Forestry and Forest Products

Report

Log End Splits Literature Review

by

Yang, J.L., Waugh, G., Peacock, M., Martin, A.

Ian Wark Laboratories, Bayview Avenue, Clayton, Victoria, Australia
Postal Address: Private Bag 10, South Clayton MDC, Clayton, Vic. 3169, Australia

Telephone: (03) 9542 2244 (Internat. +613 9542 2244)
FAX: (03) 9543 6613 (Internat. +613 9543 6133)
# Log End Splits Literature Review

Yang, J.L., Waugh, G., Peacock, M., Martin, A.

## Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summary</td>
<td>1</td>
</tr>
<tr>
<td>Introduction</td>
<td>2</td>
</tr>
<tr>
<td>1 Causes and Contributing Factors to Log End Splits</td>
<td>1</td>
</tr>
<tr>
<td>1.1 Internal Stresses</td>
<td>1</td>
</tr>
<tr>
<td>1.1.1 Growth stresses</td>
<td>1</td>
</tr>
<tr>
<td>1.1.2 Species and variability between trees</td>
<td>4</td>
</tr>
<tr>
<td>1.1.3 Moisture relations</td>
<td>4</td>
</tr>
<tr>
<td>1.2 Applied Stresses</td>
<td>5</td>
</tr>
<tr>
<td>1.2.1 Felling effect</td>
<td>5</td>
</tr>
<tr>
<td>1.2.2 Log handling post-felling</td>
<td>5</td>
</tr>
<tr>
<td>1.3 Anatomical Characteristics Contributing to Splitting</td>
<td>6</td>
</tr>
<tr>
<td>1.3.1 Interlocked grain</td>
<td>6</td>
</tr>
<tr>
<td>1.3.2 Reaction wood</td>
<td>6</td>
</tr>
<tr>
<td>1.4 Other Factors</td>
<td>7</td>
</tr>
<tr>
<td>1.4.1 Seasonality</td>
<td>7</td>
</tr>
<tr>
<td>1.4.2 Variation in growth stress around a stem</td>
<td>7</td>
</tr>
<tr>
<td>2. Growth Stresses</td>
<td>8</td>
</tr>
<tr>
<td>2.1 Definition of Growth Stresses</td>
<td>8</td>
</tr>
<tr>
<td>2.2 The Origin of Growth Stresses</td>
<td>8</td>
</tr>
<tr>
<td>2.3 Longitudinal Growth Stresses</td>
<td>9</td>
</tr>
<tr>
<td>2.4 Transverse Growth Stresses</td>
<td>10</td>
</tr>
<tr>
<td>2.5 The Role of Growth Stresses has on Splitting</td>
<td>11</td>
</tr>
<tr>
<td>2.6 Methods of Measuring Growth Strain</td>
<td>12</td>
</tr>
<tr>
<td>2.6.1 Measurement of peripheral growth strains</td>
<td>12</td>
</tr>
<tr>
<td>2.6.2 Measurement of internal strain</td>
<td>13</td>
</tr>
<tr>
<td>2.7 Calculation of Stress</td>
<td>14</td>
</tr>
<tr>
<td>3. Methods of Reducing Growth Stress Associated Defects in Logs</td>
<td>15</td>
</tr>
<tr>
<td>3.1 Correct Felling Operation</td>
<td>15</td>
</tr>
<tr>
<td>3.1.1 Felling techniques</td>
<td>15</td>
</tr>
<tr>
<td>3.1.2 Felling cuts in cross-grain</td>
<td>15</td>
</tr>
<tr>
<td>3.2 Post-felling Log Handling</td>
<td>16</td>
</tr>
<tr>
<td>3.2.1 Physical Methods</td>
<td>16</td>
</tr>
<tr>
<td>Store logs under water spray</td>
<td>16</td>
</tr>
<tr>
<td>Girdling and circumferential kerfing</td>
<td>16</td>
</tr>
<tr>
<td>Reduce log length</td>
<td>17</td>
</tr>
<tr>
<td>Banding or other radial pressure</td>
<td>18</td>
</tr>
<tr>
<td>Fasteners at log end surfaces</td>
<td>18</td>
</tr>
<tr>
<td>Boiling logs prior to sawing</td>
<td>19</td>
</tr>
<tr>
<td>3.2.2 Chemical Methods</td>
<td>19</td>
</tr>
<tr>
<td>Burying in manure</td>
<td>19</td>
</tr>
<tr>
<td>3.3 Appropriate Sawing Operation</td>
<td>19</td>
</tr>
<tr>
<td>3.3.1 Influence of specialised sawing equipment</td>
<td>19</td>
</tr>
<tr>
<td>3.3.2 Adopt backsawing strategies</td>
<td>21</td>
</tr>
<tr>
<td>3.3.3 Face cutting</td>
<td>21</td>
</tr>
<tr>
<td>3.4 Silvicultural Improvement</td>
<td>21</td>
</tr>
<tr>
<td>3.4.1 Extending rotation age</td>
<td>21</td>
</tr>
<tr>
<td>3.4.2 Slowing the growth rate</td>
<td>21</td>
</tr>
<tr>
<td>3.4.3 Other silvicultural techniques</td>
<td>22</td>
</tr>
<tr>
<td>4. Why Stresses can be Reduced</td>
<td>22</td>
</tr>
<tr>
<td>5. References</td>
<td>23</td>
</tr>
</tbody>
</table>
Log End Splits Literature Review
by
Yang, J.L., Waugh, G., Peacock, M. and Martin, A.

Summary

Log end splitting can be the combined result of internal growth stresses, external stresses such as those occurring commonly during felling and log handling, and anatomical characteristics of wood. Often log defects are unobservable until the log is cross cut and defects such as cracks and splits are free to open. Growth stresses are of primary concern when dealing with log end splits, without which splitting would not develop. Felling damage or rough handling of logs may produce splitting at the log ends. There are also many factors which may initiate, exacerbate and influence the release of growth stresses such as accelerated drying rates, and season of harvesting.

