PORTASCAN: A NEW INSTRUMENT FOR NDE OF WOODEN STRUCTURES

Gavin Wallace
Isoscan, GNS Science Ltd
PO Box 31312. Lower Hutt New Zealand

Abstract

Some years ago, the author had designed and built a portable computed tomography instrument called PortaCat for imaging wooden power poles. Independent trials in 1998 demonstrated that among a range of techniques available, PortaCat images provided the best estimates of parameters such as available bending moments. However, in spite of an urgent requirement of the power industry to adopt non-destructive techniques, PortaCat was not a commercial success.

The problem was revisited in 2005, and it was realised that while a density image of the cross section of a pole was informative, it was only a means to an end. The important information was the estimate of available bending moments, and a simpler, and much faster, method was devised to obtain this. The idea was patented using validation from the PortaCat image data, and a new instrument PortaScan has been designed and built.

1. Introduction

Wooden utility poles represent both a significant capital investment by power and telecommunications companies in distribution networks, and also a risk in discontinuity of supply. For instance, there are about 12 million poles in use in Australia, and they can last in excess of 50 years before requiring replacement. Hardwood poles are subject to attack by a range of degrading conditions, such as rot and termites. The deterioration may be entirely internal, and not visible on the outside of the pole. While concrete provides an alternative, this material can also suffer environmental degradation, and timber is still being used for new poles.

Catastrophic failure of poles is a hazard to people, both by direct contact and indirect exposure through secondary effects such as bushfires. Poles should be inspected every 5 years as part of an asset management programme. The industry standard practice to determine pole integrity is to drill holes seeking internal rot or cavities. Clearly, this is not non-destructive, and not wholly reliable. Furthermore, replacement of poles in which internal defects have been detected may not be necessary - concrete poles are usually made lacking material in their central core. If sufficient strength still remains in the defective timber poles, then replacement is an unnecessary cost.

The strength of a pole can be represented by its section modulus, **Z**, about a neutral axis $\mathbf{y_n}$. Figure 1 shows a circular cross section.

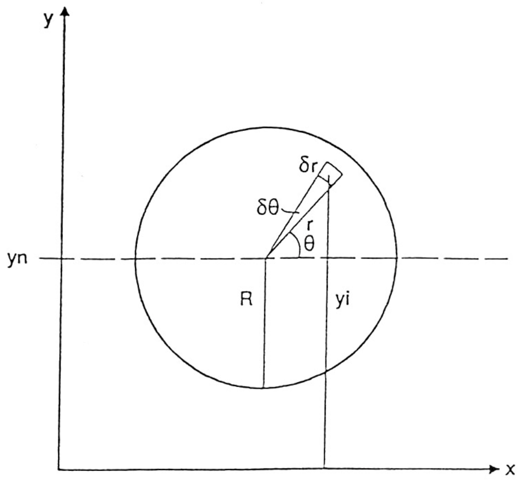

Figure 1: section modulus calculation about neutral axis y_n

The moment of inertia, **I**, about can be obtained by integration of all of the elements of area rδθ.δr about $\mathbf{y_n}$

$$I = \int_0^{2\pi} \int_0^{R} r\,d\theta\,dr\,(r\sin\theta)^2 = \frac{\pi R^4}{4}$$

and the section modulus is obtained by dividing **I** by the largest distance from $\mathbf{y_n}$

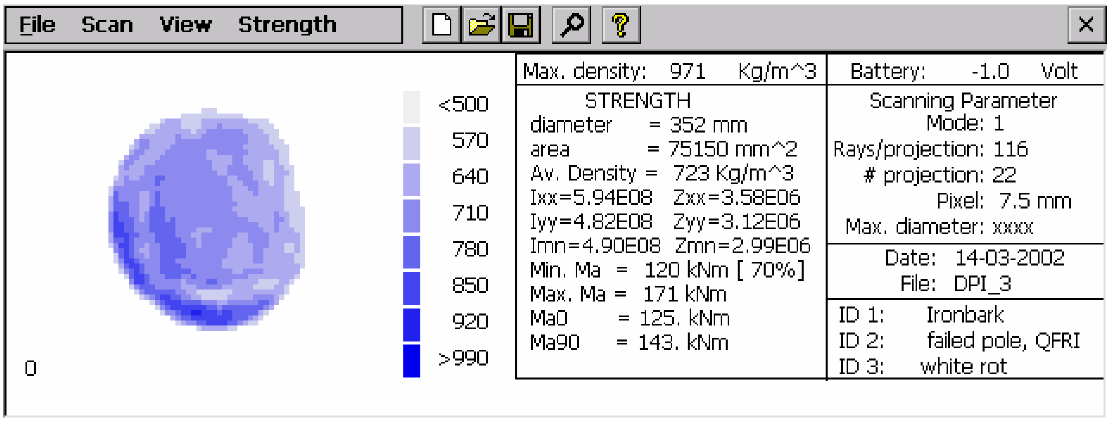

Figure 2: PortaCAT example of pole cross section evaluation

$$Z_c = \frac{I}{R} = \pi \frac{R^3}{4}$$

Clearly, the furtherest element will be under the most stress. If $\mathbf{F_m}$ is the ultimate extreme fibre stress of the timber (also referred to as the modulus of rupture, typically 70 - 100 MPa for Australian hardwoods), then the available bending moment, $\mathbf{M_A}$, of the pole at this cross section is simply

