NEMETSCHEK Scia

Theory

Timber Code Check EN 1995-1-1

Scia Engineer

Introduction

Welcome to the Timber Code Check – Theoretical Background.
This document provides background information on the code check according to the regulations given in:

Eurocode 5
Design of timber structures
Part 1-1: General – Common rules and rules for buildings
EN 1995-1-1:2004

Corrigendum EN 1995-1-1:2004/AC:2006

Addendum EN 1995-1-1:2004/A1:2008

Addendum EN 1995-1-1:2004/A2:2014

Version info

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Disclaimer

EN 1995 Code Check

In the following chapters, the consulted articles are discussed.

Consulted Articles

The member elements are checked according to the regulations given in: “Eurocode 5 Design of timber structures Part 1-1: General – Common rules and rules for buildings EN 1995-1-1:2004”.

A more detailed overview for the used articles is given in the following table. The articles marked with "X" are consulted. The articles marked with (*) have a supplementary explanation in the following chapters.

Section 1: General	X
Section 2: Basis of Design	
2.1 Requirements	X
2.2 Principles of Limit State Design	X(*)
2.3 Basic Variables	X
2.4 Verification by the Partial Factor Method	X(*)
Section 3: Material properties	
3.1 General	X(*)
3.2 Solid Timber	X(*)
3.3 Glued Laminated Timber	X(*)
Section 4: Durability	
Section 5: Basis of Structural Analysis	
5.1 General	
5.2 Members	
5.3 Connections	
5.4 Assemblies	X(*)
Section 6: Ultimate Limit States	
6.1 Design of cross-sections subjected to stress in one principal direction	X(*)
6.2 Design of cross-sections subjected to combined stresses	X(*)
6.3 Stability of Members	X(*)
6.4 Design of cross-sections in members with varying cross-section or curved shape	X(*)
6.5 Notched Members	
6.6 System Strength	X(*)
Section 7: Serviceability Limit States	
7.1 Joint Slip	
7.2 Limiting values for deflections of beams	X(*)
7.3 Vibrations	

No special rules are implemented for composed (multi-material) sections.

Basis of Design

Within **article 2.2.2** the possible procedures for carrying out the analysis of a Timber structure are specified. The following procedures are supported:

a) First order linear elastic analysis using mean values $\mathbf{E_{mean}}$ and $\mathbf{G_{mean}}$ for the stiffness properties.

b) Second order linear elastic analysis, using design values $\mathbf{E_d}$ and $\mathbf{G_d}$ for the stiffness properties.

The design values are determined as given in **article 2.4.1(2)**.

> **The design values of the stiffness properties are used only in case of a 2^{nd} order analysis, not in case of a regular non-linear analysis.**

> **The design values of the stiffness properties are used for both non-linear combination types i.e. 'Ultimate' and 'Service'.**

For the partial safety factor γ_M specified in **article 2.4** reference is made to the Theoretical Background for the National Annex to EN 1995.

Material Properties

The characteristic values of the material properties which are provided by default have been taken from the following references:

- Solid Timber: EN 338 Ref.[4]

- Glued Laminated Timber: EN 1194: Ref.[5] and Ref.[7]

> **The shear modulus $G_{0.05}$ is not given in any material code reference but is required for the Timber Code Check. This value is calculated during the Check as $E_{0.05}/16$ as given in Ref.[7] pp 109 and 209.**

Strength modification factor k_{mod}

The values of the modification factor $\mathbf{k_{mod}}$ are taken by default from **Table 3.1**.

As specified in **article 3.1.3(2)**, if a load combination consists of actions belonging to different load-duration classes a value of $\mathbf{k_{mod}}$ is used which corresponds to the action with the shortest duration.

Deformation modification factor k_{def}

The values of the deformation factor $\mathbf{k_{def}}$ are taken by default from **Table 3.2**.

In addition, as specified in **article 3.2(4)** the values given in **Table 3.2** can be increased by **1.00** for timber which is installed at or near its fibre saturation point. This can be set in the Timber Setup.

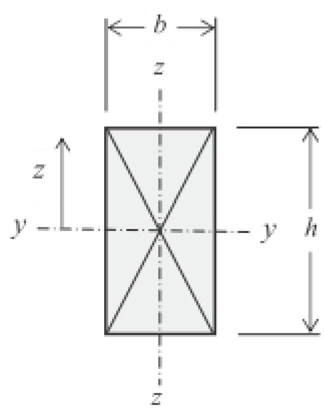
Depth factor k_h

In case the proper setting is activated in the Timber Setup the depth factor $\mathbf{k_h}$ is taken into account for both Solid Timber and Glued Laminated Timber.

According to **articles 3.2(3)** and **3.3(3)** the effect of the member size may only be accounted for in case a rectangular section is used. A rectangular section is defined as one of the following:

- **RECT** (Timber)
- **Rectangle** (Geometric shapes)
- **Full rectangular** (**Form code 7**)

In the following tables **b** is taken as the smallest dimension of the rectangle and **h** as the biggest dimension of the rectangle.



