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ASSESSING THE PERFORMANCE OF CONCRETE STRUCTURE BASED ON THE WIDTH OF THE CRACK USING UPV

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Abstract

The concrete structure is the main component to support the structure of the building, but when concrete has been used for an extended period hence, it needs to be evaluated to determine the current performance of the concrete structure. The poor quality of concrete structures will cause discomfort to the user and the safety will be affected due to lack of concrete strength. If these issues are not monitored or not precisely known performance, and no further action done then, the concrete structure will fail and eventually it will collapse. Five units of terrace houses that are built less than 10 years old with extension or renovations and have cracks appear have been selected for this study. The instrument used in this research is Ultrasonic Pulse Velocity (UPV), with the objective to determine the current strength, investigate the pulse velocity of the concrete and to determine the depth of crack line. The data showed that the average velocity of the pulse is less than 3.0 km/s and has shown that the quality of the concrete in the houses are too weak scale / doubt in the strength of concrete. It also indicates that these houses need to have an immediate repair to remain secure other concrete structures.

Keywords: UPV, Concrete structure, Cracks, Building performance.

1. Introduction

In general, the evaluation of the ability of structures are still less popular practiced in Malaysia. This is because it is not specified in the Uniform Building By-Laws (UBBL) or other specifications that define the period to carry out an assessment of reinforced concrete structures. Normally, developers, contractors and users assume that the reinforced structure is durable and rare defects or deterioration of strength.

This assumption is less precise. The importance of concrete strength inspection is not only on the structure strength but also to ensure the life of continuous structure usage, for the sake of developers and users as well as guaranteeing the quality of construction.

The final impact on users is property loss and can result in injury or death, while for developers and contractors, the result of this construction will reflect the quality of work and their image [1].

There are several of substance used as the structure in a house. The reinforcement concrete structure is widely used in construction as it gives more advantages compare to other structures in compressive and strain strength as well as heat resistance. The reinforcement concrete structure can fail due to loss of strength, durability and mechanical failure. For example, when the reinforcement concrete structure has some defects, corrosion will occur and spread to cause cracks, coating detachment together with a loss of concrete-steel strength. Cracks cause water to flow inside the concrete and will cause the reinforcement steel structure to erode. The poor concrete mixture and not enough reinforcement steel foundation lead to a crack of a concrete structure when it carries overload weight or has internal defects. Therefore, the concrete reinforcement structure needs to be evaluated to determine the quality, integrity, density, uniformity or level and types of flaws.

However, if there is a decrease in the compression strength of the concrete structure, it will not be solid, has cracks and other defects. The defects show the performance of the concrete. Early detection of any crack is substantial. It can prevent bigger or more serious problems. But, if the problems fail to be solved quickly, the buildings and houses can be severely damaged then in the future collapse. Defects and failures in certain aspects can lead to loss of quality and integrity of the concrete structure.

1.1. Non-destructive test (NDT)

The non-destructive test (NDT) is a technique that is used in the civil/structural engineering, and forensic. NDT is widely used to evaluate and determine materials property, systems as well as the components. This test can effectively reduce time and cost as it will not cause any damage [1]. A variety of instruments can be used for NDT but ‘Pundit Ultrasonic Pulse Velocity' (UPV) is used for this research. The non-destructive measurement has proved to be of real importance in all constructions and as an effective tool for inspection of concrete quality in concrete structures [2] and [3].

This measurement is intended to test the strength of the component or structure which made of concrete, steel and wood [4]. It was conducted to determine the rates and causes of bending displacement occurs and the uncertainty of a malfunction [5]. The use of ultrasonic instruments will be known whether the structure or a component has lost strength and the direction in which the line of weakness exists [5]. The visual inspection is done by an experienced civil engineer that can interpret all the data of the damaged concrete structure [4], [6]. The NDT test can only give estimation of the structure ability but not the cause of defects [7].