$$M_A = ZF_m$$

The critical zone of a wooden pole is about ground level, and $\mathbf{M_A}$ must exceed the bending moment applied by the force of overhead lines times the height of the pole.

2. PortaCAT

PortaCAT is a battery-powered portable computed tomography scanner that uses measurements of the attenuation of a gamma ray beam through a pole to produce crude cross sectional images of wood density. A 300 mCi disc source of Am-241 emitting 60 keV gamma rays is used. The source and a single detector are driven around a housing by step motors to predetermined positions for measurements. An image of N x N pixels requires $\pi N^2/4$ a minimum of attenuation measurements eg. for a pixel size of 10mm and diameter of 350mm, more than 962 measurements are required. Pixels of less than a set threshold in density are judged not to contribute to the moment of inertia or strength of a pole, and the estimates are compared with sound poles of the same diameter. As shown in fig. 2, a percentage degradation is calculated.

Along with many other instruments invited worldwide, PortaCAT [1] was evaluated in Electricity Association of NSW trials in 1998, and was judged to be the most accurate technique [2]. In spite of this, PortaCAT has not been a commercial success. There are several possible reasons – cost, fragility of the instrument, and speed of data acquisition. The industry still relies on drilling holes to ascertain internal rot in wood power poles.

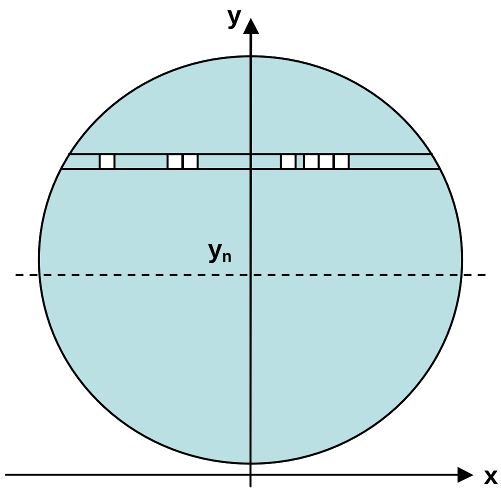

Figure 3: PortaScan principle

3. A Simpler Technique

The lack of adoption by industry prompted a re-examination of issues, and the realisation that production of a density image of a pole cross section was an unnecessary overhead. The image enabled calculation of the available bending moment, but this could be done with far fewer measurements [3]. As shown in fig. 3, the

Figure 4: PortaScan

position of good or bad pixels in a chord is irrelevant when calculating moments of inertia, or section moduli – they are all the same distance from the neutral axis. What is necessary is an estimate of the number of non-contributing pixels in the chord and, with some assumptions, this can be done much more simply:

- Assume a shape from external measurements
  - this can be circular, elliptic or rectangular
- Calculate the chord length
  - gives expected number of pixels
- Measure gamma ray attenuation through the chord
  - gives integrated chord density
- Compare measured chord density with sound density
  - gives estimate of number of bad pixels in chord

This is the principle embodied in the new PortaScan instrument. With this technique, only N measurements are required, instead of the $\pi N^2/4$ necessary for PortaCAT. An estimate of the sound density of the timber is required, and this can be obtained by using gamma rays on a sound portion of the structure. If the cross section is circular, a diameter estimate can be obtained when stepping through the chords.

4. PortaScan

There are several handheld instruments available that provide x- or gamma ray transmission inspection of components. These usually have the radioactive sources and detectors mounted on a C-frame so that the component can be sandwiched. PortaScan (fig. 4) differs in that a bar is mounted onto a pole, and the scanner is motor-driven on this bar. The position of the scanner on the bar is also measured so that recorded transmission data can be identified with cross section chords. The critical zone for pole failure is normally below ground level, and excavation is usually undertaken. Like PortaCat, PortaScan uses 60 keV gamma rays from an Am-

