Recent Trends in Civil Engineering and Built Environment Vol. 4 No. 1 (2023) 098-107

RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

Reliability of Non-Destructive Test Approach on Structural Strength Assessment

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DOI: https://doi.org/10.30880/rtcebe.2023.04.01.011
Received 06 January 2022; Accepted 15 January 2023; Available online 01 May 2023

Abstract: Complaints regarding structural integrity of an existing concrete building aroused questions and safety concerns on the actual condition of the building. Non-Destructive test approach like Rebound Hammer test and Ultrasonic Pulse Velocity Test were conducted to assess the building's in-situ compressive strength on 10 locations respectively. 5 core samples (100mm x 100mm) were collected to compare and validate both NDTs' results. Compressive strength conversion obtained through conversion curve for rebound number ranges from 37.07N/mm^2 to 56.90N/mm^2. The highest recorded reading for UPV test was 3840m/s, while lowest was 2505m/s. The quality of concrete was classified as good for 8 points, 10 doubtful, and 2 poor. Highest core strength was 32.93N/mm^2 and lowest at 15.78N/mm^2. This suggested compressive strengths obtained through rebound hammer test via the conversion curved indicated an overestimation behaviour. Using SONREB method, conversion of compressive strength using formulations by showed a nearer value to the core specimen compressive strength with highest R2 at 0.0683. Results using SONREB method showed a more reliable estimation of in-situ compressive strength. However, conventional DT method using core test still outrun the reliability of NDT approach in terms of estimation accuracy of compressive strength of existing concrete.

Keywords: Non-Destructive Test, Rebound Hammer Test, Ultrasonic Pulse Velocity Test

1. Introduction

Reinforced concrete materials are generally the most common type of materials to be found in construction due to it is durability, availability, and safety such as providing better fire-proof quality as well as relatively lower cost compared to other construction materials such as steel. Granting reinforced concrete structure being highly durable with its distinguished reliably safe reputation despite being constructed decades ago, there are still certain inevitable cases in which buildings are structurally

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compromised. With the advancement of technology, assessment of building structure conditions is no longer limited to destructive testing method such as coring test which leaves permanent damages onto structure. Non-destructive testing (NDT), considered to be a newer type of structural assessment approach, is economical without causing any damages on structure. The concrete building studied in this paper has been built and officially occupied for purposes such as offices, tutorials, lectures, and laboratories in 2013. However, in recent years complaints have been received regarding the structural integrity of the campus building. Still far from reaching the average 50 years building lifespan, arouse questions and safety concerns on the actual condition of the building. It is important to address this issue immediately in ways that leaves no potential harm to the structural integrity of the existing building. To gain a fuller understanding on the existing condition, conducting non-destructive test approach can help develop insight on the actual condition of the structural integrity.

The objectives of this research are to assess the in-situ compressive strength of existing structural integrity using Non-Destructive Testing such as Rebound Hammer test and Ultrasonic Pulse Velocity test as well as to compare and validate the Non-Destructive Test result with Destructive Test such as coring test result. UPV test was performed via direct transmission. The diameter and length of coring samples were fixed to 1.0 length to diameter ratio (100mm by 100mm) as the obtained strength result was to be compared to core strength. The number of samples for each test is as shown in Table 1.

Table 1: Number of samples for each testing method

Beam level	No. of collected samples		
	RH	UPV	Coring Test
6	4	4	2
7	6	6	2
8	4	4	1
9	6	6	-

The location of data collection using UPV and RH was at similar location or closely kept nearby each other. The collection of core samples was done on the monolithic slabs but kept near to the location of performed NDTs as to prevent any potential damage to the unknown actual integrity condition of the structure.

2. Literature Review

2.1. Rebound Hammer Test

Rebound hammer Test is used to investigate strength of concrete by measuring the rebound number obtained from the rebound hammer. Requiring less mechanical skills than other NDT methods, it is a simple, easy and inexpensive way for strength estimation in concrete structure. The rebound method concept works in the way that a rebound hammer is pressed against a smooth surface of a concrete with a gradual pressure until it causes impact from the plunger, producing a reading referred as rebound number. This method is able to be conducted from any directional angle which makes the method preferrable as testing variability for in-situ strength test, with an accuracy of 15% to 20% [1].