1.2. Ultrasonic pulse velocity (UPV)

UPV is used to evaluate the quality of the concrete structure, measure concrete uniformity and the property of concrete. Besides that, UPV can also be used to measure transit time, void presence, depth of cracks or the modulus of elasticity. Hamidian [8] reported that the pulse velocity is a good instrument to evaluate the concrete strength and its quality.

The UPV equipment includes two transducers and an indicator for showing the time of travel from the transmitter to the receiver. Ultrasonic pulse uses fast potential changes to create vibration that leads to its basic frequency. The transducer is firmly attached to concrete surface to vibrate the concrete. The pulses go through the concrete and reach the receiver [9].

There are many types of research regarding the UPV, for example, Demirboga [10] studied about the ultrasonic velocity for the high mineral concrete mixture. The NDT has been conducted using UPV to establish the relationship between the compact strength of the concrete used in Algeria [10] and [11] reported that the UPV test has been used to evaluate the small pieces of limestone. Shariati [3] used UPV test to expose the estimation in the strength increment of concrete and able to produce a better result. A literature survey in using non-destructive methods used for concrete testing summarized the benefits of NDT [12]. However, there is not any standard correlation between concrete compressive strength and the ultrasonic pulse velocity and this matter was controlled by many aspects [13].

UPV can be used not only in concrete but also woods, ceramics, cast irons, geology specimens, and others. UPV is classified into three categories of the testing methods; direct test, indirect test, and partial test. UPV is used to evaluate the quality of concrete for different component structures such as the beam, columns, roofs' frameworks and slabs [2]. Meanwhile, concrete with density of 2400 kg/m³ is considered excellent for ≥ 4.5 km/s, good for 3.5-4.5 km/s, doubtful for 3.0-3.5 km/s, weak for 2.0-3.0 km/s and very weak for ≤ 2.0 km/s [14]. Besides that, Jones [7], also describe that the minimal value for the high quality of concrete is from 4.1 to 4.7 km/s. As BS: 1881: Part 203, quality of concrete can be classified per Table 1.

Table 1. Classification of concrete quality ratings based on UPV test BS: 1881: Part 203.

Pulse velocity (km/s)	Concrete quality (Ratings)
≥ 4.5	Excellent (E)
3.5 - 4.5	Good (G)
3.0 - 3.5	Medium (M)
2.0 - 3.0	Doubtful (D)
≤ 2.0	Very weak (VW)

2. Problem Statement

Almost 82 percent of owners in housing scheme was renovated [15]. Most of the houses that have been renovated to show various perspectives such as the house cannot survive longer, the quality aspect, and the aesthetic properties are affected, showed defects to design of the facade and side effects to the neighbour's residential units [15]. Among the several factors that have been identified, the developer failed to take into consideration the current buyers need while architects were not doing some study of the requirements of potential buyers, especially for providing the perfect space and comfortable [4], [8] the original design of the house is not convenient [15], unhappy with the quality of the home and their services provided [16].

However, there is also the quality of construction of new houses was low and did not reach an acceptable standard [17]. This issue will have an impact if the owners do home renovations because the house already existing defects. Che Ani [6] found as many as 63% of new terrace houses that are at medium scale damaged. This inspection showed that the assumption of damage to the house after the renovation may occur and require proper observation.

Applicability mistakes due to lack of knowledge, the occurrence of short circuits due to miss-splicing during the renovation [4], poor quality of construction work due to lack of experience and labour inefficiencies and generally only assume that the discovery of information late in the design phase of the renovation of an impact only on a small scale against the construction of a new building [18], but it still carries a distinctive impact of disability.

In the real estate construction industry, among the main decision-makers who are developers, architects, contractors, local authorities, project managers, academics, users and clients [19]. The issues above should be taken seriously by all parties, especially the owner of the residence. Inspection of the new building is ready to be carried out, to ensure respect building standards and free of defects. However, still less a study on the quality of the result of the renovation process [20].

