Deutsches Institut für Bautechnik
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Approval body for construction products and types of construction

Bautechnisches Prüfamt

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European Technical Assessment

ETA-18/1014 of 14 May 2019

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General Part

Technical Assessment Body issuing the European Technical Assessment:	Deutsches Institut für Bautechnik
Trade name of the construction product	Kielsteg
Product family to which the construction product belongs	Pre-fabricated wood-based loadbearing stressed Skin Panels
Manufacturer	Kulmer Holz- Leimbau GesmbH Hart 65 8212 PISCHELSDORF ÖSTERREICH
Manufacturing plant	Kulmer Holz- Leimbau GesmbH Hart 65 8212 PISCHELSDORF ÖSTERREICH
This European Technical Assessment contains	34 pages including 6 annexes which form an integral part of this assessment
This European Technical Assessment is issued in accordance with Regulation (EU) No 305/2011, on the basis of	ETAG 019, used as EAD according to Article 66 Paragraph 3 of Regulation (EU) No 305/2011.

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Specific Part

1 Technical description of the product

'Kielsteg' Elements are industrially produced planar construction elements, consisting of

- Webs, which run in the longitudinal direction and have a profile in cross-section like a boat's keel (see Picture 1). The webs are made from plywood or OSB as defined in DIN EN 13986[1] and can include butt joints at right angles to the longitudinal axis of the element.
- Flanges, made of one of the following materials, each oriented flatwise parallel:
  - structural timber with rectangular cross section according to EN 14081-1[2] or according to EN 15497[3]. The timber may be visual or machine graded.
  - Glued laminated timber according to EN 14080[4].
  - Glued solid timber according to EN 14080.

Each timber member of the flange is glued along its narrow edge to a web component, the web components are also glued to each other at the level of the flanges. The fibre direction of the outer plies of the plywood webs and the strands of the outer layer of the OSB webs are always oriented parallel to the long axis of the element.

Any butt joints in adjacent webs within an element are staggered by at least 80 cm in the longitudinal direction.

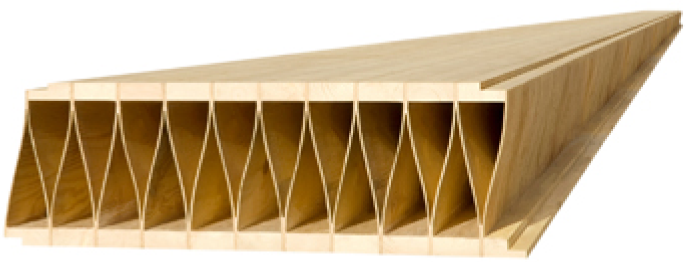

Figure 1: Kielsteg element, 3-D view

The elements conform to the following type as defined in ETAG 019[5], Section 2.1:

- Construction planked on both sides, closed box type
- With or without thermal insulation material. The insulation material does not contribute to the load-bearing ability of the element.

Kielsteg elements may be fitted with end plates made of wood-based panels in order to increase the load-bearing ability of the supports.

1	EN 13986:2004+A1:2015	Wood-based panels for use in construction – Characteristics, evaluation of conformity and marking
2	EN 14081-1:2016	Timber structures – Strength graded structural timber with rectangular cross section – Part 1: General requirements
3	EN 15497:2014	Structural finger jointed solid timber – Performance requirements and minimum production requirements
4	EN 14080:2013	Timber structures – Glued laminated timber and glued solid timber – Requirements
5	ETAG 019:2005	Pre-fabricated wood-based loadbearing stressed Skin Panels

The flanges made of timber members and the webs and end plates made of wood-based panels are not treated with wood preservatives.

The product with its dimensions and the individual components is shown in Annex 1.

2 Specification of the intended use in accordance with the applicable European Assessment Document (hereinafter EAD)

Kielsteg elements are intended to be used as load-bearing roof and floor elements in buildings. They can bear both loads perpendicular to the plane of the element and load in the plane of the element.

The performance levels in Section 3 may only be assumed if the products are used in accordance with the specifications and under the conditions set out in annex 2.

The verifications and assessment methods on which this European Technical Assessment is based lead to the assumption of a working life of the product of at least 50 years. The indications given on the working life cannot be interpreted as a guarantee given by the producer, but are to be regarded only as a means for choosing the right products in relation to the expected economically reasonable working life of the works.

3 Performance of the product and references to the methods used for its assessment

3.1 Mechanical strength and stability (BWR 1)

Essential characteristic	**Assessment**	**Performance**
Mechanical resistance and stability	See annex 3	
Serviceability	See annex 3	
Dimensional stability		
Web material		
OSB-Panels: Internal bond	EN 13986	≥ 0,3 N/mm²
OSB-Panels: Swelling in thickness	EN 13986	< 15%
Plywood-Panels: Bonding quality	EN 13986	class 3
Flange material		
Softwood: moisture content during manufacturing	EN 13183-1[6]	12% ± 3%

3.2 Safety in case of fire (BWR 2)

Essential characteristic	**Assessment**	**Performance**
Reaction to fire		
Kielsteg-element	EN 13501-1	Class E
Resistance to fire		
Kielsteg-element	NPA (For the timber members of the flange areas see Annex 2)	

6 EN 13183-1:2002 Moisture content of a piece of sawn timber. Part 1: Determination by oven dry method

3.3 Hygiene, health and the environment (BWR 3)

Essential characteristic	Assessment	Performance
Water vapour permeability μ		
Softwood (flange)	EN 14081-1 EN 15497 EN 14080	20 bis 50
OSB-Panels (Web)	EN 13986	150 (wet), 200 (dry)
Plywood-Panels (Web)	EN 13986	70 (wet), 200 (dry)
Content and/or release of dangerous substances		
OSB-Panels (Web)	EN 13986	E1, PCP ≤ 5 ppm
Plywood-Panels (Web)	EN 13986	E1, PCP ≤ 5 ppm
Softwood (flange)	EN 14081-1 EN 15497 EN 14080	E1
Other dangerous substances	ETAG 019, chapter 5.3.3	No other dangerous substances

3.4 Safety and accessibility in use (BWR 4)

The product does not include any floor surfaces, and for this reason no assessment of slip resistance was performed.

Essential characteristic	Assessment	Performance
Impact resistance	ETAG 019, chapter 5.4.2	adequate

3.5 Protection against noise (BWR 5)

Essential characteristic	Assessment	Performance
Airborne sound insulation	ETAG 019, chapter 5.5.1	NPA
Impact sound insulation	ETAG 019, chapter 5.5.2	NPA

3.6 Energy economy and heat retention (BWR 6)

The thermal resistance of the elements can be calculated in accordance with EN ISO 6946 or EN ISO 10211.

Essential characteristic	Assessment	Performance
Thermal conductivity λ		
Softwood (flange)	EN 14081-1 EN 15497 EN 14080	0,13 W/(mK)
OSB-Panels (Web)	EN 13986	0,13 W/(mK)
Plywood-Panels (Web)	EN 13986	0,13 W/(mK)
Thermal inertia		
Heat capacity c_p		
Softwood (flange)	EN 14081-1 EN 15497 EN 14080	1600 J/(kgK)
OSB-Panels (Web)	EN 13986	1700 J/(kgK)
Plywood-Panels (Web)	EN 13986	1600 J/(kgK)
Density		
Softwood (flange)	EN 14081-1 EN 15497 EN 14080	420 kg/m³
OSB-Panels (Web)	EN 13986	650 kg/m³
Plywood-Panels (Web)	EN 13986	500 kg/m³

4 Assessment and verification of constancy of performance (hereinafter AVCP) system applied, with reference to its legal base

In accordance with the Guideline for European Technical Approval ETAG No. 019, used as a European Assessment Document, the applicable European legal act is: Commission Decision 2000/447/EC[7].

The system to be applied is: 1.

[7] Official Journal of the European Communities No L 180, 19.07.2000

5 Technical details necessary for the implementation of the AVCP system, as provided for in the applicable EAD

Technical details necessary for the implementation of the AVCP system are laid down in the control plan deposited with Deutsches Institut für Bautechnik.

Issued in Berlin on 14 May 2019 by Deutsches Institut für Bautechnik

BD Dipl.-Ing. Andreas Kummerow
Head of Department

beglaubigt:
Warns

Kielsteg Element: Cross section

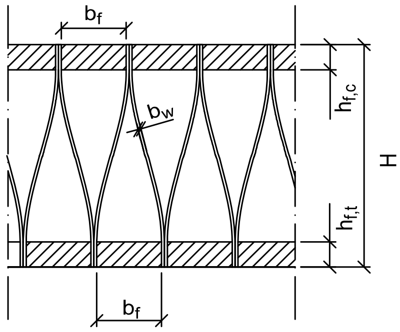

Figure 1.1: Kielsteg Element, Cross-Section

Kielsteg elements are flat elements with a minimum nominal width of 0.39 m and a maximum nominal width of 1.2 m. In the tension and compression zones at least five timber members are arranged in each flange. The timber members may have stress relief grooves parallel to their longitudinal direction.

The element heights H of Kielsteg elements with plywood webs are a minimum of 228 mm and a maximum of 380 mm. In elements with OSB webs, the element heights are a minimum of 485 mm and a maximum of 800 mm.

