EVALUATION OF REINFORCED CONCRETE'S BEAM'S CAPACITY WITH OPEN CRACK AND VARIATION OF COVER THICKNESS USING UPV AND HAMMER TEST

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ABSTRACT

Defect in building's structure can be analyzed by non-destructive method or NDT, such as UPV Test and hammer test. Furthermore the UPV, hammer test, compressive strength test, flexural test and statistical analysis show the accuration of quality test result with the NDT method. The specimen used is brick-formed with the dimension of 15x20x140 cm and the variation of cover thickness. Average relative error of hammer test of cylinder test is about 2,83% - 7,32%. While UPV's average relative error of cylinder sample is 4,74% - 55,05%. Based on statistical analysis, hammer test shows there is no significant difference, while UPV test shows that there is significant difference. Calculation of compressive strength before and after flexural loading obtains a number of relative error, in hammer test 5,58% - 10,53% and UPV test 7,35% - 13,05%.

Keywords: UPV, hammer test, NDT, concrete's compressive strength.

INTRODUCTION

Concrete is widely used in the development of advanced construction at this era. The characteristic of concrete that are durable, easy to form, and the customable quality to its function become the main reasons to use it. Flaw of concrete can cause damage in concrete's structure that decrease strength and bearing capacity as well. Repairing materials, by strengthening structures in order to restore the strength before damage (such as the use of bar reinforcement on concrete gravity's retaining) is widely used. In the construction of reinforced concrete there are common problems; one of them is mismatches planning to implementation. The differences between planning with implementation is caused by construction work's complex problem. Less expertised labor can be one of the causes.

Trivia mistakes in conducting procedure can affect the result of building construction's implementation. The results of implementation that occur due to errors in performing procedures such construction work suffered minor damage. Minor damage such as hair cracks in the structure should be avoided in order to prevent a greater effect on the construction. In overcoming minor damage certainly needed re-examination of the quality of concrete and reinforcement used. The re-examination method which had minor damage is non destructive method or *non destructive test*. Non-destructive test (NDT) is appropriate for structures that are currently in construct or already completed. This is because the test covers a wide range of fields. The wide variety of NDT methods are such as surface hardness (hammer test), penetration method (probe penetration test) and ultrasonic wave propagation method (UPV test).

The method can easily detect the quality of concrete. However, this study only uses the UPV and hammer test.

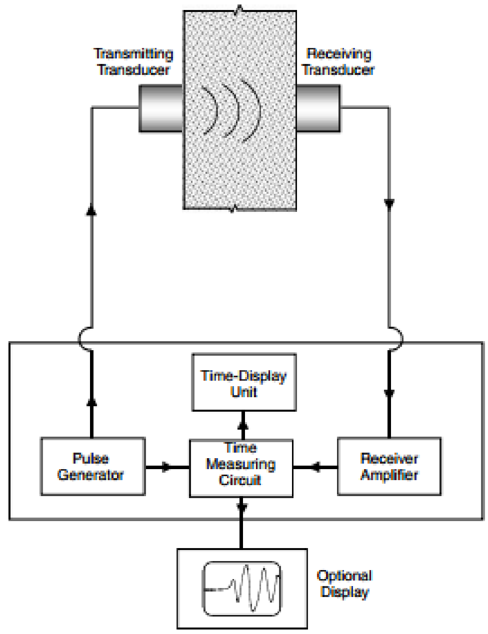
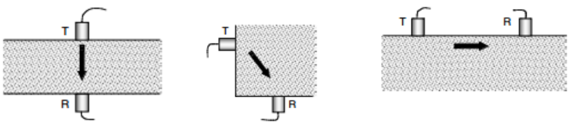


Figure 1. UPV test's flowchart
(source: V.M Maholtra dan N.J Carino, 2004)



Direct Transmission Semi-Direct Transmission Indirect Transmission

Figure 2. Methods to install transmitter and receiver
(source: V.M Maholtra dan N.J Carino, 2004)

THEORETICAL FRAMEWORKS

- UPV Test

Ultrasonic Pulse Velocity (UPV) is one of the NDT methods by using wave propagation based on the travel time and vibration of ultrasonic waves to the specimen width which is used as a wave track.