Internal growth stresses arise as a result of normal development of the growing tree. As cells differentiate and mature in the cambial layer, they tend to shorten longitudinally and expand transversely, resulting in tension and compression forces respectively. The exact nature and cause of this phenomenon is as yet unclear with two theories currently being favoured. These are the Cellulose Tension hypothesis and the Lignin Swelling hypothesis. Growth stresses can be determined by measuring strain in the standing tree or log, and calculating stress from this figure and modulus of elasticity or Young’s modulus.

Many methods have been developed and implemented on an industrial scale in order to minimise the severity and extent of log end splitting. These methods include felling techniques, post-felling log handling, sawing equipment and strategies, and silvicultural techniques. There is however, still a need to develop these methods further and expand on existing knowledge so the resultant problems can be dealt with effectively. To achieve this an understanding of what happens inside the wood when stresses are relaxed is essential in order to be able to effectively evaluate the current methods and to develop new, and perhaps more suitable techniques.
Introduction

Scope of the review

This review has been prepared following a request from the Forests and Forest Industries Council of Tasmania (FFIC) for CSIRO to investigate the underlying factors leading to the increasing problem of end-splitting of saw and veneer logs in Tasmania. The review is one of two documents which have been prepared by CSIRO and the Hollybank Forestry Centre, the accompanying report being ‘End-splitting in eucalypt sawlogs - A survey on Selected Tasmanian and Victorian Sawmills and Harvesting Operations’ by Waugh, Yang, Martin and Britton (CSIRO Forestry and Forest Products Report FFP 517, August 1996). The two documents between them examine in detail the factors contributing to end-splitting and quantifies the existing and potential problem for the Tasmanian Forest Industries.

The review examines the underlying factors and their contribution to end-splitting. It provides a detailed presentation on the contribution of growth stresses, known to be one of the major contributing factors to log end-splitting. It also describes potential methods to reduce growth stresses and background behind why such techniques can be successful.

Background

In recent years there has been a need in the forest industries to harvest and process smaller logs from younger regrowth forest resource due to the diminishing old-growth resources. It has been observed that many of the regrowth logs coming out of Tasmanian forests show an increasing tendency to end split and exhibit other log degrade problems. This can be attributed partially to the high growth stresses present in the regrowth, as well as the consequence of additional stresses applied during harvesting and subsequent processing. As a result, it has become necessary to gain a greater understanding of the factors involved which contribute to these problems and to find means by which the problems may be minimised.

1. Causes and Contributing Factors to Log End Splits

There are many factors contributing to the end splitting of logs. Internal growth stresses, applied stresses and anatomical characteristics are the most critical factors pertaining to the management of log end-splitting.

1.1 Internal Stresses

1.1.1 Growth stresses

In the standing tree, the growth stresses that are formed during normal development are balanced. Longitudinal growth stress is the most severe and the most variable form of these stresses (Wilkins, 1986). Longitudinally, the outer portion of trees is under tension and the inner portion of the trees under compression. Transverse stresses are much smaller yet wood is much weaker in the transverse plain (Kubler, 1987). In eucalypt species, longitudinal growth stresses are commonly much greater in comparison to other species (Kubler, 1987). It
is the release of the longitudinal growth stress that gives rise to defects such as end splits, end cracks and heart shakes.

During felling or cross cutting, longitudinal growth stresses are released, disturbing the balance of internal forces, which can result in log end splitting (Boyd, 1950). The wood on the periphery of the stem contracts to relieve tension forces and the core expands to relieve compression forces (Kubler, 1987). At the cut surface, the longitudinal strain is transferred into the transverse plain giving rise to transverse tensile stress (Nicholson, 1973; Chafe, 1979). This results in a slight bulging of the end faces of the log (Figure 1) that may be visually undetectable. The longitudinal strain will proportionally increase for up to a length of approximately three times the log diameter, where the full level of the longitudinal growth stresses is found. When this stress becomes large enough, the binding forces within the wood are insufficient to resist the tension perpendicular to the grain and the wood will fail. This failure can be exhibited as radial cracking which may increase in magnitude and abundance depending on the treatment of logs post-felling. When cracks extend to the periphery of the log and along the grain, the log end-splits as shown in Figure 2.

![Figure 1. Dimension changes in a log due to cross-cutting, exaggerated 400 times (Kubler, 1987).](image)

![Figure 2. Typical log end splitting.](image)

The presence of internal defects in the standing tree such as heart shakes, may also facilitate end splitting through provision of structural weaknesses in the wood (Chafe, 1979). These defects are the result of lateral forces where the tangential compression of the outer layers of the wood makes the periphery of the stem larger. As a result, the wood near the pith is placed under a radial tension stress, forming core defects if sufficiently large (Jacobs, 1965). When the growth stresses are released during felling or cross cutting, any pre-existing cracks could greatly enhance the extent and severity of the log end splits (Chafe, 1979).
Generally, the majority of end splitting will occur during the first week after felling (Hillis, 1978). However, growth stresses remain within the log for long periods and will slowly relax through time and a balance is achieved. The rate of relaxation of growth stresses is the critical determining factor that may be controlled to avoid end splitting, given that additional external stresses have not been applied to the log.

1.1.2 Species and variability between trees
Growth stresses are present in all tree species (Kubler, 1987). However, severe growth stresses do not generally occur in conifers, but can be quite excessive in many hardwood species (Bootle, 1983). Eucalypt species in particular, are known to exhibit high internal growth stresses (Malan and Toon, 1980; Kubler, 1987).

Individual trees within a species or stand, may be more prone to end splitting than others as a result of variation in growth stresses. Growth stresses in trees can vary considerably between trees and around the circumference of the tree (Nicholson et al. 1975). Leaning trees or trees with unbalanced crowns often have high internal growth stresses with large amounts of variation within the stem (Bootle, 1983). However, environmental conditions are not the sole reason for this variation. The rate of tree growth also appears to have some influence as does the genetic make-up of individual trees (Nicholson, 1973). Chafe (1979), indicated that tree diameters are correlated with splitting of stems, with logs of smaller diameter being more likely to develop heart shakes than larger ones. However, Barnacle (1970), found that larger diameter trees had larger end splits. The splits observed in this case appeared to be associated with felling damage in the upper lengths of the logs rather than growth stresses.

