Strength grading

A subtitle

STEP lecture
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Objective

To develop an understanding of the importance of strength grading in the process of converting wood, a natural raw material, into timber for structural use.

Prerequisite

A4 Wood as a building material

Summary

The lecture explains why structural timber must be strength graded, how the grading process affects the characteristic values for strength and stiffness and hence why strength grading is a prerequisite to making timber a reliable and competitive structural material.

Visual and machine strength grading are outlined and the European grading standards for visual and machine strength grading are explained.

Introduction

Wood is a natural product of trees which exhibits great variations in quality according to species, genetics, growth, and environmental conditions. Wood properties vary not only from tree to tree but also within a tree, over the cross section and along the stem axis (see STEP lecture A4). The process of converting roundwood into sawn timber interferes with the structure of the naturally grown wood. For example, wood fibres may be cut due to sloping grain and distortions around knots. This leads to considerably greater variations in the strength properties of sawn timber than in roundwood. In general, the smaller the cross-section, the greater the variability.

Thus, the strength properties of ungraded timber of any one species may vary to such an extent that the strongest piece is up to 10 times the strength of the weakest piece (see Figure 1).

Since the use of structural timber is based on its characteristic strength value, i.e. the lower 5-percentile of the population, the high strength of the majority of the pieces cannot be utilised unless the timber is graded. This shows that for economic reasons timber has to be divided into classes of different quality on a piece by piece basis. However, strength can only be determined indirectly by parameters which can be determined visually or by other non-destructive methods. Since, there exists only a limited correlation between these parameters and the strength, the variability within these classes cannot be reduced as much as would be liked. The lower the predictive accuracy of the grading method, the greater the overlapping of classes

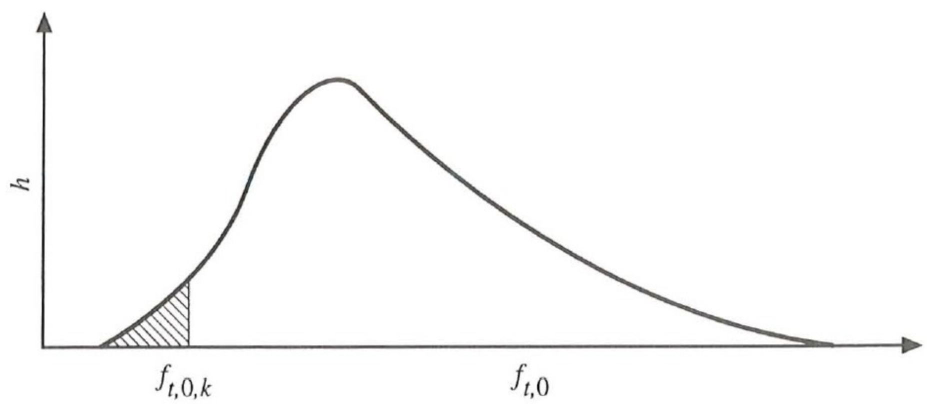

Figure 1 Distribution of tensile strength f_{t0} of ungraded structural timber. h is the frequency

will be, see Figure 2. This demonstrates the impact of the applied grading method on the economic use of timber.

Moreover, it is a necessary prerequisite that timber is available in qualities and quantities that are desired by users and that it meets all user requirements, the most important being that timber qualifies as a reliable material with defined properties.

visually recognizable characteristics can be taken into consideration and only simple combination rules are possible. Important strength determining characteristics such as density cannot be assessed satisfactorily.

The predictive accuracy of visual grading therefore has its limitations. Since the grading decision depends on the judgement of the grader it can never be totally objective.

