TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Civil Engineering and Architecture

IMPACT OF CHANGES OF EUROCODE 5 RULES TO THE FIRE RESISTANCE OF R30 GLULAM COLUMNS

EUROKOODEKS 5 REEGLITE MUUDATUSTE MÕJU LIIMPUIDUST POSTIDE R30 TULEPÜSIVUSELE

MASTER THESIS

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Juhendaja: Prof. Alar Just

Tallinn 2023

AUTHOR'S DECLARATION

Hereby I declare, that I have written this thesis independently.
No academic degree has been applied for based on this material. All works, major viewpoints and data of the other authors used in this thesis have been referenced.

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THESIS TASK

Student: Lea-Teele Saltõkova, 177591EAEI

Study programme, EAEI02/17 Structural Engineering and Construction Management

Supervisor(s): Professor Alar Just, 6202411

Thesis topic:

Impact of changes of Eurocode 5 rules to the fire resistance of R30 glulam columns

Eurokoodeks 5 reeglite muudatuste mõju liimpuidust postide R30 tulepüsivusele

Thesis main objectives:

1. Calculations according to EN1995:2006 and EN1995:2022
2. Comparison and analysis of effect of changes
3. Thermo-mechanical simulations
4. Comparison and analysis of difference between simulations and calculations

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Create excel worksheet for calculations	01.08.2022
2.	Perform simulations with SAFIR and CSTFire	01.12.2022
3.	Write main body of thesis	22.12.2022

Language: english **Deadline for submission of thesis:** January 9th 2023a

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CONTENTS

PREFACE

I would like to show my gratitude to everyone that has supported me throughout this journey. A special thanks to my supervisor Alar Just for his excellent guidance and unmatched professionalism. I deliberately chose him as my supervisor as I was sure he would challenge me with an interesting topic. The commission made by **Swedish Wood** was the biggest initiative for phrasing the topic of this thesis.

Furthermore, I would like to thank Mattia Tiso for generously offering his help and providing his input to this thesis. Additionally, I acknowledge the support I got from my family, friends and colleagues.

In this thesis, the load-capacity of columns have been calculated according to the current and revised EN1995-1-1 and EN1995-1-2. The effect of changes of the corresponding Eurocodes, have been analyzed. In addition, simulations of the fire situation have been carried out. The obtained values are compared with the new generation Eurocode EN1995-1-2:2022.

Key words: revison of Eurocodes, column, fire, timber, master thesis

List of abbreviations and symbols

Latin upper case letters

A	the area of effective cross-section
$E_{0,05}$	the fifth percentile value of the modulus of elasticity parallel to the grain
$(EI)_{fi}$	the solidity of member
I	the moment of inertia
L	the length of member
L_{ef}	the effective length of member
M_{fi}	the bending moment in fire
$N_{d,fi}$	the design compressive stress in fire
N_{cr}	the critical compressive stress

Latin lower case letters

b	width of the initial cross-section
b_{ef}	effective width of the effective cross-section
d_0	zero-strength layer depth
$d_{char,n}$	notional charring depth
d_{ef}	effective charring depth
f_{20}	the 20% fractile of a strength property at normal temperature
$f_{c,0,d}$	the design compressive strength along the grain
$f_{c,d}$	the design compressive strength along the grain
f_d	design strength
$f_{d,fi}$	design strength in fire
f_k	characteristic strength
$f_{m,k}$	design bending strength
h	height of the initial cross-section
h_{ef}	effective height of the effective cross-section
i	the radius of gyration

k	the instability factor
k_0	coefficient
k_c	Factor to account for 2nd order effects on compressive stresses for flexural buckling
k_{fi}	modification factor for a strength property for the fire situation
k_{gd}	modification factor considering grain direction
k_{mod}	modification factor
$k_{mod,fi}$	modification factor for fire
k_n	conversion factor
k_{side}	number of respective opposite sides exposed to fire
k_θ	temperature-dependent reduction factor for strength
t	time of fire exposure

Greek upper case letters

X_k	characteristic value of a strength or stiffness property in fire
X_d	design value of a strength or stiffness property
$X_{d,fi}$	design value of a strength or stiffness property in fire
Πk_i	product of applied modification factors

Greek lower case letters

β_0	basic design charring rate
β_c	imperfection factor for buckling
β_n	notional charring rate within one charring phase
γ_M	partial factor for the relevant mechanical material property
$\gamma_{M,fi}$	partial factor for the relevant mechanical material property for fire
ε_0	equivalent bow imperfection
κ_{fi}	Curvature of a member
λ	the slenderness ratio
$\lambda_{c,rel}$	the relative slenderness ratio

λ_{rel}	the relative slenderness ratio
μ	the support factor
$\sigma_{c,0,d}$	the design compressive stress along the grain
σ_{crit}	the critical compressive stress along the grain
ϕ_c	the instability factor

1. INTRODUCTION

The construction sector is striving for more environmentally friendly solutions with the goal of producing less pollution. The need for more sustainable construction materials is on the rise. One of the alternatives to common construction materials such as concrete and steel, that also meets the demands of modern buildings, is timber [1].

Figure 1.1 Glulam beams and columns

An important precondition in the use of timber in construction is adequate fire safety. Fire safety of structural timber elements needs to be assessed, therefore numerous research projects are being conducted and fire tests are performed to improve the design of timber elements in fire [2]. These improvements have led to the new version of the Eurocode 5 part 1-2.

Eurocodes are critical for a common European building market. Therefore, the European Commission as well as industries, craftsmen and engineers are very interested in the further development of the Eurocodes to achieve matching design rules across Europe [3].

In this thesis, the load-bearing capacities of glued laminated timber columns with different cross-sections are calculated using the current and revised EN1995 part 1-1. Also, the fire resistances of the same unprotected columns are calculated using the current and revised EN1995 part 1-2. R30 is the only fire resistance explored in this thesis. The effect of changes in the formulae are analysed. Besides that, simulations using 2 different programs were performed. The design methods and results were later compared.

The reduced cross-section method is used in this paper to describe the cross-section after an effective char layer has been reduced from the initial cross-section. The effective char layer is made up of a char layer and a layer beneath it with reduced stiffness and strength [4]. An Excel working platform has been developed for calculations.

Figure 1.2 Glulam column after fire

The main body of this thesis consists of the overview of the calculation methods, overview of the performed simulations and analysis.

Chapter 2 covers the revision of the Eurocode 5 part 1-1 and part 1-2. Chapter 3 gives and overview of the structural model as well as design loads used for further calculations. Chapters 4-5 expand on calculation methods according to current and revised EN1995-1-1 and EN1995-1-2.

Further chapters focus on analysing the differences between different design models. Chapter 6 is dedicated to comparing EN1995-1-1 and EN1995-1-2 using the chosen structural model and later analysing the results. Chapter 7 introduces methods used

for simulations and gives an overview of the difference between simulations and the new generation Eurocode design models.

This thesis includes 2 Appendices. Appendix 1 gives an example of the calculation using the current and revised EN1995-1-1. Appendix 2 gives an example of the calculation using the current and revised EN1995-1-2.

Key words: revison of Eurocodes, column, fire, timber, master thesis

2. REVISION OF EUROCODE 5 PART 1-1 AND 1-2

Revision process of the Eurocode 5 is briefly described in this chapter.

Revision of Eurocode 5 Part 1-1

In December 2012, the European Commission finalized a mandate for the CEN to develop a standardisation work programme for the publication of the second generation of Eurocodes. CEN/TC 250 leads the execution of the mandate regarding the design of construction works. CEN/TC 250 SC 5 deals with further development of Eurocode 5 assigning defined subjects to supporting working groups (WG). The background research for the revised parts is seen through by said working groups [3].

The revision on Eurocode 5 focuses improving the the following [5]:

- Clarity and understandability
- “Ease-of-use”
- “State-of-the-art”
- No fundamental changes to the approach to design and to the structure of the Eurocodes
- Consistency with product standards and standards for execution

The chapter covering element stability is being revised and is also relevant to this thesis. Hereafter the currently valid Eurocode 5 Part 1-1 is referred to as EN 1995-1-1:2006 and the proposal for the revised Eurocode 5 Part 1-1 as EN 1995-1-1:2022 (dated 12.09.2022)

Revision of Eurocode 5 Part 1-2

The background research for the revised fire part of Eurocode 5 (EN 1995-1-2) was collected and discussed at CEN TC250 SC5 WG4 (Fire). The revised fire part of Eurocode 5 has been drafted by Project Team 4 of CEN TC250 SC5 led by Andrea Frangi [6].

The final draft of the revised EN 1995-1-2 was published in August 2022. The final draft of EN 1995-1-2 is the basis of this master thesis. Changes relevant to this thesis were made in chapters referring to the reduced cross-section method.

Hereafter the currently valid Eurocode 5 Part 1-2 is referred to as EN 1995-1-2:2006 and the proposal for the revised Eurocode 5 Part 1-2 as EN 1995-1-2:2022 (dated 05.08.2022).

3. EVALUATED STRUCTURES

In this thesis glulam columns with three different cross-sections and two projected lengths are calculated in ambient and R30 fire conditions using the current and revised versions of EN 1995-1-1 and EN 1995-1-2. Fire exposure from 4 sides is considered. The properties of the glued laminated timber are presented in EN 14080:2013. The evaluated cross-sections are shown in Figure 3.1. Each cross-section is calculated with a length of 2,5 metres and 5 metres. Support conditions are assumed to be hinged on both ends.

The columns are designed to be under compression without horizontal loads. Additionally, with the assumption that the vertical load is centred, the bending moment is omitted. Therefore, the calculations focus on element compressive strength parallel to grain and buckling strength in ambient and R30 fire conditions.

Furthermore, the load-bearing capacities were calculated using general principles of design and EN 1995-1-1.

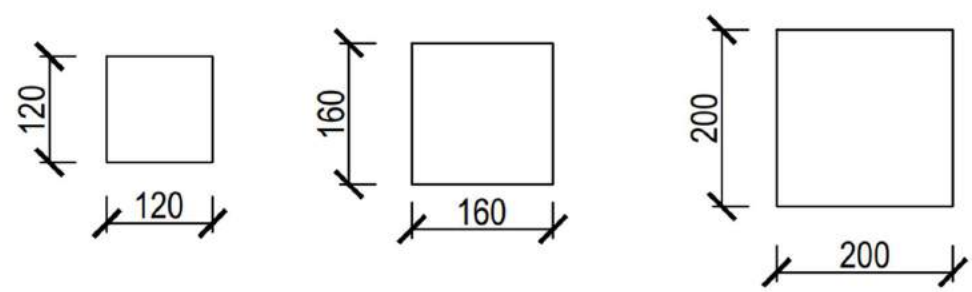


Figure 3.1 The cross-sections used for calculations

3.1 Design loads

In this thesis, the load combinations, combination coefficients, partial factors, and design situations were chosen according to the EN1990:2002. Material densities and live loads were chosen according to EN1991-1-1:2002.

The example calculations in appendices 1-2 show the load-bearing capacity of compressed columns considering buckling according to the current and revised

Eurocodes. Later on, results are compared to determine the influence of changes in Eurocode 5. The example calculations have the same design loads with only the cross-sections, buckling length, and timber strength class interchanging.

The selected structural model is shown in Figure 3.2. It consists of a column-beam system with a beam span of 8000 mm and the beam step 6000 mm. The structure is thought to be a two-story building with uniform loads: flooring, roof, and live-load. Floor and roof loads are assigned g_k=0,5 kN/m^2. The live load is g_k=2 kN/m^2 since it is a residential building [7]. The beam has a cross-section of 400*200 mm and wood strength class of GL24h. The live load is transferred into the columns.

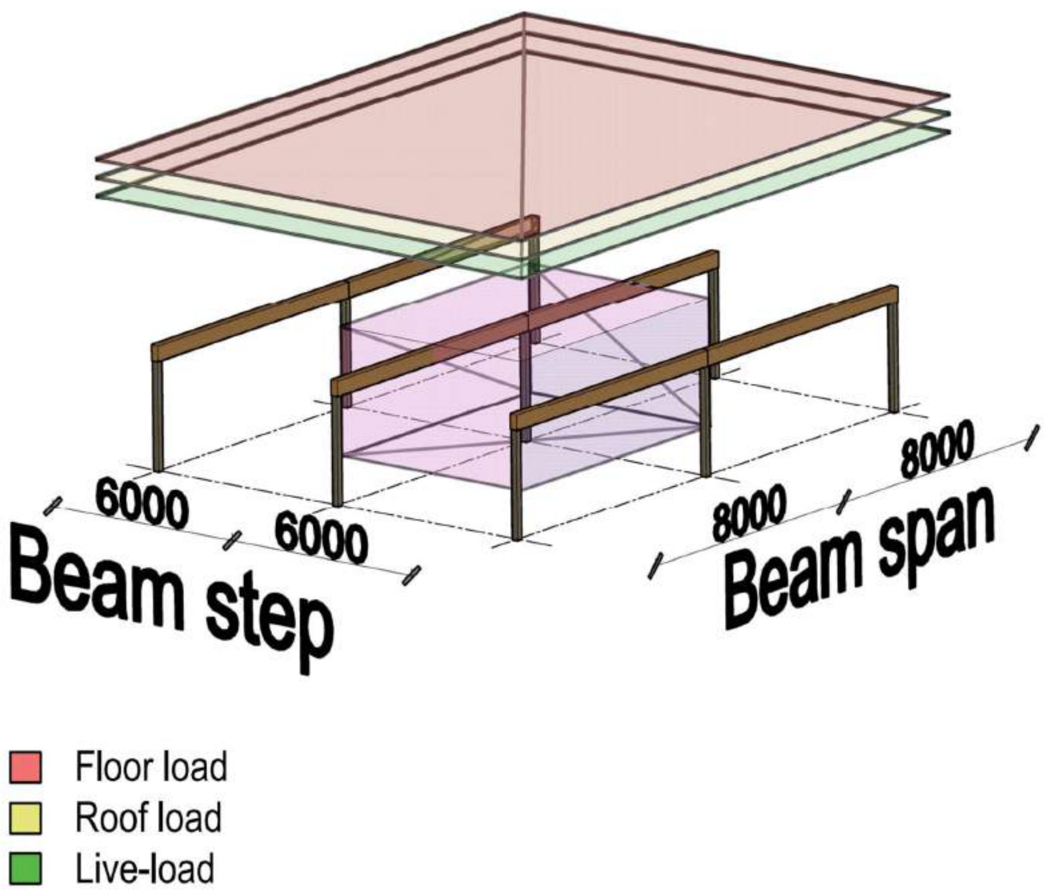


Figure 3.2 The structural model. The considered load area for the calculated column in the centre of the model is shown in pink.

4. CALCULATIONS ACCORDING TO EN1995-1-2

The following chapter covers primary parameters and formulas for designing unprotected glulam columns in fire in accordance with EN1995-1-2:2006 and EN 1995-1-2:2022. Equations are shown for both the current and revised Eurocodes with the current Eurocode equation on the left and the revised equation on the right. A schematic is shown below. The numbering system corresponds to each Eurocode for unambiguity.

EN 1995-1-2:2006 formula	*Formula number*	*EN 1995-1-2:2022 formula*	*Formula number*

4.1 Design strength of timber

The design value of strength of timber in fire is calculated using the following formulas [8] [9].

$f_{d,fi} = \frac{k_{mod,fi} f_{20}}{\gamma_{M,fi}}$,	(2.1)	$X_{d,fi} = \frac{k_{\theta} k_{fi} X_k}{\gamma_{M,fi}}$,	(4.1)

where	f_{20}	-	the 20% fractile of a strength property at normal temperature, N/mm^2,
	$f_{d,fi}$	-	design strength in fire, N/mm^2,
	$X_{d,fi}$	-	design value of strength property for the fire situation, N/mm^2,
	$k_{mod,fi}$	-	modification factor for fire,
	k_{θ}	-	temperature-dependent reduction factor for strength,
	k_{fi}	-	modification factor for a strength property for the fire situation,
	X_k	-	characteristic value of a strength property for normal temperature, N/mm^2,
	$\gamma_{M,fi}$	-	partial factor for the relevant mechanical material property for the fire situation.

Unless the National Annex states otherwise, it is recommended that $\gamma_{M,fi}$ = 1,0. As the calculations are based on an effective cross-section method, the modification factor for fire is $k_{mod,fi}$ = 1,0 and the temperature-dependent reduction factor is k_{θ} = 1,0 [8] [9].

The 20% fractile of strength property at normal temperature f_{20} is calculated according to formula (2.4) [8].

$$f_{20} = f_k k_{fi}, \qquad (2.4) \qquad - \qquad -$$

where f_k - characteristic strength value, N/mm^2,

k_{fi} - modification factor for a strength property for the fire situation.

For glued-laminated timber k_{fi} = 1,15 [8]. The characteristic glue-laminated timber strength values can be taken from European standard EN14080:2013 [10].

4.2 Charring depth

Unprotected members are initially exposed to fire from the beginning, the charring process also starts with the fire. The charring rate is constant throughout the fire exposure. Bond line integrity of face bonds is assumed to be maintained [8]. See Figure 4.1.

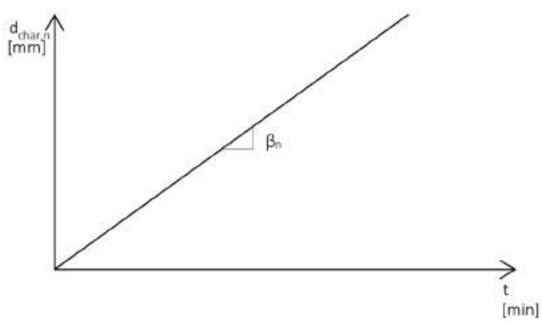


Figure 4.1 Relationship throughout the time of exposure for initially unprotected members.

