Pulse Velocity and Rebound Hammer Test on Reinforced Concrete Slab in the Former Civil Engineering Laboratory Building

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Abstract

Reinforced concrete slab is an important structure component in a building. Reinforced concrete that has been used for long time should be evaluated to determine the current strength, durability and to know how long it can be stand. Poor quality of reinforced concrete will cause discomfort to customers, safety will be affected and strength will be reduced. If the problem is not monitored properly and no improvement is made, the reinforced concrete will fail and eventually it will collapse. The former building of civil engineering laboratory that was used for 12 years from 2000 to 2012 was being investigated their strength and crack percentage. In this study, six laboratories are been prepared and assessed. Equipments that used in this study are rebound hammer test and pundit test. The rebound hammer test is used to determine the current strength while the pundit test is used to investigate the pulse velocity, presence of crack and also properties of concrete. From the data, it was found that the laboratory achieve 30-40 MPa in current compressive strength. While in Pundit Test, it was showed that the quality of concrete in the laboratory is still having a good condition but doubtful in concrete quality. Finally reinforced concrete slab for this laboratory showed the consistent strength and no large or medium crack were detected. Thus, the reinforced concrete slab at former civil engineering laboratory is still safe and meets moderate quality.

Key words: Pulse Velocity, Rebound Hammer, Non-destructive Test, Reinforced Concrete Slab, Laboratory

1. Introduction

In construction site, there are a lot of material structure are used as an example steel structure, timber structure and reinforced concrete structure. Reinforced concrete structure is the most often used in construction because it's give many advantages when compare with other material structure. Example of the advantages are it can stand when load in compression or tension, thermal compactibility, ductile and durability. Reinforced concrete structure was maintained their strength after 28 days until its lifetime if there is no failure occurred. Reinforced concrete can fail due to a reduction in strength, durability failure and mechanical failure. For example, when reinforced steel corrodes, the rust will expand and spread tends to crack, flake and loose in bonding between steel and concrete. Cracking can flow water into the concrete and make the reinforced steel seriously corrode. Besides that, poor design and inadequate reinforced steel will allow the concrete crack when under excess load or internal effects. In the other way, the reinforced concrete structure can be tested to determine their quality, integrity, uniformity and to know the presence and location of the void or defect.

However, if the reinforced concrete structure strength decrease and it show the presence of void, crack or other defect. The defect is initiated occurs near the end of the life of the concrete. This defect can become big and more seriously and it's important to detect at a very early stage. Lastly, if this entire problem can't be settled the building or construction will damage or collapse. For prevent these problem, preliminary investigation must be done to determine the initial void or small crack. Failure and defects due to certain problem eventually cause the concrete structure to lose its quality and integrity.

The former building of civil engineering laboratory that was used for 10 years from 2000 to 2012 was being investigated their integrity, quality and uniformity. There are seven laboratories in civil engineering laboratory building i.e. soil mechanics lab, structure lab, water lab, building services lab, concrete lab, hydrology lab and survey lab. In this study, only geotechnical engineering laboratory is been prepared and assessed. This study is conducted on geotechnical engineering because of the high usage, a lot of heavyweight equipment and chemical activity. Furthermore this study also can determine either the building or reinforced concrete slab can be used for other program or sector. If the reinforced concrete slab in good condition, the maintenance issue is not be taken.

Non destructive test (NDT) is analysis equipment and techniques that used in civil, structural and forensic engineering. NDT is widely used to evaluate and determine the properties of a material, system or component. This test can save time and money as they assess the material properties without causing damage. For example of NDT such as Pundit test, rebound hammer, impact echo, strain measurement, penetration resistance, initial surface absorption, half cell potential and etc.

Rebound hammer is an equipment to determine the strength of material such as concrete and rock. Its measures the rebound of a spring loaded mass impacting the surface of the material. The equipment will hit the surface of material and it's dependent on the hardness of the material. When conducting the test, the equipment should be place perpendicular to the surface. The surface must clean, clear, smooth, flat and not moist.

