DETECTION OF REBAR CORROSION BY USING GROUND PENETRATING RADAR

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DEDICATION

This thesis is dedicated to my mother Azizah Binti Ahmad for enlightening my life.

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ABSTRACT

Reinforced concrete has been proven for its versatility, resistance, and longevity but over time it also suffers from deterioration due to different physical, chemical and, mechanical actions exist the concrete. Once the corrosion process starts, there is no way to reverse the process and visual inspection is one of the methods to detect the corrosion. However, it is only effective if there is evidence of corrosion exist from the surface of concrete such as cracks, delamination and spalling. Even though there are several methods to evaluate corrosion, however, most of them have an invasive character since the method requires extracting samples. There are several non-invasive techniques to detect corrosion such as GPR but this technique is not popular since the interpretation of GPR images is very difficult. This research addresses the major issue of assessing the corrosion of rebar inside a reinforced concrete that are invasive and costly since require a large amount of time and man power assess the condition with a simple yet effective method. So, the aim of this research is to detect the corrosion in rebar using GPR non-invasive technique. There are three objectives of this study which are to obtain all the parameters used calculate the radius of rebar, compare the estimated to original rebar size and to test the result validity to ground truthing data. The work starts with finding the suitable site to scan the rebar. 3 block of reinforced concrete beam located in B04, UTM. After the scanning is done, raw data are processed using Reflexw software provided by UTM. Then, the processed data are analyzed and conclusion is made. Findings of this research is that the difference of estimated rebar diameter is 16% differ from the original diameter. This can also be seen from hyperbola. The hyperbola depth is uneven because of the corrosion that disrupts the surrounding of rebar thus affecting the time of the signal to reach the rebar. Also, this statement can be validated by ground truthing data which shows that the rebar is corroded with brownish particles surrounding the rebar that causes by forming of oxide particles. This allows the GPR user to have an extra analysis to their report which is the current condition of the underground object scanned. This statement was proven in this research study as the change in rebar radius was detected to be 16% from the original value. Then, the hyperbolic image was also analysed that indicates the rebar scanned was corroded.

ABSTRAK

Konkrit bertetulang adalah elemen yang paling popular digunakan dalam kejuruteraan awam kerana ia menawarkan kekuatan dan ketahanan. Tetapi, walaupun konkrit bertulang telah dibuktikan amat serba boleh dan tahan lama, dari masa ke semasa ia juga mengalami kemerosotan dari segi kualiti akibat tindakan fizikal, kimia dan mekanikal yang berbeza wujud di dalam konkrit. Sebaik sahaja proses kakisan bermula, tiada cara untuk membalikkan proses dan pemeriksaan visual adalah salah satu kaedah untuk mengesan kakisan. Walaubagaimanapun, ia hanya berkesan sekiranya terdapat bukti kakisan wujud dari permukaan konkrit seperti retak dan delaminasi. Walaupun terdapat beberapa kaedah untuk menilai kakisan, namun kebanyakannya mempunyai sifat invasif kerana kaedah tersebut memerlukan pengekstrakan sampel. Terdapat beberapa teknik bukan invasif untuk mengesan kakisan seperti GPR tetapi teknik ini tidak popular kerana tafsiran imej GPR adalah sangat sukar. Penyelidikan ini dapat menangani isu utama iaitu menilai kakisan bar di dalam konkrit bertetulang yang invasif dan mahal kerana memerlukan masa yang banyak dan tenaga manusia untuk menilai keadaan bar tersebut dengan menggunakan kaedah yang lebih efektif dan mudah untuk dijalankan. Oleh itu, tujuan penyelidikan ini adalah untuk mengesan kakisan pada rebar menggunakan teknik GPR bukan invasif. Kajian ini terdapat tiga objektif iaitu untuk mendapatkan kesemua parameter yang digunakan mengira jejari bar bertulang, membandingkan anggaran saiz rebar asal dan menguji kesahihan keputusan kepada kondiso bar betulang di makmal. Kerja bermula dengan mencari tapak yang sesuai untuk mengimbas bar bertulang. Terdapat 3 blok konkrit bertetulang yang terdapat di B04, UTM. Selepas imbasan dilakukan, data mentah akan diproses dengan menggunakan perisian Reflexw yang disediakan oleh UTM. Kemudian, data yang telah diproses akan di analisis dan kesimpulan akan dibuat. Dapatan kajian ini ialah perbezaan anggaran diameter rebar adalah 16% berbeza daripada diameter asal. Ini juga boleh dilihat daripada hiperbola. Kedalaman hiperbola tidak sekata kerana kakisan yang mengganggu sekeliling rebar sehingga menjejaskan masa isyarat untuk sampai ke rebar. Juga, kenyataan ini boleh disahkan oleh data trothing tanah yang menunjukkan bahawa rebar terhakis dengan zarah keperangan mengelilingi rebar yang disebabkan oleh pembentukan zarah oksida. Ini membolehkan pengguna GPR mempunyai analisis tambahan kepada laporan mereka yang iaitu keadaan semasa objek bawah tanah yang diimbas. Kenyataan ini telah dibuktikan dalam kajian penyelidikan ini kerana perubahan jejari rebar dikesan adalah 16% daripada nilai asal. Kemudian, imej hiperbolik juga di analisis yang menunjukkan bar yang diimbas telah berkarat.