The lengths of the elements are a minimum of 2 m and a maximum of 35 m.

Further, the dimensions of the timber members of the flanges are within the ranges indicated in Table 1, dependent on the element height and the web material.

Table 1.1: Dimensions of the timber members of a flange of the Kielsteg elements depending on the type of wood-based panel and the element height of the Kielsteg elements

Wood-based panel of the web (nominal thickness in mm)	element height H	Dimensions of the timber members	
		width b_f	height $h_{f,t,c}$
	mm	mm	mm
Plywood (b_w = 4,3 mm up to 5 mm)	228-300	70 – 120	30 – 70
	301-380	70 – 130	30 – 70
OSB/3 (b_w = 8 mm, 10 mm or 12 mm)	485-640	70 – 155	40 – 80
	641-800	70 – 175	50 – 90

Kielsteg

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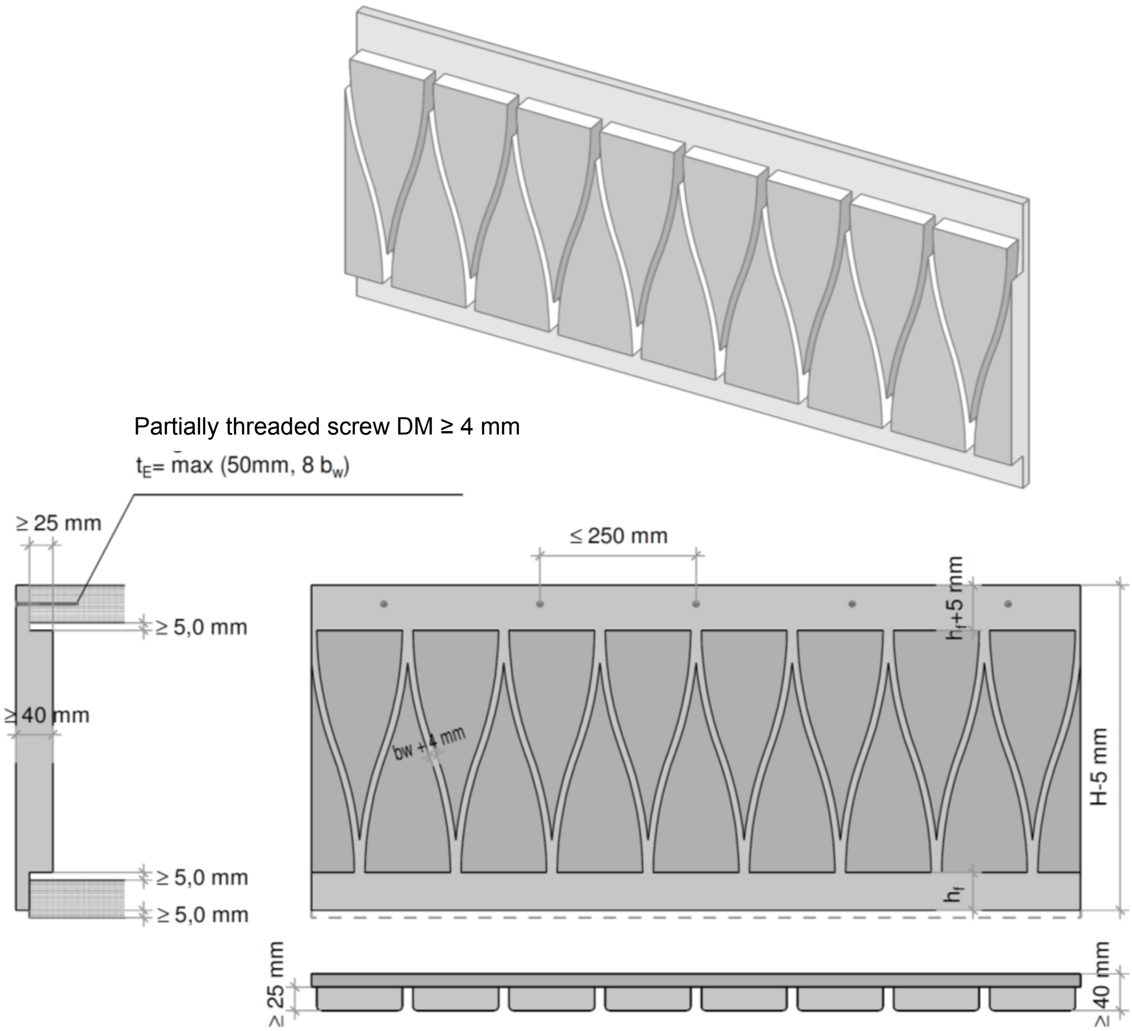
Structure and Dimensions

Kielsteg Elements: End Plates

The Kielsteg elements can be reinforced at the ends with end plates in which a sunken profile of grooves matching the S-shaped bent webs is cut. The reinforcing end plates are made of solid wood boards with at least 3 layers as defined EN 13986, of laminated veneer board with transverse plies as defined in EN 14374, of at least 7-ply plywood of the class EN 636-2 or of OSB/3 as defined in EN 13986. They have a thickness of at least 40 mm. The depth of the grooves in the reinforcing end plates is at least 25 mm.



The reinforcing plates are connected alongside the horizontal edge of the plate with the wood of the flanges by means of self-drilling partially threaded screws. The screws have a diameter of at least 4 mm. The penetration depths t_E of the screws in the solid wood of the flange is given by t_E = max (50 mm, 8b_w). The horizontal distance of the screws e_r from the lateral edges of the element is $b_f \leq e_r \leq 1.5b_f$.

Components

Flanges

The flanges are made of:

- Timber members made of softwood, which comply with the strength class C24 to C30 or T18 to T21 according to EN 14081-1 or EN 15497 respectively. The timber members are visual or machine graded.
- Homogenous glued laminated timber according to EN 14080 with a strength class GL24h to GL30h
- Glued solid timber according to EN 14080 with lamella of a strength class C24 to C30.

If the timber members of the flange are of heights $h_{f,t,c} \geq 40$ mm, they can be provided with stress-relief grooves as shown in Figure 1.2. A maximum of 2 stress-relief grooves can be made in each timber member.

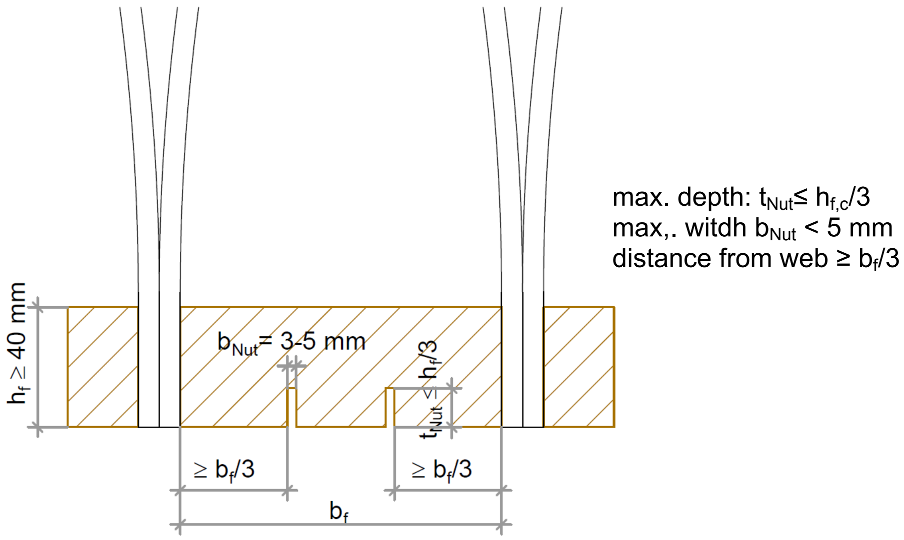


Figure 1.2: Stress-Relief Grooves

Kielsteg

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Page 4

Kielsteg-element: Structure and Dimensions

Webs

The webs are made of either three-layered plywood or OSB boards.

The plywood conforms to the requirements of EN 13986, type EN 636-2 as defined in EN 636[1] and the classes of bending strength and elasticity shown in Table 1.2.

Table 1.2: bending strength and bending modulus of elasticity of the plywood

	parallel to the grain of the outer plies		perpendicular to the grain of outer plies	
	min.	max.	min.	max.
class of bending strength	F35	F70	F10	F15
class of modulus of elasticity	E40	E100	E5	E20

The OSB boards conform to the requirements of EN 13986 and meet the requirements for boards for load-bearing applications in damp areas, Type OSB/3, in accordance with EN 300[2].

Adhesive

The finger joints, the flange-web joints and the web-web joints are made with adhesives of adhesive Type I according to EN 301[3] or according to EN 15425[4].

For the finger joints of the flange timber members an adhesive of at least the adhesive Type EN 15425 I 70 FJ 0.1 is used. For the flange-web and web-web joints at least the adhesive Type EN 301 I 70 GP 0.3S is used.

Insulation material

Insulation material with CE marks for filling the cavities of the elements can be supplied along with the Kielsteg elements. The characteristic values for the insulation material should be taken from its declaration of performance.

