Review of In-service Assessment of Timber Poles

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Abstract

Timber utility poles form an essential component of lifelines in all communities. In Australia, it is estimated that there are more than 5 million timber utility power poles in service with more than 75,000 new poles are installed per annum.

For lifelines, including electricity distribution systems, to continue functioning after an earthquake event, they must have sufficient inherent capacity to withstand the imposed actions. While timber poles may have high initial strength, they often experience deterioration and decay over their design life due to fungus or termite attacks. In most cases the damage is not visible and often below ground. Thus, electricity distribution companies conduct specific routine inspections on their poles, typically every 5 years, to assess their structural integrity. This paper provides a brief review of the common types of pole degradation and presents relevant deterioration models which predict loss of section over the design life. The paper also reviews common and new in-service assessment methods including drilling, sounding, modal testing and stress wave propagation technique which is emerging to be very effective in detecting damage above and below ground.

Keywords: Timber utility poles, non destructive testing, damage detection, stress wave propagation.

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1. INTRODUCTION

Timber utility poles represent a significant component of Australia's infrastructure. There are an estimated 5 million timber utility poles in Australia – with an estimated value of more than $10 billion (Crews and Horrigan 2000). The nationwide demand for timber power poles was approximately 62,000 in 2004, 75,000 in 2006 and was estimated to be around 91,000 in 2009. The maximum supply of poles locally was 62,300 in 2005 and 2006 which was expected to be the same (Lesley and Jack 2006).

Failure of poles can have serious life safety and economical implications. There have been a number of reported incidents where poles failed while line workers were performing operations on the poles leading to fatalities. It is also reported that failure of timber poles may have started some bush fires. Failure of poles also leads to loss of power and possibly other supported services to large communities. Failure of timber poles during an earthquake event can also severely hinder post disaster recovery.

As timber poles deteriorate over time by varying levels, power distribution companies in Australia and overseas carry out routine inspection on poles to assess the structural integrity. The most common techniques used in Australia are visual inspection, sounding and drilling. These techniques are subjective methods and require highly skilled inspectors. Drilling practice is very common and it is a reasonable method for detecting damage. However, it causes damage due to the holes left after the inspection. With frequent inspections, some poles may end up being condemned due to excessive number of holes.

It is important to accurately assess the integrity of existing poles without replacing them unnecessarily because with the fact that demand for poles exceeds supply and it is important to maintain healthy poles to prevent loss of life and services. Hence, there is a growing demand by industry to develop more accurate and reliable non-destructive methods for assessing conditions of in-service poles.

2. DURABILITY

2.1 DETERIORATION AND DECAY OF TIMBER

Timber is an organic material and therefore it is not surprising to find that it is subjected to attack by a whole host of biological agents. Most forms of decay in timber are caused by fungi that feed either on the wall tissue or cell contents of wood. There are four essential components needed for fungal attack of timber poles. They are suitable moisture content, availability of oxygen, suitable temperature and food in the form of nutrients (Mackenzie et al. 2007). Literally, proper control of any one of these four conditions will prevent fungal attack. The most practical way will be poisoning the food form i.e. preservative treatment of the wood.

2.2 IN-GROUND DECAY

In-ground decay is a major problem with timber poles widely used in electricity and telecommunication industry. Soil factors influential to in-ground decay were identified after analysis of failure data from electricity supply industries (Rahman and Chattopadhyay 2007).

Based on a comprehensive study of timber degradation, Wang et. al (2008) produced empirical models which predict in-ground timber decay. The decay rate is a function of parameters related to both wood and climate. Designers are able to predict the expected service life of a timber pole as the decay rate is calculated according to the above mentioned empirical models. In addition, they developed a software tool based on this study to evaluate the decay rates.

