BUILDING CONCRETE CRACKS DETECTION USING IMAGE-BASED NON-DESTRUCTIVE GEOTECHNICAL TECHNIQUE

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ABSTRACT: Buildings need to be maintained regularly throughout the entire of their operational life in order to extend their service lives. The building structural health monitoring system is produced to prevent the occurring of hazardous incident. However, the health information of these buildings are not being recorded and reported by the construction and building industry although it is crucial for building structure monitoring, maintenance and rehabilitation. Hence, issue of deterioration of building concrete structure in recent years had become an alarming issue that highlighted extensively throughout the world. As such, assessment of building concrete structure health, particularly the concrete cracks is crucial for ensuring the safety and health of the building as cracks are among the earliest symptoms of concrete structure degradation. Therefore, non-destructive geotechnical technique was introduced in this study to determine the physical conditions of the concrete structure for building and visual examination was conducted for results verification purposes. In doing this, experiment was conducted by exerting hydraulic load on a reinforced concrete beam to produce cracks in precast concrete beam. Then, the common used non-destructive electromagnetic (EM) device, ground penetrating radar (GPR) with 2 GHz high frequency bi-polar antenna was employed to scan the reinforced concrete beam to detect cracks. After that, visual inspection was conducted for validation of concrete cracks on the beam. Results of the study contributed main finding where the high similarity in the radar profile obtained by GPR and numerical model can trace the "safe buffer zone" for building structure maintenance work; very crucial aspects in monitoring of structural health for buildings, particularly those buildings that supporting human and economic activities, transportation and a collection of buildings that make up of urban and rural communities.

1.0 INTRODUCTION

The deterioration of urban buildings structure is a problematic issue that often occurs around the world. Building structure is decaying faster than it is being refurbished in response to dramatically increases of public infrastructure investments, inadequate investigation and maintenance, absence of uniformity and consistency in design, construction and operation routines, low funding, poor-quality installation, population growth, and narrower environmental and health prerequisites. Due to these adverse effects on the concrete structure of the building, coupled with significant growth of public infrastructure investments in several sectors, it has speed up the structural aging process of these buildings. As such, rehabilitation or maintenance is needed indeed for extending the operation lives of these buildings. Nevertheless, the social and financial costs of infrastructure maintenance, repairs or replacement is actually very costly and will caused service interruptions at the same time (Kabir et al., 2009).

For this reason, building concrete structure cracks inspection and assessment is hence essential for quantified the structure health of the buildings, as cracks are the sign of the structural stability of a building or concrete structure. It is a cost-effective and safe way for maintenance of concrete structures for the buildings in urban and sub-urban areas. By doing this, the cracks information obtained from structure cracks inspection and assessment can be used for structure rehabilitation or maintenance utilizing suitable practices to fix the fractured structure and forbid any calamitous failure (Fujita et al., 2006). During the investigation, diagnosis, sustenance and lifetime prediction of concrete structures safety, the detection of cracks on concrete surfaces plays the most important role as cracks are among the earliest signs of concrete structures deterioration (Yamaguchi and Hashimoto, 2010).

In doing this, non-destructive testing (NDT) methods play an important role. In the assessment and examination of civil engineering structures, NDT methods are employed to supply distinct information on particular problems rather than as an essential part of the comprehensive inspection program (McCann and Forde, 2001). It will be more efficient if multiple NDTs are employed in the meantime although all of these NDT approaches can work individually (Zhou, 2011). The potential of Ground Penetrating Radar (GPR), one of the well-known NDT methods for the condition evaluation of concrete structures has been acknowledged for more than 30 years since it is available in the market in the early 1970s. In North America alone, concrete surveying for locating buried objects by GPR has developed into an industry valued at USD 100 million a year (Tarussov et al., 2013). In recent years, GPR has been preferred as an effective means to ‘look through’ concrete structures and it has been employed for periodic examination and maintenance of the masonry and reinforced concrete structure for civil infrastructures such as bridge deck, road structure, tunnels, etc. (Lai et al., 2009). Several studies has been carried out on concrete bridges by using GPR technique and these studies have proven that GPR is an effective means for condition evaluation of concrete as well. Huston et al. (2000) have evaluated Good Impedance Match Antenna (GIMA), a novel antenna type of GPR for concrete bridge decks assessment while Hugenschmidt (2002) and Alani et al. (2013) have found that GPR is effective in investigating rebars and possible defects such as structural cracks in concrete bridge decks due to its high data acquisition rate minimizes the traffic flow obstruction. On the other hand, Hugenschmidt and Mastrangelo (2006) locate rebars, tendon ducts and pavement thickness in concrete bridges with millimeters accuracy while Cruz et al. (2010) discover the accurate location of tendon ducts and rebar and identify cracks in concrete successfully by using GPR. Solla et al. (2014) found that GPR is perfect for detecting the origins of the crack in-depth, as well as for the qualitative evaluation of the magnitude of this flaw, in addition to the identification and preliminary identification of the cracks. Krysinski and Sudyka (2013) have studied the effectiveness of GPR method for pavement crack diagnostics with different frequencies antennas instruments and a series of GPR signs of cracks are presented with decimeter accuracy. GPR can also be used in tunnel surveys, where Xiang et al. (2013) have used GPR for the annual inspection of Damaoshan highway tunnel as it can provide tunnel internal images information and the fine particulars of the data acquired enables the morphology, second lining thickness, rebars position and status, and probable damages areas to be identified successfully.

