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Research paper

Condition Assessment of Fire-Affected RC Slab Via GPR Signal Reflections Analysis and Visual Inspection Method

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Abstract

This study aims to assess the condition of a fire-damaged building for recommendation of repair works. The Institute of Medical Research (IMR) building, in Kuala Lumpur, Malaysia was damaged by fire in April 2011.Visual inspection (VI) is the normal assessment method, but for more accurate results, Ground Penetrating Radar (GPR) signal reflections analysis is employed. The defects analyzed are cracks and delamination of the affected area which was the reinforced concrete (RC) slab at level 3, location where the fire had started. The results obtained using GPR and visual inspection were compared. The area where cracks were detected visually was confirmed by results from the GPR signal reflections analysis but visually, only 28% of the slab area showed delamination defect. When checked with GPR, the area of delamination was actually 56 % of the slab area. Cracks and delamination damage mapping was prepared in order to help facilitate repair works. This result shows that Ground Penetrating Radar (GPR) signal reflections analysis had detected delamination in RC slab where normal visual inspection failed to detect.

Keywords: *Crack; delamination; ground penetrating radar; post-fire; visual inspection*

1. Introduction

In modern construction industry, use of reinforced concrete (RC) as building structural element is extensive due to its several advantages [1]. It is known that RC is prone to deterioration and defects due to rebar corrosion [2] through moisture and chloride intrusion [3]. For instance, in Malaysia, 172 cases of RC damages were recorded in 2013 [4] and one of the damage culprits is accidental fire event. Even though concrete is considered to be fireproof, but when exposed at prolonged duration and at high temperature due to intense burning, the physical-chemical changes in concrete properties lead to deterioration in its mechanical properties.

Apart from changes in concrete surface after exposure to elevated temperature during fire event [5], another possible types of building damages observed are cracks formation, explosive spalling and delamination. The generation of individual cracks on concrete surface exposed to fire is induced by the progressively large deflection [6] of structural members. The main cause of this scenario is due to the compressive strength lost, 10 percent, as the surface temperature increased from 0˚C to 200˚C [7]. The cracks in RC members may also originated from mistakes at design stage, construction errors or excessive loading on the building structures [8]. These initial cracks will further reduce the structural durability and influenced the integrity of the structures when exposed to fire [9].

Explosive spalling of concrete cover is commonly associated with rapid heating during fire. The amount of explosive spalling is significantly influenced by the degree of thermal shock that usually take places during the early stages (i.e. 800˚C within 20 minutes of fire) [10]. This depends on the amount of moisture presented in concrete, thermal coefficient of concrete and its permeability. Reference [11] classified two mechanisms that explain the occurrence of the explosive spalling of concrete; thermal stress and pore pressure. The former mechanism could not advance in concrete that has zero thermal expansion coefficient as experienced in some lightweight aggregates; while the latter mechanism experiences thermal expansion. It is being recommended that the use of thermal barrier which could be significantly effective in preventing explosive spalling.

On the other hand, another type of post-fire defect is delamination, a defect that is visualized as surface discontinuities of concrete. However, these discontinuities appear not to be completely detached from its mass concrete. In RC structure, delamination started either due to the existence of external forces or by the developed pressure of rebar corrosion on concrete-rebar interface, or in case of fire exposure, expansion of rebar due to the heat.

The evaluation of post-fire damages severity can be conducted by using several non-destructive methods due to its rapidness in data collection and non-invasive nature during the site investigation works. However, the typical visual inspection (VI) method is still commonly used in building defect assessment by inspecting and evaluating the damage areas based on an inspector’s experience, observation and judgement. In order to perform a comparative and more detail damage assessment evaluation, an advanced non-destructive method such as GPR is used to detect several hidden damage features such as voids, cracks, embedded element anomalies [12] and delamination in structures. Reference [13] had shown the ability of GPR to detect the cracks and rebar corrosion in reinforced concrete structure. However, the data interpretation using GPR results requires skilful operator to identify and estimate the post-fire defects on concrete structures; which will be the focus of this paper; to interpret the complex analysis from GPR images.

GPR uses the electromagnetic wave signal reflection characteristics inside the materials. The electromagnetic wave propagates through material with certain wave velocity depending on the propagating medium dielectric value. The transmitted electromagnetic wave is then reflected once the wave propagates through a different dielectric value material such as a layer of delamination, voids, rebar and cracks with certain minimum dimension. The time taken for the signal propagation and reflection are recorded by the GPR images once the propagating signal is transmitted from and reflected to the GPR antennas. However, certain factors such as high chloride content in deteriorated concrete areas and rebar corrosion may weaken the signal strength and the GPR image quality is significantly affected [14].