To demonstrate the application of the deterioration models developed by Wang et al. (2008) , the software tool was applied to the following typical pole:

Timber species and type	: Red ironbark, Hardwood, Durability Class 1
Cross section	: Circular
Mean diameter	: 300mm
Sapwood thickness	: 10mm
Above ground height	: 10m
Treatment	: K55 Creosote treated for hazard classification H4

The above pole is for a local power cable conductor in Melbourne. The output results from the tool are shown in Figure 1. No centre decay was predicted within first 25 years period of its life time. It was found that the predicted surface decay to be 10mm for the period. The corresponding residual bending strength ratio was predicted to be 80% of initial strength. At 50 years of pole's life, centre decay was predicted as shown in Figure 1 of 12mm with additional surface decay resulting in residual bending strength ratio of about 70%.

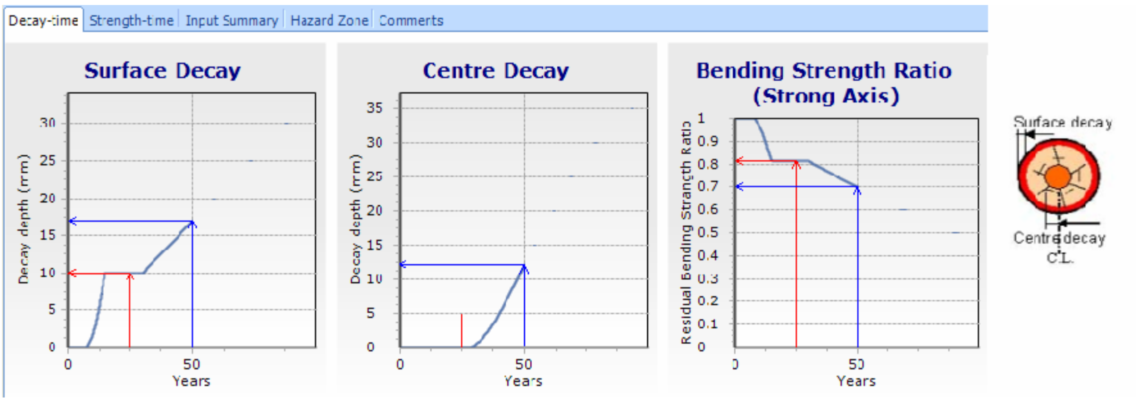

Figure 1: Details of decay rate and bending strength from software developed by Wang et al (2008).

2.3 Termite attack

Termites are the cause of the greatest economic losses of timber in-service in Australia and are a significant factor in the degradation of trees growing in forest areas (Bootle 2004). Durability against termite attack is measured differently to durability against decay. Timber species are characterised as either susceptible or not susceptible to termite attack (Australian Standard AS-5604 2005). According to Peters and Fitzgerald

(2007), termites may broadly be categorized as being either subterranean, damp wood or dry wood. Most termites that damage timber-in-service in Australia are subterranean.

Most of the studies in Australia conducted to estimate the probability of attack by termites are on houses. These studies provide basic understanding and knowledge of probability of termite attack. A detailed analysis by Leicester et al. (2008) has been made on termite tally data in houses to provide information in terms of probability of attack. There are no comparable studies made on termite attack of timber pole.

3. INSPECTION AND IN-SERVICE ASSESSMENT

Inspection of timber poles ensures the structural stability of the poles throughout their design life. Periodical inspections of poles generally cover issues related to loss of ground support, vertical alignment and deterioration. Inspections are typically performed at 5 year intervals. The following sections provide review of typical and advanced methods used for damage detection.

3.1 CURRENT INSPECTION AND ASSESSMENT TECHNIQUES

In Australia, the pole inspection procedure generally consists of the following major actions;

- Above ground line visual inspection.
- Sounding.
- Drilling.