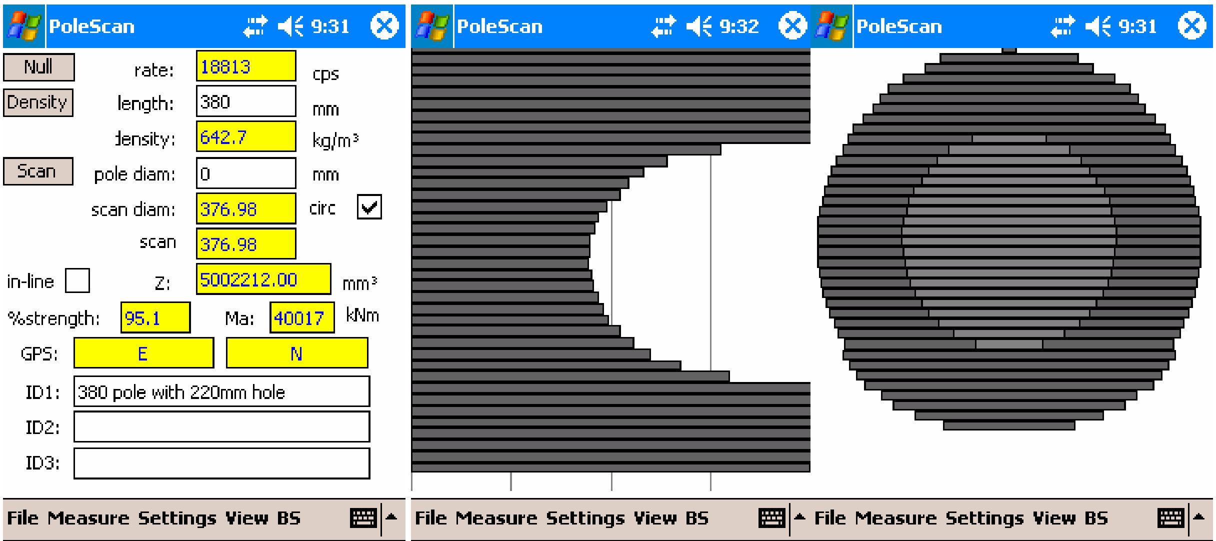

Figure 5: PortaScan PDA screens: parameters (l.), average chord density (m.), reconstructed image showing centralised missing pixels (r)

241 source. The source and detector are mounted on the ends of arms that can be swung through 90^0 to scan cross sections below ground level. The arms can also be swung to facilitate a measurement of sound wood above ground level without shifting the mounting bar. The whole instrument is designed to fold up for transporting, battery-powered and is light. A motor-driven scan takes about 1 minute, and is automated so that the operator can undertake other inspection tasks, such as yard arms, at the same time.

The microprocessor within the mounted electronics pack talks to a PDA by Bluetooth radio communications. Various displays are available on this. The PortaScan 'image' shown in fig. 5(r) is symbolic only: missing pixels are lumped together to create a central defect. However, instead of >20 scans, PortaScan needs only one to estimate bending moments (fig. 5(l)), and produce this simplified cross sectional image. If the defect is symmetric, an additional orthogonal scan can be combined to give an accurate placement of the missing pixels within the cross section.

The software does both poles and rectangular beams, and the instrument can be reconfigured to do backscatter measurements for inspection to a depth of 100mm for internal holes.

5. Results

The performance of the PortaScan device has been evaluated using known shapes cut from mdf board. It can be seen from fig. 6 that the accuracy is good over a large range of diameters and defects.

Fig. 7 is a comparison of the PortaScan principle using data recovered from PortaCAT measurements of real poles during the EANSW trials of 1998 [1]. Again, these results show that the simpler method is quite adequate to evaluate power pole integrity.

6. Discussion

A novel instrument has been developed that has the potential to address a long standing problem in asset management of power distribution networks. The degradation, and loss of strength, of wooden poles can have multiple causes, and is most difficult to assess when the decay is internal. Density has previously been found to be a good indicator of this decay. The technique requires a series of spaced gamma ray attenuation measurements in the critical zone (at, or below ground level) to be made parallel to the overhead line load supported by the pole. With some assumptions, this then allows a calculation of the available bending moment about the neutral axis that is aligned with the overhead lines. While it is

