PAPER • OPEN ACCESS

Image-based non-destructive evaluation method for building condition assessment

To cite this article: Hui Lin Ng *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **620** 012057

IOP Conf. Series: Materials Science and Engineering **620** (2019) 012057 doi:10.1088/1757-899X/620/1/012057

Image-based non-destructive evaluation method for building condition assessment

Hui Lin Ng[2, b)], Siow Wei Jaw[1, 2, a)], Mazlan Hashim[1, 2, c)], Poi Ngian Shek[3, 4, d)] and Kar Seong Lim[5]

[1]Geoscience & Digital Earth Centre (INSTeG), Research Institute of Sustainable Environment (RISE), Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia.
[2]Department of Geoinformation, Faculty of Geoinformation & Real Estate (FGHT), Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia.
[3]UTM Construction Research Centre (UTM-CRC), Institute for Smart Infrastructures and Innovative Construction (ISIIC), Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia.
[4]Department of Structure & Materials, Faculty of Civil Engineering (FKA), Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia.
[5]Geospatial & Utility Solutions Sdn. Bhd., Johor Bahru, Malaysia.

[a)]Corresponding author: swjaw@utm.my
[b)]winnie_0804@live.com
[c)]mazlanhashim@utm.my
[d)]shekpoingian@utm.my
[e)]secretary.gus@gmail.com

Abstract. Building condition assessment (BCA) is one of the important approaches in total asset management during the asset life cycle. BCA is to monitor the functional status of the asset during the asset use and maintenance phase in the asset life cycle. With regards to this, various non-destructive evaluation (NDE) technologies are adopted for building structure physical condition assessment from time to time to prevent any catastrophic incident to occur. Two case studies on inspection of internal structure condition of concrete wall and slab using image-based NDE were presented in this study. A well-known NDE technology, namely ground penetrating radar (GPR) was used to scan the concrete wall and slab to identify the internal structure condition of the concrete wall and slab. The GPR radargram obtained by the shorter wavelength radar signal is evaluated to resolve the internal structure and the defect in detail. Results of this study prove that GPR can detect the internal structure of the concrete wall and locate the moisture in the concrete slab due to poor waterproof design. With such convincing results, the application of GPR has set a new benchmark in BCA for building physical condition assessment; a crucial aspect for better building maintenance and management in total asset management.

1. Introduction
In general, concrete structure often experience defects or deterioration. There are two categories of defect, namely (i) macro; and (ii) micro defect. Macro defects are normally due to inadequacies and negligence in construction practices or design. Whilst micro defects are the very fine voids found in

IOP Conf. Series: Materials Science and Engineering **620** (2019) 012057 doi:10.1088/1757-899X/620/1/012057

the concrete structure caused by large capillary pores due to the use of low grades concrete with excessive water.

As the macro defect presence, the water and other chemicals can ingress easily into concrete and this lead to rapid deterioration of concrete structure. Meanwhile, as micro defect presence, it is discontinuous and shallow, appearance as fine cracks in most cases, where it is hardly seen by the naked eye. Initially, it does not pose a critical threat to the concrete structure. Thereafter, it will increase in length, depth and width over time in response to changes of weather conditions, temperature and the difference in loading conditions. Then, these fine cracks will combine with other fine cracks and form continuous passage, which allow the entrance of the moisture, sulphates, chlorides and other chemical substances from its surroundings. With then, it will induced concrete reinforcement corrosion and other destructive reactions.

As such, both macro and micro defects are detrimental to the health of the concrete structures and can lead to deterioration of concrete rely upon the extent of their presence, surrounding conditions of the building and maintenance conducted during its life cycle. However, macro defect is larger and can cause faster deterioration and more damage to the concrete structure as compare to the micro defect [1].

Defects can be found in the concrete structure throughout the life cycle of the assets. Concrete deterioration is hence an unavoidable natural process although careful design, material selection and proper construction method have been applied [2]. Ever since the concrete structure was being constructed, the deterioration begins [2, 3]. The aging process of this concrete structure will be speeded up as a result of population growth, exposure to aggressive environment, poor selection of material of construction, poor workmanship and quality of construction, insufficient inspection and maintenance, limited environmental and health condition, etc. [4].

For this reason, building condition assessment (BCA) or sometimes referred to facility condition assessment is needed to evaluate the physical condition of the building structure and forecast possible maintenance needed for the asset within its service lifespan. This is to ensure the functionality of the building for better delivery of services and optimize its economic benefits. Since buildings are the important civil infrastructure assets, it should be maintained effectively to ensure their satisfactory performance throughout their anticipated service lifespan.

