Condition Assessment of In-Service Timber Utility Poles Utilizing Advanced Digital Signal Processing and Multi-Sensors Array

By

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A thesis submitted in fulfilment

of the requirements for the degree of

Doctor of Philosophy

Faculty of Engineering and Information Technology

University of Technology Sydney

February 2015

CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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February 2015

Acknowledgements

This PhD project could not have been possible without the support provided by numerous people. In particular, I would like to express my special appreciation and thanks to my supervisor, Professor Robin Braun for his outstanding guidance, encouragement, wisdom and caring support provided throughout this project. Superior appreciations for my supervisor, Associate Professor Jianchun Li for his encouragement, help and support during my PhD. Utmost gratitude is also forwarded to Prof. Bijan Samali who had given the author invaluable advice, outstanding encouragement and assistance through the course of his study. Special thanks for supervisor, Dr. Ulrike Dackermann for her supports, guidance, and help through my studies.

The author also gratefully acknowledges the financial assistance provided by the University of Technology Sydney, Centre for Built Infrastructure Research (CBIR), and Centre for Real-time information Networks (CRIN) of the Faculty of Engineering, UTS, and Energy Australia an industrial partner.

Moreover, the author would like to acknowledge the Structures Laboratory staff for their help in the experimental and field work. Special thanks must also go to Peter Brown, Rami Haddad, David Hooper, David Dicker, and Richard Turnell. I would also like to thank the members of timber pole project; Amir, Saad, Roman and Ning. To friends and/or colleagues at UTS, the author wishes to express his gratitude. A special appreciation and thanks to my family. Words cannot express how grateful I am to my mother, father, my lovely sisters, and my beloved fiancée for all of the sacrifices that you have made on my behalf. Your prayer for me was what sustained me thus far.

The administrative and the support staff at UTS Faculty of Engineering and IT, Phyllis Agius, Craig Shuard, Van Lee and the IT support team for performing an excellent job in keeping the show running.

To My lovely **Mum**, **Dad, Sisters,**

and **beloved wife**

List of Publications Based on This Research

Journal Articles

1. Jozi, B., Braun, R, and Li, J., (2014), 'A novel, fast, and accurate ultrasonic Non-Destructive Testing method for condition assessment of timber structures utilizing narrow-band chirp excitation', *Journal of Ultrasonics,* (submitted and under Review).

Conference Papers

1. Bahram Jozi, Ulrike Dackermann, Robin Braun, Jianchun Li and Bijan Samali, (2013), 'SEPARATION OF BI-DIRECTIONAL STRESS WAVES FOR THE NON-DESTRUCTIVE CONDITION ASSESSMENT OF IN-SERVICE TIMBER UTILITY POLES', *The 6th International Conference on Structural Health Monitoring of Intelligent Infrastructure*, 9-11 December 2013, Hong Kong.

2. Bahram Jozi, Ulrike Dackermann, Robin Braun, Jiaunchun Li, and Bijan Samali, 'APPLICATION AND IMPROVEMENT OF CONVENTIONAL STRESS-WAVE-BASED NON-DESTRUCTIVE TESTING METHODS FOR THE CONDITION ASSESSMENT OF IN-SERVICE TIMBER UTILITY POLES', *23rd Australasian Conference on the Mechanics of Structures and Materials (ACMSM23)*, 9-12 December 2014, Byron Bay, Australia. (Accepted for presentation)

3. B. Jozi, R. Braun. (2012), 'Design and Develop a sensor and network of sensors in order to investigate the integrity of utility timber poles', *1st Australian Conference on the Applications of systems Engineering ACASE'12,* 6-8 February 2012, Sydney, Australia.

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List of Acronyms

1D	One Dimensional
2D	Two Dimensional
BW	Bending Wave
CW	Compression Wave
DFT	Discrete Fourier Transform
FEM	Finite Element Model
FFT	Fast Fourier Transform
FIR	Finite Impulse Response
F-K	Frequency Wavenumber
FT	Fourier Transform
FW	Flexural waves
GW	Guided Wave
IFFT	Inverse Fast Fourier Transform
IIR	Infinite Impulse Response
IR	Impulse Response
LW	Longitudinal Wave
NDE	Non Destructive Evaluation
NDT	Non Destructive Testing
PCA	Principal Component Analysis
QNDE	Quantitative Non-Destructive Evaluation
SE	Sonic Echo
SKM	Short Kernel Method
SVD	Singular Value Decomposition

Abstract

Timber utility poles play a significant role in the infrastructure of Australia as well as many other countries. There are over 5 million timber utility poles currently used in Australian energy networks, which are more than 80% of total utility poles in the network. Due to the advanced age of Australia's timber pole infrastructure, significant efforts are undertaken by state authorities on maintenance and asset management to prevent utility lines from failure. However, the lack of reliable information regarding their in-service condition, including the embedment length or the degree of deterioration or damage below ground level makes it extremely difficult for the asset managers to make decisions on the replacement/maintenance process with due consideration to economy, operational efficiency, risk/liability and public safety. For example, in order to avoid any failure and considering the public safety, each year approximately 300,000 poles are replaced in the Eastern States of Australia with up to 80% of them still being in a very good serviceable condition, resulting in significant waste of natural resources and money.

In order to address this problem, an R&D program commenced in 2011 at the University of Technology Sydney in collaboration with the Electricity Network Association of Australia. The aim of this study is to design and develop a Non-Destructive Testing (NDT) method with acceptable accuracy, whilst being cost efficient for the condition assessment of the in-service timber utility poles. This research project contains three phases, which will be explained briefly in the following paragraphs.

Several stress wave based NDT methods are currently available and have been used in field applications over the past decades as simple and cost-effective tools for identifying the condition and underground depth of embedded structures, such as poles or piles in service. In this regard, in the first phase of this research, the applicability and efficiency of the currently available NDT methods on the condition assessment of the timber utility poles is investigated through simulation and laboratory tests. Results of the first phase reveal that these surface NDT methods face significant challenges in the condition assessment of the timber utility poles. These challenges are due to presence of uncertainties such as complicated material properties and imperfect body (i.e. timber

pole natural cracks), environmental conditions, interaction of soil and structure, defects and deteriorations as well as an impact excitation type. It is necessary to mention that access to the top of the in-service timber utility poles is prohibitive due to the presence of the electrical or communication wires. In this regard, the hammer impact is applied to the timber pole on its side.

In order to address these complicating factors, in the second phase of this research some advanced digital signal processing methodologies are selected, modified, and employed from different groups of methodologies that can most probably provide solutions. The efficiency of these methodologies is investigated through simulation, laboratory, and field tests. Results of the second phase of this research illustrate that the behaviour of the timber pole under the lateral hammer impact excitation is very complicated. In fact, if dealing with this high level of complexities is not impossible, it is a very difficult task.

In this regard, in the third phase of this research a novel, fast, and accurate ultrasonic narrowband NDT method is proposed as an alternative proposition for the condition assessment of the timber structures. The efficacy of the proposed methodology is verified through the laboratory experiments.