CONDITION ASSESSMENT OF REINFORCED CONCRETE: BRIDGE STRUCTURE

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A proposal submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Civil)

School of Civil Engineering
Universiti Teknologi Malaysia

DECEMBER 2019

DEDICATION

Dedicated to my husband my soul,
to my father, I hoped he was with me at this moment
to my mother the dearest and lighten in my life
to my uncle Dr. Wajdi Jalal, I hoped he was with us as a family
for their continuous support, love and care

ACKNOWLEDGEMENT

I would firstly like to express my gratitude to Professor Mohammad Bin Ismail and Gardner for their support and guidance throughout my MSc studies. Their willingness to help solve any challenges helps to smooth out the somewhat bumpy road to completing an MSc. I would not have been offered this opportunity and would not be where I am today.

I would like to express my appreciation towards my previous co-supervisor, Dr. Noor Nabilah Sarbini, for the inputs and comments on my research work. Next, I would like to acknowledge all the laboratory managers, technicians and assistants of the structures and materials laboratory, especially Mr. Nawawi Mohd Salleh, who has assisted me with the laboratory works. Without their assistance, this research work will not be completed. Also, I would also like to express my sincere thanks to all my friends and colleagues from UTM University for sharing the journey.

Finally, and for many reasons, I would like to thank my husband, Mustafa Wajdi Jalal. For the countless times he sat through practice presentations, and had to listen to me explain my MSc topic every day. For the love and support, he has shown throughout, and for giving me the encouragement I needed when the finish line seemed far away.

I would like to convey my heartfelt appreciation to my family members my mother, my brother Ahmad Alhaj, my sister who have supported me in all means during my study. Their unlimited care had provided me sufficient resources to sustain the progress of this research Thank you for pushing me to be the best I can be. Aseel Abdulhaleem M. Saeed.

ABSTRAK

Kemerosotan struktur konkrit dalam beberapa dekad yang lalu memerlukan kaedah yang berkesan untuk penilaian dan penyelenggaraan keadaan. Pada masa ini, menilai prestasi dan keselamatan struktur konkrit bertetulang (RC) bergantung kepada pemeriksaan visual berasaskan rutin (VI). Walau bagaimanapun, terdapat teknik ujian tanpa musnah (NDT) lain yang boleh memberikan penilaian yang lebih tepat terhadap struktur. Oleh itu dalam kajian ini, jambatan pejalan kaki yang terletak di Jalan Tun Abdul Razak, Johor Bahru dipilih sebagai kajian kes, dan mempunyai teknik VI dan NDT yang digunakan untuk penilaian. Objektif utama penyelidikan ini adalah untuk menentukan keadaan komponen-komponen struktur jambatan dan menyiasat tahap kecacatan dan kemerosotan menggunakan ujian tanpa musnah. Kaedah kajian melibatkan pemeriksaan visual dan teknik-teknik NDT termasuk tukul memantul, meter penutup, halaju nadi ultrasonik (UPV) dan ujian ketahanan. Pendekatan kaedah kajian mengikuti rangka kerja penilaian keadaan yang telah dibangunkan oleh kajian literatur terdahulu dengan sedikit pengubahsuaian. Apabila rangka kerja tersebut dilaksanakan dengan pemilihan teknik-teknik NDT terbaik membantu dalam menentukan tahap kecacatan dan kemerosotan komponen-komponen struktur jambatan dan seterusnya cadangan mengenai keadaan jambatan. Komponen-komponen struktur jambatan yang terlibat termasuklah tiang, dek, dinding dan tangga. Penemuan daripada pemeriksaan visual menunjukkan terdapat banyak kecacatan dan kemerosotan dijumpai pada komponen-komponen struktur jambatan yang melibatkan retak, merekah, menggelupas dan berkarat. Seterusnya, teknik-teknik NDT yang dijalankan pada komponen struktur jambatan menunjukkan sesetengah daripada komponen terbabit mempamerkan risiko sederhana terhadap kakisan dan kualiti konkrit permukaan biasa sahaja. Secara umum, penyelenggaraan lanjut adalah diperlukan, terutamanya terhadap sesetengah komponen-komponen struktur jambatan yang kritikal. Oleh itu, projek penyelidikan ini menyimpulkan bahawa pemeriksaan visual dengan bantuan teknik-teknik NDT yang tepat dapat membantu untuk menyiasat keadaan semasa komponen-komponen struktur jambatan dengan lebih baik. Ini dapat membantu pemegang kepentingan untuk mengambil tindakan segera terhadap komponen-komponen dengan keadaan yang telah merosot.