The factor $\mathbf{k_h}$ is calculated based on the type of timber:

Solid Timber

Action	Conditions	k_h
Tension N_{Ed}	material density is ≤ **700 kg/m^3** dimension **h < 150 mm**	$k_h = \min\begin{cases}\left(\frac{150}{h}\right)^{0,2}\\ 1,3\end{cases}$
Bending $M_{y,Ed}$	material density is ≤ **700 kg/m^3** dimension **h < 150 mm**	$k_h = \min\begin{cases}\left(\frac{150}{h}\right)^{0,2}\\ 1,3\end{cases}$
Bending $M_{z,Ed}$	material density is ≤ **700 kg/m^3** dimension **b < 150 mm**	$k_h = \min\begin{cases}\left(\frac{150}{\mathrm{b}}\right)^{0,2}\\ 1,3\end{cases}$

In all other cases $\mathbf{k_h}$ remains **1,00**.

The code clearly defines the width for tension as the "*maximum cross-sectional dimension*" thus h is used.

Glued Laminated Timber

Action	Conditions	k_h
Tension N_{Ed}	dimension **h < 600 mm**	$k_h = \min \begin{cases} \left(\frac{600}{h}\right)^{0,1} \\ 1,1 \end{cases}$
Bending $M_{y,Ed}$	dimension **h < 600 mm**	$k_h = \min \begin{cases} \left(\frac{600}{h}\right)^{0,1} \\ 1,1 \end{cases}$
Bending $M_{z,Ed}$	-	kh = 1,00

In all other cases $\mathbf{k_h}$ remains **1,00**.

According to Ref.[7] pp 84 for glued laminated members *"… (k_h) will only apply to the beam depth where the section is loaded perpendicular to the plane of the wide faces of the laminations."* therefore k_h is not accounted for in $M_{z,Ed}$ bending.

Basis of Structural Analysis

For plane frames, the following imperfections can be defined according to **article 5.4.4(2)**:

- Global Imperfections ϕ using formula **(5.1)**
- Bow imperfections **e** using formula **(5.2)**

In addition, the shape of the elastic critical buckling mode can be used as a unique global and local imperfection.

Ultimate Limit State

The Ultimate Limit State verifications are executed according to **Section 6**.

Tension parallel to the grain

The Tension parallel to the grain check is executed according to **article 6.1.2**.

This check is executed only in case a tensile normal force $\mathbf{N_{Ed}}$ is present.

Compression parallel to the grain

The Compression parallel to the grain check is executed according to **article 6.1.4**.

This check is executed only in case a compressive normal force $\mathbf{N_{Ed}}$ is present.

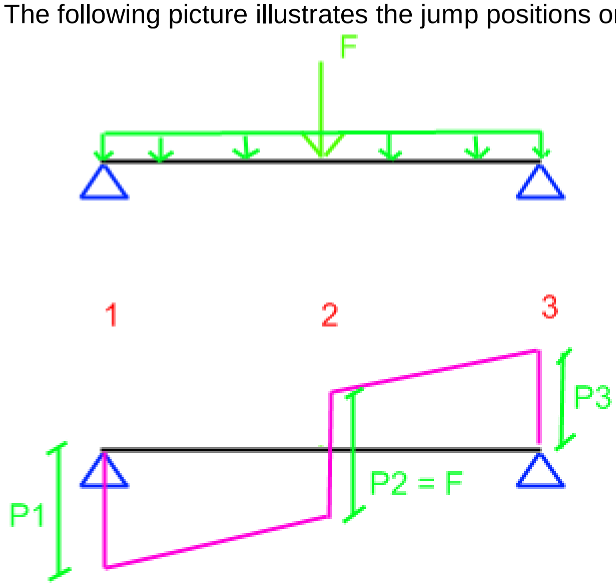
Compression perpendicular to the grain

The Compression perpendicular to the grain check is executed according to **article 6.1.5**.

This check was revised in the addendum A1 to EN 1995-1-1, see Ref.[3].

This check is executed only in case a shear force $\mathbf{V_{z,Ed}}$ is present. The check is executed on positions where there is a jump in the $\mathbf{V_{z,Ed}}$ diagram.

The following picture illustrates the jump positions on a sample member:

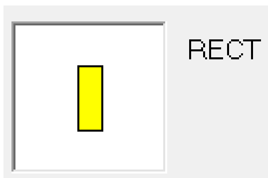
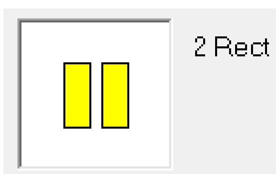
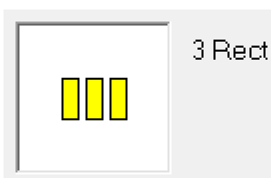
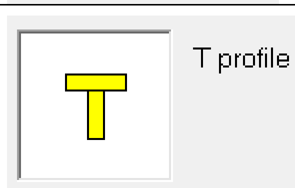
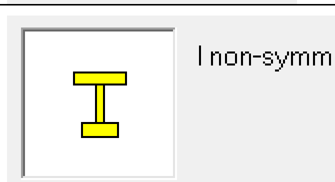


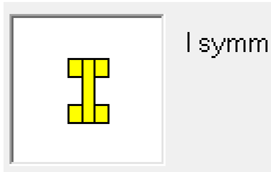
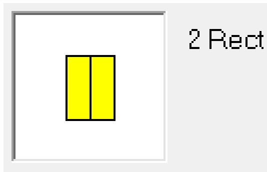
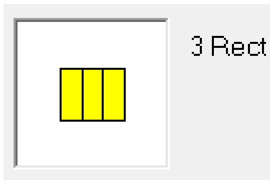
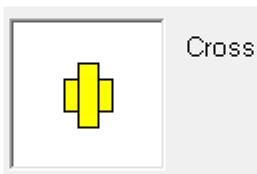
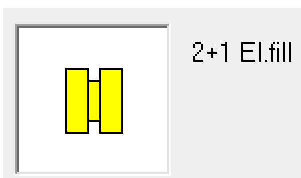
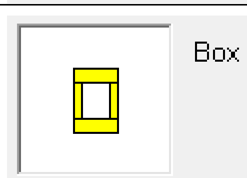
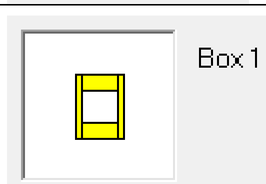
When evaluating the jumps in the shear force diagram of a given member, also the shear diagrams of the adjacent members are accounted for. Adjacent members are defined as neighbouring members within the same buckling system.

