TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

JUKKA MÄENPÄÄ

ALGORITHM-AIDED STRUCTURAL ENGINEERING OF STEEL-FRAMED WAREHOUSE

Master of Science Thesis

Examiner: Professor Mikko Malaska
Examiner and topic approved by the Faculty Council of the Faculty of Business and Built Environment on 3rd January 2018

ABSTRACT

JUKKA MÄENPÄÄ: Algorithm-Aided Structural Engineering of Steel-Framed Warehouse
Tampere University of Technology
Master of Science Thesis, 55 pages, 72 Appendix pages
January 2018
Master's Degree Programme in Civil Engineering
Major: Structural Engineering
Examiner: Professor Mikko Malaska

Keywords: Karamba, Grasshopper, algorithm-aided structural design, parametric design, steel structures

The thesis inspects algorithm-aided structural design which may be the next big development step in structural engineering. The main aims of the thesis are to examine the possibilities of algorithm-aided structural engineering in steel-framed warehouses and to examine the reliability of Karamba's components in structural design. Karamba is made for algorithm-aided design and is capable to use FEM and to design according to Eurocode 3 (2005).

The thesis utilizes two research methods: a literature review and a case study. The literature review deals with algorithm-aided design. The case study consists of three parts: pre-study, algorithm-aided modelling and algorithm-aided structural design. The pre-study concerns Karamba's abilities in the field of structural design of steel by comparing Karamba's results to RFEM's. In the second part priorly modelled warehouse is remodelled by an algorithm. The last part designs the warehouse according to Eurocode 3 (2005).

Based on the results of the case studies the structural design results by Karamba are mostly on the safe side. The accuracy and reliability of the steel design results were dependent on the critical design criteria and the software has simplifications that influences to the utilization rates. In the case study 95 % of the differences in utilization rates between Karamba and RFEM varies between -0.02 and 0.06 meaning that Karamba calculates lower resistance values for the structural members than RFEM.

The research shows that algorithm-aided structural design is a potential tool as long as the reliability of the algorithm-aided design is first verified. It is suitable for warehouses that have repetitive structures. If the structures are not repeated but the elements need to be modelled one by one the algorithm-aided modelling will be greatly slowed down.

TIIVISTELMÄ

JUKKA MÄENPÄÄ: Teräsrakenteisen varastohallin algoritmiavusteinen rakennesuunnittelu
Tampereen teknillinen yliopisto
Diplomityö, 55 sivua, 72 liitesivua
Tammikuu 2018
Rakennustekniikan diplomi-insinöörin tutkinto-ohjelma
Pääaine: Rakennesuunnittelu
Tarkastaja: professori Mikko Malaska

Avainsanat: Karamba, Grasshopper, algoritmiavusteinen rakennesuunnittelu, parametrinen suunnittelu, teräsrakenne

Tässä työssä tutkitaan algoritmiavusteista rakennesuunnittelua, joka voi olla seuraava iso kehitysaskel rakennesuunnittelussa. Työn tavoitteena on selvittää algoritmiavusteisen rakennesuunnittelun mahdollisuudet teräsrakenteisten varastorakennusten suunnittelussa ja tutkia Karamban komponenttien luotettavuus rakenteiden mitoittamisessa. Karamballa voi suorittaa algoritmiavusteisesti FEM-laskentaa ja mitoittaa teräsrakenteita Eurokoodi 3:n (2005) mukaan.

Tavoitteiden saavuttamiseksi hyödynnettiin kahta eri tutkimusmenetelmää: kirjallisuusselvitystä ja case-tutkimusta. Kirjallisuusselvitys käsittelee algoritmiavusteista suunnittelua. Case-tutkimus koostuu kolmesta osasta: esitutkimuksesta, algoritmiavusteisesta mallintamisesta ja algoritmiavusteisesta rakennesuunnittelusta. Esitutkimuksessa selvitetään Karamban kyky mitoittaa teräsrakenteita ja vertaillaan laskentatuloksia RFEM-mitoitusohjelman kanssa. Toisessa osassa mallinnetaan jo kerran suunniteltu varastohalli uudestaan, mutta nyt algoritmin avulla. Kolmannessa ja viimeisessä osassa mitoitetaan algoritmiavusteisesti mallinnettu rakennus Eurokoodi 3:n (2005) mukaan.

Tutkimus osoittaa, että Karamban laskenta on pääasiassa varmalla puolella. Sen luotettavuus teräsrakenteiden mitoittamisessa riippuu määräävästä suunnittelukriteeristä. Karamba on tehnyt joitakin yksinkertaistuksia, jotka vaikuttavat käyttöasteisiin. Case-tapauksessa, varastohallissa, 95% sauvojen käyttöaste-eroista Karamban ja RFEM:in välillä olivat -0.02–0.06. Karamba siis ylimitoitti hieman.

Tutkimuksen perusteella algoritmiavusteinen rakennesuunnittelu tarjoaa potentiaalisia mahdollisuuksia suunnitteluprosessin tehostamiseen, kunhan ensin varmistutaan mitoituksen luotettavuudesta. Varastohalliin, jossa on paljon toistuvia rakenteita, algoritmiavusteinen suunnittelu sopii hyvin. Jos rakenteet eivät toistu, vaan rakenneosat joudutaan mallintamaan yksitellen, hidastuu algoritmiavusteinen mallintaminen huomattavasti.

PREFACE

This Master's thesis was conducted between June 2017 and January 2018 at Tampere University of Technology, Finland. Professor Mikko Malaska from the faculty of Civil Engineering was the examiner of the thesis.

I would like to thank the professionals in Ramboll Finland Oy for offering their assistance throughout the course of the thesis, especially Matti Pirinen who was the supervisor of the thesis and Heikki Arvio who arranged great framework to complete the thesis. I am also thankful to Clemens Preisinger, the creator of Karamba, who helped to examine the reliability of Karamba. Also, thanks to Jessica Brenner for help with the grammatical part of the thesis. The thesis was the culmination of the 4.5 years studies in Tampere University of Technology.

Last but not least, I would like to thank my wife Katerina and my nine month old son Liam for their patience and support.

In Tampere, Finland,
on 16th January 2018

Jukka Mäenpää

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LIST OF SYMBOLS AND ABBREVIATIONS

CAAD	Computer-Aided Architectural Design, can be algorithm-aided design
CAD	Computer-Aided Design in general
Eurocode 3	Standard EN 1993-1-1: Design of steel structures
DStV	File format which is an industrial standard
FEM	Finite Element Method, a numerical method for solving problems of engineering
Grasshopper	Graphical algorithm editor tightly integrated with Rhino's 3-D modelling tools
Karamba	Parametric structural engineering tool
LTBeam	Critical moment solver for lateral torsional buckling
Mathcad	Math software for engineering calculations
RF-STEEL EC3	Add-on module for designing according to Eurocode 3 in RFEM
RFEM	Structural analysis program
Rhino	Rhinoceros 3D, computer-aided design software
Robot	Robot Structural Analysis, structural analysis program
Tekla	Tekla Structures, structural engineering program

N_{Ed}	Design normal force
N_{Rd}	Design value of the resistance to normal forces
$M_{y.Ed}$	Design bending moment about y-axis
$M_{y.Rd}$	Design value of the resistance to bending moments about y-axis
$M_{z.Ed}$	Design bending moment about z-axis
$M_{z.Rd}$	Design value of the resistance to bending moments about z-axis
ρ	Reduction factor to reduce moment resistance because of shear
C_1	Moment diagram factor for lateral torsional buckling
C_2	Moment diagram factor for lateral torsional buckling
C_3	Moment diagram factor for lateral torsional buckling
k_z	Length factor for lateral torsional buckling
k_ω	Length factor for lateral torsional buckling
ψ	Ratio of end moments
C_{my}	Equivalent uniform moment factor
C_{mz}	Equivalent uniform moment factor

