Strength assessment of timber utility poles in Australia
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SUMMARY

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. It was within this context, that two major complementary projects were developed in Australia for assessing the strength of new poles and remaining strength of in-service poles. Together, the projects involve full scale destructive testing of some 2000 timber poles.

This paper reviews and presents summary results of both projects and discusses the development of reliability based strength assessment of timber utility poles using new NDE techniques.

INTRODUCTION

Timber Utility poles represent a significant component of Australia’s infrastructure, which has often been taken for granted. There are an estimated 5 million timber utility poles in Australia – with a current net worth of about $10 billion. The average usage of power poles in the three eastern states of Australia, is approximately 60000 per annum, with a total average annual cost of replacement of approximately $18 million. Most of these poles are timber.

Optimisation of design and assessment criteria using a reliability based philosophy and an improved knowledge of the residual strength of poles, could potentially increase the level of asset reliability whilst reducing new pole costs. Significant potential savings in asset maintenance are also possible by refining inspection and development of more accurate methods of assessing in-service poles.

It was within this context, that two major complementary projects were developed in Australia for assessing the strength of new poles and remaining strength of in-service poles. The first project was initiated by the Electricity Association of New South Wales, for assessing commercial NDE technologies which could be applied to predicting remaining strength or residual life of utility poles which were perceived to be at or near the end of their service life. This has involved removing some 350 poles from service and undertaking NDE assessment using 20 different technologies (including ultrasonics, x-ray, and intrusive methods), after which all poles were removed and destructively tested to assess actual strength and failure characteristics.

The second project comprises both ingrade testing of new poles and selective testing of in-service poles; with results from the latter being used to quantify strength degradation effects. This project is 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 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.

CONTEXT FOR THE RESEARCH PROJECTS

The need for reliable strength assessment
For poles in service the power supply industry needs to maintain a high average reliability against pole failure whilst extracting the maximum value from these assets (Crews & Price – 1999). For this balance to be achievable it needs to have available to it pole evaluation techniques and procedures at least able to:

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• always classify correctly any pole with inadequate strength.
• only infrequently condemn poles with adequate strength.

This might be all that was required if maintenance of a line was the only objective. If however the purpose of testing is, for example, to assess a pole or line for its potential to carry a greater load then it would also be necessary for the systems used to give a dependable indication of remaining strength. It would be useful too, if they facilitated reasonable estimates of remaining life. At least until methods become available which can be shown without doubt to control degrade in the critical zone(s) for the term of the ensuing cycle.

An optimum method of pole assessment then would be able to indicate remaining strength, serviceability classification and remaining life with a level of reliability commensurate with that of the rest of the network. In addition it would need to do this:-

• Non destructively
• On the majority of poles in the system regardless of function, location, foundation, topography, species, type, age etc.
• Within the Occupational, Health and Safety regulations applying.
• Without risk to the public or the environment
• Economically in that the value of its outputs, eg. poles retained/upgraded data generated, exceeded the cost of its ownership and operation.

Prior to the mid 1980’s, if inspection was done at all, the procedure was usually minimal excavation followed by superficial examination and sounding with axe or hammer. Suspect poles were only sometimes drilled to check internal condition. On the collected evidence a decision was made about whether they could be climbed or retained. Such information as is available suggests the method did not keep the failure rate below the level then acceptable and resulted in waste through excessive premature condemnation.

Improving inspection procedures

Over the last decade or more most network generators have moved to improved asset management systems which involve routine inspection of poles being undertaken in order to prevent the premature failure of the pole by detecting any degradation which may be present and using this information to assess the remaining strength and service life of the pole.

The inspection method is based on the assumption that remaining strength is proportional to the modulus of cross section of the sound wood surviving in the critical plane. This development of inspection procedures was found to have reduced condemning rates by at least one third whilst also reducing incidence of failure. However, although more “reliable” than previous methods, the section modulus method still has limitations and can fail to identify low strength “rogue” poles, which often constitute the greatest risk to both injury and loss of service.

