Determination of Embedded Length and General Condition of Utility Poles Using Non-Destructive Testing Methods

By

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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.

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October 2013

Abstract

Timber utility poles play a key role for electricity distribution systems in Australia and in 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. Lack of knowledge about the current condition of existing poles such as embedded length, the degree of deterioration and damage below the ground level or on top of the pole, leads to uncertainty for replacement or maintenance works. Hence, it is essential to develop a cost effective and reliable non-destructive method to ensure safety and to reduce maintenance costs.

Different Non-destructive Testing (NDT) methods such as Sonic Echo, Bending Waves and Ultraseismic methods 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 timber poles or piles in service. Despite the wide spread use of these methods by consultants around the world, reports describing field applications have shown that the results lack both consistency and reliability. Difficulties faced in field applications are often associated with complicated and imperfect/deteriorated materials, environmental effects, interaction of soil and structure and unknown boundary conditions, which lead to a great deal of uncertainties. In order to address this problem and develop reliable methods for embedment length determination and identification of damage below ground level, an R&D program commenced in 2008 at the University of Technology Sydney in collaboration with the Electricity Network Association of Australia. The aim of this study is to investigate and future develop the current non-destructive test methods with acceptable accuracy and repeatability, whilst being cost efficient for condition assessment of timber poles and piles as a part of the main program.

To tackle the problems and evaluate effects of various factors associated with timber materials, on these NDT methods, thorough numerical investigations using Finite Element (FE) was necessary. In this study on isotropic model was used for timber material as the main object of the numerical study was to get a better understanding of wave travel in materials without any other uncertainties. The numerical evaluation will start with a free timber pole without embedment to understand the behaviour of the

timber poles under surface NDT Methods. The results will be used for benchmarking in further investigations involving structure and soil interaction and boundary conditions. The model is verified with static analysis. Then, the FE beam model is enhanced with more advanced features requiring more steps to simulate other boundary conditions. According to the results, stress wave velocity will decrease with increase in embedded length. Therefore, two different velocities, one for stress wave travelling above the soil level and one travelling inside the soil with around 20% decrease in velocity was calculated. The error of length estimation averaged between 5% and 9% depending on the boundary conditions and the reference sensor for calculations.

In order to address this problem and develop a reliable method for embedment length and identification of damage below ground level, also the bending wave method is fully investigated and verified for the potentials and limitations. The success of determining these parameters (embedded length and location of damage) mainly depends on the accuracy of measuring the bending wave velocity. However, bending wave is highly dispersive in nature and, hence, it is important to find its frequency dependent velocity. Short Kernel Method (SKM) has been used as a signal processing tool to calculate the frequency dependent velocity and also the embedded length. As there are no guidelines to select those kernel frequencies, different kernel frequencies were selected based on the results of FFT and then applying the SKM method. As a result of the bending wave velocity investigation, the appropriate kernel frequency is identified to be between 600 to 800 Hz. The results are verified using Bernoulli-Euler Beam theory and Timoshenko beam theory. Based on the length estimation, the kernel frequency of between 650 Hz to 800 Hz will result in less than 8% error in embedded length estimation.

Furthermore, the Ultraseimic method is also applied on the results of timber modelling. Based on the results of velocities below and above the soil, the stress wave velocity is decreased by 22% overall below the soil in comparison with stress wave velocity above the soil. Based on the Ultraseimic method, the length of the timber pole is estimated by cross correlating the first arrival and reflection waves. Ultraseiemic test applying impact at the middle was also investigated for a 12m timber pole. It was found that, impact at middle of the specimen generated two compressional waves (travelling down and reflecting at the butt) and tensile waves (travelling up and reflecting at the top). This wave interference makes the analysis complicated. In addition, impact from the middle with 45 degree angle generates the combination of horizontal and vertical forces which result in contribution of bending waves to longitudinal waves. As a result, the signal will include multiple wave modes which are required to be separated before calculation of velocity and length determination. It should be mentioned that, Timber pole is modelled as an isotropic material here and if the anisotropy of the material is included the analysis will be more complicated.

This study also presents the results of Sonic Echo, Impulse Response, Bending Wave and Ultraseimic methods, investigated for determining the stress wave velocity and embedded length of poles with different testing conditions in the structural laboratories at UTS and in the field at Mason Park (NSW) and Horsham (Victoria).

According to the laboratory results, the coefficient of variation of velocity estimation of timber pole is relatively higher than steel beam and timber beam due to uncertainties in timber material such as anisotropy of timber material, stress direction in regards to grain angle of timber, location of a sensor relative to other sensors in regards to the annual growth ring orientation and existence of knots or any imperfections in timber. Choosing the reflection peak for length determination is one of the main parts of these methods and this could be affected by geotechnical conditions. Based on the results, the stress wave velocity will decrease inside the soil and a reduction factor is required to be applied to stress wave velocity above the soil to obtain the stress wave velocity below the soil. This reduction factor varies depending on the different testing/boundary conditions as well as the soil depth. In SE method, the scatter of the average error for the pole specimen, associated with different tests, ranged between 1% and 20% for all cases except layer 6 with 26% using sensor 1 for calculations. By using sensor 2 for estimation of the length, the average error becomes less than 9% for all cases except for layer 7 with 32%. However, more uncertainties are involved in terms of length calculation using sensors 3 and 4 located 1.5m and 2m from the impact location in comparison with using sensors 1 and 2 for calculations.

The phase velocity is calculated for each kernel frequency under different pull out testing conditions. Also based on the results of bending wave method, the kernel frequency between of 400-800 Hz was identified for use in SKM method for phase velocity calculations. Using the SKM to estimate the length of the pole with Bending Wave method for a 5m timber pole under different pull out conditions shows the percentage of error for all boundary conditions to be between -10.5% and 0%. If the kernel frequency above 600Hz is selected, the average error for length estimation becomes less than 5% for most boundary conditions.

Also Ultraseismic method was considered for stress wave velocity estimation of timber poles impacted at the top. According to the results, using sensors close to impact location (up to 2-3m) will result in good estimation of the velocity calculations. However, these will not necessarily lead to accurate estimations. According to the results, the average error in length determination for timber poles under different pull out conditions which is more relevant to timber poles in-service is less than 18%. According to the results for Ultraseismic method using impact at the top in Horsham, the stress wave velocities were calculated with relatively good accuracy.

By considering relatively good and damaged poles in Horsham, it was found that the severe termite damage can be identified by the irregular patterns of FFT from impacted timber pole. This can be used to classify which timber poles are required to be replaced in the field.

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