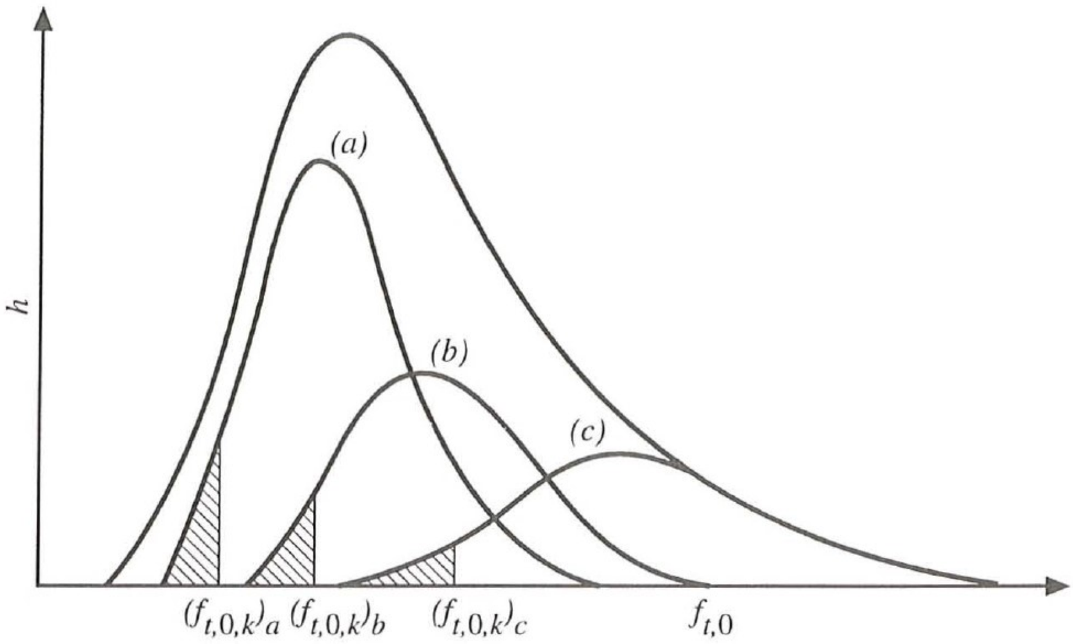

Figure 2 Scheme of tensile strength distribution of structural timber assigned to three grades a, b, c according to Diebold and Glos (1994).

Traditionally, strength grading was done by visually assessing timber, taking into account strength reducing factors that could be actually seen, mainly knots and annual ring width. Up to the beginning 20th century visual strength grading was essentially based on tradition and local experience. Detailed grading rules were introduced for the first time in 1923 in the USA and, from the 1930s onwards, successively in various European countries. Due to the great variety in wood species, timber qualities and different building traditions, for example different cross-sectional dimensions, it is hardly surprising that the grading rules developed over the last 50 years differ widely in the grading criteria as well as in the number of grades and grade limits. All these grading rules, however, have in common the general deficiency of visual grading methods: for practical reasons only

To improve the accuracy of strength grading with the aim of achieving a better utilization of the available timber qualities machine grading processes were developed from the 1960s onwards in Australia, USA, UK and, later, in other countries.

The increasing importance of quality assurance and the rising demand for high quality timber have led to a growing interest in machine strength grading and initiated the development of new machines with greater predictive accuracy.

In timber grading a general distinction must be made between the so called appearance grading and strength grading. In the former, wood is assessed according to its appearance, i.e. decorative criteria, which is important wherever timber is intended to remain visible. Appearance is the main consideration for non-structural timber, such as boards for cladding, but may also be important for structural timber where it is exposed in use. In strength grading, timber is mainly assessed according to criteria which are relevant to its strength and stiffness. From this, it follows that where structural timber is exposed in use and the appearance is important, timber may have to be graded for both strength and appearance. However, this lecture will deal only with the strength grading of sawn timber.

General requirements for strength grading

Strength grading is intended to ensure that the properties of timber are satisfactory for use and in particular that the strength and stiffness properties are reliable. Therefore, grading rules have to define grade limits for characteristics which are sufficiently correlated to the strength and stiffness of timber. In traditional visual strength grading the most important strength determining factors are rate of growth, indicated by the annual ring width, and the strength reducing factors such as knots, slope of grain, fissures, reaction wood, fungal and insect damage and mechanical damage. In machine strength grading it is possible to determine other characteristics such as bending modulus of elasticity, which are better correlated with strength properties. In addition to grading rules for strength and stiffness, it is also necessary to define grade limits for geometric properties, for example wane and distortion such as bow, spring and twist which may also affect the structural use of wood.

Since the wood moisture content influences distortion, fissures and wood dimensions, the grade limits have to be related to a reference moisture content, which is set at 20%. Moisture content is also important in machine strength grading when moisture-dependent properties of the timber are being measured.