In this research, all columns are exposed to fire from 4 sides. Consequently, the notional charring depth should be taken into consideration. It is calculated according to the following formulas [8] [9].

$$d_{char,n} = \beta_n \mathrm{t} \qquad 3.2 \qquad d_{char,n} = \beta_n \mathrm{t} \qquad 5.1$$

where $d_{char,n}$ - notional charring depth, mm,

β_n - notional design charring rate, which includes the effect of corner roundings and fissures, mm/min,

t - time of exposure, min.

In EN 1995-1-2:2006 the notional charring rate β_n for glued laminated timber with a characteristic density of ≥ 290 kg/m^3 is 0,7 mm/min [8].

In EN 1995-1-2:2022 the notional charring rate β_n should be calculated using the applicable modification factors for charring [9].

- - $$\beta_n = \prod_{k_i} \beta_0 \quad 5.2$$

- - $$\beta_n = \beta_0 k_n k_{gd} \quad 5.2$$

where Π_{ki} - Product of applied modification factors,

β_0 - Basic design charring rate, mm/min.

Modification factors are used in the calculation of the notional charring rate. For glued-laminated timber columns only the factors k_{gd} and k_n must be considered.

Modification factor k_{gd} takes into account the increased heat flux in the grain direction.

where $k_{gd} = \begin{cases} 1{,}0 \\ 2{,}0 \end{cases}$ - for heat flux perpendicular to the grain direction
- for heat flux in the grain direction

In this thesis, heat flux is perpendicular to the grain direction, therefore k_{gd} = 1,0 [9]. Another modification factor is k_n. It is the conversion factor that considers the effect of corner roundings and the effect of cracks and fissures on the surface of the linear member. The value for k_n for other than circular members should be taken as follows.

where $k_n = \begin{cases} 1{,}23 \\ 1{,}08 \end{cases}$ - for solid linear timber members made of softwood and beech
- for all other linear timber members

This research is about glulam linear members, therefore, k_n = 1,08 [9].
The basic design charring rate for glued-laminated timber β_0=0,65 mm/min [9].

$\beta_n = 0{,}7$ $\quad\quad$ $\beta_n = 0{,}65 * 1{,}08 * 1{,}0 = 0{,}702$

4.3 Effective cross-section of the column

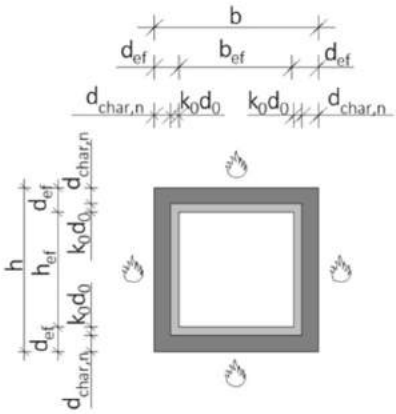


Figure 4.2 Effective cross-section for columns

As seen in Figure 4.2, the effective cross-section is found by reducing the initial cross-section by the effective charring depth d_{ef} from every side that is exposed to fire. The effective charring depth is calculated according to formula (7.3) or (4.1) [8] [9].

$$d_{ef} = d_{char,n} + k_0 d_0 \qquad (4.1)$$
$$d_0 = 7 \text{ mm}$$

$$d_{ef} = d_{char,n} + d_0 \qquad (7.3)$$
$$d_0 = 14 \text{ mm}$$

where $d_{char,n}$ - Notional charring depth, mm,

β_0 - Basic design charring rate, mm/min,

k_0 - Coeffiecient,

d_0 - Zero-strength layer, mm.

For unprotected surfaces and t > 20min k_0=1,0 [8].

The dimensions of the charred cross-section are an effective height h_{ef} and an effective width b_{ef}. In this research, columns are open to fire from 4 sides. In that case, the measurements of the effective cross-section are shown in Figure 3.2 and is calculated according to formulas (7.4) and (7.5) [9].

$$b_{ef} = b - k_{side} d_{ef} \qquad (7.4)$$

$$h_{ef} = h - k_{side} d_{ef} \qquad (7.5)$$

where b_{ef} - Width of the effective cross-section, mm,

h_{ef} - Height of the effective cross-section, mm,

b - Width of the initial cross-section, mm,

h - Height of the initial cross-section, mm,

k_{side} the number of respective opposite sides exposed to fire.

5. CALCULATIONS ACCORDING TO EN1995-1-1

Columns subjected to compression considering buckling are the focus of this thesis. The following chapters cover the parameters and formulas necessary for calculating glulam columns in ambient conditions according to EN 1995-1-1:2022 and EN-1995-1-1:2006.

5.1 Design strength of timber

The design value of strength property is calculated with the following formulas [11] [12].

$$X_d = \frac{k_{mod} X_k}{\gamma_M} \quad (2.14) \qquad f_d = \frac{k_{mod} \Pi k_i f_k}{\gamma_M} \quad (5.6)$$

where f_d - design value of strength property, N/mm^2,

X_d - design value of a strength property, N/mm^2,

k_{mod} - modification factor considering the effect of the duration of load and moisture content,

Πk_i - product of applicable modification factors, in addition to k_{mod},

f_k - characteristic value of the strength property of the material, N/mm^2,

X_k characteristic value of a strength property of the material, N/mm^2,

γ_M - partial factor for the material property.

γ_M for glued laminated timber is 1,25 [11] [12].
k_{mod} values depend on the length of the action and the service class of the glulam. k_{mod} values for glued laminated timber for EN-1995-1-1:2006 are presented in Table 5.1 and for EN-1995-1-1:2022 in Table 5.2.

Table 5.1 Values of k_{mod} for EN-1995-1-1:2006

	Service class	Permanent action	Long term action	Medium term action	Short term action	Instantaneous action
Glued laminated timber	1	0,6	0,7	0,8	0,9	1,1
	2	0,6	0,7	0,8	0,9	1,1
	3	0,5	0,55	0,65	0,7	0,9

Table 5.2 Values of k_{mod} for EN-1995-1-1:2022

	Service class	Permanent action	Long term action	Medium term action	Short term action	Instantaneous action
Glued laminated timber	1	0,6	0,7	0,8	0,9	1,1
	2	0,6	0,7	0,8	0,9	1,1
	3	0,55	0,6	0,7	0,8	1,0

5.2 Compression parallel to grain

Columns are subjected to compression parallel to grain and according to both Eurocodes the following formula should be satisfied [11] [12].

$$\sigma_{c,0,d} \leq f_{c,0,d} \qquad (6.2) \qquad\qquad \sigma_{c,0,d} \leq f_{c,0,d} \qquad (8.3)$$

where $\sigma_{c,0,d}$ - Design compressive stress parallel to grain, N/mm^2,

$f_{c,0,d}$ - Design compressive strength parallel to grain, N/mm^2,

5.3 Stability

When calculating the stability of members, the following expression must be satisfied for the verification of members against flexural buckling [11] [12].

$$\frac{\sigma_{c,0,d}}{k_c f_{c,0,d}} \leq 1 \qquad (6.23) \qquad\qquad \frac{\sigma_{c,0,d}}{k_c f_{c,0,d}} \leq 1 \qquad (8.39)$$

where $\sigma_{c,0,d}$ - Design compressive stress parallel to grain, N/mm^2,

$f_{c,0,d}$ - Design compressive strength parallel to grain, N/mm^2,

k_c - Factor to account for 2nd order effects on compressive stresses for flexural buckling

The factors to account for the 2nd order for flexural buckling should b calculated with formulas (6.25) and (8.41) [11] [12].

$$k_c = \frac{1}{k + \sqrt{k^2 - \lambda_{rel}^2}} \qquad (6.25) \qquad\qquad k_c = \frac{1}{\varphi_c + \sqrt{\varphi_c^2 - \lambda_{c,rel}^2}} \qquad (8.41)$$

where $\lambda_{c,rel}$ - Relative slenderness ratio for flexural buckling,

λ_{rel} - Relative slenderness ratio for flexural buckling,

φ_c - Instability actor for the calculation of k_c,

k - Instability actor for the calculation of k_c.

To calculate the instability factor k_c, another instability factor k is needed. Formulas (6.27) and (8.42) show how to calculate the instability factor k [11] [12].

$$k = 0.5[1 + \beta_c(\lambda_{rel} - 0.3) + \lambda_{rel}^2] \qquad (6.27) \qquad \varphi_c = 0.5\left[1 + \beta_c\left(\lambda_{c,rel} - 0.3\right) + \lambda_{c,rel}^2\right] \qquad (8.42)$$

where β_c - Imperfection factor (straightness factor) for buckling.

According to EN1995-1-1:2006 the straightness factor β_c for glulam is 0,1 [11]. As for EN1995-1-1:2022 the factor is calculated according to the following formula from Table 8.2 in EN1995-1-1:2022 [12].

$$\beta_c = 0.1 \qquad (6.29) \qquad\qquad \beta_c = \varepsilon_0 \pi \sqrt{\frac{3E_{0,05}}{f_{c,0,k}} \frac{f_{c,0,k}}{f_{m,k}}} \qquad (\text{TBL } 8.2)$$

where ε_0 - Equivalent bow imperfection.

For glulam the equivalent bow e should be taken as follows [12].

- -

$$\varepsilon_0 \rightarrow \pm e = \frac{L}{1000} \qquad (7.15)$$

The relative slenderness ration is calculated according to following formulas [11] [12]. As the columns have equal height and width, it is necessary to evaluate the slenderness only in one direction.

$$\lambda_{rel} = \frac{\lambda}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0,05}}} \quad (6.22)$$

$$\lambda_{c,rel} = \sqrt{\frac{f_{c,0,k}}{\sigma_{crit}}} \quad (8.36)$$

where λ - Slenderness ratio corresponding to bending

$E_{0.05}$ - the fifth percentile value of the modulus of elasticity parallel to the grain.

σ_{crit} - Critical stress for buckling.

The critical stress σ_{crit} is calculated with formula (8.38) [12].

- -

$$\sigma_{crit} = \pi^2 \frac{E_{0,05} I}{A L_{ef}^2} \quad (8.38)$$

where I - Moment of inertia, mm^4,

A - Are of the cross-section, mm^2,

L_{ef} - Effective length for flexural buckling, mm.

The following formula is taken from “Ehituskonstruktori käsiraamat” going forward referred to as (EKKR). The slenderness ratio is calculated as follows [13].

$$\lambda = \frac{L_{ef}}{i} \quad \text{(EKKR 4.9.1)}$$

- -

The effective length of a member is calculated with formula from (EKKR) [13].

$$L_{ef} = \mu L \quad \text{(EKKR 4.9.1)}$$

$$L_{ef} = \mu L \quad \text{(EKKR 4.9.1)}$$

where μ - Support factor.

In this thesis the support conditions for columns are pinned from both ends. That means $\mu=1$ [13].

The moment of inertia for rectangular members is calculated according to formula from EKKR [13].

$$I = \frac{bh^3}{12} \quad \text{(EKKR TBL 3.1)}$$

As we know the effective cross-section and the moment of inertia, it is possible to calculate the radius of gyration, using the formula from (EKKR) [13].

$$i = \sqrt{\frac{I}{A}} \qquad \text{(EKKR TBL 3.1)}$$

6. COMPARISON OF CALCULATIONS

In order to create a clear comparison between the current and revised Eurocodes an Excel spreadsheet was created. The main objective of the spreadsheet is to compare strength values of glulam columns using the formulas described in chapters 3 and 4. As mentioned before the strength values used for comparison is compression strength considering buckling.

The spreadsheet was created as user-friendly as possible, meaning other people can use it to determine whether a column maintains its load-bearing capacity. It includes pre-defined cells that contain mostly formulas that depend on the user input. The following are user defined values in the spreadsheet: dimensions of the column, strength class of the column, service and load-duration class, dimensions and strength class of beams, load values and combination factors.

To achieve simplicity and unity of the results some user-defined values remained constant throughout the calculations such as the service and load-duration class, load values, beam cross-section dimensions and strength class and combination factors. The values of the beam span and beam step were varied to create comparison graphs that would indicate the difference between EN1995:2006 and EN1995:2022.

6.1 Comparison of EN1995-1-1:2006 and EN1995-1-1:2022

In case of EN1995-1-1 calculations are performed in ambient conditions without fire. The ultimate limit state of the columns is taken into consideration. From EN1990:2002 we take partial factor 1,2 for permanent actions and 1,5 for variable actions such as live-load [14].

The following images contain the summarized results of the calculations according to EN1995-1-1:2006 and EN1995-1-1:2022. The numerical result shows whether a distinct cross section with a specific strength class and length will maintain its load-bearing capacity. The load of the beam is a result of varying beam step and span under constant floor-, roof- and live-load. The numerical value is the ratio between the column load-bearing capacity and compression stress considering buckling.

When the ratio is ≥1,0 the distinct cell turns green in color. For values 0,9-1,0 the color is yellow and anything ≤0,9 is red.

6.1.1 Cross-section 200x200 mm

In this section only 200x200 mm cross-sections will be considered.

Beam step, m	Beam span, m								
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	32.87	16.43	10.96	8.22	6.57	5.48	4.70	4.11
	4.0	16.82	8.41	5.61	4.20	3.36	2.80	2.40	2.10
	6.0	11.30	5.65	3.77	2.83	2.26	1.88	1.61	1.41
	8.0	8.51	4.25	2.84	2.13	1.70	1.42	1.22	1.06
	10.0	6.82	3.41	2.27	1.71	1.36	1.14	0.97	0.85
	12.0	5.70	2.85	1.90	1.42	1.14	0.95	0.81	0.71
	14.0	4.89	2.44	1.63	1.22	0.98	0.81	0.70	0.61
	16.0	4.28	2.14	1.43	1.07	0.86	0.71	0.61	0.54

Figure 6.1 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 200x200mm GL28c 2,5 m glulam columns according to EN1995-1-1:2006

Beam step, m	Beam span, m								
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	30.54	15.27	10.18	7.64	6.11	5.09	4.36	3.82
	4.0	15.63	7.81	5.21	3.91	3.13	2.60	2.23	1.95
	6.0	10.50	5.25	3.50	2.63	2.10	1.75	1.50	1.31
	8.0	7.91	3.95	2.64	1.98	1.58	1.32	1.13	0.99
	10.0	6.34	3.17	2.11	1.59	1.27	1.06	0.91	0.79
	12.0	5.29	2.65	1.76	1.32	1.06	0.88	0.76	0.66
	14.0	4.54	2.27	1.51	1.14	0.91	0.76	0.65	0.57
	16.0	3.98	1.99	1.33	0.99	0.80	0.66	0.57	0.50

Figure 6.2 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 200x200mm GL28c 2,5 m glulam columns according to EN1995-1-1:2022

In Figures 6.1 and 6.2 the same values calculated according to different Eurocodes are compared. The figures show 64 different combinations of beam span and beam step and the cells show the final value of $k_c*f_{c,d}/\sigma_{c,d}$. In both cases the timber strength value of the cross-section is GL28c, and length is 2,5 m. The first table shows that according to EN1995-1-1:2006 in 10 instances, which makes 15,6% of all instances, the load-bearing capacity is not verified. The second table shows that according to EN1995-1-1:2022 in 11 instances, which makes 17,2% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin increased from 3 to 4. The number of instances, where the load-bearing capacity is ≥1,0 lowered from 51 to 49. In percentages the change is 3,9%.

When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much it decreases. On average the values corresponding to EN1995-1-1:2022 are 7,0% lower than the counterpart.

Beam step, m	Beam span, m							
	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
2.0	17.78	8.89	5.93	4.45	3.56	2.96	2.54	2.22
4.0	9.10	4.55	3.03	2.27	1.82	1.52	1.30	1.14
6.0	6.11	3.06	2.04	1.53	1.22	1.02	0.87	0.76
8.0	4.60	2.30	1.53	1.15	0.92	0.77	0.66	0.58
10.0	3.69	1.85	1.23	0.92	0.74	0.62	0.53	0.46
12.0	3.08	1.54	1.03	0.77	0.62	0.51	0.44	0.39
14.0	2.64	1.32	0.88	0.66	0.53	0.44	0.38	0.33
16.0	2.32	1.16	0.77	0.58	0.46	0.39	0.33	0.29

Figure 6.3 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 200x200mm GL28c 5 m glulam columns according to EN1995-1-1:2006

Beam step, m	Beam span, m							
	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
2.0	13.59	6.79	4.53	3.40	2.72	2.26	1.94	1.70
4.0	6.95	3.48	2.32	1.74	1.39	1.16	0.99	0.87
6.0	4.67	2.34	1.56	1.17	0.93	0.78	0.67	0.58
8.0	3.52	1.76	1.17	0.88	0.70	0.59	0.50	0.44
10.0	2.82	1.41	0.94	0.71	0.56	0.47	0.40	0.35
12.0	2.35	1.18	0.78	0.59	0.47	0.39	0.34	0.29
14.0	2.02	1.01	0.67	0.51	0.40	0.34	0.29	0.25
16.0	1.77	0.88	0.59	0.44	0.35	0.29	0.25	0.22

Figure 6.4 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 200x200mm GL28c 5 m glulam columns according to EN1995-1-1:2022

In Figures 6.3 and 6.4 the same values calculated according to different Eurocodes are compared. In both cases the timber strength value of the cross-section is GL28c, and length is 5 m. The first table shows that according to EN1995-1-1:2006 in 26 instances, which makes 40,6% of all instances, the load-bearing capacity is not verified. The second table shows that according to EN1995-1-1:2022 in 33 instances, which makes 51,6% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin increased from 2 to 3. The number of instances, where the load-bearing capacity is ≥1,0 lowered from 36 to 28. In percentages the change is 22,2%.

When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-1:2022 are 23,7% lower than the counterpart.

