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The Investigation of Cracks and Repairing Methods on Residential Building: Case Study at Kompleks Penghulu Ayer Hitam, Muar

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Abstract

Malaysia is among one of the development countries that growing rapidly in all sectors which include the sector in construction. Nevertheless, some of the new buildings are poorly constructed. The aim of this study is to investigate the residential house wall cracks on the residential building at Kompleks Penghulu Ayer Hitam, Muar, to inspect the crack occurred on the residential building, to conduct a statically analysis to compare the relationship between ultrasonic pulse velocity and crack repair method and to propose efficient method for reducing the cracks problem. There are 52 number of visible cracks with different length and width has been detected. For measuring the concrete strength, a non-destructive testing (NDT) was used using Ultrasonic Pulse Velocity (UPV). The total 3 point was tested on column and wall inside the residential house by using one modes of transmission for UPV testing which was indirect transmission. The result of UPV has been analyse using statistical evaluation. From the result, it is found that the epoxy injection can cure the crack while seal using OPC and silicone seal does not help much. For overall cracking and concrete strength quality, it is also found that the residential building needs proper maintenance as the settlement still happened, and it is affected the residential building's safety.

1. Introduction

The problem of cracks in architecture has become a complex puzzle for engineers, and strength has been a preventable solution for any structure while designers have tried to eliminate many instances of cracks. Many designs allow for different elements. A crack is incomplete separation of concrete into two or more parts due to destruction or cracking. Generally, a crack occurs when a piece of concrete breaks away into two or more parts because of breaking or fracture [1]. There are two types of cracks: non-structural and structural. Structural cracks are a major problem that should be inspected, monitored, and corrected by experts [2]. Internal forces created in structures because of variations in the size of building components due to moisture fluctuation, temperature variation, and the action of gases, liquids, and solids generally cause non-structural cracks [3].

Cracking has become one of the most prevalent building diseases throughout time, impacting not only the outside facades but also the inner parts. This phenomenon arises because of bad design or execution, or simply as a result of practically impossible-to-predict unexpected effects [4]. Several ways can be found to fix cracks from this research. Masonry grouting methods, requirements for grouting agents and mixes. Materials that include strong fibres (carbon, aramid, glass) with suitable adhesives (resin or polymer-modified cement mixes) can be applied as all-surface fabric on damaged masonry structures suffering from tensile or shear cracks [5]. Another method is polyurethane concrete crack injection; the resin can be used to fill cracks and voids as well as seal porous channels inside concrete elements that can be regarded as weak areas. Additionally, it fills honeycombs that are formed in concrete because of improper aggregate proportioning, poor mixing, inappropriate compaction, or all of the above [6].

In this investigation will be using epoxy injection, sealing using OPC and sealing using silicone sealant. Epoxy injection is a cost-effective method for repairing cracks in concrete walls, slabs, columns, and piers, since it may restore the concrete's original strength [1]. Epoxy injections may also be used to make repair mortars, but cannot be utilized as a binding or bonding agent in concrete [7]. Sealing refers to the establishment of a barrier against specific environmental factors, which, depending on the application, may include humidity, driving rain, still or pressurized water, draughts, sand, dust, etc. The crack will be detected using an ultrasonic pulse velocity test. While in terms of mitigation, mortar and concrete specifications play a critical role in reducing the occurrence of cracking in structures. Aside from strength and durability, standards for mortar and concrete should be based on achieving products with the least amount of drying shrinkage and creep, as well as acceptable resistance to sulphate attack [8].

2. Methodology

2.1 Building Inspection

The majority of these cracks are categorized as very severe stability cracks with an average width exceeding 25mm in the foundation walls and the required 0.3mm on the columns and beams. They seem to have originated simultaneously, probably as a consequence of excessive settlement caused by a poorly built foundation and poor workmanship. Monitoring of the cracks revealed that the building's cracks are active, as shown by the formation of new crack edges during the building inspection.

2.2 Ultrasonic Pulse Velocity

This study uses the method of an ultrasonic pulse through concrete in accordance with BS 1881: Part 203. This approach has now been widely used to check the quality of concrete in construction as it was easy to use and did not damage the specimen. Figure 1 shows the components of the UPV test set used in the UPV test for concrete.