European grading rules require that a piece of timber be graded based on its most unfavourable cross-section. The grade will at least be on the safe side if the timber is cut into shorter lengths later on. However, the grade may change if the cross-sectional dimensions are reduced after grading, for example by re-sawing or planing. This reduction in size may affect the average density or the knot ratio of the piece. The grading rules should therefore state the amount of dimensional change that is permissible to avoid the need for re-grading.

Graded timber should be marked. This marking shall as a minimum give the following information: grade, wood species or species combination, producer, and the standard to which the timber is graded.

The minimum requirements for visual grading standards have been laid down in EN 518 "Structural timber - Grading - Requirements for visual strength grading standards". Requirements for machine grading can be found in EN 519 "Structural timber - Grading - Requirements for machine strength graded timber and grading machines ".

Visual strength grading

There are currently many different visual strength grading rules for timber in use in Europe. They differ in the number of grades and grade limits and, also, in the way grading characteristics are measured. In particular, there is a wide range of methods for determining knots.

Knots in sawn timber vary greatly in shape. They vary with sawing patterns and timber dimensions and are difficult to determine and classify. Strength is mainly reduced by grain deviations around knots rather than by the actual knots. This is also evident from the fact that, in general, failure starts from extreme fibre deviations in the vicinity of knots and not from the knots themselves. Wood structure may be even more affected when several knots are situated close together in a piece of timber. Thus, knot ratio is usually calculated from the sum of knots within a defined section along the length of a piece of timber rather than merely from the biggest knot. Edge knots and knots in tensile zones have a greater effect on strength than centre knots or knots in compression zones. Therefore, the position of knots within cross-sections of timber is often also taken into account in grading rules.

Efforts to harmonize visual grading rules throughout Europe were not successful because no single set of grading rules would cover the different species, timber dimensions and uses in an economically satisfactory manner.

Therefore, EN 518 merely gives the minimum requirements for visual strength grading of both softwoods and hardwoods and permits the use of all national standards which fulfil these requirements. According to these limitations, the following characteristics have to be taken into account:

- limitations for strength reducing characteristics: knots, slope of grain, density or rate of growth, fissures.
- limitations for geometrical characteristics: wane, distortion (bow, spring, twist)
- limitations for biological characteristics: fungal and insect damage
- other characteristics: reaction wood, mechanical damage.

In order to determine these characteristics, all four faces of each piece of timber must be examined. Economic restraints, however, do not allow for a slow, deliberate examination. For example, in a sawmill a piece of timber is graded in two to four seconds. This clearly shows that visual grading rules should be as simple as possible and under these conditions only a rough estimate can be made of these characteristics. Since the reliability of the grading process has to be guaranteed, the grader will therefore generally introduce a further safety margin to the required grade limits, thus further reducing the efficiency of visual grading.

- In summary, the advantages and disadvantages of visual strength grading are as follows:
- it is simple, easily understood and does not require great technical skill.
- it does not require expensive equipment.
- it is labour intensive and rather inefficient in that wood structure and density which influence strength (see Figure 3) are not sufficiently taken into consideration.
- it lacks objectivity which makes it even more inefficient.
- it is an effective method, if correctly applied.

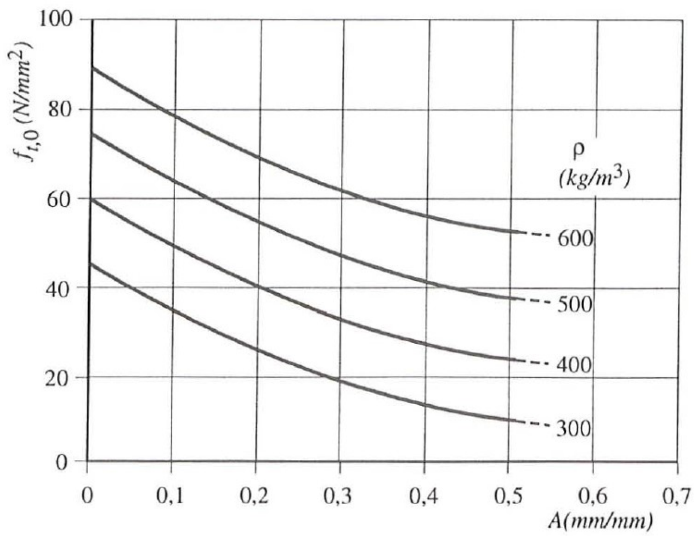

Figure 3: Effect of knot ratio A and density on tensile strength of structural timber according to Glos (1983).