Beam step, m		Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	33.71	16.85	11.24	8.43	6.74	5.62	4.82	4.21
	4.0	17.25	8.62	5.75	4.31	3.45	2.87	2.46	2.16
	6.0	11.59	5.80	3.86	2.90	2.32	1.93	1.66	1.45
	8.0	8.73	4.36	2.91	2.18	1.75	1.45	1.25	1.09
	10.0	7.00	3.50	2.33	1.75	1.40	1.17	1.00	0.87
	12.0	5.84	2.92	1.95	1.46	1.17	0.97	0.83	0.73
	14.0	5.01	2.51	1.67	1.25	1.00	0.84	0.72	0.63
	16.0	4.39	2.19	1.46	1.10	0.88	0.73	0.63	0.55

Figure 6.5 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 200x200mm GL32c 2,5 m glulam columns according to EN1995-1-1:2006

Beam step, m		Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	31.75	15.88	10.58	7.94	6.35	5.29	4.54	3.97
	4.0	16.25	8.12	5.42	4.06	3.25	2.71	2.32	2.03
	6.0	10.92	5.46	3.64	2.73	2.18	1.82	1.56	1.36
	8.0	8.22	4.11	2.74	2.06	1.64	1.37	1.17	1.03
	10.0	6.59	3.30	2.20	1.65	1.32	1.10	0.94	0.82
	12.0	5.50	2.75	1.83	1.38	1.10	0.92	0.79	0.69
	14.0	4.72	2.36	1.57	1.18	0.94	0.79	0.67	0.59
	16.0	4.13	2.07	1.38	1.03	0.83	0.69	0.59	0.52

Figure 6.6 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 200x200mm GL32c 2,5 m glulam columns according to EN1995-1-1:2022

In Figures 6.5 and 6.6 the same values calculated according to different Eurocodes are compared. In both cases the timber strength value of the cross-section is GL32c, and length is 2,5 m. The first table shows that according to EN1995-1-1:2006 in 10 instances, which makes 15,6% of all instances, the load-bearing capacity is not verified. The second table shows that according to EN1995-1-1:2022 in 10 instances, which makes 15,6% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin increased from 1 to 3. The number of instances, where the load-bearing capacity is ≥1,0 lowered from 53 to 51. In percentages the change is 3,8%.

When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-1:2022 are 5,8 % lower than the counterpart.

Beam step, m		Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	19.01	9.50	6.34	4.75	3.80	3.17	2.72	2.38
	4.0	9.73	4.86	3.24	2.43	1.95	1.62	1.39	1.22
	6.0	6.53	3.27	2.18	1.63	1.31	1.09	0.93	0.82
	8.0	4.92	2.46	1.64	1.23	0.98	0.82	0.70	0.62
	10.0	3.95	1.97	1.32	0.99	0.79	0.66	0.56	0.49
	12.0	3.29	1.65	1.10	0.82	0.66	0.55	0.47	0.41
	14.0	2.83	1.41	0.94	0.71	0.57	0.47	0.40	0.35
	16.0	2.47	1.24	0.82	0.62	0.49	0.41	0.35	0.31

Figure 6.7 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 200x200mm GL32c 5 m glulam columns according to EN1995-1-1:2006

Beam step, m		Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	14.75	7.38	4.92	3.69	2.95	2.46	2.11	1.84
	4.0	7.55	3.78	2.52	1.89	1.51	1.26	1.08	0.94
	6.0	5.07	2.54	1.69	1.27	1.01	0.85	0.72	0.63
	8.0	3.82	1.91	1.27	0.95	0.76	0.64	0.55	0.48
	10.0	3.06	1.53	1.02	0.77	0.61	0.51	0.44	0.38
	12.0	2.56	1.28	0.85	0.64	0.51	0.43	0.37	0.32
	14.0	2.19	1.10	0.73	0.55	0.44	0.37	0.31	0.27
	16.0	1.92	0.96	0.64	0.48	0.38	0.32	0.27	0.24

Figure 6.8 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 200x200mm GL32c 5 m glulam columns according to EN1995-1-1:2022

In Figures 6.7 and 6.8 the same values calculated according to different Eurocodes are compared. In both cases the timber strength value of the cross-section is GL32c, and length is 5 m. The first table shows that according to EN1995-1-1:2006 in 24 instances, which makes 37,5% of all instances, the load-bearing capacity is not verified. The second table shows that according to EN1995-1-1:2022 in 30 instances, which makes 46,9% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin decreased from 4 to 3. The number of instances, where the load-bearing capacity is ≥1,0 lowered from 36 to 31. In percentages the change is 13,9%.

When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-1:2022 are 22,4% lower than the counterpart.

6.1.2 Cross-section 160x160 mm

In this section only 160x160 mm cross-sections will be considered.

Beam step, m		Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	19.71	9.85	6.57	4.93	3.94	3.28	2.82	2.46
	4.0	10.08	5.04	3.36	2.52	2.02	1.68	1.44	1.26
	6.0	6.78	3.39	2.26	1.69	1.36	1.13	0.97	0.85
	8.0	5.10	2.55	1.70	1.28	1.02	0.85	0.73	0.64
	10.0	4.09	2.05	1.36	1.02	0.82	0.68	0.58	0.51
	12.0	3.41	1.71	1.14	0.85	0.68	0.57	0.49	0.43
	14.0	2.93	1.47	0.98	0.73	0.59	0.49	0.42	0.37
	16.0	2.57	1.28	0.86	0.64	0.51	0.43	0.37	0.32

Figure 6.9 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 160x160mm GL28c 2,5 m glulam columns according to EN1995-1-1:2006

Beam step, m		Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	17.50	8.75	5.83	4.37	3.50	2.92	2.50	2.19
	4.0	8.95	4.48	2.98	2.24	1.79	1.49	1.28	1.12
	6.0	6.02	3.01	2.01	1.50	1.20	1.00	0.86	0.75
	8.0	4.53	2.26	1.51	1.13	0.91	0.75	0.65	0.57
	10.0	3.63	1.82	1.21	0.91	0.73	0.61	0.52	0.45
	12.0	3.03	1.52	1.01	0.76	0.61	0.51	0.43	0.38
	14.0	2.60	1.30	0.87	0.65	0.52	0.43	0.37	0.33
	16.0	2.28	1.14	0.76	0.57	0.46	0.38	0.33	0.28

Figure 6.10 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 160x160mm GL28c 2,5 m glulam columns according to EN1995-1-1:2022

In Figures 6.9 and 6.10 the same values calculated according to different Eurocodes are compared. In both cases the timber strength value of the cross-section is GL28c, and length is 2,5 m. The first table shows that according to EN1995-1-1:2006 in 24 instances, which makes 37,5% of all instances, the load-bearing capacity is not verified. The second table shows that according to EN1995-1-1:2022 in 26 instances, which makes 40,6% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin stayed the same. The number of instances, where the load-bearing capacity is ≥1,0 lowered from 38 to 36. In percentages the change is 5,3%.

When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-1:2022 are 11,2% lower than the counterpart.

Beam step, m	Beam span, m							
	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
2.0	7.58	3.79	2.53	1.90	1.52	1.26	1.08	0.95
4.0	3.88	1.94	1.29	0.97	0.78	0.65	0.55	0.49
6.0	2.61	1.30	0.87	0.65	0.52	0.43	0.37	0.33
8.0	1.96	0.98	0.65	0.49	0.39	0.33	0.28	0.25
10.0	1.57	0.79	0.52	0.39	0.31	0.26	0.22	0.20
12.0	1.31	0.66	0.44	0.33	0.26	0.22	0.19	0.16
14.0	1.13	0.56	0.38	0.28	0.23	0.19	0.16	0.14
16.0	0.99	0.49	0.33	0.25	0.20	0.16	0.14	0.12

Figure 6.11 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 160x160mm GL28c 5 m glulam columns according to EN1995-1-1:2006

Beam step, m	Beam span, m							
	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
2.0	6.12	3.06	2.04	1.53	1.22	1.02	0.87	0.77
4.0	3.13	1.57	1.04	0.78	0.63	0.52	0.45	0.39
6.0	2.11	1.05	0.70	0.53	0.42	0.35	0.30	0.26
8.0	1.59	0.79	0.53	0.40	0.32	0.26	0.23	0.20
10.0	1.27	0.64	0.42	0.32	0.25	0.21	0.18	0.16
12.0	1.06	0.53	0.35	0.27	0.21	0.18	0.15	0.13
14.0	0.91	0.46	0.30	0.23	0.18	0.15	0.13	0.11
16.0	0.80	0.40	0.27	0.20	0.16	0.13	0.11	0.10

Figure 6.12 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 160x160mm GL28c 5 m glulam columns according to EN1995-1-1:2022

In Figures 6.11 and 6.12 the same values calculated according to different Eurocodes are compared. In both cases the timber strength value of the cross-section is GL28c, and length is 5 m. The first table shows that according to EN1995-1-1:2006 in 44 instances, which makes 68,8% of all instances, the load-bearing capacity is not verified. The second table shows that according to EN1995-1-1:2022 in 49 instances, which makes 76,6% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin decreased from 4 to 1. The number of instances, where the load-bearing capacity is ≥1,0 lowered from 16 to 14. In percentages the change is 12,5%.

When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-1:2022 are 19,3% lower than the counterpart.

Beam step, m		Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	20.35	10.18	6.78	5.09	4.07	3.39	2.91	2.54
	4.0	10.41	5.21	3.47	2.60	2.08	1.74	1.49	1.30
	6.0	7.00	3.50	2.33	1.75	1.40	1.17	1.00	0.87
	8.0	5.27	2.63	1.76	1.32	1.05	0.88	0.75	0.66
	10.0	4.22	2.11	1.41	1.06	0.84	0.70	0.60	0.53
	12.0	3.53	1.76	1.18	0.88	0.71	0.59	0.50	0.44
	14.0	3.03	1.51	1.01	0.76	0.61	0.50	0.43	0.38
	16.0	2.65	1.33	0.88	0.66	0.53	0.44	0.38	0.33

Figure 6.13 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 160x160mm GL32c 2,5 m glulam columns according to EN1995-1-1:2006

Beam step, m		Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	18.43	9.21	6.14	4.61	3.69	3.07	2.63	2.30
	4.0	9.43	4.72	3.14	2.36	1.89	1.57	1.35	1.18
	6.0	6.34	3.17	2.11	1.58	1.27	1.06	0.91	0.79
	8.0	4.77	2.39	1.59	1.19	0.95	0.80	0.68	0.60
	10.0	3.83	1.91	1.28	0.96	0.77	0.64	0.55	0.48
	12.0	3.19	1.60	1.06	0.80	0.64	0.53	0.46	0.40
	14.0	2.74	1.37	0.91	0.69	0.55	0.46	0.39	0.34
	16.0	2.40	1.20	0.80	0.60	0.48	0.40	0.34	0.30

Figure 6.14 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 160x160mm GL32c 2,5 m glulam columns according to EN1995-1-1:2022

In Figures 6.13 and 6.14 the same values calculated according to different Eurocodes are compared. In both cases the timber strength value of the cross-section is GL32c, and length is 2,5 m. The first table shows that according to EN1995-1-1:2006 in 24 instances, which makes 37,5% of all instances, the load-bearing capacity is not verified. The second table shows that according to EN1995-1-1:2022 in 24 instances, which makes 37,5% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin increased from 0 to 4. The number of instances, where the load-bearing capacity is ≥1,0 lowered from 40 to 36. In percentages the change is 10%.

When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-1:2022 are 9,4% lower than the counterpart.

Beam step, m		Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	8.14	4.07	2.71	2.03	1.63	1.36	1.16	1.02
	4.0	4.16	2.08	1.39	1.04	0.83	0.69	0.59	0.52
	6.0	2.80	1.40	0.93	0.70	0.56	0.47	0.40	0.35
	8.0	2.11	1.05	0.70	0.53	0.42	0.35	0.30	0.26
	10.0	1.69	0.84	0.56	0.42	0.34	0.28	0.24	0.21
	12.0	1.41	0.71	0.47	0.35	0.28	0.24	0.20	0.18
	14.0	1.21	0.61	0.40	0.30	0.24	0.20	0.17	0.15
	16.0	1.06	0.53	0.35	0.26	0.21	0.18	0.15	0.13

Figure 6.15 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 160x160mm GL32c 5 m glulam columns according to EN1995-1-1:2006

Beam step, m		Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	6.66	3.33	2.22	1.67	1.33	1.11	0.95	0.83
	4.0	3.41	1.70	1.14	0.85	0.68	0.57	0.49	0.43
	6.0	2.29	1.15	0.76	0.57	0.46	0.38	0.33	0.29
	8.0	1.72	0.86	0.57	0.43	0.34	0.29	0.25	0.22
	10.0	1.38	0.69	0.46	0.35	0.28	0.23	0.20	0.17
	12.0	1.15	0.58	0.38	0.29	0.23	0.19	0.16	0.14
	14.0	0.99	0.50	0.33	0.25	0.20	0.17	0.14	0.12
	16.0	0.87	0.43	0.29	0.22	0.17	0.14	0.12	0.11

Figure 6.16 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 160x160mm GL32c 5 m glulam columns according to EN1995-1-1:2022

In Figures 6.15 and 6.16 the same values calculated according to different Eurocodes are compared. In both cases the timber strength value of the cross-section is GL32c, and length is 5 m. The first table shows that according to EN1995-1-1:2006 in 43 instances, which makes 67,2% of all instances, the load-bearing capacity is not verified. The second table shows that according to EN1995-1-1:2022 in 48 instances, which makes 75% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin increased from 1 to 2. The number of instances, where the load-bearing capacity is ≥1,0 lowered from 20 to 14. In percentages the change is 30%.

When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-1:2022 are 18,1% lower than the counterpart.

6.1.3 Cross-section 120x120 mm

In this section only 120x120 mm cross-sections will be considered.

Beam step, m	Beam span, m								
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	8.55	4.27	2.85	2.14	1.71	1.42	1.22	1.07
	4.0	4.38	2.19	1.46	1.09	0.88	0.73	0.63	0.55
	6.0	2.94	1.47	0.98	0.73	0.59	0.49	0.42	0.37
	8.0	2.21	1.11	0.74	0.55	0.44	0.37	0.32	0.28
	10.0	1.77	0.89	0.59	0.44	0.35	0.30	0.25	0.22
	12.0	1.48	0.74	0.49	0.37	0.30	0.25	0.21	0.19
	14.0	1.27	0.64	0.42	0.32	0.25	0.21	0.18	0.16
	16.0	1.11	0.56	0.37	0.28	0.22	0.19	0.16	0.14

Figure 6.17 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 120x120mm GL28c 2,5 m glulam columns according to EN1995-1-1:2006

Beam step, m	Beam span, m								
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	7.42	3.71	2.47	1.85	1.48	1.24	1.06	0.93
	4.0	3.80	1.90	1.27	0.95	0.76	0.63	0.54	0.47
	6.0	2.55	1.27	0.85	0.64	0.51	0.42	0.36	0.32
	8.0	1.92	0.96	0.64	0.48	0.38	0.32	0.27	0.24
	10.0	1.54	0.77	0.51	0.38	0.31	0.26	0.22	0.19
	12.0	1.29	0.64	0.43	0.32	0.26	0.21	0.18	0.16
	14.0	1.10	0.55	0.37	0.28	0.22	0.18	0.16	0.14
	16.0	0.97	0.48	0.32	0.24	0.19	0.16	0.14	0.12

Figure 6.18 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 120x120mm GL28c 2,5 m glulam columns according to EN1995-1-1:2022

In Figures 6.17 and 6.18 the same values calculated according to different Eurocodes are compared. In both cases the timber strength value of the cross-section is GL28c, and length is 2,5 m. The first table shows that according to EN1995-1-1:2006 in 43 instances, which makes 67,2% of all instances, the load-bearing capacity is not verified. The second table shows that according to EN1995-1-1:2022 in 44 instances, which makes 68,8% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin increased from 1 to 4. The number of instances, where the load-bearing capacity is ≥1,0 lowered from 20 to 16. In percentages the change is 20%.
When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-1:2022 are 13,4% lower than the counterpart.

Beam step, m	Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	2.46	1.23	0.82	0.61	0.49	0.41	0.35	0.31
	4.0	1.26	0.63	0.42	0.31	0.25	0.21	0.18	0.16
	6.0	0.85	0.42	0.28	0.21	0.17	0.14	0.12	0.11
	8.0	0.64	0.32	0.21	0.16	0.13	0.11	0.09	0.08
	10.0	0.51	0.26	0.17	0.13	0.10	0.09	0.07	0.06
	12.0	0.43	0.21	0.14	0.11	0.09	0.07	0.06	0.05
	14.0	0.37	0.18	0.12	0.09	0.07	0.06	0.05	0.05
	16.0	0.32	0.16	0.11	0.08	0.06	0.05	0.05	0.04

Figure 6.19 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 120x120mm GL28c 5 m glulam columns according to EN1995-1-1:2006

Beam step, m	Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	2.10	1.05	0.70	0.52	0.42	0.35	0.30	0.26
	4.0	1.07	0.54	0.36	0.27	0.21	0.18	0.15	0.13
	6.0	0.72	0.36	0.24	0.18	0.14	0.12	0.10	0.09
	8.0	0.54	0.27	0.18	0.14	0.11	0.09	0.08	0.07
	10.0	0.44	0.22	0.15	0.11	0.09	0.07	0.06	0.05
	12.0	0.36	0.18	0.12	0.09	0.07	0.06	0.05	0.05
	14.0	0.31	0.16	0.10	0.08	0.06	0.05	0.04	0.04
	16.0	0.27	0.14	0.09	0.07	0.05	0.05	0.04	0.03

Figure 6.20 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 120x120mm GL28c 5 m glulam columns according to EN1995-1-1:2022

In Figures 6.19 and 6.20 the same values calculated according to different Eurocodes are compared. In both cases the timber strength value of the cross-section is GL28c, and length is 5 m. The first table shows that according to EN1995-1-1:2006 in 61 instances, which makes 95,3% of all instances, the load-bearing capacity is not verified. The second table shows that according to EN1995-1-1:2022 in 61 instances, which makes 95,3% of all instances, the load-bearing capacity is not verified. The number of instances, where the load-bearing capacity is ≥1,0 stayed the same.