The above ground visual inspection generally includes features such as variation of depth in ground by inspecting the ground level changes and vertical alignment. Reduced embedded depths of poles in ground can severely reduce the stability of the pole. It is important to be aware that road re-alignment and pavement works can lower the ground level relative to the pole. An identification plate (pole disc) on each pole gives the exact length of pole, which is a good indicator to find the depth in ground of the pole by evaluating the above ground height. It is essential to inspect the vertical alignment of a pole and is required to look for reasons why a pole is leaning and the consequences of the lean such as reduced conductor clearance or traffic obstruction caused by pole leaning into a traffic lane or driveway. Poles with leaning angles more than 10^0 are noted in the inspection report for re-erection or replacement (Energy Australia 2006).

Sounding and drilling are used to examine the quality of wood and assess extent of deterioration due to fungal decay or termite. Sound testing of timber poles is carried out with a hammer to as far as can be reached below groundline. Beyond the reach of a hammer a rounded point bar is used to test the pole from the bottom of the excavation up to groundline as indicated in Figure 2.

Drilling is normally used to assess the pole between the groundline and 350mm below ground as shown in Figure 3. This section of the pole is commonly referred to as the critical zone because it is subjected to the highest bending moment and generally suffers the greatest degradation due to the moisture and oxygen availability in this layer of soil. The drilling may be accompanied by excavation around the pole.

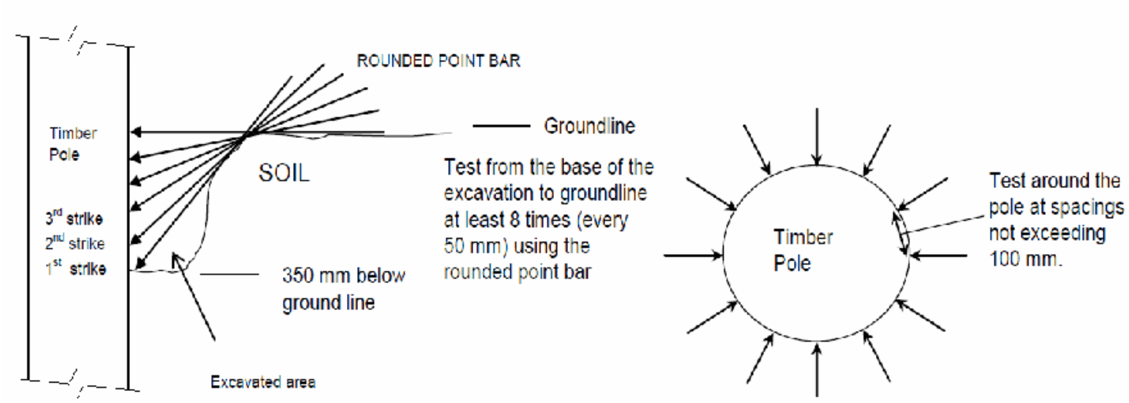

Figure 2: Illustration of sound testing

Source: Pole inspection & treatment procedures (Energy Australia 2006)

All below ground inspection holes are drilled at 45° to the pole and all above ground inspection holes are drilled at 90° to the pole face except the inspection holes for reinforced poles (Figure 3). All inspection holes drilled are generally sealed with blue plugs (Energy Australia 2006).

Figure 3: Details of inspection below ground line

Source: Pole inspection & treatment procedures (Energy Australia 2006)

Drilling assessment is based on the concept that the drill will indicate to the inspector whether it is penetrating sound timber or decayed timber where the drilling is taking place. The sound the drill makes, smell of the wood shavings, feel of the drill, resistance to its progress and how strongly the worm on the drill pulls into the timber will all provide indications about the condition of the timber. This is limited to the drilling location and provides subjective results depending on personal observations.

Crews and Horrigan (2000) suggested that an ideal method of pole assessment would be able to indicate a pole's remaining strength, serviceability and remaining life with a level of reliability. Based on anecdotes and industry experience Crews and Horrigan (2000) found that current inspection methods did not keep the failure rate below acceptable levels and that premature pole condemnation was excessive.

