Straight and tapered glulam beams

STEP lecture E4
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Objectives

To give examples of the use of straight glulam members, and of joints between beams and other structures. Further, to describe the strength and stiffness properties for inhomogeneous glulam members.

Summary

The lecture begins with examples of plane structures made from straight glulam members. For single span beams with constant depth guidelines are given on recommended span/depth ratios. Some typical details are shown.

The advantages of tapered beams are described and some details of the design are given, e.g. determination of the maximum bending stresses and deflections.

Lastly, the determination of characteristic values for glulam with different lamination qualities in the outer and inner laminations is described, together with an example of the calculations.

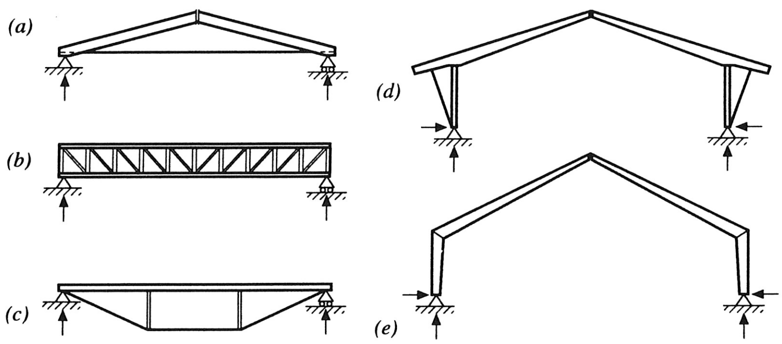

Figure 1 *Examples of plane structures made from straight members. (a) Truss made of two beams and with a tension tie of steel (or glulam). (b) Large truss with top and bottom chord of glulam. The lattice can be made of glulam, solid timber or steel (tension members). (c) Trussed beam with top chord and posts in glulam. The tension tie can be made of steel or glulam. (d) Frame with glulam columns and (steel) tension tie. (e) Frame made of 2 × 2 straight members. The corner can be made with gusset plates of plywood or steel or with large finger joints.*

Introduction

Straight glulam members with constant cross-section are one of the most common structural elements.

Beams can in principle be produced in any size. In practice, the size is limited by the capacity of the production equipment and transportation problems. Volumes above 10 m^3 require special consideration, but beams up to 40 m^3 with lengths up to 50 m have been produced.

The minimum width is about 60 mm. Beams with widths less than about 70 mm are often made by cleaving wider beams; they therefore have a tendency to warp and the surface quality may be slightly inferior. If this is not acceptable, the buyer will have to specify that the members shall be produced directly to the specified width. For widths over about 200 *mm*, each lamination is often made from two boards placed side by side. This gives a more costly production, and it may often be cheaper to use twin members. If a lateral interaction is required, it can be ensured by mechanical connections or gluing. However, gluing of this type is not covered by European standards.

The minimum depth is 100-135 *mm* corresponding to three laminations.

Straight members can be used alone as beams or columns, but can also be used to build up more complicated 2- or 3-dimensional structures. Examples of plane structures are given in Figure 1. This paper deals only with simple beams.

Single span beams with constant depth

Straight beams with constant cross-section are commonly used in roofs and floors, and as wall plates. The minimum depth is about $l/20$ to $l/17$, where l is the span. To reduce problems with lateral instability the width should not be less than $h/7$, where h is the depth. Most glulam factories produce "standard beams" according to a national size standard. "Standard beams" normally have a shorter delivery time and are cheaper than individually produced beams.

Free spanning beams are normally cambered corresponding to at least the final deflection from the dead load and the quasi permanent part of the variable loads. Normally only deflections u_m from bending are taken into consideration. The deflection from shear u_v can be found from

$u_v/u_m \approx 15(h/l)^2$ for a uniformly distributed load

$u_v/u_m \approx 19(h/l)^2$ for a single midspan force

For $l/h \geq 15$ the contribution from shear is less than about 8%.