In this paper, the identification of the cracks and delamination in the fire-damaged slab of the Institute of Medical Research (IMR) building using both methods were explored and quantified.

2. Methodology

2.1. Site location description

In this study, a fire-damaged building (IMR) has been selected as the damage evaluation case study (Figure 1). The IMR was built in 1974, and in 2011, a massive fire event had occurred and had destroyed partially the building structural elements. The room storing chemicals located at level 3 of the building, where the fire had started was the area with the worst damages (Figure 2). This study focusses on the slab in the room. The damages checked were the cracks and delamination. Figure 2 shows location "A" where the considered slab is suspected to suffer delamination defects while location "B" is suspected to suffer cracks.

Fig. 1: Location map of building site

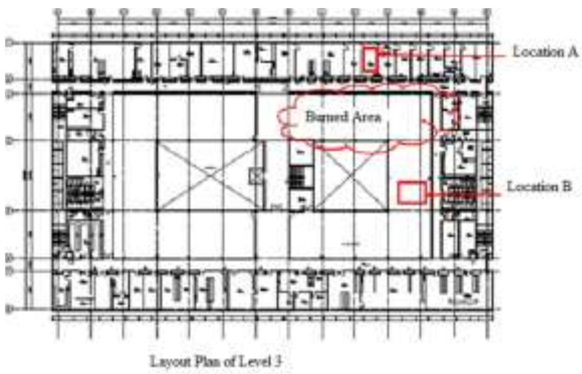

Fig. 2: Location of investigated area

2.1. Investigation location and grid arrangement

The initial investigation work started by defining the working areas with rectangular grid of 3000 mm × 3000 mm on each slab. The working areas (A and B) were marked and grid with a smaller rectangular grid of 600 mm × 600 mm squares as shown in Figure 3. Post-fire slab defects assessment was conducted using GPR by scanning the slabs in two directions perpendicularly as shown in Figure 3.

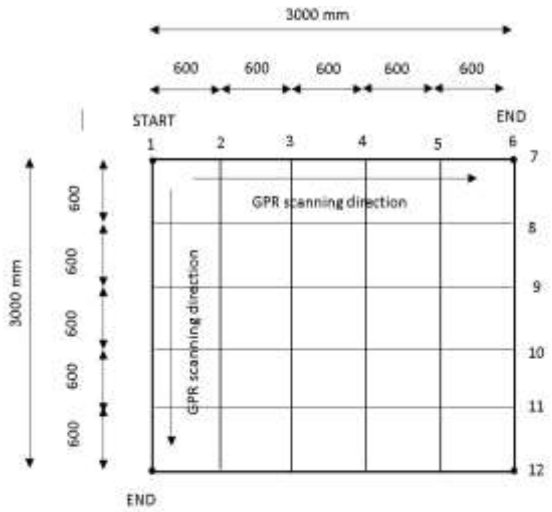

Fig. 3: Grid mark divisions scheme of the slab and GPR scanning direction

2.2. Visual inspection investigation work

The visual inspection was conducted based on inspector's eyes to visually inspect and access the surface defects on both slabs. The qualitative assessment of the inspection is based on the building checklists established by the Public Work Dept. [15]; which graded the slabs surface defect using the numerical system scaled from 1 to 5 (Table 1).

Table 1: Defect evaluation scale [15]

Rating Scale	General Definition
1	No damage found such as cracks, spalling, corrosion and delamination and no maintenance required as a result of inspection.
2	Damage detected, and it is necessary to record the condition for observation purposes.
3	Damage detected is slightly critical and thus it is necessary to implement routine maintenance work.
4	Damage detected is critical and thus it is necessary to implement repair work or to carry out detailed inspection to determine whether any rehabilitation works are required or not.
5	Being heavily and critically damaged and possibly affecting the safety of the building, it is necessary to implement emergency temporary repair work immediately or rehabilitation work without delay after the evacuation of occupants and apply site blockage.

2.2. GPR slab subsurface investigation work

GPR SIR-3000 system with central frequency of 1600 MHz was employed to investigate the subsurface condition on both slabs in the building. The output of the signals is in the form of electromagnetic wave reflection images. The GPR system is equipped with one central processing unit (CPU) with antennas to transmit and receive electromagnetic wave through the slabs. The GPR subsurface images of the slabs were then further analysed by RADAN 7 software to interpret the extent and severity of delamination and cracks on both slabs.