Fig. 1 *Proceq ultrasonic tester*

An ultrasonic pulse velocity test is performed by passing a pulse of ultrasonic waves through the concrete to be tested. The team measures the time it takes for the pulse to traverse the structure. A high speed usually indicates that the material is continuous and of good quality, while low speeds can indicate that the concrete has many voids or cracks. Figure 2 shows three methods of positioning a transducer: a) direct transmission, b) semi-direct transmission, and c) indirect transmission.

J. of Structural Monitoring and Built Environment Vol. 4 No. 1 (2024) p. 33-41

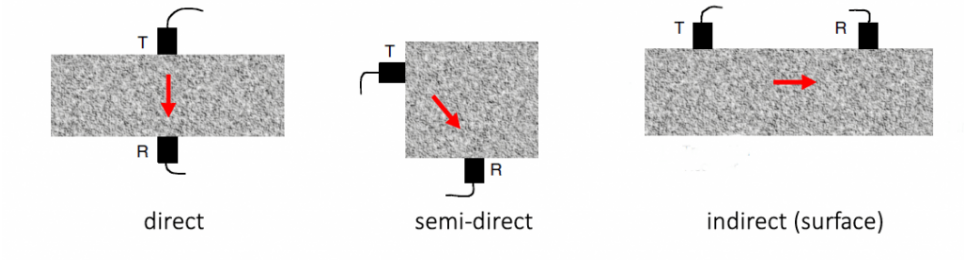

Fig. 2 *UPV transmission method, where T is transmitter and R is receiver*

The following equation will be used to determine the Ultrasonic Pulse Velocity (UPV) in the specimen:

$$V = \frac{L}{t} \tag{1}$$

V = pulse velocity
L = path length
t = transit time

For UPV test, the transducer is possible to be used is indirect transmission. There 3 points will be mark at the proposed area before the testing begin. The equipment will be calibrated by placing the transducer and receiver at either end of the reference bar. Suitable test location will be chosen for each transducer arrangement and the surface of test location needed to be clean, smooth and dry. The path length is vital to be measured and it can be measure using measuring tape, ruler or callipers. Then, coolant will be applied to the surface of the test location to ensure proper contact between the transducer with the concrete surface and the transducer will be positioned at the chosen test location. Table 1 shows the path length for wall.

Table 1 *The mode of transmission and the path for wall*

No	Point	Mode of transmission	Path length (m)
1	1	Indirect	0.10
2	2	Indirect	0.10
3	3	Indirect	0.10

The data has the UPV value calculated manually and the UPV results show the specific quality ratings based on the UPV BS: 1881: Part 203 test as shown in Table 2.

Table 2 *Concrete quality ratings based on UPV test BS: 1881: part 203*

Pulse Velocity (km/s)	Concrete quality (Rating)
≥ 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)

2.3 Repairing Method

The three methods that will be used in this research to illustrate effective crack mending techniques. Which is epoxy injection, seal using silicone sealant, and seal using OPC.

a) Epoxy injection

The following are the fundamental steps for successful crack injection. However, the type of epoxy or polyurethane used, as well as the time required for injection, will vary depending on the crack width, wall thickness, and other factors.

- Surface Preparation by clean the crack to remove any loose material from the crack.
- Spacing of the injection port 200-500mm evenly along the crack before attaching
- Attaching the injection port by gun the Anchorfix 1 to the perimeter of the base of the injection port then press firmly over the crack.
- Fill the surface of the crack between the injection port using additional sika Anchorfix-1.
- After approximately 30 minutes of curing of the Achorfix 1 the crack is ready to inject. If slower the setting epoxies are used these may need to be left over night before injecting.
- Mixing the Sikadur-20 crack seal.
- Over-fill the low-pressure crack injection plastic syringe with Sikadur-20 crack seal mixture.
- Injecting the Sikadur-20 crack seal mixture
- Clean up after injection

b) Sealing using silicone sealant

Applying silicone sealant is a simple procedure that you can complete quickly. Note, however, that it may take some time to dry. The following steps show the correct application of silicone sealant:

- Prepare the required items.
- Clean the surface to seal with a sponge soaked in soap.
- Install the silicone sealant through into caulking gun. At this point the tube of silicone sealant should be locked in place and you should be able to easily release its contents with the trigger.
- Remove the silicone sealant tube, to minimize the size of the hole as much as possible, make the cut very close to the top.
- Apply the silicone sealant by position the caulking gun about 45 degrees relative to the surface.
- Apply the sealant over the opening. Press down on the sealant with a spatula and evenly push it into the gap. Then smooth the surface with the spatula.
- Allow the silicone sealant to dry

c) Sealing using Ordinary Portland Cement (OPC)

The following processes are utilised in the rehabilitation using OPC for hairline cracks in concrete.