The building condition assessment is generally consists of physical inspection of building and identification of necessary maintenance work based on the inspection result. In the physical inspection, remote sensing approach, which well known for its ability in obtaining physical information of an object or area by analyzing the data acquired by a device without physical contact with the object or area under observation can be used. Remote sensing plays an important role in the physical inspection of building as it capable to collect data at inaccessible areas and it “see” over a broader portion of electromagnetic spectrum than the human eye.

With this regards, non-destructive evaluation (NDE), using concept of remote sensing plays an important role in assessing and examining the civil infrastructure. It is the process of inspecting, testing and evaluating the building structure without destroying the serviceability of the structure. NDE has been used to provide distinct information on specific problems other than comprehensive inspection [5]. In this sense, this adding value to the application of NDE in civil engineering, especially in subsurface inspection.

Ground penetrating radar (GPR), an NDE technology with frequency ranges from 10 MHz to 2 GHz, has the ability in examining the man-made structure, especially in determining its location and depth [6]. It is at present the most promising sensing tool in NDE technology that can be used to inspect concrete thickness, location of voids, pipes or objects concealed in the walls or floors. It uses wave propagation method to transmit and receive the microwaves to map the karst feature (e.g. voids or cavities), fractures in bedrock, concrete or soil layer thickness. In this sense, a high frequency GPR system (2 GHz) was used in this study to inspect the internal condition of a concrete wall and slab. The inspection result obtained from the GPR, provides significant indication for the management and maintenance of public assets, especially those assets that serves for corporate or commercial purpose.

2. Methods

GPR can be implemented without any surface preparation by moving the antenna over the concrete surface. Large coverage area data can be acquired in the shortest time. In addition, GPR can penetrate different medium, such as the concrete structures due to the nature of electromagnetic waves. However, it unable to penetrate through metals as the metallic layer is an impenetrable border. Nevertheless, it can pass through the gaps between the rods of reinforcement within limits [7]. In this regards, it can be used to evaluate the status of concrete structures [8].

By using GPR, it can locate voids, cracks and reinforcing bars (rebars) in the concrete structures. The presence and location of the internal embedment can be disclosed in non-destructive and non-invasive manner using the electromagnetic waves reflection phenomenon when it is applied to the introspection of ground [9]. From these reflected waves, reinforcement corrosion and delamination, material characteristics, rebars, honeycomb, concrete cracking and voids can be detected and interpreted [10].