1	EN 636:2012+A1:2015	Plywood – Specifications
2	EN 300:2006	Oriented Strand Boards (OSB) – Definitions, classification and specifications
3	EN 301:2017	Adhesives, phenolic and aminoplastic, for load-bearing timber structures – Classification and performance requirements
4	EN 15425:2017	Adhesives – One component polyurethane (PUR) for load-bearing timber structures – Classification and performance requirements

Kielsteg

**Annex 2
Page 1**

Provisions for the intended use

A.1.1 intended use and loads

Kielsteg elements are intended to be used as load-bearing roof and floor elements in buildings. They can bear both loads perpendicular to the plane of the element and load in the plane of the element. Structural calculations for the elements are done in accordance with DIN EN 1995-1-1[5] as a uniaxial beam.

Kielsteg elements shall only to be subjected to static and quasi-static actions only.

Kielsteg elements are intended to be used in service classes 1 and 2 as defined in DIN EN 1995-1-1.

A.1.2 General assumptions

Design

The European Technical Assessment applies only to the manufacturing and use of the elements shown here. The verification of the stability and fitness for use of the structures built using Kielsteg element is outside the scope of this European Technical assessment.

The performance of the products for the intended use is stated under the following conditions:

- Design of the elements is carried out under the responsibility of an engineer experienced in such products.
- Design of the works accounts for the protection of the solid wood slab elements.
- The elements are not exposed to any harmful moisture. The definitions of the use classes 1 and 2 of EN 1995-1-1 apply. Formation of condensate on or around the elements must be reliably prevented.
- The elements are installed correctly.

The design of the products can be done in accordance with EN 1995-1-1 in conjunction with Section 3 and annexes 4 to 6 of this European Technical Assessment.

For the timber members of the flange areas the charring rates given in EN 1995-1-2[6] for solid wood may be assumed.

A.1.3 Packaging, transport, storage

The elements must be protected during transport and storage from all kinds of damage and any harmful effects of moisture. The elements should be stored elevated off the ground. Damaged products must not be installed.

A.1.4 Installation

The elements should be installed by qualified personnel under the supervision of the person responsible for engineering matters at the site.

During construction, the elements may only be lifted and moved using clearly marked and statically approved anchor points.

In the course of installation, the narrow edges of the webs attached to the outermost flanges of the elements must not be wetted more than briefly.

If reinforcements of the supports for the elements are to be made on site, the end plates are to be made in the factory and must be attached to the ends of the elements in accordance with the instructions in annex 1. Damaged elements may not be installed.

5	EN 1995-1-1:2004+AC2006 +A1:2010+A2:2014	Eurocode 5: Design of timber structures – Part 1-1: General – Common rules and rules for buildings.
6	EN 1995-1-2:2004 +AC:2006 +A1:2008	Eurocode 5: Design of timber structures – Part 1-2: General – Structural fire design

Kielsteg

Annex 3
Page 1

Characteristics of the Product in Respect of Mechanical Strength and Stability (BWR 1)

Mechanical strength and stability in use as a flat element / beam

As a mechanical model, the calculation for an ideal I-section beam is used as set out in Annex 4. Annex 5 provides instructions for the calculation according to EN 1995-1-1. Annex 6 shows in an example, how the resistance of the elements arise from the characteristics of the components.

The characteristics of the components represent the characteristics of the Kielsteg-element with regard to mechanical resistance and stability. The following performance characteristics are used for calculation:

Table 2.1: Characteristics of the components in respect of mechanical resistance

Essential characteristic	Assessment	Performance
Web material		
Bending modulus of elasticity (mean value) of the web material $E_{m,o,w,mean}$	EN 13986	≥ 3600 N/mm²
Shear modulus (mean value) of the web material under load in plane $G_{Scheibe,w,mean}$	EN 13986	≥ 220 N/mm²
Bending modulus of elasticity (mean value) of the web material perpendicular to the plane $E_{m,90,w,mean}$	EN 13986	≥ 450 N/mm²
Compression modulus (mean value) in plane of the web material perpendicular to the direction of the grain of the cover layer $E_{c,90,w,mean}$	EN 13986	≥ 400 N/mm²
characteristic effective shear strength $f_{v,w,eff,k}$ of the web material in plane of the web	ETAG 019, chapter 5.1.1.2	See table 2.2
characteritistic effective bending strength of the web material perpendicular to the elements plane $f_{m,90,w,eff,k}$	ETAG 019, chapter 5.1.1.2	≥ 7,0 N/mm²
characteristic compression strength of the web material in plane perpendicular to the direction of the grain of the cover layer $f_{c,90,w,k}$	EN 13986	≥ 2,5 N/mm²
Flange material		
Strength class	EN 14081-1, EN 14080 or EN 15497, based on material	At least C24

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Kielsteg **Annex 3**
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Characteristics of the Product in Respect of Mechanical Strength and Stability (BWR 1)

Table 2.2: characteristic effective shear strength $f_{v,w,eff,k}$ of the web material in plane of the web in N/mm²

Web-cross section aspect ratio h_w/b_w	characteristic effective shear strength $f_{v,w,eff,k}$ of the web material in plane of the web in N/mm²	
	Sperrholz	OSB/3
< 30	7,5	-
$30 \leq h_w/b_w \leq 66$	$7{,}5\left[0{,}1124+772\cdot\left(\frac{b_w}{h_w}\right)^2\right]$	
$45 \leq h_w/b_w \leq 66$	-	$4\left[-0{,}0133+2144\cdot\left(\frac{b_w}{h_w}\right)^2\right]$

Kielsteg **Annex 4**
Page 1

Calculation Model for Loading as a Beam

It is assumed that the calculations for Kielsteg elements are handling the elements as simple beams in accordance with EN 1995-1-1, Section 9.1.1 "Glued thin-webbed beams".
The calculation model uses the simplification of treating the elements as ideal I-section beams in which the S-shaped bent webs of thickness b_w are treated as though they were vertical.

Calculation model for bending loads

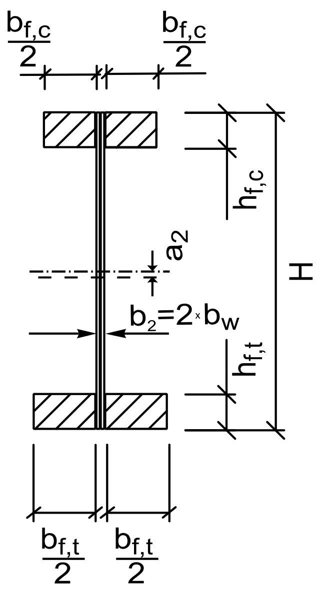

Figure 3.1:
Ideal cross-section

The web of the ideal I-section beam with the ideal web thickness $b_2 = 2\ b_w$ consists of two webs of the Kielsteg element. The idealised web is joined symmetrically to flanges of width $b_{f,t}/2$ bzw. $b_{f,c}/2$ on the bending compression and bending tension side. The complete element consists of a group of n_b uniform beams where n_b denotes the number of ideal I-sections making up the whole element. Half-sections of the ideal beam unit at the edge of the element can also be included in the calculation (see Figure 3.2.). Any flanges that are cut (in the direction of the flange width) may be entered into the calculation only with half their width, $b_{f,c}/2$ or $b_{f,t}/2$.

The calculation model assumes that each virtual I-section beam rests on structural supports at its ends. If this is not possible for reasons of the geometry of the structure, then it is recommended to implement appropriate structural measures in order to arrive at a configuration that can be well approximated by a model of support at both ends as assumed in the calculation model. With this provision, Kielsteg elements can be used in situations where the edges are cut at an angle, as long as the minimum widths are complied with.

The performance figures given in the declaration of performance account for the actual curved form of the web material.

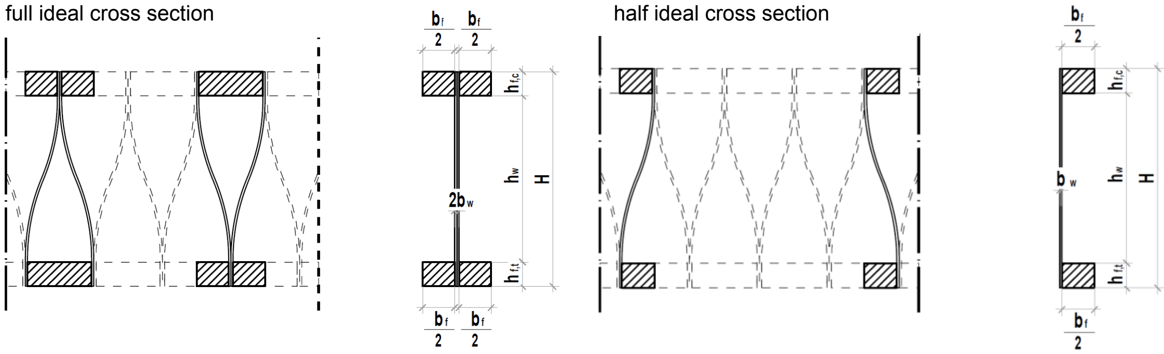

Figure 3.2 complete and half ideal cross sections

Kielsteg

Calculation model for the loading capacity of the web in the area of structural supports

The calculation is done assuming an ideal I-section beam according to the method set out in EN 1995-1-1, Section 9.1.1 "Glued thin-webbed beams". To account for the special geometry, the following extended calculation model can be used to calculate the effective support strength F_{Rk} accounting for web buckling of half of the ideal cross section, defined by the vertical symmetry plane (1 web and one half of a flange width b_f).