- Prepare the required items
  i. Cement bucket
  ii. Cement Powder
  iii. Water
  iv. Spade
- Clean the surface to seal by remove any unwanted substances that has covered the crack area before adding the filling substance.
- Mixing water and cement. Stir it vigorously until the water is fully mixed with the cement and a liquid result is obtained.
- Apply the cement using a spatula. Fill the cracks and smooth the surface.
- Allow the cement to dry for five days, moisten the patch once a day and keep it covered at all other times. After five days, the patch should be finished drying and safe to leave exposed and dry.

2.4 Crack Mitigation

Both during and after the concrete has cured, preventative steps must be taken to minimise cracks. What matters most is: The quality of the concrete will be impacted if the water cement ratio is too low. This is known as the W/C ratio because of the ratio of water to cement weight. Too much water will weaken the concrete, resulting in cracking. The lower the water content, the less shrinkage. Cracking shrinkage in slabs is 12 inches for every 100 feet of length. Surface crack are the consequence of concrete shrinkage pulling the slab apart.

Avoid using additives that promote shrinking (such as accelerators, dirty aggregate and cement with high shrinkage characteristics). Use correct finishing methods and timing during and between finishing processes. Vibrate correctly to remove trapped air, which causes cracking over time. The area under the concrete slab must be adequately and thoroughly compacted to avoid soil settling in the future.

J. of Structural Monitoring and Built Environment Vol. 4 No. 1 (2024) p. 33-41

3. Result and Discussion

3.1 Visual Building Inspection

Prior to crack repair, the state of the home's environs was visually assessed. The structure was built in the early 2000s. The building is located in Kompleks Penghulu Mukim Ayer Hitam, next to a ditch. Figure 3 illustrates an architectural drawing of the ground floor of the location. There is a single-story residence with three bedrooms, one bathroom, and a porch on the property. The building also includes an apron throughout its length. The residence is 20 feet by 40 feet and is 800 square feet in size.

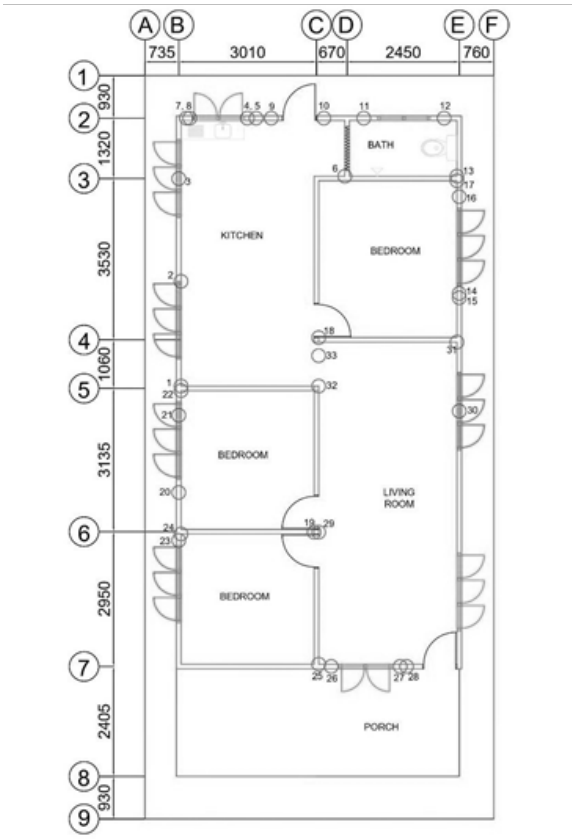

Fig. 3 *Architectural drawing of residential building*

3.1.1 Assessment of Crack at Residential Building

After the inspection, the length and breadth of cracks were measured using a ruler. The majority of the crack was located on the wall, as determined by the examination. A total of 52 cracks ranging in length from 0.33m to 1.2m and width from 0.3cm to 1.4cm were observed on the property. There are four different varieties of cracks: horizontal, vertical, diagonal, and stair-step. However, only three kinds of cracks were detected in the residential building: horizontal, vertical, and diagonal. Table 3 details the kind of crack identified in the residential structure. 20 cracks were vertical, followed by 17 horizontals and 16 diagonal cracks, respectively.