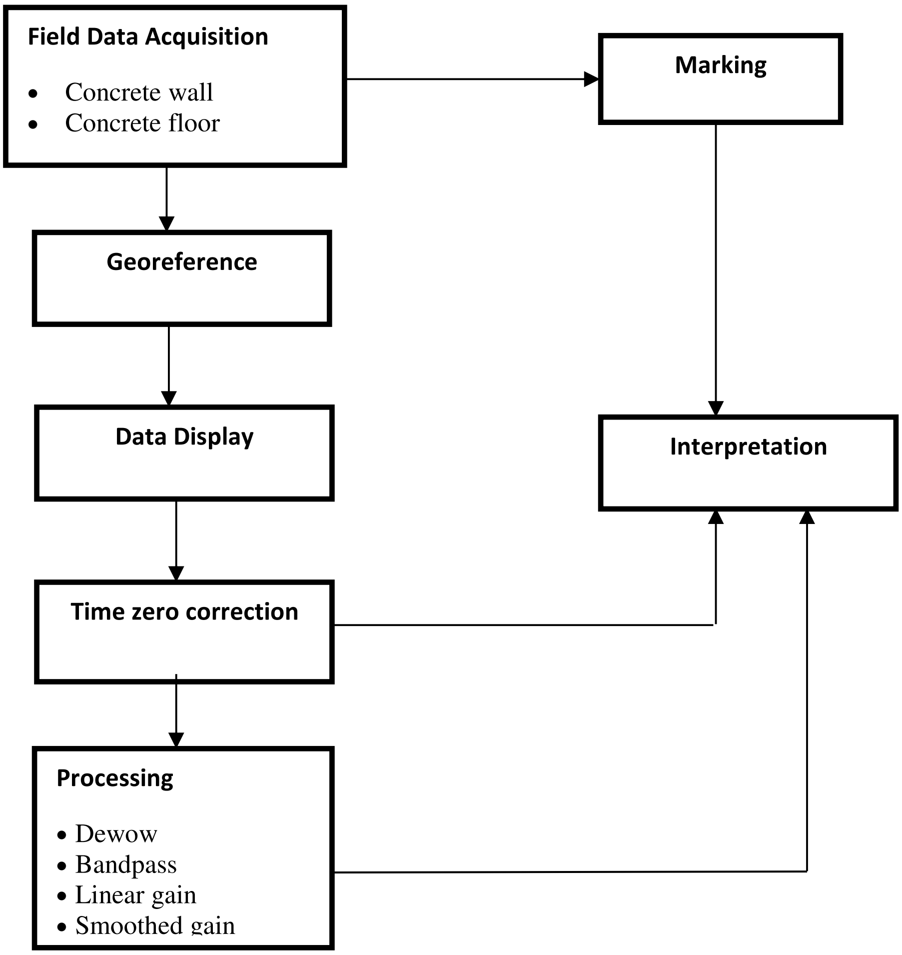


Figure 1. Methodology flowchart

For civil engineering related application, high frequency radar are used, as the object or area to be inspected is relatively thin surface and only high frequency radar can use to detect small or shallow target [11]. Therefore, a 2 GHz bi-polar GPR system, which provide high resolution data and fast data acquisition is adopted to inspect a concrete wall and slab. It allows both Horizontal-Horizontal (HH) and Vertical-Vertical (VV) polarization data to be acquired in one scan. These reduce the time for data acquisition, allowing inspection of large area in shorter time. Figure 1 shows the details on the processing steps undergone in this study.

The data acquired are then undergone processing steps to remove the noise and produce a better focus radargram for interpretation. The data were thereafter georeferenced with time-zero correction to correct the start time in order to align with the surface position [12]. These georeferenced data were filtered with dewow, bandpass, linear gain and smoothed gain filter to eliminate the non-target or background noise, which might affected final interpretation. Consequently, the radargram were ready for information extraction with the aid of the three-dimensional (3D) GPR model produced from these radargram.

3. Results and discussion

Two case studies were presented here. The first case study was conducted on a concrete wall to investigate the internal structure condition of the wall for wall demolition. For second case study, scanning was performed at a concrete slab, which suspected ingress with water due to poor waterproofing design, in order to locate the moisture in the slab.

3.1. Case study 1: concrete wall internal structure

A concrete wall of a commercial building was inspected to identify its internal structure condition for wall demolition to build a new door. The wall was investigated to identify the anomalies and objects concealed inside the wall to avoid unnecessary accidents when demolishing the wall.

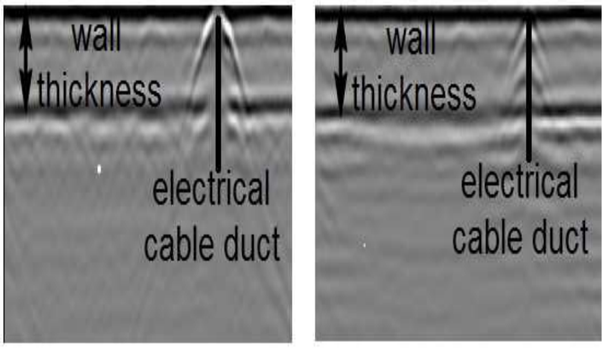
Fig. 2 shows the radargrams acquired in both HH (Fig. 2(a)) and VV (Fig. 2(b)) polarization. From these radargrams, it shows that the concrete wall thickness is about 0.125 metre (m). This clear hyperbola, with the limbs projected downwards like an inverted “V” shape is a buried object [11]. This denotes that there is a cylindrical object concealed in the wall. This hyperbola was confirmed to be an electrical cable duct with on-site inspection, where a socket is found on the concrete wall. In this case, HH polarization showed a better result compared to the VV polarization as the hyperbola in the radargrams can be seen clearly in the HH polarized radargrams compared to VV polarization radargram.

From the above results, it is proposed that the wall demolition should not be executed at the area where the electrical cable duct was located. This is to avoid incident of damaging the electrical cable when demolishing the wall. This is not only lead to power disruption of electricity or short circuit, which might lead to explosion. Alternatively, the location of the electrical cable duct location, then remove the cable duct before hacking. It proves that NDE using GPR is one of the most helpful and cost-effective method for pre-demolition inspection. It can provide important detailed information of the internal structure, especially its condition to ensure that demolition work can be done at the lowest possible cost and risk.