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LIST OF ABBREVIATIONS

GPR	-	Ground Penetrating Radar
NDT	-	No-Destructive testing
3D	-	Three Dimensional
MLP	-	Multi-Layer Perception
EM	-	Electromagnetic
REBAR	-	Reinforced bar
RC	-	Reinforced Concrete
SNR	-	Signal to noise ratio

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LIST OF SYMBOLS

E	-	Long dimension radius of the energy footprint
λ	-	Wavelength
H	-	Depth from the surface to the reflection surface
ε	-	Average relative dielectric permittivity of the material for the depth (H)
r	-	Radius of rebar

CHAPTER 1

INTRODUCTION

1.1 Background

Concrete is already strong and durable material but it needs assistance such as weight in the middle of beam to be able to perform well under compression force such as cars driving on a concrete driveways. It also need support from changes in surrounding temperature. Thus, rebar plays a vital role in supporting concrete from this issue. Reinforced concrete are the most popular element used in civil engineering as it offers versatility, strength and durability (Solla, Lagüela, Fernández, & Garrido, 2019). It is a combination of cement, water, sand, aggregates and reinforced bar or rebar. A steel rod or rebar is embedded in such a manner that the two materials act together in resisting forces thus increasing resistance of the concrete. The tensile strength of rebar combining with the strength of concrete will make it able to sustain stress for over considerable time spans. It is common feature in many concrete application. Rebar comes in various type which are carbon steel which are used in majority of concrete pour due to its cost and strength, glass fiber which are an alternative to steel rebar and have better tensile strength, galvanized rebar that are used where corrosion tends to happen because rebar are coated with zinc and lastly epoxy coated which are a rebar that is coated with epoxy to prevent it from corrosion.

Which each of them serves different functions. Concrete could be regarded as an isotropy while rebar can be considered as an abnormal object. A radar can detect the rebar inside a concrete because there is a strong abnormality between the two medium (He, 2009).

Ground Penetrating Radar (GPR) are one of the equipment used for non-

invasive scanning in locating utilities buried underground (Petrovačk, 2007). It is widely considered as the most reliable non-destructive testing (NDT) method in detecting underground utility. GPR is a geophysical method that allows for the analysis of the propagation capacity of electromagnetic waves through media with different dielectric constants (M. Solla, Pérez-Gracia, & Fontul, 2021). One of its major strength is that data can be collected at high speed continuously thus reducing the cost and time for the user. The main limitation of detecting underground utilities using GPR is that the radargram generated by GPR is non-intuitive and require a lot of skill to properly process and interpret the measurement. Other than surveying industries, civil engineering has also been using GPR application in their work. It has been used since the early 70 to detect buried utility, inspecting pavement and rebar location determination in reinforced concrete.

