

Growing fit-for-purpose structural timber

What is the target and how do we get there?

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Abstract

In order to grow trees which yield structural timber which is going to be internationally competitive in terms of price and performance characteristics, it is important that forest growers understand the needs of end-users and there is good communication in both directions along the supply chain. Structural engineering design is required to prevent collapse of the structure, the ultimate limit state, and ensuring the structure is still able to fulfil its intended purpose, its serviceability limit state. The latter is focused on limiting deflection of structural elements.

Therefore, engineers require timber which is sufficiently stiff and strong for their designs, while fabricators of timber elements also need timber which has low levels of distortion and low knot content. The main ways that forest managers can influence the quality of structural timber produced from their forests are reviewed briefly. Forest growers will respond to price signals, but the price they actually receive will depend on market conditions at the time of harvest. This means that silvicultural regimes need to be flexible to allow for future market conditions. As an industry, we should look to developing systems that use our timber rather than trying to compete in the sawn timber commodity market. The latter is where our timber has performance characteristics well below those of some of our competitors, such as in northern European countries.

Introduction

New Zealand has used a large amount of wood in the residential component of its built environment. A survey undertaken by the Building Research Association of New Zealand (BRANZ) for NZ Wood found that in 2006 timber still had 93 per cent of the house framing market, which was down from 98 per cent in 2000. Timber also dominates the market for floor joists, although there has been a shift away from solid timber joists to engineered wood products.

Timber has just under 20 per cent of the market share in non-residential framing and this is where the major growth opportunities may exist. A further BRANZ study commissioned by NZ Wood looked at where the opportunities for growth exist and the additional volume of structural timber elements – solid timber and engineered wood products – that might be required. Under their moderate scenario they estimated that timber could increase its share of the non-residential construction market by 20 per cent, corresponding to an additional volume of approximately 50,000 cubic metres.

Given that New Zealand produces approximately four million cubic metres of sawn timber a year, with this figure set to rise as the annual cut increases, it is obvious that we need to focus on overseas markets for our sawn timber, which includes structural products. In targeting these overseas markets we are not only competing against other materials, such as steel and concrete, but also against other producers of structural wood products. In these overseas markets, New Zealand products will face competition in terms

of both price and quality from overseas producers. In fact, we may even face stiff competition in our own domestic market. Northern European countries are now the principal supplier of wood into the Australian market and the marginal distance from Australia to New Zealand is relatively small for a ship which has already sailed from Europe.

In this paper, I will address the topic of structural timber from both the perspective of the end-user and the forest grower. I will give a brief overview on the information required by engineers when designing a structure and the performance characteristics that are important to them. I will also explain the New Zealand structural timber grading standard and compare this with the equivalent European standard to show how our timber measures up. Finally, I will review the actions that forest managers can take to improve the quality of structural timber coming from their forests and discuss the need for better communication between forest growers and end-users of timber.

Structural timber – an end-user perspective

Structural engineers working with timber follow a limit state design approach – New Zealand and European design codes use this. The approach links the structural reliability to clearly defined states beyond which the structure no longer satisfies specific performance criteria (Porteous and Kermani, 2007). Two types of limit state are recognised – ultimate limit state and serviceability limit state.

Ultimate limit states are those associated with collapse or other forms of structural failure, while

serviceability limit states are those associated with the effective use of the structure for its intended purpose, such as deflection limits which affect the appearance or function of a structure. The ultimate limit state is deemed to be satisfied if structural timber members are proportioned so that their design strengths are not less than the factored design loads. Engineers accept that material properties vary and normally assume a characteristic value of strength for a material based on a lower percentile, usually the lower fifth percentile, value obtained from a large number of strength tests.