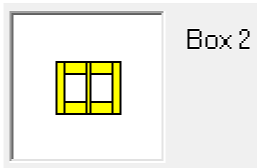
Effective contact area

The effective contact area $\mathbf{A_{ef}}$ is determined as follows: $\mathbf{A_{ef} = l_{ef} * b}$

The width **b** concerns the contact width of the cross-section and is determined by default as follows:

Cross-section	Contact Width b
	B
	10 mm
	2 * tha
	3 * tha
	tha
	Min (Bb ; Bc)

	tha + 2 * Bb
	2 * B
	3 * B
	tha
	2 * Bb
	2 * Bb
	3 * Ba
	Ba
	Bb + 2 * Ba

	2 * Bb + 3 * Ba
Any other section	10 mm

The length $\mathbf{l_{ef}}$ concerns the effective contact length and is calculated from the contact length **l** as specified in **article 6.1.5(1)**.

> **Both the contact width and the contact length can be overruled at any position for any cross-section using 'Compression perpendicular to the grain' additional data.**

Factor kc,90

The factor $\mathbf{k_{c,90}}$ is by default determined for a member on 'discrete supports' as follows:

In case $\mathbf{l_1 \geq 2 * h}$ AND **Solid timber** with name starting with "**C**" (= Softwood) => $\mathbf{k_{c,90} = 1{,}50}$

In case $\mathbf{l_1 \geq 2 * h}$ AND **Glulam timber** with $\mathbf{l \leq 400}$ **mm** => $\mathbf{k_{c,90} = 1{,}75}$

In all other cases $\mathbf{k_{c,90} = 1{,}00}$.

For a member on 'continuous supports', the factor $\mathbf{k_{c,90}}$ is determined as follows:

In case $\mathbf{l_1 \geq 2}$ * h AND **Solid timber** with name starting with "**C**" (= Softwood) => $\mathbf{k_{c,90} = 1{,}25}$

In case $\mathbf{l_1 \geq 2 * h}$ AND **Glulam timber** => $\mathbf{k_{c,90} = 1{,}50}$

In all other cases $\mathbf{k_{c,90} = 1{,}00}$.

> **By default the support condition is taken as 'discrete'. Using 'Compression perpendicular to the grain' additional data the support condition can be set to 'continuous'.**

In the above, in case there are neighbouring jumps to the left and right of the considered position, the length **l1**, between the contact lengths of two jumps, is taken as the minimal value of the length to the left and the length to the right.

The distance **a** is measured to the end of the buckling system, not the end of the actual member.

The depth h of a member is determined as $\mathbf{h = (y_{\_max} - y_{\_min})}$

With : $y_{\_max}$ = maximal vertical fiber coord.
$y_{\_min}$ = minimal vertical fiber coord.

Bending

The Bending check is executed according to **article 6.1.6**.

This check is executed only in case a bending moment $\mathbf{M_{y,Ed}}$ and/or $\mathbf{M_{z,Ed}}$ is/are present.

For the determination of the stress redistribution factor $\mathbf{k_m}$, a rectangular section is defined as one of the following:

- **RECT** (Timber)
- **Rectangle** (Geometric shapes)
- **Full rectangular** (**Form code 7**)

Shear

The Shear check is executed according to **article 6.1.7**.

This check was revised in the addendum A1 to EN 1995-1-1, see Ref.[3].

This check is executed only in case a shear force $\mathbf{V_{y,Ed}}$ and/or $\mathbf{V_{z,Ed}}$ is/are present.

The design shear stress $\boldsymbol{\tau_d}$ is calculated as follows:

$$\tau_{y,d} \qquad \frac{V_{y,Ed} * (\tau_{y,unit})}{k_{cr}}$$

$$\tau_{z,d} \qquad \frac{V_{z,Ed} * (\tau_{z,unit})}{k_{cr}}$$

With $\boldsymbol{\tau_{y,unit}}$ and $\boldsymbol{\tau_{z,unit}}$ the maximal unit shear stresses per fibre as taken from the cross-section.

The shear modification factor $\mathbf{k_{cr}}$ is determined depending on the National Annex. Reference is made to the Theoretical Background for the National Annex to EN 1995. By default this factor is taken as **0,67** for both Solid and Glued Laminated Timber.

Interaction of combined shear

EN 1995-1-1 does not give an interaction equation in case of combined shear.

The following interaction check is executed as NCCI:

$$\left(\frac{\tau_{y,d}}{f_{v,d}}\right)^2 + \left(\frac{\tau_{z,d}}{f_{v,d}}\right)^2 \leq 1$$

This interaction equation is taken from the German National Annex Ref.[8].

Torsion

The Torsion check is executed according to **article 6.1.8**.