Continuous beams with constant depth

Beams over several spans are often made as continuous beams or as cantilever beams, see Figure 2. They have a more favourable moment distribution, especially where there is more than one load case, and continuous beams are stiffer than corresponding simply supported beams. The minimum depth can therefore be reduced to about $l/25$ - $l/20$. Generally, continuous beams are not given any camber.

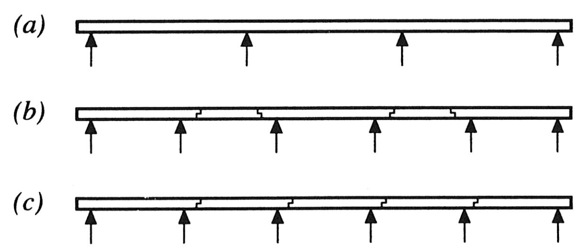

Figure 2 *(a) Continuous beam. (b) and (c) Cantilever beams. For cantilevered beams the joint pattern shown in (b) should be chosen. For the pattern (c) there is an unnecessary risk of progressive collapse.*

Cantilever beams are very common in structures made from structural timber because of problems in getting long lengths. In glulam structures continuous beams are normally more advantageous. In cantilever systems the joints should be located in such a way that the bending capacity is utilised both in sagging and hogging (often corresponding to different load cases) and such that failure in one beam will not spread to the whole structure. To avoid tension perpendicular to the grain failures in the notched beam ends, the short beams should preferably be hanging from the cantilevered beams.

Single tapered beams

Single tapered beams, see Figure 3a, are very common both alone and as part of roof panels. The volume is slightly higher than for a corresponding beam with constant depth, but they are often advantageous because secondary beams, roof panels, etc. can be placed directly on them, and eaves boards are avoided. The slope is normally between 1/40 and 1/10 ($\alpha \approx 5°$). The mid-depth should not be less than about $l/20$ and the minimum depth $l/30$.

The beams can be made with camber.

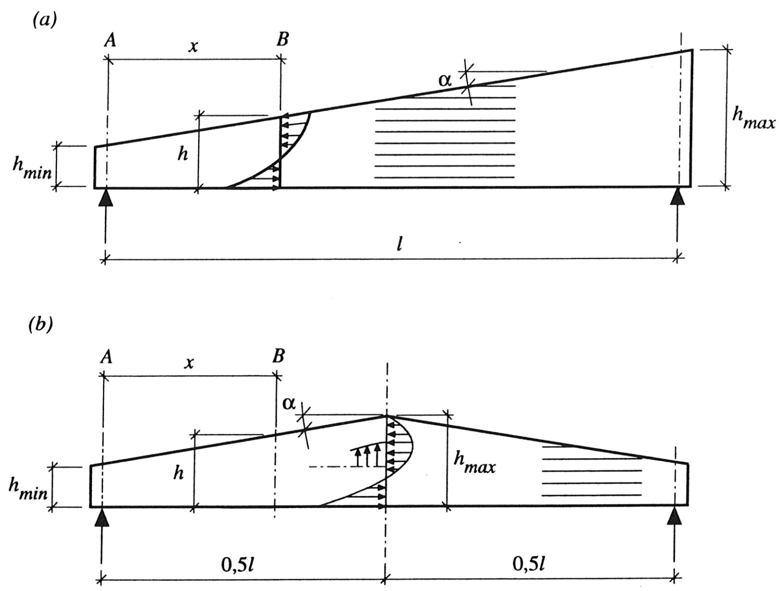

Figure 3 (a) Beam with single taper. (b) Beam with double taper. The beam widths are b.

The strength has to be controlled at two cross-sections: section A, where the shear stresses are maximum, and section B, where the bending stresses are maximum. For simply supported beams with a uniformly distributed load, q, the distance x from the support to the critical section is

$$x = l\ h_{min}/(h_{min} + h_{max}) \tag{1}$$

and the maximum bending stress is

$$\sigma_{m,d} = 0,75\ q_d\ l^2/(b\ h_{min}\ h_{max}) \tag{2}$$

For other types of load, or if the characteristic value of the bending strength is increased by the factor k_h for depths less than 600 mm, the maximum stress is found by calculating the stresses at different cross-sections at regular intervals along the span.