3.2 Advanced Assessment Methods

Given the limitations of sound testing which only detects surface and near surface damage and the destruction and subjective nature of drilling, other testing methods have been explored for assessing in service timber poles. These methods are generally non-destructive and include;

- Stress wave testing
- Experimental modal analysis
- Resistance drilling

In addition, it is noted that non-destructive evaluation with strain energy-based methods are emerging as a promising damage detection technique. Yang et al. (2001) identified cracks in vibrating beams by computing the changes in strain energy due to cracks. Further, Choi et al. (2007), (2008) computed damage index which utilises modal strain energy and statistical approach in an experimental timber beam to detect damages.

3.2.1 Stress Wave Techniques

Several techniques that utilize stress wave propagation have been researched for use in non-destructive testing (NDT). Speed-of-sound transmission and attenuation of induced stress waves in material are frequently used as NDT parameters (Turner 1997).

Stress wave propagation is widely used in the piling industry for the evaluation of concrete piles. Stress wave testing was examined as a technique for evaluating structural stability of timber bridges (Robert et al. 1999). The presence of decay greatly affects stress wave propagation velocity in wood. Propagation velocities for non-degraded Douglas-fir are approximately 1250m/s, whereas severely degraded members exhibit velocity values as low as 310 m/s (Robert et al. 1999).

To assess the applicability of stress wave technique to timber poles, Groundline Pty Ltd performed several field investigations. In 2005, Groundline tested 450 poles around Perth metropolitan area in Western Australia. Twenty percent of poles selected were already classified as “Unserviceable” using traditional drilling methods. The stress wave analysis was performed with a pile tester where it involved striking the timber pole with a hammer instrument with a load cell. The pole response was measured close to the striking location with a geophone. The force and velocity data were then analysed in both time and frequency domains.

A typical plot of velocity versus time for a good timber pole is shown in Figure 4. A good pole clearly shows signal reflections from the top and the bottom of the pole. The majority of the poles tested during the investigation showed reflections which enabled length measurements to be made. However, the time domain was limited with respect to the separation of multiple reflections on aged poles. Additional analysis is therefore necessary.

Additional information on the tested pole can be obtained by calculating Impedance (Z) expressed by Equation (1):

$$Z = \rho \, C \, A \qquad (1)$$

Where: ρ – Density of the pole material
C– Propagation velocity of the stress wave
A– Cross sectional area of the pole

The characteristic mechanical admittance, mobility (M) is the inverse of impedance is (Davis and Dunn 1974):

$$M = 1/Z = 1/(\rho \, C \, A) \qquad (2)$$

The frequency domain plot of velocity per unit force versus frequency shows the Mobility of the medium under testing as shown in Figure 5. The dynamic stiffness of the pole was derived from the tangent at the initial part of the plot. The 100-500 Hz frequency range of the plot was taken for average mobility (M) of the pole. Also, the height of the pole can be assessed by picking clear peaks of the plot within the above frequency range. The pole height was determined using typical stress wave propagation velocity in timber pole within the range of 900-1100 m/s as the propagation velocity was not evaluated at the phase of inspection.

From the field trials performed by Groundline Pty Ltd, it was empirically found that poles with mobility rating less than 35000 (10^{-9} m/Ns) are structurally satisfactory. Poles with a mobility rating greater than 35000 (10^{-9} m/Ns) are likely to be structurally inadequate.