3. Method

Safety is the most important factor in the assessment of the ability of structure. Assessment ability of this structure will be designed to identify the causes, evaluation and action. Identifying the causes will include the process of gathering data and records non-destructive tests by using UPV.

All this information is crucial in comparing the strength of the original design with the current strength. Thus, predictions can be made on the strength of concrete in the future. Information design and function of the building is required to identify critical locations that often threaten the strength of reinforced concrete structures.

Detailed in-situ observation is an effective method to get an overview of the current concrete strength. As usual, photographs will be taken as evidence and records for subsequent evaluation work plan. Detailed observation allows researchers to predict the causes of force or failure and subsequent planned valuation techniques that are appropriate.

The slabs structures on ninth units of the terrace houses were investigated at Taman Samar Indah, Taman Desa Ilmu and Midway Garden at Samarahan, Sarawak. The age of samples that has less than 10 years have been investigated on strength and concrete solidity. These houses have undergone extensive renovation and have cracks on the structure elements were selected.

The aim is to determine the condition of the current concrete structure or the evaluation of structure capacity and identify the critical crack line of the slab structure. In the first stage, visual inspection of the concrete is done before non-destructive test. This visual inspection gives information regarding concrete damages the causes of defects and the crack line.

In the second stage, all the crack line on the slab structural at the ninth units of the terrace houses were identified. The line was recorded per the certain codes in the record forms. Fig. 1 shows the crack line in one of the slab and the method how to conduct the experiment. Transducers UPV placed in the range of 100 mm interval in the left and right of the crack line [9].

Fig. 1. Measuring crack depth by UPV.

4. Results and Discussions

Table 2 and Fig. 2 shows the result of UPV test for transit time, the depth of crack line and pulse velocity. There is a total of 21 crack line for all ninth units of houses. Only six lines out of 21 cracks line was identified on the slab structure in the TDI, meanwhile TSI with 10 cracks line and MG with 5 cracks line. Ninth crack line with more than 1.8 mm width detected on the slab, which is consider as the medium-large cracks width [3]. Meanwhile the depth of cracks for the same crack line is about 36 to 75 mm depth, with the TSI7.1 have the largest crack depth (74.84 mm). The current condition of the structure is doubtful with pulse velocity (PV) between 1.74 to 2.93 km/s. It illustrates that it is defective due to cracks at an alarming rate and need of repair.

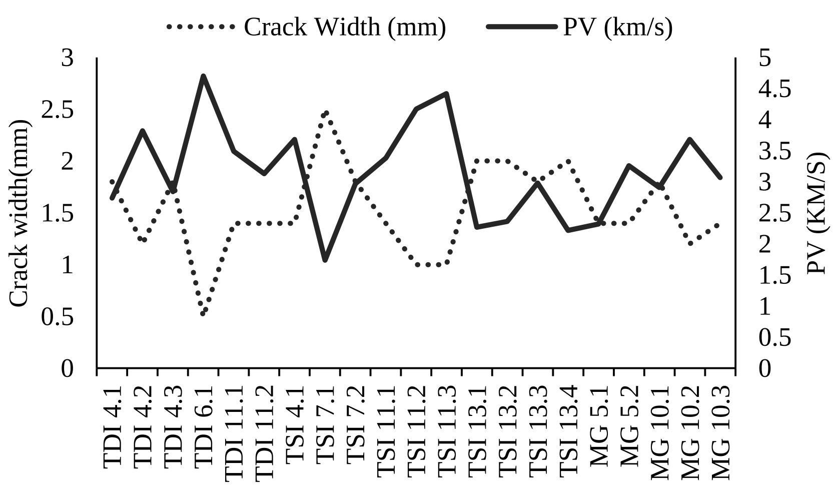

Fig. 2. Performance of each crack line by using UPV for slab structure.

