A Fundamental Hammering Sound Test to assess the Degree of Deterioration in Reinforced Concrete Structure

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Abstract. Conventional hammering method is the most common used inspection tools in the industry. This method requires skilled inspector to inspect. However, it is cheap and easy to use. This research is to associate spectral analyzer together with conventional analyzer to gather quantitative data. Research was conducted on both laboratory and site testing. Laboratory specimens were created with polystyrene replicating the defects. The depths and thickness were determined to vary the degree of defects. The sound pressure produced from the impact of the hammer is then evaluated with the degree of defect. From laboratory testing, healthy mortar specimen produced higher sound pressure than defective mortar specimens. The void affected the results on the defective mortar specimen. Finishing surface (plastering) also affected the sound pressure produced. Plastering on reinforced concrete (RC) structure plays huge role in inspecting as the bonding of the plastering can affect the sound pressure produced. Conventional hammering can be associated with spectral analyzer to inspect existing RC structures. Conventional hammering can replace other expensive NDT method such as infrared thermography, GPR, and etc.

1. Introduction

Concrete is widely used in modern construction. Design life of reinforced concrete (RC) structures can last for 50 years. However, over years, inspections ought to be conducted from time to time to ensure the serviceability of the structure. There are several kinds of defects such as spalling, delamination, cracking, and honeycombing which can be detected easily [1]. Some defects require comprehensive non-destructive testing (NDT) equipment to detect the inner defect of the structure such as void formed due to the inner corrosion of the reinforcement. Inspections have to be conducted to maintain the integrity of the RC structure [2].

This research study considered the usage of conventional hammering testing on laboratory specimens and existing RC structure. In addition, this research also incorporated spectral analyzer in order to transform sound pressure into frequency-time graph to determine the degree of deterioration on concrete.
structure. From the result (sound pressure and frequency) healthy and unhealthy specimens can be clearly distinguished.

2. Conventional hammering test and hammering sound test

2.1 Conventional hammering test

There are many NDT method that can be used on RC structures in order to determine the level of defects [3-5]. However, according to Sonoda and Kawabata, (2010) [6] conventional hammering test is regarded as relatively easy and inexpensive method. Therefore, it can be used to inspect larger structure easily. However, conventional hammering test requires high level of skills to be able to evaluate the sound produced from the impact. Skilled inspector will determine the healthy and defective RC structure based on the sound produced by the hammer. Moreover, it also requires great deal of labour and time when it is used to inspect a large structure [6]. In addition, hammering test can only distinguished healthy and defective spots under the surface of the RC structure such as void and delamination. However, this method cannot assess the degree of deterioration within the RC structure.

2.2 Hammering sound test

Hammering sound test brings a whole new level to conventional hammering test. Hammering sound test is established to evaluate the degree of deterioration of a concrete structure. Converse to conventional hammering test, this test does not depend upon the experience and subjective sense of the inspector as well as it does not require large and expensive equipment to run.

The acceleration and the pressure of sound are examined between healthy and defective spots [6]. Specialized equipment such as impulse hammer (shown in Figure 1(a)) is used to measure the hammering power as most of the inspector might produce a different degree of hammering power. Therefore, with introduction of hammering sound test, determining the degree of defect under the concrete structure is possible. The sound produced from the impact of the hammer is an audible sound. It is detectable by normal human hearing. Therefore the sound produced from the impact is able to be captured by the microphone which is connected to the analyser (Figure 1(b)).

![Figure 1. (a) Impulse hammer and (b) Measurement of sound pressure using impulse hammer [6]](image)

2.3 Spectral analyser

This tool will be the main equipment in producing quantitative data from the hammering test. Acoustic emission emitted from the surface of concrete upon impact will be captured by the
measuring microphone and then is transmitted to the analyzer. Then the frequency spectrum of the emitted acoustic is produced in the display.

3. Methodology
Research was conducted both in laboratory and on-site. On-site test was carried out to verified data collected from laboratory test.

3.1 Laboratory test
For laboratory test, mortar specimens with the size of 100 mm (width) × 100 mm (height) × 300 mm (length) was used. The polystyrene was used to replicate the existing defect in the mortar specimen. The size of polystyrene was 50 mm (width) × 100 mm (length) with varying thickness of 10 mm, 20 mm, and 30 mm. The polystyrene was placed 25 mm, 30 mm, and 35 mm from the surface of the impact of the hammer. For each combination of thickness and depth of polystyrene, 9 specimens were casted plus 9 specimens with solid mortar (control specimens). All specimens are denoted with “T” and “D” that represented the thickness and depth of polystyrene in the mortar specimen, respectively. The specimens were cured for 7 days before commencing of the test.