C_{mLT}	Equivalent uniform moment factor
k_{yy}	Interaction factor
k_{yz}	Interaction factor
k_{zy}	Interaction factor
k_{zz}	Interaction factor
$L_{cr.y}$	Buckling length
$L_{cr.z}$	Buckling length
L_{ω}	Buckling length
L_{T}	Buckling length
M_{cr}	Elastic critical moment
$V_{pl.y.Rd}$	Plastic shear force resistance
$V_{pl.z.Rd}$	Plastic shear force resistance
$M_{pl.z.V.Rd}$	Plastic moment resistance reduce d due to shear force
k_{c}	Correction factor
$\chi_{LT.mod}$	Reduction factor
χ_{y}	Reduction factor
χ_{z}	Reduction factor
I_{z}	Moment of inertia about weak axis
I_{ω}	Warping constant
I_{t}	Torsional constant
E	Modulus of elasticity
G	Shear modulus
L	Length between lateral restraints
z_{g}	Distance between the point of load application and the shear centre
z_{a}	Distance of the point of load application
z_{s}	Distance of the shear centre
z_{j}	Distance related to the effects of asymmetry about y-axis
k	Abbreviation for effective length factors when they are equal
u_{x}	Degree of freedom: translation in x-axis
u_{y}	Degree of freedom: translation in y-axis
u_{z}	Degree of freedom: translation in z-axis
φ_{x}	Degree of freedom: rotation about x-axis
φ_{y}	Degree of freedom: rotation about y-axis
φ_{z}	Degree of freedom: rotation about z-axis
φ'_{x}	Degree of freedom: warping
ν	Degree of freedom: translation in y-axis

Θ	Degree of freedom: rotation about x-axis
ν'	Degree of freedom: rotation about z-axis
ω	Degree of freedom: warping
α_{cr}	Factor by which the design loading would have to be increased to cause elastic instability in a global mode
F_{Ed}	Design loading on the structure
F_{cr}	Elastic critical buckling load for global instability mode based on initial elastic stiffnesses
L_e	Effective length
K	Effective length factor

1 INTRODUCTION

Nowadays, advanced technology carries out structural design tasks according to the user's commands. Automated procedures can be an efficient way to speed up this process. Algorithm-aided structural design can be a helpful option to support this concept.

1.1 Background

Structural design is an essential part of a building project. First, the engineer receives the outline of the building which sets requirements of its structures and design parameters. Usually FEM based design programs including design methods according to the Eurocode are applied in structural design. Although typical engineering software tend to ease the design process it still requires the user to perform many manual tasks before the calculations can begin, such as modelling structures, selecting cross-sections and setting loadings. Structural design is an iterative process, whereas cross-sections need to be defined wisely for the members to have desired utilization rates. Reducing manual work and iteration process, design can become more effective and time-saving.

Many parameters are repeated throughout the course of projects, like geometry, loadings, materials, cross-sections and design methods. These and many more can be combined and used as an input for the algorithm. One simple algorithm can cover the entire length and width of a building. During all the changes the structural design is being taken care of, resulting in a model made matching the outline. Changing the parameters will redefine the model and its design is automatically redone, enabling effective managing changes.

The author has taken an interest to programming and structural design, leading him to the topic of this thesis. The topic was acquired in cooperation with Ramboll Finland, for who this research is done for. Since Ramboll also relies on algorithm-aided design, this subject was found to be convenient for both the examiner and the company.

1.2 Aims and limitations

The main aims of the thesis are to examine the possibilities of algorithm-aided structural engineering in steel-framed warehouses and to examine the reliability of Karamba's components in structural design. Further, the parametrization of a particular type of building is to be ascertained in order to program an algorithm which can automatically create a customised structure for analysis.

The following programs and plug-ins are used in the study: Rhino, Grasshopper, Karamba, RFEM, RF-STEEL EC3 and Mathcad. Rhino serves as the background program and visualizer showing the model programmed in Grasshopper. Grasshopper is a plug-in for Rhino where all the algorithms are written. Karamba is a group of components for Grasshopper that includes FEM calculations and designing according to Eurocode 3. RFEM is a FEM program that has an add-on module called RF-STEEL EC3 for designing according to Eurocode 3. Mathcad is a math software for engineering calculations. Since Grasshopper is used by engineers throughout the whole company of Ramboll, it seemed the ideal tool for programming. The versions of the programs are following: Rhinoceros 5 SR12 64-bit (5.12.50810.13095, 08/10/2015), RFEM 5.10.01.132654, Mathcad Prime 3.1 64-bit and Karamba 1.3.0 - build 171127.

The repetition and similarities of structures makes convenient programming possible and also enables reusing the algorithms for other similar buildings. Therefore the case study is based on a steel-framed warehouse, although algorithm-aided structural design can also be used on other materials and construction types. The loads do not include imperfections and only one load combination is designed.

1.3 Research methods

The thesis begins with a literature review of algorithm-aided structural design. The following chapter consists of the case study which is split three way. The first part is a pre-study concerning Karamba's abilities in the field of structural design of steel. The second part attends to algorithm-aided modelling. Concluding the case study will be algorithm-aided structural engineering.

The case study gives an insight into the framework conditions for steel-framed warehouses, under what circumstances algorithm-aided structural engineering can fit steel structure designing. It also reveals the possible influences algorithm-aided designs can have on the design process.

2 ALGORITHM-AIDED STRUCTURAL DESIGN

The thesis is a continuation to the Erkkilä's (2017) thesis "Utilization of algorithm-aided design in the design process of precast concrete elements". He created an algorithm-aided design process that utilizes an architectural model and transforms its concrete structures into prefabricated concrete elements to Tekla Structures via Rhino and Grasshopper. His thesis goes into detail in the theory of algorithm-aided design and has abundant references for deeper aspect. This theses handles algorithm-aided design in different aspect by focusing on to algorithm-aided structural design. Therefore the theory of algorithm-aided design is not studied deeply here.

Algorithm-aided design is a new way to think. It does not involve only new fancy tools but is a dynamic process instead of static. It is a creative process that shows the train of thought of the designer. It proceeds logically from the very beginning to the end and is easily modifiable. It allows user to go quickly through different variations and to select the best ones. With evolutionary algorithm one can find a new aspect to the problem and get unexpected but rational solutions that have not been thought before. (Tanska & Österlund 2014)

By parametrizing the design process, changing one parameter runs the algorithm dynamically and gives a new result in real time. Algorithm-aided design leaves more time for designing and comparing different options. In the first project algorithm-aided design is slower than manual design but when the same algorithm can be used for further projects it speeds up the process. Traditional two-dimensional computer-aided design (CAD) softwares are stepping aside while computer-aided architectural design (CAAD) softwares are coming up in architectural field. CAD uses manual design without algorithms while CAAD can utilize algorithms. (Tanska & Österlund 2014)

According to Lundén and Österlund (2008) algorithm is basically series of commands and it is not linked only to computers but it serves a way to think different kind of processes. Therefore it is difficult to date the beginning of the use of algorithm. They write that in architecture algorithms have been used in a big way for more than ten years and indirectly they have been used even longer. Algorithm-aided design is very useful for handling extraordinary shapes. It enables modelling geometry that is impossible or at least extremely difficult to model without an algorithm. Algorithm can be used in small daily tasks to automate repetitive group of functions but it is the most effective when it is used comprehensively.

2.1 Researches of algorithm-aided structural design

There does not seem to be much researches concerning algorithm-aided structural design when searching in academic researches. Here the algorithm-aided structural design means design where both the model and the structural design is done with an algorithm. The field is quite new which is supported by the fact that researches written about algorithms in structural design are made in 2015.