When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-1:2022 are 15% lower than the counterpart.

Beam step, m	Beam span, m							
	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
2.0	9.05	4.52	3.02	2.26	1.81	1.51	1.29	1.13
4.0	4.63	2.32	1.54	1.16	0.93	0.77	0.66	0.58
6.0	3.11	1.56	1.04	0.78	0.62	0.52	0.44	0.39
8.0	2.34	1.17	0.78	0.59	0.47	0.39	0.33	0.29
10.0	1.88	0.94	0.63	0.47	0.38	0.31	0.27	0.23
12.0	1.57	0.78	0.52	0.39	0.31	0.26	0.22	0.20
14.0	1.35	0.67	0.45	0.34	0.27	0.22	0.19	0.17
16.0	1.18	0.59	0.39	0.29	0.24	0.20	0.17	0.15

Figure 6.21 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 120x120mm GL32c 2,5 m glulam columns according to EN1995-1-1:2006

Beam step, m	Beam span, m							
	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
2.0	7.97	3.98	2.66	1.99	1.59	1.33	1.14	1.00
4.0	4.08	2.04	1.36	1.02	0.82	0.68	0.58	0.51
6.0	2.74	1.37	0.91	0.68	0.55	0.46	0.39	0.34
8.0	2.06	1.03	0.69	0.52	0.41	0.34	0.29	0.26
10.0	1.65	0.83	0.55	0.41	0.33	0.28	0.24	0.21
12.0	1.38	0.69	0.46	0.35	0.28	0.23	0.20	0.17
14.0	1.18	0.59	0.39	0.30	0.24	0.20	0.17	0.15
16.0	1.04	0.52	0.35	0.26	0.21	0.17	0.15	0.13

Figure 6.22 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 120x120mm GL32c 2,5 m glulam columns according to EN1995-1-1:2022

In Figures 6.21 and 6.22 the same values calculated according to different Eurocodes are compared. In both cases the timber strength value of the cross-section is GL32c, and length is 2,5 m. The first table shows that according to EN1995-1-1:2006 in 41 instances, which makes 64,1% of all instances, the load-bearing capacity is not verified. The second table shows that according to EN1995-1-1:2022 in 43 instances, which makes 67,2% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin decreased from 2 to 1. The number of instances, where the load-bearing capacity is ≥1,0 lowered from 21 to 20. In percentages the change is 4,8%.

When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-1:2022 are 11,8% lower than the counterpart.

Beam step, m	Beam span, m							
	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
2.0	2.64	1.32	0.88	0.66	0.53	0.44	0.38	0.33
4.0	1.35	0.68	0.45	0.34	0.27	0.23	0.19	0.17
6.0	0.91	0.45	0.30	0.23	0.18	0.15	0.13	0.11
8.0	0.68	0.34	0.23	0.17	0.14	0.11	0.10	0.09
10.0	0.55	0.27	0.18	0.14	0.11	0.09	0.08	0.07
12.0	0.46	0.23	0.15	0.11	0.09	0.08	0.07	0.06
14.0	0.39	0.20	0.13	0.10	0.08	0.07	0.06	0.05
16.0	0.34	0.17	0.11	0.09	0.07	0.06	0.05	0.04

Figure 6.23 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 120x120mm GL32c 5 m glulam columns according to EN1995-1-1:2006

Beam step, m	Beam span, m							
	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
2.0	2.28	1.14	0.76	0.57	0.46	0.38	0.33	0.29
4.0	1.17	0.58	0.39	0.29	0.23	0.19	0.17	0.15
6.0	0.78	0.39	0.26	0.20	0.16	0.13	0.11	0.10
8.0	0.59	0.30	0.20	0.15	0.12	0.10	0.08	0.07
10.0	0.47	0.24	0.16	0.12	0.09	0.08	0.07	0.06
12.0	0.40	0.20	0.13	0.10	0.08	0.07	0.06	0.05
14.0	0.34	0.17	0.11	0.08	0.07	0.06	0.05	0.04
16.0	0.30	0.15	0.10	0.07	0.06	0.05	0.04	0.04

Figure 6.24 Values of $k_c*f_{c,d}/\sigma_{c,d}$ for 120x120mm GL32c 5 m glulam columns according to EN1995-1-1:2022

In Figures 6.23 and 6.24 the same values calculated according to different Eurocodes are compared. In both cases the timber strength value of the cross-section is GL32c, and length is 5 m. The first table shows that according to EN1995-1-1:2006 in 60 instances, which makes 93,8% of all instances, the load-bearing capacity is not verified. The second table shows that according to EN1995-1-1:2022 in 61 instances, which makes 95,3% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin decreased from 1 to 0. The number of instances, where the load-bearing capacity is ≥1,0 stayed the same.

When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-1:2022 are 13,7% lower than the counterpart.

6.1.4 Analysis

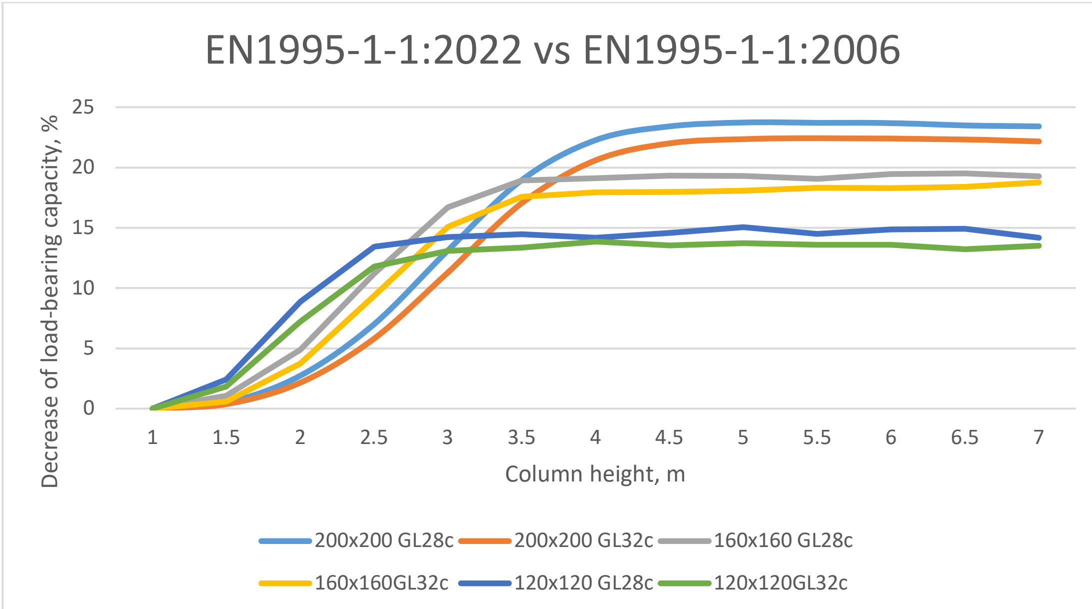


Figure 6.25 Effect of changes on load-bearing capacity between EN1995-1-1:2022 and EN1995-1-1:2006.

To wrap up the results from section 6.1 a graph was created. It reflects how much the changes to the Eurocode 5 part 1 have on the load-bearing capacity of glulam columns. On the horizontal axis is the buckling length of the column and on the vertical axis the percentage by how much load-bearing capacity has decreased.

Most changes have been done to the stability section of EN-1995-1-1 and it is apparent when looking at the graph. The longer the column the greater is the difference between existing and revised design models. For example, the curve "200x200 GL28c" shows that with column length of 2 metres the difference is 2,7% and with 4 metres it increases to 22,3%. The same happens with other curves. The change is exponential in the first stage and later subsides.

From Figure 6.25 it can observed that depending on the columns cross-section, strength class and/or height the load-bearing capacity in buckling can decrease by up to 24%.

6.2 Comparison of EN1995-1-2:2006 and EN1995-1-2:2022

In case of EN1995-1-2 calculations are performed in fire conditions. The ultimate limit state of the columns in fire is taken into consideration. From EN1995:2002 we take combination factor 0,5 for the live load and from EN1990:2002 we take partial factor 1,0 for permanent actions [14].

The following images contain the summarized results of the calculations according to EN1995-1-2:2006 and EN1995-1-2:2022. The numerical result shows whether a reduced cross section with a specific strength class and length will maintain its load-bearing capacity from multiple dead-loads and live-load. The numerical value is the ratio between the load-bearing capacity of column and compression stress considering buckling.

When the ratio is ≥1,0 the distinct cell turns green in color. For values 0,9-1,0 the color is yellow and anything ≤0,9 is red.

6.2.1 Cross-section 200x200 mm

	Beam span, m								
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
Beam step, m	2.0	44.56	22.28	14.85	11.14	8.91	7.43	6.37	5.57
	4.0	22.97	11.49	7.66	5.74	4.59	3.83	3.28	2.87
	6.0	15.48	7.74	5.16	3.87	3.10	2.58	2.21	1.93
	8.0	11.67	5.83	3.89	2.92	2.33	1.94	1.67	1.46
	10.0	9.36	4.68	3.12	2.34	1.87	1.56	1.34	1.17
	12.0	7.82	3.91	2.61	1.95	1.56	1.30	1.12	0.98
	14.0	6.71	3.36	2.24	1.68	1.34	1.12	0.96	0.84
	16.0	5.88	2.94	1.96	1.47	1.18	0.98	0.84	0.74

Figure 6.26 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 200x200mm GL28c 2,5 m glulam columns according to EN1995-1-2:2006

	Beam span, m								
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
Beam step, m	2.0	28.44	14.22	9.48	7.11	5.69	4.74	4.06	3.56
	4.0	14.66	7.33	4.89	3.67	2.93	2.44	2.09	1.83
	6.0	9.88	4.94	3.29	2.47	1.98	1.65	1.41	1.23
	8.0	7.45	3.72	2.48	1.86	1.49	1.24	1.06	0.93
	10.0	5.98	2.99	1.99	1.49	1.20	1.00	0.85	0.75
	12.0	4.99	2.50	1.66	1.25	1.00	0.83	0.71	0.62
	14.0	4.28	2.14	1.43	1.07	0.86	0.71	0.61	0.54
	16.0	3.75	1.88	1.25	0.94	0.75	0.63	0.54	0.47

Figure 6.27 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 200x200mm GL28c 2,5 m glulam columns according to EN1995-1-2:2022

In Figures 6.26 and 6.27 the same values calculated according to different Eurocodes are compared. The figures show 64 different combinations of beam span and beam step and the cells show the final value of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$. In both cases the timber strength value of the cross-section is GL28c, and length is 2,5 m. The first table shows that according to EN1995-1-2:2006 in 0 instances the load-bearing capacity is not verified. The second table shows that according to EN1995-1-2:2022 in 8 instances, which makes 12,5% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin increased from 1 to 2. The number of instances, where the load-bearing capacity is ≥1,0 lowered from 63 to 54. In percentages the change is 14,3%.

When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-2:2022 are 36,2% lower than the counterpart.

		Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
Beam step, m	2.0	18.42	9.21	6.14	4.61	3.68	3.07	2.63	2.30
	4.0	9.56	4.78	3.19	2.39	1.91	1.59	1.37	1.20
	6.0	6.46	3.23	2.15	1.61	1.29	1.08	0.92	0.81
	8.0	4.88	2.44	1.63	1.22	0.98	0.81	0.70	0.61
	10.0	3.92	1.96	1.31	0.98	0.78	0.65	0.56	0.49
	12.0	3.27	1.64	1.09	0.82	0.65	0.55	0.47	0.41
	14.0	2.81	1.40	0.94	0.70	0.56	0.47	0.40	0.35
	16.0	2.46	1.23	0.82	0.62	0.49	0.41	0.35	0.31

Figure 6.28 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 200x200mm GL28c 5 m glulam columns according to EN1995-1-2:2006

		Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
Beam step, m	2.0	10.36	5.18	3.45	2.59	2.07	1.73	1.48	1.29
	4.0	5.38	2.69	1.79	1.34	1.08	0.90	0.77	0.67
	6.0	3.63	1.82	1.21	0.91	0.73	0.61	0.52	0.45
	8.0	2.74	1.37	0.91	0.69	0.55	0.46	0.39	0.34
	10.0	2.20	1.10	0.73	0.55	0.44	0.37	0.31	0.28
	12.0	1.84	0.92	0.61	0.46	0.37	0.31	0.26	0.23
	14.0	1.58	0.79	0.53	0.39	0.32	0.26	0.23	0.20
	16.0	1.38	0.69	0.46	0.35	0.28	0.23	0.20	0.17

Figure 6.29 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 200x200mm GL28c 5 m glulam columns according to EN1995-1-2:2022

In Figures 6.28 and 6.29 the same values calculated according to different Eurocodes are compared. In both cases the timber strength value of the cross-section is GL28c, and length is 5 m. The first table shows that according to EN1995-1-2:2006 in 24, which makes 37,5% of all instances, the load-bearing capacity is not verified. The second table shows that according to EN1995-1-2:2022 in 37 instances, which makes 57,8% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin stayed the same. The number of instances, where the load-bearing capacity is ≥1,0 lowered from 36 to 23. In percentages the change is 36,1%.

When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-2:2022 are 43,8% lower than the counterpart.

	Beam span, m								
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
Beam step, m	2.0	57.10	28.55	19.03	14.27	11.42	9.52	8.16	7.14
	4.0	29.65	14.82	9.88	7.41	5.93	4.94	4.24	3.71
	6.0	20.02	10.01	6.67	5.01	4.00	3.34	2.86	2.50
	8.0	15.11	7.56	5.04	3.78	3.02	2.52	2.16	1.89
	10.0	12.14	6.07	4.05	3.03	2.43	2.02	1.73	1.52
	12.0	10.14	5.07	3.38	2.54	2.03	1.69	1.45	1.27
	14.0	8.71	4.35	2.90	2.18	1.74	1.45	1.24	1.09
	16.0	7.63	3.82	2.54	1.91	1.53	1.27	1.09	0.95

Figure 6.30 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 200x200mm GL32c 2,5 m glulam columns according to EN1995-1-2:2006

	Beam span, m								
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
Beam step, m	2.0	37.45	18.73	12.48	9.36	7.49	6.24	5.35	4.68
	4.0	19.45	9.72	6.48	4.86	3.89	3.24	2.78	2.43
	6.0	13.13	6.57	4.38	3.28	2.63	2.19	1.88	1.64
	8.0	9.91	4.96	3.30	2.48	1.98	1.65	1.42	1.24
	10.0	7.96	3.98	2.65	1.99	1.59	1.33	1.14	1.00
	12.0	6.65	3.33	2.22	1.66	1.33	1.11	0.95	0.83
	14.0	5.71	2.86	1.90	1.43	1.14	0.95	0.82	0.71
	16.0	5.01	2.50	1.67	1.25	1.00	0.83	0.72	0.63

Figure 6.31 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 200x200mm GL32c 2,5 m glulam columns according to EN1995-1-2:2022

In Figures 6.30 and 6.31 the same values calculated according to different Eurocodes are compared. In both cases the timber strength value of the cross-section is GL32c, and length is 2,5 m. The first table shows that according to EN1995-1-2:2006 in 0 instances the load-bearing capacity is not verified. The second table shows that according to EN1995-1-2:2022 in 6 instances, which makes 9,4% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin increased from 1 to 2. The number of instances, where the load-bearing capacity is ≥1,0 lowered from 63 to 56. In percentages the change is 11,1%.

When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-2:2022 are 34,4% lower than the counterpart.

Beam step, m	Beam span, m							
	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
2.0	19.79	9.89	6.60	4.95	3.96	3.30	2.83	2.47
4.0	10.27	5.14	3.42	2.57	2.05	1.71	1.47	1.28
6.0	6.94	3.47	2.31	1.73	1.39	1.16	0.99	0.87
8.0	5.24	2.62	1.75	1.31	1.05	0.87	0.75	0.65
10.0	4.21	2.10	1.40	1.05	0.84	0.70	0.60	0.53
12.0	3.51	1.76	1.17	0.88	0.70	0.59	0.50	0.44
14.0	3.02	1.51	1.01	0.75	0.60	0.50	0.43	0.38
16.0	2.64	1.32	0.88	0.66	0.53	0.44	0.38	0.33

Figure 6.32 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 200x200mm GL32c 5 m glulam columns according to EN1995-1-2:2006

Beam step, m	Beam span, m							
	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
2.0	11.26	5.63	3.75	2.81	2.25	1.88	1.61	1.41
4.0	5.85	2.92	1.95	1.46	1.17	0.97	0.84	0.73
6.0	3.95	1.97	1.32	0.99	0.79	0.66	0.56	0.49
8.0	2.98	1.49	0.99	0.75	0.60	0.50	0.43	0.37
10.0	2.39	1.20	0.80	0.60	0.48	0.40	0.34	0.30
12.0	2.00	1.00	0.67	0.50	0.40	0.33	0.29	0.25
14.0	1.72	0.86	0.57	0.43	0.34	0.29	0.25	0.21
16.0	1.51	0.75	0.50	0.38	0.30	0.25	0.22	0.19

Figure 6.33 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 200x200mm GL32c 5 m glulam columns according to EN1995-1-2:2022

In Figures 6.32 and 6.33 the same values calculated according to different Eurocodes are compared. In both cases the timber strength value of the cross-section is GL32c, and length is 5 m. The first table shows that according to EN1995-1-2:2006 in 24, which makes 37,5% of all instances, the load-bearing capacity is not verified. The second table shows that according to EN1995-1-2:2022 in 37 instances, which makes 57,8% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin increased from 1 to 3. The number of instances, where the load-bearing capacity is ≥1,0 lowered from 39 to 24. In percentages the change is 38,5%.

When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-2:2022 are 43% lower than the counterpart.