ABSTRACT

The deterioration of concrete structures in the last few decades demands for effective methods for condition evaluation and maintenance. Currently, assessing the performance and safety of reinforced concrete (RC) structures relies on routine-based visual inspection (VI). However, there are other non-destructive test (NDT) techniques that can provide a more accurate assessment of the structures. Thus in this study, a pedestrian bridge located in Jalan Tun Abdul Razak, Johor Bahru is chosen as a case study, and has both VI and NDT techniques used for assessment. The main objective of this research is to determine the condition of bridge structural components and investigate its level of defect and deterioration using non-destructive tests. The methodologies involved are visual inspection and NDT techniques include the rebound hammer, cover meter, ultrasonic pulse velocity (UPV) and resistivity test. The methodology approach follows a condition assessment framework that was developed by previous literature with some modification. The framework when implemented with the best selection of NDT techniques helps in determine the level of defect and deterioration of the bridge structural components and next recommendation regarding the condition of the bridge. The involved bridge structural components includes column, deck, wall and staircase. Findings from the visual inspection shows that there were many defects and deteriorations found at the bridge structural components which includes crack, spalling, delamination and rusting. Further, NDT techniques that were carried out at the selected bridge structural component shows that some of the components exhibited moderate risk of corrosion and fair concrete surface quality. In general, further maintenance is needed specifically to some critical structural components of the bridge. Therefore, this research project concluded that visual inspection assisted with correct NDT techniques will help to investigate better current condition of bridge structural components. This will assist the stakeholders to take action immediately to the components with deteriorated conditions.

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LIST OF ABBREVIATIONS

RC	Reinforced Concrete
BS	British Standards
CP	Cathodic Protection
EIS	Electrochemical Impedance Spectroscopy
LPR	Linear Polarization Resistance
OPC	Ordinary Portland Cement
RE	Reference Electrode
PH	Alkali Or Acidity Level
UPV	Ultrasonic Pulse Velocity
ASTM	American Society For Testing And Material
NDT	Non-Destructive Test
NDE	Non-Destructive Evaluation
C1	First Column
C2	Second Column
D1	First Soffit
D2	Second Soffit
DS1	First Damage
DS2	Second Damage

LIST OF SYMBOLS

Mε	Microstrain
δε	Strain Variation
λb	Bragg Wavelength
δλb	Variation Of Bragg Wavelength
neff	Effective Index Of Refraction
λ	Grating Period
α	Coefficient Of Thermal Expansion
ξ	Thermo-Optic Coefficient
pe	Strain-Optic Coefficient
δl	Variation Of Cavity
δνb(ε,t)	Brillouin Frequency Shift
δz	Spatial Resolution
τ	Pulse Width
δt	Temperature Change
ν_{pump}	Pump Frequency
ν_{probe}	Probe Frequency
va	Acoustic Wave Velocity
n	Fibre Core Index Of Refraction
λp	Wavelength Of Pump Pulse

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

A very substantial number of bridges are made of reinforced concrete. These bridges have over time started to corrode and deteriorate. Some of these effects can cause serviceability issues, as well as damages that can cause injury or loss of life, as well as disruption in the traffic area.

Concrete degradation, steel corrosion, and weakening of connections in structures over time are significant concerns in crossing pedestrian bridges. If bridges are not maintained, and the damage is ignored, then over time the bridge will deteriorate. Thus, bridges are required to be constantly monitored and assessed (Islam *et al.*, 2014).

Corrosion of steel reinforcement is the primary type of deterioration in Concrete structures. It is one of the worst kinds of deterioration in concrete structures, and sometimes it results in cracking and causes severe damages to structures. Other dangerous deterioration processes that do severe damages to concrete structures include alkali-silica reactions and damages caused by freeze-thaw processes (Afzal *et al.*, 2012).

Corrosion Mechanism has, for long, been established as a severe problem of steel-reinforced concrete structures. Structures such as bridges that are directly exposed to the environments are very vulnerable to corrosion. There are generally two mechanisms when it comes to steel corrosion. The first relates to a reduction of alkalinity by leaching of alkaline substances with water or partial neutralization by reaction with carbon dioxide or other chemical agents (Song *et al.*, 2007). The second mechanism is the electrochemical action involving chloride ions in the presence of

oxygen. The concrete can itself be a source of these chemical agents, however some will also originate from the surrounding environment (Ahmed *et al.*, 2013)

The electrochemical corrosion processes around a corrosion pit on steel in concrete are illustrated, and the electrochemical reactions can be summarized as process depicted in Figure 1.1. In this figure, the first three lines are the process in which the corrosion reacts, in the last line, the rust reaction occurs.

$$Fe \leftrightarrow 2e^- + Fe^{2+}$$
$$\tfrac{1}{2}O_2 + H_2O + 2e^- \leftrightarrow 2(OH)^-$$
$$Fe^{2+} + 2(OH)^- \rightarrow Fe(OH)_2$$
$$4Fe(OH)_2 + 2H_2O + O_2 \rightarrow 4Fe(OH)_3$$

