Timber in construction

STEP lecture A5
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Objective

To focus attention on the essential properties of timber which have to be considered in the design, detailing and construction of timber structures.

Summary

The production of timber and other wood-based structural materials is described. Two methods to counteract the high variability of timber properties, namely grading and reconstitution are outlined. The essential properties of timber in service are summarised including the effects of moisture content, long-term loading, creep, shrinkage and swelling and the behaviour in fire. General guidance for the design of timber structures is given.

Introduction

Wood is a natural resource that is widely available throughout the world. With proper management, there is a potential for an endless supply of timber and other wood-based materials. Due to the low energy required and the low pollution during manufacture timber has a far less detrimental impact on the environment than other building materials. One example is the process of photosynthesis, in which trees absorb carbon dioxide, store the carbon as wood and release oxygen. Growing trees therefore reduce the carbon dioxide in the atmosphere.

Timber is a live material. Its properties are anisotropic, they change with changes in environmental conditions and load duration has also a significant effect upon strength and deformation. The properties not only vary from species to species but even within a particular species. Due to climatic differences and different forestry practices, spruce from Northern Europe, for example, has different properties than spruce from Southern Europe. To be able to design timber structures successfully, the practising engineer needs to be aware of the particular properties of the timber being specified.

Production of timber and wood-based materials

Historically the size of trees in the forest determines the size of the timber that may be produced. One hundred years ago timber with cross-sections of 150 x 450 *mm* and lengths up to 20 *m* were commonly available. Today, in many countries, timber over 75 x 225 *mm* and more than 5 *m* long attracts a cost premium due to scarcity. However, if larger sizes are required, several timber members can be combined to form a composite member, for example a glulam member.

Because timber is produced by nature, strength and stiffness properties are highly variable. There are basically two ways to counteract variability and hence provide a reliable structural material. Timber can be graded and classified into different qualities. These different qualities can then be used to satisfy different uses or requirements. Reconstitution is also possible. Here, trees are divided into smaller parts which are then reformed, normally with the addition of glue.

Classification of timber
Timber can be assigned to a particular strength class by grading procedures, either machine strength grading or visual grading. Grading is based on established relationships between measured parameters and the strength of the timber. In machine strength grading procedures, the main grading parameter is the modulus of elasticity (see STEP lecture A6). Visual strength grading is mainly based on knot sizes and positions.

Classifying timber by strength classes simplifies the design process. Once a strength class is selected, a number of timber species from different geographical sources may be available to meet the designers' requirements. However, other factors can have an influence on the choice of the material; for example, visual appearance, durability of the timber in relation to the environment in service and whether it can take the preservative treatment, facility for jointing and gluing and the ability to receive decoration. Additionally all these facets must be related to material cost. Standardised cross-section sizes are more economical to use because they can be bought from stock and preference should be given to their specification.

In certain circumstances specification of species, grade and even the mill producing the timber may be necessary to achieve the particular properties required. An analogy is the specification of a concrete requiring particular sands, aggregates and cement together with a closely controlled water/cement ratio to satisfy a particular end use.

Reconstituted wood-based products
The natural growth of wood causes a distinct inhomogeneity of the material. Knots, pitch pockets and other growth characteristics influence the strength and hence cause a considerable variability within the members. By dividing large pieces of wood into smaller units and then rejoining them, the defects are distributed within the material and consequently the variability of the material properties decreases. The larger load-bearing capacity of glued laminated timber compared to sawn timber is not caused by a higher average capacity of glulam, but by the decreased variation in strength properties and hence higher characteristic strengths. Generally, the strength variability of the wood-based materials noted below decreases with increasing amount of processing:

Product	*Component parts*
- pole timber	- logs
- sawn timber	- planks
- glued laminated timber	- planks
- laminated veneer lumber	- veneers
- plywood	- veneers
- parallel strand lumber	- veneer strips
- oriented strand board	- flakes
- particleboard	- chips
- fibreboard	- fibres

Poles are the exception since they are hardly processed at all but nevertheless are particularly strong because the wood fibres are not cut leading to the fact that the continuous fibres guide the stresses smoothly around the knots.

Properties of timber and wood-based materials

Wood as a natural material has very different properties in different directions. Parallel to the grain, i.e. in the direction of the trunk of the tree, the strength of the material is particularly high, whereas perpendicular to the grain the strength properties are low. The tension strength of wood parallel to the grain is for example about 40 times greater than the tension strength perpendicular to the grain. It is quite easy to split wood along the fibres using an axe, but it is much more difficult to cleave a piece of wood perpendicular to the grain. These large differences of strength and stiffness properties in different directions are overcome in most wood-based panels. Since the wood fibres in many panel types have random orientations, the in-plane properties depend much less on the direction than in solid wood.

Timber is a hygroscopic material. Consequently the moisture content depends on the surrounding climate and changes accordingly. If timber dries below about 30% moisture content, it shrinks perpendicular to the grain whereas the shrinkage along the grain is small enough to be ignored. The shrinkage can amount up to about 7% of the cross-sectional dimensions. Therefore, timber should be installed at a moisture content close to the equilibrium moisture content likely to be achieved in service. Hindered shrinkage deformations in service can, for example in connections, cause tension perpendicular to the grain and hence potential failure.

Because of the different shrinkage in radial and tangential directions, splits can occur if large cross-section timber dries too fast. In general, splits do not reduce the strength of the timber members. They can be minimised by kiln drying.

In timber frame construction drying shrinkage can affect other materials. Brickwork, for example, tends to expand after construction so interfaces between timber and masonry must accommodate the differential movements. Similar effects can occur with plastic pipework installed in winter and expanding with the heating of the building. For similar reasons, the installation of lifts in multi-storey timber framed buildings requires special consideration.