1.1.3 Moisture relations
Drying stresses can develop relatively quickly in freshly cut eucalypt logs since many eucalypt species are susceptible to collapse shrinkage, which takes place well above fibre saturation point. Drying stresses resulted from collapse shrinkage and normal shrinkage which occurs below fibre saturation point become superimposed on growth stresses as a log dries. As a result, defects quite different to those commonly observed caused by growth stresses alone are formed. As a log dries, the wood shrinks far more in the tangential rather than the radial direction initiating surface checks. This has the potential to increase the extent of end splitting in logs by allowing greater release of the growth stresses already operating.

The rate of moisture loss that is allowed to take place after logging has a significant impact on the end-splitting problem. In a study carried out by Barnacle (1971), it was found that short log sections that were subjected to very mild drying conditions, displayed heart cracking after only twenty minutes of exposure. These shorter logs would have minimal strain at the cross cut face as a result of growth stresses and therefore the cracks observed can be considered to be the result of drying effects. Heart cracking can significantly increase the occurrence of end splitting in logs. Therefore, if logs are left in the sun at the landing site, are not end coated or are not kept under water spray at the log-yard, the rate of drying of the logs may induce large stresses at the ends of the logs and result in end splits.
1.2 Applied Stresses

Applied stresses may be introduced during the logging procedure, handling of the logs at the landing site, and treatment of the logs in the log-yard. These stresses are not the cause of end splitting, but rather exacerbate the effect of growth stresses by applying further stress on the logs. In some cases the applied stress may be sufficient to initiate end-splitting or radial cracking where the normal growth stresses were not great enough to cause the wood to fail alone. In this situation, the applied stress functions as the catalyst required to hasten the release of the growth stress. However, poor logging practices can initiate chordal cracks at the end of logs which are not the result of growth stresses (Barnacle, 1970; 1973).

1.2.1 Felling effect

There are two ways in which logging practices may induce end splitting of logs. The first of these is the impact of the tree with the ground (Chafe, 1979). Any impact degrade can be described as a function of:

"(i) The stiffness (length/diameter ratio) of the stem; (ii) the energy to be dissipated on impact which in turn, must be a function of (a) the diameter, and hence mass of the tree, and (b) stem height, and hence the velocity with which the tree strikes the ground; (iii) the time over which the impact energy is dissipated and the manner in which such dissipation takes place, ie. how much of this energy is absorbed internally rather than by large external movements of the tree trunk; (iv) the hardness or compressibility of the soil which could well be dependant on the season of he year, soil type, or locality of growth; (v) branch geometry and possibly crown size in relation to stiffness of trunk; (vi) the nature of impact of large branches with the ground, i.e. whether they "spear" into the ground or deflect (bend) on impact; or (vii) whether the head cantilevers (whips) over an irregularity in the surface of the ground.” (Barnacle, 1973).

Damage to the stem may not be observable in the first instance. Concealed fractures may arise as a result of felling which do not become obvious until cross-cutting where cracks may open rapidly as growth stresses are released (Barnacle, 1970). At this stage, if the split intersects the stem periphery, severe damage to the end of the log will occur.

The second manner through which end splits may be initiated is in the bending moments introduced by the hinge into the falling stem (Mattheck and Walther, 1992). As the tree falls, the stemwood above the hinge is strained causing it to bend (Kubler, 1987). When the hingewood does not break easily when the tree falls, the stem splits at the back edge of the hinge forming a chordal crack (Figure 3).

1.2.2 Log handling post-felling

Freshly felled logs may also crack from other causes (Barnacle, 1970). The handling of these logs once felled, has a detrimental effect on the stress balance within the logs. If the logs are roughly handled on site during snigging, loading, unloading etc, the incidence and extent of log end splits may be dramatically increased. The incidence of “cowboy” handling could be considerably minimised through education and adequate operational practices.
1.3 Anatomical Characteristics Contributing to Splitting

1.3.1 Interlocked grain
Species such as the ash group of eucalypts are straight grained and more susceptible to log end splits than other species such as River Red Gum (Eucalyptus camaldulensis) which exhibits interlocked grain. Interlocked grain is a condition in which a regular reversal of right handed and left handed grain orientation takes place in successive growth increments (Corkhill, 1979). It markedly increases the resistance of wood to splitting in the radial plane.

1.3.2 Reaction wood
High growth stresses are often associated with tension wood and splitting defects in felled stems (Saurat and Gueneau, 1976). The high stresses originate from the formation of the inner-most ‘gel layer’ of the cell wall. This layer appears like a ‘rubber band’ inside the cross-section of a cell when viewed at microscopic level (Figure 4), consisting almost entirely of alpha cellulose layed down at a very small angle to the longitudinal axis of the cell.

Figure 3. The formation of chordal cracks and crushing of notch faces can occur in standard felling techniques which exacerbates end splitting of logs. (Mattheck and Walther, 1992)

Figure 4. Microscopic section showing both normal and tension wood cells characterised by an inner ‘gel’ layer to the cell wall which in most cells in the figure has become detached from the other layers.
Characteristic reaction wood can occur distributed with normal cells (Nicholson et al, 1975), in which case they will contribute to high growth stresses and end splitting. This situation was found in young plantation-grown *E. globulus*, which had considerable amounts of end-split than some other eucalypt species (Yang and Waugh, 1996). However, tension wood is normally associated with leaning stems, where it forms on the upper side of leaning stems and branches, but may also occur where there is little evidence of pith eccentricity (Panshin and Zeeuw, 1964). In this instance it will create high stresses on one side of a stem and will usually dictate the end-splitting pattern found on the end of a log.

1.4 Other Factors

1.4.1 Seasonality
Seasonal variation appears to have a significant effect on certain species (Chafe, 1979). Tree species such as pigeon-berry ash (*Cryptocarya erythroxylon*), have a greater tendency to end split severely if felled during high growth periods. This is particularly noticeable in the wet season in northern NSW and Queensland where pigeon-berry ash has a strain value 2-3 times greater than that observed in the dry season. Victorian species also exhibit this characteristic, although the seasonal variation appears to be of a lesser magnitude.