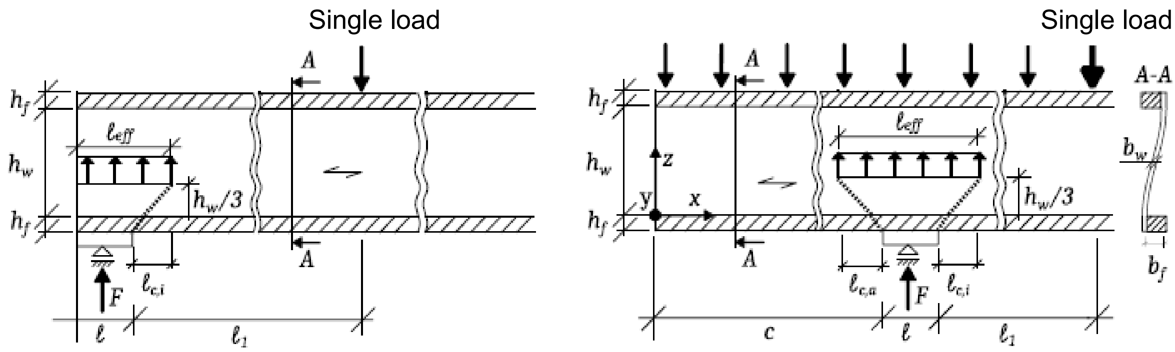

Figure 3.3: Support loading calculation

Following the calculation model, F_{Rk} is calculated from the implicit relation

$$\frac{M_{F,k}(F_{Rk},F_{I,crit})}{W_w}=f_{m,90,w,eff,k}$$

where

$W_w=\frac{b_w^2}{6}$ — Resistance moment of the web against lateral bending with unit length of 1

$f_{m,90,w,eff,k}$ — Effective bending strength of the web material perpendicular to plane of the web

$$M_{F,k}=0{,}7\ M_H+M_H\left(A_1\left(\frac{F_{Rk}}{F_{I,crit}}\right)+A_2\left(\frac{F_{Rk}}{F_{I,crit}}\right)^2+A_3\left(\frac{F_{Rk}}{F_{I,crit}}\right)^3+A_4\left(\frac{F_{Rk}}{F_{I,crit}}\right)^4\right)$$

$M_H=\frac{b_f\cdot b_w{}^3\cdot E_{m,90,w,sec,mean}}{4\cdot L^2}$ — Internal stress moment resulting from manufacturing

Kielsteg

Calculation model for the loading capacity of the web in the area of structural supports

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Page 3

L — curved length of the web between the inside edges of the flanges:

approximate solution: $L(h_w,b_f)=\sqrt{h_w^2+\left(\frac{b_f}{2}\right)^2}$

Exact solution:

$$=\frac{\sqrt{4+\left(\frac{3b_f}{2h_w}\right)^2}\,h_w\left(4b_f^{\,6}+25b_f^{\,4}h_w^{\,2}+50b_f^{\,2}h_w^{\,4}+32h_w^{\,6}\right)}{\left(\left(\frac{3b_f}{2}\right)^2+(2h_w)^2\right)^3}$$

A_1 to A_4 — Load and overhang-dependent coefficients

Support type	overhang	coefficients			
	c	A_1	A_2	A_3	A_4
End support	$c\leq\frac{h}{4}$	-0.117	0.242	-0.0249	0.00143
End support	$\frac{h}{4}<c\leq h$	-0.312	0.600	-0.128	0.0108
Cantilever arm and continuous beam	c>h	-0.308	0.557	-0.144	0.0170
Load introduction	c>2 h	-0.0607	0.218	-0.0344	0.00207

$F_{I,crit}=F_{crit,\infty}\cdot(1+k_f)\cdot k_{rel}$ — Stability load of the fictional I-section beam

where

$$F_{crit,\infty}=\frac{\pi^2\sqrt{E_{m,0,w,mean}\cdot E_{m,90,w,sec,mean}}\cdot I_w\cdot\sqrt[4]{\left(\frac{E_{m,90,w,sec,mean}}{E_{m,0,w,mean}}\right)}\cdot K(\bar{\ell},\xi)}{L}$$

$$k_f=\frac{2\cdot\left(b_f\cdot E_{m,0,f,mean}+2\cdot b_w\cdot E_{m,0,w,mean}\right)\cdot h_f^2\cdot(4\cdot h_f+3\cdot L)}{b_w\cdot E_{m,0,w,mean}\cdot(2\cdot h_f+L)^3+b_f\cdot E_{m,0,f,mean}\cdot h_f\cdot\left(4\cdot h_f^2+6\cdot h_f\cdot L+3\cdot L^2\right)}$$

$$k_{rel}=1+\frac{-0{,}63}{1+\left(\left(\frac{c+\ell/8}{L\cdot 0{,}27}\right)\left(\frac{E_{m,90,w,sec,mean}}{E_{m,0,w,mean}}\right)^{0{,}25}\right)^{2{,}3}}$$

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Kielsteg

Annex 4
Page 4

Calculation model for the loading capacity of the web in the area of structural supports

$I_w = \frac{b_w^3}{12}$	Area moment of inertia of the web with the unit length of 1
$K(\xi,\bar{\ell}) = a_0(\xi) + a_1(\xi)\,\bar{\ell} + a_2(\xi)\,\bar{\ell}^2$ where	Dimensionless buckling coefficient
$\bar{\ell} = \sqrt[4]{\frac{E_{m,90,w,sec,mean}}{E_{m,0,w,mean}}} \cdot \frac{\ell}{L}$	Normalized supported length
$\xi = \frac{2 \cdot G_{Scheibe,w,mean}}{\sqrt{E_{m,0,w,mean} \cdot E_{m,90,w,sec,mean}}}$	Cross number
$a_0(\xi) = 3.15 + 1.51\,\xi$	$a_i(\xi)$ coefficient range $0.3 \le \xi \le 1$
$a_1(\xi) = 0.21 - 0.09\,\xi$	
$a_2(\xi) = 1.74 - 0.46\,\xi$	
$E_{m,0,w,mean}$	Bending modulus of elasticity (mean) of the web material
$G_{Scheibe,w,mean}$	Shear modulus (mean) of the web material under load in plane
b_f	Width of the wood of the flanges
b_w	Thickness of the web material
h_w	Free height of the web between the flanges
$E_{m,90,w,sec,mean}$	Secant bending modulus of elasticity of the web material under bending perpendicular to the plane with $E_{m,90,w,mean}$ as the bending module of elasticity: $E_{m,90,w,sec,mean} = 0.85 \cdot E_{m,90,w,mean}$
ℓ	Supported or load transfer length, see Figure 3.3

When using reinforcing end plates according to annex 1 the characteristic value of the support loading capacity F_{Rk} may be raised as follows:

- Products with plywood webs, supported length ≥ 50 mm, overhang length c ≤ 20 mm:
  Increase by factor 1.7
- Products with plywood webs, supported length ≥ 50 mm, overhang length $h_f \le c \le h$:
  Increase by factor 1.2
- Products with OSB webs, supported length ≥ 50 mm, overhang length 0 ≤ c ≤ h:
  Increase by factor 1.1

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Remarks for calculations acc. to EN 1995-1-1 (informative)

To improve the thermal or acoustic insulation, the cavities between the webs of the elements can be filled with insulation material. The tension load on the webs and the resultant shear load on the flange-web joints due to the weight of the insulation material must be accounted for in the structural calculations. It is recommended to treat the interaction between the shear loads in the flange-web joints, with one component parallel to the long axis of the flanges arising from compression due to bending, and another component perpendicular to the long axis of the flanges due to transverse tension, as linear. It should be ensured that the capacity of the wooden flange strips to resist rolling shear should not be used to more than 20 %.

The position and configuration of cutouts, openings, penetrations etc. must be considered in the design and structural calculations. It is assumed that single openings of up to 50 mm can be considered negligible in the calculations.

It is recommended to avoid tension loads of the flanges across the grain direction.

Stress-relief grooves in the flanges should be accounted for in the calculation of the cross-sectional values.

Web sections that are no longer connected at full strength to the top and bottom flanges due to cutouts should not be subjected to load.

Loading as beam

The structural calculation can be done using the calculation model shown in Annex 3.

For the verification of the centre-of-gravity stress in the wooden tension flanges, the characteristic tension strength parallel to the grain direction can be raised by the factor 1.2. The factor k_h as defined in EN 1995-1-1 should not be applied.

The calculation of shear loading on the webs in the web plane can be done using the characteristic effective shear strengths in the web plane $f_{v,w,eff,k}$, without more detailed verification, implicitly covering the buckling risk and the S-shaped curve of the webs perpendicular to the web plane.

For the verification of the flange-web glued joints and the web-web glued joints, the equations (9.10) of EN 1995-1-1 can be applied by analogy. In contrast to these methods, the verification for the effective web thickness should be done using the single thickness of the web sheet material $b_{eff} = b_w$. The reduction factor for the joint strength as set out in the equations (9.10) of EN 1995-1-1 should be applied if the condition $h_{f,c(t)} > 4\ b_w$ is true.