GPR is thus an efficient technique that can disclose the presence and location of embedded objects in a non-destructive and non-invasive manner using the electromagnetic (EM) wave reflection phenomenon when it is applied to the introspection of ground. (Barrile and Pucinotti, 2005). From the reflected waves, delamination, material characteristics, rebars, and voids can be detected and interpreted by using GPR (Buyukozturk and Yu, 2009). Moreover, GPR is able to scan wide area under inspection in a short period of time and its high sensitivity to subsurface moisture and buried metal allows it to distinguish both metallic and non-metallic substances. Despite that, there are lack of related publications reviewing the capabilities of GPR for building concrete structure assessment and monitoring (e.g. determination of features construction, estimation of rebar size, concrete cracks, and also dimensions and localization of voids). For this reason, GPR is being adopted in this study to assess the physical conditions of the concrete for selected structure of the building with the main aim to detect cracks in reinforced concrete structure by using GPR. The ability of the GPR in detecting cracks in a reinforced concrete structure was tested using visualization inspection and digital image processing methods in interpreting radargram obtained by GPR and numerical modelling.

2.0 MATERIALS AND METHODS

2.1 Data Acquisition

Data acquisition was conducted at Structure and Material Laboratory, Faculty of Civil Engineering (FKA), Universiti Teknologi Malaysia (UTM). In order to simulate the actual condition of cracks on concrete beam caused by external force such as sudden hit, extreme or destructive events, the laboratory experiments were conducted by exerting hydraulic load on a reinforced precast concrete beam to produce cracks on it. Then, the commonly used non-destructive EM device, Aladdin GPR with 2 GHz frequency bi-polar antenna was employed to scan the reinforced concrete beam specimen to detect cracks on it for each 50 kN hydraulic load exerted onto the specimen until the reinforced concrete beam failure. In this study, as metallic objects such as rebars are present in the reinforced concrete beam, data is collected by sliding the device over the specimen surface from left to right in the longitudinal direction (i.e. perpendicular to the direction of the reinforcement steel). For each beam specimen, a total of 37 scan lines are obtained begin from the bottom of the beam specimen to the top part of the beam specimen by following the pad survey guide. The details of the reinforced concrete beam specimen and the scanning details are shown in Figure 1.

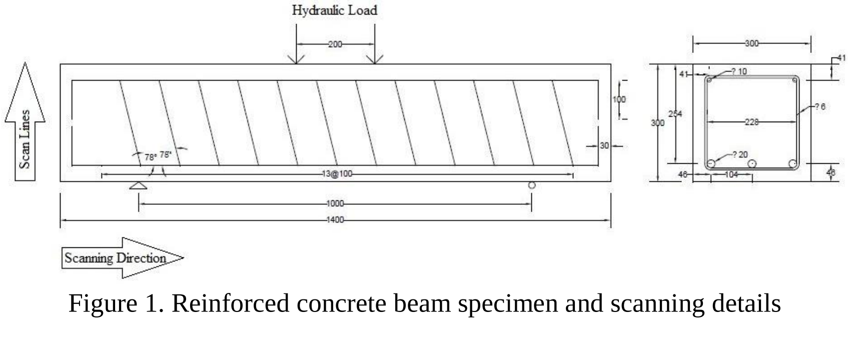


Figure 1. Reinforced concrete beam specimen and scanning details

2.2 Data Processing

After acquired data, some simple processing steps, such as editing, dewow filtering and applied gain were performed at site during data acquisition to check the quality of the data obtained. Initially, editing is done to remove and correct bad or poor data and sorting data files. Then, dewow filtering is performed to correct the low frequency and wow noises (i.e. nonlinear noises that associated with the antenna characteristics) in data. In doing this, the initial DC signal element or DC bias and successive fading of low frequency signal trend or 'wow' existing in the data is removed. It is a crucial procedure as it decreases the data to a mean zero level and hence, positive-negative colour filling is allowed to be applied in the documented traces. As such, it the most time-consuming task as large volume of data need to be sorted and rearranged for further processing for better final interpretation.