Only cracks width less than 1.8 mm give the better condition of slab concrete structures which is medium condition. Six crack lines give the medium PV in between 3.307 - 3.47 km/s, meanwhile another five cracks line represent the good condition (3.68 – 4.42 km/s) with cracks width less than 1.5 mm. Only TSI4.1 with crack depth 10.91 mm give the excellence condition (4.7 km/s). Schedule or regular maintenance are recommended to make sure the structure is always in good condition.

The TSI 7 and TSI 13 has a scale of dubious quality in the concrete slab elements with PV average value of 2.4 km/s. The pulse velocity in concrete structures decreases if there are obstacles such as air holes, cracks or other defects. From the results, the integrity of concrete in all the houses is classified as medium condition. This is because the average value obtains on the slab structures is 3.2 km/s.

Table 2. Data spread slab structure using UPV test.

House no.	Crack line	Crack width (mm)	Crack depth (mm)	Pv (km/s)	Concrete quality
TDI 4.1	RDL1	1.8	39.94	2.74	D
TDI 4.2	RDL2	1.2	18.57	3.82	G
TDI 4.3	RDL3	1.8	36.28	2.84	D
TDI 6.1	RDL1	0.5	10.91	4.7	E
TDI 11.1	RDL1	1.4	26.91	3.49	M
TDI 11.2	RDL2	1.4	27.2	3.13	M
TSI 4.1	RDL1	1.4	27.04	3.68	G
TSI 7.1	RDL1	2.5	74.84	1.74	D
TSI 7.2	RDL2	1.8	39.65	2.97	D
TSI 11.1	AL1	1.4	25.27	3.38	M
TSI 11.2	AL2	1	14.59	4.17	G
TSI 11.3	AL3	1	11.27	4.42	G
TSI 13.1	RDL1	2	50.25	2.27	D
TSI 13.2	RDL2	2	46.56	2.36	D
TSI 13.3	RDL3	1.8	36.81	2.98	D
TSI 13.4	RDL4	2	47.05	2.22	D
MG 5.1	RDL1	1.4	26.29	3.32	M
MG 5.2	RDL2	1.4	27.4	3.26	M
MG 10.1	RDL1	1.8	38.7	2.91	D
MG 10.2	RDL2	1.2	20.92	3.68	G
MG 10.3	RDL3	1.4	25.57	3.07	M
Average		1.5	32.0	3.2	M

R-square value of 0.9185 in Fig. 3 describe the crack width is directly proportional to the depth of the cracks on the slab structure. While Fig. 4 shown the R-square is 0.9356, the PV is directly proportional to the width of the crack. The wider crack give PV value is small (doubtful condition) otherwise if the narrow crack, the PV is given better value (good condition) of the concrete. If the crack width is more than 1.5 mm, the value of PV will decrease to below than 3.0 km/s and the crack depth is more than 35 mm depth. (Fig. 4) the PV will decrease 3.0 km/s. R-square of Fig. 5 present directly proportional at 0.8892 which is close to 1.0.

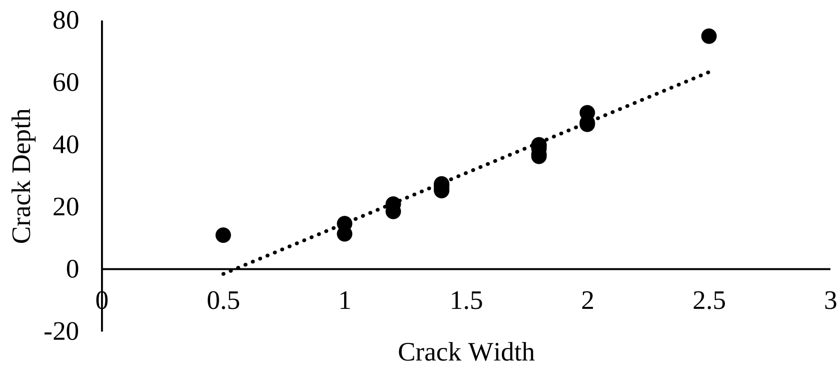

Fig. 3. Directly proportional crack depth vs crack width.