NDT methods are not directly provides results and value as the Destructive Test or DT. It required a lot of testing in order to obtain results.

UPV basically sending Vibration's wave on concrete. It receive and magnify vibration for then calculated the propagation of vibration waves's length. The wave which is used in the UPV method is the type of Electro-acoustical transducers. In the implementation of the test, the transmitter and receiver were given a gel-like light medium. Gel is useful to get a smooth surface on the surface of the specimen so the wave can easily propagate. There are several methods to install the transmitter and receiver on the surface of the concrete, including:

1. Direct Transmission
2. Semi-Direct Transmission
3. Indirect Transmission
4. Direct transmission is simpler in case of installation and very effective to obtain the wave's signal. Indirect transmission is a less effective way to get a wave signal as compared to direct transmission. Wave signal itself depends on how the spread of the wave in a medium. Vibration wave is influenced by situation of concrete's surface and the distance between the transmitter and receiver. In indirect transmission it is need to consider on the distance of transmitter and receiver to be arraged first as desired.

UPV is classified as NDT method so the quality of its accuracy is different from DT. There are various factors that affect the measurements of UPV test, including:

1. Concrete's surface condition
2. Concrete's temperature
3. The distance of transmitter and receiver
4. The influence to rreinforcement

Concrete's compressive strength's estimation by using SONREB (Sonic and Rebound) method, the measurement method using both UPV and rebound hammer to improve the accuracy of concrete's compressive strength's estimation. The methods used here were following Gasparik (1992) as follows:

$$fck = 8{,}06x10^{-8}V^{1{,}85}S^{1{,}246}$$

with:

fck = concrete's cimpressive strength (MPa)

V = wave's velocity in concrete (m/s)

S = rebound number (Q)

There are several influences on steel reinforcement in UPV test (see **Figure 3**) which is explained in **Table 1** and **Table 2**.

With:

V = Velocity in reinforced concrete (m/s)

V_c = Velocity in concrete (m/s)

V_s = Velocity in steel reinforcement (m/s)

L = Total distance between transmitter and receiver (m)

L_s = Total distance of wave propagation in steel reinforcement (m)

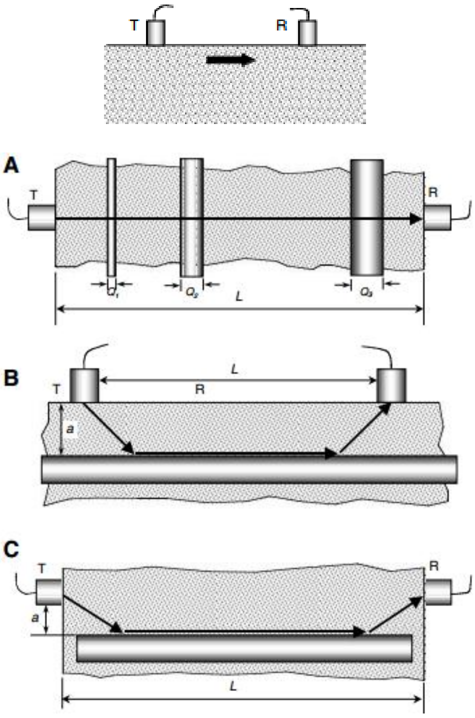


Figure 3. Measurement of reinforced concrete
(source: V.M Maholtra dan N.J Carino, 2004)

Table 1. Effect of steel reinforcement perpendicular to the axis of the rod reinforcement

Ls/L	V_c/V		
	For V_c = 3000 m/s	**For V_c = 4000 m/s**	**For V_c = 5000 m/s**
1/12	0,96	0,97	0,99
1/8	0,94	0,96	0,98
1/6	0,92	0,94	0,97
1/4	0,88	0,92	0,96
1/3	0,83	0,89	0,94
1/2	0,75	0,83	0,92