2.2. Ultrasonic Pulse Velocity

Ultrasonic pulse velocity test measures the time taken for the waves produced by transmitting transducer propagating through a concrete specimen to arrive at the receiving transducer. Ultrasonic pulse velocity test can be conducted in three methods, namely direct, semi-direct and indirect, depending on the accessibility of the specimen surface. It is a simple and inexpensive way to estimate the in-situ uniformity and durability of concrete. However, embedded reinforcement could affect the reliability of the test result [1].

2.3. Core Test

Core test or also known as the compression test is a destructive test where progressive load is applied through the compression testing machine until it crushes the specimen. The core specimen is collected by using a core cutter machine to drill out hardened concrete material, of which selection of location must consider the presence of any possible reinforcement as core shall not contain any reinforcement member [2]. Procedure of core test shall be conducted according to standard provided in technical codes such as ASTM or BS EN.

2.4. Previous Case Study on Structural Assessment using SONREB Method

In a study conducted by [3] utilizing combined NDT (rebound hammer and UPV) to evaluate concrete strength from existing building according to IS standards. The result shows strength can be calculated by knowing the rebound number and value of UPV. The accuracy on estimation of compressive strength was increased by adopting the SONREB (combined two methods – rebound hammer and UPV), compared to just rebound hammer or UPV. SONREB method showed higher correlation coefficient at 0.441 compared to rebound values and UPV at 0.003 and 0.352 respectively. Based on study by [4] the result from rebound hammer test and destructive test is close and reliable for testing of existing structural strength. On the other hand, UPV is suitable for uniformity and homogeneity checking as well as internal defects such as cracks or voids underneath the structure surface. However, it is not as reliable when it comes testing of concrete strength unless performed with a cross-validation procedure in which destructive tests cannot achieve [5]. Hence, the combined SONREB method has been a common approach in estimating concrete strength more accurately when using non-destructive approaches.

3. Methodology

3.1. Rebound Hammer Test

The principle of rebound hammer test was by forcing a mass through a spring which hits a plunger in contact with the surface of beam. The reading from the rebound hammer was the rebound distance of the mass from the plunger, was used to estimate the in situ compressive strength of the beam structures. The test was performed in accordance with the standard test method for determination of rebound number stipulated in BS EN 12504-2 (2012) [6]. The rebound hammer test was carried out in horizontal position, perpendicular to the side of the beam surface. Apparatus involved to perform rebound hammer test were rebound hammer, reference anvil, and abrasive stone. Rebound number of the test location was taken as the median of all the readings obtained and expressed as a whole number. If more than 20% of total taken readings varies from the calculated median by more than 30%, a new set of reading was taken. The calculated median for each of the rebound numbers set were converted into compressive strength using the conversion curves provided in the manual by the rebound hammer equipment manufacturer PROCEQ SA shown in Figure 1 [7]. The location of each test point was illustrated in Figure 2.

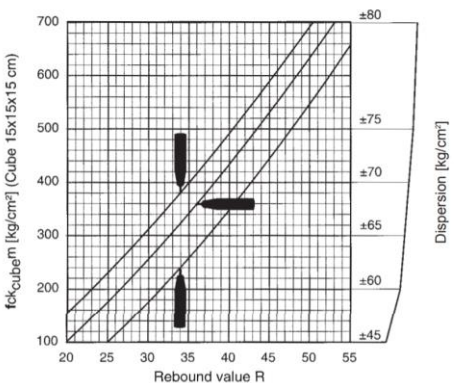


Figure 1: Conversion curves [7]