There are some plug-ins for Grasshopper and Rhino such as Salamander, Karamba and Geometry Gym that have ability to export structural model to another structural analysis program. But there is only one pioneer, Karamba, which is able to do structural analysis and design according to Eurocode by itself. According to Preisinger (2013) Karamba is intended to be a fast and lightweight tool for architects and structural engineers for structural optimisation and early stage design in real-world structures. Its origins are in a research project entitled Algorithm Generation of Complex Space Frames which was done in the University of Applied Arts Vienna in collaboration with Bollinger + Grohmann Engineers in 2010. Preisinger (email interview, autumn 2017) writes that Karamba has been used mostly in the early stage design. But in some projects it has also been used for later phase design for example in Hyundai Motorstudio Goyang in Seoul, South Korea. Nevertheless, the results have always been verified with another FEM-program. There are some theses research where Karamba has been used and Karamba's website (www.karamba3d.com) also shows projects and research works where the software has been utilized. However, it is difficult to find researches where Karamba's design approach and methods are widely verified.

Reissmüller (2015) has studied the FEM calculation of Karamba but reveals only small amount of results. His thesis explores the concepts of performance-driven design in the AEC (Architecture, Engineering and Construction) -industry by using a genetic algorithm. His aim was to develop an optimization methodology for complex structures. The case study was a roof structure made from steel that is covered with glass panels. He improved the model of architectural proposal in order to reduce displacements. The FEM-analysis was done with Karamba and verified with another FEM-program Midas Gen. The structural analysis according to Eurocode 3 was done with Midas Gen. The study shows the results of Karamba's maximum forces, maximum moments and maximum displacements mostly differed 2 percent at the most compared to Midas Gen results. But there were one exception, torsional moment $M_{x.max}$, where the difference was almost 2000%. Noteworthy is that the values were $0.01kNm$ for Karamba and $0.19kNm$ for Midas Gen which is not significantly big difference since the values are quite small. Reissmüller does not specify the version of Karamba he used and how the data was exported to Midas Gen.

There is no wider comparison between Karamba and Midas Gen in the thesis.

Humppi's (2015) thesis "Algorithm-Aided Building Information Modeling: Connecting Algorithm-Aided Design and Object-Oriented Design" touches on the Karamba. He exported a model created with Karamba to Robot by using the Geometry Gym plug-in. He went through different optimisation methods and used optimisation plug-in Galapagos in some cases. He wrote that Karamba has been used as a first stage analysis tool in Louisiana State Museum and Sports Hall of Fame. The main structural analysis was made in Robot. Henriksson and Hult (2015) has also explored Karamba in their thesis. The aim was to study the methods to rationalize free-form architectural shapes into buildable structures. They used Karamba for structural analysis and optimization but the results were not verified with another software.

2.2 Differences between conventional and algorithm-aided design processes

In literature (Hauschild & Karzel 2011; Woodbury 2010) algorithm-aided design process is shown to be more efficient than the conventional design process. Figure 1 shows the differences between them. The design processes in the figure involve architectural and structural design. The classic design process does not require much more time than the programmed one when the algorithm is created for the first time. This can be seen in the first and the second bar of Figure 1. However, the algorithm-aided process leaves more time to the development and formulation of concept compared to classic design since the time used to the implementation and formation of variations can be reduced.

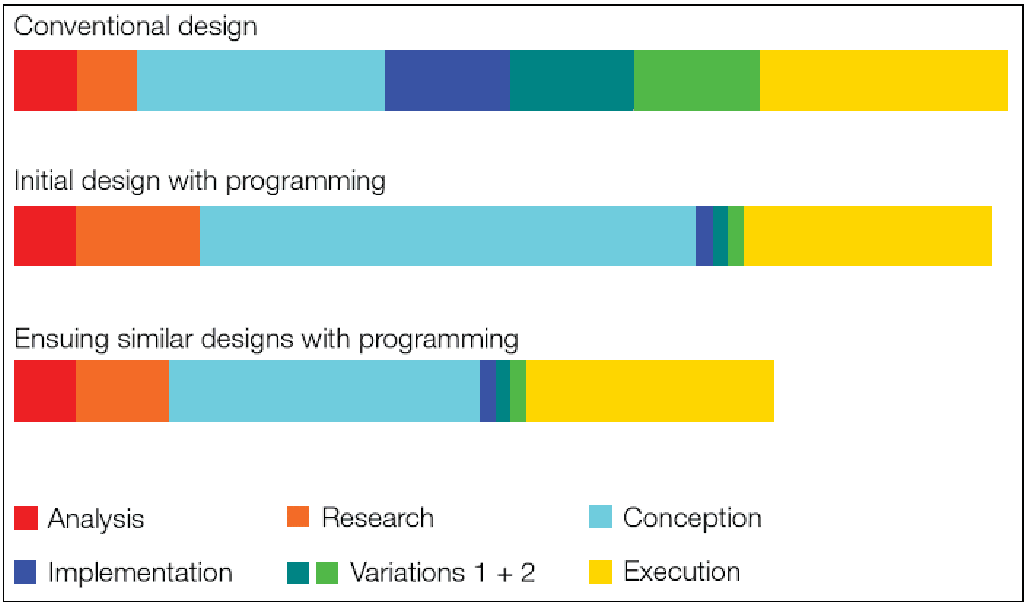


Figure 1. *Differences between conventional and algorithm-aided design processes, adapted from an original source (Hauschild & Karzel 2011).*

Algorithms include programming tasks. Some of them are developed exclusively for a specific task and some can be used again for similar tasks in other projects. A modular structure in the algorithm makes it possible to utilize individual parts of the code for other projects and to form the foundation for digital workflow. It enables substantial time savings when similar tasks arise which can be seen as a reduction in the conception. This is represented in the third bar in the Figure 1. (Hauschild & Karzel 2011)

2.3 Design process of algorithm-aided structural design

The design process of algorithm-aided structural design is presented in Figure 2. The process assumes that the outline comes from the customer and the structures are modelled and designed by the structural engineer. First the customer gives the dimensions of the building and the loadings to the structural engineer. The engineer models the building and structures by an algorithm by modelling lines and identifying them. The initial cross-sections are defined here too. The modeling of the building is then followed by structural design process. The design includes definition of the supports, joints and loadings. The elements are created from the lines and the selected cross-sections. Now the structure can be designed. The cross-sections can be optimized in order to avoid time-consuming definition of cross-sections. If needed, different variations of the structure can be worked through for the best solutions. In the end the model needs to be exported to third party structural design software for the verification. This can be excluded in the future if the algorithm-aided structural design program will be well verified.

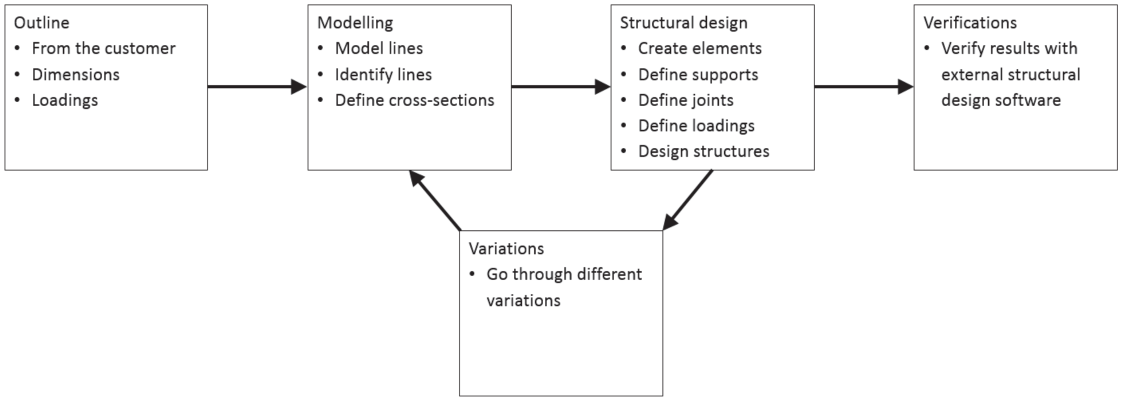


Figure 2. *Design process of an algorithm-aided structural design.*

The algorithm-aided structural design differs from the conventional process. The conventional design process may include many individual models that composes the whole model for example if the design is done using 2D models. In the algorithm-aided design one algorithm can construct the 3D model of the whole building. The algorithm may have ability to show and select all those members of the model which need to be designed so that the design can be done in 2D models. This helps the design as all the modifications can be done to only one model instead of many. It also reduces the time used for changes. If the dimensions of the building change the algorithm relocates the structures automatically whereas conventional design process demands manual remodelling. Algorithm-aided modelling enables easy comparison between different variations since modifications of the structures can be done easily and even optimised by an algorithm.