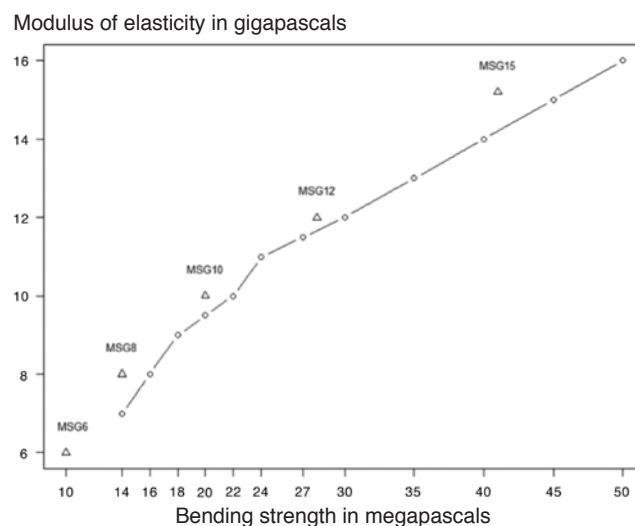
The main focus when designing for the serviceability limit state is on limiting deflection. As deflection under a given load is affected by the stiffness or modulus of elasticity of the material, this becomes the main property of interest for these calculations. The need to limit the deflection of elements within a timber structure is often the main design criteria and therefore timber stiffness is the most important material property from the perspective of the engineer.

Stiffness is also the property which is most commonly measured by strength grading machines and used to assign timber to a particular grade. The reason for this is obvious – strength cannot be measured non-destructively. In New Zealand, there are five structural timber grades for machine graded timber and their characteristic values of strength and stiffness are given in NZS3603 and are shown in the table below. These values are used by engineers in their design calculations. Characteristic values of bending, compression and tensile strength are based on the lower fifth percentile value.

Radiata pine structural timber produced in New Zealand generally meets the requirements for MSG8, although there are regional differences. Structural timber from other species, such as Douglas fir may meet the requirements for higher grades such as MSG10. If New Zealand structural timber is going to compete internationally then we need to understand how it compares with that produced in other parts of the world.

Given my earlier reference to timber coming from Europe to Australia, I will focus briefly on the European system of timber strength classes. This system has 12 strength classes for softwood timber, each of which is named for its characteristic value of bending strength (CEN, 2009). These range from C14 up to C50. The New Zealand machine strength grades approximately correspond to the European strength classes, although the New Zealand grades have a higher characteristic value of modulus of elasticity for a given value of bending strength.

The main point to note here is that MSG6 does not meet the requirements for the C14 strength class, while MSG8 can only meet the requirement of the C14 strength class, but not that of the C16 strength class. C16 is normally the lowest strength class used in practice in Europe in applications such as stud walls. Many European timber producers can supply large volumes of material which is C27 and above and smaller volumes of C40 timber. This higher strength class material is particularly desirable for truss and lintel manufacturers and engineers designing long span timber structures where there is a need to limit deflections.



Mapping of New Zealand structural timber grades against the European strength classes given in EN338:2009

New Zealand structural timber grades and their characteristic stresses (from NZS3603:1993)

Grade	Modulus of elasticity gigapascals		Bending strength megapascals	Compression strength megapascals	Tensile strength megapascals
	Mean	Minimum			
MSG6	6.0	4.0	10.0	15.0	4.0
MSG8	8.0	5.4	14.0	18.0	6.0
MSG10	10.0	7.5	20.0	20.0	8.0
MSG12	12.0	9.0	28.0	25.0	14.0
MSG15	15.2	11.5	41.0	35.0	23.0

Other factors such as distortion and knots affect the performance of sawn timber. Knots are a problem for frame and truss manufacturers, particularly those who use automated nailing jigs, because large and frequent knots cause problems with nail fouling. Excessive distortion is also a problem for frame and truss manufacturers as well as all users of solid timber. For example, Johansson et al, (1994) report that in Sweden, building contractors have stated that the quality of structural timber has deteriorated for some years. In this case the problem was mostly excessive distortion and as a result timber was losing market share to other products.

Problems with excessive distortion are not unique to Sweden and have been noted in many countries, including New Zealand (e.g. Cown et al, 1996). Johansson et al (1994) suggested that current limits specified in the grading rules are more generous than the acceptable limits of end-users. For example, in Europe the maximum permitted amounts of distortion over the worst two metre length for timber of strength class C18 or below are given in EN14081-1 (CEN, 2005) as – bow = 20 mm, spring = 12 mm, twist = 2 mm per 25 mm width, cup = no limit. Sawmills therefore often develop their own limits over and above those specified in EN14081-1 based on feedback from their customers.