1.4.2 Variation in growth stresses around a stem.
A number of factors: tree lean, crown and root distribution and buttressing in older trees can influence the circumferential variation in growth stresses around a tree (Nicholson et al, 1975) as demonstrated in a polar graph in Figure 5 (Nicholson, 1973).

![Figure 5. Polar graph of growth stresses in 40-year-old *E. regnans* regrowth tree, showing the effect of tree lean on stem eccentricity and variation of growth stress around the stem periphery.](image)

This variation can influence both the location and magnitude of end-splits. Three or four splits will usually develop in a concentric tree, if end splits develop, with approximately equal angles between them (Figure 6). However, high stresses perhaps from tension wood on one side of a log typically with sweep, will usually result in an end-split across the log and through the pith at right-angles to the sweep (Figure 6). Two or four splits in a log do usually
allow a sawyer to align a saw with the end-splits, but this is not possible in the case where three splits are present.

Figure 6. Typical log end-splits associated with different growth stress patterns and handling damage

2. Growth Stresses

2.1 Definition of Growth Stresses

Growth stress refers to the mechanical stresses found in the green woody stems of living trees (Jacobs, 1945; Dinwoodie, 1966; Wilkins, 1986). Post (1979), described growth stresses as "the forces that develop in the wood of growing plants" which are not caused by external forces. These stresses therefore do not include stresses resulting from the weight of the tree crown nor those due to diurnal and seasonal variation of sap tension (Kubler, 1987). Growth stresses occur in all tree genera but are most significant in angiosperms, Eucalypts being especially prone (Nicholson, 1973). Younger trees are more problematic in relation to growth stresses than mature trees, which is of major concern to industry where the old-growth resource available is diminishing (Nicholson, 1973). As such, an understanding of growth stresses is critical to effectively minimise the resultant problems.

2.2 The origin of Growth Stresses

The formation of growth stresses is the result of normal development of woody tissue where maturation strains are induced in the cambial layer of the growing tree (Chafe, 1979; Fournier et al, 1990). As the cells differentiate and mature, they tend to shrink in the longitudinal direction and expand in the transverse direction, inducing tension and compression forces respectively (Boyd, 1950a; Jacobs, 1965).

There have been a number of theories put forward which attempt to explain how growth stresses are generated. The two leading theories are the "Lignin swelling hypothesis" (Munch,
1938 cited by Kubler 1987) and the "Cellulose tension hypothesis" (Bamber, 1978 cited by Kubler, 1987). The Lignin swelling attributes growth stresses to the encrusting lignin that is deposited between the cellulose fibrils. This causes transverse expansion of wood fibres as the cell walls swell (Kubler, 1987). Longitudinal contraction of the fibres is induced as a result due to the spiral arrangement of the fibrils. Older, neighbouring cells restrain the maturing cells resulting in longitudinal tension and tangential compression in the outer layers of wood.

Kubler (1987, citing Bamber, 1978), suggested the Cellulose tension hypothesis where tension arises from the contraction of crystallising cellulose in the microfibrils within the S2 layer of the cell wall. This process requires both “well-ordered and distinctly disordered phases, which cause the fibrils to contract longitudinally” (Kubler, 1987). There have been numerous papers discussing the limitations and usefulness of both hypotheses in explaining some aspects of growth stress origins. Whatever the causes, growth stresses are initiated in the maturing cell as the tree grows.

When a stress is applied to wood, it produces a strain which can be measured as a dimensional change (Kubler, 1987). Stress is usually derived from measurement of the strain and MOE (Modulus of Elasticity). The MOE refers to the ratio of stress to strain which is constant due to the directly proportional relationship between stress and strain up to the point of elasticity.

2.3 Longitudinal Growth Stresses

Longitudinal tensile stresses are produced as a result of axial contraction of maturing cells as new layers of wood are formed. As a result, the tensile strain in the previous growth sheaths is eased and the older wood comes under compression (Jacobs, 1939). As the tree ages and continues to grow, a longitudinal compression stress at the inner core is induced as these stresses accumulate (Jacobs, 1939, 1945, 1965).

The longitudinal tensile strain decreases in magnitude from the cambium towards the pith until a zero point at about two-thirds of the radius from the pith. After this point, the strain becomes compressive which gradually increases until the pith is reached (Archer, 1986; Boyd, 1950a; Kubler, 1987). This strain distribution applies to trees of all diameters and is described by Equation (1) below:

\[ e_l = e_{lp} \left[ 1 + 2 \ln \left( \frac{r}{R} \right) \right] \]

where:
- \( e_l \) = longitudinal strain at a specified location
- \( e_{lp} \) = constant peripheral longitudinal strain
- \( r \) = distance of that specified location from the pith
- \( R \) = radius of the stem
The larger the tree diameter, the smaller the longitudinal strain gradient becomes, the greater the theoretical longitudinal compressive strain and the larger the zone of wood around the pith that is under compression. However, longitudinal tensile strain around the periphery does not appear to be related to stem diameter (Jacobs, 1945). These concepts are shown in the graphical representation of the above equation in Figure 7. In deriving this model, Kubler (1959), disregarded variations in wood density associated with juvenile wood, Poisson effects\(^1\) and the soft pith which generates little stress during its growth and resists little stress exerted by the wood.

Longitudinal growth strains are highly variable within the tree around its circumference, particularly in leaning trees (Saurat and Gueneau, 1976). This variation is considered to be associated with both the need for the tree to re-orient itself into favourable directions (thereby producing reaction wood) and the effort of trees to maintain their position in the canopy.

There is also considerable variation in growth stresses between species, within species, with height and seasonally (Chafe, 1979). Even under identical environmental conditions, there can be considerable variation within a stand. As such, there is considered to be a significant genetic component to growth stresses in trees.

2.4 Transverse Growth Stresses

Transverse growth stresses are significantly smaller than longitudinal growth stresses, being approximately one tenth of the latter (Kubler, 1987). However, wood is much weaker transversally so that even quite small stresses in the transverse direction may lead to splits in logs and diametral timber. Transverse growth stresses can be described as being either tangential (at a tangent to the growth rings) or radial (perpendicular to the growth rings or the same direction as the rays).