It should be verified that

$$k_{taper}\ \sigma_{m,d} \leq k_\alpha\ f_{m,d} \tag{3}$$

The factors k_{taper} and k_{α} take into account the influence of taper on the stress distribution and on the strength, see STEP lecture B8.

The maximum bending deflection u_m from a uniformly distributed load can be calculated from the corresponding deflection u_0 for a beam with a constant depth of $(h_{min} + h_{max})/2$ as

$$u_m = k_u \, u_0 \tag{4}$$

where k_u is given in Figure 4.

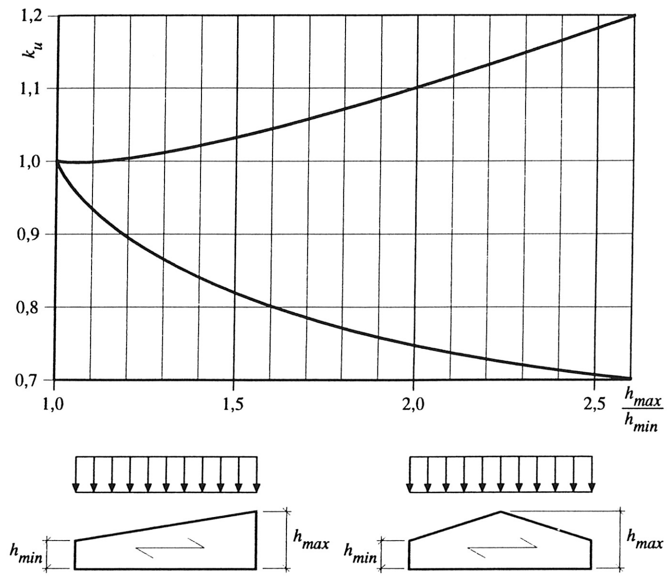

Figure 4 *Factor k_u to determine the maximum bending deflection of a beam with single taper (top) and double taper (bottom).*

Double tapered beams

Beams with double taper have the same advantages as single taper beams. In addition, the material economy is better because the depth follows the moments. Normally the maximum depth should not be less than about $l/20$.

The strength verification is in principle as for tapered beams. In addition, the strength of the apex cross-section should be verified in accordance with EC5, see STEP lecture B8.

For a uniformly loaded, symmetrical, simply supported beam, the bending strength of the apex cross-section will never be critical. The most unfavourable bending situation will in this case be found at section B with a distance x from the support of

$$x = 0{,}5 \; l \; h_{min}/h_{max} \tag{5}$$

and the maximum bending stress - for which (3) applies - is

$$\sigma_{m,d} = 0{,}75 \; q_d \; l^2/(b \; h_{min}(2 \; h_{max} - h_{min})) \tag{6}$$

For other types of load the bending strength of the tapered beam parts as well as the apex cross-section have to be verified.

The maximum design tensile stress perpendicular to the grain can be found from the apex moment $M_{apex,d}$ as

$$\sigma_{t,90,d} = 0{,}2 \tan\alpha \cdot 6\, M_{apex,d}/(b\, h_{max}^2) \tag{7}$$

For a uniform load the midspan deflection can be found from Figure 4 as for a beam with single taper; in this case the deflection is smaller than for a corresponding beam with a constant depth $(h_{min} + h_{max})/2$.

Details

Some typical details are shown below (numbering as shown in Figure 5).