In the future, engineers working with structural timber are likely to demand increased performance in terms of improved strength and stiffness and reduced distortion. This will be driven by the desire to use timber in more demanding applications such as long span structures and multi-storey structures. The use of engineered wood products will undoubtedly increase to meet the demands of end-users, but in many cases they will simply take market share from solid wood, rather than from other materials such as steel and concrete. In addition, those engineered wood products that offer the best performance characteristics also have the most demanding raw material requirements.

A grower's perspective

Now that we have heard what the end-users want in terms of performance, and of course they want it at a price which is acceptable to them, what can forest growers do to help meet these expectations? If the yield of structural timber is mainly limited by the ability to produce material that is sufficiently straight and stiff, then the forest grower, in some cases in conjunction with the processor, has a number of options for improving the quality of the structural timber they produce. Some of these are discussed in more detail by many others. What I present here is very much an overview of some of the research that underpins our knowledge about the effects of different factors on the quality of structural timber. A

good overview of recent New Zealand studies is also given by Mason (2008).

Site selection

It is well-known in New Zealand that wood density and also stiffness are strongly related to temperature (Beets et al, 2007; Watt et al, 2006; Scion, unpublished data) with sites in the north of the country having higher wood density than those in the south. Wood density is also related to site fertility, particularly the available nitrogen supply (Beets et al, 2001); wood density increases with an increase in the ratio of carbon to nitrogen. Trees growing under wind exposed conditions can also have reduced wood stiffness (Grabianowski et al, 2004; Bascunan et al, 2006).

While it might appear that the site you have is what you have, there a number of treatments, such as weed control and fertilisation that can be used to modify the site and these can influence wood properties (Watt et al, 2005, Mason, 2006). Knowledge about the inherent potential of a site to produce structural timber is important for guiding silvicultural decision making. On good sites, appropriate silvicultural regimes can enhance the natural potential to yield wood with good structural qualities, while on poorer sites remedial actions may be necessary if the aim is to produce structural timber at all.

Genetics

There is a considerable opportunity to improve wood quality using genetics, as most wood quality traits have higher heritability than growth traits, and significant progress has already been made in this area. Early selections have focused on improving growth and form, which have resulted in a large increase in harvest index – the ratio of utilisable biomass to total biomass. This improves the yield but not necessarily the performance of the structural timber, unless an improvement in stem form can be linked to a reduction in the amount of compression wood.

While there has been some debate in the literature suggesting that past efforts in genetic improvement have had a negative effect on wood quality (Walker, 2007; 2010), this is countered by others (Burdon, 2010) who argue that tree breeders are well aware of the adverse genetic correlations that exist between stem volume and most wood properties. One of the problems facing tree breeders is that they require good information on the relative economic worth of different traits in order to develop their breeding objectives. If there is a strong economic argument for improving wood quality then this will be reflected in breeding objectives.

The focus of current research by the Radiata Pine

Breeding Company is on increasing wood density because this property is positively associated with wood stiffness. Research is also focused on increasing the stiffness of the core wood – the wood found in the first 10 to 12 annual rings from the pith at all heights in the tree, and some effort is also directed at reducing spiral grain as this is associated with distortion.

There are a number of challenges with breeding for improved wood properties. The first is having rapid assays for assessing wood properties and having the ability to screen trees early in order to shorten the breeding cycle. However, recent work within the compromised wood project has made considerable advances in this area (Apiolaza, 2009), but further work is needed to ensure that early assays are correctly ranking trees relative to their later-age rankings. The second challenge is avoiding unintended consequences. As someone who has focused on the biomechanics of trees, I have tried to understand why there are strong radial gradients in wood properties in many tree species and why trees are flexible when they are young. Being flexible allows young trees to bend through large angles when they are loaded with wind or snow, and high microfibril angle is associated with high critical strain, meaning that the wood does not fracture easily (Lachenbruch et al, 2011). Core wood also has a high factor of safety against drought effects (Lachenbruch et al, 2011), therefore we need to guard against any unintended consequences from breeding for improved core wood stiffness.