Table 2. Effect of steel reinforcement which is in the same direction with the axis of the rod reinforcement

α/L	Vc/V			
	Vc/V = 0,9	**Vc/V = 0,8**	**Vc/V = 0,71**	**Vc/V = 0,60**
0	0,9	0,8	0,80	0,60
1/20	0,94	0,86	0,86	0,68
1/15	0,96	0,88	0,88	0,71
1/10	0,99	0,92	0,92	0,76
1/7	1	0,97	0,97	0,83
1/5	1	1	1	0,92
¼	1	1	1	1

- Hammer Test

Rebound Hammer is one of the concrete test equipment in NDT. To test the concrete, rebound hammer's body is pressed so the rod bat held by concrete's surface. When rebound hammer pressed, weight-bearing load is locked and release load. The load apart and hit the rod bat to press conccrete's surface and bounce back because of the force that is produce by spring. Load bounce is read by indicator as rebound (R) value. The reding of load's bounce can be locked to ease rebound value reading.

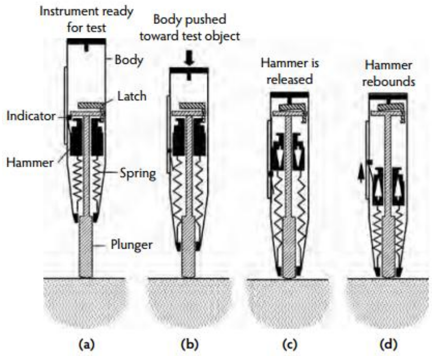


Figure 4. The condition of hammer test
(Source: V.M Maholtra & N.J Carino, 2004)

Table 3. Rebound's average rate with concrete's quality

Rebound**average rate**	**Concrete's quality**
>40	Very good
30-40	Good
20-30	Fair
<20	Bad
0	Very bad

(Source: V.M Maholtra & N.J Carino, 2004)

Concrete surface hardness is proportional to the strength of concrete. If the rebound's rate (R) which is generated by the rebound hammer is low, it indicates that the concrete surface is soft and low power. Rebound value which is is read by the rebound hammer is not only used to measure the hardness of concrete but also to determine concrete's compressive strength. The high rate rebound shows that the concrete is rigid and strong.

In estimating compressive strength with rebound rate is using standard curve that is lower 10% percentile. The formula of lower 10% percentile curve is:

$$fck = 2{,}77e^{0{,}048Q}$$

with:

fck = concrete's compressive strength (MPa)

Q = rebound rate (Q)

The valid range is from 22 Q to 75 Q, which is same with vary compressive strength 8 MPa to 100 MPa.

RESEARCH METHODS

- Concrete's Compressive Strength

Specimen used in this test is a cylindrical with a diameter of 15 cm and 30 cm high. In this research from 1 concrete's casting require 2 cylindrical samples. Therefore, in each variation, which is consist of 4 specimens, needs 4 casting. So in total, there are 40 samples of cylindrical test for all specimens.

- Hammer Test

Hammer test is performed on each test specimen in the form of concrete blocks with dimensions of 20 x 15 x 140 of 20 cpecimens, consists of 5 variations and each variation has 4 specimens. The test is conducted by hitting and pressing hammer bat 10 times upright concrete's surface. Each specimen is measured in 3 locations, see in **Figure 5**.

- UPV Test

UPV test is performed on each test specimen in the form of concrete blocks with dimensions of 20 x 15 x 140 cm of 20 cpecimens, consists of 5 variations and each variation has 4 specimens. UPV test is carried out by indirect transmission method which is installing UPV's transducer in a certain distance, B = 10 cm and 2B = 20 cm. Each specimen is measured in 3 locations, see in **Figure 6**.