The measuring microphone was used to record the sound produced from the impulse hammer. Then it was later amplified before transferring the signal into the datalogger. The spectrums that were produced at the display and the data will be recorded. The spectrum of the frequency produced was recorded for the data analysis. DEWESOFT datalogger was used in this test. Datalogger and microphone used for the test is as shown in Figure 2. The data logger comes together with the measuring microphone and impulse hammer to complete the data collection. The data of frequency, sound pressure and force were recorded and extracted from the datalogger. The extracted data were moved to Microsoft excel for further analysis.

![Figure 2. (a) DEWESOFT datalogger and (b) microphone used to amplified the hammering sound](image)

3.2 On-site test
The same test was carried out on an existing RC structure. Swan Garden Hotel, Melaka is selected for the on-site testing. Based on visual observation, there were already cracking visible on the surface of the structures. Aside from that, the structure was also located approximately 100 m away from the sea. Therefore, the hotel was chosen as the on-site testing. This test is to validate the data obtained from the laboratory with existing concrete structure. Results obtained from the existing structure are compared to know the difference between laboratory testing and on-site testing.

The specimens selected were column structure and wall structure. As mention before, structure with visible cracking were chosen. Mesh with the size of 400 mm x 400 mm were drawn on both column and wall structure. The spacing between the nodes are 100 mm vertically and horizontally separated. The structure is as shown in Figure 3. For both laboratory and on-site testing, the impacts
were conducted 5 times per specimen to obtain the uniformity of the data. The measuring microphone is placed approximately 50 mm away from the impact point.

![Image](image1.png) ![Image](image2.png)

**Figure 3.** Selected (a) column and (b) wall structures for on-site testing

4. **Result and discussion**

The results obtained from the analysis on the mortar specimens are shown in Figure 4. From the figure, N indicates control specimens. As for specimens with varying thickness and depth of polystyrene, T10D25 indicates specimens having thickness of polystyrene of 10 mm with 25 mm depth from the surface of the specimens.

From the graph obtained, the control mortar specimen (N) displays the highest sound pressure at 0.13 Pa at the frequency of 700 Hz. Whereas for the defective mortar specimens, the peak sound pressure produced falls within the range of 0.07 to 0.08 Pa. However, their peak frequency varies with thickness of the polystyrene 10 mm, 20 mm and 30 mm, and depth of the polystyrene to the impact point of 25 mm, 30 mm and 35 mm. Defective mortar specimen display lower sound pressure than normal mortar specimen.

The percentage difference between healthy and defective mortar specimen is in the range of 40 – 50 %. The sound pressure is captured by the measuring microphone and is transmitted to the data logger. From the findings, solid mortar specimen gives off higher amplitude than of hollow mortar. This is due to the void under the surface of the mortar that reduces the sound pressure produced from the impact of the impulse hammer on the surface.

As for the site structures, the results is as shown in Figure 5. The structure is categorized accordingly to the sound pressure produced together with the physical sound produced upon impact. The red region indicated that the sound pressure produced from the impact of the hammer is less than 0.02 Pa. The sound produced is due to the incomplete bonding of the plastering to the concrete surface. Therefore the sound pressure is low. Whereas for the green region, the sound pressure produced is in the range of 0.02 to 0.025 Pa for the column structure. However, for the wall structure, the sound pressure produced on the green region gives off the value of 0.03 Pa to 0.07 Pa which is different as compared to the sound pressure produced on the wall structure. The physical sound produced from the impact is still the same. As for the last blue region, the physical sound produced from the impact is as there is a hollow beneath the concrete structure. The sound pressure produced by the column structure is in the range of 0.03 to 0.05 Pa. The sound pressure produced on the wall structure is in the range of 0.03 to 0.09 Pa. From the findings, the result obtained from a node can be affected by the neighbouring nodes. The external crack can also be part of the factor which can affect the sound pressure produced.
5. Conclusion

Hammering test can be used to inspect existing structure. The degree of defect can also be determined from the frequency produced. The laboratory and site testing is conducted with the presence of spectral analyzer, measuring microphone, and impulse hammer to obtain quantitative data for the research. The amplitude produced from the healthier mortar specimen is higher than the defect mortar specimen. However, the peak frequencies produced from the defective mortar specimens vary respectively. The plastering layer can affect the sound pressure produced upon impact. The uniformity of the plaster bonding can also affect the data obtained in the site testing.

Several recommendations to be done such as removal of plastering layer before conducting test to ensure the uniformity of the sound pressure produced. A set of frequencies according to the degree of defect is to be made for commercial uses in the future for hammering inspection.
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