THE SECTION MODULUS METHOD

Description of inspection process

The section modulus method is accomplished by drilling inspection holes into the pole in the ground line region, and estimating the effect loss of section. The section properties are estimated by examination of the depth to any decay voids and the colour of the wood shavings extracted during the inspection drilling. The section modulus “Z” is then calculated by subtracting the area(s) of decayed wood from the theoretical sound wood area based on the pole diameter. The bending capacity is calculated as the section modulus “Z” multiplied by the wood strength (usually assumed to be 80 – 100 MPa for native hardwood poles).

In recent times the Section Modulus method has been widely applied usually by a computerised interactive means facilitated in the field by hand held units. This system depends on a comparison between the design load applied to a pole and its working capacity or remaining strength which is taken to be proportional to the modulus of the cross-section of the sound wood surviving at the critical point. The strength of the pole is assumed to be adequate not only at the time of the test but until the next inspection if it is 100% or more than required when determined by this means.

Limitations of the section modulus method
Although a significant step forward from previous “adhoc” practices it falls short of satisfying the key reliability criteria discussed above. For example, it is invasive if not destructive, since determining the extent of the remaining sound wood involves drilling one or more holes in the critical section at each inspection. The amount of wood removed and the affect of this on strength may be minimal especially if drilled in the neutral axis but there is evidence that exploratory holes can promote deterioration.

More significantly, the assumption is made that it is feasible by drilling, probing etc. to accurately determine the proportion of wood in the critical section which is ‘sound’. The conclusions drawn by the inspector on the extent of sound wood depend on the remote tactile examination of the usually unseen interior of the hole(s) and the pole shavings produced. Given that before the changes in colour, structure and density detectable by such means have occurred some forms of decay, common in poles, can cause significant impairment of strength properties, there is reason to view the results with caution.

Another assumption made in the application of the section modulus method is that any remaining sound wood has the minimum fibre stress designated by Standards Australia for the strength class to which the pole timber species is assigned. In this classification system the mean values for a species of the results of various strength tests on small clear specimens are required to exceed designated minima. It can’t be regarded as precise because the tests are limited in number and the variations large. It follows that the bending strength of the wood in a significant number of poles will be less than the designated class minimum.

Prior to the current projects, the accuracy of the section modulus method and the validity of the assumed pole strength have not been known with any degree of reliability for pole strength assessment in Australia. Despite its widespread use, no research had been undertaken in Australia to compare pole strength determined by the Section Modulus method with actual data from the destructive testing of full sized poles. Research undertaken for EPRI in the USA indicates that, as used there, the section modulus method tends to overestimate remaining strength. Yet, without relevant data it has not been possible to know if the same occurs in Australia or if the safety factors used are adequate to allow for both low strength and ongoing deterioration.

There has been anecdotal evidence for some time, that the inspection process is both subjective and may also contribute to weakening of the pole section and increasing the risk of decay. Yet in spite of these limitations it has a legitimate claim to be regarded as current best practice.

NDE METHODS FOR ASSESSING “IN-SERVICE” POLES

Over a period of many years a variety of non destructive testing devices, some already in use in other applications/countries have been proposed or tried for the inspection of timber poles in Australia. To the present day none of these has come into routine and general use in the industry despite some serious attempts to achieve this end.

Within this context, numerous NDE devices and proof testing methods have appeared on the market, claiming to either accurately map the section and / or predict the residual strength of a timber pole. Prior to commencement of the EANSW project, no objective assessments of either these new NDE methods or the traditional section modulus predictions have been undertaken.

The EANSW project is unprecedented and in many respects represents a world first in terms of its objective assessment of the international “State of the art” in non destructive evaluation of timber poles. Whilst the technical philosophy underlying many of the methods differs, the basic predictive outputs are very similar – with most techniques focusing on determining the pole cross section at ground level. The traditional section modulus method used by the power distribution industry represents the most basic method for determining the cross section at the ground line.

