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In Situ Structural Timber Strength Measurement Advances Using Qualitative Resistography and Quantitive Resisto-Fractometry

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Abstract

In situ and on site evaluation of timber used for structural purposes has largely been based on methodologies that give qualitive assessments that describe condition aspects, rather than providing measurable "strength" data. This is largely due to the absence of site-friendly equipment and processes that provide the various "strength" values engineers need for meaningful structural evaluation. Even when such methodologies are used, sample size, the degree of destructive investigation and the difficulties in quickly relating ultimate values to yield strength and/or to various local or international code requirements present issues. This document describes a paired methodology based on electronic resistography, used alone and in concert with incremental core type fractometry coupled by using software that permits a high degree of integration of results.

This is acknowledged to be a starter paper with limitations, based on preliminary and limited research undertaken in house by a very small company, in a remote corner of the globe, undertaken by field technicians looking for solutions to a real experienced problem. It highlights, arguably, a novel direction in this area whereby specific strength characteristics of wooden structural elements can be determined on site. Largely it identifies tools and methodologies with a strong emphasis on site applications.

Keywords: digital Resistograph, digital Fractometer, fractometry, resisto-fractometry, control tests, yield strength, Woodchecker, in situ, on-site, timber strength.

Introduction

Background

As late as 2010 a comprehensive analysis by Kasal and Tannert [1] underscored that, while there were a large number of methodologies for assessing timber in situ, most had limitations. Data generated generally indicated varying aspects of timber condition, - but useable compressive, bending, and tensile strength values were not easily derived, and where they were, samples usually needed to be processed at a remote testing facility and/or samples needed to be substantial in number and dimension. Resultant delays in reports, cost of testing, acceptability of damage to structures in obtaining samples and representivity of samples are common issues.

Resisto-Fractometry

'Resisto-fractometry' is an in-house quasi-technical term coined that reflects the object the team had in fusing two separate technologies so as to:

1) Develop a control sample based method using a digital microdrill (specifically an IML Resistograph PD) whereby graphic profiles from suspect or questionable integrity areas were compared against known sound wood of the same specie and from the same structure. The use of control graphic profiles to compare subsequent profiles obtained from concern areas made identifying of anomalies more easy and gave a greater degree of confidence in identifying sound timber profiles. This improved qualitive timber condition evaluation when the Resistograph was used in isolation.

2) 4.9 mm core samples were tested for compressive strength parallel to grain (using an IML electronic Fractometer) to provide qualitive strength data. The check methodology involved taking core samples approximately 20 mm from microdrill test points on the same grain plane to build a higher degree of confidence in the likely compressive strength implied by the electronic resistographic data. This required the in-house development of software to facilitate the various comparative sets of data generated and to derive averaged ultimate and averaged yield strength values. It also required sourcing a good and increasing selection of ISOs, ASTMs and similar local building code requirements relating to timber strength requirements and including their specifics in reports generated.

Developmental Summary

Very clear correlation between a standard Resistograph profile and x-ray density of a sample from the same location have been shown by others. In addition the general correlation between density and overall timber strength characteristics has been commented on by many. It was noted that while Fractometer technology has been available for some time, it had reportedly not been used to compare against resistographic data and vice versa. Scientific literature is, apparently, silent in regard to inputs from digital Fractometers (portable compression testing unit with 60 MPa capacity that in base form, compresses 5mm length sections of 4.9-5.0 mm timber core pellets, parallel to grain, to determine ultimate strength results). Research indicates that the Digital Fractometer Print used is the only site-friendly digital compression tester currently available.