The core element of the research is explained in chapter two, which instils with the notion of GPR, reinforced concrete and image segmentation and clustering as well as various theories and applications used in this study. This chapter examines an innovative research study on several rebar estimation techniques that has been done.

1.2 Problem Statement

Although reinforced concrete has been proven for its versatility, resistance and longevity, over the time it also suffers from deterioration due to different physical, chemical and mechanical action exist inside the concrete. This is because the concrete has porosity from construction, production and aging. The permeability of the concrete is provoked thus creates an air passage for water chloride and other materials to enter. These will cause corrosion to the rebar embedded inside the concrete. Usually, there are two main factors which cause corrosion of rebar in concrete structures, carbonation and ingress of chloride ions. When chloride ions penetrate in concrete more than the threshold value or when carbonation depth exceeds concrete cover, then it initiates the corrosion of reinforced concrete structures

(Verma, Bhadauria, & Akhtar, 2014). Corrosion of reinforced steel bar inside a concrete will cause sub-surface crack thus causing structural degradation and delamination to the concrete (Zaki, 2020). An experience has shown that a large number of concrete structures show significant signs of degradation after only 20 to 30 years due to the joint action of mechanical and environmental effects. The causes of degradation are mainly the consequence of corrosion, which on a global scale increases the annual maintenance costs to more than 3% of the world's Gross Domestic Product (GDP) (Tesic, Baricevic, & Serdar, 2021). As a result, structure that usually requires around 40-50 before service need an early inspection (Dobrescu & Vasilescu, 2015).

Once the corrosion process starts, there is no way to reverse the process and visual inspection is one of the method to detect the corrosion (Solla et al., 2019). However, it is only effective if there is evidence of corrosion exist from the surface of concrete such as cracks, delamination and spalling. There are several non-invasive technique to detect corrosion such as GPR but this technique is not popular since the interpretation of GPR images is very difficult. The heterogeneous concrete and the capability of GPR system in highlighting discontinuities within the concrete structure (Zaki, 2020). So a much simpler yet effective technique of GPR data interpretation is needed to identify the condition of embedded rebar.

This project addresses the major issue of assessing the corrosion of rebar inside a reinforced concrete that are invasive and costly since require a large amount of time and manpower assess the condition with a simple yet effective method. The hypothesis of this research is that corrosion of rebar can be detected from post processing of GPR scanning data. The approach is called digital imaging technique in which the parameter that is obtain from processing of the data will be used to estimate the radius of rebar in which can be used to determine the condition of rebar. This approach has an accuracy of ±2.5% (K Ambika Lakshmi, 2016).

The aim of this study is to determine the condition of rebar embedded inside the concrete by estimating its radius using GPR non-invasive technique. Digital imaging method allows the user to estimate the size of underground object such as metal, pipes and cables mathematically. Since the size of an object can increase and decrease from corrosion depending on the product of chemical reaction done to the

object. This technique is effective and easy to interpret as it requires the user to only obtain some parameter to mathematically calculate the radius of rebar by using GPR data thus solving the main issue of this study which is to simplify the interpretation of GPR data to determine the condition of the rebar.

1.3 Research Questions

There are several research questions as outlined below:

i. What are the values that is needed to be used to calculate the size of rebar?
ii. Can this method detect the changes in size of rebar?
iii. Does this result correspond to ground truth information?

1.4 Research Aim and Objectives

The aim of this research is to determine the condition of rebar embedded inside the concrete by estimating its radius using GPR non-invasive technique. To achieve the aim, the following objectives have been setup.

1. To obtain all the parameters used calculate the radius of rebar such as E, L and R.
2. To compare the estimated to original rebar size.
3. To validate the initial hypothesis with ground truth information.