Tangential strains are formed by the ‘swelling’ of the cells at the same time as longitudinal strains are formed during cell maturation (Jacobs, 1945). These strains are renewed in each new sheath of cells throughout the tree’s life at the same value. Compression stress of the new layers causes them to expand diametrically which in turn, pulls on the older wood relieving the compression stresses placed on this wood (Kubler, 1987). This ‘pulling’ effect accumulates through time reaching a minimum at a point approximately one third the radius of the tree from the pith, and changes to tangential tensile stress which increases towards the pith.

Radial stress is effectively zero at the stem periphery due to differentiating cells meeting little resistance when it grows in this direction. As maturing cells tend to expand diametrically, a radial tensile strain is created which accumulates and increases progressively towards the pith (Kubler, 1987).

---

\(^1\) Poisson effects refer to the situation where longitudinal strain inevitably produces some transverse strain and, conversely, transverse strain produces some longitudinal strain.
Figure 7: Longitudinal strain profiles with an hypothetical peripheral strain for stems of three different diameters, based on the model by Kubler (1959). The tensile strains are expressed by the positive values, and the compressive strain by the negative values.

The relations for both tangential and radial strains in trees have been described by Kubler (1959) in the following equations (2) and (3):

\[ e_t = e_{t0} \left( 1 + \ln \left( \frac{r}{R} \right) \right) \]  
\[ e_r = 0.5 e_{t0} \ln \left( \frac{r}{R} \right) \]

where:
- \( e_{t0} \) = constant peripheral tangential strain  
- \( e_{r} \) = tangential strain at a specified spot  
- \( e_{r} \) = radial strain at a specified spot

In derivation of these equations, Kubler disregarded Poisson's effect. By examination of the smaller the gradients of tangential strain, the greater the theoretical maximum tangential strain and the larger the zone of the pitch and extensive. These equations are also shown in graphical form in Figure 8.

2.5 The Role of Growth Stresses

Growth stresses provide certain benefits to the living tree. Whether the benefits are a fortuitous chance result or have evolved as an essential element in the life support of the tree is still being debated. One-sided longitudinal stresses enable trees to bend or re-orientate themselves into more favourable directions or optimal positions, this process may be very
slow in older stems (Kubler, 1987). When drastic re-orientation is required, trees produce reaction wood in order to achieve the preferred position. However, it is difficult to distinguish between tension wood and strongly stressed normal wood by examination of the wood itself.

Figure 8. Distribution of growth strains in stems according to Equations (2) and (3). Tension areas are marked +, compression areas -. At left: thin trunk; at right: thick trunk. (source: Kubler, 1987).

It has been suggested by Clarke (1939, as cited in Kubler, 1987), that growth stresses contribute to the rigidity of trees. Jacobs (1938, as cited in Kubler, 1987), also speculated that growth stresses may have some significance in the stability of tree stems. The tension in the outer layers of the tree was considered by Boyd (1950b), to minimise compression failures when trees bend in the wind. The tangential compressive growth stress in sapwood is thought to counteract the formation of cracks caused by frost or by severe water tension in periods of drought (Kubler, 1987).

2.6 Methods of Measuring Growth Strain

Various methods for measuring growth-related strains in wood have been developed to facilitate the particular needs of researchers (Kubler, 1987). These methods can be classified into two types, the measurement of peripheral strains and the measurement of internal strains.

2.6.1 Measurement of peripheral growth strain

There are many methods for measuring peripheral strain in tree stems and logs. Mechanical dial extensometers which touch two pin targets driven into the wood surface a few centimetres apart have been used extensively world-wide. Nicholson (1971), adapted this method, making it more practical for his purposes. Many authors have used electrical wire strain gauges bonded either directly to the wood or to reusable strain clips (Kubler, 1987). Okuyama et al, (1981) used tiny wire gauges and released the strain by cutting one layer of tissue. Kikata's method uses wire gauges at the stem surface and releases the stresses via the drilling of two holes at either end of the gauge (Gueneau and Kikata, 1973 cited by Kubler, 1987).
Nicholson’s method (1971)
This method has been widely used in Australia for the measurement of the magnitude of the longitudinal growth strains near the surface of trees or logs. This technique involves the application of measuring points via a small magnetic jig prior to removal of a small section from the tree. The 10 mm (3/8 inch) deep, 19 mm (3/4 inch) wide, and 89 mm (3 1/2 inch) long section is then cut from the log/stem. It is necessary to make the measurements comparable by returning the section to it’s ‘in-log’ curvature before measuring the strain present. The curvature is particularly important in small diameter logs where it is greater than in larger logs. The final strain is then measured using a ‘Tensotast’ gauge. Nicholson (1971), found that instead of using pin or screw points, gauge points attached by adhesive gave much more satisfactory results.

Nicholson (1971), also proposed a simplified version of this procedure which is less time consuming to use on large diameter logs. This method involves the cutting of a 19 mm (3/4 inch) wide and 10 mm (3/8 inch) deep cut across the grain and a 16 mm (5/8 inch) cut from each point. The points are then re-measured despite the fact that all the stresses are not released. Error factors appear to combine to give a relatively accurate result although Nicholson cautioned preliminary testing in order to establish the method’s usefulness for a particular application. It has the advantage however, of being very quick and can be carried out easily in the field.

2.6.2 Measurement of internal strains
Measuring internal strains of trees and logs essentially involves the measurement in length of a diametral board before and after it is severed from the two round log ends (Kubler, 1987). Jacobs (1945), used logs of more than 4 metres in length and removed the wood from the central 2.5 metres until a diametral plank remained as shown below in Figure 9.

![Figure 9. Jacob's method for measurement of longitudinal growth strains inside stems (source: Clarke, 1939).](source: Clarke, 1939).

This plank was then measured along marked guidelines, removed from the log ends, ripped into strips and remeasured. Thus internal strain could be determined although the measurements for core wood were a fraction too small and the strains near the bark too large. There have been variations of this method, such as Kikata’s method (1972), which incorporates wire strain gauges to measure strain before and after felling of the stem (Kubler,
1987). Post et al (1980), determined the relationships in strain between logs and planks, and planks and strips in order to calculate the log to strip growth strain in the whole log.

