table 3 above, it can be seen that the addition of load on KR-1 of 0.1P₀ will increase the pulse velocity transmitter 0.96%. Whereas when the R/C column cracked the pulse velocity transmitter was decreased 7.47% and became increased 3.6% compared to the time of cracking, even though the value was smaller than without axial load. After post-repaired the value of pulse velocity decreases 3.10% compared to R/C column of crack. The KR-2 specimen shows that with 0.3P₀ it can reduce the pulse velocity value of 0.71%. The conditions in the R/C column are crack, the pulse velocity was decrease 0.75%. After post-repaired the value of pulse velocity decreases by 3.10% compare with R/C column during cracks. Whereas KR-3 shows that the load at 0.5P₀ will reduce the pulse velocity transmitter of 6%. The condition of the R/C column decreases at the crack of 1.26% and post-repaired increases of 5.61% although the value is still beneath the initial value (before crack).

Afterwards, repairing method with the injection and grouting can improve performance of R/C column structure 9.51% or higher than the average initial pulse velocity transmitter values. The R/C column at KR-3 has a very significant level of performance because the load of 0.3P₀ is quite large resulting in spalling of the structure. Therefore, the load of 0.3P₀ repairs becomes easier only using grouting materials. Conversely, the injection of concrete with small cracks does not guarantee that the injection material is able to fill the crack completely [15]. This is evidenced by the results of testing at KR-2, where the injection material has not been able to restore the performance of the post-repaired structure.

Last but not least, the final result is state of the art from a system of finishing structures and careful attention must be given to the presence of the bond between the substrate or the epoxy itself, resulting in lower strength. Failure of the injection method is more likely to bond to the surface. In small cracks the material is difficult to penetrate into the concrete pore, so the repair process is not perfect [15]. Based on theory, if a pulse velocity can pass through the injection material, the speed of wave propagation will increase. This is because the testing of pulse velocity for injection material has 1.5 higher than that of concrete material.

Finally, concrete quality and pulse velocity classification according to [3] as presented in Table 4.

| No | Pulse Velocity by Cross Probing (km/s) | Concrete Quality Grading |
|----|--------------------------------------|--------------------------|
| 1  | Above 4.5                            | Excellent                |
| 2  | 3.5 to 4.5                            | Good                     |
| 3  | 3.0 to 3.5                            | Medium                   |
| 4  | Below 3.0                             | Doubtful                 |
From Table 4, the concrete quality category is based on the pulse velocity transmitter. In general, the average value of the test results for three specimens is 4.21 km/s, which means that the quality control of concrete both before and after repaired is good category [3].

3.4. Prediction of compressive stress based on pulse velocity transmitter

Ultrasonic pulse velocity test results for the prediction of concrete compressive strength as presented in Table 5.

Table 5. Compressive strength of concrete based on ultrasonic pulse velocity test

| Specimen | Axial Load | Without Axial Load | Compressive Stress Using Direct Method | Concrete Cylinders (28 Days) |
|----------|------------|--------------------|---------------------------------------|-----------------------------|
|          | (kN)       | (MPa)              | Axial Load (MPa) R/C Crack (MPa) After Repairing (MPa) | (MPa) |
| KR-1     | 0.1P₀      | 25.85              | 24.73 24.17 31.74                      |                 |
| KR-2     | 0.3P₀      | 26.68              | 25.05 23.20 30.44                      | 28.81          |
| KR-3     | 0.5P₀      | 26.13              | 24.97 22.37 24.68                      |                 |

The test results show that in general the average compressive strength for all specimens is 28.95 MPa. The compressive strength is similar to the test results of the cylindrical compressive strength from laboratory experiment that the value of 28.81 MPa. In principle, the compressive strength of concrete can be predicted through its pulse velocity transmitter. Therefore, UPV testing using direct method is very accurate to predict the compression strength of concrete as presented by [9,12].

4. Conclusions

Based on the test results can be concluded as follows:

- Standard deviation and coefficient of variants show a relatively small percentage, which means the quality of testing has a good performance
- The statistical tests showed that the KR-1 injection process was unsuccessful, while the damage to KR-2 and KR-3 which was repaired by grouting showed positive results
- R / C column both before and after repaired is included in the good category [3]
- UPV test using direct method can predict the compressive strength of concrete with level of accuracy 99.52% with a margin of 0.48% compared to experimental testing

5. References

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