The NDE technologies currently under investigation can be broadly categorised into two groups –

1. those which determine the physical geometry / section properties of the pole at ground line
2. those which, in addition to (1), also are able to indicate one or more of: wood density, stiffness, hardness of fibre strength
A total of 20 devices collected data on the project test population over a 5 month period. Eight of these are being, or have in the past been used on poles or piles. The rest are prototypes in development. The techniques employed may be described as:-

<table>
<thead>
<tr>
<th>Method</th>
<th>Number of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiographic imaging</td>
<td>2</td>
</tr>
<tr>
<td>Radiographic densitometer</td>
<td>2</td>
</tr>
<tr>
<td>Drill probes</td>
<td>2</td>
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<tr>
<td>Ultrasonic tomography</td>
<td>2</td>
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<tr>
<td>Sonic stress wave timers</td>
<td>3</td>
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<tr>
<td>Acoustic/Resonance</td>
<td>5</td>
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<tr>
<td>Force applying (MPT)</td>
<td>1</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>3</td>
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</tbody>
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Many of the NDE technologies “map” the cross section in a manner which not only produces an “image” of the physical dimensions of the section, but also provides information about the relative density of the wood, which can be an accurate indicator of the presence and extent of decay. These technologies also have the potential to predict the strength of the pole using correlations with density and or stiffness – although considerable development work is likely to be necessary to establish reliable strength predictive methods.

However, despite the fact that many of the technologies will require further development, all of the non-intrusive NDE methods (acoustic / x-ray / ultrasonic / dynamic / resistance drilling) generally represent a significant potential increase in reliability and repeatability over the traditional section modulus method.

**TESTING METHODOLOGIES AND PROCESSES**

**Description of the ingrade testing project**

The ingrade project will involve full scale MOE / MOR testing of over 1200 poles, including both new and ex-service poles, from numerous locations around Australia. Each “local” population consists of at least 50 poles (usually more) and where possible, is restricted to single species groups. For the ingrade testing programs, the pole testing rig was moved to the region where the poles were either manufactured or removed from service. For each test, the following data is collected (where available):

- 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

The poles where all tested to destruction using a 4 point bend test, which has been reported elsewhere (Horrigan, et al – 1999; Crews et al – 1998). 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. Whilst this simplification has a negligible effect for determining the strength of new poles, it can be significant for older poles. 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, using components of the “post mortem” procedures used in the EANSW project.

**Description of the NDE testing project**

For the EANSW project the acquisition of the requisite poles started with a target of 350, some from each distributor authority either untreated and/or preservative impregnated to be supplied to some simple criteria. These included size limits, critical zone condition and if possible a link between the pole supplied and its service location and history. As several thousand of the 2 million wood poles in NSW were then being condemned and replaced annually it was expected to happen quickly and according to plan. In fact, it took over 18 months to get 336 poles. Over 2,000 poles were examined in the line or depots around the state and of these, approximately 500 were shipped to the test site about 50 km
west of Sydney. Each of these was then inspected for suitability and a significant proportion were rejected as too “good”, and a few as too “bad”.

Groundline diameters for the poles removed from service ranged from 170mm to 490 mm with an average of 300 mm. Pole lengths were not critical for the EANSW project, which was focusing on the groundline region, and ranged between 6 and 14 metres, with most in the 10m to 12m range. Critical zone condition ranged from “collapse imminent” to “totally sound”. All the usual causes of wood pole degrade are represented, ie. internal and external brown and white rot, impregnated sapwood soft rot, subterranean termite, glyptotermes, grub holes, checking and mechanical damage. More than one of these are present in varying proportions in most poles and almost all of the test population have some exploratory drill holes and many have diffusible rod internal treatment holes drilled into the zone around groundline.