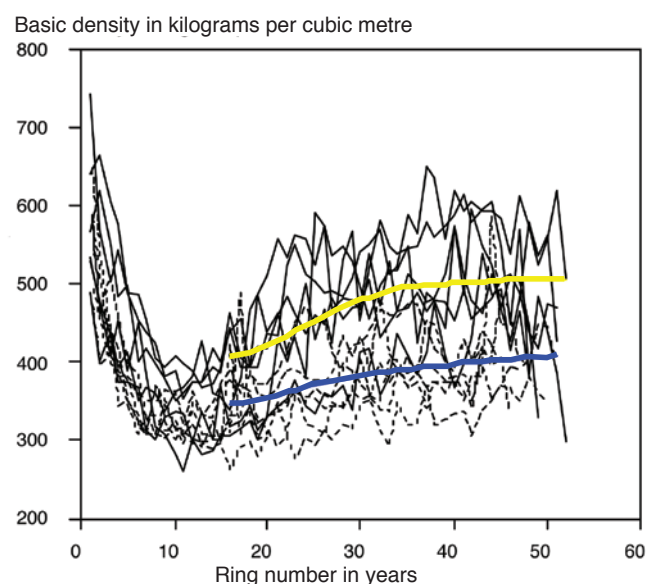
Species choice

There are large differences in the performance characteristics of timber from different species. Douglas fir and many of the eucalypt species have values of stiffness and strength well above those of radiata pine. Fundamentally, for the forest grower it will come down to what combination of growth rate and wood quality will give them the best return on their investment and what level of risk they are prepared to accept.

Silviculture

The main silvicultural treatments that can be used to influence wood quality, and therefore structural timber properties, are manipulation of the available growing space and choice of rotation length. A number of studies have looked at the effect of different treatments for manipulating growing space, such as initial planting spacing, thinning intensity and final stand density, on properties such as wood density, microfibril angle, stress wave velocity and sawn timber properties (e.g. Cown and McConchie, 1981; Lasserre et al, 2004; Waghorn et al, 2007).

These silvicultural treatments not only influence the size of the core wood zone within a tree (West, 1997), but they can also result in differences in wood properties on an equivalent annual ring basis. Increased stand density also reduces branch size. One thing to be aware of is that for the same initial planting spacing, trees grown to a higher final stand density will have a higher percentage of core wood than trees grown to a lower final stand density. Numerous studies in a range of different species have shown that, as expected, trees grown on longer rotations have better wood properties than those on shorter rotations (e.g. Cown and McConchie, 1982; Bilbis et al, 1993; Duchesne, 2006; Moore et al, 2012). In British-grown Sitka spruce, increasing the rotation length from 45 years to 80 years was shown to increase the strength class of the resulting timber from C16 up to C24 (Moore et al, 2012). For radiata pine, we do not have the equivalent data to show how sensitive the grade recovery of structural timber is to rotation length. Even if we did, would long rotations be economically viable?



Comparison of the radial profile of basic density in Sitka spruce grown at contrasting initial spacing, 1.8 by 1.8 metres blue line, and 5.4 by 5.4 metres yellow line

While there is considerable opportunity to improve the quality of structural timber with appropriate silviculture, there is also the possibility to do harm by inappropriate silviculture. If the mean stiffness of timber is very close to the threshold for a particular grade, then care must be taken not to do anything that could further reduce wood stiffness. Otherwise there could be considerable negative consequences in terms of structural timber grade recovery, which will have a negative effect on the profitability of a sawmill.