6.2.2 Cross section 160x160 mm

		Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
Beam step, m	2.0	18.83	9.41	6.28	4.71	3.77	3.14	2.69	2.35
	4.0	9.78	4.89	3.26	2.44	1.96	1.63	1.40	1.22
	6.0	6.60	3.30	2.20	1.65	1.32	1.10	0.94	0.83
	8.0	4.98	2.49	1.66	1.25	1.00	0.83	0.71	0.62
	10.0	4.00	2.00	1.33	1.00	0.80	0.67	0.57	0.50
	12.0	3.34	1.67	1.11	0.84	0.67	0.56	0.48	0.42
	14.0	2.87	1.44	0.96	0.72	0.57	0.48	0.41	0.36
	16.0	2.52	1.26	0.84	0.63	0.50	0.42	0.36	0.31

Figure 6.34 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 160x160mm GL28c 2,5 m glulam columns according to EN1995-1-2:2006

		Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
Beam step, m	2.0	9.81	4.91	3.27	2.45	1.96	1.64	1.40	1.23
	4.0	5.09	2.55	1.70	1.27	1.02	0.85	0.73	0.64
	6.0	3.44	1.72	1.15	0.86	0.69	0.57	0.49	0.43
	8.0	2.60	1.30	0.87	0.65	0.52	0.43	0.37	0.32
	10.0	2.09	1.04	0.70	0.52	0.42	0.35	0.30	0.26
	12.0	1.74	0.87	0.58	0.44	0.35	0.29	0.25	0.22
	14.0	1.50	0.75	0.50	0.37	0.30	0.25	0.21	0.19
	16.0	1.31	0.66	0.44	0.33	0.26	0.22	0.19	0.16

Figure 6.35 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 160x160mm GL28c 2,5 m glulam columns according to EN1995-1-2:2022

In Figures 6.34 and 6.35 the same values calculated according to different Eurocodes are compared. The figures show 64 different combinations of beam span and beam step and the cells show the final value of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$. In both cases the timber strength value of the cross-section is GL28c, and length is 2,5 m. The first table shows that according to EN1995-1-2:2006 in 24, which makes 37,5% of all instances, the load-bearing capacity is not verified. The second table shows that according to EN1995-1-2:2022 in 41 instances, which makes 64,1% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin decreased from 2 to 0. The number of instances, where the load-bearing capacity is ≥1,0 lowered from 38 to 23. In percentages the change is 39,5%.

When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-2:2022 are 48,9% lower than the counterpart.

Beam step, m	Beam span, m							
	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
2.0	5.12	2.56	1.71	1.28	1.02	0.85	0.73	0.64
4.0	2.66	1.33	0.89	0.66	0.53	0.44	0.38	0.33
6.0	1.80	0.90	0.60	0.45	0.36	0.30	0.26	0.22
8.0	1.36	0.68	0.45	0.34	0.27	0.23	0.19	0.17
10.0	1.09	0.54	0.36	0.27	0.22	0.18	0.16	0.14
12.0	0.91	0.45	0.30	0.23	0.18	0.15	0.13	0.11
14.0	0.78	0.39	0.26	0.20	0.16	0.13	0.11	0.10
16.0	0.68	0.34	0.23	0.17	0.14	0.11	0.10	0.09

Figure 6.36 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 160x160mm GL28c 5 m glulam columns according to EN1995-1-2:2006

Beam step, m	Beam span, m							
	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
2.0	2.55	1.28	0.85	0.64	0.51	0.43	0.36	0.32
4.0	1.33	0.66	0.44	0.33	0.27	0.22	0.19	0.17
6.0	0.90	0.45	0.30	0.22	0.18	0.15	0.13	0.11
8.0	0.68	0.34	0.23	0.17	0.14	0.11	0.10	0.08
10.0	0.54	0.27	0.18	0.14	0.11	0.09	0.08	0.07
12.0	0.45	0.23	0.15	0.11	0.09	0.08	0.06	0.06
14.0	0.39	0.19	0.13	0.10	0.08	0.06	0.06	0.05
16.0	0.34	0.17	0.11	0.09	0.07	0.06	0.05	0.04

Figure 6.37 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 160x160mm GL28c 5 m glulam columns according to EN1995-1-2:2022

In Figures 6.36 and 6.37 the same values calculated according to different Eurocodes are compared. In both cases the timber strength value of the cross-section is GL28c, and length is 5 m. The first table shows that according to EN1995-1-2:2006 in 52, which makes 81,3% of all instances, the load-bearing capacity is not verified. The second table shows that according to EN1995-1-2:2022 in 60 instances, which makes 93,8% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin decreased from 2 to 1. The number of instances, where the load-bearing capacity is ≥1,0 lowered from 10 to 3. In percentages the change is 70%.

When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-2:2022 are 50% lower than the counterpart.

Beam step, m		Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	20.09	10.05	6.70	5.02	4.02	3.35	2.87	2.51
	4.0	10.43	5.22	3.48	2.61	2.09	1.74	1.49	1.30
	6.0	7.05	3.52	2.35	1.76	1.41	1.17	1.01	0.88
	8.0	5.32	2.66	1.77	1.33	1.06	0.89	0.76	0.66
	10.0	4.27	2.14	1.42	1.07	0.85	0.71	0.61	0.53
	12.0	3.57	1.78	1.19	0.89	0.71	0.59	0.51	0.45
	14.0	3.07	1.53	1.02	0.77	0.61	0.51	0.44	0.38
	16.0	2.69	1.34	0.90	0.67	0.54	0.45	0.38	0.34

Figure 6.38 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 160x160mm GL32c 2,5 m glulam columns according to EN1995-1-2:2006

Beam step, m		Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	10.62	5.31	3.54	2.65	2.12	1.77	1.52	1.33
	4.0	5.51	2.76	1.84	1.38	1.10	0.92	0.79	0.69
	6.0	3.72	1.86	1.24	0.93	0.74	0.62	0.53	0.47
	8.0	2.81	1.41	0.94	0.70	0.56	0.47	0.40	0.35
	10.0	2.26	1.13	0.75	0.56	0.45	0.38	0.32	0.28
	12.0	1.89	0.94	0.63	0.47	0.38	0.31	0.27	0.24
	14.0	1.62	0.81	0.54	0.40	0.32	0.27	0.23	0.20
	16.0	1.42	0.71	0.47	0.35	0.28	0.24	0.20	0.18

Figure 6.39 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 160x160mm GL32c 2,5 m glulam columns according to EN1995-1-2:2022

In Figures 6.38 and 6.39 the same values calculated according to different Eurocodes are compared. In both cases the timber strength value of the cross-section is GL32c, and length is 2,5 m. The first table shows that according to EN1995-1-2:2006 in 23, which makes 35,9% of all instances, the load-bearing capacity is not verified. The second table shows that according to EN1995-1-2:2022 in 37 instances, which makes 57,8% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin increased from 1 to 4. The number of instances, where the load-bearing capacity is ≥1,0 lowered from 40 to 23. In percentages the change is 42,5%.

When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-2:2022 are 47,2% lower than the counterpart.

Beam step, m	Beam span, m							
	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
2.0	5.51	2.75	1.84	1.38	1.10	0.92	0.79	0.69
4.0	2.86	1.43	0.95	0.71	0.57	0.48	0.41	0.36
6.0	1.93	0.97	0.64	0.48	0.39	0.32	0.28	0.24
8.0	1.46	0.73	0.49	0.36	0.29	0.24	0.21	0.18
10.0	1.17	0.59	0.39	0.29	0.23	0.20	0.17	0.15
12.0	0.98	0.49	0.33	0.24	0.20	0.16	0.14	0.12
14.0	0.84	0.42	0.28	0.21	0.17	0.14	0.12	0.10
16.0	0.74	0.37	0.25	0.18	0.15	0.12	0.11	0.09

Figure 6.40 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 160x160mm GL32c 5 m glulam columns according to EN1995-1-2:2006

Beam step, m	Beam span, m							
	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
2.0	2.77	1.39	0.92	0.69	0.55	0.46	0.40	0.35
4.0	1.44	0.72	0.48	0.36	0.29	0.24	0.21	0.18
6.0	0.97	0.49	0.32	0.24	0.19	0.16	0.14	0.12
8.0	0.73	0.37	0.24	0.18	0.15	0.12	0.10	0.09
10.0	0.59	0.29	0.20	0.15	0.12	0.10	0.08	0.07
12.0	0.49	0.25	0.16	0.12	0.10	0.08	0.07	0.06
14.0	0.42	0.21	0.14	0.11	0.08	0.07	0.06	0.05
16.0	0.37	0.19	0.12	0.09	0.07	0.06	0.05	0.05

Figure 6.41 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 160x160mm GL32c 5 m glulam columns according to EN1995-1-2:2022

In Figures 6.40 and 6.41 the same values calculated according to different Eurocodes are compared. In both cases the timber strength value of the cross-section is GL32c, and length is 5 m. The first table shows that according to EN1995-1-2:2006 in 50, which makes 78,1% of all instances, the load-bearing capacity is not verified. The second table shows that according to EN1995-1-2:2022 in 59 instances, which makes 92,2% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin decreased from 4 to 2. The number of instances, where the load-bearing capacity is ≥1,0 lowered from 10 to 3. In percentages the change is 70%.

When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-2:2022 are 50% lower than the counterpart.

6.2.3 Cross-section 120x120 mm

Beam step, m	Beam span, m							
	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
2.0	2.90	1.45	0.97	0.73	0.58	0.48	0.41	0.36
4.0	1.51	0.75	0.50	0.38	0.30	0.25	0.22	0.19
6.0	1.02	0.51	0.34	0.25	0.20	0.17	0.15	0.13
8.0	0.77	0.38	0.26	0.19	0.15	0.13	0.11	0.10
10.0	0.62	0.31	0.21	0.15	0.12	0.10	0.09	0.08
12.0	0.52	0.26	0.17	0.13	0.10	0.09	0.07	0.06
14.0	0.44	0.22	0.15	0.11	0.09	0.07	0.06	0.06
16.0	0.39	0.19	0.13	0.10	0.08	0.06	0.06	0.05

Figure 6.42 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 120x120mm GL28c 2,5 m glulam columns according to EN1995-1-2:2006

Beam step, m	Beam span, m							
	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
2.0	1.03	0.52	0.34	0.26	0.21	0.17	0.15	0.13
4.0	0.54	0.27	0.18	0.13	0.11	0.09	0.08	0.07
6.0	0.36	0.18	0.12	0.09	0.07	0.06	0.05	0.05
8.0	0.27	0.14	0.09	0.07	0.05	0.05	0.04	0.03
10.0	0.22	0.11	0.07	0.05	0.04	0.04	0.03	0.03
12.0	0.18	0.09	0.06	0.05	0.04	0.03	0.03	0.02
14.0	0.16	0.08	0.05	0.04	0.03	0.03	0.02	0.02
16.0	0.14	0.07	0.05	0.03	0.03	0.02	0.02	0.02

Figure 6.43 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 120x120mm GL28c 2,5 m glulam columns according to EN1995-1-2:2022

In Figures 6.42 and 6.43 the same values calculated according to different Eurocodes are compared. The figures show 64 different combinations of beam span and beam step and the cells show the final value of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$. In both cases the timber strength value of the cross-section is GL28c, and length is 2,5 m. The first table shows that according to EN1995-1-2:2006 in 59, which makes 92,2% of all instances, the load-bearing capacity is not verified. The second table shows that according to EN1995-1-2:2022 in 63 instances, which makes 98,4% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin decreased from 1 to 0. The number of instances, where the load-bearing capacity is ≥1,0 lowered from 4 to 1. In percentages the change is 75%.

When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-2:2022 are 64,3% lower than the counterpart.

Beam step, m		Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	0.75	0.37	0.25	0.19	0.15	0.12	0.11	0.09
	4.0	0.39	0.19	0.13	0.10	0.08	0.06	0.06	0.05
	6.0	0.26	0.13	0.09	0.07	0.05	0.04	0.04	0.03
	8.0	0.20	0.10	0.07	0.05	0.04	0.03	0.03	0.02
	10.0	0.16	0.08	0.05	0.04	0.03	0.03	0.02	0.02
	12.0	0.13	0.07	0.04	0.03	0.03	0.02	0.02	0.02
	14.0	0.11	0.06	0.04	0.03	0.02	0.02	0.02	0.01
	16.0	0.10	0.05	0.03	0.02	0.02	0.02	0.01	0.01

Figure 6.44 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 120x120mm GL28c 5 m glulam columns according to EN1995-1-2:2006

Beam step, m		Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	0.26	0.13	0.09	0.06	0.05	0.04	0.04	0.03
	4.0	0.13	0.07	0.04	0.03	0.03	0.02	0.02	0.02
	6.0	0.09	0.05	0.03	0.02	0.02	0.02	0.01	0.01
	8.0	0.07	0.03	0.02	0.02	0.01	0.01	0.01	0.01
	10.0	0.06	0.03	0.02	0.01	0.01	0.01	0.01	0.01
	12.0	0.05	0.02	0.02	0.01	0.01	0.01	0.01	0.01
	14.0	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.00
	16.0	0.03	0.02	0.01	0.01	0.01	0.01	0.00	0.00

Figure 6.45 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 120x120mm GL28c 5 m glulam columns according to EN1995-1-2:2022

In Figures 6.44 and 6.45 the same values calculated according to different Eurocodes are compared. In both cases the timber strength value of the cross-section is GL28c, and length is 5 m. The first table shows that according to EN1995-1-2:2006 in 64, which makes 100% of all instances, the load-bearing capacity is not verified. The second table shows that according to EN1995-1-2:2022 in 64 instances, which makes 100% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin stayed the same. The number of instances, where the load-bearing capacity is ≥1,0 stayed the same at 0 instances.
When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-2:2022 are 64,4% lower than the counterpart.

Beam step, m		Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	3.12	1.56	1.04	0.78	0.62	0.52	0.45	0.39
	4.0	1.62	0.81	0.54	0.40	0.32	0.27	0.23	0.20
	6.0	1.09	0.55	0.36	0.27	0.22	0.18	0.16	0.14
	8.0	0.83	0.41	0.28	0.21	0.17	0.14	0.12	0.10
	10.0	0.66	0.33	0.22	0.17	0.13	0.11	0.09	0.08
	12.0	0.55	0.28	0.18	0.14	0.11	0.09	0.08	0.07
	14.0	0.48	0.24	0.16	0.12	0.10	0.08	0.07	0.06
	16.0	0.42	0.21	0.14	0.10	0.08	0.07	0.06	0.05

Figure 6.46 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 120x120mm GL32c 2,5 m glulam columns according to EN1995-1-2:2006

Beam step, m		Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	1.12	0.56	0.37	0.28	0.22	0.19	0.16	0.14
	4.0	0.58	0.29	0.19	0.14	0.12	0.10	0.08	0.07
	6.0	0.39	0.20	0.13	0.10	0.08	0.07	0.06	0.05
	8.0	0.30	0.15	0.10	0.07	0.06	0.05	0.04	0.04
	10.0	0.24	0.12	0.08	0.06	0.05	0.04	0.03	0.03
	12.0	0.20	0.10	0.07	0.05	0.04	0.03	0.03	0.02
	14.0	0.17	0.09	0.06	0.04	0.03	0.03	0.02	0.02
	16.0	0.15	0.07	0.05	0.04	0.03	0.02	0.02	0.02

Figure 6.47 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 120x120mm GL32c 2,5 m glulam columns according to EN1995-1-2:2022

In Figures 6.46 and 6.47 the same values calculated according to different Eurocodes are compared. In both cases the timber strength value of the cross-section is GL32c, and length is 2,5 m. The first table shows that according to EN1995-1-2:2006 in 59, which makes 92,2% of all instances, the load-bearing capacity is not verified. The second table shows that according to EN1995-1-2:2022 in 63 instances, which makes 98,4% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin stayed the same. The number of instances, where the load-bearing capacity is ≥1,0 lowered from 5 to 1. In percentages the change is 80%.

When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-2:2022 are 64,3% lower than the counterpart.

Beam step, m		Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	0.80	0.40	0.27	0.20	0.16	0.13	0.11	0.10
	4.0	0.42	0.21	0.14	0.10	0.08	0.07	0.06	0.05
	6.0	0.28	0.14	0.09	0.07	0.06	0.05	0.04	0.04
	8.0	0.21	0.11	0.07	0.05	0.04	0.04	0.03	0.03
	10.0	0.17	0.09	0.06	0.04	0.03	0.03	0.02	0.02
	12.0	0.14	0.07	0.05	0.04	0.03	0.02	0.02	0.02
	14.0	0.12	0.06	0.04	0.03	0.02	0.02	0.02	0.02
	16.0	0.11	0.05	0.04	0.03	0.02	0.02	0.02	0.01

Figure 6.48 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 120x120mm GL32c 5 m glulam columns according to EN1995-1-2:2006

Beam step, m		Beam span, m							
		2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
	2.0	0.28	0.14	0.09	0.07	0.06	0.05	0.04	0.04
	4.0	0.15	0.07	0.05	0.04	0.03	0.02	0.02	0.02
	6.0	0.10	0.05	0.03	0.02	0.02	0.02	0.01	0.01
	8.0	0.07	0.04	0.02	0.02	0.01	0.01	0.01	0.01
	10.0	0.06	0.03	0.02	0.01	0.01	0.01	0.01	0.01
	12.0	0.05	0.02	0.02	0.01	0.01	0.01	0.01	0.01
	14.0	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.01
	16.0	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.00

Figure 6.49 Values of $k_c*f_{c,d,fi}/\sigma_{c,d,fi}$ for 120x120mm GL32c 5 m glulam columns according to EN1995-1-2:2022

In Figures 6.48 and 6.49 the same values calculated according to different Eurocodes are compared. In both cases the timber strength value of the cross-section is GL32c, and length is 5 m. The first table shows that according to EN1995-1-2:2006 in 64, which makes 100% of all instances, the load-bearing capacity is not verified. The second table shows that according to EN1995-1-2:2022 in 64 instances, which makes 100% of all instances, the load-bearing capacity is not verified. Additionally, instances that are in the lower error margin stayed the same. The number of instances, where the load-bearing capacity is ≥1,0 stayed the same at 0 instances.

