IN-GRADE TESTING OF UTILITY POLES IN AUSTRALIA

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SUMMARY

An extensive in-grade testing program for timber utility poles in Australia aims to test 1200 new poles and over 450 in-service poles to establish grading parameters for utility poles, characteristic strength values for round timber poles, and examine methods for determining residual strength of in-service poles. The project has yielded some preliminary results, which indicate that current design and grading rules are overly simplistic.

1 INTRODUCTION

It is estimated that there are 5 million timber utility poles in Australia – with a current net worth of $10 billion. In South East Queensland alone, there are currently 500 000 poles in service [1]. The cost per annum of maintenance to this asset (for this one electricity supply association) is $4 million. The annual cost of maintenance of timber poles across the three eastern states of Australia is $26 million. In addition to this cost, are the costs associated with risk obligations against failure, and lost income from disrupted supplies.

Preliminary investigations, focusing on the development of asset management systems for the power distribution industry, have shown that the design and assessment methods that form current industry practices in Australia are imprecise and often unreliable. Optimisation of design criteria using a reliability-based philosophy, and an improved knowledge of the residual strength of poles, could potentially increase the level of reliability whilst reducing new pole costs. Significant potential savings in asset maintenance are also possible by refinement of inspection methods and development of more accurate techniques for assessing performance of in-service poles.

Within this context, a project supported by the Forest and Wood Products Research and Development Corporation, NSW and QLD Electricity Associations and Queensland Forestry Research Institute was developed in Australia. The aim of the project is to characterise the design properties of new poles from regrowth and plantation sources, and develop tools for assessing the remaining life of in-service poles.

The project is linked with a separate investigation into the success of Non-Destructive Evaluation (NDE) in estimating residual strength of power poles [2].

2 IN-GRADE POLE TEST PROJECT

The project objectives can be classed as either:

- *applicable to new poles:*
Development of improved grading methods for new, treated poles and defining appropriate design data (characteristic strength values and modification factors) for utility poles
- *appropriate for in-service poles:*
Development of improved residual life estimation and residual strength assessment methods

2.1 Scope of the Project

The project uses in-grade testing techniques and has three main areas of focus:

- The in-grade test results will establish characteristic design properties for new poles – both current supply and future resource plantation and regrowth material, through the use of full scale destructive testing.

- The same testing technique is used to establish remaining strength in poles that have been removed from service. A separate project managed by EANSW [2] and undertaken by the University of Technology, Sydney will use remaining strength data from a further 350 poles quantify degradation techniques and to assess commercial non destructive testing devices.
- Careful observation of the characteristics of the poles and correlations with performance will enable better grading processes to be developed. Design rules that truly reflect pole performance can also be derived from the test results.

The current testing program will see the destructive testing of over 1200 new poles, and approximately 450 ex-service poles. An additional 350 ex-service poles will be used to assess current commercial NDE technologies as part of the NDE project [2].

2.2 Benefits of the Project for New Poles

For the utility pole producers, the improvement in design and grading criteria will allow greater flexibility in supply and would enable timber poles to compete more successfully with other manufactured pole products, such as those from concrete and steel. For example, if inefficient design of timber poles led to a loss of market of 2 percent per annum, this would equate to a $0.52 million per annum loss in market share.

The benefits of using reliability based design procedures for the pole supply industry, are based on the fact that many poles which fail to meet current specifications, can in fact be used quite satisfactorily. This benefit is only possible when the design is based on quantified performance criteria rather than somewhat arbitrary assumptions of tip load capacity. This is because the characteristic strengths obtained from full sized 'in-grade' testing gives a much more accurate indication of pole performance than present strength assignment methods.

2.3 Benefits of the Project for In-service Poles

Both the electricity supply industry and the power pole supply industry will benefit from the improved knowledge of "life cycle" data for poles which will be generated from these projects.

The potential economic and risk management benefits from these linked projects accrue in two ways: - (1) simply by reducing the number of poles being replaced which are still capable of performing in service and (2), identifying more accurately those poles which constitute a risk to both system reliability and human life.

This would in turn see a continuing shift from "reactive" maintenance of poles, to "preventative" maintenance as a part of an asset management system. This improvement in the management of the pole asset will benefit electricity boards on a national level, with potential to reduce the cost of inspection and maintenance, and increase the level of system reliability. This could in turn benefit the pole supply industry, as the "life cycle" costs for timber poles are reduced, improving their cost competitiveness with other pole products.

