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PROBABILISTIC CONDITION ASSESSMENT TECHNIQUE FOR TIMBER POWER POLES

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Timber poles are extensively used in Australia to support overhead electric and telecommunication facilities. The strength of the pole degrades over time, and pole failure can have serious safety and economic implications. The failure occurs when stresses exceed the remaining strength of the timber element. In this paper, a probabilistic framework is developed to estimate the remaining life of the timber power pole system. The developed framework permits the user to consider the variability in the capacity of the timber pole and cross-arm, loading and deterioration processes, and to propagate the uncertainty associated in each stage of the assessment procedure. Further, the time-dependent failure rate of the pole system is estimated to develop the risk matrix to improve the current renewal and replacement decision making process used by the utility companies in Australia.

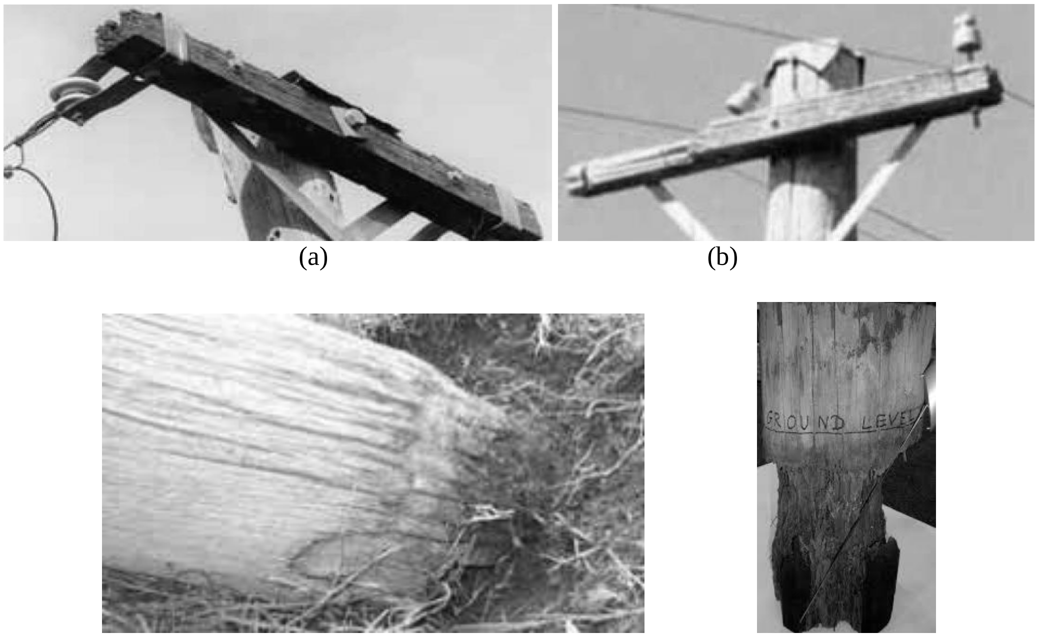
Keywords: Timber pole, Deterioration models, Probabilistic approach, Time-dependent.

1 INTRODUCTION

Timber utility poles represent a significant component of Australia's infrastructure, as they are extensively used to support overhead electric and telecommunication facilities. They are high in strength, low in cost, and have excellent durability. There are an estimated 5.3 million timber utility poles in Australia, with an estimated total value of more than $12 billion (Rahman and Chattopadhyay 2007). However, due to various deterioration processes, the strength of the pole degrades with time, which potentially reduces the life of the pole. Failure of poles can have serious safety and economic implications. Therefore, one of the main areas of interest of electricity distribution companies is to assess the condition of the timber poles and optimize the life of the existing timber pole system (including poles and cross-arms) in the network. The strength of the pole and cross-arm affected by multiple factors, such as age, service, extreme loads on the pole system, climate conditions, soil characteristics, and quality of the timber material.

The failure occurs when stresses generated within the pole system exceed the remaining strength of the timber element. According to the National Electric Safety Code, timber poles should be replaced when the initial strength falls below 66%. Most of the utilities estimate the service life of a timber pole to be 30 to 40 years (Bingel 1995, Mankowski *et al.* 2002). However, past failure analysis and surveys show that the service life can range from 60 to 80 years depending on species, location, and maintenance (Morrell 2008, Stewart 1996). Hence, the service life of the pole system can exhibit large variability depending on the induced damage and damage progression.