Machine strength grading

The above disadvantages of visual strength grading can be overcome by machine strength grading. Most of the grading machines in use to-day are the so-called bending machines which determine average bending modulus of elasticity over short lengths (Fewell, 1982).

Timber is fed continuously through the grading machine. The machine bends each piece as a plank (i.e. about the weaker axis) between two supports which are some 0,5 to 1,2 m apart and either measures the applied load required to give a fixed deflection or measures the deflection under a particular load. From these values it calculates local modulus of elasticity taking into account the cross-sectional dimensions and natural bow of the piece of timber which is either measured or eliminated by deflecting the piece in both directions.

Since the introduction of machine strength grading about 30 years ago research work has been conducted to further improve the grading process. Numerous investigations have dealt with the determination of modulus of elasticity by methods other than bending, such as vibration, microwaves and ultrasound. The latter have the advantage of not mechanically stressing the timber and, hence avoiding damage. Furthermore, the maximum thickness of timber need not be limited to about 80 mm as in bending machines. Recent research has shown that predictive accuracy of machine grading can be further improved by technical modifications of the machine and by a combination of several grading parameters.

For example, the combination of modulus of elasticity (E) and knots has a better correlation with strength than E by itself (Table l). The incorporation of density into the grading process can also contribute to the grading results, as this can be used to produce grades with higher characteristic density and also to reject timber with significant portions of reaction wood. The presence of knots may be determined by optical scanning across the four surfaces or by radiation, while density may be determined by weighing or radiation (see Figure 4).

In radiation, for example by microwaves or gamma rays, part of the irradiation is being absorbed. The greater the mass that is being irradiated, i.e. the higher the density, thickness and moisture content of the piece of timber, the higher the absorption will be. Knots can be determined by radiation since knot density, on the average, is 2,5 times higher than that of normal timber.

Grading parameter	Correlation with		
	f_m	$f_{t,0}$	$f_{c,0}$
Knots	0,5	0,6	0,4
Slope of grain	0,2	0,2	0,1
Density	0,5	0,5	0,6
Ring width	0,4	0,5	0,5
Knots + ring width	0,5	0,6	0,5
Knots + density	0,7 - 0,8	0,7 - 0,8	0,7 - 0,8
Modulus of elasticity E	0,7 - 0,8	0,7 - 0,8	0,7 - 0,8
E + density	0,7 - 0,8	0,7 - 0,8	0,7 - 0,8
E + knots	> 0,8	> 0,8	> 0,8

Table 1: Correlation coefficients between possible grading characteristics and strength properties according to Glos (1983). Species: European spruce.

In optical scanning the four timber surfaces are monitored by video cameras. Knots are detected via shades of grey and may be differentiated from other effects not related to strength such as dirt or stain by analysing the surrounding texture. Values for knot ratio may be determined via image analysis.

Naturally, the higher efficiency of machine strength grading is more costly. The grading machines currently available vary greatly in performance and price. When comparing different machines or machine grading and visual grading the cost, efficiency and speed have to be taken into account.

One important difference between visual and machine grading is that with visual grading, it is possible to check at any time the correctness of the grade assignment even with timber which is in use. In contrast, in machine grading this check is not possible by visual measures.