3 PRE-STUDY: STRUCTURAL DESIGN OF STEEL BEAMS IN KARAMBA

The study begins with a preceding research concerning Karamba's abilities in the fields of structural design of steel. It involves 14 identical beams with same length, material and cross-section properties. The beams are divided into two elements in order to add point loads in Karamba.

3.1 Prerequisites and assumptions

Material properties and cross-section properties are copied from RFEM to Karamba to ensure a comparable starting point for the analysis. In the model all the loads are assumed to act through the shear centre of a member. Design is done according to Eurocode 3 using first order theory. Interaction factors k_{yy}, k_{yz}, k_{zy}, k_{zz} are calculated according to method 2 described in Annex B. For sets of members, RFEM has option to use equivalent member method (Chapters 6.3.1 - 6.3.3 in Eurocode 3), or general method (Chapter 6.3.4 in Eurocode 3). In this thesis the equivalent member method is used. The formula 6.2 in Eurocode 3 is not used as it is considered a conservative approximation of the utilization ratios. The utilisation ratio is calculated using the following equation:

$$\frac{N_{Ed}}{N_{Rd}} + \frac{M_{y,Ed}}{M_{y,Rd}} + \frac{M_{z,Ed}}{M_{z,Rd}} \leq 1, \quad (1)$$

where N_{Ed} is design normal force, N_{Rd} is design value of the resistance to normal force, $M_{y,Ed}$ is design bending moment about the y-y axis, $M_{y,Rd}$ is design value of the resistance to bending moment about the y-y axis, $M_{z,Ed}$ is design bending moment about the z-z axis and $M_{z,Rd}$ is design value of the resistance to bending moment about the z-z axis.

3.2 Procedure

To become acquainted with Karamba's way of designing, the outlines of the calculations have to be the same throughout Karamba, RFEM and Mathcad. Hence, the pre-study is carried out in two phases; the first set of calculations are made with Karamba's simplifications and the second set without. All the results in the first set should be very similar, whereas in the second phase the differences between the simplifications and the actual design become apparent.

The length of the beams is 5 meters and the cross-section profile is IPE200. The cross-section properties may vary amongst standards and manufacturers. The selected profile is from standard Euronorm 19-57. One end of the beam has fork support. The other end has also fork support but with the axial degree of freedom (parallel to x-axis) released. Fork support means that translations in x-, y- and z-directions and rotation about the longitudinal axis of the beam are fixed whereas rotation about y- and z-axis and warping are free to occur. The beams' material properties are presented in Table 1 and the cross-section properties in Table 2.

Table 1. *Beam material properties.*

Property	Symbol	Value	Unit
Material		S355	
Modulus of elasticity	E	210 000	N/mm^2
Shear modulus	G	80 769.2	N/mm^2
Specific weight	γ	78.5	kN/m^3
Coefficient of thermal expansion	α	1.20 E-05	$1/°C$
Yield strength	f_{yd}	355	N/mm^2

Table 2. *Beam cross-section properties.*

Property	Symbol	Value	Unit
Section height	h	200	mm
Section width	b	100	mm
Web thickness	t_w	5.6	mm
Flange thickness	t_f	8.5	mm
Root radius	r	12	mm
Cross-sectional area	A	28.5	cm^2
Effective shear area	$A_{v,y}$	17.99	cm^2
Effective shear area	$A_{v,z}$	14.02	cm^2
Moment of inertia	I_y	1 943	cm^4
Moment of inertia	I_z	142	cm^4
Torsional constant	I_t	6.92	cm^4
Radius of gyration	i_y	82.6	mm
Radius of gyration	i_z	22.4	mm
Elastic section modulus	$W_{el,y}$	194	cm^3
Elastic section modulus	$W_{el,z}$	28.5	cm^3
Plastic section modulus	$W_{pl,y}$	221	cm^3
Plastic section modulus	$W_{pl,z}$	44.61	cm^3
Warping constant of cross-section	I_w	13 000	cm^6
Statical moment	Q_y	110.5	cm^3
Statical moment	Q_z	10.63	cm^3
Buckling curve	BC_y	a	
Buckling curve	BC_z	b	

The beams' loading conditions are shown in Figure 3. On the left side of the figure the beams are visualized by Grasshopper and on the right side the same beams are delineated by RFEM. Additionally the numbering of the elements are shown. Several beams are rotated at a 90° angle for an improved view over the applied loads along the weaker axis. The loading conditions are set to cover common structural design cases. The resistances of the cross-sections are calculated in ultimate limit state.