The ultrasonic pulse velocity (UPV) technique is used to evaluate the quality of concrete structure, measure of concrete uniformity and evaluate the properties of concrete. Besides that, UPV also can measure the transit time, presence of voids, path length, perpendicular crack depth and elastic modulus. UPV can be used not only for concrete but also for timber, ceramics, cast iron, geological specimens and other materials. UPV is classify into three category of reading, direct test, indirect test and semi direct test. The schematic diagram of these three categories of reading is illustrated in Fig 1. UPV is used to assess of concrete quality for different structural components like roof beams, crane girders, shell beams, columns, shell roof and etc (Sahu and Jain, 1998). According to Whitehurst, 1951 concrete with density of 2400 kg/m^3 are considered excellent for 4500 m/s and above, good for 3500 – 4500 m/s, doubtful for 3000 – 3500 m/s, poor for 2000 – 3000 m/s and very poor for 2000 m/s and below. Besides that, the lower limit for good quality concrete is between 4100 – 4700 m/s (Jones & Gatfield, 1955). As per IS: 13311 (Part 1) – 1992, concrete quality can be classified according to Table 1. Hamidian et. al. (2011) reported the pulse velocity is a good equipment to evaluate concrete strength and quality

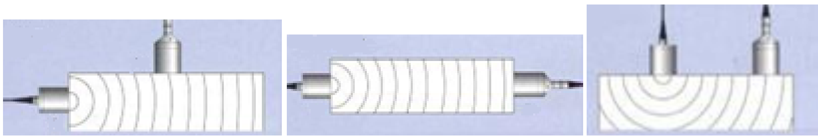
(a) (b) (c)

Fig 1: UPV test for (a) semi-direct, (b) direct and (c) indirect test

Pulse Velocity (km/second)	Concrete Quality (Grading)
Above 4.5	Excellent
3.5 to 4.5	Good
3.0 to 3.5	Medium
Below 3.0	Doubtful

Table 1. Concrete quality and pulse velocity classification according to IS: 13311 (Part 1) – 1992

There a many studies related to the UPV and rebound hammer for example Demirboga et al., 2004 studied ultrasonic velocity for high-volume mineral-admixture concrete. Yang et al., 2009 evaluated the residual compressive strength of concrete subjected to evaluated temperature. Evaluation of concrete containing crumb rubber (rubbercrete) as a fine aggregate replacement using rebound hammer and ultrasonic pulse velocity (Mohammed et al., 2010). Non-destructive testing was carried out using UPV and impact rebound hammer techniques to establish a correlation with the compressive strengths of compression tests of concrete used in Algeria (Hobbs and Kebir, 2007). Solis-carcano & Moreno (2008) reported the ultrasonic pulse velocity tests are used to evaluate of concrete made with crushed limestone aggregate. Shariati et. al. (2011) used ultrasonic pulse velocity and Schmidt rebound hammer to reveals an improvement in the concrete strength estimation and produces more reliable results.

2. Methodology

Reinforced concrete slab is one type of structural element with thickness between 10 cm until 50 cm. It’s used to construct floors and supported on foundations or directly on the soil. First part, geotechnical laboratory reinforced concrete slab was drawn grid and marked black points on each grid. These grid lines are measured from the wall of 0.5 m and each grid point to another grid point (left and right) also measured of 0.5 m. Fig 2 and Fig 3 show the grid line and point of the geotechnical laboratory. Every grid point was marked with a grid of letters and numbers to differentiate each grid. The length 0.5 m between the grid points to other grid points are for the accuracy in the reading as shown in Fig 4. The sufficient length can avoid the presence of any error due to its heterogeneity. The void or crack to be able to easily detect when the transmitter and receiver are not far from each other.