This check is executed only in case a torsional moment $\mathbf{T_{Ed}}$ is present.

The design torsional stress $\tau_{tor,d}$ is calculated as follows:

$$\tau_{tor,d} \qquad T_{Ed} * (\tau_{tor,unit})$$

With $\tau_{tor,unit}$ the maximal unit torsion stress per fibre as taken from the cross-section.

> **In case the unit torsion stress is not calculated in the cross-section and a torsional moment is present, the torsion check cannot be executed. In this case the proper analysis should be set in the cross-section. (For example activating the 2D FEM analysis).**

For the determination of the shape factor $\mathbf{k_{shape}}$, a distinction is made between rectangular and circular cross-sections.

A rectangular section is defined as one of the following:

- **RECT** (Timber)
- **Rectangle** (Geometric shapes)
- **Full rectangular** (**Form code 7**)

With **b** taken as the smallest dimension of the rectangle and **h** as the biggest dimension of the rectangle.

A circular section is defined as one of the following:

- **CIRC** (Timber)
- **Circle** (Geometric shape)
- **Full circle** (**Form code 11**)

For any sections which are nor rectangular nor circular $\mathbf{k_{shape}}$ is taken as 1**,00**.

Interaction of combined shear and torsion

EN 1995-1-1 does not give an interaction equation for combined shear and torsion.

The following interaction check is executed as NCCI:

$$\left(\frac{\tau_{tor,d}}{k_{shape} \cdot f_{v,d}}\right) + \left(\frac{\tau_{y,d}}{f_{v,d}}\right)^2 + \left(\frac{\tau_{z,d}}{f_{v,d}}\right)^2 \leq 1$$

This interaction equation is taken from the German National Annex Ref.[8] as well as Ref.[7] pp 125.

Combined Bending and Axial Tension

The Combined Bending and Axial Tension check is executed according to **article 6.2.3**.

This check is executed only in case the following conditions are met:

- A tensile normal force $\mathbf{N_{Ed}}$ is present
- A bending moment $\mathbf{M_{y,Ed}}$ and/or $\mathbf{M_{z,Ed}}$ is present

Combined Bending and Axial Compression

The Combined Bending and Axial Compression check is executed according to **article 6.2.4**.

This check is executed only in case the following conditions are met:

- A compressive normal force $\mathbf{N_{Ed}}$ is present
- A bending moment $\mathbf{M_{y,Ed}}$ and/or $\mathbf{M_{z,Ed}}$ is/are present

Columns subjected to compression or combined compression and bending

The stability check for members subjected to compression or combined compression and bending is executed according to **article 6.3.2**.

This check is executed only in case a compressive normal force $\mathbf{N_{Ed}}$ is present.

For the calculation of the buckling ratio several methods are available:

- General formula (standard method)
- From Stability Analysis
- Manual input

Calculation of Buckling ratio – General Formula

For the calculation of the buckling ratios, some approximate formulas are used. These formulas are treated in reference [9], [10] and [11].

The following formulas are used for the buckling ratios (Ref.[9],pp.21):

For a non-sway structure

$$l/L = \frac{(\rho_1\rho_2 + 5\rho_1 + 5\rho_2 + 24)(\rho_1\rho_2 + 4\rho_1 + 4\rho_2 + 12)2}{(2\rho_1\rho_2 + 11\rho_1 + 5\rho_2 + 24)(2\rho_1\rho_2 + 5\rho_1 + 11\rho_2 + 24)}$$

For a sway structure

$$l/L = x\sqrt{\frac{\pi^2}{\rho_1 x} + 4}$$

With:	L	System length
	E	Modulus of Young (mean)
	I	Moment of inertia
	C_i	Stiffness in node i
	M_i	Moment in node i
	φ_i	Rotation in node i

$$x = \frac{4\rho_1\rho_2 + \pi^2\rho_1}{\pi^2(\rho_1 + \rho_2) + 8\rho_1\rho_2}$$

$$\rho_i = \frac{C_i L}{EI}$$

$$C_i = \frac{M_i}{\phi_i}$$

The values for M_i and ϕ_i are approximately determined by the internal forces and the deformations, calculated by load cases which generate deformation forms, having an affinity with the buckling shape.

The following load cases are considered:
load case 1: on the beams, the local distributed loads qy=1 N/m and qz=-100 N/m are used, on the columns the global distributed loads Qx = 10000 N/m and Qy =10000 N/m are used.
load case 2: on the beams, the local distributed loads qy=-1 N/m and qz=-100 N/m are used, on the columns the global distributed loads Qx = -10000 N/m and Qy= -10000 N/m are used.

In addition, the following limitations apply (Ref[9],pp.21):
- The values of ρ_i are limited to a minimum of 0.0001
- The values of ρ_i are limited to a maximum of 1000
- The indices are determined such that $\rho_1 \geq \rho_2$
- Specifically for the non-sway case, if $\rho_1 \geq 1000$ and $\rho_2 \leq 0,34$ the ratio l/L is set to 0,7

The used approach gives good results for frame structures with perpendicular rigid or semi-rigid beam connections. For other cases, the user has to evaluate the presented bucking ratios. In such cases a more refined approach (from stability analysis) can be applied.

The following rule applies specifically to ky: in case both the calculation for load case 1 and load case 2 return ky = 1,00 then ky is taken as kz. This rule is used to account for possible rotations of the cross-section.