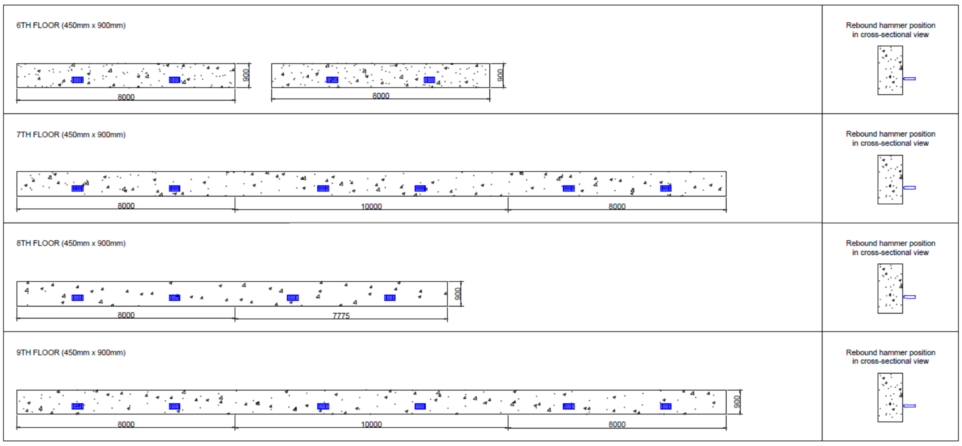


Figure 2: Schematic diagram of rebound hammer test points on beam structures

3.2. Ultrasonic Pulse Velocity Test

Ultrasonic Pulse Velocity (UPV) test were conducted according to standard stipulated in the BS EN 12504-4 (2004) guideline [8]. The apparatus involved in conducting UPV test were an electric pulse generator, a pair of transducers consisting of a transmitter and a receiver, an amplifier, an electronic timing device measuring the time interval of onset pulse until its arrival, a calibration bar, abrasive stone and coupling agent. Transducer (T) and receiver (R) were arranged in manner which met the direct method approach was conducted to estimate the beam structure condition as both sides of the members' surface were accessible. Classification of concrete quality was identified by comparing the obtained reading through filed test with Table 2 containing a series of figures in certain ranges suggested by Whitehurst for concrete density of approximately 2400kg/m^3 [9]. Figure 3 illustrates each test point that was carried out on the beam structure on different floor.

Table 2: Classification of the quality of concrete on the basis of pulse velocity. [9]

Longitudinal pulse velocity, km/s (10^3)	Quality of concrete
≥4.5	Excellent
3.5 – 4.5	Good
3.0 – 3.5	Doubtful
2.0 – 3.0	Poor
≤2.0	Very poor

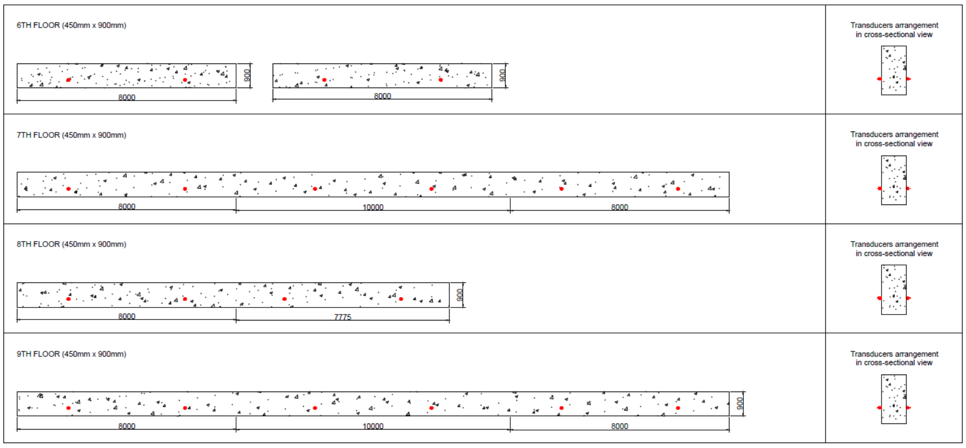


Figure 3: Schematic diagram of Ultrasonic Pulse Velocity test points on beam structures

3.3. Core Test

The core test was carried out in accordance to the standard test method for obtaining and testing core specimens stipulated in the technical code by BS EN 12504-1 (2009) [11]. The apparatus involved for core test were core drill, compression testing machine, balance or scale, callipers and ruler, gauge, squares and gauges. Testing for compression was carried out using a compression testing machine. Compressive strength determination for each specimen was obtained by dividing the maximum load by the cross-sectional area of the specimen computed from the average diameter. The calculated result was expressed to the nearest $0.5N/mm^2$.

3.4. SONREB Analysis

SONREB method is the most common method used to estimate strength of concrete using non-destructive testing. Reliability of data obtained through RH and UPV will be tested using the suggested formula shown in Table 3. Using Microsoft Excel, a simple regression analysis of proposed models was plotted and compared.