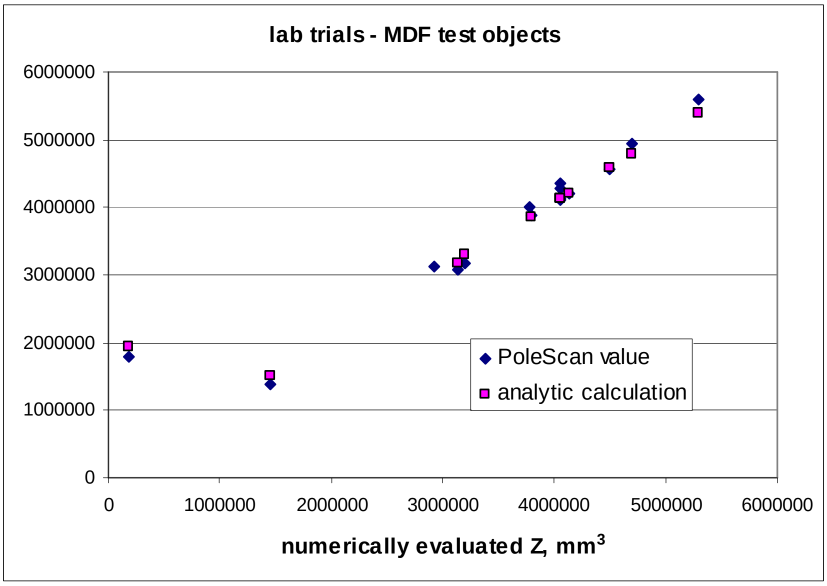

Figure 6: comparison of section moduli. The objects range in diameter from 340 to 380 mm, both solid and with holes of 200 to 300 mm diameter. The squares are calculated from the formulae for circles, and the diamonds are from PortaScan analysis. The horizontal values are from numerical calculations.

normally transverse to the line that the maximum bending moment of the load is applied to a pole, measurements can equally be made at other angles. Similarly, the technique is not confined to poles. It can also be applied to the wooden beams of bridges or other structures.

In implementing the technique, three assumptions are made. The first is that the density of the sound wood can be measured well above ground level where decay is unlikely. The second assumption is that degraded wood is of zero density. Unless the degradation is due to termite infestation, cracking or advanced decay, this is unlikely to be true. Rotted timber is more likely to have a lowered, non-zero density. However, the rot is usually from the centre out, and the pole centre is a minor contributor to the section modulus. Therefore, the assumption is unlikely to contribute much by way of error. The effect of assigning zero pixel densities is to underestimate the amount of degraded wood, therefore over-estimating the section modulus. Degraded wood can be assigned a non-zero density to overcome this.

The third assumption is the outer shape of the pole; a circular shape for poles is the default approximation. An elliptical shape can be imposed by using with a tape measure, and this would improve accuracy provided either the major or minor axis was aligned with the neutral axis.

There is one further qualification that pertains to any technique based on the use of gamma rays, including CT imaging. It is not possible to differentiate between wood and water. Therefore, the moisture content of wood, whether sound or decayed, boosts the observed density. Fortunately, experience with PortaCAT has indicated that this is not a serious problem. In-service poles become quite dry, and even in sodden ground, water does not penetrate very far into the pole surface. The

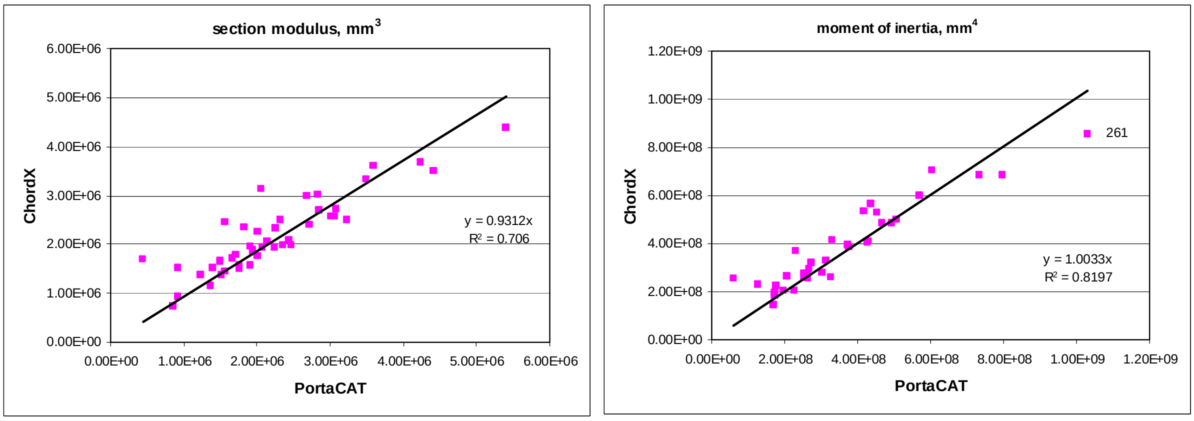

Figure 7: comparison of moments of inertia and section moduli of real poles using PortaCAT data measured during EANSW 1998 trials reprocessed according to the PortaScan principle.

density of internal wet rot is still well below that of sound timber, and this degraded material was readily detectable by PortaCAT. Moreover, wet rot will tend to be central, in an area unlikely to make a major contribution to the section modulus.

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