3. Results and discussions

3.1. Visual inspection results

Based on the visual inspection evaluation on both slabs, the concrete delamination was detected at location "A" and cracks were identified in RC slab at location "B". Figure 4 shows the existence of delamination on slab at location "A" and cracks at location "B" are depicted in Figure 5.

Fig. 4: Delamination at soffit of slab surface

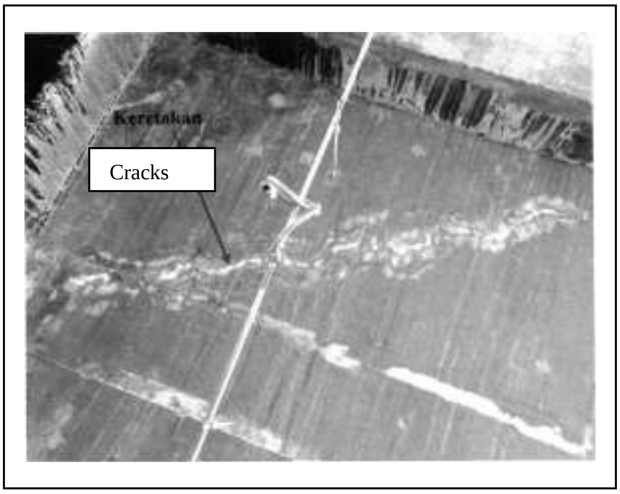

Fig. 5: Cracks at soffit of slab surface

The deterioration of both slabs was found on the slab soffit and they were identified as in a critical deterioration state (Rate 4 from Table 1); which needs more detail inspection method to determine the necessary repairing or rehabilitation works to restore the slabs to its original state (Table 2). Rate 4 suggested detail inspection method needs to be done, thus the employment of the GPR signal reflections analysis on the slabs.

Table 2: Visual inspection assessment on both slabs

Deterioration Type	Surface	Visual inspection grading scale	Severity interpretation
Delamination (Location A)	Soffit of slab	4	Critical
Cracks (Location B)	Soffit of slab	4	Critical

3.2. GPR image interpretation

Two subsurface images at location "A" and "B" were studied after B-scan data using GPR were collected by scanning the antennae over the slabs' surfaces.

Figure 6 shows the image taken at grid number 4 at location "A" that has been analysed using RADAN 7 software. It can be seen that hyperbolic reflections wave had appeared at depth of 210 mm, which is the depth of the rebar. The hyperbolic reflections are identified as the rebar. Upon observation of the hyperbolic reflections, weak hyperbolic reflections were detected at distance 550 mm to 950 mm and from 1600 mm to 2000 mm from the initial scanning position, showing there exist different medium (void or rust) other than steel. This hypothesized that the delamination at location "A" is located at depth 210 mm from the soffit slab surface with the length of 400 mm.

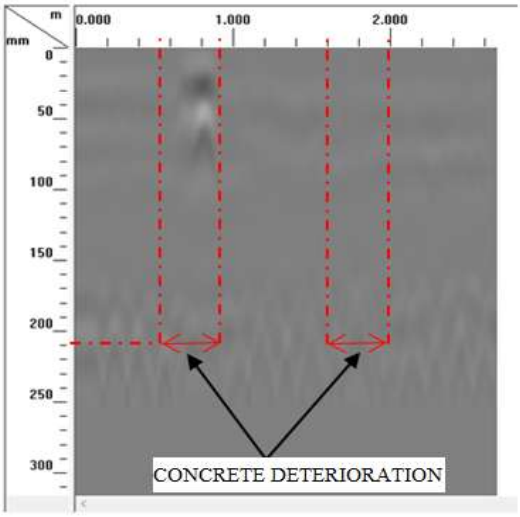

Fig. 6: Subsurface image at location "A"

At location "B" of the slab, cracks images were displayed by a strong hyperbolic feature as shown in Figure 7. This image was taken at grid number 9 at location "B" using GPR and analysed by RADAN 7 software. It can be hypothesized that cracks were initiated from distance of 1100 mm and 2000 mm at depth of 25 mm from the slab soffit surface. The cracks defect was detected based on the travel time difference observed at location marked by the oval (K1 and K2) in Figure 7. At location K1 and K2, the time taken for the wave to travel two ways is shorter than at any other locations, showing different medium other than concrete existed (air - crack).