Calculation of Buckling ratio – From Stability Analysis

When member buckling data from stability are defined, the critical buckling load $\mathbf{N_{cr}}$ for a prismatic member is calculated as follows:

$$N_{cr} = \lambda \cdot N_{Ed}$$

Using Euler's formula, the buckling ratio **k** can then be determined:

$$N_{cr} = \frac{\pi^2.E.I}{(k.s)^2} \Rightarrow k = \frac{1}{s}.\sqrt{\frac{\pi^2.E.I}{N_{cr}}}$$

With:	λ	Critical load factor for the selected stability combination
	N_{Ed}	Design loading in the member
	E	Modulus of Young (mean)
	I	Moment of inertia
	s	Member length

Beams subjected to bending or combined bending and compression

The stability check for members subjected to bending or combined bending and compression check is executed according to **article 6.3.3**.

This check is executed only in case a bending moment $\mathbf{M_{y,Ed}}$ is present.

The critical moment $\mathbf{M_{y,crit}}$ is determined using the general formula **(6.31)**.

The shear modulus $G_{0.05}$ is not given in any material code reference but is required for the Timber Code Check. This value is calculated during the Check as $E_{0.05}/16$ as given in Ref.[7] pp 109 and 209.

Effective length Lef

The effective length for Lateral Torsional Buckling is modified depending on the loading type and load position.

Loading Type

The ratio between the effective length $\mathbf{L_{ef}}$ and the span length is determined according to **Table 6.1**.

The current moment distribution is compared with several standard moment distributions. These standard moment distributions are:

- Moment line generated by a distributed q load
- Moment line generated by a concentrated F load
- Moment line which has a maximum at the start or at the end of the beam

The standard moment distribution which is closest to the current moment distribution determines the loading type.

Table 6.1 distinguishes between simply supported and cantilever beams. A cantilever is defined as a member at the end of a buckling system which has free ends for both buckling about the y-y and z-z axis. In addition, the LTB length should correspond to the full system length of the buckling system.

Loading Position

As specified in **Table 6.1** the effective length $\mathbf{L_{ef}}$ is modified depending on the load position.

In case **Influence of load position** in the buckling data is set to '**Destabilizing**':
$L_{ef} = L_{ef} + 2\ h$

In case **Influence of load position** in the buckling data is set to '**Stabilizing**':
$L_{ef} = L_{ef} – 0,5\ h$

With **h** taken as the maximal vertical dimension of the cross-section:
$h = (z_{max} – z_{min})$
z_{max} = maximal vertical fibre coordinate
z_{min} = minimal vertical fibre coordinate

Interaction

In case, beside a bending moment $\mathbf{M_{y,Ed}}$, also a compressive normal force $\mathbf{N_{Ed}}$ is present the following additional check according to formula **(6.35)** is executed:

$$\left(\frac{\sigma_{m,d}}{k_{crit}.f_{m,d}}\right)^2 + \frac{\sigma_{c,0,d}}{k_{c,z}.f_{c,0,d}} \leq 1$$

> **This interaction only accounts for lateral torsional buckling and weak axis flexural buckling. Strong axis flexural buckling and bending about the weak axis are not accounted for.**
> **In case the German National Annex is chosen, additional interaction checks are executed which do account for these effects. Reference is made to the Theoretical Background for the National Annex to EN 1995.**

Members with varying cross-section or curved shape

Specific checks for members with varying cross-sections or curved shapes are executed according to **article 6.4**.

In general, any non-uniform member is checked in each section using the actual cross-section properties at that section.

In addition, specific rules are applied for members which are detected as tapered or curved:

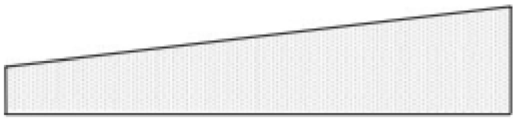
- Rules for single tapered beams are given in **article 6.4.2**
- Rules for double tapered beams are given in **article 6.4.3**
- Rules for curved beams are given in **article 6.4.3**

> **Pitched cambered members are not supported.**

All additional checks for tapered and curved members are only executed in case a bending moment $\mathbf{M_{y,Ed}}$ is present.

Single tapered beams

The specifics for single tapered beams are given in **article 6.4.2**.



Definition

A single tapered member is defined as a member with the following characteristics:

- A rectangular cross-section
  - **RECT** (Timber)
  - **Rectangle** (Geometric shapes)
  - **Full rectangular** (**Form code 7**)
- Material type **Glued, laminated**
- Only the height varies linearly <u>over the total member length</u>
- The height at the biggest end has to be larger than the width of the cross-section
- The haunch/arbitrary alignment is one of the following:
  - top surface
  - top left
  - top right
  - bottom surface
  - bottom left
  - bottom right

> **EN 1995-1-1 only gives rules in case of members with a single tapered edge thus a default alignment (both faces tapered) is not supported.**

Only tapered members which have a geometry which complies with the above definition are seen as actual single tapered beams for which the additional rules of EN 1995-1-1 apply.

Stresses at the tapered edge

Depending on the sign of the moment, the tapered edge is either in compression or in tension.