2.7 Calculation of Stress

Stress may be calculated once Young’s modulus or Modulus of Elasticity is known and the strain measured for a particular log or tree. This method of calculation assumes that the dimensional changes that occur during the measurement of strain are elastic and that the radial stress on the tree surface is zero. From Schaffner (1981):

Assume: \( \sigma_R = 0 \),

Then:

\[
\varepsilon_T = \frac{\sigma_T}{E_T} - \mu_{ZT} \frac{\sigma_Z}{E_Z} \tag{4}
\]

\[
\varepsilon_Z = \frac{\sigma_Z}{E_Z} - \mu_{TZ} \frac{\sigma_T}{E_T} \tag{5}
\]

The longitudinal and tangential stresses on the surface of the tree are expressed respectively as:

\[
\sigma_T = \frac{E_t}{1 - \mu_{TZ} \mu_{ZT}} \left( \varepsilon_T + \mu_{ZT} \varepsilon_Z \right) \tag{6}
\]

\[
\sigma_Z = \frac{E_z}{1 - \mu_{TZ} \mu_{ZT}} \left( \varepsilon_Z + \mu_{TZ} \varepsilon_T \right) \tag{7}
\]

Where:

\( \sigma_z \) = longitudinal Stress
\( \sigma_t \) = tangential Stress
\( E \) = Young’s Modulus
\( \varepsilon \) = strains measured
\( \mu_{zt} \) = longitudinal to tangential Poisson Ratio
\( \mu_{tz} \) = tangential to longitudinal Poisson Ratio

Schaffner (1981) states that the longitudinal to tangential Poisson ratio is somewhere in the order of \( \mu_{zt} = 0.5 \). However, the tangential to longitudinal ratio is approximately \( \mu_{tz} = 0.025 \), about 20 times that of the former.

---

2 These equations were derived by Dr. A. Hunter.
3. Methods of Reducing Growth Stress Associated Defects in Logs

It can be seen from discussion above that in order to manage end splitting of logs it is vitally important to reduce the growth stresses within the logs. There are various techniques that have been devised for this purpose which are described below:

3.1 Correct Felling Operation

3.1.1 Felling techniques
End splits are initiated as the tree stem is cut during felling (Kubler, 1987). The bending stress in the holding wood between the backcut and the undercut in hand felling may contribute to the defect. Felling techniques have been trialed overseas in recent years in order to prevent log damage that is associated with the bending moment of the stem and impact of the stem with the ground. Mattheck and Walther (1992), devised a method that combines a keyhole cut which minimises the bending moment introduced into the stem by the hinge, and a slanted cut that reduces the lateral stresses operating. A diagram showing the cuts involved in this method is shown below in Figure 10.

![Diagram of felling technique](https://example.com/diagram.png)

**Figure 10.** Individual steps of the new felling technique. (source: Mattheck and Walther, 1992).

Methods of mechanised felling involve the use of a feller-buncher which holds the tree upright while the stem is cut (Kubler, 1987). This avoids damage associated with the bending moment which occurs as a result of hand felling practices. End splitting can be exacerbated by the ‘whipping’ motion of the log as the tree falls, particularly if the log makes contact with the stump (Kubler, 1987). If the tree is mechanically harvested then layed on the ground, then this defect can be avoided. However, the shears used for this purpose may have a detrimental impact on the base of the stem, introducing butt shatter. In addition, mechanical felling so far only suits small trees.

3.1.2 Felling cuts in cross-grain
It has been found by Liese (1961, as cited in Kubler, 1987), that end splits in logs are greatly reduced by making the felling cuts closer to the ground. This is a particularly useful method if the stems can be cut in the root collar where there is cross grain. Cross-grain is defined as
being where the fibre alignment of a section of wood does not coincide with the longitudinal axis of the material (Panshin and Zeeuw, 1964). It may come about as the result of uneven growth rings, intersection of branches or roots with the stem, and interlocked or spiralling fibres (Corkhill, 1979). According to Dinwoodie (1966), a number of forest workers have recommended that trees be felled with cuts made as close to the ground as possible and cross cut at the fork in the stem after felling so as to maximise the amount of cross grain at the cut. The lower longitudinal growth stresses occurring in the butt are the result of there being little wood underneath the ground to counter balance them (Kubler, 1987). When a tree is felled by a cut close to the ground, the growth stresses released are minimal.

Assessment of felling techniques:
Appropriate felling techniques reduce the incidence of sudden release of growth stresses. They prevent the occurrence of defects such as chordal cracks and minimise the occurrence of log end splits. Mechanical harvesting, normally used on small diameter trees, incidentally reduces growth stress defects by limiting “chordal cracks” although there may be additional damage in the form of butt shatter if shear type fellers with blunt blades are used. Both these methods do not actually contribute to the reduction or relaxation of growth stresses but instead minimise the effect growth stresses can have on logs during the harvesting process. It may be beneficial to investigate these techniques further to develop more efficient and easily implemented methods.

3.2 Post-felling Log Handling

3.2.1 Physical methods

Store logs under water spray
Water spray storage has been used extensively in the sawmilling industry as a means of reducing degrade associated with drying (Nicholson, 1973). Mill operators using this procedure have indicated that this practice has had some benefit in reducing longitudinal growth stress effects. Nicholson (1973) found that water spray storage reduced residual mean growth stresses by approximately 20% when logs were stored for a period of 300 days. This method also has the advantage of ensuring a constant supply of logs in the log yard in areas where winter logging may be impossible.

Assessment of this technique:
By maintaining moisture levels within the logs in the log yard, it is possible to relax the growth stresses within the logs to some extent over long periods of time (approximately 1 year). As has been explained in Section 4, the presence of water weakens the wood’s molecular adhesion and therefore facilitates relaxation. Due to the absence of heat however, the process of relaxation takes much longer than is achievable in the log boiling technique.

Girdling and circumferential kerfing
Girdling refers to the cutting of a kerf around the standing tree at some height above where the felling cut is anticipated (Kubler, 1987). Circumferential grooving involves the cutting of grooves around each end of the log prior to cross cutting (Barnacle and Gottstein, 1968). This method has been found to be reasonably successfully and has the advantage of being easily achieved with a chainsaw in the field. Circumferential grooving is preferable to girdling as both ends of the log have growth stresses reduced rather than just one.
Assessment of this technique:
Girdling and circumferential kerfing releases the growth stresses at the cut interface. As such it plays no part in actually reducing or relaxing the growth stresses in the log as a whole, except for that associated with shorter log length, but reduces the stresses released during the cross cut.