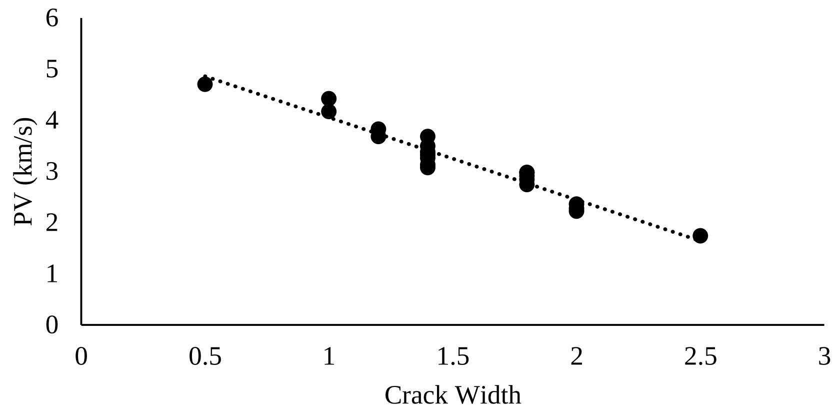

Fig. 4. Directly proportional PV vs crack width.

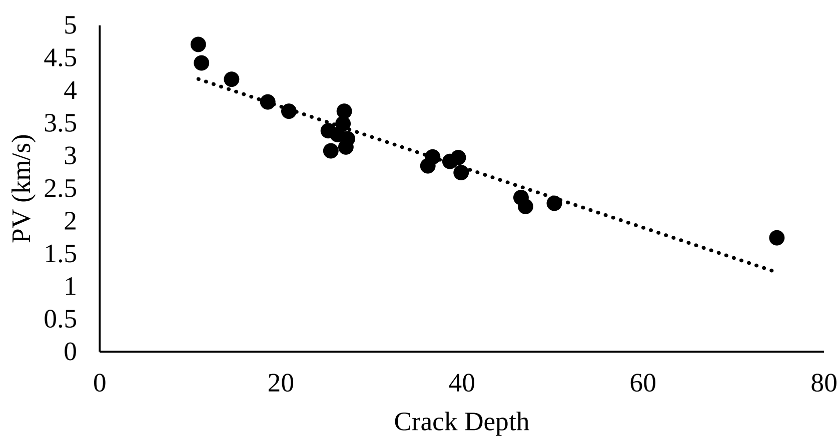

Fig. 5. Directly proportional PV vs crack depth

Recommendation of action to overcome of the concrete condition will not end with repair only, but it also involves maintenance and continuous observation in the likelihood presence of structural changes.

5. Conclusion

From the research data, we conclude that the average value of velocity is 3.2 km/s which is far from the excellent category of concrete quality. It falls near to doubtful category or weak that is less than 3.5 km/s which is less than acceptable value (good condition). Less than 57 % of the structure is in medium and good categories. Therefore, the house owners are advised to do repair and restoration immediately to ensure the safety of consumer as well as other structures remain secure, meanwhile almost 43% of structure element fall in doubtful category of structure quality which is less than 30 MPa. The largest crack depth is 78.8 mm was representing the weekend structure. Terrace house at TSI and MG are in medium condition compare to TDI with the average values at 3 km/s, 3.2 km/s and 3.5 km/s respectively.

The conclusion of the research is, if the width of crack line is more than 1.5 mm, it is will present the PV value is in medium condition (< 3.0 km/s) and show the crack depth is almost 35 mm.

UPV testing tool has been used to evaluate the concrete structure is not enough to obtain compressive strength to confirm the reinforcement concrete true performance. Perhaps, rebound hammer instrument can be used together in this test.

From the interview during UPV is carried out, most of the house owners employed craftsman service or contractor which are not registered with Construction Industry Development Board Malaysia CIDB and Contractor Service Centre. They mostly consist of family members and friends who have limited skills and collaborated in finishing the renovation task.

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