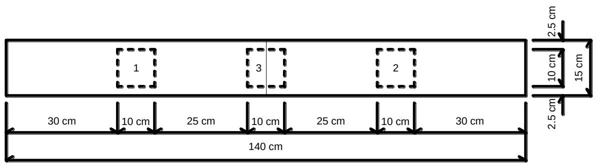


Figure 5. Hammer test's data collection's top view

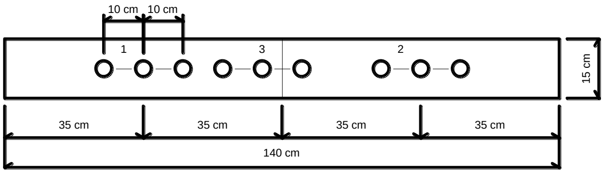


Figure 6. UPV test's data collection top view

- Concrete Beam's Flexural Loading

Flexural loading is measured by placing a load cell in the middle of the span and at the bottom of the dial reader 3 pieces. The data collection is conducted by reading dial gauge in a certain place. Specimen's flexural loading is divided into 2, for unreinforced specimens the maximum loading is 400 kg with dial gauge reading in 20 kg loading multiply. While for reinforced specimens, the maximum load given is 1000 kg with dial gauge reading in 40 kg loading multiply.

- After Loading-NDT

The test is performed on each test specimen that has undergone flexural cracks due to flexural loading. The instrument used is the hammer and UPV tests just like test before flexural loading.

RESULTS AND DISCUSSION

- Concrete's Compressive Strength

After the 28 day, compressive strength test is conducted to determine the top quality of concrete that have been made.

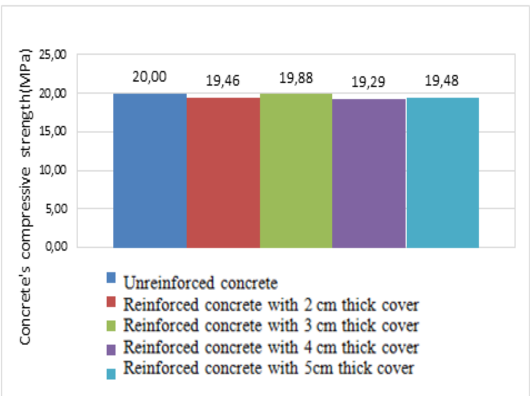


Figure 7. Average compressive strength test result

(Source: experimental results)

- Hammer Test

Figure 8 shows comparison of hammer's average compressive strength and average cylinder compressive strength of each variation.

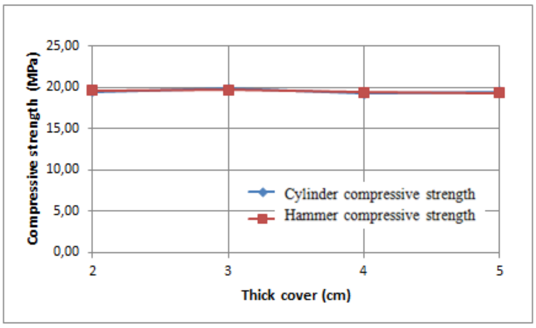


Figure 8. Comparison of average compressive strength of cylinder and hammer test.

(Source: experimental result)

- UPV Test

Figure 9 shows that compressive strength which is gained from UPV test that compared to cylinder is different. In a variation of reinforced concrete beams with 2 cm thick cover, UPV compressive strength and cylinders compressive strength have significant differences and continued to decrease in thick covers variation 3, 4 and 5 cm. **Figure 9** also shows a comparison of the average compressive strength of hammer with average compressive strength of cylinders in each variation.