When comparing two of the corresponding load-bearing capacity ratios it is possible to calculate the percentage by how much load-bearing capacity decreases. On average the values corresponding to EN1995-1-2:2022 are 64 % lower than the counterpart.

6.2.4 Analysis

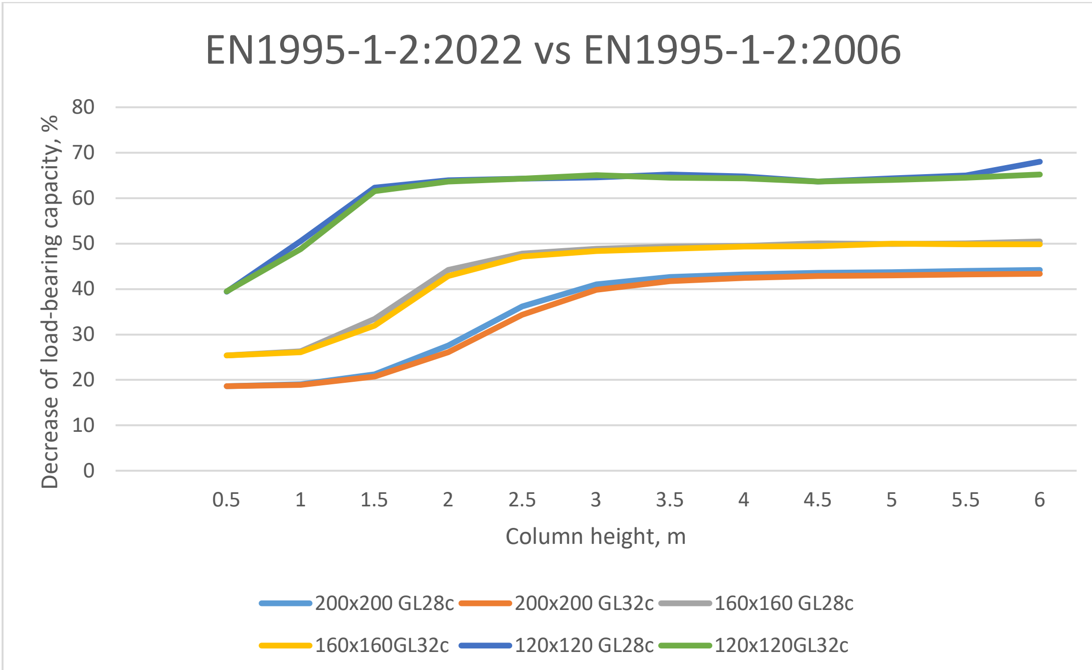


Figure 6.50 Effect of changes on load-bearing capacity between EN1995-1-2:2022 and EN1995-1-2:2006.

To wrap up the results from section 6.2 a graph was created. It reflects how much the changes to the Eurocode 5 part 2 have on the load-bearing capacity of glulam columns. On the horizontal axis is the buckling length of the column and on the vertical axis the percentage by how much load-bearing capacity has decreased.
The most notable change is the increase of the zero-strength layer thickness from 7 mm to 14 mm. Besides that, the stability of members that is discussed in section 6.1.4 affects the results. As previously explained, the column height creates a curve that is in the beginning exponential and later subsides. The strength class of timber does not have and apparent effect on changes. The increase of zero-strength layer thickness increases the percentage of change. Compared to the analysis in section 6.1.4 the percentage of change for "200x200 GL28c" shows that with column length of 2 metres the difference goes from 4,86% to 27,6% and with 4 metres it goes from 22,18% to 43,25%. The same can be observed with other curves.

As mentioned before Figure 6.25 shows that the changes made to EN1995-1-1 can decrease the load-bearing capacity of the column by up to 24%. When observing Figure 6.50 it is noticeable that depending on the columns length and cross-section the load- bearing capacity can decrease by up to 64%.

6.3 Comparison of EN1995:2006 and EN1995:2022

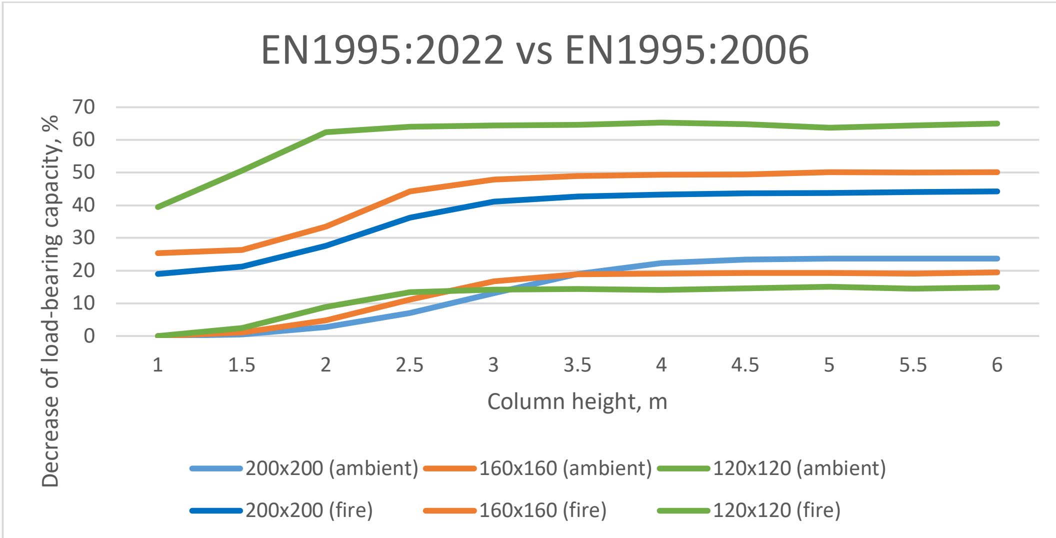


Figure 6.51 Effect of changes on load-bearing capacity between EN1995:2022 and EN1995:2006.

Figure 6.51 shows a summary of sections 6.1 and 6.2. with three lines representing decrease of load-bearing capacity of EN1995-1-1:2022 compared to EN1995-1-1:2006 and the other three lines represent decrease of load-bearing capacity of EN1995-1-2:2022 compared to EN1995-1-2:2006. Three cross-sections with the characteristic strength of GL28c are compared. The figure shows that all three lines representing ambient conditions are far below the lines representing fire conditions. From that it can be assumed that fire conditions are more critical and thus determine the load-bearing capacity of the column.

7. SIMULATIONS

In this chapter the process of performing thermo-mechanical simulations to acquire additional data is described. The additional data is later used to compare with Eurocode calculations and analyse the outcomes.

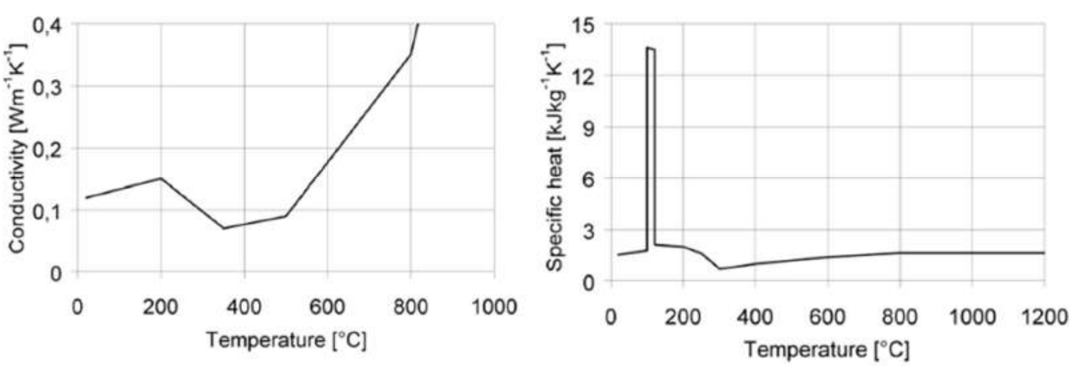
Simulations were performed using the following two programmes: SAFIR 2022 and CSTFire. SAFIR 2022 was necessary as pre-processor for CSTFire, which was later used for the structural analysis of the timber columns.

7.1 Introduction to CSTFire

CSTFire is written as a Visual Basic macro which is embedded in Excel. It has been developed at the RISE Research Institutes of Sweden and later modified by Mattia Tiso at the Tallinn University of Technology for his doctoral thesis. This program can compute the bending moment capacities of timber members in fire conditions. Iterative calculations are used to complete the calculations [15].

To run a simulation the program takes the temperature distribution of the timber cross-sections from the heat-transfer analysis performed by SAFIR 2022, which is finite-element software package [15]. SAFIR considers thermal properties of wood according to Annex B of EN1995-1-2:2006 [8]. See Figure 7.1.

With the temperature distribution CSTFire assigns temperature-dependent strength and stiffness reductions to points, calculates the geometrical properties of the residual cross-section, and determines the curvatures (κ_{fi}) and related bending moment capacities (M_{fi}) over the time of fire exposure [15]. The reduction of strength and solidity in tension and compression were assumed according to Annex B of EN1995-1-2:2006 [8]. See Figure 7.2.



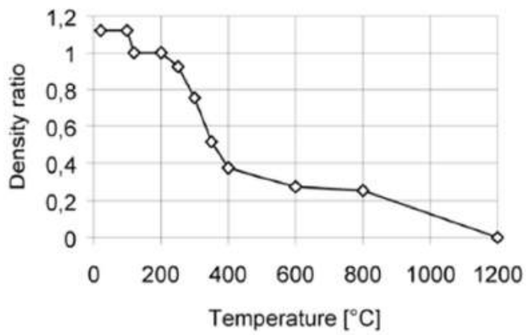


Figure 7.1 Graph 1 – Temperature-thermal conductivity relationship for wood and the char layer. Graph 2 – Temperature-specific heat relationship for wood and charcoal. Graph 3 – Temperature-density ratio for softwood with an initial moisture content of 12% [8].

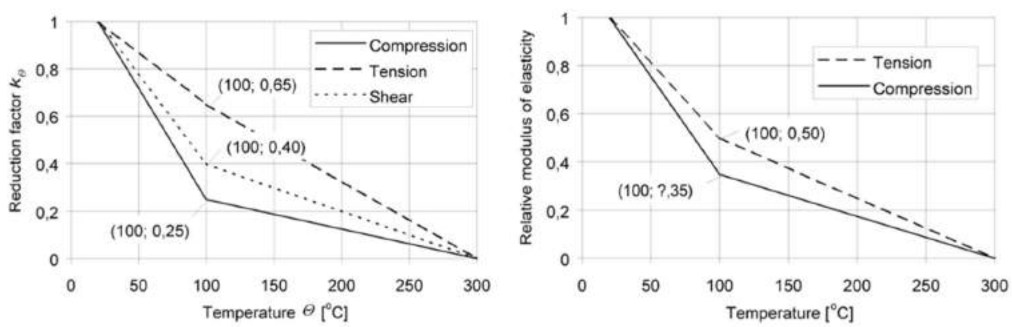


Figure 7.2 Graph 1 – Reduction factor for strength parallel to grain of softwood. Graph 2 – Effect of temperature on modulus of elasticity parallel to grain of softwood [8].

The results that can be extracted from CSTFire are the bending moment capacity Mfi and curvature κ_{fi} in a plastic design model. These two are necessary to calculate the critical buckling load for a member under fire conditions [15].

$$N_{cr} = \frac{\pi^2 (EI)_{fi}}{L_{ef}^2}$$ EKKR (5.3)

where N_{cr} - The buckling resistance, N

$(EI)_{fi}$ - The solidity of a member, Nmm^2

L_{ef} - The effective buckling length, mm

The solidity of a member under fire conditions is taken from CSTFire as:

$$(EI)_{fi} = \frac{M_{fi}}{\kappa_{fi}}$$ EKKR

(5.3)

where M_{fi} - Bending moment capacity, Nmm

κ_{fi} - Curvature of a member, mm^{-1}

7.2 Comparing simulations to test results

In order to prove the validity of the results from CSTFire a trial run of previous fire tests was performed. The results from "Experimental investigation of structural failure during the cooling phase of a fire: Timber columns" were used. In those fire tests three 280x280 mm^2 glulam timber columns with strength property GL24h were subjected to ISO 834 fire until failure and their respective fire resistance was 78, 55 and 58 min. The first column had a boundary condition of hinged-fixed and the other two were hinged-hinged. These boundary conditions affect the buckling length of the column thus influencing the calculated critical buckling resistance [16].

The objective was for the CSTFire calculated buckling resistance and the load used in the fire tests to be equal. The results are in Figure 7.3.

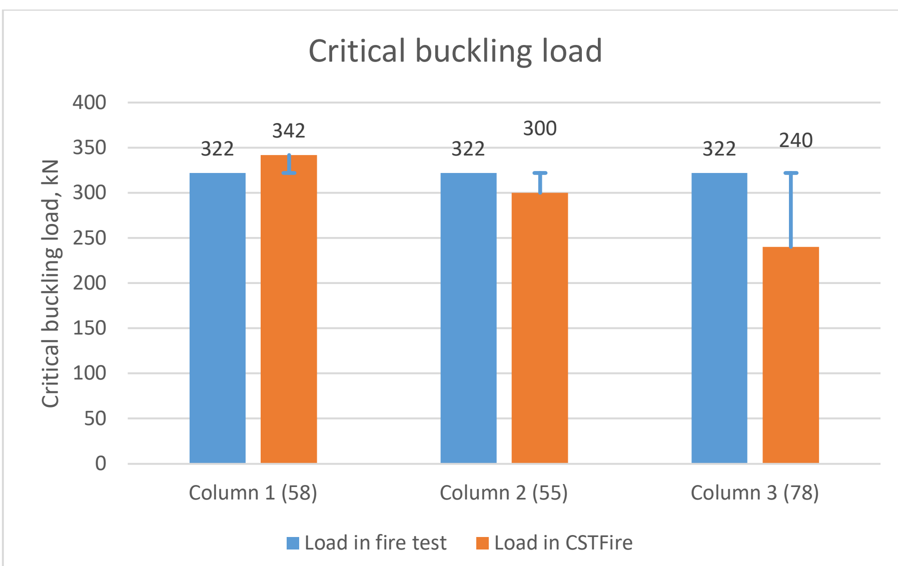


Figure 7.3 Critical buckling load applied to columns until failure. Blue shows the load applied to columns in experiments. Orange shows loads from CSTFire for simulations with identical parameters.

The results show that the first column with both ends hinged failed at 58 minutes with the applied load of 322 kN. CSTFire simulations shows that the load could be 342 kN. The difference between results is 6.2%.

Second column failed at 55 minutes with the same load. Simulations show that the load could be 300 kN. The difference between results is 6.8%.

In the article Gernay assumed that the columns failed before reaching the 60-minute benchmark, because of the milling grooves for the inner thermocouple wires [16].

The third column with only one end hinged and the other fixed burned longer than 60 minutes, namely 78 minutes. It failed with an applied load of 322 kN. CSTFire simulations show that with so much of the cross-section burned the critical load would have been 240 kN. The difference between results in 25%.

According to the comparison the results from CSTFire are trustworthy and can be used to perform further simulations.

7.3 Comparing EN1995-1-2:2022 and simulations

Simulations made with CSTFire and calculations according to EN1995-1-2:2022 were compared. A heat transfer analysis made with SAFIR 2022 made it possible to calculate the remaining cross-section after 30 minutes of burning. Thus, the notional charring depth $d_{char,n}$ could also be calculated. The results show that in a simulated fire more of the cross-section is charred than according to EN:2022. Results from SAFIR show that the notional charring depth is 25-38% greater than in calculations from EN1995-1-2:2022. The different notional charring depths according to simulations and calculations are in Figure 7.4.

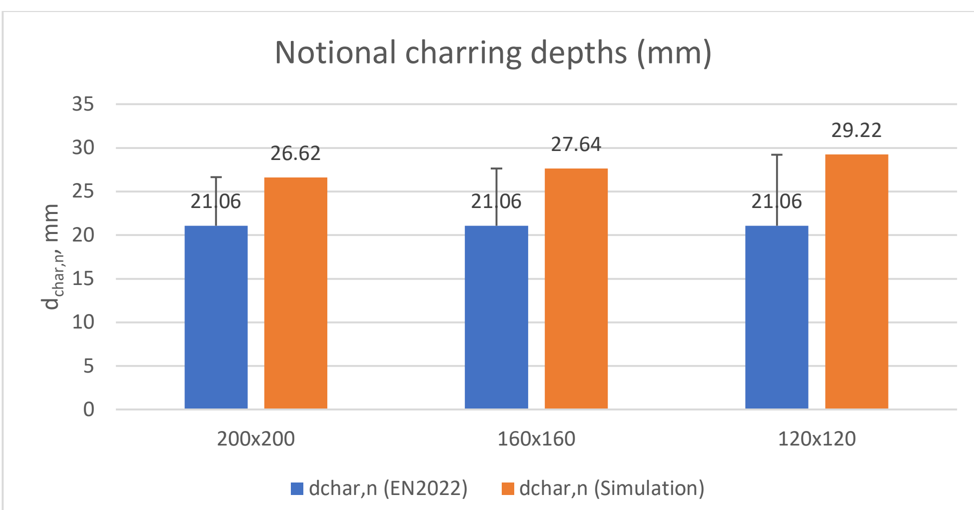


Figure 7.4 Notional charring depth of different cross-sections after 30 minutes. Blue shows $d_{char,n}$ from calculations according to EN1995-1-2:2022. Orange shows $d_{char,n}$ from SAFIR.