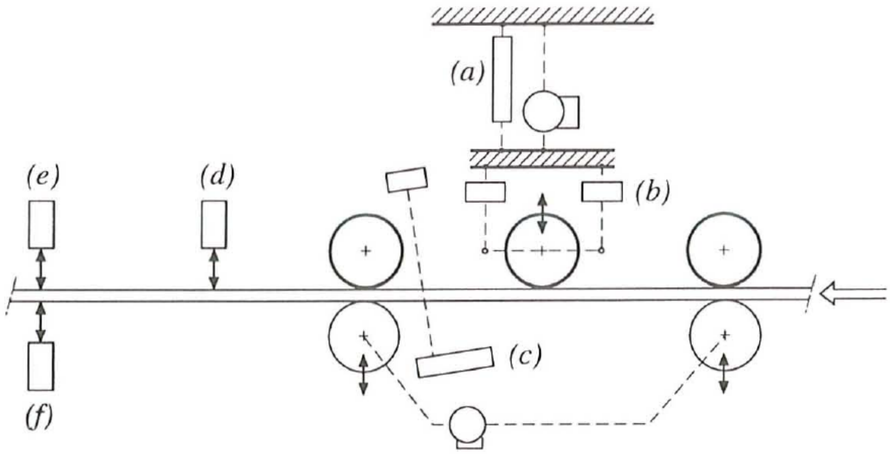

Figure 4: Scheme of a European grading machine with multiple sensing devices for measuring deformation (a), load (b), radiation absorption (c), bow (d), thickness (e) and moisture content (f).

For this reason, there has to be frequent and regular control of the reliability of machine grading. In various parts of the world two distinct control methods have been developed, the so-called output-controlled system and the machine-controlled system.

The output-controlled system was developed in North America. Control is based on the frequent destructive strength testing of samples of the machine graded timber. This system is relatively costly but permits a modification of machine settings in order to optimize yield. To be economical, this method requires great quantities of timber of the same size and grade. These conditions rarely exist in Europe, where a great variety of sizes, species and grades in smaller quantities are typical. For these conditions the machine-controlled system was developed. With this system mills generally do not have to test the graded timber but rather rely on the strict assessment and control of the machines as well as on considerable research efforts in determining the machine settings which remain constant for all machines of the same type.

EN 519 outlines the requirements for the machine strength grading operation and for grading machines. Both output-controlled systems and machine-controlled systems are allowed. The acceptance of grading machines and machine settings requires a thorough experimental and theoretical examination of the machine's principle of operation, performance, and reliability, involving hundreds of strength tests to establish the effects of all variables that may affect the machine's performance, such as timber sizes, tolerances, surface finish, moisture content, temperature, throughput speed, timber orientation, etc. Independent test data must be provided to verify that the machine graded timber has characteristic strength and stiffness properties that meet the specifications of the grade.

Machine proof-grading

In some countries, such as Australia, machine proof-grading has been adopted instead of machine strength grading. In the former, a piece of timber is loaded on edge to a level corresponding to the design load of the desired grade times a predetermined safety factor. If the timber sustains this proof load without failure, excessive deformation, or other signs of damage it will be allocated to the desired grade.

Compared to machine strength grading this method is straightforward and, in particular, requires little *a priori* data about the timber source to be graded. However, it permits a yes/no decision only, i.e. the grading into one specific grade. It is also wasteful, as with low proof loads, timber is not efficiently being utilized whereas, with high proof loads, a certain percentage of the timber will be damaged and discarded. Therefore, proof-grading is not considered adequate for the European market.

Concluding summary

- Structural timber must be strength graded in order to ensure that its strength and stiffness properties are reliable and satisfactory for use.
- Strength grading can be based on a visual assessment of the timber (visual strength grading) or on the non-destructive measurement of one or more properties (machine strength grading).
- Machine grading is more expensive but has greater predictive accuracy. It results in higher yields of higher grades and in the allocation of timber to higher strength classes.
- Current research shows that grading methods can be further improved. Strength grading must be developed further in order to ensure that timber remains an economic and competitive structural material.
- Requirements for strength grading are set out in EN 518 (visual strength grading) and EN 519 (machine strength grading). Both standards leave room for future technical developments.

References

Diebold, R. and Glos, P. (1994). Improved timber utilization through novel machine strength grading. Holz als Roh- und Werkstoff 52: 222.

Fewell, A.R. (1982). Machine stress grading of timber in the United Kingdom. Holz als Roh- und Werkstoff 40: 455-459.

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Update notes

Timber strength classes are now common place with Solid timber covered by EN 338 and Glue Laminated timber covered by EN 1194

EN 338 Structural timber – Strength classes for solid Softwood and Hardwood
EN 1194 Glued laminated timber – Strength classes and determination of characteristic values