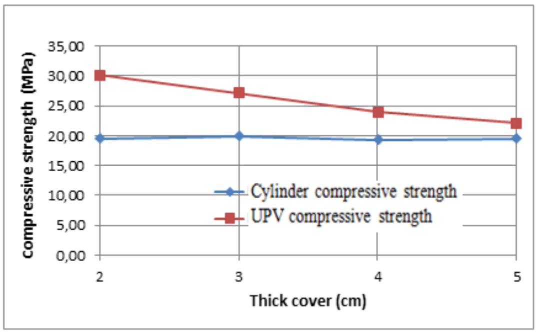


Figure 9. The comparison of average compressive strength of cylinder and UPV

(Source: experimental result)

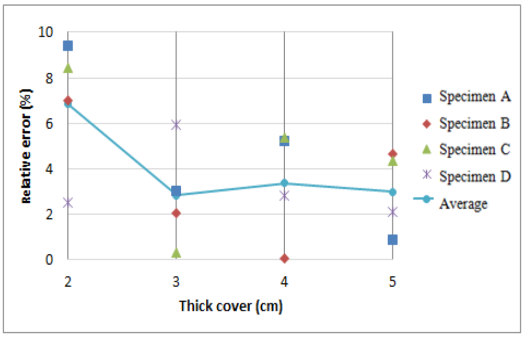


Figure 10. Average of compressive strength relative error results
(Source: experimental result)

The relative absolute error of compressive strength measurements hammer

The difference between the results of cylinder compressive strength test in concrete beams with compressive strength test using a hammer on each concrete cover thickness variations indicate certain relative error. Relative error on each variation obtained from the average relative error for each object in each concrete cover thickness variation.

Figure 10 shows the relative error hammer compressive strength of the average variation in each successive thick covers on reinforced concrete beams with 2 cm thick covers, reinforced concrete beams with a 3 cm thick covers, reinforced concrete beams with 4 cm thick cover and reinforced concrete beams with a 5 cm thick cover was 6.85%, 2.83%, 3.39% and 3.00%. While the variation of unreinforced concrete beams the relative error is 7.32%.

The relative absolute error of UPV compressive strength measurement

The difference between the results of cylinder compressive strength test of concrete and beams compressive strength using UPV for each concrete cover thickness variations indicate a certain value of relative error. Relative error on each variation obtained from the average relative error for each object in each concrete cover thickness variation.

Figure 11 shows the relative error hammer compressive strength of the average variation in each successive thick covers on reinforced concrete beams with 2 cm thick covers, reinforced concrete beams with a 3 cm thick covers, reinforced concrete beams with 4 cm thick cover and reinforced concrete beams with a 5 cm thick cover was 55,05%; 36,47%; 23,88% and 13,44%. While the variation of unreinforced concrete beams the relative error is 4,74%.

The relative error can be seen that the thicker the concrete cover, the error in the reading of compressive strength using UPV tool will be smaller and otherwise, the thinner cover of concrete resulting to greater relative error.

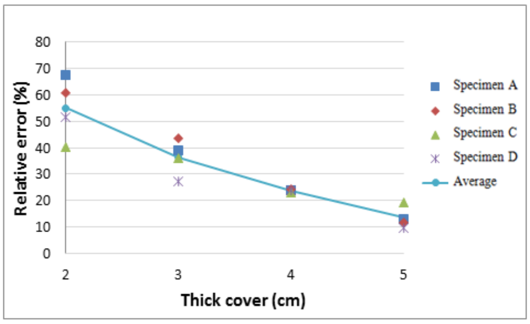


Figure 11. The average of UPV compressive strength relative error
(Source: experimental result)

The relative absolute error of NDT compressive strength test

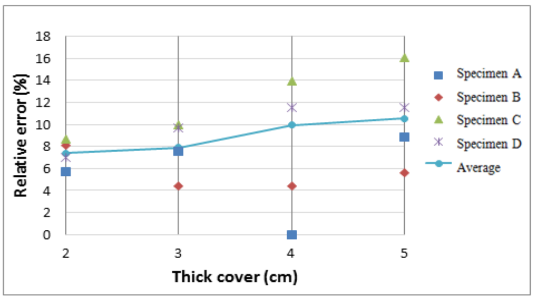


Figure 12. Average of Hammer compressive strength test relative error
(Source: experimental result)