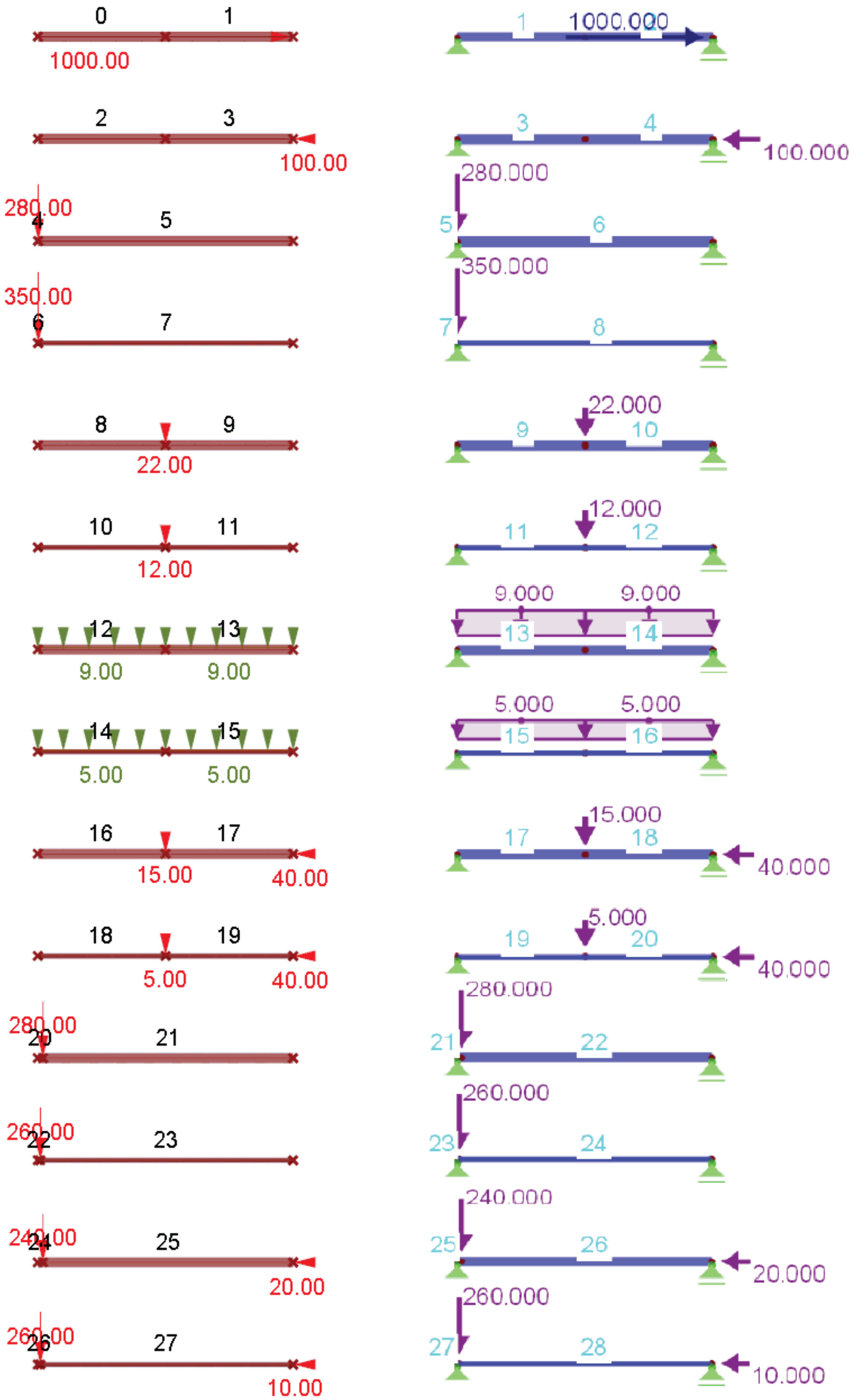


Figure 3. *Load cases and element numbering. On the left side beams are visualized in Rhino by Grasshopper and on the right side are same beams in RFEM.*

In Table 3 can be found the planned critical design criteria. The first column of the table refers to Karamba's element numbering and the second to RFEM's element numbering.

Table 3. *Planned critical design criteria. First two columns are element numberings.*

Karamba	RFEM	Planned critical design criteria
0 1	1 2	Tension
2 3	3 4	Flexural buckling about z-axis
4 5	5 6	Shear force in z-axis
6 7	7 8	Shear force in y-axis
8 9	9 10	Bending about y-axis
10 11	11 12	Bending about z-axis
12 13	13 14	Bending about y-axis
14 15	15 16	Bending about z-axis
16 17	17 18	Bending and compression
18 19	19 20	Bending and compression
20 21	21 22	Bending about y-axis and shear force
22 23	23 24	Bending about z-axis and shear force
24 25	25 26	Bending about y-axis, shear and axial force
26 27	27 28	Bending about z-axis, shear and axial force

3.3 Results

The results of the pre-study lead to different utilization rates amongst Karamba and RFEM. Intermediate results were an essential tool to become aware of the differences. RFEM gives the majority, if not all, of the intermediate results for Eurocode 3 calculations, making the comparison fairly convenient. Karamba also provides numerous intermediate results, also easing the process of identifying differences. The differences in utilization rates were caused by the loss of data during the export from Karamba to RFEM. The other reasons included the limitations and simplifications of Karamba software. Discussions with one of Karamba's creators, Clemens Preisinger, helped clarifying the reasons for the differences.

3.3.1 Limitations and simplifications of Karamba

Using Karamba comes with certain limitations and simplification which need to be considered. The following are Karamba's limitations and simplifications according to Karamba's manual (2016) and Preisinger (email interviews, autumn 2017).

- Karamba does not have load combinations but they need to be defined as load cases
- Buckling length of a beam element is calculated as the distance between two nodes which connect to more than two beams. This means that a beam can be divided into several elements and the buckling length will still be the length of the whole beam. If another beam is connected to that beam the buckling lengths are measured from the end of the beam to the node that connects the beam. If one end of a beam is free (cantilever) the buckling length is doubled
- Gravitational acceleration is 10 $kg\ m/s^2$ by default but it can be changed
- The point load has to be applied through a node at the end of an element
- When having class 4 cross-sections Karamba uses class 3 design approach and does not reduce the cross-section
- The reduction factor ρ to reduce moment resistance due to high shear force is the minimum of the factors of y and z axis direction
- $C_1 = 1.0$, $C_2 = 1.6$ and $C_3 = 1.0$ for lateral torsional buckling
- $k_z = 1.0$ and $k_\omega = 1.0$ for lateral torsional buckling
- $\psi = 1.0$ for elements which buckling length is larger than the actual element length. The factor ψ impacts on the factors C_{my}, C_{mz} and C_{mLT}
- C_{my}, C_{mz} and C_{mLT} are limited from 0.9 to 1.0 when the member is subjected to bending and axial compression. The factors affect the interaction factors k_{yy}, k_{yz}, k_{zy}, k_{zz}.

3.3.2 Export to RFEM

Karamba has a component called "Export Model to DStV" which is able to export models as DStV file for Dlubal's RStab and RFEM programs and also for Autodesk's Robot Structural Analysis Professional program. The DStV file does not include certain important data such as buckling lengths. These need to be transferred manually to RFEM. If the buckling lengths are not imported to RFEM, the program refers to element length as buckling length by default, leading to incorrect results in some cases. During the first phase of the pre-study simplifications and assumptions of Karamba were exported manually, too. In Karamba the numbering starts from 0 and in RFEM from 1. Therefore the index of each element, node and load case are shifted by 1 in RFEM.

In the study z-axis is pointed in an upward position in Karamba. If the model is imported to RFEM with its default settings, locally oriented loads in Karamba are reversed in RFEM. Globally oriented loads are imported as they are in Karamba. If the settings in RFEM's importer are programmed to locate the z-axis downwards, the loads will be oriented in the correct position. The importer in RFEM has an option to create a set of members automatically. However, this option creates the set of members for single elements which is not desired because in the pre-study two elements should construct the set of member. Therefore, the sets of members has been created manually.

3.3.3 Calculations in RFEM

Using RFEM and its module RF-STEEL EC3 requires dedication and precision. Settings are abundant and the software gives entirely different results if the settings and modifications required have not been done correctly. In the module the results were taken from "Design by x-location" in order to get the same internal forces as in Karamba. "Design by member" gives the same utilization rate but the location in the beam is not always the same as in Karamba. In order to efficiently compare results, the location needs to be same to get the same internal forces and intermediate values.

When the beams consist of two elements they have to be combined to act as continuous beams. In RFEM this can been done by creating set of members. Without the sets of members the coefficients defined according to the moment diagram will be incorrect since the moment diagram would not be taken into account entirely. In lateral-torsional buckling the coefficient C_1 depends on the moment diagram. Also, when the member is subjected to bending and axial compression, the equivalent uniform moment factors C_{my}, C_{mz}, C_{LT} depend on the moment diagram.

By default RF-STEEL EC3 module sets that small moments and compressions are not considered when the bending moments and normal force act simultaneously. This is changed, so that moments and compressions are always taken into account.

The factor C_1 can be found in RFEM version 5.07.07.121238 but not in the version 5.10. Additionally, the set of members cannot be used here, therefore the beams has been recreated so that they consist of one element instead of two. This is done only to retrieve C_1 factors; and all the other calculations were done in the version 5.10.

3.3.4 Simplified design

In the pre-study the bending about y-axis cannot be a critical design criteria since lateral torsional buckling occurs in I-profiles. All the cases where bending about y-axis was a planned critical design criteria, it turned into lateral torsional buckling, bending and compression or shear force in z-axis direction.

The first phase's utilization rates of Karamba, RFEM and Mathcad are presented in Table 4. Now simplifications of Karamba are taken into account and the results are presumed to be identical. In RFEM the following applies: the elements are not combined to set of members, buckling lengths $L_{cr,y}$, $L_{cr,z}$, L_w, L_T and the elastic critical moment M_{cr} is defined manually to be the same as in Karamba and the equivalent uniform moment factors are defined to be $C_{my} = 0.9$ and $C_{mz} = 0.9$. For the last factors RFEM has another option which is calculating them. These options follows Table B.3 in Eurocode 3 (2005) where the factors are supposed to be $C_{my} = 0.9$ and $C_{mz} = 0.9$ for members with sway buckling mode and calculated in other cases. The Mathcad calculation sheet can be found in Appendix A and the results with intermediate values can be found in Appendix B.