Alignment top && $M_{y,Ed}$ > 0 => Tapered edge in **tension**

Alignment top && $M_{y,Ed}$ < 0 => Tapered edge in **compression**

Alignment bottom && $M_{y,Ed}$ > 0 => Tapered edge in **compression**

Alignment bottom && $M_{y,Ed}$ < 0 => Tapered edge in **tension**

> **The stresses at the tapered edge are based solely on $M_{y,Ed}$, not on the combination of N_{Ed}, $M_{y,Ed}$, $M_{z,Ed}$ since their interaction is taken into account in the interaction formulae.**

Strength Reduction factor

Depending on the stresses at the tapered face, the strength reduction factor $\mathbf{k_{m,\alpha}}$ is determined.

Tapered face in **tension:**

$$k_{m,\alpha} = \frac{1}{\sqrt{1 + \left(\frac{f_{m,y,d}}{0,75 f_{v,d}} \tan\alpha\right)^2 + \left(\frac{f_{m,y,d}}{f_{t,90,d}} \tan^2\alpha\right)^2}}$$

Tapered face in **compression:**

$$k_{m,\alpha} = \frac{1}{\sqrt{1 + \left(\frac{f_{m,y,d}}{1,5 f_{v,d}} \tan\alpha\right)^2 + \left(\frac{f_{m,y,d}}{f_{c,90,d}} \tan^2\alpha\right)^2}}$$

The slope angle of the tapered edge is calculated as follows:

$$\tan(\alpha) = \frac{H_L - H_S}{L}$$

With:	H_L	Height at the largest end
	H_S	Height at the smallest end
	L	Member length

> **Both reduction factors are limited to a maximum of 1,00.**

Influence on the Section checks

For the bending check as well as the combined bending and axial tension/compression checks the following modifications are made:

- The strong axis bending resistance $\mathbf{f_{m,y,d}}$ is multiplied by $\mathbf{k_{m,\alpha}}$.

For example:

$$\frac{\sigma_{m,y,d}}{f_{m,y,d}} \longrightarrow \frac{\sigma_{m,y,d}}{k_{m,\alpha} * f_{m,y,d}}$$

- The depth factor $\mathbf{k_{h,y}}$ is calculated using the cross-section properties at the LARGEST end of the beam ($\mathbf{H_L}$).

Influence on the Stability check for buckling

For the buckling check (Columns subjected to compression or combined compression and bending), the EN 1995-1-1 code does not give any specific rules. This implies the following:

- The strong axis bending resistance $\mathbf{f_{m,y,d}}$ is multiplied by $\mathbf{k_{m,\alpha}}$.

- The slenderness in each section is calculated using the actual area and inertia at that given section.

Influence on the Stability check for LTB

For the LTB check (Beams subjected to bending or combined bending and compression) the following modifications are made based on the stresses at the tapered edge:

Tapered edge in tension

In case the tapered edge is in tension it means LTB does not occur at that side. In that case the critical moment $\mathbf{M_{y,crit}}$ and the critical bending stress $\boldsymbol{\sigma_{m,crit}}$ are calculated using the cross-section properties at the LARGEST end of the beam ($\mathbf{H_L}$). This implies that **It**, **Iz** and **Wy** as well as **h** used in **Lef** are all taken from the largest cross-section of the tapered member as opposed to the actual section.

Tapered edge in compression

In case the tapered edge is in compression it means LTB occurs at that side. In that case the following modifications are made:

- The strong axis bending resistance $\mathbf{f_{m,y,d}}$ is multiplied by $\mathbf{k_{m,\alpha}}$.

$$\sigma_{m,y,d} \leq k_{crit}\, f_{m,y,d} \longrightarrow \sigma_{m,y,d} \leq k_{crit}\, k_{m,\alpha}\, f_{m,y,d}$$

- The relative slenderness is calculated including $\mathbf{k_{m,\alpha}}$.

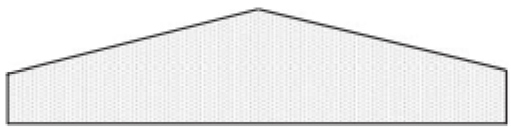
$$\lambda_{rel,m} = \sqrt{\frac{f_{m,k}}{\sigma_{m,crit}}} \longrightarrow \lambda_{rel,m} = \sqrt{\frac{k_{m,\alpha}\, f_{m,k}}{\sigma_{m,crit}}}$$

- The critical moment $\mathbf{M_{y,crit}}$ and the critical bending stress $\boldsymbol{\sigma_{m,crit}}$ are calculated using the cross-section properties at the LARGEST end of the beam ($\mathbf{H_L}$). This implies that **It**, **Iz** and **Wy** as well as **h** used in **Lef** are all taken from the largest cross-section of the tapered member as opposed to the actual section.

For background information to the above modifications reference is made to Ref.[7].

Double tapered beams

The specifics for double tapered members are given in **article 6.4.3**.



Definition

A double tapered member is defined as a member with the following characteristics:

- A rectangular cross-section
  - **RECT** (Timber)
  - **Rectangle** (Geometric shapes)
  - **Full rectangular** (**Form code 7**)
- Material type **Glued, laminated**
- One member with an arbitrary definition of two spans:
  - Each span length is half of the member length
  - Only the height varies linearly over the span length
  - On the first span the height varies from small to large, on the second span from large to small.
  - The height at the beginning of the first span and the end of the second span is equal.
  - The height at the end of the first span and the beginning of the second span is equal.

- The height at the end of the first span has to be larger than the width of the cross-section
- The arbitrary alignment of both spans is the same and is one of the following:
    - top surface
    - top left
    - top right
    - bottom surface
    - bottom left
    - bottom right

Only tapered members which have a geometry which complies with the above definition are seen as actual double tapered beams for which the additional rules of EN 1995-1-1 apply.