Reduce log length
The degree of distortion in a piece of wood attaining equilibrium conditions after being cut from a log which contains a pre-existing strain profile can be predicted using Newton's theorem. The relationship can be expressed as (see Figure 11):

\[ D = \frac{(\varepsilon_1 - \varepsilon_2) L^2}{8h} \]  

(8)

Where:
- \( D \) = distortion in the sawn boards, measured as a displacement at the centre of the board;
- \((\varepsilon_1 - \varepsilon_2)\) = the strain difference between the two sides of the board in the plane being considered. For example, between the faces of a back-sawn board;
- \( L \) = length of the board
- \( h \) = distance between the two sides of the board.

Figure 11. A distorted sawn board and the parameters for calculating the distortion.

It can be seen from Equation 8 that distortion in a sawn board is highly dependant on the length of the board. If the log length is halved, the distortion in the board will be reduced by a factor of four. However, shorter log lengths may affect the marketing of the resulting timber and the productivity of the mill.

Following is an example showing how to calculate distortion.

Assuming a longitudinal peripheral strain of 8x10^{-4}, which would approximate a stress of 10 MPa for *E. regnans*, being a high stress experienced every day by sawyers. For a 25 mm thick, 4.8 m long, backsawn board, sawn 50 mm under the bark from a log 600 mm in
diameter, the strain in the two faces of the board can then be calculated using Kubler's model (Equation 1):

\[ \varepsilon_1 = 8 \times 10^{-4} \times (1 + 2 \ln (250/300)) = 5.08 \times 10^{-4} \]
\[ \varepsilon_2 = 8 \times 10^{-4} \times (1 + 2 \ln (225/300)) = 3.40 \times 10^{-4} \]

Applying this strain difference to the distortion model (Equation 8):

\[ D = \frac{(5.08 - 3.40) \times 10^{-4} \times 4.82}{(8 \times 0.025)} = 0.0193 \text{ (m)} \]

The distortion in the back-sawn board is therefore 19.3 mm (bow), well inside the accepted limits. If the same exercise is carried out on a 2.4 m diameter log, the amount of distortion would be 4.8 mm.

**Assessment of this technique**: Growth stresses can be reduced in magnitude by reducing the length of the log as distortion levels are a function of log length. However, reducing log length must be under the restraint of standard lengths of timber supplied to the market as well as sawing productivity.

**Banding or other radial pressure**

This method involves the stretching of steel bands around the stem close to where cross cutting is to take place (Kubler, 1987). Banding has been unsuccessfully used in South Africa (de Villiers, 1973). Even in logs where some weeks were allowed to pass before removal of the metal bands, end splitting of logs and of timber during sawing still occurred. However, Kubler and Chen (1975) claim that cross cutting strains can be successfully neutralised in logs of 30 cm diameter, by the application of 7 cm wide, 2 mm thick steel bands when located at the very ends of the log. Kubler (1987) states that growth stress defects can be controlled in larger logs providing wider and thicker bands are used.

**Fasteners at log end surfaces**

Fasteners can be used immediately after felling and cross cutting by pressing various metal or plastic devices for the purpose into the log ends (Kubler, 1987). S-shaped hooks hammered into log ends have been used widely (Dinwoodie, 1966). However, they demonstrated little help in combating log end splits as found by many researchers (cited in Kubler, 1987).

**Assessment of banding and fastening techniques**: The banding method is more suitable to being used in conjunction with other techniques such as boiling as the growth stresses are merely restrained while the bands are in place. It is not considered to be very useful for eucalypts due to the bands requiring removal prior to sawing which then release the very strong stresses associated with this genus (Kubler, 1987).

Fasteners act in the same way as banding, holding the log together before processing. Plastic fasteners don't need to be removed from logs as they can be sawn through. Due to their limited usefulness particularly in eucalypts, this method should be restricted to a minimum and used only where other methods are not available or not suitable.
**Boiling logs prior to sawing**

It has been a common practice in veneer industry to heat logs in water (hydrothermal treatment) to soften the wood prior to peeling or slicing if the wood is dense. The higher the moisture content, the lower the softening temperature is required and the greater the absolute softening is achieved (Fengel and Wegener, 1984). The softening of lignin and other amorphous components is physical rather than chemical. Below a certain temperature, the amorphous components lose plasticity and consolidate again (Fengel and Wegener, 1984).

Attempt has been made to use hydrothermal treatment to release residual growth stresses in logs. In an experiment conducted by Skolmen (1967), it was found that residual growth stresses could be reduced by as much as half after being boiled for 24 hours. Although stress release related defects are reduced, this treatment results in increased shrinkage which results in decreased mill productivity. The excessive shrinkage arising from collapse is associated with water tension in the completely filled cell cavities (Kubler, 1987). Other contributing factors to excessive shrinkage include transverse drying stresses and the plasticity of hot moist wood.

**Assessment of this technique:** The application of heat while moisture is available has the benefit of relaxing the growth stresses permanently in the wood (See Section 4). However there are disadvantages associated with this method such as excessive shrinkage and being impractical for sawmill situation.

**3.2.2 Chemical methods**

**Burying in manure**

In a study conducted by Giordano and Curro (1973, as cited in Kubler, 1987), it was found that longitudinal growth stresses could be reduced by one third in five months and two thirds in seven months by burying fresh eucalypt logs in manure. It is considered that this effect is the result of combined high temperatures (around 60°C), stable moist conditions and in particular to ammoniacal vapour. Concentrated ammonia has been used extensively in the bending of solid wood in furniture making due to its highly effective plasticising property (Kubler, 1987).

**3.3 Appropriate Sawing Operation**

**3.3.1 Influence of specialised sawing equipment**

The release of growth stresses during sawing results will causes distortion in flitches, which has the potential to result in both distortion and sizing variation in final products. The line-bar log carriage (Figure 12) is a good example of equipment designed to handle distorted flitches, enabling resawing to be referenced from distorted saw cuts, and ensuring products uniformly dimensioned. Sawing strategies have been developed around the capabilities and constraints of using this equipment for sawing high-stress eucalypts.