Table 4. *Utilization rates of the simplified design.*

Beam Id RFEM	Utilization rate RFEM	Karamba	Mathcad	Critical design criteria in RFEM
1	0.988	0.988	0.988	Tension
2	0.988	0.988	0.988	Tension
3	0.952	0.952	0.952	Flexural buckling about z-axis
4	0.952	0.952	0.952	Flexural buckling about z-axis
5	0.973	0.972	0.972	Shear force in z-axis
6	0.099	0.099	0.099	Lateral torsional buckling
7	0.948	1.105	0.947	Shear force in y-axis
8	0.221	0.221	0.220	Bending about z-axis
9	0.976	0.976	0.976	Lateral torsional buckling
10	0.976	0.976	0.976	Lateral torsional buckling
11	0.947	0.947	0.947	Bending about z-axis
12	0.947	0.947	0.947	Bending about z-axis
13	0.998	0.998	0.998	Lateral torsional buckling
14	0.998	0.998	0.998	Lateral torsional buckling
15	0.987	0.987	0.987	Bending about z-axis
16	0.987	0.987	0.987	Bending about z-axis
17	0.974	0.947	0.974	Bending and compression
18	0.974	0.947	0.974	Bending and compression
19	0.925	0.986	0.925	Bending and compression
20	0.925	0.986	0.925	Bending and compression
21	0.974	2.334	0.974	Lateral torsional buckling
22	0.974	0.974	0.974	Lateral torsional buckling
23	0.956	0.964	0.956	Bending about z-axis and shear force
24	0.813	0.813	0.813	Bending about z-axis
25	0.980	1.093	0.980	Bending and compression
26	0.980	0.963	0.980	Bending and compression
27	0.956	1.190	0.956	Bending about z-axis, shear and axial force
28	0.924	1.016	0.924	Bending and compression

Table 4 shows that differences between programs occurring when having shear force, bending and shear force, bending and compression, lateral torsional buckling or bending, shear and axial force. In several elements the critical design criteria is not the same in Karamba and RFEM due to the differences in the intermediate values changing the critical design criteria. The differences in utilization rates between Karamba and RFEM according to the Table 4 can be seen in Figure 4. The figure does not include the results of Mathcad since they are so close to RFEM.

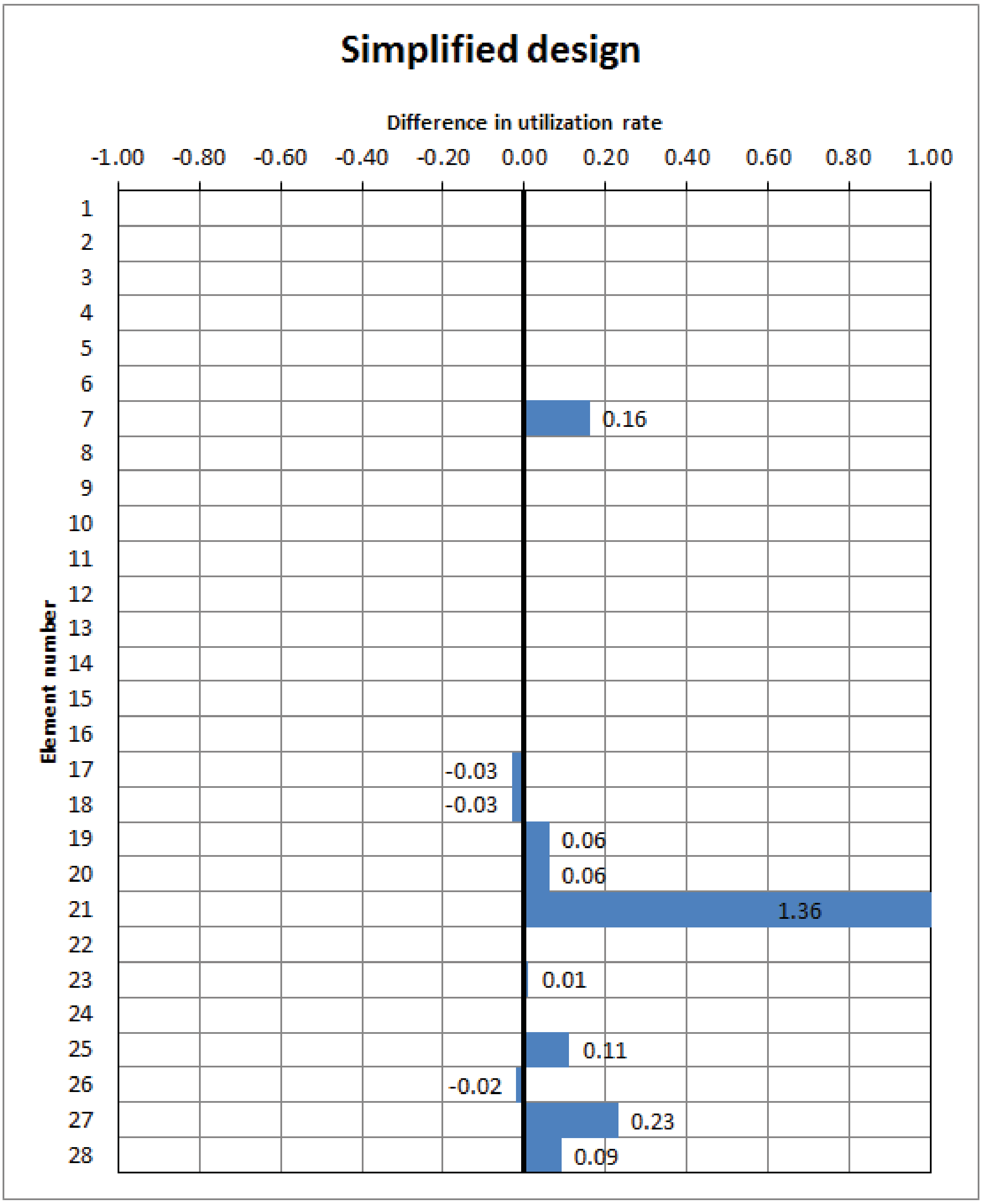


Figure 4. *Results of simplified design. The utilization rates of Karamba compared to RFEM.*

There are slight differences in shear force resistances $V_{pl.y.Rd}$ and $V_{pl.z.Rd}$ between RFEM and Karamba. The differences are $0.09kN$ and $0.08kN$ respectively for the profile IPE200. Karamba and Mathcad provided the same results. Dlubal has been informed about the difference, who presume the decimal places may be the cause of the differences. Albeit, the difference is of minor extent and therefore does not have an impact on the results of the utilization rate. Further reasons for varying results are as follows:

- Element 7: Difference in moment resistance reduced due to shear $M_{pl.z.V.Rd}$ and in critical design criteria
- Elements 13-14: Difference in correction factor k_c
- Elements 17-20: Differences in interaction factors k_{yy}, k_{yz}, k_{zy}, k_{zz}
- Element 21: Difference in reduction factor $\chi_{LT.mod}$
- Element 23: Difference in moment resistance reduced due to shear $M_{pl.z.V.Rd}$
- Element 25: Differences in reduction factors χ_y, χ_z, $\chi_{LT.mod}$ and in interaction factors k_{yy}, k_{yz}, k_{zy}, k_{zz}
- Element 26: Differences in interaction factors k_{yy}, k_{yz}, k_{zy}, k_{zz}
- Element 27: Differences in reduction factors χ_y, χ_z, in interaction factors k_{yy}, k_{yz}, k_{zy}, k_{zz}, in moment resistance $M_{pl.z.V.Rd}$ and in critical design criteria
- Element 28: Differences in interaction factors k_{yy}, k_{yz}, k_{zy}, k_{zz}