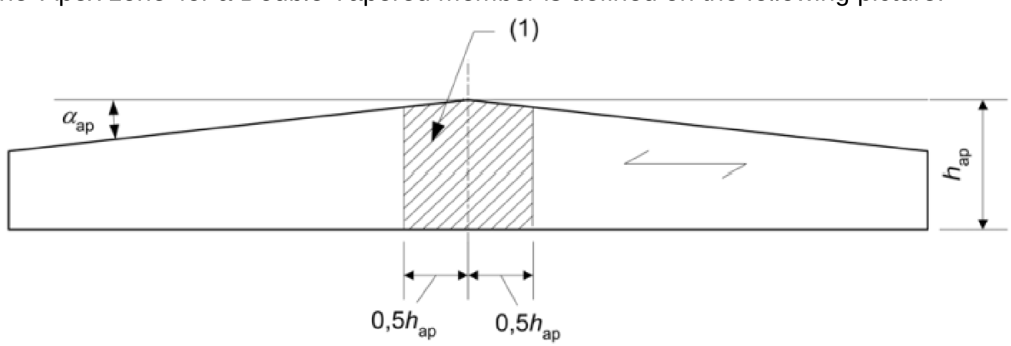
Single tapered beam

In each section of the double tapered beam also the modifications as listed in the paragraph for single tapered beams apply.

The member length **L** used for the determination of the slope angle is in this case taken as the span length.

Apex zone

The 'Apex zone' for a Double Tapered member is defined on the following picture:



For the sections located at the Apex (all sections in the hatched zone) additional checks are executed:
- Bending stress in the Apex zone
- Tension perpendicular to the grain in the Apex zone
- Combined tension perpendicular to the grain and shear in the Apex zone

For a Double tapered beam the radius r = ∞

Bending stress in the Apex zone

For a double tapered beam, the bending stress at the Apex is checked according to **article 6.4.3(3)**. As indicated in Ref.[7] this formula is enhanced to include also the reduction factor for LTB:

$$\sigma_{m,d} \leq k_{crit} \cdot k_r \cdot f_{m.d}$$

> **Following Ref.[12] pp.6 the influence of the tapered edge of a single tapered beam ($k_{m,\alpha}$) is not included in the verification formula for the bending stress in the apex zone. The k_{crit} used in the above verification can include this factor.**
>
> **As indicated in Ref.[13] pp.B8/8 the EN 1995-1-1 rules assume a constant moment acts over the Apex zone. Therefore $M_{ap,d}$ is taken as the maximal moment from all sections in the Apex zone.**

Tension perpendicular to the grain in the Apex zone

For a Double Tapered member, the tension perpendicular to the grain at the Apex is checked according to **article 6.4.3(6)**.

The total volume of the beam $\mathbf{V_b}$ is calculated as follows for a double tapered beam:

$$b * L * \left[h_{ap} - 0{,}25 * L * \tan\left(\alpha_{ap}\right)\right]$$

The stressed volume **V** of the Apex zone is calculated as follows for a double tapered beam, see Ref.[7]:

$b * h_{ap}^2 * \left[1 - 0{,}25 * \tan\left(\alpha_{ap}\right)\right]$ and limited to $\mathbf{(2/3)V_b}$

With	b	Width of the beam
	h_{ap}	Height at the Apex zone
	α_{ap}	Slope angle of the tapered edge
	L	Member length

> **In case the alternative formula (6.55) is used the line load p_d is calculated as the equivalent line load for the given moment diagram. In addition this line load is taken as positive in case it causes compression at the tapered edge.**

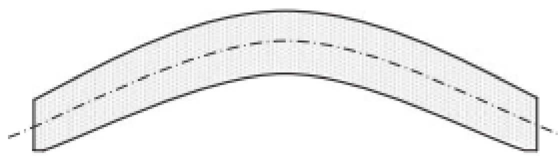
Combined tension perpendicular to the grain and shear in the Apex zone

For a double tapered beam, the combined shear and tension perpendicular to the grain at the Apex is checked according to **article 6.4.3(7)**.

This check is executed only in case a shear force $\mathbf{V_{z,Ed}}$ is present.
This shear force is taken for the actual section in which the check is executed.

Curved beams

The specifics for curved members are given in **article 6.4.3**.



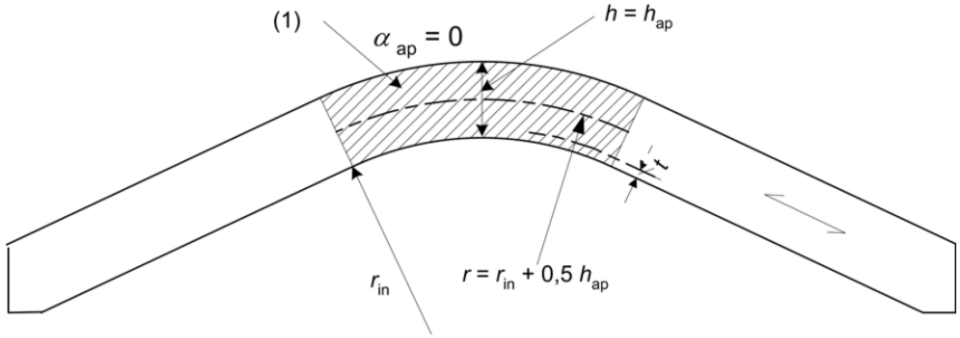
Definition

A curved beam is defined as a member with the following characteristics:

- A rectangular cross-section
    - **RECT** (Timber)
    - **Rectangle** (Geometric shapes)
    - **Full rectangular** (**Form code 7**)
- The height has to be larger than the width of the cross-section
- Material type **Glued, laminated**
- The member is uniform i.e. no haunch or arbitrary data
- The member has shape type **Polyline** with following characteristics:
    - All nodes are in one plane
    - The polyline has a sequence of type 'Line', 'Circle arc', 'Line'
    - The polyline is 'symmetric'

Apex zone

The 'Apex zone' for a curved beam is defined on the following picture:



For the sections located at the Apex (all sections in the hatched zone) additional checks are executed:

- Bending stress in the Apex zone
- Tension perpendicular to the grain in the Apex zone
- Combined tension perpendicular to the grain and shear in the Apex zone

Bending stress in the Apex zone

For a curved beam, the bending stress at the Apex is checked according to **article 6.4.3(3)**. As indicated in Ref.[7] this formula is enhanced to include also the reduction factor for LTB:

$$\sigma_{m,d} \leq \ k_{crit} \cdot k_r \cdot f_{m.d}$$

> **As indicated in Ref.[13] pp.B8/8 the EN 1995-1-1 rules assume a constant moment acts over the Apex zone. Therefore $M_{ap,d}$ is taken as the maximal moment from all sections in the Apex zone.**

Tension perpendicular to the grain in the Apex zone

For a curved beam, the tension perpendicular to the grain at the Apex is checked according to **article 6.4.3(6)**:

$$\sigma_{t,90,d} \ \leq \ k_{dis} \ k_{vol} \ f_{t,90,d}$$

The stressed volume **V** of the Apex zone is calculated as follows for a curved beam, see Ref.[7]:

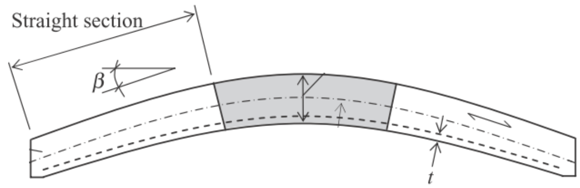
$$\frac{\beta\pi}{180} b\left(h_{ap}^2 + 2h_{ap}r_{in}\right)$$

This is limited to **(2/3)V**$_{\mathbf{b}}$

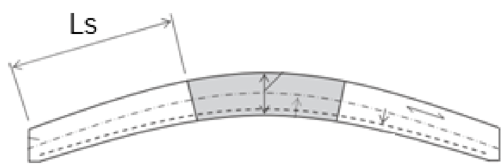
The total volume of the beam $\mathbf{V_b}$ is calculated as follows for a curved beam:

$$V + 2 * b * h_{ap} * L_s$$

With:	b	Width of the beam
	h_{ap}	Height of the beam
	β	Slope angle of the straight parts



	L_s	Length of one straight part



	r_{in}	Inner radius of the curved beam

Combined tension perpendicular to the grain and shear in the Apex zone

For a Curved beam, the combined shear and tension perpendicular to the grain at the Apex is checked according to **article 6.4.3(7)**.

This check is executed only in case a shear force $\mathbf{V_{z,Ed}}$ is present.
This shear force is taken for the actual section in which the check is executed.

System Strength

As specified in **article 6.6**, when several equally spaced similar members, components or assemblies are laterally connected by a continuous load distribution system, the member strength properties may be multiplied by a system strength factor $\mathbf{k_{sys}}$.

By default, the factor $\mathbf{k_{sys}}$ is taken as **1,00** so no system strength is used. However, through the use of Timber member data, the system strength factor $\mathbf{k_{sys}}$ can be defined for a given member.
In this case the design strengths for this member are increased by the inputted factor.

Serviceability Limit State

The Serviceability Limit State verifications are executed according to **article 2.2.3**.

Both the instant and the final relative deflections (including creep) are checked.

The final deformation is calculated according to **formula (2.2)**.

$$u_{fin} = u_{fin,G} + u_{fin,Q_1} + \sum u_{fin,Q_i}$$

As specified in article 2.2.3(5) this formula assumes a linear relation between the actions and corresponding deformations. Therefore, this relative deformation check cannot be executed for non-linear combinations.

For each load case, the final deformation with creep is calculated based on the type of action, as given in **formulas (2.3), (2.4), (2.5)**:

- Permanent action (**G**)

$$u_{fin,G} = u_{inst,G}\left(1 + k_{def}\right)$$

- Leading Variable action (**Q_1**)

$$u_{fin,Q,1} = u_{inst,Q,1}\left(1 + \psi_{2,1} k_{def}\right)$$

- Accompanying Variable action (**Q_i**)

$$u_{fin,Q,i} = u_{inst,Q,i}\left(\psi_{0,i} + \psi_{2,i} k_{def}\right)$$

The above is determined automatically in case Serviceability combinations according to the code are used:

- EN-SLS Characteristic
- EN-SLS Frequent
- EN-SLS Quasi-Permanent

In case the check is executed for a single variable load case, this is seen as a Leading Variable action.

In case the check is executed for a Linear serviceability combination or an Envelope serviceability combination, it is not possible to determine if the variable load cases are leading or accompanying. Therefore, every variable load case in such a combination is seen as a Leading Variable action.

Precamber according to article 7.2 is not supported.

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