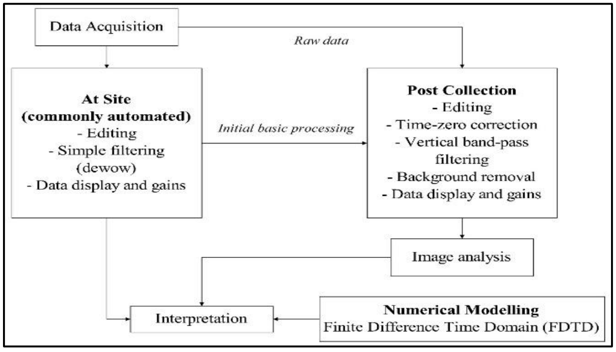


Figure 2. Flow chart of methodology

The data which undergone basic pre-processing in the site were then collected for post-processing in the laboratory. Post collection processing were done to enhance the visualization of the data for better interpretation (Cassidy, 2009). In doing this, the data were first being edited to remove and correct bad or poor data and sorting data files. With large volume of data collected from site, the editing process is most time consuming task. Then, the time-zero correction step was take place in order to align the depth scale of the data obtained from site to the actual depth of the site. The Ground wavelet first arrival time or 'leaps' in the air which caused by the electronic instability, thermal drift, cable length variations and differences in antenna air gap were removed through time-zero correction.

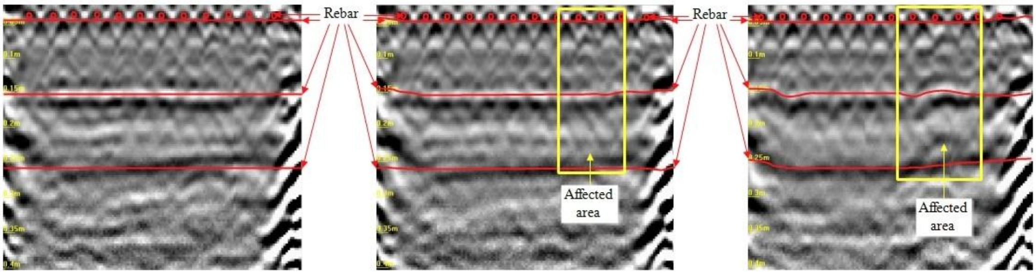
By doing this, this can reduce the effects of ground interface by adjusting the scanline to a prevalent time-zero position ahead and it can improve the signal-to-noise ratio (SNR) as well. After that, vertical band-pass and Clear-X filtering were performed to remove the background noise which caused by unwanted reflection and to eliminate the noise outside the specific region of the main GPR signal bandwidth which defined by the users (Kim et al., 2007; Jol, 2009; Jaw and Hashim, 2013). Lastly, the gain function was applied to the radargram based on suitable operation for better data presentation and easier for interpretation during analysis for identifying the target from the radargram based on user's experience. The overview of the methods used in this study is shown in Figure 2.

3.0 RESULT AND DISCUSSION

A series of scanning has been carried out on the reinforced concrete beam and bulky data has been processed. Only GPR profiles with significant changes are selected to be discussed (refers Figure 3).

(a) (b)

Figure 3. Reinforced concrete beam (a) Pre-stressed, (b) Failure



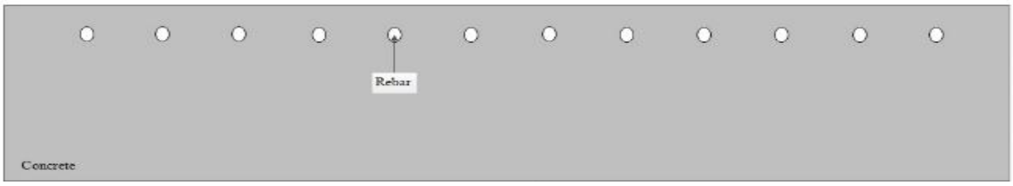
(a) Load = 0 kN (b) Load = 249.4 kN (c) Load= 500.3kN