1.5 Scope of Study

GPR technology is widely used for detecting underground object. In surveying field, GPR is mainly used to determine the position of the underground utility. There are many aspects to be considered in analyzing the data from GPR. To

achieve this research objectives, the main scope covers the following criteria:

1.5.1 Study Area

This study was executed in Block D04 Civil Engineering Testing Unit, UTM having area of 0.55 km2 (Figure 1.1). There were two labs sharing in the same building with structures and materials laboratories in which both were operated under the department of Structure and Materials. These laboratories can only be utilized by UTM student whether undergraduate or postgraduate student. The laboratories are filled with high technology testing equipment that were capable in constructing static and dynamic testing for various structural components such as reinforced concrete beam, slabs, columns and truss. This study area was chosen because there were already a premade concrete beam that could be used for this study.

Figure 1.1 Block D04, Civil Engineering Testing Unit, UTM

1.5.2 Data and Equipment

The GPR technology has evolve massively with time. Each and every GPR has its own frequency ranging from 10MHz to 2.6GHz. In order to obtain the best

result for this research, the GPR that will be used in this research is dual frequency GPR model IDS RIS MF Hi-MOD GPR. This GPR was chosen to be the main equipment of this research is because it has a high frequency signal that will produce clearer images. Also it has dual frequency that allow user to choose the clearest images between the two frequencies. The frequency of GPR that are used in the study are 400/900 MHz. It is a high frequency GPR that will help in obtaining a better image resolution of GPR data.

1.6 Methodology

The GPR survey line were determined according to the size of concrete slab. Then after the GPR scanning is done, the raw data will then be processed using Reflexw software. The process involves time zero correction, pass butterworth, background removal and velocity adaptation. This will generate a clearer hyperbola images that will be used for analysis. The distance between to foot of hyperbola (L) will also be obtained to calculate the radius of rebar. Then, the depth between the surface of concrete slab and rebar (H) are determined on field by using measuring tape. This parameter will also be used during the calculation of rebar radius. Next, the radius obtained from this research will be compare to the original size of the rebar. Then, an initial hypothesis can be made regarding the condition of the rebar. The hypothesis then will be strengthen with the comparison of hyperbola between corroded and non-corroded rebar from previous study done by (A. Zaki, Megat Johari, Wan Hussin, & Jusman, 2018) and (Solla et al., 2019). The hypothesis will also be backed up by ground trothing data which is the current condition of the rebar.

1.7 Significance of Study

There were several values obtain from GPR scanning data that were vital in this study such as depth from surface to the rebar (H), footprint of GPR signal (E) and

footprint of hyperbolic diameter (L). These parameters plays an important role in estimating the radius of the rebar. Since this study was about to determine the condition of rebar without having to destroy the concrete, the changes in size of rebar was the main characteristic to detect the condition of rebar. Then, by obtaining these values from GPR scanning allows the size of rebar to be calculated.

This study done with the help of civil engineering faculty. The concrete slab was made by one of the students to determine the strength of the reinforced concrete and the longevity of it. With the aid of this study findings, those two criteria can also be determined by identifying the condition of rebar since corrosion will greatly decrease the sustainability and durability of the reinforced concrete. The digital imaging technique that was applied in this study can assist civil engineering field to make a further analysis towards the condition of rebar inside a concrete.

1.8 Structure of Thesis

This thesis consists of five chapters. The first chapter explains the general overview about the details of the research. It includes the aim and objectives, research questions and also scope of this research study.

Then chapter two discuss in detail about the research literature review. It consist of literature review regarding GPR technology, properties of reinforced concrete and also characteristic of corrosion.

The methodological research is covered in chapter three. It consists of some field techniques, data collecting, and data processing in order to validate the data to the control size of rebar. This allows study to investigate the best technique to assess and determine the size of rebar. This chapter will critically analyse the findings from both of the technique used which are GPR scanning and image processing.

The results of the study will be covered in chapter 4. The results and interpretation of the results will be displayed using tables and 3D images. Then, result

of rebar diameter estimation will be explained in this chapter. All of the calculations will be shown and explained thoroughly.

The last chapter main focus is to answer the research question and the completion of all the research objectives. It also suggest some recommendation that may be useful for future studies.

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