Twin saw systems provide another solution for handling high growth stresses. Removing slabs of uniform dimensions, simultaneously from both sides of a log reduces distortion of saw cuts as stresses are evenly balanced and even if some distortion occurs, then the centre cant will still remain uniformly dimensioned, as shown by the distortion figures in Figure 13(b). However, this system does not dissipate stresses, but rather, increases the stress.
gradient in the plane of the saw cuts, as outside wood in tension is removed, enabling the high compression core to relax, placing a higher tension stress on the remaining outer wood. The strain gradient in line with the saw cuts can double, as shown in Figure 13(a) and 13(b). This will result in any end-splits in the log enlarging, in fact often to the extent of running the complete log length. If the centre cant is turned over and sawn with a single saw along the heart, then the two resultant flitches will demonstrate considerable distortion. In fact, in many cases, the cant will develop an uncontrolled split ahead of the saw as soon as the log touches the saw. In the example provided in Figures 13 and 14, for a 400 mm diameter log, 4.8 metre in length, the distortion in the flitches as shown in Figure 11(c), would be about 50 mm. Once this was straightened, there would only be 100 mm of the original 200 mm in the radial plane for sawing to full-length products. If log length was halved, distortion would be about 12 mm, which after straightening, would leave about 175 mm in the radial plane.

Figure 13. *Sawing simulation program demonstrating high residual strain profile in centre cant (b) when using twin saw systems and anticipated distortion on stress release (c).*
3.3.2 Adopting backsawing strategies
This balances stresses and maximises the quantity of backsawn products. However, backsawn products may exhibit undesirable features such as surface checking and face knots.

3.3.3 Face cutting
Continuously making extra cuts assists in straightening distorted flitches and products. However, this practice reduces sawmill productivity and recovery.

Assessment of the above techniques: It can be seen that there are considerable advantages and disadvantages associated with each of the options outlined above. Individually, these techniques are not sufficient to overcome the growth stress problem. The application of a combination of these methods may be required in order to adequately reduce the impact of growth stresses. Technically these are not methods of reduce growth stresses; instead the effects of growth stresses are minimised through optimum sawing strategies and technologies. This area has some room for improvement although good equipment is readily available and in use.

3.4 Silvicultural Improvement

3.4.1 Extending rotation age
By extending the rotation length for a particular stand of trees, it is possible to reduce the effects of growth stresses (Hillis, 1978). This results in a greater volume of timber that has considerably less distortion than is possible to achieve in a smaller stem. However financial constraints may make this option not feasible.

3.4.2 Slowing the growth rate
Slowing down growth rates without causing the death of the trees, can reduce growth stresses in standing trees (Hillis, 1978). This may be achieved by defoliation of particular areas of forest prior to harvesting, using a suitable herbicide (Nicholson, 1973). As the trees are not killed by the process, stress relaxation can take place without the degrade normally associated with dead timber. Waugh (1977), undertook a study to determine the feasibility and usefulness of such a technique. It was found that peripheral growth strain could be reduced in the order of 20%, twelve months post-treatment. This may however present a fire danger as the foliage dries out providing more fine fuel.
Although above approaches did reduce the amount of growth stresses in standing trees, the reasons for the reduction remains unclear and the feasibility of these methods are questionable, as pointed out by Kubler (1988).

3.4.3 Other silvicultural techniques
There are many silvicultural options which may be advantageous to implement in the long term. Species can be propagated that naturally have low levels of stress or breeding programs can be initiated to breed individuals with fewer growth stresses (Kubler, 1987). Eucalypts can be successfully bred to maximise desirable characteristics as diameter increment in particular is not related to growth stress levels (Boyd, 1980). It has been found by Polge (1981, as cited in Kubler, 1987), the growth stresses can also be reduced by thinning. Thinning reduces the trees' tendency to orientate the crown towards the light as more light is available due to decreased competition. The same principle can be observed in wider spaced plantings. Hillis (1984) claims that by providing a uniform environment and even spacing between stems, growth stress levels can be reduced.

Assessment of silvicultural methods: The process of how growth stress reduction in the standing tree occurs is not clearly understood and as such it is impossible to clearly determine this technique's advantages and application. There are a number of factors contributing to growth stresses including genetic control. Work has been done on thinning, defoliating, inheritability and stocking rates but more work is required on understanding the fundamental processes that occur within the wood during the relaxation period.

4. Why Stresses can be Reduced

Growth stresses can be reduced through relaxation which involves the slipping of molecules relative to each other within the wood (Kubler, 1987). Wood that is in the stress-relaxed state still appears to be strained as the wood dimensions appear the same. However, the strain is plastic not elastic and as such, there is no tendency for the wood to expand, contract, warp or split. If the bonds between molecules in wood can be imagined as rubber rods, stress can be explained as the stretching or squeezing of these rods in tension and compression wood respectively. As such, molecules are at abnormal distances from each other and when placed under strong stress, some rods may break. Other rods will pull or push a molecule until they reach normal lengths in the stress free state. In other words, slipping of molecules relax the stresses while wood dimensions remain the same. Molecules slip under strong stress when incidentally coinciding molecular motions of neighbour molecules impose additional stress on a rod (Kubler, 1987). As heat induces a state of higher energy, the enhanced molecular motion that results, accelerates stress relaxation (Kubler, 1987). Moisture assists in the stress relaxation process through the presence of water between the aggregates of wood molecules, weakening the wood's molecular adhesion. Figure 15 below displays the compensatory nature of heat and moisture content in relaxation of growth stresses.

Studies carried out to date have been unable to adequately explain why growth stresses are released in dead trees and in trees which have had their growth rate decreased. It seems clear from experiments conducted by Stubbings (1973, as cited in Kubler, 1987), that maintaining
the tree standing is a key factor in the reduction of growth stresses, as trees felled and left for several months with the crown attached, still exhibited extensive end splitting.

![Figure 15. Stress relaxation and lignin softening for different levels of wood temperature and moisture content (Kubler, 1987).](image)

5. References