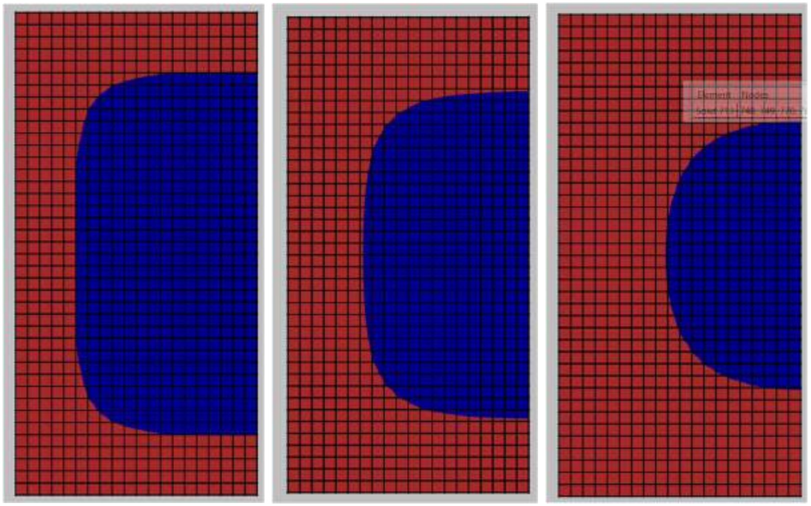


Figure 7.5 Images from SAFIR post-processor Diamond. Red indicates temperature above 300°C and blue indicates temperatures below 300°C. Left image: half 200x200 mm column with square size 5 mm. Middle image: half 160x160 mm with square size 4 mm. Right image: half 120x120 mm column with square size 3 mm.

The charring depth from SAFIR does not include the zero-strength layer. In order to find the optimal zero-strength layer thickness d_0, the buckling load-bearing capacity of the column N_{dfi} is calculated and compared to the critical load N_{cr} derived from parameters from CSTFire. N_{dfi} is calculated using the area of the charred cross-section from SAFIR. The goal is to find a value of d_0 that satisfies the following equation.

$$\mathrm{N}_{dfi} = \mathrm{N}_{cr} \qquad \text{A1}$$

where N_{dfi} - Buckling load-bearing capacity of column, kN

N_{cr} - Critical buckling load, kN

$$\mathrm{N}_{dfi} = k_c * A_{fi} * f_{c,d} \qquad \text{A2}$$

Same process is repeated with EN1995-1-2:2022, however the notional charring depth is calculated according to the formula (5.2). In the end an optimal d_0 value is found that satisfies the same equation.

The zero-strength layer thickness values for different cross-sections are shown in the following tables with a graph that shows the results visually.

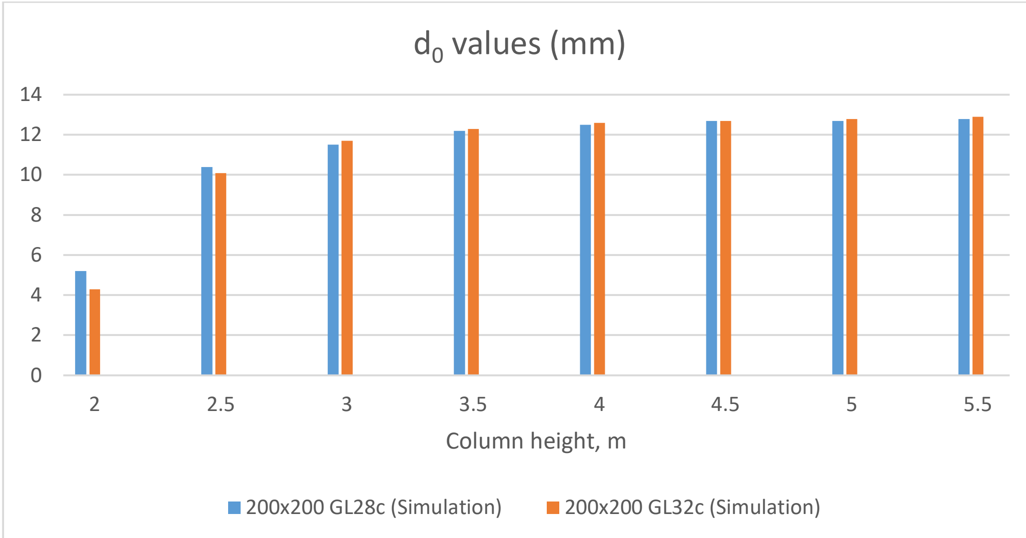


Figure 7.6 d_0 values according to simulations for cross-section 200x200 mm GL28c and GL32c.

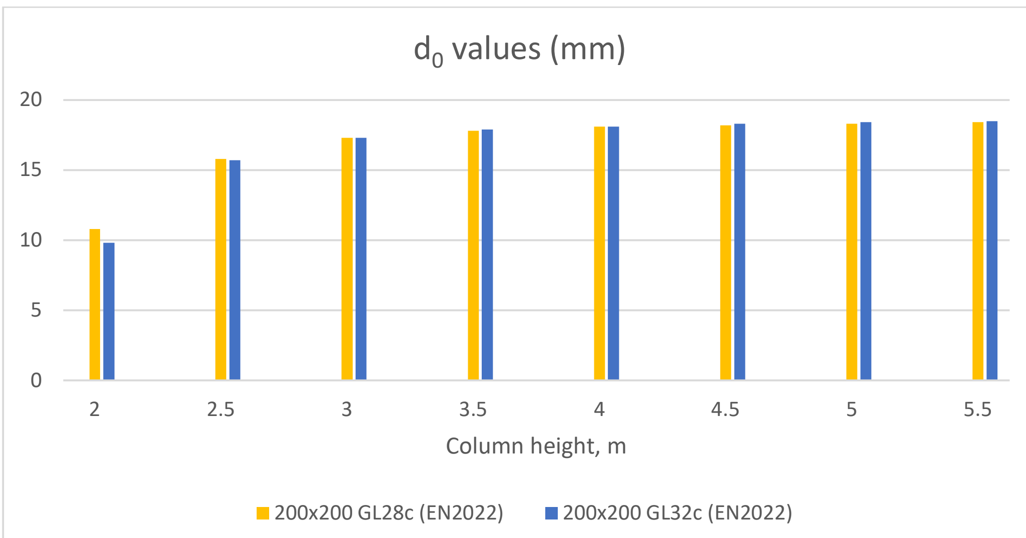


Figure 7.7 d_0 values according to EN1995-1-2:2022 for cross-section 200x200 mm GL28c and GL32c.

Table 7.1 d_0 values according to simulations and EN1995-1-2:2022 for cross-section 200x200 mm GL28c and GL32c.

Column height, m	2	2.5	3	3.5	4	4.5	5	5.5
200x200 GL28c (Simulation)	5.2	10.4	11.5	12.2	12.5	12.7	12.7	12.8
200x200 GL32c (Simulation)	4.3	10.1	11.7	12.3	12.6	12.7	12.8	12.9
200x200 GL28c (EN2022)	10.8	15.8	17.3	17.8	18.1	18.2	18.3	18.4
200x200 GL32c (EN2022)	9.8	15.7	17.3	17.9	18.1	18.3	18.4	18.5

The figures and table shown above show the optimal value of the zero-strength layer thickness for the cross section 200x200 mm with varying column heights. Simulations show an average value of 11,2 mm and for EN2022 the value is 16,8 mm. The value of d_0 for simulations is smaller compared to EN1995-1-2:2022. For column height of 2 m the difference is 51% and with increase in height the difference decreases to 30%. It is notable that for simulations the value is between 7 and 14 mm, which are respective official values for d_0 in the current and revised Eurocode. In comparison the values for EN2022 mostly exceed the official value of 14 mm. The results are quite predictable since the notional charring depth for simulations is bigger compared to EN2022, thus it is logical that the zero-strength layer thickness is smaller. The difference in strength properties does not greatly affect the value of d_0 with the average difference being 3,6%.

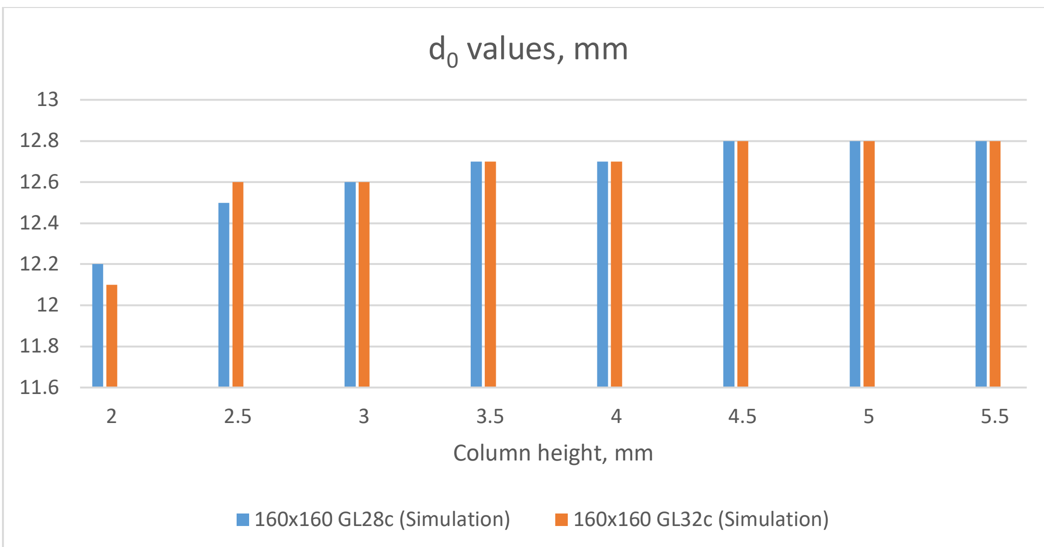


Figure 7.8 d_0 values according to simulations for cross-section 160x160 mm GL28c and GL32c.

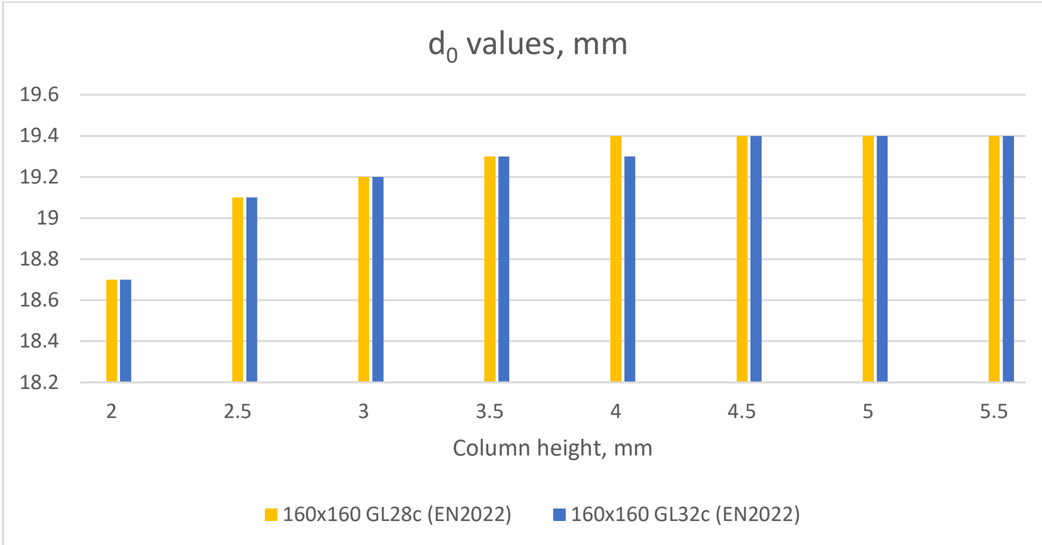


Figure 7.9 d_0 values according to EN1995-1-2:2022 for cross-section 160x160 mm GL28c and GL32c.

Table 7.2 d_0 values according to simulations and EN1995-1-2:2022 for cross-section 160x160 mm GL28c and GL32c.

Column height, m	2	2.5	3	3.5	4	4.5	5	5.5
160x160 GL28c (Simulation)	12.2	12.5	12.6	12.7	12.7	12.8	12.8	12.8
160x160 GL32c (Simulation)	12.1	12.6	12.6	12.7	12.7	12.8	12.8	12.8
160x160 GL28c (EN2022)	18.7	19.1	19.2	19.3	19.4	19.4	19.4	19.4
160x160 GL32c (EN2022)	18.7	19.1	19.2	19.3	19.3	19.4	19.4	19.4

The figure and table shown above show the optimal value of the zero-strength layer thickness for the cross section 160x160 mm with varying column heights. Simulations show an average value of 12,6 mm and for EN2022 the value is 19,2 mm. The value of d_0 for simulations is smaller compared to EN1995-1-2:2022. The average difference between simulation and EN2022 results is 34%. It is notable that for simulations the value stays between 7 and 14 mm. In comparison the values for EN2022 exceed the official value of 14 mm. The results are quite predictable since the notional charring depth for simulations is bigger compared to EN2022, thus it is logical that the zero-strength layer thickness is smaller. The difference in strength properties does not greatly affect the value of d0 with the average difference being 0,2%.

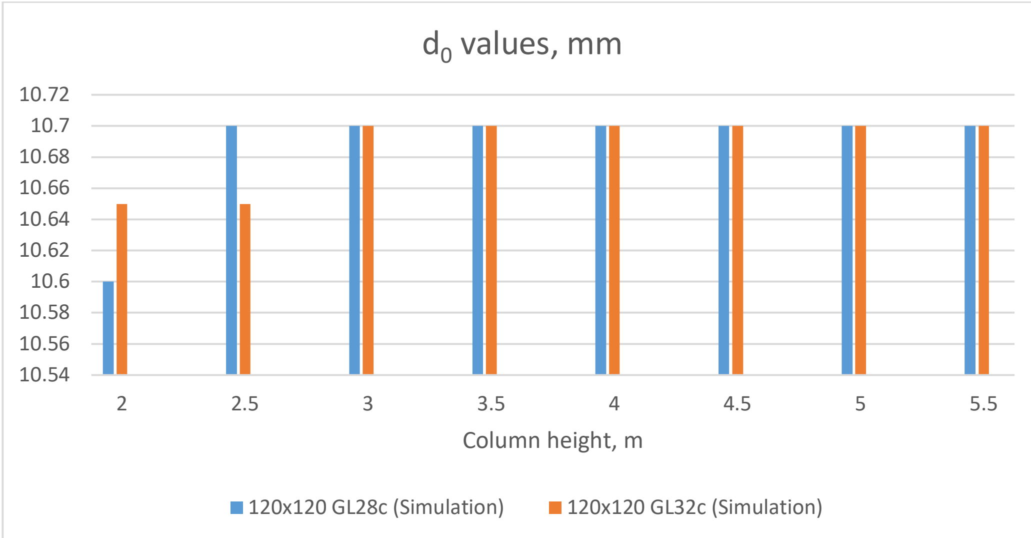


Figure 7.10 d_0 values according to simulations for cross-section 120x120 mm GL28c and GL32c.

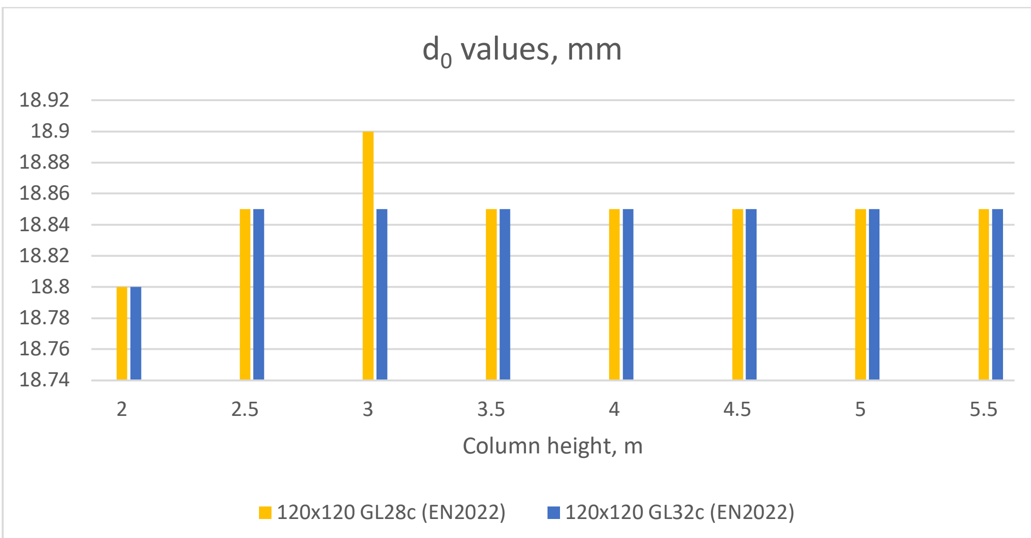


Figure 7.11 d_0 values according EN1995-1-2:2022 for cross-section 120x120 mm GL28c and GL32c.

Table 7.3 d_0 values according to simulations and EN1995-1-2:2022 for cross-section 120x120 mm GL28c and GL32c.

Column height, m	2	2.5	3	3.5	4	4.5	5	5.5
120x120 GL28c (Simulation)	10.65	10.6	10.7	10.7	10.7	10.7	10.7	10.7
120x120 GL32c (Simulation)	10.6	10.65	10.65	10.7	10.7	10.7	10.7	10.7
120x120 GL28c (EN2022)	18.8	18.8	18.85	18.85	18.85	18.85	18.85	18.85
120x120 GL32c (EN2022)	18.75	18.8	18.85	18.85	18.85	18.85	18.85	18.85

The figure and table shown above show the optimal value of the zero-strength layer thickness for the cross section 120x120 mm with varying column heights. Simulations show an average value of 10,7 mm and for EN2022 the value is 18,8 mm. The value of d_0 for simulations is smaller compared to EN1995-1-2:2022. The average difference between simulation and EN2022 results is 43,2%. It is notable that for simulations the value stays between 7 and 14 mm. In comparison the values for EN2022 exceed the official value of 14 mm. The results are quite predictable since the notional charring depth for simulations is bigger compared to EN2022, thus it is logical that the zero-strength layer thickness is smaller. The difference in strength properties does not greatly affect the value of d0 with the average difference being 0,17%.