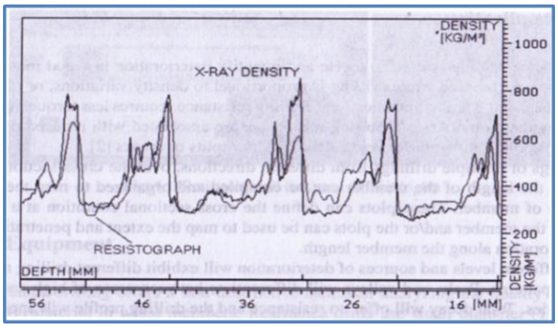

Fig 1- Graph [1] illustrating similarity of profiles between Resistograph readings and x-ray density readings of same sample

An additional function of Fractometer s includes determining bending strength of parallel to grain cores. However comparing Fractometer core sample compression strength profiles to Resistograph profiles has been the subject of little to no appreciable research. This was largely understood to be because until recently, a) Resistographs and Fractometers were mechanical only b) the Fractometer in particular has for some time been viewed more as an arborist's tool for wet timber. A third issue was that core samples used with a Fractometer need to be very cleanly cut to obtain consistent results. While cores were traditionally extracted using incremental borer type augers, this type of core drill tends to penetrate quickly and tear the outer face of dry wood samples (particularly soft specie early wood such as that of Pinus Radiata). This causes them to fail somewhat prematurely under parallel to grain compression tests. Use of a high speed dendochronological type coredrill such as the Berliner type was found to significantly reduce the number of compromised compression tests. It also enabled removal of cores from more difficult points in buildings and structures. The handles of a standard incremental borer restrict application i.e. when removing samples from bottom plates of walls, whereas a drywood corer is designed to fit a standard lightweight power drill.

Fig 2a, 2b - Comparison of 'Berliner' type dendochronological high speed dry wood core drill and standard hand operated auger incremental borer. **Fig 2c –** Core with damaged external surface

Initial comparisons between Resistograph graphic profiles and those obtained using the Fractometer presented a good to very good commonality.

Control based resistography

Digital Resistography

The local driver for the development of this approach was the need to determine the amount of degradation of enclosed light timber wall framing in leaky homes. Assessment as to what framing needs to be replaced (in New Zealand) has largely been based on the recording of high moisture levels, visible staining or degradation. Occasionally this is supplemented with some largely non-representative microbiological analysis of fungi presence / damage coupled with occasional spot testing for preservative presence, type and residual salts levels. Generally this required a large number of cut-outs in walls to quantify damage and determine remediation scope. A frequent comment was that if a dwelling did not need a reclad before the inspection(s) it usually needed one afterward as seamless repairs to the exterior of monolithically finished claddings are inherently difficult.

Resistography allowed assessments to be less intrusive (2.0 mm holes in skirting or hidden behind peeled back wallpaper) and more intensive, providing a better indication of overall condition and has been found to be particularly useful in locating hidden decay between framing timbers.

A key issue was wood variability: Most light timber framed construction in New Zealand over the last 50 or more years has been plantation grown Pinus Radiata. With selective breeding programs extending back to the early 1930's growth characteristics have changed. Plantations are grown in climatically different areas and varied soils. In recent years timber average bending strengths of newer generation trees has decreased, requiring increased timber beam depths in code type documents.

This led to developing a control based approach for each dwelling being checked.

Control Comparison Approach

The methodology developed is to take 3-5 or more test readings on internal walls that were known to be sound timber, checking graphs for commonality, representivity and lack of anomalous indications and then selecting one of the lower amplitude but sound profiles as the control sample. Using developed software, this was then overlaid as a graphic template profile over all the following tests of comparable timber in the same building - effectively a control graph against which subsequent tests were compared.