Table 3 *Summary of type of crack at residential building*

Location of crack	Type of crack			Total
	Horizontal	Vertical	Diagonal	
Inside of house	11	14	8	33
Outside of house	6	5	8	19
Total	17	19	16	52

According to Table 4, 29 of the wall cracks identified at the residential building are very slight, making them the most prevalent. The cracks are confined to interior wall surfaces and are not apparent on the outside brickwork. After that, 16 cracks are noted to be minor. The entrance door was seen to be somewhat difficult to open due to its proximity to a small wall crack. Additionally, the cracks are not outwardly noticeable. A little crack may cause the door to get somewhat blocked, although cracks are not always evident from the outside. The next severity level is a significant crack with a score of 6, and it has issues with doors and windows sticking. This is shown by the fact that windows in the front building and kitchen area are difficult to open and exterior cracks are obvious. Lastly, one major crack is visible from the outside on the building's rear side. Some common damages caused by major cracks include warped windows and door frames, sloping floors and leaning walls, thereby validating what has transpired at the residence.

Table 4 *Summary of crack categories at the residential building*

Location of crack	Crack width (mm)					Total
	Very slight (≤ 1.0)	Slight (≤ 5.0)	Moderate (5 - 15)	Severe (15- 25)	Very severe (> 25)	
Inside of house	20	9	3	1	0	33
Outside of house	9	7	3	0	0	19
Total	29	16	6	1	0	52

3.1.2 Crack Evaluating

From the site visual inspection, data of crack width have been measured and recorded by visual inspection method. For crack width, the data taken consist of 3 values at location where the crack gap is wider. It aims to find out the largest value of crack width measured, which will be used in determining the category of cracks. Then, overall crack severity of the building was decided. The three strategies that will be studied in this research to illustrate effective crack repair techniques. Table 5 summarises the crack activity and method used.

Table 5 *Summary of crack activity and method used*

No.	Location	Crack Width (cm)	Crack activity	Category	Method used
1	1	0.30, 0.30, 0.30	Dormant	slight	Seal using silicone sealant
2	2	0.40, 0.40, 0.40	Dormant	slight	Epoxy injection
3	3	0.20, 0.20, 0.20	Dormant	slight	Seal using OPC

3.2 Ultrasonic Pulse Velocity (UPV) Result

The ultrasonic pulse velocity measurement has been tested on the residential building's wall. There is a total of three points measured, all of which are at the wall. The path length of each point is measured at a distance of 0.10m. When using the UPV equipment on the structure, the indirect transmission was utilised to determine the time it took for the wave to flow through the structure from the transducer to the transmitter. The wave velocity is then estimated manually using a calculation based on ASTM C597. Table 6 gives the requirements for producing a concrete quality rating based on the UPV test BS: 1881: Part 203.

J. of Structural Monitoring and Built Environment Vol. 4 No. 1 (2024) p. 33-41

Table 6 *Classification of concrete quality ratings based on UPV test BS: 1881: Part 203*

Pulse Velocity (km/s)	Concrete quality (Rating)
≥ 4.5	Excellent (E)
3.6 - 4.5	Good (G)
3.0 - 3.5	Medium (M)
2.0 – 3.0	Doubtful (D)
≤ 2.0	Very Weak (VW)

Every point uses indirect transmission as its mode of transmission. The path length was measured at 0.100m and is the same in all locations. The summary of UPV result before repairing process is shows in Table 7. The test results for walls showed that concrete is very weak in location 1 with a velocity of 829 m/s, while location 2 is also very weak with a velocity of 427 m/s, and location 3 is doubtful with a velocity of 2247 m/s, which is highest than the other two locations. The low UPV for this wall was caused by cracks and smoothness of wall surface, which affected the UPV readings.

Table 7 *Summary of UPV result before repairing process*

No	Location	Mode of Transmission	Path length (m)	Time taken (s)	Velocity (m/s)	Classification
1	1	Indirect	0.10	0.0001205	829	Very Weak
2	2	Indirect	0.10	0.0002340	427	Very Weak
3	3	Indirect	0.10	0.0000445	2247	Doubtful

The summary UPV test result after repairing process is shown in Table 8. For all locations, the indirect transmission mechanism was used. The path length was measured to be 0.100m and is constant throughout. The results of the UPV tests indicated that the result is good after repairing using epoxy injection at a velocity of 3730 m/s and sealing using OPC at a velocity of 3530 m/s. With a velocity of 1530 m/s, the silicone sealant earned a very weak UPV grade for concrete quality.