From all previous analyses it can be concluded that column height and therefore buckling affect the value of the zero-strength layer thickness. Therefore for longer columns the d_0 value of 14 mm is optimal and for shorter columns it should be below 14 mm. All in all is zero-strength layer thickness value 14 mm a safe choice, but simulations show that the real value is between 7 mm and 14 mm.

SUMMARY

Eurocode 5 parts 1-1 and 1-2 contain new calculation methods that affect load-capacity calculations of glulam columns. In this thesis, the load-capacity of columns with three different cross-sections, two different strength classes and two different lengths have been calculated in an ambient situation and in R30 fire situation. The results of the calculations, which show the effect of changes of the corresponding Eurocodes, have been analyzed. In addition, simulations of the fire situation have been carried out in the calculation programs SAFIR and CSTFire. The obtained values are compared with the new generation Eurocode EN1995-1-2:2022 to find out the optimal thickness of the zero-strength layer.

The analysis of EN 1995-1-1:2006 and EN 1995-1-1:2022 calculation models revealed the following:

- the formulas in the buckling calculation changed the most;
- there were no changes in the calculation of the compressive load-bearing capacity.

The analysis of EN 1995-1-2:2006 and EN 1995-1-2:2022 calculation models revealed the following:

- the biggest change is the increase of the zero-strength layer thickness from 7 mm to 14 mm.

The analysis of the calculation results of EN 1995-1-1:2006 and EN 1995-1-1:2022 revealed the following:

- changes in buckling calculations reduce the load-bearing capacity of the column depending on the cross-section up to 24%;
- the difference in buckling load-bearing capacity grows exponentially with increase in column length.

The analysis of the calculation results of EN 1995-1-2:2006 and EN 1995-1-2:2022 revealed the following:

- increasing the thickness of the zero-strength layer and changing the buckling formulas in EN1995 part 1-1 reduces the load-bearing capacity of the column by up to 64%, depending on the cross-section.

The calculation results were compared with the simulations. The comparison revealed the following:

- in a simulated fire, the nominal charred layer thickness is greater by 25-38%;
- the thickness of the zero-strength layer obtained through simulations is between 7-14 mm.

KOKKUVÕTE

Eurokood 5 osad 1-1 ja 1-2 sisaldavad uusi arvutusmeetodeid, mis mõjutavad liimpuitpostide kandevõime arvutusi. Käesolevas lõputöös on arvutatud kolme erineva ristlõike, kahe erineva tugevusega ja kahe erineva kõrgusega postide kandevõimet normaalolukorras ja R30 tuleolukorras. Arvutuste tulemused, mis näitavad vastavate eurokoodide arvutusskeemide muudatuste mõju, on analüüsitud. Lisaks on läbi viidud tuleolukorra simulatsioonid arvutusprogrammides SAFIR ja CSTFire. Saadud väärtusi võrreldakse uue põlvkonna eurokoodiga EN1995-1-2:2022, et selgitada välja optimaalne null-tugevusega kihi paksus.

EN 1995-1-1:2006 ja EN 1995-1-1:2022 arvutusmudelite analüüsis selgus järgnev:

- kõige rohkem muutusid valemid posti nõtkekandevõime arvutuses;
- posti survekandevõime arvutuses ei esinenud muudatusi.

EN 1995-1-2:2006 ja EN 1995-1-2:2022 arvutusmudelite analüüsis selgus järgnev:

- kõige suurem muudatus on null-tugevusega kihi paksuse suurendamine 7 mm-lt 14 mm-le.

EN 1995-1-1:2006 ja EN 1995-1-1:2022 arvutustulemuste analüüsis selgus järgnev:

- stabiilsuse arvutustes muudetud valemid vähendavad posti nõtkekandevõimet olenevalt ristlõikest kuni 24%;
- nõtkekandevõime tulemuste erinevus kasvab ekponentsiaalselt posti kõrguse suurendamisega kuni posti kandevõime ammendumiseni.

EN 1995-1-2:2006 ja EN 1995-1-2:2022 arvutustulemuste analüüsis selgus järgnev:

- null-tugevusega kihi paksuse suurendamine ja EN1995 osas 1-1 muudetud stabiilsuse valemid vähendab posti kandevõimet olenevalt ristlõikest kuni 64%.

Arvutustulemusi võrreldi simulatsioonidega. Võrdluses selgus järgnev:

- simuleeritud tules on puidu nominaalne söestumiskihi paksus suurem 25-38% võrra;
- simulatsioonide kaudu saadud null-tugevusega kihi paksus jääb 7-14 mm vahele, kuna nominaalne söestumiskihi paksus on suurem.

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APPENDICES

GEOMETRY

b=	200	mm	Column width
h=	200	mm	Column height
L=	2.5	m	Column length
A =	0.04	m^2	$= h \cdot b / 10^6$
I =	1.33E+08	mm^4	$= h \cdot b^3 / 12$

MATERIALS

	GL28c		Strength class
$f_{m,k}$=	28	MPa	
$f_{c0,k}$=	24	MPa	
$E_{0.05}$=	10400	MPa	
γ_M=	1.25		
	1		Service class
	KK		Load duration
k_{mod}=	0.8		

LOADS

n=	2		Number of floors
	GL24h		Column supported beam strength class
h=	400	mm	Column supported beam cross-section height
b=	200	mm	Column supported beam cross-section width
l=	8	m	Beam span
s=	6	m	Beam step
ρ_{mean}=	420	kg/m^3	
$g_{k,floor}$=	0.5	kN/m^2	Floor load
$g_{k,roof}$=	0.5	kN/m^2	Roof load
q_k=	2	kN/m^2	Live load

When number of floors value n=1, then live-load changes to snow load
In that case load-duration class should be changed.

$g_{k,dead}$=	2.688	kN	$= [\{\rho_{mean} / 100\} \cdot b \cdot h \cdot 10^{-6} \cdot l] \cdot [n - 1]$
$g_{k,floor}$=	24	kN	$= [g_{k,floor} \cdot s \cdot l] \cdot [n - 1]$
$g_{k,roof}$=	24	kN	$= g_{k,roof} \cdot s \cdot l$
g_k=	50.688	kN	$= g_{k,dead} + g_{k,floor} + g_{k,roof}$
q_k=	96	kN	$= [q_k \cdot s \cdot l] \cdot [n - 1]$

Ultimate Limit State EN1995-1-1:2006

ULS: $\gamma_{G,sup}Gk+\gamma_{Q1}Qk$

$\gamma_{G,sup}$=	1.2		Partial factor for permanent action
γ_{Q1}=	1.5		Partial factor for live-load
g_d=	60.83	kN	$= g_k \cdot \gamma_{G,sup}$
q_d=	144.00	kN	$= q_k \cdot \gamma_{Q1}$

p_d=	204.83 kN	$= g_d + q_d$
$f_{c,d}$=	15.36	

$\sigma_{c,d}$ =	5.12 MPa	$= p_d \cdot 10^3 / (A \cdot 10^6)$
$f_{c,d}/\sigma_{c,d}$ =	3.00 x	$= f_{c,d} / \sigma_{c,d}$
Load capacity verified		

Buckling verification

i =	57.73502692	$= \sqrt{(I / [A \cdot 10^6])}$
λ =	43.30127019	$= L \cdot 10^3 / i$
λ_{rel} =	0.66	$= \lambda / \pi \cdot \sqrt{(f_{c0,k} / E_{0.05})}$
β_c =	0.1	
k =	0.74	$= 0.5 \cdot (1 + \beta_c \cdot [\lambda_{rel} - 0.3] + \lambda_{rel}^2)$
k_c =	0.9419	$= 1 / (k + \sqrt{[k^2 - \lambda_{rel}^2]})$

$\sigma_{c,d}$ =	5.12 MPa	$= p_d \cdot 10^3 / (A \cdot 10^6)$
$k_{c*fc,d/\sigma c,d}$ =	2.83 x	$= f_{c,d} \cdot k_c / \sigma_{c,d}$
Load capacity verified		

<u>Ultimate Limit State prEN1995-1-1:2022</u>

ULS: $\gamma_{G,sup}Gk+\gamma_{Q1}Qk$

$\gamma_{G,sup}$=	1.2	Partial factor for permanent action
γ_{Q1}=	1.5	Partial factor for live-load

g_d=	60.83 kN	$= g_k \cdot \gamma_{G,sup}$
q_d=	144.00 kN	$= q_k \cdot \gamma_{Q1}$
p_d=	204.83 kN	$= g_d + q_d$
$f_{c,d}$=	15.36	$= f_{c0,k} \cdot k_{mod} / \Upsilon_M$

$\sigma_{c,d}$ =	5.12 MPa	$= p_d \cdot 10^3 / (A \cdot 10^6)$
$f_{c,d}/\sigma_{c,d}$ =	3.00 x	$= f_{c,d} / \sigma_{c,d}$
Load capacity verified		

Bucling verification

i =	57.73502692 mm	$= \sqrt{(I / [A \cdot 10^6])}$
λ =	43.30127019	$= L \cdot 10^3 / i$
$\lambda_{c,rel}$ =	0.66	$= \lambda / \pi \cdot \sqrt{(f_{c0,k} / E_{0.05})}$
ε_0=	0.00	$= L / 1000$
β_c =	0.24	$= \varepsilon_0 \cdot \pi \cdot \sqrt{(3 \cdot E_{0.05} / f_{c0,k})} \cdot (f_{c0,k} / f_{m,k})$
ϕ_c=	0.76	$= 0.5 \cdot (1 + \beta_c \cdot [\lambda_{c,rel} - 0.3] + \lambda_{c,rel}^2)$
k_c =	0.8752	$= 1 / (\phi_c + \sqrt{[\phi_c^2 - \lambda_{c,rel}^2]})$

$\sigma_{c,d}$ =	5.12 MPa	$= p_d \cdot 10^3 / (A \cdot 10^6)$
$k_{c*fc,d/\sigma c,d}$ =	2.63 x	$= f_{c,d} \cdot k_c / \sigma_{c,d}$
Load capacity verified		

Appendix 2 - Calculation of tilber column load-bearing capacity in fire conditions according to EN1995-1-2:2006 and EN1995-1-2:2022

GEOMETRY

b=	120	mm	Cross-section height
h=	120	mm	Cross-section width
L=	2.5	m	Column height
A =	0.0144	m^2	
I =	1.73E+07	mm^4	

MATERIALS

	GL32c		Wood strength class
$f_{m,k}$=	32	MPa	
$f_{c0,k}$=	24.5	MPa	
$E_{0.05}$=	11200	MPa	
γ_M=	1.25		
	1		Service class
	KK		Load-duration class
k_{mod}=	0.8		

LOADS

n=	2		Number of floors in building
	GL24c		Column supported beam strength class
h=	400	mm	Column supported beam cross-section height
b=	200	mm	Column supported beam cross-section width
l=	8	m	Beam span
s=	6	m	Beam step
ρ_{mean}=	400	kg/m^3	
$g_{k,floor}$=	0.5	kN/m^2	Floor load
$g_{k,roof}$=	0.5	kN/m^2	Roof load
q_k=	2	kN/m^2	Live load

When number of floors value n=1, then live-load changes to snow load
In that case load-duration class should be changed.

$g_{k,dead}$=	2.56	kN	$= [\{\rho_{mean} / 100\} \cdot b \cdot h \cdot 10^{-6} \cdot l] \cdot [n - 1]$
$g_{k,floor}$=	24	kN	$= [g_{k,floor} \cdot s \cdot l] \cdot [n - 1]$
$g_{k,roof}$=	24	kN	$= g_{k,roof} \cdot s \cdot l$
g_k=	50.56	kN	$= g_{k,dead} + g_{k,floor} + g_{k,roof}$
q_k=	96	kN	$= [q_k \cdot s \cdot l] \cdot [n - 1]$

Fire EN1995-1-2:2006

ULS: 1.0Gk+ $\psi_{1.1}$ Qk

$\psi_{1.1}$=	0.5		Factor for combination value
$g_{d,fi}$=	50.56	kN	$= g_k \cdot 1$
$q_{d,fi}$=	48.00	kN	$= q_k \cdot \psi_{1.1}$
$p_{d,fi}$=	98.56	kN	$= g_{d,fi} + q_{d,fi}$

$t=$	30	min	
$\beta_n =$	0.7	mm/min	
$d_{char,n} =$	21	mm	$= \beta_n \cdot t$
$d_0 =$	7	mm	
$d_{ef} =$	28	mm	$= d_{char,n} + d_0$
$h_{fi} =$	64	mm	$= h - 2 \cdot d_{ef}$
$b_{fi} =$	64	mm	$= b - 2 \cdot d_{ef}$
$A_{fi} =$	0.004096	m^2	$= h_{fi} \cdot b_{fi} / 10^6$
$k_{mod,fc,fi} =$	1		
$k_{fi} =$	1.15		
$\gamma_{M,fi} =$	1		
$f_{c,d,fi} =$	28.175	MPa	$= k_{mod,fc,fi} \cdot k_{fi} \cdot f_{c0,k} / \gamma_{M,fi}$
$\sigma_{c,fi} =$	24.06	MPa	$= p_{d,fi} \cdot 10^3 / (A_{fi} \cdot 10^6)$
$f_{c,d,fi} / \sigma_{c,fi} =$	1.17	x	$= f_{c,d,fi} / \sigma_{c,fi}$
Load capacity verified			

Bucling verification

$I_{fi} =$	1398101.333		$= h_{fi} \cdot b_{fi}^3 / 12$
$i =$	18.47520861		$= \sqrt{(I_{fi} / [A_{fi} \cdot 10^6])}$
$\lambda =$	135.3164693		$= L \cdot 10^3 / i$
$\lambda_{rel} =$	2.01		$= \lambda / \pi \cdot \sqrt{(f_{c0,k} / E_{0.05})}$
$\beta_c =$	0.1		
$k =$	2.61		$= 0.5 \cdot (1 + \beta_c \cdot [\lambda_{rel} - 0.3] + \lambda_{rel}^2)$
$k_c =$	0.2335		$= 1 / (k + \sqrt{[k^2 - \lambda_{rel}^2]})$
$\sigma_{c,fi} =$	24.06	MPa	$= p_{d,fi} \cdot 10^3 / (A_{fi} \cdot 10^6)$
$k_{c*fc,d,fi / \sigma c,fi} =$	0.27	x	$= f_{c,d,fi} \cdot k_c / \sigma_{c,fi}$
Load capacity not verified			

<u>Fire EN1995-1-2:2022</u>

ULS: 1.0Gk+ $\psi_{1.1}$ Qk

$\psi_{1.1}=$	0.5		Factor for combination value
$g_{d,fi}=$	50.56	kN	$= g_k \cdot 1$
$q_{d,fi}=$	48.00	kN	$= q_k \cdot \psi_{1.1}$
$p_{d,fi}=$	98.56	kN	$= g_{d,fi} + q_{d,fi}$
$t=$	30	min	
$\beta_0 =$	0.65	mm/min	
$\beta_n =$	0.702	mm/min	$= \beta_0 \cdot 1.08$
$d_{char,n} =$	21.06	mm	$= \beta_n \cdot t$
$d_0 =$	14	mm	

d_{ef} =	35.06	mm	$= d_{char,n} + d_0$
h_{fi} =	49.88	mm	$= h - 2 \cdot d_{ef}$
b_{fi} =	49.88	mm	$= b - 2 \cdot d_{ef}$
A_{fi} =	0.002488014	m^2	$= h_{fi} \cdot b_{fi} / 10^6$
$k_{mod,fc,fi}$ =	1		
k_{fi} =	1.15		
$\gamma_{M,fi}$ =	1		
$f_{c,d,fi}$ =	28.175	MPa	$= k_{mod,fc,fi} \cdot k_{fi} \cdot f_{c0,k} / \gamma_{M,fi}$
$\sigma_{c,fi}$ =	39.61	MPa	$= p_{d,fi} \cdot 10^3 / (A_{fi} \cdot 10^6)$
$f_{c,d,fi} / \sigma_{c,fi}$ =	0.71	x	$= f_{c,d,fi} / \sigma_{c,fi}$
Load capacity not verified			

Bucling verification

I_{fi} =	515851.3046	$= h_{fi} \cdot b_{fi}^3 / 12$
i =	14.39911571	$= \sqrt{(I_{fi} / [A_{fi} \cdot 10^6])}$
λ =	173.621773	$= L \cdot 10^3 / i$
λ_{rel} =	2.58	$= \lambda / \pi \cdot \sqrt{(f_{c0,k} / E_{0.05})}$
ε_0=	0.00	$= L / 1000$
β_c =	0.22	$= \varepsilon_0 \cdot \pi \cdot \sqrt{(3 \cdot E_{0.05} / f_{c0,k})} \cdot (f_{c0,k} / f_{m,k})$
ϕ_c=	4.10	$= 0.5 \cdot (1 + \beta_c \cdot [\lambda_{rel} - 0.3] + \lambda_{rel}^2)$
k_c =	0.1375	$= 1 / (\phi_c + \sqrt{[\phi_c^2 - \lambda_{rel}^2]})$

$\sigma_{c,fi}$ =	39.61	MPa	$= p_{d,fi} \cdot 10^3 / (A_{fi} \cdot 10^6)$
$k_{c*fc,d,fi} / \sigma_{c,fi}$ =	0.10	x	$= f_{c,d,fi} \cdot k_c / \sigma_{c,fi}$
Load capacity not verified			