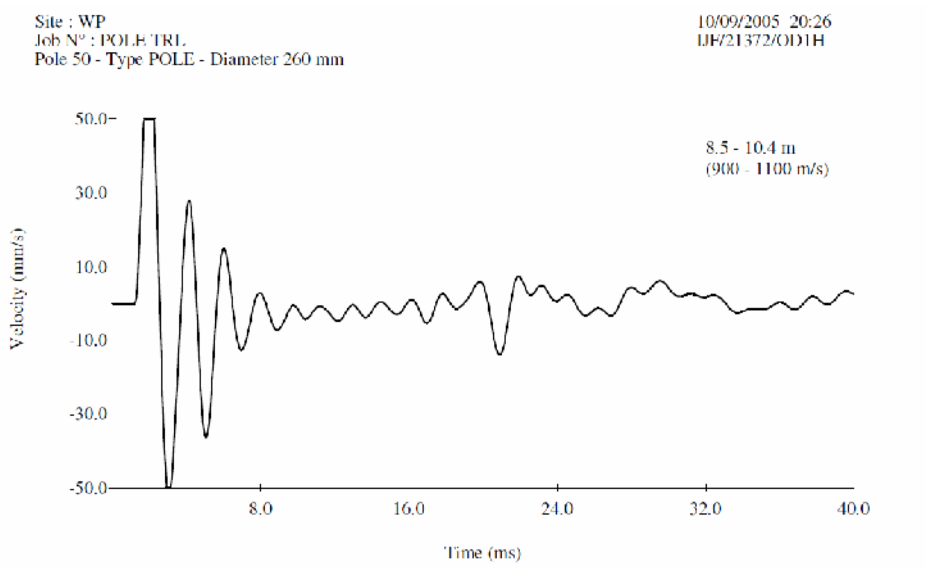

Figure 4: Typical time domain trace.

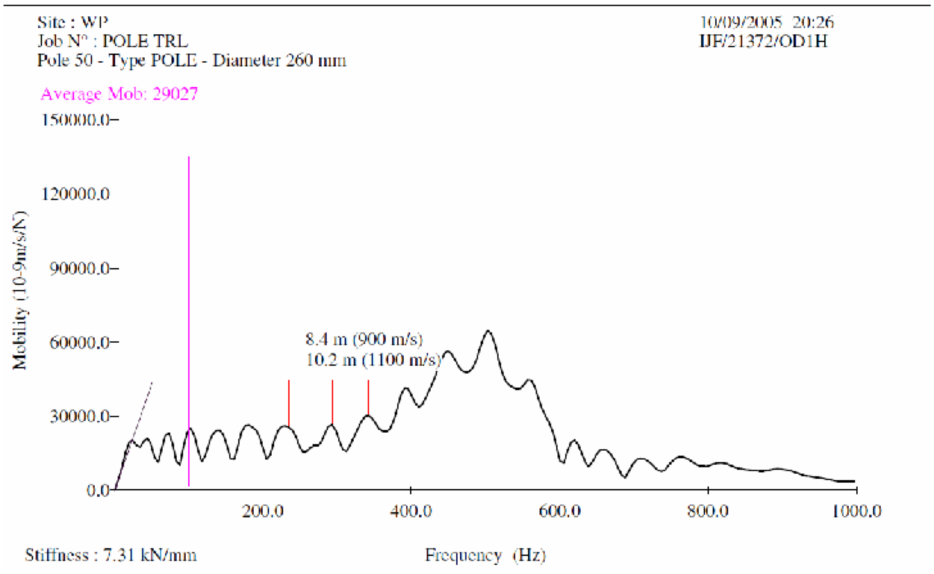

Figure 5: Typical frequency domain trace results.

Based on the preliminary work performed by Groundline Pty Ltd, it appears that the Stress Wave Technique is a promising method for assessing the structural integrity of in-service timber poles. However, further study is required to examine the following issues.

- Influence of reinforcement and additional restraints on pole response.
- Establishing of wave propagation velocities for different species of timber.
- Degree of sensitivity of the technique to identify small defects.
- Automated damage identification below and above ground and calculation of remaining service life.

3.2.2 Experimental Modal Analysis

There has been extensive research done on the use of dynamic parameters for damage detection. Changes in structural properties lead to change in dynamic modal parameters such as natural frequencies, mode shapes and modal damping values. These parameters can be obtained from dynamic (vibration) testing (Avitabile 2001).

The most useful damage detection methods are probably those using changes in resonant frequencies because frequency measurements can be quickly conducted and often reliable (Salawu 1997). Abnormal loss of stiffness is inferred when measured natural frequencies are substantially lower than expected or compared to signature values in as new condition.