Table 3: Formulation suggested by different authors

Year	Author	Equation used	
1993	RILEM [12]	(Power) $fc = 9.27 \times 10^{-11.11} \times R^{1.4} \times V^{2.6}$	*Eq.* 1
1994	Di Leo & G. Pascale [13]	(Power) $fc = 1.2 \times 10^{-9} \times R^{2.446} \times V^{1.058}$	*Eq.* 2
1999	G.F. Kheder [14]	(Power) $fc = 0.0158 \times R^{1.1171} \times V^{0.4254}$	*Eq.* 3
2004	Menditto et al. [15]	(Power) $fc = 0.00004 \times R^{1.88148} \times V^{0.80840}$	*Eq.* 4

fc = cube strength, N/mm2

R = rebound number

V = ultrasonic pulse velocity, m/s

4. Results and Discussion

4.1. Result Analysis

The overall median for each set of data showed a relatively good strength condition, with highest at 47.5 located at point level 8 1 and level 9 beam 2/3. The lowest obtained median was located at point level 6 4, with calculated value of 37.5. The difference between the highest and lowest reading is 10. This signifies a consistency in reading which is desirable in achieving reliable data. Table 4 shows the compressive strength conversion obtained from converison curves provided in the manual by rebound hammer's manufacturer. The results range from $37.07N/mm^2$ to $56.90N/mm^2$. Lowest compressive strength was found at point 4 of beam level 6 while highest at point 2 of beam level 8 and point beam 2/3 of level 9 continuous member. Based on this range, an initial assumption of the study before validation was made, believing the tested beams are in good condition.

Table 4: Rebound number to compressive strength conversion

Level	Point	Median	RN to Compressive Strength, N/mm^2	Level	Point	Median	RN to Compressive Strength, N/mm^2
6	1	39.5	41.40	8	1	47.5	56.90
	2	40	42.58		2	47	55.92
	3	43	48.07		3	42.5	47.28
	4	37.5	37.07		4	42	46.11
7	Span 1/1	39.5	41.40	9	Beam 1/1	38	39.24
	Span 1/2	43	48.07		Beam 1/2	40.5	43.26
	Span 2/1	38.5	39.44		Beam 1/3	42	46.11
	Span 2/2	42.5	47.28		Beam 2/1	46	53.96
	Span 3/1	45	51.99		Beam 2/2	38.5	39.44
	Span 3/2	44.5	51.01		Beam 2/3	47.5	56.90

Table 5 shows the collected result from Ultrasonic Pulse Velocity test for each floor. The highest recorded reading was located at point 1 of level 8 with pulse rate of 3840m/s, while lowest at located at point beam 1/1 of level 9 with pulse rate of 2505m/s. Out of the 20 readings at different test points, only 8 were classified as good, 10 doubtful, and 2 poor. Beam structure at level 9 showed the most worrying quality of concrete as out of the six test points, two were doubtful, while both poorest readings were also obtained from the same continuous member. The overall result showed worthy of concern on the condition of the existing building structures.

Table 5: 6th, 7th, 8th, and 9th floor UPV test result

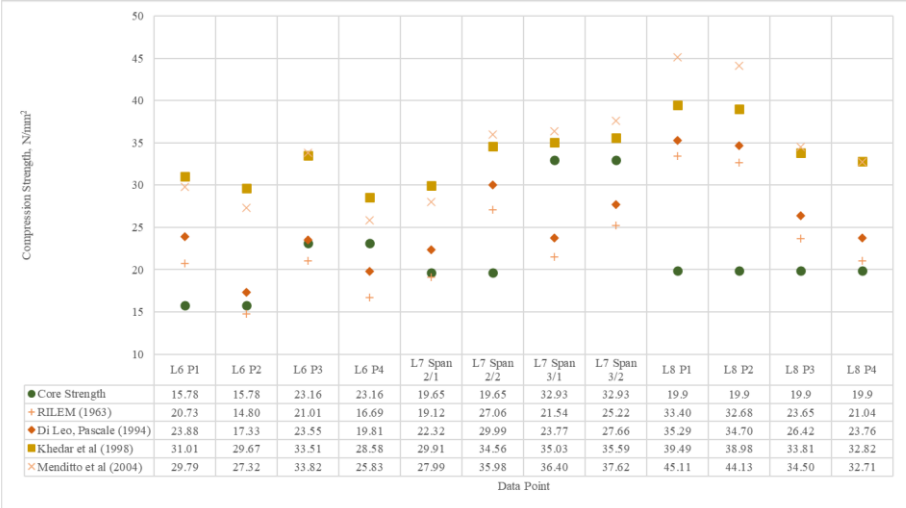
Level	Point	UPV, m/s	UPV, km/s (10^3)	Quality of Concrete	Level	Point	UPV, m/s	UPV, km/s (10^3)	Quality of Concrete
6	1	3530	3530	Good	8	1	3840	3840	Good
	2	3080	3080	Doubtful		2	3830	3830	Good
	3	3390	3390	Doubtful		3	3570	3570	Good
	4	3340	3340	Doubtful		4	3435	3435	Doubtful
7	Span 1/1	3050	3050	Doubtful	9	Beam 1/1	2505	2505	Poor
	Span 1/2	3440	3440	Doubtful		Beam 1/2	3555	3555	Good
	Span 2/1	3470	3470	Doubtful		Beam 1/3	3690	3690	Good
	Span 2/2	3760	3760	Good		Beam 2/1	3105	3105	Doubtful
	Span 3/1	3340	3340	Doubtful		Beam 2/2	2895	2895	Poor
	Span 3/2	3570	3570	Good		Beam 2/3	3460	3460	Doubtful