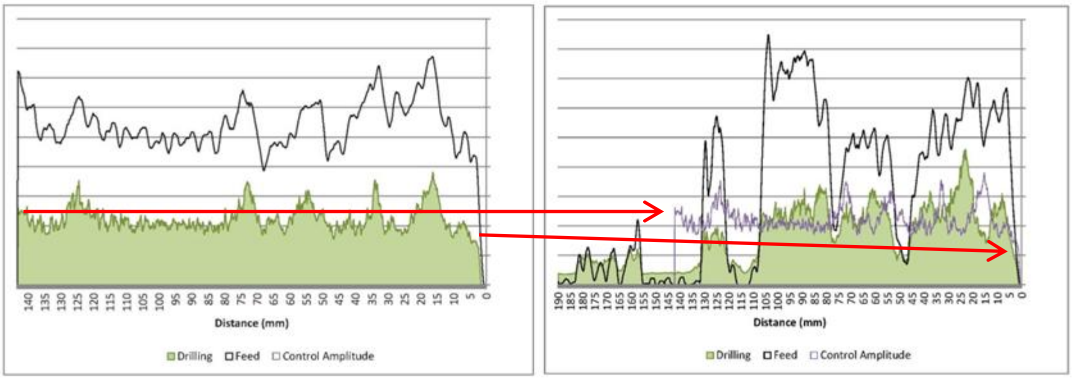

Fig 3a, 3b - Representative control graph at left overlaid as on right hand graph in purple as a template. Note: Graphs read from right to left, Right hand graph indicates anomalous material at 50 mm mark and from 110 - 200 mm

Where the technology permitted, wireless Windows based tablets are used to process data and generate reports on site in real time. The aim being to complete a report on site and export wirelessly to end users.

Caution: While this is a logical development of the technology, resistography in isolation must still be considered a qualitative tool.

Fractometry

Resistographic and Fractometric Data Comparisons

The determining by others that resistographic profiles were nearly identical with x-ray density profiles provided the base step to the integration of data from the two units. It was obvious that when cores are taken from the side of structural timber, irrespective of whether the core is radial or tangential, the compression of the side of the core, if aligned correctly would always mean compression parallel to grain with similar earlywood and latewood peaks. Reason being that while such a core sample being taken would be perpendicular to grain, when the core is cut into sections to fit into the Fractometer the compressive force is applied at 90 degrees, so each 5 mm core would effectively be being tested parallel to grain, i.e force being applied parallel to grain direction on the curved edges of the core "pellets".

It was postulated that if a core sample for use in a Fractometer was removed and taken parallel to a Resistographic drill point and the data compared, there may be a reasonable degree of correlation.

Fig 4a, 4b - Digital Fractometer with 'pellet' being inserted into jaws at left. Optional bending strength feature with timber core being placed at right

Fig 5a, 5b - Core sample in jaws with force being applied from left and right. Second photo with failure occurring prematurely by shearing as timber grain not in alignment with plane of jaws.

Much of the testing undertaken was based on 90 x 45 mm p.rad framing. With each core being 90mm long and sectioned with a scalpel into 5mm tablets – providing 18 samples, each of which was compressed to determine ultimate strength.

Note: A digital Fractometer such as the IML Print unit applies up to 60MPa force. Load is increased in a stepped manner at increments of 0.005 mm. With Pinus Radiata samples, failure commonly occurred within 100 incremental steps. When the swinging arm feature on the top of the unit is used it provides bending strength data on cores. New Zealand plantation based timber is considered unsuitable for such testing given the wide early wood bands – often exceeding 30 mm.

Resisto-fractometry

Resistographic and Fractometric Data Comparisons and Integration

Initial tests showed a very good comparison between individual pairs of resistographic data and fractometric data profiles. However when both sets of data were applied to the same graph there was the issue of aligning values on the y-axis, as resistographic data is displayed as a percentile degree of amplitude, while the fractometric data is a simple success of compression strength values in MPa. In addition it was appreciated that testing would frequently be undertaken involving drilling through skirting/trim and plasterboard/sheetrock before accessing the structural frame elements. The degree of graphic profile alignment was found to be high but variables such as the quality of the core extracted, and the accuracy of alignment of samples in the Fractometer (parallelity with grain) needed to be addressed carefully. Some offset of results was noted occasionally with graphs appearing similar but not aligning as closely at the greatest depth of tests. This was attributed to the need for Resistograph and Fractometer tests to be separated by approximately 10 mm (difficulty in drilling a hole in a hole or right beside a hole). New Zealand Pinus Radiata is not especially straight grained wood, particularly non-clear specimens that have been downgraded for framing usage. While side by side drilling may be seen to be at the same grain plane at the drills' points of entry, compound changes in grain flow at depth are considered to influence results slightly. Reportedly microdrill bits can wander as they penetrate timber of varying hardness and density. It is considered likely that more slowly growing, straight grained timber would provide more consistent results. It follows that correlations between results will obviously have a degree of variance depending on timber specie.