Simple models for cost benefit analysis used by Electricity Authorities suggest that a ten percent improvement in assessment and structural analysis of poles, would equate to a $2.5 - $3 million per annual saving in the cost of maintenance.

3 CURRENT DESIGN METHODS

Current structural design procedures for poles rely on working stress principles and "assumed" factors of safety, closely coupled with materials properties derived from the strength group / stress grade system used for timber design in AS1720.1, 1988 [3] and also adopted in the current pole standard [4]. Whilst the introduction of limit states design for structural timber [11] was essentially a "soft conversion", the capacity factors used in the new code do reflect a probabilistic, reliability basis – albeit, a somewhat simplistic one [14].

3.1 Grading of Poles

The grading system for poles and round timbers has essentially remained unchanged since the mid 1960's when the four strength group categories (denoted A, B, C, and D) [5] were expanded to seven strength groups (S1 to S7) [6],[7] to cater for a wider variety of timber, including plantation softwoods.

For natural round mature poles, the basic working stresses were assumed to be equivalent to the stresses derived from 'small clear' (defect free) tests. This assumption was based upon limited testing and comparative analysis.

During the 1960's, Dr J.D. Boyd (CSIRO Division of Forest Products) [8] carried out extensive research and testing on eucalypt species and radiata pine. His research highlighted the inefficiencies in deriving pole design stresses based on the traditional strength group/ stress grade system and he proposed a more probabilistic approach to the derivation of stresses and design of timber poles. Even so, current design methods reflect earlier work. The only reduction to 'small clear' strength values was to account for shaving, trimming and immaturity of poles.

In 1979, Dr G.R.Siemon (Department of Forestry Queensland) [9] also conducted a limited study on CCA treated slash pine poles from Queensland and found that the use of historical methods based on 'small clear' data did not provide a reliable predictor of pole bending strength.

Dr G.B Walford (Forest Research Institute, New Zealand) [10] conducted extensive studies on New Zealand plantation softwood poles. He derived a 4 point testing method for the base or butt of poles - and found good correlation between cantilever and 4 point methods. His work established recommended characteristic stresses for inclusion in the New Zealand Limit State Design Code, and concluded that outer wood pole density is a more reliable predictor of pole strength than clear wood strengths.

3.2 Reliability-based Design

National and International structural design standards [11] and codes have moved towards a reliability-based design method using Limit State Design procedures. In addition to this, Power Distribution Authorities are implementing risk cost management principles, which in turn require probabilistic consideration of matters such as the structural design of infrastructure, including overhead power reticulation.

- For new poles, the current grading does not appear to give a particularly good indication of initial strength, and certainly does not correlate well with in-service performance. Small clears data seems unconservative, even for the strongest poles in a population. Some different grading criteria are needed.
- For determining the strength of existing poles, rot and other degradation change both the physical properties and the cross-section. It is very hard to estimate the extent of these changes and hence very hard to determine residual strength. The strength of the small clears of the species to which the pole belongs is of little help here!

In both cases, the weaker poles in a population will have strengths and failure modes that depend on some growth or service characteristic that ultimately define the characteristic strength of the pole. The strength of the clear wood only really helps to predict the maximum attainable strength of the stronger poles in the population.

3.3 In-grade Testing of Poles

In Australia there is currently no standard methodology for the testing of full timber rounds. There are however two methods of test which have achieved (varying) levels of international acceptance:

- The cantilever test method (developed by the American Society for Testing and Materials, ASTM) and
- The four point bending test, used by the Forest Research Institute, New Zealand.

The three point testing method (as used by Boyd in his research) [8] is very similar in principle to the cantilever test method, but gives a more predictable bending moment in the region below the ground-line. The disadvantage of this method is that it places large bearing stresses on the pole at the ground-line, which may cause premature failure in that region. As well, the large rate of change of shear force at ground-line has caused problems in previous tests and resulted in the load application point being located some two to three metres above the nominal ground-line.

The cantilever and four point test methods and their various 'strengths and weaknesses' have been examined in a previous paper [12]. The advantages favouring the four point method are discussed, together with the fact that the ASTM cantilever method is machine dependent (due to its specialised clamping arrangements).

4. PRELIMINARY PROJECT RESULTS

In order to reduce the potential problems associated with bearing conditions at and below the ground-line, the four point bending test illustrated in Figure 1, has been chosen as the standard test method for this project.