The variations are based on:

- Difference in moment resistance reduced due to shear $M_{pl.z.V.Rd}$: reduction factor ρ is chosen to be the minimum of the y and z axis for both of the axis in Karamba. Element 7 is impacted by this circumstance: in Karamba the critical design resistance is calculated according to the moment resistance, whereas in RFEM it is calculated according to the shear force.
- Difference in correction factor k_c: it is different in RFEM and in Mathcad because there is no table value for half parables in Eurocode. The value $k_c = 1.0$ is used in Mathcad to be on the safe side. In the pre-study it did not have an impact on the utilization rate.
- Differences in interaction factors k_{yy}, k_{yz}, k_{zy}, k_{zz}: Moment factors C_{my}, C_{mz}, C_{mLT} and ψ are causing the difference. RFEM has the option to set the factors $C_{my} = 0.9$ and $C_{mz} = 0.9$ while Karamba uses values between 0.9 and 1.0 for all the C_m factors. Karamba uses $\psi = 1.0$ for elements which buckling length exceeds the actual element length.
- Difference in reduction factors χ_y, χ_z, $\chi_{LT.mod}$: the reason is unknown.

The differences of the elements 17-20 and 25-28 are based on the differences in factors C_{my} and C_{mz} this not being an error as such seeing as the factors are locked to RFEM and vary between 0.9 and 1.0 in Karamba. The actual differences are located in the elements 7, 21, 23, 25, 27.

3.3.5 Non-simplified design

The utilization rates of the non-simplified design of Karamba, RFEM and Mathcad are presented in Table 5. Here, the simplifications of Karamba are not taken into account. In this phase the actual differences will become visible. In RFEM the following procedure is applied: the elements are combined with the set of members, buckling lengths $L_{cr,y}$, $L_{cr,z}$, L_w, L_T are placed, the elastic critical moment M_{cr} is defined automatically by the eigenvalue method, the equivalent uniform moment factors C_{my}, C_{mz}, C_{mLT} are calculated by RFEM. The moment factor C_1 and the correction factor k_c have been copied from RFEM to Mathcad calculations because there are no table values for every case. The results with the intermediate values can be found in Appendix C.

Table 5. *Utilization rates of the non-simplified design.*

Beam Id RFEM	Utilization rate RFEM	Karamba	Mathcad	Critical design criteria in RFEM
1	0.988	0.988	0.988	Tension
2	0.988	0.988	0.988	Tension
3	0.952	0.952	0.952	Flexural buckling about z-axis
4	0.952	0.952	0.952	Flexural buckling about z-axis
5	0.973	0.972	0.972	Shear force in z-axis
6	0.061	0.099	0.061	Lateral torsional buckling
7	0.948	1.105	0.947	Shear force in y-axis
8	0.221	0.221	0.220	Bending about z-axis
9	0.755	0.976	0.755	Lateral torsional buckling
10	0.755	0.976	0.755	Lateral torsional buckling
11	0.947	0.947	0.947	Bending about z-axis
12	0.947	0.947	0.947	Bending about z-axis
13	0.900	0.998	0.900	Lateral torsional buckling
14	0.900	0.998	0.900	Lateral torsional buckling
15	0.987	0.987	0.987	Bending about z-axis
16	0.987	0.987	0.987	Bending about z-axis
17	0.866	0.947	0.866	Bending and compression
18	0.866	0.947	0.866	Bending and compression
19	0.925	0.986	0.925	Bending and compression
20	0.925	0.986	0.925	Bending and compression
21	0.955	2.334	0.955	Shear force in z-axis
22	0.611	0.974	0.611	Lateral torsional buckling
23	0.956	0.964	0.956	Bending about z-axis and shear force
24	0.813	0.813	0.813	Bending about z-axis
25	0.819	1.093	0.819	Shear force in z-axis
26	0.699	0.963	0.699	Bending and compression
27	0.956	1.190	0.956	Bending about z-axis, shear and axial force
28	0.924	1.016	0.924	Bending and compression

The transition from the simplified design to the non-simplified design reveals new differences amongst the programs. Tables 4 and 5 show that for elements 21 and 25 the critical design criteria has been changed. In addition to the simplified design, differences occur in numerous other elements. The differences of the utilization rates between Karamba and RFEM according to the Table 5 is presented in Figure 5. The figure does not include the results of Mathcad since they are so close to RFEM.

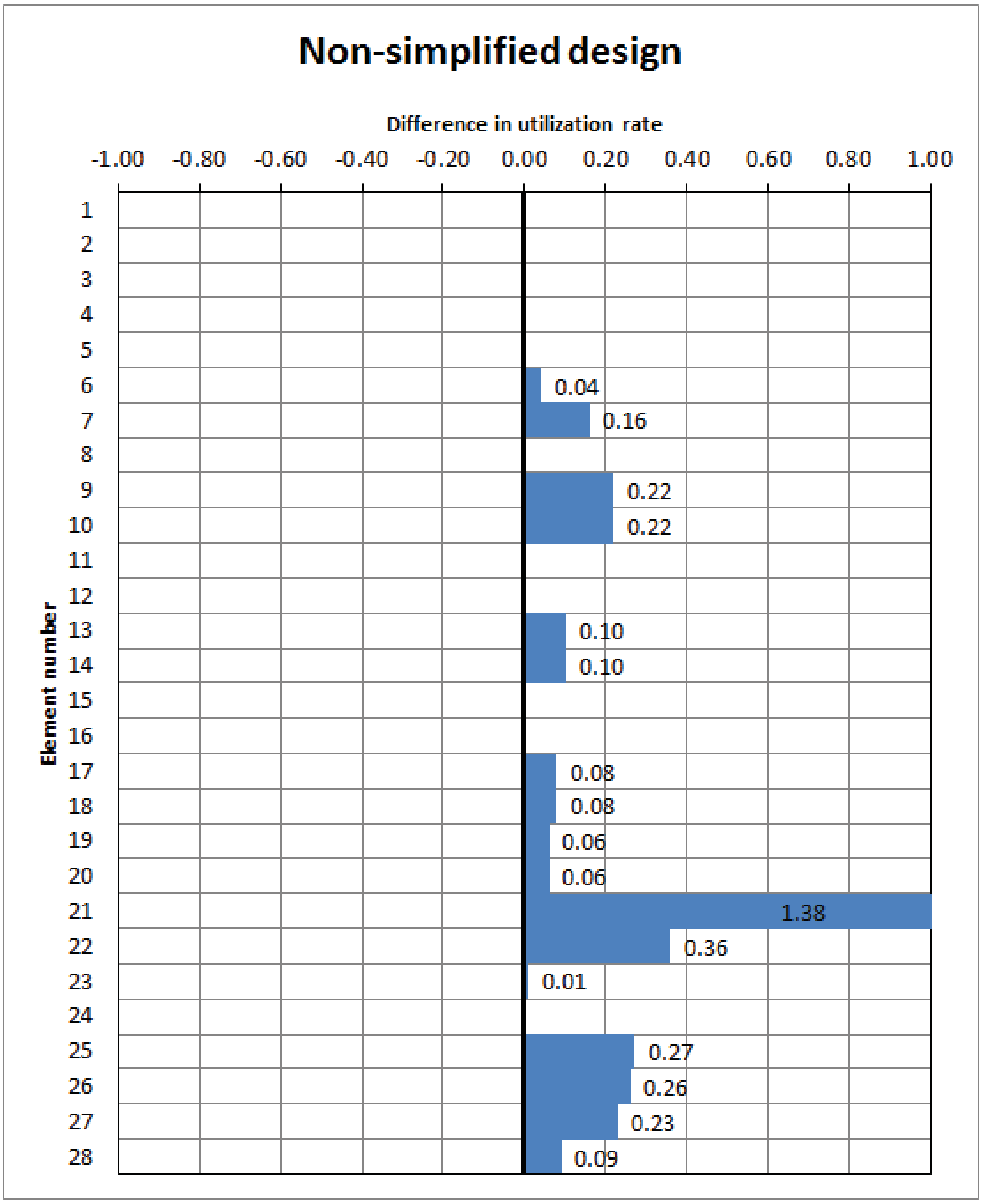


Figure 5. *Results of the non-simplified design. The utilization rates of Karamba compared to RFEM.*