Software Development (Woodchecker)

Software was developed in-house to move raw data to end user report formats and allow overlaying of graphic results from the two technologies. To compensate for these graphic overlay offset effects, the software included 'sliders' to, a) enable the Fractometer data to be moved laterally to align with the same point of origin of the framing being evaluated - i.e same start point, and b) allowed the Resistograph based percentile graph to be increased in amplitude by an appropriate factor to more closely align with the height profile of the Fractometer graph.

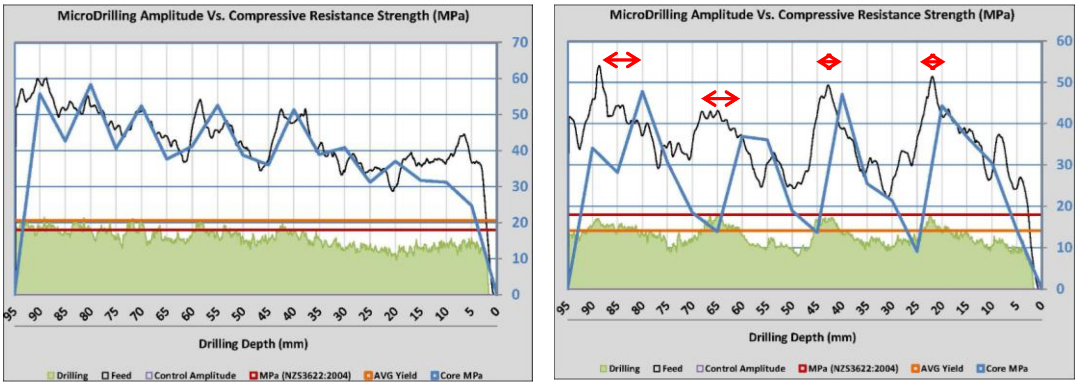

Fig 6 – Resistographic total data (black upper line) with Fractometric data overlaid (blue) Average yield strength as horizontal orange line. Code strength document (NZS:3622) as horizontal red line. Note offset of data in graph 2 of Resistograph amplitude and accompanying Fractometer MPA peaks, likely differences in grain planes.

Features included permitting adjustments to be made as, a) the *y* axis of a Resistograph is basically a percentile measurement while the Fractometers scale was MPa, and, b) the Resistograph PD takes readings at the rate of 1/mm while the Fractometer takes readings at the rate of 200/mm per 5mm tested sample. The resultant overlaid graphs for a typical 100 mm width framing timber have 1000 and 20 nodes respectively.

It should be appreciated that the key object of the developments remains determining a methodology that would objectively advance on site timber condition evaluation and strength measurement relative to a local leaky building crisis. Again, looking for solutions to local problems: two of the three largest cities in New Zealand have experienced significant earthquakes in the last two years, with Christchurch losing much of its CBD. A program to evaluate whether 190,000 older buildings meet 30% of current earthquake code requirements is commencing. It is hoped that having equipment, software and the methodologies described in this paper, can enable prompt, realistic, virtual, NDT, quantitive strength measurement of critical structural timber components, leading to a reduction in the need for the usual conservative strength assumptions.

Fractometer data presentation

It is readily acknowledged that the need for further development of fractometry and resisto-fractometry is essential to give validity to the outlined methodology. Coupled with the test/measurement processes developed it was also became apparent that the software that integrated data could be enhanced to provide both a tool for users of the technology in the field, as well as a means for increasing the scope and range of other in situ timber "strength' measurements needed for calculation purposes.