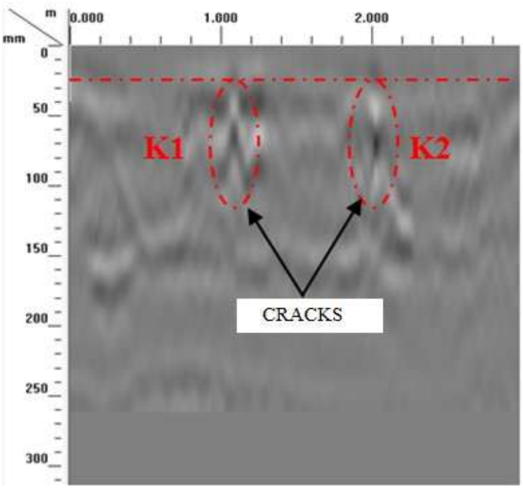

Fig. 7: Subsurface image at location "B"

3.3. Comparison of results between the visual inspection and GPR method

Almost 90 % of the detected delamination work done by the visual inspection method were also able to be identified by the GPR inspection work (Figure 8), but more areas where VI does not shows delamination were detected by GPR. It can be seen that the delamination damage than can be detected by GPR inspection work is 56 % of the slab area, while visual inspection method only captured the similar damage type at less locations, only 28 % of the slab. This shows that GPR can detect delaminations of rebar under concrete cover, where our eyes fail to see them.

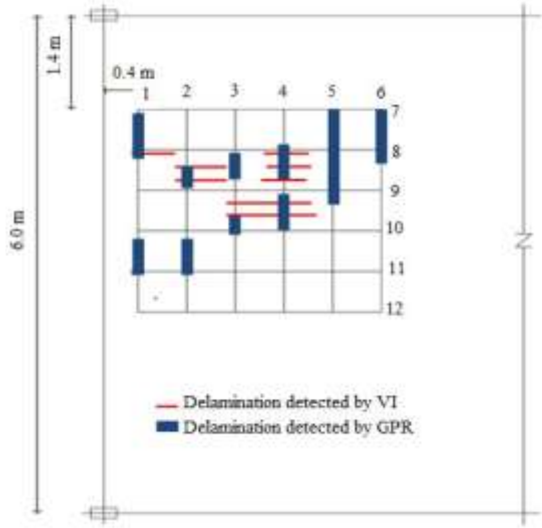

Fig. 8: Comparison of delamination results

During VI, one crack with 1.5-meter length was found on the slab soffit surface (Figure 5). However, the 1.5-meter length actually extend up to 2.4 meter as shown in Figure 9, detected by GPR measurement and another a 1.8-meter length crack actually was also detected in the reinforced concrete slab using GPR, which is not visible to the naked eyes. This also concludes that GPR can detect cracks inside concrete, which could not be detected by VI.

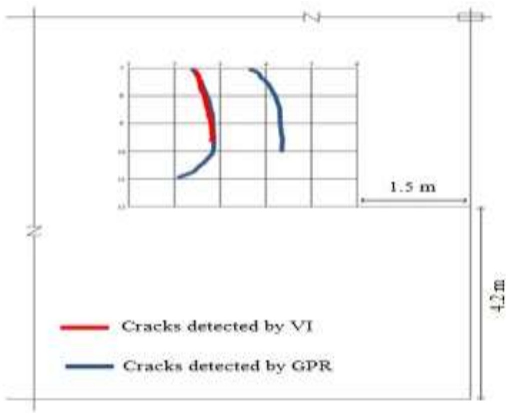

Fig. 9: Comparison of crack detection results

4. Conclusion

It was observed that the delamination and crack defects can be identified and detected using the visual inspection method and GPR, however, visual inspection could not detect hidden or buried defects in the RC. GPR is needed to determine the extent of the defects. At location "A", GPR inspection works have successfully quantified 56 % the slab area as actually had delamination damage but visually, only 28 % of the slab area is identified as having delamination problem. GPR subsurface images showed the delamination features due to the presence of weak hyperbolic wave reflection inside the RC slab at location "A".

At location "B", two cracks damages have been quantified by GPR with the length of 2.4m and 1.8 m when only one crack with the length of 1.5 m was detected by the visual inspection method. It is worth to note that the first position of the crack detected by GPR is same as the visual inspection method with dissimilar crack length, but the extent of the internal cracks could only be detected through GPR.

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