Figure 4. Comparison of experimental results acquired with 2 GHz GPR system

In this case, high frequency antenna GPR system was used to detect the crack on the precast concrete beam after applying hydraulic load on it. By using an antenna with frequency of 2 GHz, which can provide fine and high resolution radargram with penetration depth up to 0.4 metres into the concrete structures, cracks can be detected. However, this vary depends on the types and conditions of the material to be scanned. Objects nearer to the surface can be viewed more detail and clear compared to objects further beneath the surface. From Figure 4, it shows that the objects located further from the scanning surface cannot be identified as clear as objects located few centimetres from the surface. The resolution and details in the radargram decreases as the depth increases. The first and second horizontal rebar at a depth of about 46 millimetres and 150 millimetres can be observed clearly in the radargram while the third horizontal rebar at a depth of 254 millimetres are unclear. The bottom of the reinforced concrete beam with a depth of 300 millimetres are blur and not well defined. The rebars in the precast beam were represented by the inverted “V” shape hyperbola appear in the radargram. This is proved in the work of Yelf (2007) where discrete buried objects such as pipes, cavities and rebars usually present as hyperbolic reflections in the GPR profiles, with the limbs of the hyperbola projected downwards and look alike an inverted “V” shape.

The number and position of rebars detected in the radargram are same as those in the reinforced concrete beam specimen. For this results, it proved that high sensitivity of GPR to embed metal allows it to detect both metallic and non-metallic objects easily (Zheng et al., 2003). It cannot penetrate metals but it can pass through the gaps between the rods of reinforcement within limits (Wiggenhauser, 2009). This allows the rebars in concrete structure to be identified and located accurately. Besides, the greater contrast in electrical conductivity between the material and target will result in brighter reflection. High conductive materials, for example, metals may produce brightest reflection and hence, they are easier to be detected (Underground Surveying, 2014). As such, cracks can be easily observed from the radargram as there are changes in the internal structure of the reinforced concrete beam. This can be clearly seen in Figure 4(c), where the horizontal rebars experienced change and bent when the concrete beam approaches failure as compared to its original condition at the same point. When these rebars bent and broke the concrete, cracks appeared. When there is crack, there is air gap between the surface of the reinforced concrete beam and the rebars, hence, the dielectric constant and electrical conductivity at the area where cracks appeared will become darker as air has a lower dielectric constant and electrical conductivity compared to metal. The cracks region has a darker and dull presentation of rebars in the radargram because the difference in electrical conductivity and dielectric constant decreased the reflection and contrast of the rebars (refers Figure 4 (b) and (c)). According to Krysinski and Sudyka (2013), cracks visibility on radargram is connected to the structural noise created by the uneven medium structure and this may cause difficulties in detecting micro-cracks or cracks that are too fine as this may resulted in misinterpretation.

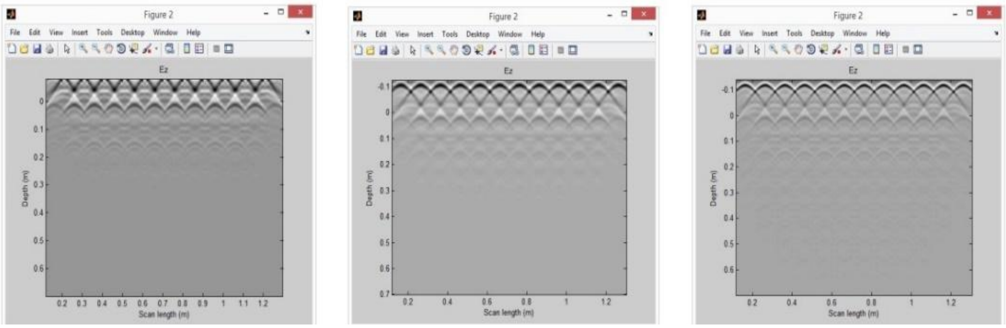
As comparison to the results obtained using 2 GHz GPR system, numerical modelling is carried out in this study. In doing this, Finite Difference Time Domain (FDTD) method was adopted to simulate the concrete structure in good condition and with cracks. In this study, different antenna frequencies settings were used for numerical modelling, ranging from 1 GHz, 1.5 GHz to 2.0 GHz. High frequency antenna setting was used in this study as cracks are in micro scale where it has fine outline in the concrete and hardly can be distinguished with low frequency antenna setting. Hence, the antenna frequency with lower than 1GHz was not considered to be used in this study for simulating the cracks condition in a concrete beam. For this study, the simulation is according to reinforce concrete beam specimen (refer Figure 1) in good condition and cracks condition for better comparison purpose. Figure 5 (a) shows the schematic drawing of reinforced concrete beam without crack while Figure 5 (b) shows the schematic drawing of reinforced concrete beam with crack. The results obtained are shown in Figure 6 and 7.