Each of the poles selected was:

- Examined to locate and mark the ‘in service’ groundline position.
- Measured for overall length and mean diameter at the top, ‘in service’ groundline and butt.
- Butt end, groundline (3 positions) and gross anomalies photographed.
- Hammer sounded around groundline.
- Circumferential paint line applied around ‘in service’ groundline
- A primary reference line oriented to the king bolt hole or ID disc where present, was painted upwards from the groundline. A secondary reference line painted upwards from the groundline 90o around the pole.
- Depth of surface softening determined at a point 75 mm below groundline in the plane of both the primary and secondary vertical reference lines.
- Radial thickness of remaining sound wood determined by drilling and probing 6mm holes entering at a point 75 mm below groundline in the plane of both the primary and secondary reference lines.
- A project pole number assigned and painted on.
- Record made of pole supplier and type and where available treated ID disc details and all numbers/letters likely to aid identification.

Preparation for installation included the removal of loose sapwood and all extraneous fittings except pole caps and ID discs. All drilled holes were cleared, filled with Boron/Fluoride diffusing rods then closed with hardwood timber plugs which were cut flush. A core sample of sound hardwood was taken from the top half of the pole and sent to a specialist wood scientist for species identification purposes. Each pole was installed to its original ‘in service’ setting depth as marked ± 50 mm before backfilling and consolidation.

Following installation the poles were left for a period of not less than 2 months to allow some equilibration to occur between butt and soil moisture, before the NDE practitioners were given access to the site. NDE assessments commenced in April / May, 1998 and were completed in August / September 1998, after which all poles were removed and destructively tested to assess actual strength and failure characteristics. The “failed” poles were then subjected to extensive post mortem procedures to identify decay patterns and accurately map the pole cross section for a precise determination of the section modulus at the ground line of each pole.

A select sample of 50% of the MoR / MoE test data was then be released to NDE practitioners to enable the opportunity to calibrate their respective systems; before submitting a “final” report which must include predictions of capacities for remaining 50% of poles. This first data release was undertaken in two phases – during May and July 1999. The final reports prepared by the NDE practitioners are expected to be completed by February 2000, after which the University of Technology, Sydney (UTS) research team will report on test results and the correlation of NDE predictions (NDE reports) with actual data, recommendations and comments on effectiveness of each system.

Post mortem procedures
Once the poles were broken, segment samples were cut at GL and at failure point (if the latter is not in the GL region). The purpose of this process is to determine the actual section geometry and compute static values i.e. centroid, moment of inertia and finally section modulus Z.

The post mortem processes can be summarised as follows:
1. Moisture content readings are taken on both faces of the samples at two different locations with an electric resistance device (Deltron DCR11C).

2. The samples are then laid on a clean light base with a blue axes system, which helps to determine the position of the sample i.e. tensile and compression zone. A measuring tape is placed on the top of the sample to help working out the scale on the further steps. Photographs of each sample face are taken with a high-resolution (1.4 million pixels) digital camera and a 35mm slide camera.

3. The photograph JPG files are down loaded into a computer and opened using CorelDraw. The outer and inner perimeter is traced with points connected by lines and the scale is adjusted to match that of the timber section as measured.

4. The file is saved in a DXF format so points are recorded with their coordinates. The DXF file is then exported into a cross-sectional analysis program, to compute the relevant section properties.

5. The samples were then wrapped in plastic bags to prevent them to dry out prematurely and send to UTS laboratories. The samples are then weighted and their volume is computed by mean of water displacement. A mean density is determined, by keeping the samples in plastic bags so that voids are taken into account.

6. Moisture content using the oven-dry method. Samples are cut in small clear wood cubes, measured, weighted, left in a oven set at 103°C for 24 hours and weighted again.

RESULTS

The results indicate that the 5th percentile strength of all poles (without regard to species) was approximately 25 MPa assuming a gross section and 33 MPa using the actual section properties (determined from the GL segments), with a GL capacity of 89 kNm. Interestingly, 34% of poles failed in the vicinity of inspection holes – although the statistical significance of this observation is yet to be assessed. The average GL diameter of the poles was slightly under 300mm and the average age of the population was 26 years. A comparison of actual capacity and the predicted capacity using section modulus methods is presented graphically in figure 1.