- The four point testing method has the ground-line placed at centre span in the test with an effectively constant moment region over that part of the pole immediately above and below the ground-line. This constant moment over the region where it is expected the pole will fail means that regardless of the actual position of failure, the strength of the fibres at the failure location can be easily calculated. (Where there is a significant moment distribution over the length of the failure, the actual stress at the failure is not unique).
- The cantilever test method requires a clamp at the ground-line. The clamping forces affect the wood fibres in that region in a manner that may not accurately reflect the nature of forces in the ground-line area of poles in service. The clamping forces may also induce premature failure of the pole in the clamped region, and these failures cannot therefore be included as valid indicators of pole strength.

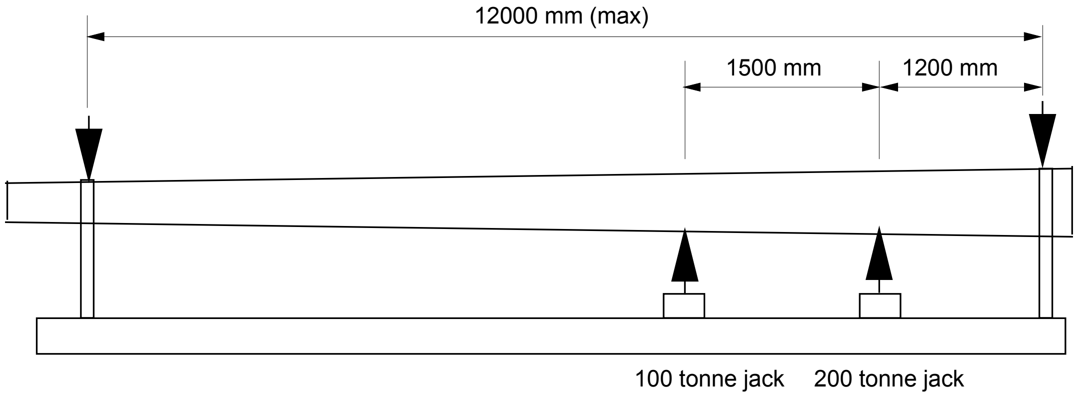

Figure 1 – Schematic Sketch of Pole testing Rig

4.1 In-grade Test Results

While there has been a large amount of data collected, there are still many more poles to be tested in the experimental program. For each test, the following data was collected (where possible):

- Service details - length of service, soil type, orientation of pole, loadings
- Pole details - height, diameter, species, condition
- Failure load, load and corresponding deflections (flexural stiffness)
- Failure characteristics (including photographs of failure region)
- Growth or service characteristics in the failure region

Whilst the actual bending strength at failure (kNm) is accurately known, the MOR strength of each pole has been determined using the measured external diameter of the pole. This is because the actual shape and section modulus of the remaining wood in a partially degraded pole is difficult to assess.

The Modulus of Rupture (MoR) derived from the test load is an equivalent strength assuming a full section. Future work on in-service poles will undertake more comprehensive section modulus analysis, similar to that used in the EANSW project [2].

Preliminary analyses of data have been undertaken, including comparisons between populations of new poles and poles removed from service. Table 1 shows the comparison between characteristic strengths of the two populations derived using an analysis based on the standard in-grade test evaluation [13]. Figure 2 shows the Modulus of Rupture distribution for both the new and ex-service populations. Note that all results relate to graded poles from species *corymbia maculata* (spotted gum) samples.

At present, there is a small number of poles in the test sample for which comparisons can be made between new and in-service poles of the same grade and species. These show that generally there is a reduction in strength over time in service.

NEW POLES		**EX-SERVICE POLES (5 to 35 years)**	
No of Samples	60	No of Samples	103
Coefficient of Variation	35%	Coefficient of Variation	36%
Fifth Percentile	103.45 MPa	Fifth Percentile	56.6 MPa
Characteristic Strength	99.2 MPa	Characteristic Strength	55.5 MPa

Table 1: Comparison of modulus of rupture values for the populations of new poles and ex-service poles