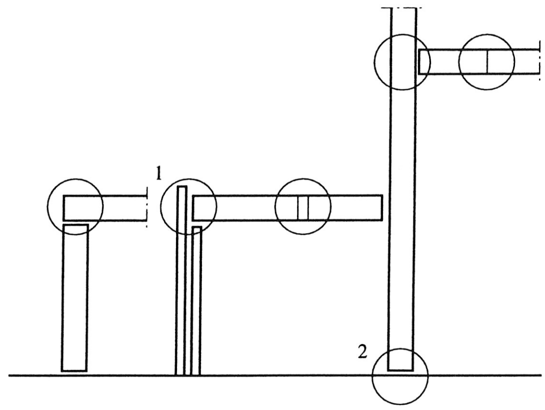

Figure 5 *Joint types. Joint types numbered 1 and 2 are shown in this lecture. The others are shown in STEP lectures D5 and D8.*

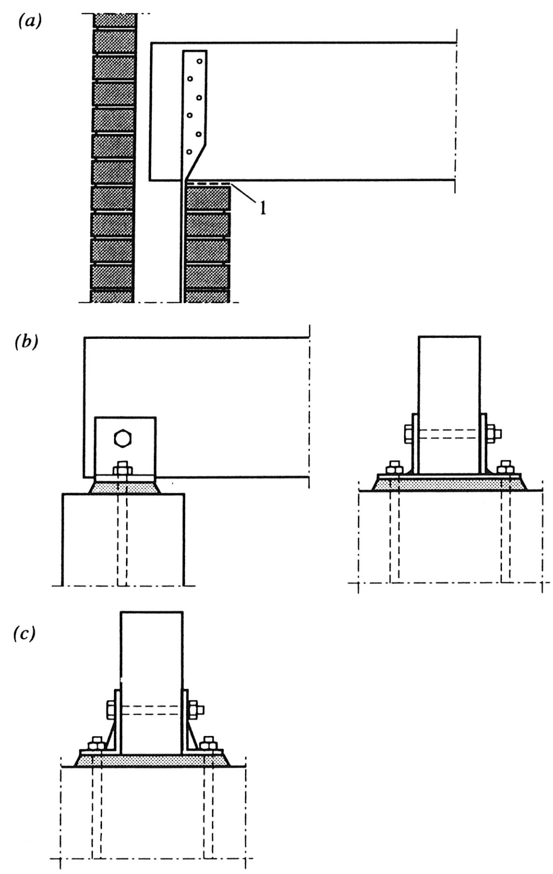

Figure 6 *Joint type 1, beam to wall. (a) Steel strap from the foundation nailed to the beam. (b) (c) Anchoring with a steel shoe or two steel angles. In the latter case, the angles as well as the bolts have to be designed for the eccentricity moments. 1 = asphalt felt.*