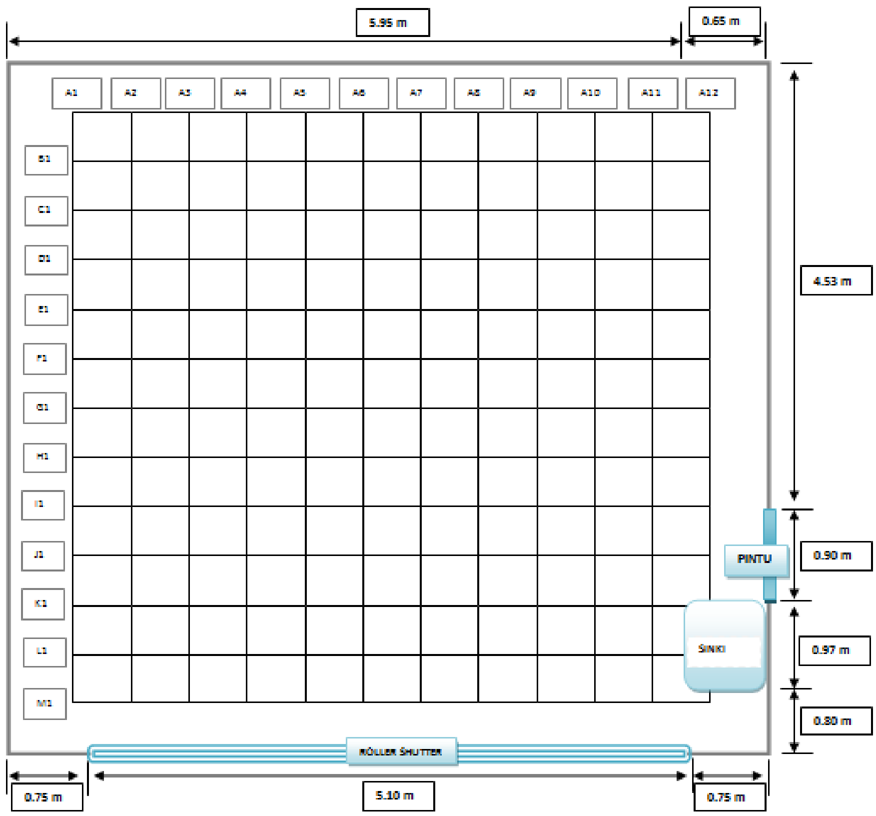

Fig 2: Grid line and grid point of the former geotechnical laboratory

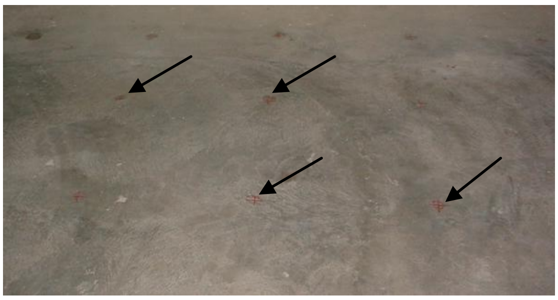

Fig 3: Actual grid point on the concrete slab

Fig 4: Distance between transmitter and receiver on concrete slab

The ultrasonic test equipment that used in this study is PUNDIT (Portable Ultrasonic Non-destructive digital Indicating Tester) test and followed the BS 1881-203 standard. UPV method based on measuring the velocity of compression wave and the velocity travelling in a solid material depends on the density and elastic properties of material. The equipment consists of a transducer for transmitter and transducer for receiver. Transducer for transmitter is which wave or pulses are transmitter while transducer for receiver is wave are received and directly indicate the time of travel. Concrete surface must be smoothed from rough and smooth surface so that the transducers easy to be placed. The data was obtained by using method that specified in the BS 1881-203. In this study, UPV data for reinforced concrete slab is conducted only in indirect testing as shown in Fig 1. This is because the slab surface only in one layer horizontally. Data of pulse velocity, path length, transit time and elastic modulus were taken directly from UPV equipment for every grid point to grid point.