(a) Concrete in good condition

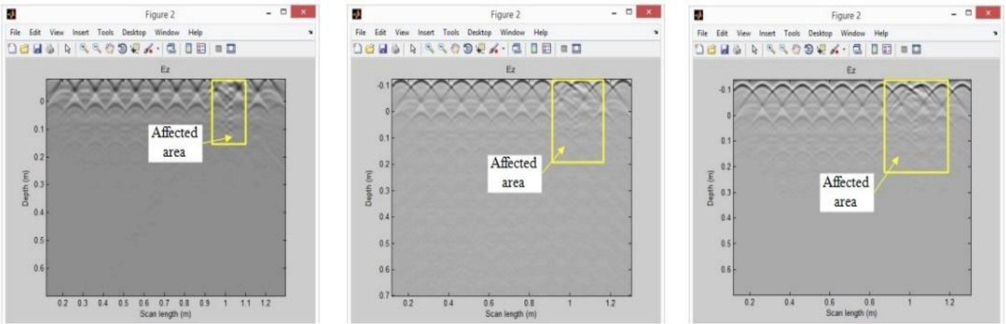
(b) Concrete structure with crack

Figure 5. Schematic drawing of simulation models



(a) 1GHz (b) 1.5 GHz (c) 2 GHz

Figure 6. Simulated models where concrete in good condition



(a) 1GHz (b) 1.5 GHz (c) 2 GHz

Figure 7. Simulated models with cracks

From the simulated models in Figure 6, it shows that higher frequency antenna provide higher and finer resolution data. The inverted "V" hyperbola of rebars in the radargram in Figure 6(c) appears to be finer as compared to Figure 6 (a), where the hyperbola appears to be coarser. The condition of the crack is crucial in the GPR detection as revealed by the synthetic data obtained (Solla et al., 2014). From Figure 7, the effects of cracks on the reflections of rebars and on the concrete structure can be observed. Cracks are easier to be distinguished with higher frequency antenna where its effects on the surrounding materials. The effects of cracks on the reflections of rebars hyperbola are very clear in Figure 7(c) but it is difficult to be identified in Figure 7(a). Therefore, an antenna with higher frequency of 2 GHz is more suitable for cracks detection in concrete structures. With synthetic data, the behavior of different materials when cracks present can be predicted and it is useful for interpretation of radargram as it can be used as reference for building structure maintenance work. The level of damage for a building concrete structure can be evaluated easily based on this reference and yet the "safe buffer zone" for the maintenance work of concrete structure can be determined as well. With such comparison between the practical work of observation and simulation using numerical modelling, the probabilities of misinterpretation can be reduced and the accuracy can be increased at the same time.

4.0 CONCLUSION

The experimental data observed have proven the ability of GPR in detecting cracks. When cracks are detected, the affected areas can be identified from the radargram due to the differences in dielectric constant and electrical conductivity. From the GPR profiles obtained, it can be observed when cracks occur, the reflection from the rebars will be lower and rebars in the cracks region will appear darker or dull compared to rebars in non-cracks region that appear brightest in the radargrams. Besides, changes in the horizontal rebars in the cracks zone can be detected where the bending of the rebars can be observed from the radargrams. The numerical models reveal that high frequency antenna with 2 GHz is the most suitable for cracks detection in concrete structures compared to antenna with frequency of 1.5 GHz or 1 GHz as cracks are normally appears to be fine, higher resolution data are required for building structure concrete cracks detection. Although cracks affected areas can also be detected in coarse resolution data simulated with lower antenna frequencies, the details of changes in reflections of rebar in the cracks region are not as clear as those detected with antenna frequency of 2 GHz. The high similarity in radargrams obtained by GPR scanning and FDTD numerical models has proven the advantages of utilizing NDT methods for inspecting building structural health, especially in detecting cracks in the reinforced concrete structure. With such finding, this study proven that the usability of high frequency GPR system in the application of building structure monitoring and structure health detection. This new benchmark opens up new application and facility of GPR in civil infrastructure maintenance and management, particularly for assessment of the physical conditions for building structure concrete using GPR, a non-destructive approach for studying the cavity and rebars of the inner structure in a building.

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