Figure 1.1 Electrochemical corrosion process

Even though concrete has become a popular material for construction and building, it is has some very core practical limitations such as its lack of flexibility and deformation. Using steel as a reinforcement agent where tensile stresses are located. However, this creates a challenge not only as to how this material can be embed into concrete, but also as to how they will react with one another. These two materials are relatively compatible in most areas, mainly due to the fact that they share the same thermal expansion coefficient. There are also corrosion control methods that can be used that can prolong the duration at which the metal and electrolytes interact, slowing down the rate of corrosion considerably (Hartt *et al.*, 2004)

Corrosion is a wide-spread problem that is not only limited to humid areas, but also the whole world. In the oil and gas industry alone, corrosion has cost billions of dollars a year in the US. Corrosion is not limited to only metallic materials, but also concrete, as it can deteriorate it overtime and create damage to the structures. This complicated processes is mainly the results of a reaction between the environment, and the concrete (Hartt *et al.*, 2004).

There are significant advances in non-destructive electrochemical techniques for the measurement of corrosion rates of reinforcement embedded in concrete. An inspection of a bridge, which involves a systematic check on the physical condition of a bridge, is effective in preventing any undesirable incident such as failure from happening. This involves early detection and recommendations of any problems that may arise from propagating to a critical condition. Another motivation for bridge inspection is in the preservation of capital investment, as maintaining a bridge, is much cheaper than rebuilding one. Proper monitoring solution can ultimately lead to reduced costs over time. Hence, focusing on assessing the condition of structures and bridges effectively, can lead to the preservation of time and resources.

1.2 Problem Statement

Over time, bridges and structures deteriorate and require maintenance, replacement or rehabilitation. However, there is a need for cost effective methods and strategies that can accomplish that. Asian countries, particularly those located in the South East have high degree of humidity, which increases the risk of corrosion. Malaysia in particular has a high degree of humidity, particularly in the southern regions. Thus, a routine inspection of the structures is needed to ensure that corrosion is not spearing or progressing to a degree in which it can't be controlled anymore (Wyant, 2002). In many cases, a visual inspecting is not enough to reveal the corrosion rate. Thus, in addition to a visual inspection, other none destructive tests are required in order to indicate other problems that the structure might be facing.

1.3 Research Objectives

The main research objectives of the study condition assessing of the study are:

i. To propose a Condition Assessment Framework that uses non-destructive tests and techniques in order to assess a bridge condition.

ii. To determine the level of defect and deterioration using the proposed condition assessment framework on a pedestrian bridge.

iii. To formulate recommendations based on the observed and identified deterioration types.

1.4 Significance of Study

In most scenarios, a single none destructive test is used to assess the corrosion rate of concrete bridges. This is most of the time not enough to indicate the specificities of the condition of the bridge, which may lead to false conclusions made by consultants that are responsible for the bridges assessment. This may incur costs that are not predicted and may even cause delays in the construction if not handled properly. Thus, the use of three or more techniques could lead to a better understanding of how corrosion operates. (Gu *et al.*, 1996). This can eventually increase the level of accuracy in predicting corrosion.

A proper framework that can use several none destructive tests and techniques in a cost-effective and strategic way can allow engineers in effectively and efficiently monitor structures. This can ultimately prevent them from premature collapse or destruction of the aforementioned structures.

With the up to date research on NDT testing, NDT testing is applicable especially to concrete bridges. The planning and selection of NDT testing proposed different damage levels based on crack lengths, spalling of concrete cover, and corrosion of reinforcement along with visual inspection type where suggested.

1.5 Scope of Study

In this study the scope is limited to performing the inspection and assessment on the pedestrian bridge. The pedestrian bridge was owned by Johor Bahru Local Authority in Malaysia. The non-destructive tests include visual inspection, rebound hammer, UPV, and resistivity testing. This study was performed as visual inspection and non-destructive testing of reinforced concrete bridge components. The study attends to evaluate the accuracy and reproducibility of corrosion rate data obtained by various devices in the testing of bridge concrete structures. The data obtained and the procedures used will serve to gain insight into the kind of repair needed. The time, temperature, and relative humidity corresponding to all parts in the bridge (deck, column, and stairs) evaluation were also recorded.

1.5 Thesis Organization

This thesis contains five chapters. In the first chapter the general background of the study, the problem statement, research objectives and scope of the study are elaborated on. In the study chapter, the literature review is listed. In the third Chapter, the reserch methodlogy is elaborated. The fourth chapter focuses on the results of the experiment and inspection, with a discussion peformed at the end of the chapter. Finaly, in the fifth chapter, the study is concluded and recommendations are given for future work, as well as a reflection of the work that has been thus far completed.

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