Segregation

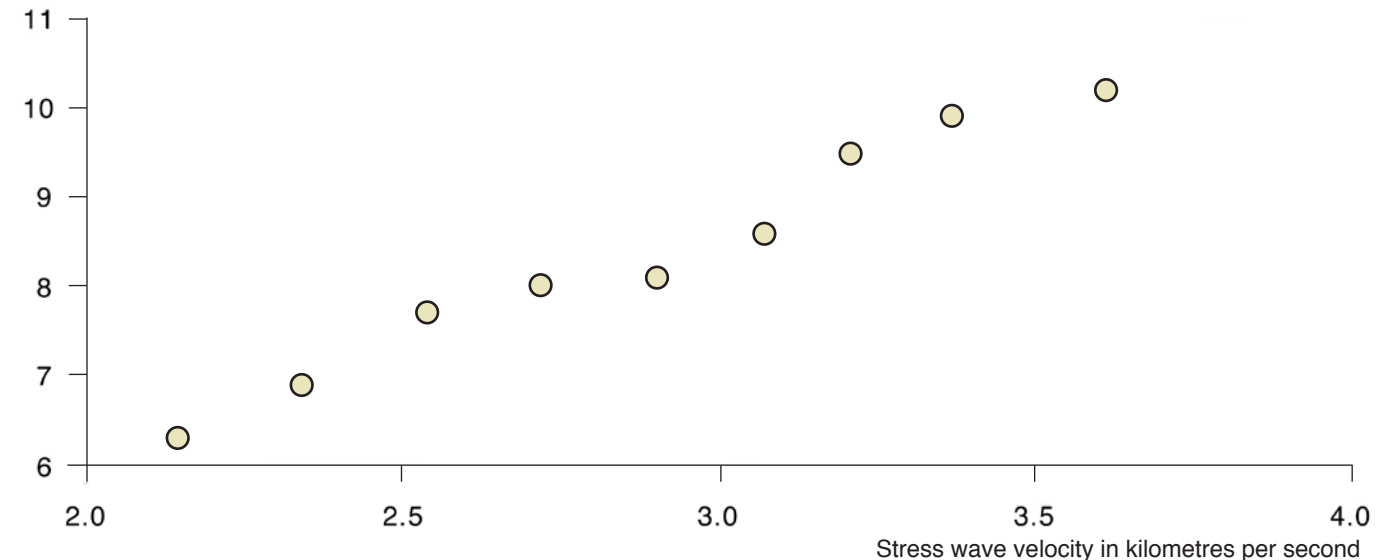
Segregation is an action that either a forest grower or a sawmiller could take, but I have included it here as it is something that a producer rather than an end-user would do. There are a number of intervention points ranging from in-forest segregation of standing trees through to segregation of logs and sawn boards in the sawmill.

Portable acoustic tools have been used extensively by researchers and the forest industry to assess wood stiffness in trees and logs (e.g. Walker and Nakada, 1999; Tsehaye et al, 2000; Matheson et al, 2002; Dickson et al, 2004; Carter et al, 2006). Tsehaye et al, (2000) showed that by sorting logs into groups based on their stress wave velocity, the mean modulus of elasticity of the resulting sawn timber could be increased. Moore et al, (in review) extended this concept by ranking logs according to their stress wave velocity and examined the effect that setting different stress wave velocity thresholds for logs had on the resulting average modulus of elasticity of the sawn lumber as well as the proportion of logs that would be rejected.

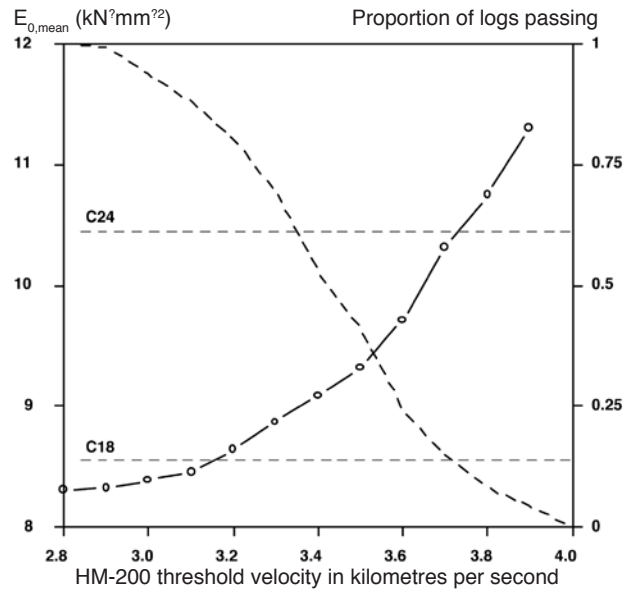
Stratum	Modulus of elasticity	Density	Modulus of rupture
Site	26.3	22.7	18.3
Tree within site	36.2	51.1	25.2
Log within tree	2.2	1.4	4.5
Within log	35.3	24.9	51.9

Percentage of total variation in modulus of elasticity, density and modulus of rupture values attributable to each stratum in a study of Sitka spruce structural timber from 12 contrasting sites in Great Britain

Timber modulus of elasticity in gigapascals



Mean modulus of elasticity of sawn timber cut from logs grouped by stress wave velocity (based on data from Tsehaye et al, 2000).