For Kielsteg elements with plywood webs, the calculation of the value for the shear strength of the glued joints should be done using the characteristic shear strength of the plywood under load perpendicular to the plane of the plywood of 1.3 N/mm². For Kielsteg elements with OSB webs, the calculation of the value for the shear strength of the glued joints should be done in dependence on the OSB thickness $8 \le b_w$ (mm) ≤ 12 using a maximum value for the characteristic shear strength of $f_{v,OSB,k} = 1.2 - 0.05\ b_w$ (N/mm²) (b_w in mm).

For the calculation of deflection of the Kielsteg elements, the mean value of the modulus of elasticity of the wooden flanges according to EN 14081-1 or EN 15497 can be increased by the factor 1.04.

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Page 2

Remarks for calculations acc. to EN 1995-1-1 (informative)

Combined bending-compression-buckling verification

It is recommended to carry out the combined bending and compression calculation in the supported zone as follows:

$$\left(\frac{2}{3}\frac{0{,}95\cdot F_{Ed}}{\ell_{eff}\cdot b_w\cdot 2\cdot f_{c,90,w,d}}\right)^2+\left(\frac{F_{Ed}}{2\cdot F_{Rd}}\right)\leq 1$$

F_{Ed} Design value for the load on the support per ideal cross-section

$\ell_{eff} = \ell + \ell_{c,a} + \ell_{c,i}$ Effective load distribution length, as in Figure 3.3

where

$\ell_{c,i} = \min\left(30\text{ mm}; \ell_1/2; \ell\right) + \frac{h_w}{3} < \ell_1/2$, see Figure 3.3.

$\ell_{c,a} = \min\left(30\text{ mm}; c; \ell\right)$ Overhang c load-free, see Figure 3.3.

$\ell_{c,a} = \min\left(30\text{ mm}; c; \ell\right) + \frac{h_w}{3} < c$ Overhang c under load, see Figure 3.3.

F_{Rd} Design value for the support resistance force taking into account the web buckling of half the ideal cross-section, based on the vertical symmetry axis (1 web and half of one flange width b_f)

Compression stress verification along the supported area

For the flange:

$$\frac{F_{f,Ed}}{\ell\cdot b_f\cdot k_{c,90}\cdot f_{c,90,f,d}}\leq 1$$

where

$$F_{f,Ed}=F_{Ed}\frac{E_{m,90,f,mean}\cdot b_f}{E_{m,90,f,mean}\cdot b_f+2\cdot E_{c,90,w,mean}\cdot b_w}$$

and

$F_{f,Ed}$	design value for the fractional support force on the solid wooden flange
F_{Ed}	design value for the total support force per ideal cross-section
$E_{m,90,f,mean}$	Modulus of elasticity of bending (mean) of the flange wood perpendicular to the grain direction
$E_{c,90,w,mean}$	Modulus of elasticity of compression (mean) in the plane of the web material perpendicular to the grain direction of the outer plies or to the major axis
$K_{c,90}$	Coefficient for compression loading perpendicular to the grain direction for solid wood as defined in EN 1995-1-1; $k_{c,90}$=1.25
$F_{c,90,f,d}$	design value for the compression strength of the wooden flanges perpendicular to the direction of the grain.
ℓ	Supported length / load application length

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Remarks for calculations acc. to EN 1995-1-1 (informative)

For the web:

$$\frac{F_{w,Ed}}{2 \cdot \ell \cdot b_w \cdot f_{c,90,w,d}} \leq 1$$

where

$$F_{w,Ed} = F_{Ed} \frac{2 \cdot E_{c,90,w,mean} \cdot b_w}{E_{m,90,f,mean} \cdot b_f + 2 \cdot E_{c,90,w,mean} \cdot b_w}$$

$F_{w,Ed}$	design value of the fraction of the support force on the web of thickness $2 \cdot b_w$
$F_{c,90,w,d}$	design value for the compression strength of the web material in plane perpendicular to the grain direction of the outer plies or to the major axis

Loading in plane

For Kielsteg elements in roofs and structural floors subject to loads in plane, it is recommended to calculate as though only one flange layer is present as a rigid diaphragm, with the dimensions:

Flange thickness $h_{f,c,t}$ x element width b x element length l

The diaphragm should be directly connected to the substructure.

If multiple Kielsteg elements are used to form a diaphragm, then the joints between the elements should be made rigid to shear forces. If the joints between the elements are made with mechanical fastenings, then it is recommended to take into account the joint slip of these connections in the calculations.

Connectors

The verification of the connection of the Kielsteg elements to the structure of the building using mechanical fasteners can be done according to EN 1995-1-1. The fasteners should always be situated in the wooden flanges and should comply with the minimum distances from the edges of the elements.

The verification of shearing failure should consider only the wooden flanges of the flange layer that is directly fastened to the substructure. Verification of axial pulling out of screws (e.g. due to wind suction forces) should be based on the lengths of threaded screw sections in the top and bottom flanges.

Lateral fastening of the Kielsteg elements via the webs at the level of the internal cavities is not intended. If the flanges are fastened laterally, the fasteners may penetrate the outside webs.

Durability

The product is intended to be used in the use classes 1 or 2. Due to the open structure, especially if the elements are not fully insulated, hygrothermic calculations should ensure that condensate that may be formed from the vapour diffusion flow at the level of the webs can be fully absorbed by capillary action or absorption in every season of the year. Precipitation of non-absorbed condensate and fungal growth on any surfaces of the element must be reliably prevented.

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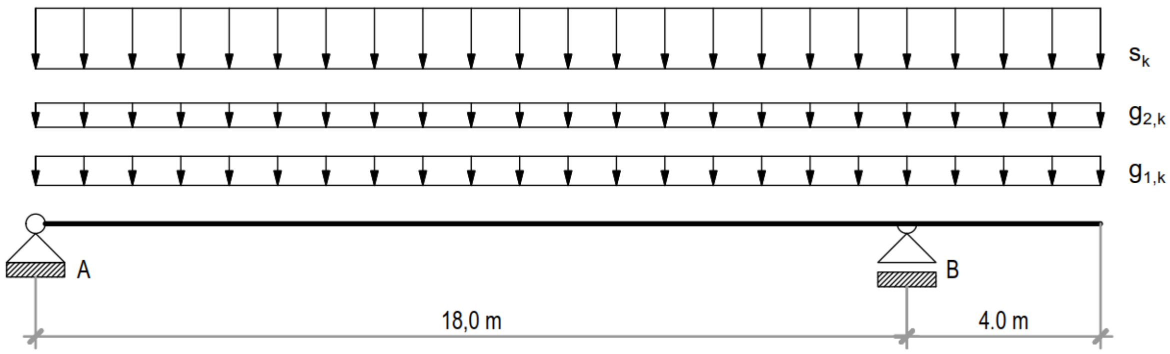
Calculation example (informative)

The calculation is done according to EN 1995-1-1, especially chapter 9.1 with the specifications given in annex 4 of this ETA.

structural system: one field-beam with cantilever arm



Roof element in service class 2, several elements parallel, width of an element 1170 mm. Length of the support l = 100 mm on both supports.

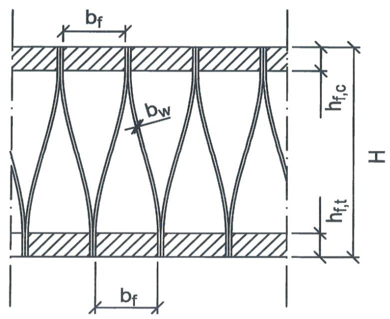
Load

Selfweight of the element	$g_{1,k}$	1.20 kN/m²
Permanent load	$g_{2,k}$	1.0 kN/m²
Snow load	s_k	2.5 kN/m²

Composition of the element

Element KSE 730/80/134
Webmaterial OSB/3, flanges softwood C24

Overall height	H = 730 mm
Height of the flanges	h_f = 80 mm
Width of the flanges	b_f = 134 mm
Width of a web	b_w = 10 mm
Height of the web area	h_w = 570 mm



Material characteristics

Flange material (Index f)

	$E_{f,0,mean}$	11000	N/mm²
	$E_{m,90,f,mean}$	370	N/mm²
	$f_{c,0,f,k}$	21.0	N/mm²
	$f_{t,0,f,k}$	14.0	N/mm²
C24	$f_{c,90,f,k}$	2.5	N/mm²
	k_{sys}	1.2	
	$f_{m,f,k}$	24.0	N/mm²
	$\rho_{mean,f}$	420	kg/m³

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Page 2

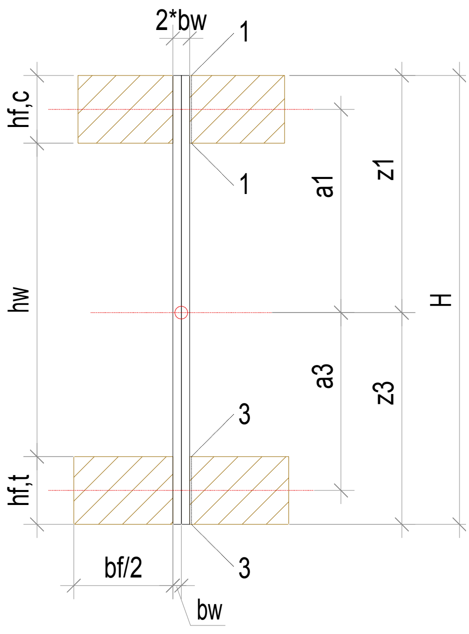
Calculation example (informative)

Web material (Index w)

	$E_{t/c,0,w,mean}$	3800	N/mm²
	$E_{m,0,w,mean}$	4930	N/mm²
	$E_{m,90,w,mean}$	2180	N/mm²
	$E_{c,90,w,mean}$	3000	N/mm²
	$G_{plane,\ w,mean}$	1080	N/mm²
	$f_{m,90,w,k}$	12.70	N/mm²
OSB/3	$f_{c,0,w,k}$	15.90	N/mm²
	$f_{t,0,w,k}$	9.90	N/mm²
	$f_{c,90,w,k}$	12.90	N/mm²
	$f_{v,w,eff,k,OSB/3}$ (see table 2.2)	2.59	N/mm²
	$f_{v,90,w,k}$	1.0	N/mm²
	$\rho_{mean,w}$	600	kg/m³

Calculations on the ideal cross section

The calculation of the cross section is done on the ideal cross section derived from the flanges and webs, contracted to 1 m.