The rebound hammer or Schmidt hammer that used in this study is simple and provides a quick reading. According to BS 1881-202, the equipment is conduct to assess the general quality, uniformity and strength of concrete. Before start of a test, the equipment should be tested their reliable results by using the test anvil. Then, the equipment was applied and pressed with keeping perpendicular to the surface. It was pressed until the hammer impacts and the button on it also be pressed to note the reading. The average of three reading for every grid point was taken. In this study, the equipment was measured the compressive strength of the concrete slab. The concrete can be checked either the concrete is in good quality or not quality and poor concrete by using Table 2. There are many factors that influence readings, including moisture content, surface smoothness, surface of finishing, types of coarse aggregate and the presence of carbonation in concrete.

Average Rebound Hammer (MPa)	**Quality of Concrete**
>40	Very good hard layer
30 to 40	Good layer
20 to 30	Fair
<20	Poor concrete
0	Delaminated

Table 2. Average rebound reading with condition of concrete (BS 1881-202)

3. Result and Discussion

A. Rebound Hammer

The results of rebound hammer on the slab were analyzed by determine the average value of each point. Table 3 shows the average compressive strength value of each point on the slab. The maximum compressive strength is 45.33 MPa were found at grid A1, while minimum compressive strength is 24 MPa were found at grid M1. The contour line for 40 MPa and 30 MPa were identified to illustrate the region of concrete condition. It shows that the strength of the laboratory is non uniform across the floor slab. Four big areas located at grid A-C/1-12 is in highest strength between 32 MPa to 45.33 MPa. From Table 2, it shows that only 1% of total area in laboratory is classified as fair in condition of quality. While 94% and 5% of total area are considered as good layer and very good hard layer in condition of quality respectively.

	1	2	3	4	5	6	7	8	9	10	11	12
A	45.33	40.67	40.00	41.33	38.67	40.67	41.00	44.00	38.67	38.67	42.00	40.67
B	30.00	43.33	41.33	41.33	32.67	40.67	36.00	40.00	35.33	40.67	41.33	42.00
C	34.00	38.67	39.33	38.67	32.00	32.00	40.67	33.33	34.00	41.33	39.33	36.67

D	30.67	32.00	40.00	38.00	32.67	31.33	32.00	35.33	39.33	35.33	41.33	39.33
E	38.00	32.67	40.67	40.00	32.67	38.67	36.00	31.33	32.67	41.33	34.67	34.67
F	34.67	32.00	40.67	40.67	39.33	34.00	30.67	40.00	40.00	37.33	37.33	33.33
G	39.33	43.33	41.33	43.33	41.33	34.67	40.00	40.00	35.33	37.33	33.33	25.33
H	36.00	36.00	40.00	39.00	31.33	30.00	34.67	32.00	32.67	26.67	40.00	26.00
I	31.33	33.33	36.67	42.67	40.00	40.00	27.33	40.00	35.33	32.00	36.67	36.00
J	40.67	34.00	36.67	40.67	39.33	40.00	34.67	41.33	32.67	32.00	36.00	32.00
K	34.67	34.00	35.33	40.00	38.67	42.00	39.33	37.33	41.00	34.67	36.00	32.67
L	30.67	40.00	38.67	32.67	38.00	34.67	36.00	39.33	37.33	40.67	36.00	22.67
M	24.00	39.33	35.33	39.33	40.67	36.00	35.33	34.67	40.33	42.00	32.67	30.67

Table 3. Average compressive strength of the floor slab at each grid point (all in MPa)

B. Pundit Test

Table 4 show the results of Pundit test for Transit time, Path length and Velocity. Grid point E illustrates the highest transit time and velocity of pulse value. Then, grid point K and J show the lowest transit time and velocity value are range about 220 to 250 usec and 1000 to 1010 m/s respectively. Average for this lab is 341.47 usec for transit time and 1362.69 for pulse velocity reading. According to standard IS in Table 1, this lab can be graded as doubtful category below 3000 m/s. Velocity of pulse in concrete structure decreases if there are any obstacles such as air void, cracks or other defects. From the result, integrity of concrete on this lab is classified as moderate and defected. From the observation, the reinforcement in the slab can influenced the reading of the pundit test. The pulse velocity that measured near the reinforcing steel bars and the amount of steel bars is not representing the true reading (Concrete Technology, 2004). In the other hand, the presence of a lot of small void in this concrete and aggregate size also can affect the pulse velocity reading.