Therefore, reliable estimates of system state and long-term performance depend directly on the accuracy of the estimation of defects/damage, and damage progression/deterioration of timber and the loadings and their variance. The parameters stated above such as age of the component, species, intended carrying loads and direction, weather related to the location, treatment type, deterioration levels, and inspection holes (if applicable), are factored into the estimation of residual strength or the remaining service life of poles and cross arms. Especially for timber cross-arms, the deterioration and strength reduction occur mainly due to weather, termites, or fungal rot and loading. Figure 1 shows the typically observed defects in timber cross-arm (a, b) and pole (c, d).



(a) (b)

(c) (d)

Figure 1. Deteriorated cross-arms (a, b) and pole (c, d) (adopted from Powercor, Australia: http://www.esv.vic.gov.au/Portals/0/consumers/files/POEL%20borchure1.pdf).

In order to reliably assess the condition and remaining life of the timber pole system, it is important to consider the uncertainty associated with each input variable stated above. In this paper, a probabilistic framework is developed to estimate the remaining life of the timber power pole system. The developed framework permits the user to consider the variability in the capacity of the timber pole and cross-arm, loading and deterioration process and propagate the uncertainty associated in each stages of the assessment procedure. Further, the time-dependent failure rate of the pole system is estimated to develop the risk matrix that helps to improve the current the renewal and replacement decision making process used by the utilities in Australia.

2 DETERIORATION MODEL FOR TIMBER POWER POLE SYSTEM

The rate of deterioration of timber depends on several factors such as timber species, weather conditions (i.e., temperature, rainfall, and humidity), initial preservative treatment, and nature of fungal/insect attack. This means that any decay model can only be an approximation. There are models developed to estimate the rate of deterioration in timber poles. Li *et al.* (2006) developed one based on field data of poles, collected in Iowa, ranging from one to 79 years. The effective cross-sectional area at the ground line was assessed by drilling. It was found that there is a time lag of 10 years for the deterioration to start, and then it increases linearly. Later, Shafieezadeh *et al.* (2014) modified Li's model to estimate the strength of the pole at any given time as follows:

$$R(t) = R_0\{1-(a_1t-a_2)(b_1t-b_2)\} \tag{1}$$

where R_0 is the initial strength of the pole, a_1, a_2, b_1, and b_2 are the regression constant calibrated to be 0.1442, 0.1068, 0.004 and 0.04 respectively, assuming the time lag is 10 years. The covariance of pole strength with time shows that the uncertainty in the strength increases with time.

Wang *et al.* (2008) developed a deterioration model for in-ground timber considering strength reduction due to termite/fungi attack using Australian field data. The strength reduction follows a bilinear model with time and the decay depth at any time, t is given in Eq. (2):

$$d_t = \begin{cases} ct^2 & if \;\; t \le t_{d_0} \\ (t-t_{lag})r & if \;\; t \ge t_{d_0} \end{cases} \tag{2}$$

where d_t is the decay depth, t lag is the time lack before the decay starts (years), t_{d0} is the time in which decay reaches its threshold depth (d_0), which is assumed to be 5 mm if there is no data, and r is the decay rate that is depends on the wood parameter and climate. The bending strength of the pole at time t is given as:

$$R(t) = f_b \frac{\pi}{32}\left(D-2d_t\right)^3 \tag{3}$$

where f_b is the bending strength of the timber.

There is no timber deterioration model for the cross-arm, which is above ground and mainly affected by climate. The deterioration models developed for timber poles may not be directly applicable to cross-arms. Further, a reliable prediction of pole failure depends on the accuracy of estimating the strength reduction of a pole during its lifetime, which depends on the deterioration model and its parameters. It is noted that the variability among the deterioration model and model parameters is significant; therefore the prediction of strength reduction also varies largely. Figure 2 shows the variability in the strength reduction factor (SRF) with time estimated using different deterioration models. The strength reduction factor was calculated as a ratio between the initial strength and the strength at time t. The observed variability in SRF is significant, and consequently affects the factor of safety and remaining-life calculation of the pole system. Therefore, the selection of deterioration model and the estimation of model parameters will have a significant impact on the asset renewal and rehabilitation decision making process.