Effect of log segregation using the HM-200 on the characteristic stiffness of Sitka spruce sawn timber. The dashed line indicates the proportion of logs with an acoustic velocity greater than or equal to a particular threshold. The characteristic timber stiffness values for the C18 and C24 strength classes are indicated with dashed grey lines.

This highlights one of the challenges with segregation, which is what to do with the rejected logs. Because of the large amount of intra-log variation in wood properties, rejected logs will contain material that would still yield structural timber.

Grading is another form of segregation. Without getting into too much detail around the statistics of timber grading, the fundamental problem with trying to target higher grades such as MSG10 and MSG12 when our timber is inherently MSG8 is the bandwidth correction, which would result in a reduction in the yield of MSG8. In many cases there

is little price premium for the higher grades, but a big penalty attached with dropping below MSG8 or MSG6.

The problem is particularly acute when trying to target two adjacent grades such as MSG8 and MSG10. To illustrate this point, consider a hypothetical population of timber which has a mean value of MOE of 8.2 GPa with a standard deviation of 1.4 GPa. These are typical values for radiata pine sawn timber. If the timber is graded to MSG8, then 97.2 per cent of the pieces exceed the minimum threshold value for this grade.

In order to meet the requirements for MSG10, a minimum threshold of 9.24 GPa must be set. The yield of MSG10 is 25.7 per cent. The mean modulus of elasticity of the remaining timber is now only 7.62 GPa, so the minimum threshold for MSG8 needs to be increased to 6.63 GPa to satisfy the mean modulus of elasticity requirement for MSG8. The yield of MSG8 timber is 60.9 per cent and the overall yield across the two grades is 86.6 per cent, a drop of 10 per cent compared with simply grading for MSG8. The price premium for MSG10 would have to be considerable before a sawmill would consider a 10 per cent reduction in yield.

Strengthening the structural timber supply chain

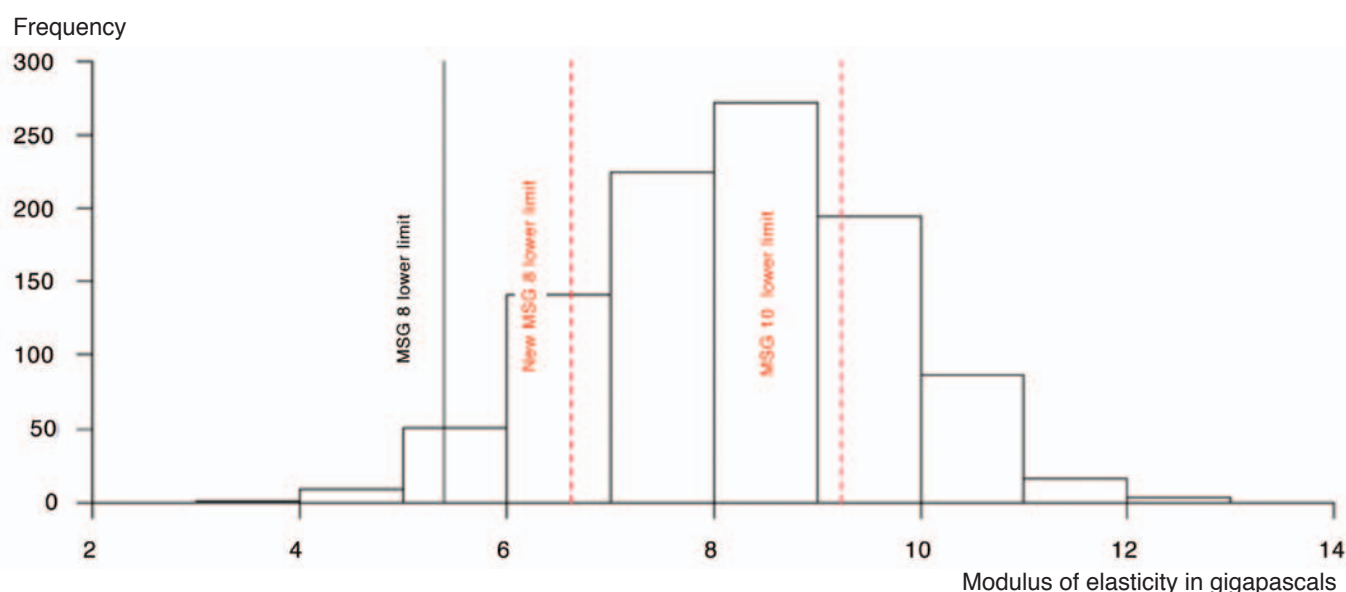
Overall, there are a number of challenges to be overcome if our aim is to grow trees which yield structural timber that is going to be internationally competitive, both in terms of price and performance characteristics. To achieve this, it is important that forest growers understand the needs of end-users and that there is good communication in both directions along the supply chain.