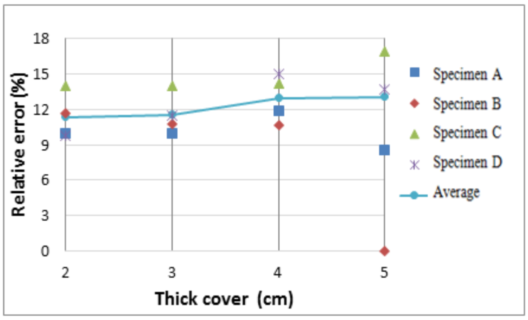


Figure 13. Average of UPV compressive strength relative error
(Source: experimental result)

The difference between the results of the compressive strength using NDT before loading with compressive strength after loading on each concrete cover thickness variations indicate the relative error. Relative error on each variation obtained from the average relative error for each object in each concrete cover thickness variation.

The average relative error of hammer compressive strength after loading compared with a hammer before loading's compressive strength ranged from 5.58% - 10.53%.

The average relative error of UPV's compressive strength after loading compared with the compressive strength of the UPV before loading are ranged between 7.35% - 13.05%.

Hypothesis

Hypothesis is conducted by statistical analysis, which is one-way F test. Hypothesis is conducted in order to know who had made the hypothesis can be accepted or rejected.

1. Hammer test statistical analysis
   Obtained F_{table} = 3,06 and F_{count} = 3,007, then $F_{count} < F_{table}$ so H_o is accepted which means there are no significant differences in the relative error of measurement results using the concrete compressive strength test hammer between concrete cover thickness variations to the cylinder test.
2. UPV test statistical analysis
   Obtained F_{table} = 3,06 and F_{count} = 35,949, then $F_{count} > F_{table}$ so H_o is rejected or H_1 is accepted which means there are significant differences in the relative error of measurement results using the concrete compressive strength test UPV between concrete cover thickness variations to the cylinder test.
3. NDT test statistical analysis
   Obtained F_{table} = 3,06 and F_{count} = 2,407, then $F_{count} < F_{table}$ so H_o is accepted which means there are no significant differences in the relative error of measurement results using a test concrete compressive strength with UPV before loading after loading between the variation thick concrete covers.

CONCLUSIONS

From these results it can be concluded as follows:

1. The results of measurements on the compressive strength of the cylinder test to hammer test, the relative error obtained on unreinforced concrete beams, concrete beams reinforced with a thick cover 2cm, 3cm, 4cm and 5cm respectively 7.32%, 6.85%, 2.83 %, 3.39% and 3.00%. While the results of the measurement of compressive strength test at the UPV test to cylinder, the relative error obtained on unreinforced concrete beams, concrete beams reinforced with a thick cover 2cm, 3cm, 4cm and 5cm respectively 4.74%, 55.05%; 36, 47%, 23.88% and 13.44%. This indicates that the thicker the concrete cover, the measurement error relative compressive strength at the UPV test will be smaller.
2. In the calculation of one-way analysis of F test with α = 0.05, it was concluded that there was no significant

difference in the relative error of measurement results using the compressive strength of concrete test hammer variations between concrete cover (unreinforced concrete and reinforced concrete beam with cover 2cm, 3cm, 4cm and 5cm) by using cylinder test. While in UPV, it can be concluded there are significant differences in the relative error of measurement results using the concrete compressive strength test between variations UPV concrete cover (beams without reinforcement and reinforced concrete beams with a cover 2cm, 3cm, 4cm and 5cm) to cylinder test.

3. Result of compressive strength measument using *hammer* test before and after loading, obtains relative error which is among 5,58% - 10,53%. After analyzed by using one-way F with $\alpha = 0{,}05$, it can be concluded that there was no significant difference in the relative error of measurement results using the compressive strength of concrete test hammer after loading before loading with variation between thick cover of concrete due to cracking that occurred. The results of compressive strength measurements at the UPV test before loading and after loading, it was found that the relative error ranged from 7.35% - 13.05% After analyzed one-way F test with $\alpha = 0.05$, it was concluded that there was no significant difference in the relative error of measurement results using a test concrete compressive strength with UPV before loading after loading between the variation due to the thick cover of concrete cracking that occurred.

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