Table 8 *Summary of UPV result after repairing process*

No	Location	Mode of Transmission	Path length (m)	Time taken (s)	Velocity (m/s)	Classification
1	1	Indirect	0.10	0.0000655	1530	Very Weak
2	2	Indirect	0.10	0.0000134	3730	Good
3	3	Indirect	0.10	0.0000283	3530	Good

3.2.1 Comparison Between UPV Result Before and After Repairing Process

The comparison between UPV test result before and after repairing process is shown in Figure 4. The sealing using silicone sealant, epoxy injection method and seal using OPC are categories of method that being perform during the repairing process. There two sub-categories which is velocity value of UPV test before and after the repairing process. This allows the researcher to compare how the crack curing is performing after repairing process and identify the most effective repairing method by addressed performance at the crack location.

By having a glance at the chart, it can be seen that the value of velocity for epoxy injection sharply increased from 427m/s which classify as very weak concrete to 3730m/s which is classified as good concrete at location 2. From the result, the value of velocity at location 2 and 3 also slightly increased after sealing using silicone sealant and OPC by 829m/s (very weak) to 1530m/s (very weak) and 2247m/s (doubtful) to 3530 (good) respectively.

As shown in Figure 4, there is a clear upward trend in the value of velocity at the three locations after the repairing process has proven that these three methods can cure the crack; however, while the value of velocity is increasing after using these three methods, repairing using epoxy injection shows the most effective repairing method.

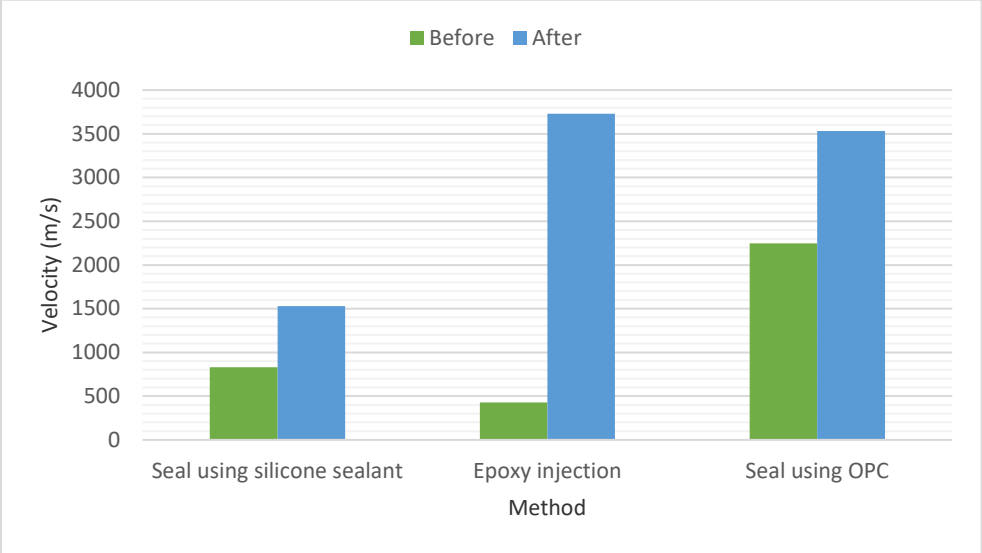

Fig. 4 *Comparison between UPV test result before and after repairing process*

4. Conclusion

The purpose of this study was to examine the residential building's cracking. During the examination, a total of 52 cracks ranging in length from 0.33m to 1.20m were identified inside the structure. Only horizontal, vertical, and diagonal cracks were discovered in the residential structure. From the visual examination, it can be inferred that the most prevalent kind of wall cracks at the residential structure is a slight crack, since 29 of the detected wall cracks are very slight. Thus, the first aim is met. The second purpose of this research was to conduct a statical analysis to assess the relationship between ultrasonic pulse velocity and repair technique. With a pulse velocity of 2.0 to 3.0 km/s, the UPV test revealed that the majority of the concrete was of dubious quality and very weak. The fact that the observed velocity increased after the repair process, and it prove that the repair approach affects the UPV. From the observation there is a clear upward trend in the value of velocity at the three locations after the repairing process has proven that these three methods can cure the crack; however, while the value of velocity is increasing after using these three methods, repairing using epoxy injection shows the most effective repairing method.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: study conception and design: Author 2; data collection: Author 1; analysis and interpretation of results: Author 1, Author 2; draft manuscript preparation: Author 1, Author 2. All authors reviewed the results and approved the final version of the manuscript.

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