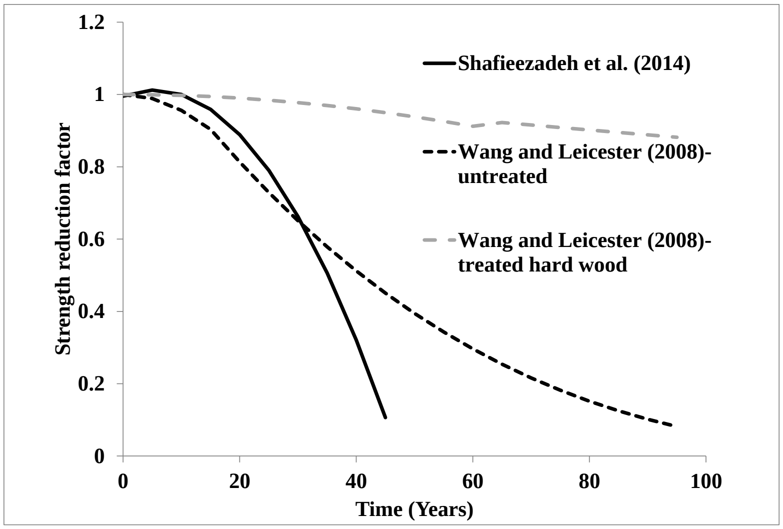


Figure 2. Variability in strength reduction factor with time using different deterioration models.

3 PROBABILISTIC APPROACH TO ESTIMATE THE REMAINING LIFE OF THE POLE SYSTEM

The current practice in Australian utilities for pole condition assessment is very subjective and the accuracy of the methods is questionable. The most common techniques used are the visual inspection, sounding with a hammer, and boring with a drill. There is significant uncertainty associated with the estimation of pole and cross-arm capacity, selection of deterioration models and estimation of model parameters, and the estimation of loads/extreme loads. The deterministic condition assessment of a single pole system may not be suitable to consider uncertainty in input variables, and leads to un-conservative and over-conservative predictions. Therefore, incorporating the probabilistic approach into the condition assessment technique allows the user to propagate the uncertainty associated with input parameter and to quantify the variation in condition-assessment predictions.

It is not possible or useful for the utility to assess the condition of each and every pole in their network. The location-based network analysis helps to predict the gross possible failures and expected expenditure for replacement in a targeted year. The network analysis uses the past pole and cross-arm failure data and possible uncertainty in the deterioration model and loading via a probabilistic approach. This approach has been successfully used and currently being used by water and gas pipeline asset owners to plan the renewal and replacement decision making process. Therefore, it is possible to adopt the approach to power pole network with modifications for better management of the asset. A possible probabilistic asset management framework for adaptation is provided below:

- Step 1: Develop a database for the capacity of timber poles and cross-arms. Laboratory testing on the new pole and cross-arm samples for different loading range and conditions will provide the structural capacity and its variability.
- Step 2: Develop a deterioration model especially for cross-arms. The deterioration model for poles has been already developed (although the model parameters need to be calibrated according to the location), but there is no deterioration model available for cross-arms.
- Step 3: Develop a past failure database for timber poles and cross-arms. This allows the development of failure-rate curves for poles and cross-arms depending on the location and climatic condition.
- Step 4: Develop probabilistic possible loading models for poles and cross-arms. The intensity of the loading and its occurrence data need to be developed to the fragility curve for the pole system and probability of failure.
- Step 5: Develop failure-rate curves for timber poles and cross-arms, with an updating algorithm to correct the rate curve using the current failure data and condition-assessment data.
- Step 6: Develop a renewal and replacement decision making algorithm based on simulations. This will provide the time-dependent reliability index or probability of failure for poles and cross-arms. The risk matrix as shown in Figure (3) has been developed using the probability of failure and consequence of failure to rate the pole system.

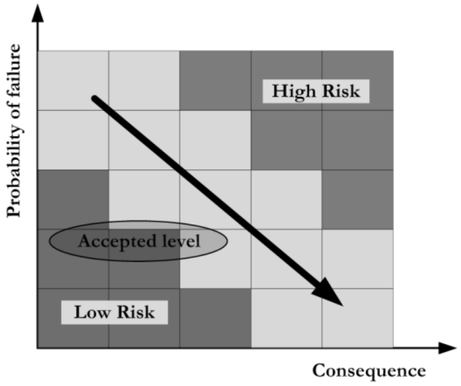


Figure 3. Generated risk matrix for a timber pole system applying the decision making algorithms.

4 CONCLUSION

This paper provided a possible probabilistic framework for a timber power pole system to help the renewal and replacement decision making process. The framework allows for the incorporation of uncertainty in the input variables and the propagation of them during each step of the decision making process. Further, the past failure data of poles and cross-arms has been integrated to develop a failure rate curve, which can be improved with additional failure and condition assessment data. Finally, the risk matrix has been developed for the pole network to rate the condition of the pole system, and is expected to improve the current decision making process used by the Australian utilities.

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