Natural frequencies may be measured using a single or few sensors whereas mode shape or dynamic flexibility requires multiple sensors or to be placed at multiple location. Some of the most successful results of damage identification through experimental modal analysis have been achieved on laboratory scale structures, where the lack of rotational degrees of freedom (DOFs) and ease of accessibility allow entire mode shapes to be measured (Kosmatka and Ricles 1999). However, even with a large number of sensors the measurement of modal characteristics is usually incomplete.

Salawu (1997) reviewed 65 publications dealing with the detection of structural damage through frequency changes. He revealed that the frequency values obtained from periodic vibration testing can be used to monitor structural behaviour and also assess structural condition. However, many of the proposed methods require either a theoretical model of damage or a set of sensitivity values to be computed before physical measurements are taken (Peter and Fanning 2004). To be truly realistic, the methods would require consideration of all possible damage events at various locations on the structure.

Chen et al. (1995) questioned the effectiveness of using the changes in natural frequencies to indicate damages in a structure. The first four frequencies of a steel channel exhibited no shifts greater than 5% due to a single notch severe enough to cause the channel to fail at its design load. The frequency variation due to incidental/ambient vibration and environmental effects can be as high as 5-10%, they argued that lower frequency shifts would not necessarily be useful damage indicators. This suggests that relying on natural frequency changes to identify defects in timber poles needs to be considered carefully as the sensitivity of this method may not be suitable.

Damage to poles can also lead to changes in the mode shapes. However, the mode shapes can be difficult to obtain experimentally as a large number of sensors (accelerometers or geophones) need to be attached to the pole along its height. This may not be possible or practical in many cases.

3.2.3 Resistance Drilling

Resistance drilling can be used to characterise wood properties and to detect abnormal physical conditions in structural timbers. This is an automated form of mechanical probing of woods. The drilling size is only 1.5-3.0mm in diameter. Based on the drilling test, a resistograph is produced. This is a record of the relative resistance of the wood to the rotating drill bit (Ross et al. 2006). While this method has shown good results in assessing timber structures, it only provides health assessment at the location of drilling. Even though the hole size produced is relatively small, repeated drilling may weaken the pole locally.

4. CONCLUDING REMARKS

This paper provided a brief review of the factors which affect the durability of timber utility poles and prediction of decay rate with respect to different timber species and environmental conditions. Current damage detection techniques and their advantages and limitations were also presented for timber poles. Further, this paper discussed the development of advanced non-destructive assessment techniques to evaluate timber pole integrity. It should be noted that detecting damage in timber poles is more challenging than in homogeneous, isotropic materials such as metals, concrete and polymers due to the inherent natural defects.

Commonly used visual and sounding inspections provide results only related to surface and near surface condition of a pole. While a drilling inspection provides direct results, it is limited to the drilling location. In addition, repetitive drilling inspections weaken the pole locally which is normally the location of maximum stresses (base of the pole). The above inspection techniques are subjective as the evaluations greatly depend on inspector’s observations and experience.

Experimental modal analysis has successfully been employed in structures and bridges for damage detection. Changes in dynamic modal parameters such as natural frequencies, mode shapes and modal damping values can be used as indicators of structural damages. Changes in the natural frequencies may be used to indicate potential damage in timber poles as natural frequencies can easily be acquired from simple vibration tests. However, obtaining the mode shapes would be practically difficult as it requires several sensors (accelerometers or geophones) to be placed along the pole. Access to high positions along the pole may not be feasible or desirable from safety point of view.

The stress wave technique has been successfully used for a long time in integrity testing of reinforced concrete pile. Stress wave propagation velocity and reflections are affected by the properties of the medium the wave is traveling through and the presence of cracks or discontinuities. Based on some field trials, it appears that this testing technique is a promising method for assessing the structural integrity of in-service timber poles. However, further research is required to examine issues such as sensitivity of detecting small defects, establishing wave propagation velocities for different timber species and influence of reinforcement along the pole. These issues are part of an on-going research project undertaken by the authors.

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