As seen in Fig. 2, the objects or anomalies that concealed in the concrete structure can be detected from GPR radargrams. In this sense, the healthy condition or the safety of the building structures, include beam, slab, column, etc., can be inspected using NDE to perform indirect assessment. The advantage of using NDE in BCA is that NDE can avoid concrete damage during assessment, where the inspection is done without any harm to the concrete structure [13]. Moreover, NDE can be done in anytime at everywhere continuously, as the inspection can be applied when the building is in-service. As such, NDE can be applied for high rise building (e.g. apartment tower, residential tower, etc.), commercial building (e.g. shopping mall or business complex) as well as 24 hours operation infrastructure (e.g. airport, custom, hospital, etc.).

The regular inspection of building structure condition is, therefore, need to be carried out as structure that lack of maintenance will cause structure distress and leading to corrosion and cracking when time passes. This is to ensure the safety and serviceability of the building structure along the life of a structure. The concrete structures such as bridge decks and tunnels that are exposed to heavy traffic need to be monitored and inspected from time to time by using NDE as a part of BCA. The condition (physical property) and capacity (mechanical property) of the concrete structure, such as the capacity loading when heavy traffic traveled across these big civil infrastructures need to be evaluated [14].

IOP Conf. Series: Materials Science and Engineering **620** (2019) 012057 doi:10.1088/1757-899X/620/1/012057



(a) (b)

Figure 2. (a) HH polarization, (b) VV polarization. Radargrams of concrete wall

3.2. Case study 2: concrete slab with poor waterproof design

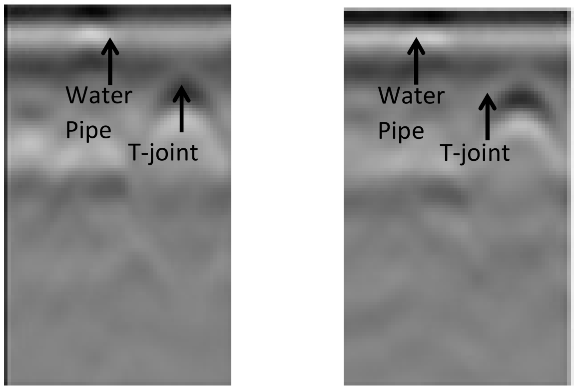
Water marks and adhesive stains of moisture are seen at the ceiling of the ground floor of a two-storey residential building, and therefore, it is suspected that the upper floor concrete slab is ingress with water or there is seepage due to poor waterproof design at the expansion joint. As a result, the poorly design and substantial expansion joint has led to leaks and waterproofing failure. Hence, GPR inspection was carried out on the upper floor concrete slab to inspect the condition of the concrete slab and expecting to locate the moisture inside the concrete slab.

Fig. 3 shows the radargrams acquired in both HH (Fig. 3(a)) and VV (Fig. 3(b)) polarization. The radargram reflecting that the concrete slab contains excessive moisture as the radargram looks blur. The saturation or wetness in the concrete will disturb the radar signal, caused the sharp “V” shape in the radargram appear to be blur in the radar profile (refers Fig. 3 comparing with Fig. 2). However, the hyperbola of the water pipe still can be seen. The hyperbola of the water pipe near to the surface of the floor was seen to be unclear as compared to a T-joint at a deeper location. This is because the size of the water pipe is smaller. The results revealed that HH polarization performed better than the VV polarization where the hyperbola in the HH polarized radargrams can be seen clearer.

Referring to the results, we found that the concrete beneath the slab looks damp, where moisture is exist. We noticed that there is continuous source of water from the wall and ingress into the slab when we remove the ceramic tile from the concrete slab, causing the slab never dries out. Further moisture testing work need to done to measure the moisture content, as the results of the NDE for BCA will be more convincing or accurate for assessment with combination of different NDE methods due to each method has their own limitation and individual merits in BCA. It is suggested immediate maintenance, such as concrete repair, installing moisture barrier under the concrete slab or applies penetrating concrete sealer need to be carried out to solve the issue. If not moisture excessive moisture will ruin the slab or tile flooring leading to flooring failure.

As proven by the results from this study, NDE can be applied during post occupancy, using of asset or even during the disposal of asset along the service life of the structure. The as-built map of the internal structure condition of the building, for example, the thickness of the wall, the location and diameter of the rebar or delamination caused by human error and other factors is crucial to be used as the reference during renovations or maintenance. In this context, GPR has carried out important responsibilities as shown in this study.