Figure 2 Pole strength distribution

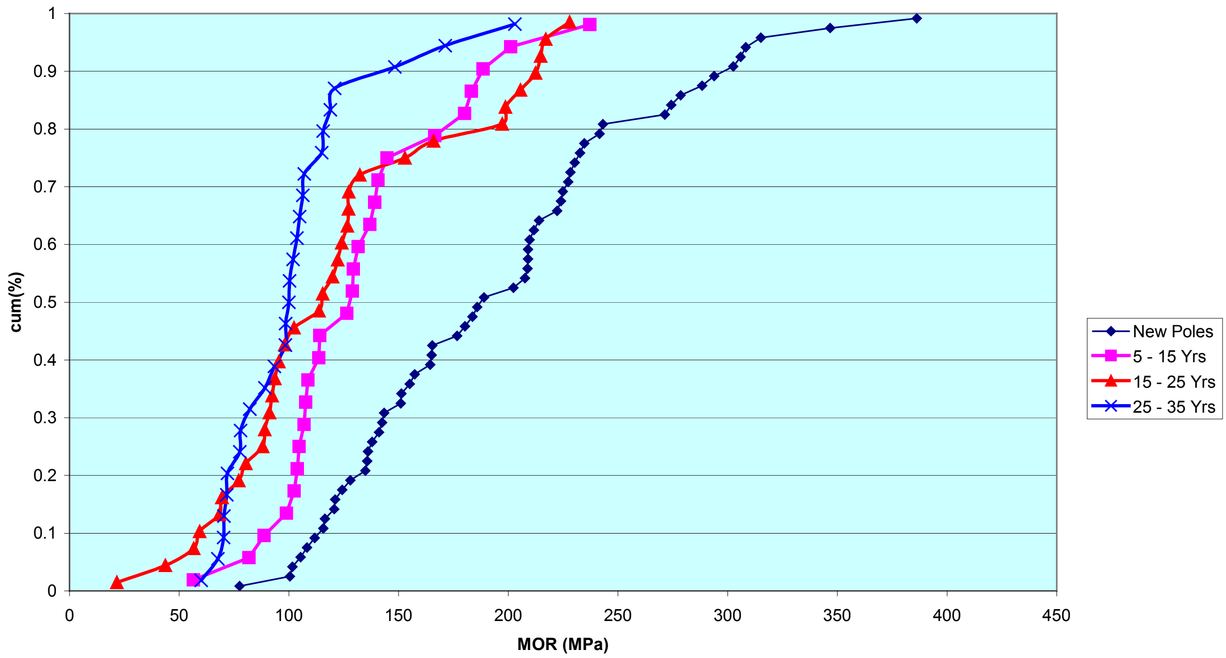

Figure 2: MOR Distribution

However, even with this limited sample some interesting trends can be seen:

- There appears to be a general reduction in strength with time in service. This can be seen by a leftward shift in the cumulative frequency distributions shown in Figure 2.
- There was a significant shift in the stronger poles even for small periods in service. Typically the upper end of timber strength frequency distributions tends to follow the trends established for small clear specimens. This may indicate that there is a step degradation in wood strength at the ground-line soon after the poles are placed in service. The degradation may be due to some installation practice, or a rapid change in wood behaviour after it has made ground contact.

- Near the lower end of the distribution, there was not a clear distinction between the curves for poles of different lengths of service. This indicates that the deterioration incorporates other factors as well as the duration of service.

These and other observations will be refined over the remainder of the project when the bulk of the data becomes available for analysis.

Observation of the failure characteristics of those poles in the region near the lower 5%ile will give an indication of the growth or service characteristics that affect the long-term strength of poles. This will contribute to a better understanding of grading for poles. Correlations with strength will also quantify (at least in part) those factors that affect the strength of in-service poles, and enable the development of more realistic design and maintenance methods.

5 CONCLUSIONS

The four-point bending test for utility poles utilised during the test program has produced failures similar to those observed for utility poles in-service. This includes failures below ground line. On the basis of the limited data presented in this paper, the following trends have been observed.

- There is a general deterioration of poles with time in service. This reduces the bending capacity and appears to reduce the fibre strength of the poles.
- For higher strength poles, there seems to be a fairly rapid reduction in strength at ground-line near the commencement of service. This may be associated with installation of the pole or other hardware, or may be a step reduction in strength after ground contact.
- For lower strength poles (near the 5%ile) the deterioration cannot be attributed to age of service alone. Correlation with the extend of degradation (loss of section), growth and service characteristics will enable the trends to be fully investigated.

Once the testing phase of the project has been completed, and all of the data analysed, the results will help provide:

- comprehensive and more accurate grading rules,
- reliable characteristic strength values for commonly used utility pole species and grades.
- guidelines for identifying (1) poles which have a significant risk of failure, and (2) poles which have had considerable service, but are still capable of delivering satisfactory performance. (The results of the NDE test project will be linked to assist in this task. [2])

These improvements in design and grading criteria, and in residual life estimation will ultimately be reflected in the improved cost competitiveness of timber over other pole products. The project has the potential to benefit both the utility pole producers and the Electricity Supply Corporations.

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