Professor Robert Kliger, a structural engineer from Chalmers University, Sweden, and his colleagues refer to the 'broken chain from forest to building industry' and stress that to develop a future supply of high quality timber, communication between forest growers, wood processors and end-users of wood products must improve (Johansson et al. 1994). This is often made more difficult by the fact that the views of what constitutes quality differ between these three groups. For example, high quality logs from a forester's perspective, which are straight with fine branching, will not necessarily yield high quality timber from an end-user perspective.

Perstorper et al (1995) argues that to improve their profitability it is important that forest managers understand the connection between forest management and product quality. Any process optimisation is focussed on end-user quality related variables rather than on substitute parameters. As can be seen in the previous section, much of the forest growing research which has been undertaken has focussed on the effect of silvicultural treatments on wood properties and log attributes, rather than on the properties of structural timber.

Research currently being undertaken at Scion is focussing on developing a modelling framework that can link product performance back to forest management. This approach is based on product quality prediction via deterministic simulation. A simulation based, rather than purely empirical approach such as sawing studies, is adopted because the latter would be impractical given the range of genotypes, environments and management regimes that occur in New Zealand's planted forests.

The process of developing a system that connects



Hypothetical grading example illustrating the bandwidth correction that must be applied when grading for MSG8 and MSG10

forest management to product quality can be divided into three parts –

- Development of a suite of tools, mainly employing finite element methods, to evaluate the qualities of stiffness and stability of individual timber products based on three-dimensional descriptions of wood quality variation
- A statistical model, dependent on forest management decisions of site, silviculture and genetics, which in conjunction with a growth model, predicts the internal wood property distributions for individual trees
- A destructive sampling programme which collects the data required to measure the statistical model at acceptable cost.

Once completed, it is hoped that this system will enable forest managers to understand the effects of the decisions on product quality and to be able to develop silvicultural regimes that will result in improved structural timber. The motivation for growers to focus on timber quality must come in the form of price signals, but will these now be the same as those at the end of the rotation? The general model for commercial forestry in New Zealand is to maximise profit by growing the maximum volume of valuable wood in the shortest time possible.

Much of our silvicultural thinking during the 1970s and 1980s was based around growing large pruned logs in the shortest time to supply the market for clear wood. Should the focus now move to targeting improved structural timber? My own view is that we should try to develop silvicultural regimes which yield trees with attributes that are suitable for a wide range of products. Trying to optimise regimes for a single target market is dangerous, particularly if it removes flexibility.

If our structural timber is going to struggle to compete with timber from northern Europe, then should we focus on trying to develop systems and products that use our timber rather than simply entering the commodity market? As an example, the United States and Canada have developed whole house systems based on their timber and engineered wood products, which they then sell to markets such as China and Japan. Is this an opportunity for New Zealand, particularly as the value of a unit volume of prefabricated house is several orders of magnitude greater than that of a unprocessed log or even sawn timber?

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