Therefore, GPR can be adopted to inspect the structure condition of the historical building or infrastructures since they are important asset to the country. These historical infrastructures will decay over times due to ageing of the structures, environmental factors and natural disasters, such as earthquakes and floods. The regular inspection of these historical infrastructures is indispensable for better preservation and rehabilitation of the historical infrastructure. In doing this, GPR inspection can be carried out to examine the structure of these historical building to enable appropriate repairing and rehabilitating works to be conducted in order to preserve the historical buildings as identical as possible to its original state.



(a) (b)

Figure 3. (a) HH polarization, (b) VV polarization. Radargrams of concrete slab

4. Conclusion

GPR is proven to be an effective tool for NDE in the context of BCA. From the case studies presented in this study, the electrical cable duct embedded in the concrete wall can be identified clearly from the radargram. With this, it can provide guidance to the related stakeholders in demolition of wall or any structures. A 3D model of the structure can be constructed to get a more detail presentation of the internal structure of the concrete wall, such as the wall thickness.

In addition, the internal structure condition of the concrete slab due to excessive moisture can be seen as well from the radargram by integrating with others NDE methods as a total solution package for BCA. With this, the physical condition of the building, the deficiencies existing in the building structure as well as the serviceability of a structure can be known. This is beneficial to the facility management personnel for long-term maintenance and repair work of any deficiencies obtained from BCA using NDE.

The contribution of NDE, especially the GPR in BCA is being recognise and its' capability has been tested in-situ as well. The results of this study proven that the usability of GPR, an image-based NDE method in the application of building structure physical condition inspection or assessment for BCA. Therefore, GPR can provide valuable information by revealing the unobserved or unknown defects in a building structure. This opens up new application of GPR, particularly in civil infrastructure condition or health assessment. Through this assessment, it can manage the asset better throughout its serviceability life, especially for asset's maintenance or repair work planning.

5. Acknowledgement

This study is funded by Fundamental Research Grant Scheme (R.J130000.7827.4F747). We also thank Universiti Teknologi Malaysia for providing the financial and technical assistance given in this study. Thanks also appertain to anonymous for their constructive reviews and comments regarding this study.

6. References

[1] The Constructor, "Types of crack in concrete structures," http://theconstructor.org/concrete/types-of-crack-in-concrete-structures/5385/, (2014)

[2] S N F Zuraidi, Z A Akasah and M A A Rahman M A A , C*ivil engineering and architectural building features disparity and preservation of structural and fabrics integrity in heritage*

IOP Conf. Series: Materials Science and Engineering **620** (2019) 012057 doi:10.1088/1757-899X/620/1/012057

building: A Review, Proceedings of the International Building & Infrastructure Technology Conference (2011), pp 94-104
[3] S Assaf, A. –M. Al-Hammad and M Al-Shihah M , Journal of Performance of Constructed Facilities, **10**, 171-174, (1996)
[4] S Kabir, P Rivard, D –C He and P Thivierge, Construction and Building Materials, **23**, 3166-3174 (2009)
[5] D M McCann and M C Forde, NDT&E International, **34**, 71-84 (2001)
[6] Y Zhao, J Wu, J Wang, and M Wan, "Ground Penetrating Radar Technique and it's Application in Non-Destructive Testing of Reinforced Concrete," Proceedings of the 10th Asia-Pacific Conference on Non-Destructive Testing, http://www.ndt.net/apcndt2001/papers/1110/1110.htm, (2011)
[7] H Wiggenhauser, "Advanced NDT methods for the assessment of concrete structures," in *Concrete Repair, Rehabilitation and Retrofitting II*, edited by M G Alexander *et al.* (Taylor & Francis Group, London, 2009), pp 21-33
[8] M Goueygou, O Abraham and J –F Lataste, NDT&E International, **41**, 448-456 (2008)
[9] V Barrile and R Pucinotti, NDT&E International, **38**, 596-604 (2005)
[10] Buyukozturk and T –Y Yu, Construction and Building Materials, **23**, 1678-1689 (2009)
[11] R J Yelf, Electromagnatic Phenomena, **7(1(18))**, 102-117 (2007)
[12] N J Cassidy, *Ground Penetrating Radar Data Processing, Modelling and Analysis in Ground Penetrating Radar Theory and Applications*, edited by H M Jol, (Elsevier B V , Amsterdam, 2009), pp 141-176
[13] S K Verma, S S Bhadauria and S Akhtar, Journal of Construction Engineering 2013, **1-11** (2013)
[14] M Sanayei, J E Phelps, J D Sipple, E. S Bell and B R Brenner, Journal of Bridge Engineering, **17**, 130-138 (2012)