Software development

The software was initially developed for in-house use but has been developed to include:

a) Bluetooth import of data friendly

b) Data export options to cloud based hosting sites.

c) An integrated database that allows data from multiple sources / locations to be merged. This would be useful for research and analytical work - for example a nationwide integration of testing of utility poles with remote data pooled and centrally analysed to develop pole replacement prioritisation and scheduling.

d) An open report template allowing data to be entered on site progressively using tablet or laptops and that includes marked photographic or drawing records identifying test points and results.

e) Provision of compression strength individual and whole of sample strength graphs.

f) A method of selecting an appropriate and recognized method of converting ultimate strength values to useable recognized yield strengths – particularly important for assessment of older structures with bolted or similar connections.

g) A method of selecting from a range of building/structural code values so that the degree of compliance of tests can be easily appreciated by end users of reports, particularly decision makers who may lack an appreciation of the beauties and subtleties of timber strength measurement. Alternatively user specified values can be chosen

h) A modular base to the software that allows for adaptions and developments of fractometry that may increase the types of on-site / in situ timber strength tests available.

Research Directions

It is considered that the four tools (speed programmable electronic Resistograph, electronic Fractometer, dendochronological quality core drills and Woodchecker software) provide the basic equipment for arguably a somewhat novel direction in in situ /on site timber strength evaluation and measurement.

In addition a specie by specie comparison of "paired" resistographic and fractometric tests, focusing on a comparison of averaged amplitude vs averaged parallel to grain compressive strength is considered warranted. This will allow sets of statistical analyses that would determine the degree of confidence one can have in resistography as a largely standalone means of providing timber parallel to grain compressive strength. Therefore part of current research is aimed at determining the degree of correlation between the averages of three variables 1) Resistograph amplitude average 2) Adjacent Fractometer test average ultimate strength of timber, and 3) Average yield strength derived from Fractometer data. Samples are taken within 20 mm to determine statistically whether there is an appreciable degree of correlation – that would allow resistography in isolation to provide a qualified indicative or even a, possible actual strength range. It is hoped formulae similar to the following will be developed for a range of familiar timber strength measurements.

$$a = fp \pm\text{-}\ Evar$$

For s specie where: a equals average amplitude percentage of Resistographic test, fp equals average compression strength parallel to grain Evar equals the statistical degree of expected variance in samples strength and where Resistograph penetrative speed is l /mm/sec and rotational speed is m rpm.

Currently development of a drywood core bit with 300 mm x 45 mm sample size and not requiring a full length pilot hole is being considered. Such a core from a large section structural timber element would theoretically allow two core samples up to 300 mm long for parallel to grain compression testing and up to thirty number 40-45 mm samples for bending strength and or compression strength perpendicular to grain.

Summary

Novelty and independent review of methodologies

It is readily and clearly conceded that the preceding outlines an approach that may be novel, but is yet to be repeated or reviewed by persons more learned, experienced, financed and equipped than the writer. As at the time of writing, digital Resistographs with programmable set horizontal feed and rotational speed settings are becoming more common, while electronic Fractometers remain few and far between and dendro quality core drills are not easily sourced.

However it is suggested that the consistently positive results of the 1,000 plus tests undertaken comparing Resistograph and Fractometer profiles do provide a basis for considering that research at a higher level, based on the methodology and equipment described in this paper, will provide good subject material for research by others and hopefully a quick, useful and cost effective method for quantifying specific timber strength characteristics of existing structures and enhancing the degree of confidence in Resistographic tests.

References

1 Kasal and Tannert. 2010 RILEM *State of the Art Reports: In Situ Assessment of Structural Timber*

2 Rinn, F., Schweingruber, F.H., and Schar, E. Resistograph and X-ray density charts of wood. Comparative evaluation of drill resistance profiles and X-ray density of different wood species. *Holzforschung*, Vol. 50, pp. 303-311, 1996.