Another result of moisture content changes is the change in mechanical properties. With decreasing moisture content, the strength and modulus of elasticity values increase. Timber under load shows an increase of deformation with time. In a constant climate, creep deformations only exceed the elastic deformations by about 50% in 20 years. If the moisture content of the wood varies, however, the creep deformations may exceed several hundred percent of the initial deformations. Creep deformations are not only important because of possible excessive deformations but also because they can lead to a reduction in load-carrying capacity due to creep-buckling effects.

Apart from the moisture content, the duration of the load significantly influences the strength and deformations of timber and timber structures. With increasing load duration, the strength of timber decreases. The designer therefore has to assign each load to a load duration class and subsequently modify the characteristic strength properties based on the duration of the combination of loads. The influence of load duration on the deformations is taken into account by an increase in creep deformations.

The thermal properties of timber are good; the low thermal conductivity means that cold bridging is not a problem to the building designer and low expansion across and along the grain with temperature change is a particularly beneficial attribute in fire conditions.

Fire doors made of wood are expected to be a barrier between a fire at close to 1000°C and an escape corridor that is at a temperature of 30°C. The general perception of timber in a fire is poor, it can be ignited and will sustain and spread fire due to the volatile gases it gives off when hot. However its combustion is a predictable process and the spread of flame can be minimised by treating or finishing the wood. In fire conditions the exposed timber surfaces of sections with dimensions exceeding about 50 *mm* will char and deplete at a constant rate. Within the depleted section the strength and stiffness of the timber remain essentially unchanged and hence the strength of a timber member after a period of fire can be assessed from the residual cross-section. Consequently, large glulam cross-sections show an excellent behaviour in fire whereas smaller sections, for example, trussed rafter members, have to be protected. Because of the predictable behaviour of timber in fire, steelwork is sometimes protected by a layer of sacrificial timber. Steel fasteners in timber connections may also have to be protected to achieve an adequate fire resistance of the structure.

Timber as a natural material is part of a natural growing-decaying cycle. Once trees are felled they are prone to biological decay but the onset of decay and the rate of decay can be controlled by the design and use of the wood. There are three approaches to this problem:

- design the construction and the details to eliminate the high moisture conditions likely to lead to decay and/or insect attack,
- select timbers that are naturally durable in the service environment or
- preservative-treat the timbers.

Examples of the good durability of timber can be seen in old buildings throughout Europe. However the changes in use of timber nowadays means that much greater care is necessary in detailing the construction and in treating timber.

Design of timber structures

In several respects, timber as a structural material is similar to steel. Both materials are available in similar shapes and even jointing of timber or steel members, respectively, is often comparable. On the other hand, there are marked differences between both materials leading to different design problems. Table 1 shows an overview of similarities and differences regarding steel and timber.

Timber members are particularly capable of acting as tension, compression and bending members. If tension perpendicular to the grain occurs, however, timber is prone to cleavage along the grain. Because of its high strength to weight ratio, it is widely used as a structural material for roofs and pedestrian or bicycle bridges. Compared to steel or concrete, the modulus of elasticity is low. This is often counteracted by choosing a stiff structural form, for example I-beams instead of rectangular cross-sections for bending members. Another example would be the use of folded plate and shell structures as roofs.

Due to the ease of workability, timber members can be produced in many sizes and shapes. However, designing timber structures often requires more effort than designing comparable steel or concrete structures. This is caused by the orthotropic properties of timber and by the requirements of mechanical fasteners used to connect timber members. In the fabrication of trussed rafters using punched metal plate fasteners, the design process is automated using Computer Aided Design thus substantially reducing design costs and resulting in very competitive structures.

Steel	Timber
Similarities	
hollow sections	poles
bars, angles	sawn timber
I-beam	I-beam
sheets	panels
welding	gluing
bolting	bolting
Differences	
isotropic	anisotropic
manufactured	grown, graded
uniform	variable, heterogeneous
affected by temperature	affected by moisture

Table 1 Similarities and differences between steel and timber as structural materials.

Because timber is a sympathetic, warm material it is not only used as a structural material but also as internal finishing and is much appreciated by architects. The texture and appearance of timber makes it very suitable for use in visually exposed structures. Since timber and wood-based panels can be visually exposed it is possible to make economic savings by utilising the same timber for both structural and visual functions.

The combination of steel and timber often produces light and competitive structures with timber as compression and steel as tension members. Because of the necessary cross-sections for timber compression members, buckling is often only a minor problem in design when compared with steel compression members. Although most timber is found in buildings having a simple rectangular form used, for example, in floor joists, rafters and other roof components or for walls in timber framed housing, large structures can be built economically in other forms such as domes and examples exist spanning over 100 metres.

Timber may also be used compositely with concrete. For instances in bridges the concrete may provide a strong wearing surface and protecting the timber structure below. The timber then provides the tensile reinforcement and may act as a permanent formwork.

Concluding Summary

- Because timber is a natural material the essential properties vary considerably. In order to use timber efficiently as a reliable structural material, strength grading is necessary.

- It is a lightweight material with a high strength to weight ratio.

- The strength and stiffness properties of timber are highly dependant on the angle between load and grain. Timber is strong and stiff parallel to the grain whereas it is prone to cleavage along the grain if tension stresses perpendicular to the grain occur. It has a low shear strength and shear modulus.

- Timber strength and stiffness properties change with changing moisture content. Especially creep deformations are increased by varying moisture content. Shrinkage and swelling have to be considered during the detailing of timber structures.

- Although timber is combustible and ignitable its performance in a fire can be calculated and it is very suitable for use in large sections without protection and in specialist situations e.g. fire doors.

- Timber acts well compositely with both steel and concrete.