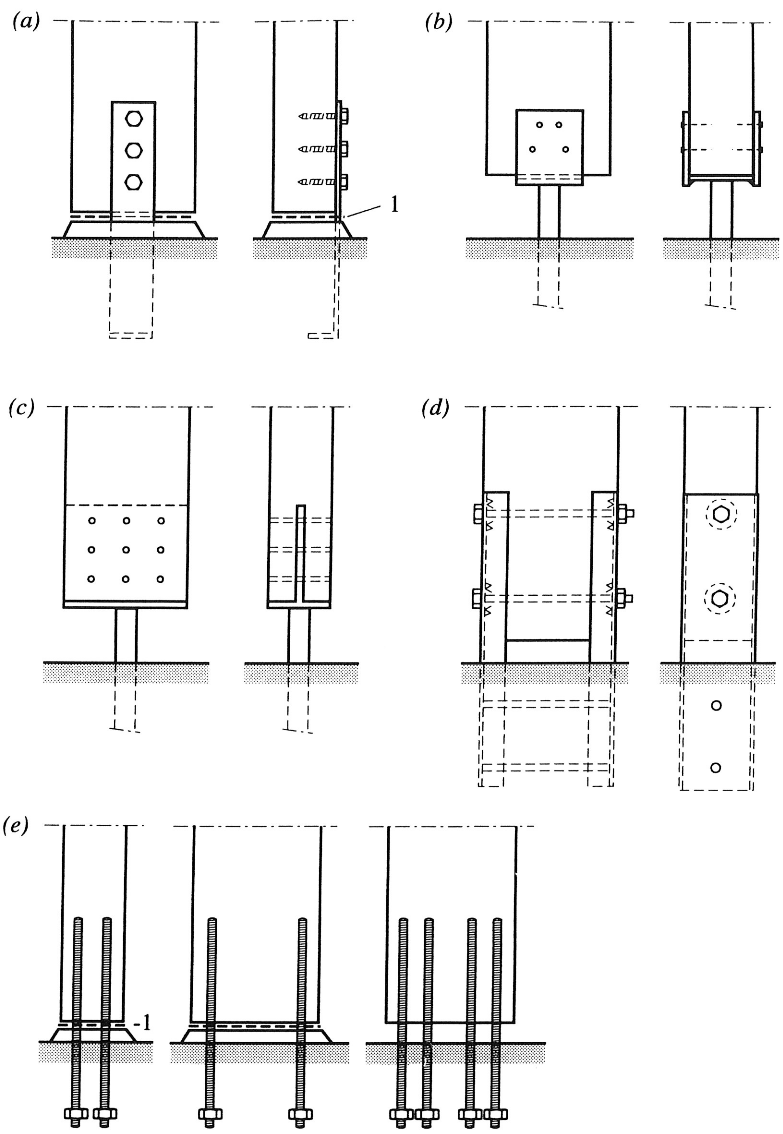

Figure 7 *Joint type 2, column to foundation. (a) (b) Simply supported columns with nailed, bolted or screwed steel bar or column shoe. (c) Simply supported column with steel plates in a slot. It is important to place an effective vapour barrier between wood and concrete. (d) (e) Built-in columns with channels or glued in bolts cast into recesses in the foundation. The column end can be free or packed up to increase the load-carrying capacity in compression as well as bending. 1 = asphalt felt.*

Characteristic values

The characteristic values for glulam shall be determined in accordance with European Standard EN 1194 "Glued laminated timber - Strength classes and determination of characteristic properties". This standard also gives the characteristic values for a range of glulam qualities produced by most glulam manufacturers. For special lay-ups the characteristic values are normally calculated and published by the manufacturer. In both cases glulam is designed as a homogenous material.

The designer may prefer a special lay-up, e.g. to utilise local materials. The calculations needed in this case are briefly described below for the symmetrical non-homogenous glulam cross-section shown in Figure 8.

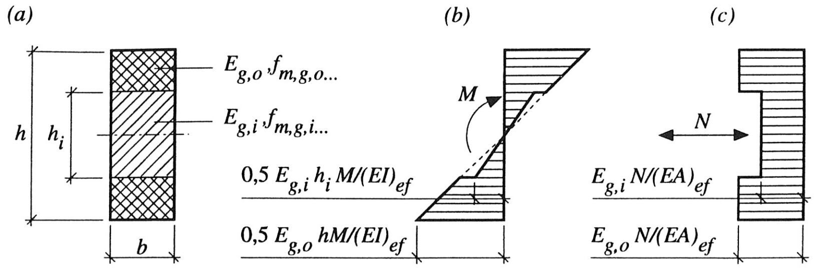

Figure 8 *(a) Cross-section of a glulam beam made with two different lamination qualities. (b) Stress distribution in bending. (c) Stress distribution under axial load.*

Regarded as solid timber, the inner laminations have the properties E_i, $f_{m,i}$, $f_{t,i}$ etc. (note that some subscripts have been omitted for the sake of simplicity. For example, $f_{t,i}$ denotes the characteristic tensile strength parallel to the grain for the inner laminations for which the complete notation is $f_{t,0,i,k}$). The outer laminations - of a better quality - have the properties E_o, $f_{m,o}$, $f_{t,o}$ etc.