The highest core strength was 32.93N/mm^2, which was located near to beam at span 3/1 and span 3/2 of level 7 of the existing building. However, there was a stark difference between the highest and the lowest core sample strength, which was only 15.78N/mm^2. The weakest core sample was collected from area nearby point 1 and 2 of level 6. The other obtained compressive strength for the in-situ core samples were also relatively low, ranging around 19N/mm^2 to 23N/mm^2. The core strength for each sample taken onsite were tabulated in Table 6. By applying the four different formulations suggested by different authors mentioned in the methodology, the calculated values are tabulated into Table 6.

Table 6: Comparison between calculated compressive strength using four proposed formulations and compressive strength of core specimen

Level	Point	Core Strength, N/mm^2	RILEM	Di Leo, Pascale	Khedar et al	Menditto et al
6	1	15.78	20.73	23.88	31.01	29.79
	2		14.80	17.33	29.67	27.32
	3	23.16	21.01	23.55	33.51	33.82
	4		16.69	19.81	28.58	25.83
7	Span 1/1	N/A	14.17	16.71	29.14	26.47
	Span 1/2		21.83	24.41	33.72	34.23
	Span 2/1	19.65	19.12	22.32	29.91	27.99
	Span 2/2		27.06	29.99	34.56	35.98
	Span 3/1	32.93	21.54	23.77	35.03	36.40
	Span 3/2		25.22	27.66	35.59	37.62
8	1	19.9	33.40	35.29	39.49	45.11
	2		32.68	34.70	38.98	44.13
	3		23.65	26.42	33.81	34.50
	4		21.04	23.76	32.82	32.71
9	Beam 1/1	N/A	8.05	9.93	25.66	20.99
	Beam 1/2		21.86	24.92	31.98	31.40
	Beam 1/3		25.35	28.30	33.84	34.65
	Beam 2/1		18.38	20.32	34.81	35.77
	Beam 2/2		11.94	14.33	27.69	24.18
	Beam 2/3		25.47	27.35	37.78	41.47

Based on the table of comparison between the four calculated values in Table 6 a rough estimate showed that formulations by RILEM and Di Leo, Pascale showed a nearer value to the core specimen compressive strength. Compressive strength calculated using formulation by Menditto et al demonstrated the furthest from the core sample compressive strength. Hence, to understand the accuracy of the SONREB method further and better and consecutively the reliability of NDT approach on structural assessment, line graph (Figure 4) and XY graph (Figure 5) were plotted to allow better comprehension on the result trend. The line graph demonstrated in Figure 4 showed value from RILEM and Di Leo, Pascale had more interception tendency with the core specimen strength. However, XY graph in Figure 5 indicated RILEM and Di Leo, Pascale had weaker relationship to the core specimen, with coefficient of determination, R2 of 0.0129 and 0.0074. Value calculated using Khedar's formula had the highest R2 by 0.0683, followed by Menditto at 0.0663. The overall calculated median results from RH test shown previously in Table 4 indicated that without SONREB method of analysis, the acquired values might have overestimated the actual strength of the existing structure.



	L6 P1	L6 P2	L6 P3	L6 P4	L7 Span 2/1	L7 Span 2/2	L7 Span 3/1	L7 Span 3/2	L8 P1	L8 P2	L8 P3	L8 P4
Core Strength	15.78	15.78	23.16	23.16	19.65	19.65	32.93	32.93	19.9	19.9	19.9	19.9
RILEM (1963)	20.73	14.80	21.01	16.69	19.12	27.06	21.54	25.22	33.40	32.68	23.65	21.04
Di Leo, Pascale (1994)	23.88	17.33	23.55	19.81	22.32	29.99	23.77	27.66	35.29	34.70	26.42	23.76
Khedar et al (1998)	31.01	29.67	33.51	28.58	29.91	34.56	35.03	35.59	39.49	38.98	33.81	32.82
Menditto et al (2004)	29.79	27.32	33.82	25.83	27.99	35.98	36.40	37.62	45.11	44.13	34.50	32.71