Point	**Transit time (usec)**	**Path length (m/mm)**	**Velocity (m/s)**
A	281.5	141	1126
B	412.2	73	1644
C	293.8	169	1176
D	487.5	102	1944
E	537.2	60	1998
F	273.3	110	1088
G	462.0	103	1846
H	271.0	110	1085
I	269.5	111	1077

J	251.7	135	1004
K	225.6	118	1006
L	294.7	98	1220
M	379.1	79	1501
AVERAGE	341.47	108.38	1362.69

Table 4. Pundit test result for every grid point

Grid Point	Highest Transit time (usec)	Pulse Velocity (m/s)
A1-B1	281.5	1126
B10-B11	412.2	1644
C1-D1	312.9	972
D1-E1	487.5	1944
D12-E12	375.5	1673
E1-E2	459.5	1910
E12-F12	537.2	1998
F11-G11	273.3	1088
G3-G4	462.0	1846
G11-H11	293.3	1072
G12-H12	288.2	1040
H6-I6	271.0	1085
I10-J10	269.5	1077
I10-I11	254.2	1021
J8-K8	273.6	848
K3-K4	248.8	975
L4-L5	249.8	966
L5-L6	247.1	824
M10-M11	379.1	1501

Table 5. The grid point with value of pulse velocity and higher transit time

Grid line is the mesh line that conveyed between two grid points on the slab. Total grid point is 300 point. Based on the results from UPV test, it was found 18 grid points were results in higher value of transit time ranging between 254 µsec to 537 µsec. The higher values of transit time were correspondent to higher value of pulse velocity. The slowest pulse velocities were found at grid point C1-D1, J8-K8, K3-K4, L4-L5 and L5-L6 with value of 972 m/s, 848 m/s, 975 m/s, 966 m/s and 824 m/s respectively. Table 5 was shows the critical grid points which can be consider as good condition of slab where this area may not have void or crack present in the slab. However, the critical location is only 6 % of total area of the slab. Other points ware shown lower value of transit time from 493 m/s to as low as 122.8 µsec at grid point C5-C6. The fastest pulse velocity were found at E12-F12 with value 1998 m/s. 42 % of all link is results more than 900 m/s pulse velocity, balance 58% were results below than 900 m/s. Hence the slab is still considered as good condition.

4. Conclusion

From the experimental data, the following conclusions can be drawn:

i. The average of compressive strength on the geotechnical laboratory is 30 – 40 MPa.
ii. The average of pulse velocity is 1362.69 m/s far from the excellent category in concrete quality.

iii. Overall of the concrete structure can be categorized as moderate because the strength is good but the presence of the void or crack is doubtful.

The rebound hammer and Pundit test equipment have been used to evaluate the concrete structures are not sufficient in this study because of high variations are obtained. This is because the equipment just had result on the surface of the concrete structure. Some other NDT method and equipment should be used in this study to investigate the precise data such as Pull out Tester, Half Cell Potential and Strain measurement. The use of combined methods also can produces results that are more reliable when compared with the use of the above equipment separately (Hobbs and Kebir, 2007).

The following recommendation can be made from the study:

i. Extension the study by checking the temperature of concrete and minimize the length of transducers.
ii. Extension the study by checking the moisture content of the reinforced concrete structure.
iii. Extension the study to evaluate the reinforced concrete structure by using other method or equipment of NDT.

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