The corresponding properties for the laminations regarded as blocks of glulam are denoted $E_{g,i}$, $f_{m,g,i}$ and $f_{t,g,i}$ etc. and are found from EN 1194, e.g.:

$$E_{g,i} = \max \begin{cases} (1{,}25 - E_i/60000)\ E_i \text{ with } E_i \text{ in } N/mm^2 \\ 1{,}05\ E_i \end{cases} \tag{8}$$

$$f_{m,g,i} = 1{,}2\ f_{t,i} + 9\ N/mm^2 \tag{9}$$

$$f_{t,g,i} = 0{,}7\ f_{m,g,i} \tag{10}$$

The effective stiffnesses $(EI)_{ef}$ in bending and $(EA)_{ef}$ under axial load are given by

$$(EI)_{ef} = (E_{g,o}(h^3-h_i^3) + E_{g,i}\ h_i^3)\ b/12$$

$$= (1-(1-E_{g,i}/E_{g,o})(h_i/h)^3)E_{g,o}bh^3/12 = k_I\ E_{g,o}bh^3/12 \tag{11}$$

$$(EA)_{ef} = (1-(1-E_{g,i}/E_{g,o})(h_i/h))\ E_{g,o}bh = k_A\ E_{g,o}bh \tag{12}$$

This corresponds to a formal modulus of elasticity in bending for the glulam regarded as a homogenous material of

$$E_g = k_I\ E_{g,o} \tag{13}$$

For axial load a slightly lower modulus of elasticity - $k_A\ E_{g,o}$ - is found, but EC5 permits the use of E_g in all cases.

The stress distribution in bending is shown in Figure 8b. The strength will always be determined by the stress in the outermost fibres. The characteristic bending capacity is thus

$$M_k = 2\ (EI)_{ef} f_{m,g,o}/(E_{g,o}h) = k_I\ f_{m,g,o}bh^2/6 \tag{14}$$

corresponding to a formal bending strength of

$$f_{m,g} = k_I\ f_{m,g,o} \tag{15}$$

The stress distribution under axial load is shown in Figure 8c. The strength will normally be determined by the stress in the outermost fibres, and the formal axial tensile strength is then

$$f_{t,g} = k_A\, f_{t,g,o} \qquad (16)$$

and correspondingly for the compressive strength. In rare cases the stress in the inner laminations may be critical. In this case, the formal tensile strength is

$$f_{t,g} = k_A\, f_{t,g,i}\, E_{g,o}/E_{g,i} \qquad (17)$$

Example

As an example, the properties of a glulam member with h_i/h = 2/3 and with laminations of strength class C27 and C16 according to European Standard EN 338 "Structural timber - strength classes" are calculated. The laminations have the following properties:

C27	$E_o = 12000\ N/mm^2$	$f_{m,o} = 27\ N/mm^2$	$f_{t,o} = 16\ N/mm^2$
	$E_{g,o} = 12600\ N/mm^2$	$f_{m,g,o} = 28{,}2\ N/mm^2$	$f_{t,g,o} = 19{,}7\ N/mm^2$
C16	$E_i = 8000\ N/mm^2$	$f_{m,i} = 16\ N/mm^2$	$f_{t,i} = 10\ N/mm^2$
	$E_{g,i} = 8930\ N/mm^2$	$f_{m,g,i} = 21{,}0\ N/mm^2$	$f_{t,g,i} = 14{,}7\ N/mm^2$

$$E_{g,i}/E_{g,o} = 0{,}709$$

$$k_I = 1-(1-0{,}709)(2/3)^3 = 0{,}914$$

$$k_A = 1-(1-0{,}709)\ 2/3 = 0{,}806$$

$$E_g = 0{,}914 \cdot 12600 = 11500\ N/mm^2$$

$$f_{m,g} = 0{,}914 \cdot 28{,}2 = 25{,}6\ N/mm^2$$

$$f_{t,g} = \min \begin{Bmatrix} 0{,}806 \cdot 19{,}7 = 15{,}9 \\ 0{,}806 \cdot 14{,}7 \cdot 12600/8930 = 16{,}7 \end{Bmatrix} = 15{,}9\ N/mm^2$$