UNIVERSITY OF TECHNOLOGY, SYDNEY

Numerical Modelling and Condition Assessment of Timber Utility Poles using Stress Wave Techniques

by

Ning Yan

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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.

Signature of Candidate

Ning Yan

Sydney, June 2015

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Abstract

Timber utility poles are traditionally used for electricity and telecommunication distribution and represent a significant part of the infrastructure for electricity distribution and communication networks in Australia and New Zealand. Nearly 7 million timber poles are in service and about $40-$50 million is spent annually on their maintenance and asset management. To prevent the ageing poles from collapse, about 300,000 electricity poles are replaced in the Eastern States of Australia every year. However, up to 80% of the replaced poles are still in a very good condition (Nguyen et al., 2004). Therefore, huge natural resources and money is wasted. Accordingly, a reliable non-destructive evaluation technique is essential for the condition assessment of timber poles/piles to ensure public safety, operational efficiency and to reduce the maintenance cost.

Several non-destructive testing (NDT) methods based on stress wave propagation have been used in practice for the condition assessment of timber poles. However, stress wave propagation in timber poles especially with the effect of soil embedment coupled with unknown pole conditions below ground line (such as deterioration, moisture etc.) is complicated, and therefore it hindered the successful application of these NDT methods for damage identification of timber poles. Moreover, some stress wave based NDT methods are often based on over-simplified assumptions and thus fail to deliver reliable results.

In the presented study, in order to gain an in-depth understanding of the propagation of stress waves in damaged poles and to develop an effective damage detection method, a solid numerical study of wave behaviour is undertaken and novel wavelet packet energy (WPE) method is investigated for damage identification. Numerical studies utilises finite element (FE) models to track the wave propagation behaviour characteristics considering different boundary conditions, material properties as well as impact and sensing locations.

WPE is a sensitive indicator for structural damage and has been used for damage detection in various types of structures. This thesis presents a comprehensive investigation on the novel use of WPE for damage identification in timber utility poles using FE models. The research study comprises several aspects of investigations such as a comparative study between 2D and 3D models, a sensitivity study of mesh density for 2D models, and a study of the novel WPE-based technique for damage classification and detection in timber poles. Support vector machine (SVM) is imported for damage classification and particle swarm optimisation (PSO) is selected to achieve the classification. The results clearly show the effectiveness of the proposed novel WPE based damage identification technique.

Damage prediction based on optimisation procedure is also carried out in this thesis. Several numerical models with different damage conditions are created and the damage size is predicted according to optimisation procedure based on information from sample damaged model. Genetic algorithm and artificial fish swarm algorithm are used as optimisation algorithms and the comparative study is conducted based on the prediction results.

The influence of damage on the strength of timber utility poles is also studied in this thesis. The damage conditions are changes in diameter, length as well as location. Wind is considered as a main reason to cause the collapse of timber utility poles in this research. Wind load is defined based on Australian standards and the Ausgrid manual, and the corresponding stress is calculated through FE analysis. According to this analysis, it can be found that under specific damage conditions, some small damage may cause collapse; however, for certain conditions, the timber poles can still be safe even when large damage exists.

In conclusion, a novel WPE based damage detection method has been successfully developed to address the limitations of existing methods for condition assessment of timber utility poles. The numerical verification has shown the method is effective for identification of the classification and severity of damage.

List of Publications Based on This Research

Refereed Conference Papers

1. N. Yan, J. Li, U. Dackermann and B. Samali, (2012), 'Numerical and Experimental Investigations of Stress Wave Propagation in Utility Poles under Soil Influence', *Proceedings of 22nd Australasian Conference on the Mechanics of Structures and Material,* 11–14 December2012, University of Technology Sydney, Australia.
2. N. Yan, U. Dackermann, J. Li and B. Samali, (2013), 'Numerical Investigations of Stress Wave Behaviour in Timber Utility Poles', *Proceedings of 6st International Conference on Structural Health Monitoring of Intelligent Infrastructure,* 9-11 December 2013, Hongkong, China.
3. N. Yan, J.C. Li, U. Dackermann and B. Samali, (2014), 'A Numerical Investigation on the Damage Identification of Timber Utility Poles Based on Wavelet Packet Energy', *Proceedings of 23rd Australasian Conference on the Mechanics of Structures and Materials,* 9-12 December 2014, Byron Bay, Australia.

Refereed Journal Papers

4. M. Subhani, J. Li, B. Samali and N. Yan (2013), 'Determination of the embedded lengths of electricity timber poles utilising flexural wave generated from impacts', *Australian Journal of Structural Engineering*, vol. 14, no. 1, pp. 85.

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Nomenclature

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β	velocity adjustment factor
ε	elastic strain vector
γ	shear strain vector
σ	stress vector
ν	Poison's ratio
$\{\varepsilon\}$	strain tensor
$\{\sigma\}$	stress tensor
$[C]_{orth}$	orthotropic elastic matrix
u_r	displacement components along radial direction
u_θ	displacement components along tangential direction
u_z	displacement components along longitudinal direction
k	wavenumber
ω	angular frequency
c_0	wave speed
c	phase velocity
$\varphi(t)$	mother wavelet
$x[n]$	original signal
g(k)	group-conjugated orthogonal filters
h(k)	group-conjugated orthogonal filters
$C_{j,k}^i$	wavelet packet coefficients
f_j^i	component signal in a WP tree
2D	two-dimensional
3D	three-dimensional
ASFA	artificial fish swarm algorithm
BEM	boundary element method
BW	Bending Wave method
CWT	continuous wavelet transform
Dav	average diameter of the pole
DEC	difference of each energy component among the sensors
DOF	degree of freedom
DWT	discrete wavelet transform
E	elastic modulus
$E_{f_j^i}$	component energy of the decomposed signal
EF	parameter of the energy feature
E_{Di}	total WP energy under the damaged conditions
E_{Si}	total WP energy under the intact condition
F	measured frequency interval
FDM	finite difference method

FE	finite element
FEA	finite element analysis
FEM	Finite element method
FFT	Fast Fourier Transform
FF	parameter of the frequency feature
FT	tip strength of a pole
f_{Di}	frequency of the corresponding mode under damaged conditions
f_{Si}	frequency of the corresponding mode under intact conditions
FRF	Frequency Response Function
G	shear modulus
GA	genetic algorithm
GW	guided wave
IR	impulse response method
L (for timber material)	longitudinal direction
L	Length of the pole
L_d	length of pole in the dry zone
L_T	length between the location of the sensor and the bottom of a pole or the location of a defect
L_w	length of a pole in the wet zone
LCR	rate of the maximum load capacity
NDT	non-destructive testing
OAO	multi-class classification using SVM: one-against-one
OAR	multi-class classification using SVM: one-against-the rest
PSO	particle swarm optimization
R (for timber material)	radius direction
R	cross-correlation coefficients
SE	sonic echo method
SEM	spectral element method
SVM	support vector machines
T	time difference between the first arrival event and the first reflection event of stress wave
T (for direction)	tangential direction
US	Ultraseismic method
V	velocity of the longitudinal wave
V_d	wave velocity of the dry wood
V_w	wave velocity of the wet wood
WP	wavelet packet
WPT	wavelet packet transform