Figure 4: Comparison between core strength and compressive strength by SONREB conversion

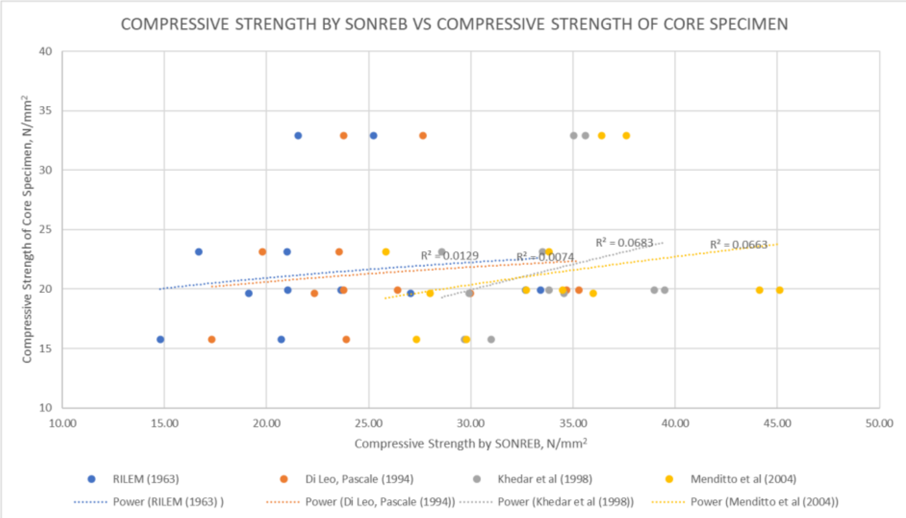


Figure 5: Compressive strength by SONREB vs compressive strength of core specimen

4.2. Discussion

Based on the analysis of collected data, conducting rebound hammer test alone to estimate the in-situ compressive strength of concrete was not reliable. The medians from the rebound numbers shown a clear disparity between the compressive strength reading of RH test and core test. Results from RH test represents the estimation of surface hardness of concrete. Calculated median values could be easily mistaken the actual compressive strength of the structural member, in which all values overestimated the actual compressive strength of concrete if assumed so. However, even after conversion of rebound number to compressive strength, the values were also too far off compared to the compressive strength of core specimens collected onsite. Compared to the available core test results, The RH test on every floor overestimated the surface hardness of the onsite beam. Results from UPV test point to performing UPV test alone was also clearly insufficient to estimate the actual strength of concrete. UPV test result only gave a preliminary empirical prediction on the condition of concrete in deeper thickness compared to surface hardness by RH test or which was unable to be detected through visual inspection.

By applying combined SONREB method, estimation of concrete strength had successfully showed closer result to the compressive strength of core specimens. However, despite values from RILEM and

Di Leo, Pascale being nearest to compressive strength obtained through core specimens, some still had apparent difference between the calculated and experimental values. The difference in values believed to be contributed by location of core which was a little further from the NDT test points. Directly performing core test on desired beam structure defeats the purpose of the research on checking the reliability of NDT on structural strength reinforcement. Since the slab and beam structures were casted monolithically, coring tests were instead done on slab to avoid causing potential damage which could be critical to the unknown beams' condition. Hence, the difference using SONREB method and core test method was inevitable. Existing maintenance and services also limited the accessibility to some of the NDT test points.

5. Conclusion

In a conclusion, RH test and UPV test were done as NDT approach in estimating the structural strength of the selected existing beams on level 6, 7, 8, and 9. The results from individual tests was not sufficient and reliable to assess the in-situ compressive strength of the existing structural integrity. However, when results from RH test and UPV test were combined using SONREB method, the outcome showed a more reliable estimation of in-situ compressive strength. Conventional DT method using core test still outrun the reliability of NDT approach in terms of estimation accuracy of compressive strength of existing concrete. Since the study is limited to using previously proposed formulations by other authors to estimate existing unknown structure condition, further study on the relationship between RH and UPV and core test using controllable specimens in laboratory are recommended to investigate the reliability and accuracy of NDT approach efficiently and effectively in structural strength assessment.

Acknowledgement

The authors would also like to thank the Faculty of Civil Engineering and Built Environment, UniversitiTun Hussein Onn Malaysia for its support.

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