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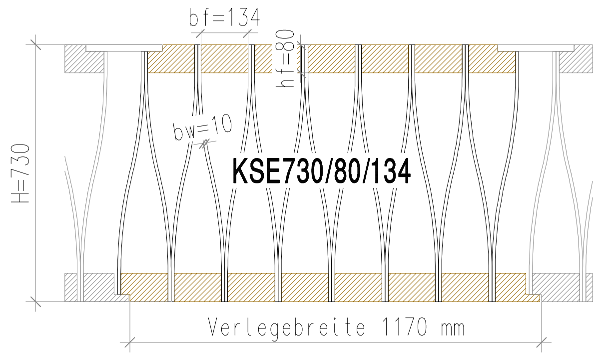
Calculation example (informative)

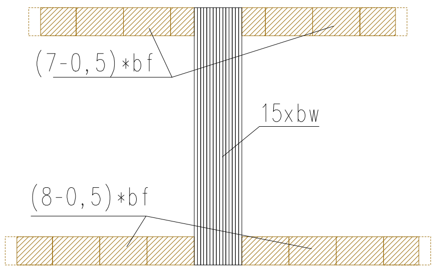
Determination of the calculated number of flanges n_f and webs n_w per meter taking into account the geometry of the Kielsteg-element and the shaping of gaps

The geometry of a common Kielsteg-element with an element width of 1170 mm and the reduction of the cross section by joints on the longitudinal edges are taken into account for by an adapted net cross section in this example.
Therefore both flanges of the elements cross section are reduced by half the width of a flange piece and the cross section is recalculated to an element width of 1 m. Other width of the element and compositions of gaps or joints could be handled in the same way.

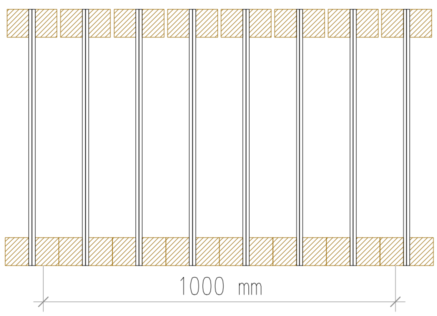
Real element cross section



Simplified element net cross section



Ideal cross section per meter



Kielsteg

Calculation example (informative)

$$n_{f,c,net} = \frac{n_{f,c} - 0.5}{1.17} = \frac{7 - 0.5}{1.17} = 5.556 \text{pieces} / \text{m}$$

$$n_{f,t,net} = \frac{n_{f,t} - 0.5}{1.17} = \frac{8 - 0.5}{1.17} = 6.410 \text{pieces} / \text{m}$$

$$n_{w,net} = \frac{n_w}{1.17} = \frac{15}{1.17} = 12.821 \text{pieces} / \text{m}$$

Ideal dimensions:

$$\text{Ideal top flange}: b_1 = n_{f,c,net} \cdot b_f = 744.50 \text{ mm}$$

$$\text{Ideal web}: b_2 = n_{w,net} \cdot b_w = 128.21 \text{ mm}$$

$$\text{Ideal bottom flange}: b_3 = n_{f,t,net} \cdot b_f = 858.94 \text{ mm}$$

z_s = 346.46 mm ; a_1 = 343.54 mm ; a_3 = 306.46 mm

Area Moments and stiffnesses

Bending stiffness
For the initial state:

$$EI = \sum \frac{E_i \cdot b_i \cdot h_i^3}{12} + \sum E_i \cdot b_i \cdot h_i \cdot a_i^2 = 166.82 \text{ MN/m²}$$

Equivalent cross section of the same bending stiffness with E_{ref} = 11000 N/mm² for the calculation of the stress resultants:

$$E_{ref} I = EI \Rightarrow I = 1516545 \text{ cm}^4 \text{ ; } H = 73 \Rightarrow b_{ref} = 46.78 \text{ cm}$$

For the limit states analogue with

$$E_{GZT,fin,Material} = \frac{E_{mean,Material}}{1 + \psi_2 \cdot k_{def,Material}} \qquad E_{GZG,fin,Material} = \frac{E_{mean,Material}}{1 + k_{def,Material}}$$

For simplification ψ_2=1,0 is used.
Flange C24, service class 2: k_{def}= 0,8, γ_M=1,3
Web OSB3, service class 2: k_{def}= 2,25, γ_M=1,3

	Initial state		Ultimate limit state		Serviceability limit state	
	E_{mean}	EI	$E_{GZT,fin}$	$EI_{GZT,fin}$	$E_{GZG,fin}$	$EI_{GZG,fin}$
	N/mm²	MN/m²	N/mm²	MN/m²	N/mm²	MN/m²
flange: C24	$E_{f,0,mean}$ = 11000	164.98	4701	67.4661	6111	87.7032
Web: OSB/3	$E_{t/c,0,w,mean}$ = 3800		899		1169	

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Calculation example (informative)

Section moduli

	Initial state				end state = ultimate limit state			
	Distance from gravity center		Section moduli		Distance from gravity center		Section moduli	
Edge stress top flange	z1	383.54 mm	W_1	39104 cm³	z1	385.37 mm	$W_{1,fin}$	37241 cm³
Edge stress bottom flange	z3	346.46 mm	W_3	43289 cm³	z3	344.63 mm	$W_{3,fin}$	41643 cm³
Stress at center of gravity top flange	a1	343.54 mm	$W_{1,S}$	43657 cm³	a1	345.37 mm	$W_{1,S,fin}$	41554 cm³
Stress at center of gravity bottom flange	a3	306.45 mm	$W_{3,S}$	48939 cm³	a3	304.63 mm	$W_{1,S,fin}$	47111 cm³
Edge stress web top	z1	383.54 mm	$W_{2,c}$	113194 cm³	z1	385.37 mm	$W_{2,c,fin}$	194736 cm³
Edge stress web bottom	z3	346.46 mm	$W_{2,t}$	125310 cm³	z3	344.63 mm	$W_{2,t,fin}$	217758 cm³

Static Moments

	Initial state		end state = ultimate limit state	
Vertical glue line flange/web top	$ES_{1,}$	$1.75545 \cdot 10^{10}$ Nmm	$ES_{1,fin}$	$7.54213 \cdot 10^{9}$ Nmm
Vertical glue line flange/web bottom	ES_3	$1.80689 \cdot 10^{10}$ Nmm	$ES_{3,fin}$	$7.67582 \cdot 10^{9}$Nmm
Center of gravity of the web	ES_2	$2.60891 \cdot 10^{11}$ Nmm	$ES_{3,fin}$	$1.05252 \cdot 10^{11}$ Nmm

Support forces and stress resultants

Structural System: see above. Ultimate limit state for the leading load combination: $\gamma_{G,J}$*$G_{k,j}$+$\gamma_{q,1}$*$Q_{k,1}$
$k_{mod,\ C24}$ = 0.90; $k_{mod,OSB/3}$ = 0.70

		LF1: $g_{1,k} + g_{2,k}$	LF 2: s_k	E_d acc. to EN 1995-1-1
Shear force left support, supporting force A	$V_{A,re}$	18.82 kN	21.39 kN	57.49 kN
Shear force right support, left side	$V_{B,li}$	-20.78 kN	-23.61 kN	**-63.47 kN = V_d**
Shear force right support, right side	$V_{B,re}$	8.80 kN	10.00 kN	26.88 kN
Bending moment, right support	M_B	-17.60 kNm	-20.00 kNm	-53.76 kNm
Maximum moment	M_{max}	80.52 kNm	91.50 kNm	**245.94 kNm = M_d**
supporting force B	B	29.58 kN	33.61 kN	**90.35 kN = B_d**

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Calculation example (informative)

Stresses and verifications

In this example only the verification for the initial state is shown. The verification for the ultimate limit state is analogue.
The material safety factor is assumed to be γ_M = 1.3 for web and flange in this example (According to EN 1995-1-1, table 2.3, γ_M = 1.20 would be applicable for the web).