![Cumulative Frequency - Ultimate Bending Moment at GL](image-url)

**Figure 1 – Comparison of Actual and Predicted bending capacities**
The average “actual” section modulus (based on the image analysis) was approximately 92% for the “A” face (GL +150mm) and 91% for the “B” face (GL – 150mm) of the gross section. The respective 5th percentiles were 71% for the “A” face and 65% for the “B” face.

An analysis of the bending capacity data (Crews – 1999) indicates the following:

- the traditional method will over predict the ultimate GL bending capacity about 65-70 % of the time and significantly it will over estimate the capacity of the lower 5%, where rogue poles are most likely to occur
- using the traditionally derived section modulus with strength group characteristic bending properties (which are species dependent) will improve the reliability of the residual strength prediction significantly, with no over estimation at the lower tail and non-conservative predictions of the ultimate GL bending capacity about 50-60 % of the time.
- any technology which accurately maps the critical GL section will yield further improvements, with over estimation reduced to about 40% of the time and generally restricted to the higher strength poles in the population.

A comparison of section modulus predicted using the “traditional” inspection drilling method with the actual values determined from analysis of the ground line segments indicates that below the GL face, the traditional methods over estimated the section modulus by more than 10% in about 36% of assessments and over estimated by more than 40% in approximately 11% of cases.

This latter figure is perhaps the most significant – in a pole where advanced decay has occurred not only is there a loss of section, but also it is probable that the wood fibre strength has also deteriorated. In simple terms, these poles represent the potential rogues that are not identified using the traditional inspection techniques. The effect of fibre strength degradation is still being investigated. A related study (Horrigan et al – 1999) comparing single species (corymbia maculata) populations of new poles and poles removed from service has confirmed similar effects with the 5th percentile bending strength reducing from 100 MPa to 55 MPa.

Analysis of the MoR data using species and durability groupings confirms a similar trend. For high natural durability the long term fifth percentile strength is about 55% of that of the population of “new” poles, reducing to approximately 40% for durability classes 2 to 4. Whilst the mechanisms associated with this are not yet fully understood, it is clear that the trends clearly point to a significant reduction in wood fibre strength for poles in-service.

**DISCUSSION**

This all begs the question – why don’t we get more pole failures?

The answer is really two-fold:

- When it comes to actual bending capacity at the GL, many poles are much stronger than thought. However, it is not the strong ones that present a problem, it is the weaker ones and detection of these is critical to improve reliability
- The factors of safety used by the industry in the past have been very conservative and have covered a “multitude of sins”. Unfortunately, they have also perpetuated a great deal of ignorance regarding the real initial and remaining capacity of timber poles. Limit states design attempts to quantify the level of uncertainty and ascribe an acceptable level of “safety” using transparent and statistically based processes. Arbitrary factors of safety have no place in reliability based strength assessment of timber poles.

Observation of the failure characteristics of poles 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 both grading for new poles and assessment of in-service 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.

**CONCLUSIONS**

The physical testing results of this project have highlighted some deficiencies in existing inspection methods and reinforced the urgent need for more accurate and reliable means of assessing the capacity of in-service timber utility poles.
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 a significant number (65%) of failures at or below the ground line. Analysis of results to date indicate the following trends:

- 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 lower strength poles (near the 5% ile) the deterioration cannot be attributed to age of service alone. Correlation with the extent of degradation (loss of section), growth and service characteristics will enable the trends to be fully investigated.
- NDE technologies which can accurately map the section geometry of poles to determine the section modulus will enable a significant increase in assessment reliability

Once the analysis phase of the project has been completed, the results will help provide:

- comprehensive and more accurate residual strength assessment procedures,
- 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.

Ongoing work to develop fibre strength assessment techniques is necessary in order to accurately predict residual strength, even when the section mapping is accurate. These improvements in design and 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.

**REFERENCES**