Edge stresses of the wood of the flange

$$\sigma_{1,d} = \frac{M_d}{W_1} = \frac{245{,}94\text{ kNm}}{39104\text{ cm}^3} = 6{,}29\text{ N/mm}^2 \leq f_{m,d,C24} = 16{,}62\text{ N/mm}^2$$

$$\sigma_{3,d} = \frac{M_d}{W_3} = \frac{245.94\text{ kNm}}{43289\text{ cm}^3} = 5.68\text{ N/mm}^2 \leq f_{m,d,C24} = 16.62\text{ N/mm}^2$$

Stress at center of gravity: tension / compression

$$\sigma_{1,S,d} = \frac{M_d}{W_{1,S}} = 5.63\text{ N/mm}^2 \leq f_{c,d,C24} \quad ; \quad \sigma_{3,S,d} = \frac{M_d}{W_{3,S}} = 5.03\text{ N/mm}^2 \leq 1.2 \cdot f_{t,d,C24}$$

(Increased $f_{t,d,C24}$ with 1.2 according to annnex 4.)

Edge stress of the web

$$\sigma_{2,c,d} = \frac{M_d}{W_{2,c}} = 2.17\text{ N/mm}^2 \leq f_{c,d,OSB/3} = 8.56\text{ N/mm}^2$$

$$\sigma_{2,t,d} = \frac{M_d}{W_{2,t}} = 1.96\text{ N/mm}^2 \leq f_{t,d,OSB/3} = 5.33\text{ N/mm}^2$$

Shear stress in the glue line web / flange

$$\tau_{1,d} = \left|\frac{V_d \cdot ES_1}{EI \cdot h_f}\right| = \left|-0.08442\right|\text{ N/mm}^2 \leq k_1 \cdot f_{v,90,d,OSB/3} = 0.22\text{ N/mm}^2$$

$$\tau_{3,d} = \left|\frac{V_d \cdot ES_3}{EI \cdot h_f}\right| = \left|-0.08689\right|\text{ N/mm}^2 \leq k_1 \cdot f_{v,90,d,OSB/3} = 0.22\text{ N/mm}^2$$

where

$$k_1 = \begin{cases} 1{,}0 & h_f \leq 4 \cdot b_w \\ \left(\frac{4 \cdot b_w}{h_f}\right) & h_f > 4 \cdot b_w \end{cases} \qquad => k_1 = \left(\frac{4 \cdot 10}{80}\right)^{0.8} = 0.574$$

$$f_{v,90,k} = \begin{cases} 1.2 - 0.05 \cdot b_w & \text{Maximum value according to annex 5} \\ 1.0 & \text{Material value according to DoP} \end{cases}$$

Shear stresses at center of gravity

$$\left|\tau_{2,d}\right| = \left|\frac{V_d \cdot ES_2}{EI \cdot b_2}\right| = \left|-0.7828\right| N/mm^2 \leq f_{v,w,eff,05,d,OSB/3} = 1.39\ N/mm^2$$

Calculations at support B

Verification of compression stresses along the support area at support B according to annex 4

F_{Ed} Design value of the whole supporting forces per ideal cross section

$$F_{Ed} = \frac{B_d}{n_{f,t,net}} = 14.10\ kN$$

Compression stress within the flange section:

$$\frac{F_{f,Ed}}{\ell \cdot b_f} = \frac{6.38\ kN}{100\ mm \cdot 134\ mm} = 0.476\ N/mm^2 \leq k_{c,90} \cdot f_{c,90,f,d} = 1.25 \cdot 1.73 \frac{N}{mm^2}$$

where

$F_{f,Ed}$ Design value of the partial support load of the softwood flange

$$F_{f,Ed} = F_{Ed} \frac{E_{m,90,f,mean} \cdot b_f}{E_{m,90,f,mean} \cdot b_f + 2 \cdot E_{c,90,w,mean} \cdot b_w}$$

$k_{c,90}$ = 1.25 according to EN 1995-1-1

ℓ support length 100 mm

Compression stress within the web section:

$$\frac{F_{w,Ed}}{2 \cdot \ell \cdot b_w} = \frac{7.72\ kN}{2 \cdot 100\ mm \cdot 10\ mm} \leq f_{c,90,w,d} = 6.95 \frac{N}{mm^2}$$

where

$F_{w,Ed}$ Design value of the partial support load of the web with thickness $2 \cdot b_w$

$$F_{w,Ed} = F_{Ed} \frac{2 \cdot E_{c,90,w,mean} \cdot b_w}{E_{m,90,f,mean} \cdot b_f + 2 \cdot E_{c,90,w,mean} \cdot b_w}$$

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Calculation example (informative)

Determination of the design value of the supporting force F_{Rd} (1 web and half of the flange width b_f)

The determination of F_{Rk} is done according to annex 3 from the implicit relation:

$$\frac{M_{F,k}(F_{Rk},F_{l,crit})}{W_w}=f_{m,90,w,eff,k}$$

$f_{m,90,w,eff,k}=f_{m,90,w,k}$ for this calculation example.

Detection:
$E_{m,90,w,sec,mean}=0.85\cdot E_{m,90,w,mean}=1853\ N/mm^2$

Cross number $\xi=\frac{2\cdot G_{Scheibe,w,mean}}{\sqrt{E_{m,0,w,mean}\cdot E_{m,90,w,sec,mean}}}=0.714$

$a_0(\xi)=3.15+1.51\ \xi=4.23$
$a_1(\xi)=0.21-0.09\ \xi=0.15$
$a_2(\xi)=1.74-0.46\ \xi=1.41$

Curved length $L=\frac{\sqrt{4+\left(\frac{3b_f}{2h_w}\right)^2}\,h_w\left(4b_f{}^6+25b_f{}^4h_w{}^2+50b_f{}^2h_w{}^4+32h_w{}^6\right)}{\left(\left(\frac{3b_f}{2}\right)^2+(2h_w)^2\right)^3}=574.9\ mm$

normalized length $\overline{\ell}=\sqrt[4]{\frac{E_{m,90,w,sec,mean}}{E_{m,0,w,mean}}}\cdot\frac{\ell}{L}=0.136$

buckling value $K(\xi,\overline{\ell})=a_0(\xi)+a_1(\xi)\ \overline{\ell}+a_2(\xi)\ \overline{\ell}^2=4.275$

coefficients:

$$k_f=\frac{2\cdot\left(b_f\cdot E_{m,0,f,mean}+2\cdot b_w\cdot E_{m,0,w,mean}\right)\cdot h_f^2\cdot(4\cdot h_f+3\cdot L)}{b_w\cdot E_{m,0,w,mean}\cdot(2\cdot h_f+L)^3+b_f\cdot E_{m,0,f,mean}\cdot h_f\cdot\left(4\cdot h_f^2+6\cdot h_f\cdot L+3\cdot L^2\right)}=0.239$$

$$k_{rel}=1+\frac{-0.63}{1+\left(\left(\frac{c+\ell/8}{L\cdot 0.27}\right)\left(\frac{E_{m,90,w,sec,mean}}{E_{m,0,w,mean}}\right)^{0.25}\right)^{2.3}}=0.9994$$

with c = 3950 mm

Resistance moment and moment of inertia of the web panels

$W_w=\frac{b_w^2}{6}=16.67mm^2$ $\qquad I_w=\frac{b_w^3}{12}=83.33\ mm^3$

Kielsteg

Calculation example (informative)

Stability load of the fictional I-Profil $F_{I,crit}=F_{crit,\infty}\cdot(1+k_f)\cdot k_{rel}$

$$F_{crit,\infty}=\frac{\pi^2\sqrt{E_{m,0,w,mean}\cdot E_{m,90,w,sec,mean}\cdot I_w}\cdot\sqrt[4]{\left(\frac{E_{m,90,w,sec,mean}}{E_{m,0,w,mean}}\right)}\cdot K(\ell,\xi)}{L}=14475\text{ N}$$

$F_{I,crit}$ = 17927 N

manufacturing restraining torque

$$M_H=\frac{b_f\cdot b_w^3\cdot E_{m,90,w,sec,mean}}{4\cdot L^2}=187.8\text{ Nm/m}$$

Iterative determination of F_{Rk} with the formula:

$$M_{F,k}=0.7\ M_H+M_H\left(A_1\left(\frac{F_{Rk}}{F_{I,crit}}\right)+A_2\left(\frac{F_{Rk}}{F_{I,crit}}\right)^2+A_3\left(\frac{F_{Rk}}{F_{I,crit}}\right)^3+A_4\left(\frac{F_{Rk}}{F_{I,crit}}\right)^4\right)=f_{m,90,w,eff,k}\cdot W_w$$

Coefficient according to annex 3, load application, extended length at the support c > 2h:

A_1	A_2	A_3	A_4
-0.0607	0.218	-0.0344	0.00207

Iteration with the Newton-Procedure

$$f(F_{R,k})=0.7\ M_H+M_H\left(A_1\left(\frac{F_{Rk}}{F_{I,crit}}\right)+A_2\left(\frac{F_{Rk}}{F_{I,crit}}\right)^2+A_3\left(\frac{F_{Rk}}{F_{I,crit}}\right)^3+A_4\left(\frac{F_{Rk}}{F_{I,crit}}\right)^4\right)-f_{m,90,w,eff,k}\cdot W_w=0$$

$$f'(F_{R,k})=M_H\left(A_1\frac{1}{F_{I,crit}}+A_2\frac{2\cdot F_{Rk}}{F_{I,crit}^2}+A_3\frac{3\cdot F_{Rk}^2}{F_{I,crit}}+A_4\frac{4\cdot F_{Rk}^3}{F_{I,crit}^4}\right)$$

$$F_{R,k,n+1}=F_{R,k,n}-\frac{f(F_{R,k})}{f'(F_{R,k})}$$

Starting of the iteration: $F_{r,k(0)}=2\cdot F_{I,crit}=35854$ N

F_{Rk}=32.641 kN after iteration (tolerance range 10^{-4} N)

$F_{Rd}=k_{mod}\frac{F_{Rk}}{\gamma M}=17.56$ kN (k_{mod} = 0.7)

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Calculation example (informative)

Combined verification of bending compression and buckling according to annex 4

$$\left(\frac{2}{3}\frac{0.95 \cdot F_{Ed}}{\ell_{eff} \cdot b_w \cdot 2 \cdot f_{c,90,w,d}}\right)^2 + \left(\frac{F_{Ed}}{2 \cdot F_{Rd}}\right) = 0.42 \leq 1$$

where

ℓ_{eff} effektive length of load distribution, see annex 3, Figure 3.3

$\ell_{eff} = \ell + \ell_{c,a} + \ell_{c,i} = 100+220+220=540$ mm

Calculations at support A

Verification of compression stresses along the support area at support A according to annex 4

F_{Ed} Design value of the whole supporting forces per ideal cross section

$$F_{Ed} = \frac{A_d}{n_{f,t,net}} = 8.97 \text{ kN}$$

Compression stress within the flange section:

$$\frac{F_{f,Ed}}{\ell \cdot b_f} = \frac{4.06 \text{ kN}}{100 \text{ mm} \cdot 134 \text{ mm}} = 0.30 \text{ N/mm}^2 \leq k_{c,90} \cdot f_{c,90,f,d} = 1.25 \cdot 1.73 \frac{\text{N}}{\text{mm}^2}$$

where

$F_{f,Ed}$ Design value of the partial support load of the softwood flange

$$F_{f,Ed} = F_{Ed} \frac{E_{m,90,f,mean} \cdot b_f}{E_{m,90,f,mean} \cdot b_f + 2 \cdot E_{c,90,w,mean} \cdot b_w}$$

$k_{c,90}$ = 1.25 according to EN 1995-1-1

ℓ support length 100 mm

Compression stress within the web section:

$$\frac{F_{w,Ed}}{2 \cdot \ell \cdot b_w} = \frac{4.91 \text{ kN}}{2 \cdot 100 \text{ mm} \cdot 10 \text{ mm}} \leq f_{c,90,w,d} = 6.95 \frac{\text{N}}{\text{mm}^2}$$

where

$F_{w,Ed}$ Design value of the partial support load of the web with thickness $2 \cdot b_w$

$$F_{w,Ed} = F_{Ed} \frac{2 \cdot E_{c,90,w,mean} \cdot b_w}{E_{m,90,f,mean} \cdot b_f + 2 \cdot E_{c,90,w,mean} \cdot b_w}$$

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Annex 6
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Calculation example (informative)

Determination of the design value of the supporting force F_{Rd} (1 web and half of the flange width b_f)

The determination of F_{Rk} is done according to annex 3 from the implicit relation:

$$\frac{M_{F,k}(F_{Rk},F_{l,crit})}{W_w}=f_{m,90,w,eff,k}$$

$f_{m,90,w,eff,k}=f_{m,90,w,k}$ for this calculation example.

Detection:
$E_{m,90,w,sec,mean}=0.85\cdot E_{m,90,w,mean}=1853\ N/mm^2$

Cross number $\xi=\frac{2\cdot G_{Scheibe,w,mean}}{\sqrt{E_{m,0,w,mean}\cdot E_{m,90,w,sec,mean}}}=0.714$

$a_0\,(\xi)=3.15+1.51\ \xi=4.23$
$a_1(\xi)=0.21-0.09\ \xi=0.15$
$a_2(\xi)=1.74-0.46\ \xi=1.41$

Curved length $L=\frac{\sqrt{4+\left(\frac{3b_f}{2h_w}\right)^2}h_w\left(4b_f^{\,6}+25b_f^{\,4}h_w^{\,2}+50b_f^{\,2}h_w^{\,4}+32h_w^{\,6}\right)}{\left(\left(\frac{3b_f}{2}\right)^2+(2h_w)^2\right)^3}=574.9\ mm$

normalized length $\overline{\ell}=\sqrt[4]{\frac{E_{m,90,w,sec,mean}}{E_{m,0,w,mean}}}\cdot\frac{\ell}{L}=0.136$

buckling value $\kappa(\xi,\overline{\ell})=a_0\,(\xi)+a_1(\xi)\ \overline{\ell}+a_2(\xi)\ \overline{\ell}^2=4.275$

coefficients:

$$k_f=\frac{2\cdot\left(b_f\cdot E_{m,0,f,mean}+2\cdot b_w\cdot E_{m,0,w,mean}\right)\cdot h_f^2\cdot(4\cdot h_f+3\cdot L)}{b_w\cdot E_{m,0,w,mean}\cdot(2\cdot h_f+L)^3+b_f\cdot E_{m,0,f,mean}\cdot h_f\cdot\left(4\cdot h_f^2+6\cdot h_f\cdot L+3\cdot L^2\right)}=0.239$$

$$k_{rel}=1+\frac{-0.63}{1+\left(\left(\frac{c+\ell/8}{L\cdot 0.27}\right)\left(\frac{E_{m,90,w,sec,mean}}{E_{m,0,w,mean}}\right)^{0.25}\right)^{2.3}}=0.371$$

with c = 0 mm

Resistance moment and moment of inertia of the web panels

$W_w=\frac{b_w^2}{6}=16.67mm^2$ $\qquad I_w=\frac{b_w^3}{12}=83.33\ mm^3$

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Calculation example (informative)

Stability load of the fictional I-Profil $F_{I,crit}=F_{crit,\infty}\cdot(1+k_f)\cdot k_{rel}$

$$F_{crit,\infty}=\frac{\pi^2\sqrt{E_{m,0,w,mean}\cdot E_{m,90,w,sec,mean}\cdot I_w}\cdot\sqrt[4]{\left(\frac{E_{m,90,w,sec,mean}}{E_{m,0,w,mean}}\right)}\cdot K(\bar{\ell},\xi)}{L}=14475\ \text{N}$$

$F_{I,crit}=6656.63$ N

Manufacturing restraining torque

$$M_H=\frac{b_f\cdot b_w^3\cdot E_{m,90,w,sec,mean}}{4\cdot L^2}=187.8\ \text{Nm/m}$$

Iterative determination of F_{Rk} with the formula:

$$M_{F,k}=0.7\ M_H+M_H\left(A_1\left(\frac{F_{Rk}}{F_{I,crit}}\right)+A_2\left(\frac{F_{Rk}}{F_{I,crit}}\right)^2+A_3\left(\frac{F_{Rk}}{F_{I,crit}}\right)^3+A_4\left(\frac{F_{Rk}}{F_{I,crit}}\right)^4\right)=f_{m,90,w,eff,k}\cdot W_w$$

Coefficient according to annex 3, extended length at the support c < h/4:

A_1	A_2	A_3	A_4
-0.0117	0.242	-0.0249	0.00143

Iteration with the Newton-Procedure

$$f(F_{R,k})=0.7\ M_H+M_H\left(A_1\left(\frac{F_{Rk}}{F_{I,crit}}\right)+A_2\left(\frac{F_{Rk}}{F_{I,crit}}\right)^2+A_3\left(\frac{F_{Rk}}{F_{I,crit}}\right)^3+A_4\left(\frac{F_{Rk}}{F_{I,crit}}\right)^4\right)-f_{m,90,w,eff,k}\cdot W_w=0$$

$$f'(F_{R,k})=M_H\left(A_1\frac{1}{F_{I,crit}}+A_2\frac{2\cdot F_{Rk}}{F_{I,crit}^2}+A_3\frac{3\cdot F_{Rk}^2}{F_{I,crit}}+A_4\frac{4\cdot F_{Rk}^3}{F_{I,crit}^4}\right)$$

$$F_{R,k,n+1}=F_{R,k,n}-\frac{f(F_{R,k})}{f'(F_{R,k})}$$

Starting of the iteration: $F_{r,k(0)}=2\cdot F_{I,crit}=13313$ N

F_{Rk}=11.785 kN after iteration (tolerance range 10^{-4} N)

$F_{Rd}=k_{mod}\frac{F_{Rk}}{\gamma M}=6.35$ kN   ($k_{mod}=0.7$)

Combined verification of bending compression and buckling according to annex 4

$$\left(\frac{2}{3}\frac{0.95 \cdot F_{Ed}}{\ell_{eff} \cdot b_w \cdot 2 \cdot f_{c,90,w,d}}\right)^2 + \left(\frac{F_{Ed}}{2 \cdot F_{Rd}}\right) = 0.72 \leq 1$$

where

ℓ_{eff} effektive length of load distribution, see annex 3, Figure 3.3

$\ell_{eff} = \ell + \ell_{c,a} + \ell_{c,i} = 100+220+220=540$ mm

Despite the support reaction force at support B being larger, support A turns out to be design- relevant due to the unfavorable support situation without overhang.