The reasons for differences in addition to simplified design are following

- Element 6: Difference in the elastic critical moment M_{cr}
- Elements 9 and 10: Difference in the elastic critical moment M_{cr}
- Elements 13 and 14: Difference in the elastic critical moment M_{cr}
- Elements 17-18: Difference in the elastic critical moment M_{cr} and in the interaction factors k_{yy}, k_{yz}, k_{zy}, k_{zz}
- Elements 19-20: Difference in the interaction factors k_{yy}, k_{yz}, k_{zy}, k_{zz}
- Element 21: Difference in the elastic critical moment M_{cr} therefore the critical design criteria has been changed from lateral torsional buckling to shear force in the z-axis
- Element 22: Difference in the elastic critical moment M_{cr}
- Element 25: Difference in the elastic critical moment M_{cr} therefore the critical design criteria has been changed from bending and compression to shear force in the z-axis
- Element 26: Difference in the elastic critical moment M_{cr} and in the interaction factors k_{yy}, k_{yz}, k_{zy}, k_{zz}

The only variations that are between the simplified and non-simplified design are the elastic critical moment M_{cr} and the interaction factors k_{yy}, k_{yz}, k_{zy}, k_{zz} increasing the difference between Karamba and RFEM. The difference in interaction factors is due to the difference in moment factors C_{my}, C_{mz}, C_{mLT}. The moment factor C_1 influences the M_{cr} which influences directly to the reduction factor $\chi_{LT.mod}$. The comparison between the simplified and non-simplified design shows that the utilization rates reduce up to 0.36 in RFEM.

3.3.6 FEM

The results of FEM analysis were the same among Karamba and RFEM in the pre-study. However, there might be differences in more complex structures. Therefore the results are compared in a different case. In addition, another FEM program, Autodesk Robot Structural Analysis, is involved to the comparison for better contrast.

RFEM and Robot have the options to use the Euler-Bernoulli beam theory or the Timoshenko beam theory. In RFEM this can be changed in the "Calculation Parameters" dialog box by ticking the check box "Activate shear stiffness of members (cross-sectional areas A_y, A_z)". In Robot it can be changed in "Advanced bar properties" dialog box by ticking the check box "Consider shear forces in deformation calculations". According to Preisinger (email interview, autumn 2017), Karamba uses beam elements where points on a plane initially perpendicular to the axis stay on that plane, but the plane can rotate independently from the deformed axis in order to take shear deformation into account. This seems to be just like the Timoshenko beam theory. The differences between the theories can be seen in Figure 6.

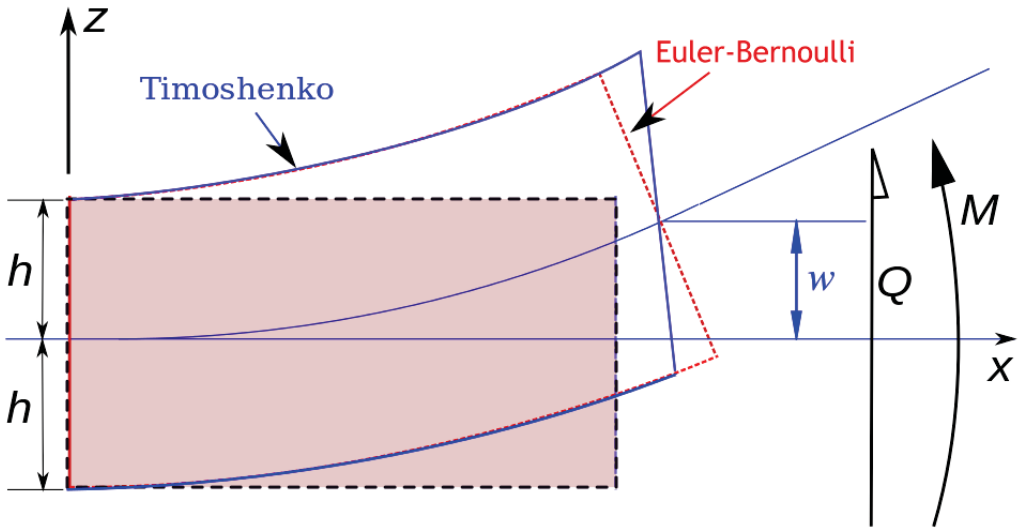


Figure 6. *Euler-Bernoulli beam theory is shown in red and Timoshenko beam theory is shown in blue (Timoshenko beam theory).*

The difference of the theories lie especially in the assumptions. The Euler-Bernoulli theory assumes that the cross-section is perpendicular to the bending curve, whereas Timoshenko theory allows a rotation between the cross-section and the bending curve. The rotation comes from a shear deformation which is excluded in Euler-Bernoulli theory. Therefore Euler-Bernoulli theory beam is stiffer than Timoshenko theory beam. The shorter the beam is, the higher the difference will become between the theories since the shear effects increase to matter for the beams with smaller length to thickness ratio. The Timoshenko theory beam is superior to Euler-Bernoulli theory beam to predict the beam response. (Aldraihem et al. 1996) The differences of the theory are examined in a small case which is shown in Figure 7.

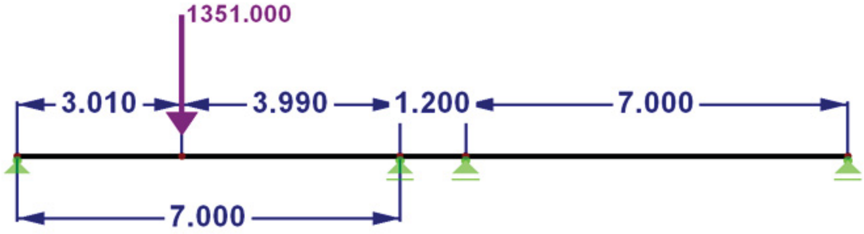


Figure 7. *A beam example to demonstrate the differences between Euler-Bernoulli and Timoshenko beam theory.*

Two cross-sections, HEB300 and HEB800, were used for the test to see the differences in reaction forces and maximum moments. Both of the theories were used in RFEM and Robot and Timoshenko theory was used in Karamba. The shape of the moment diagram and the shear force diagram can be seen in Figures 8 and 9 which are screen shots from Rhino.

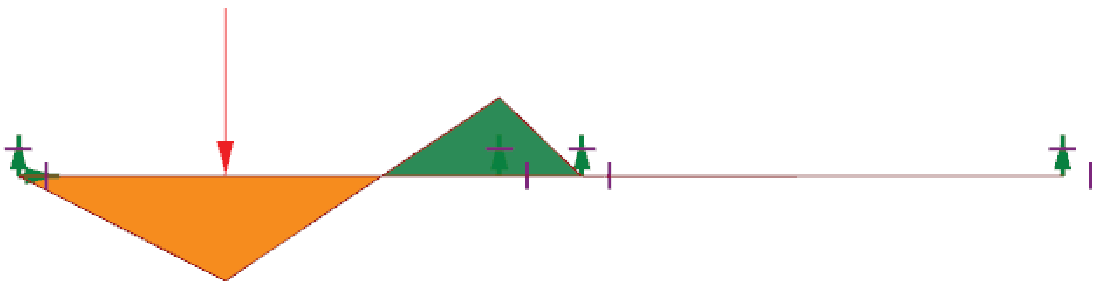


Figure 8. *The shape of the moment diagram.*

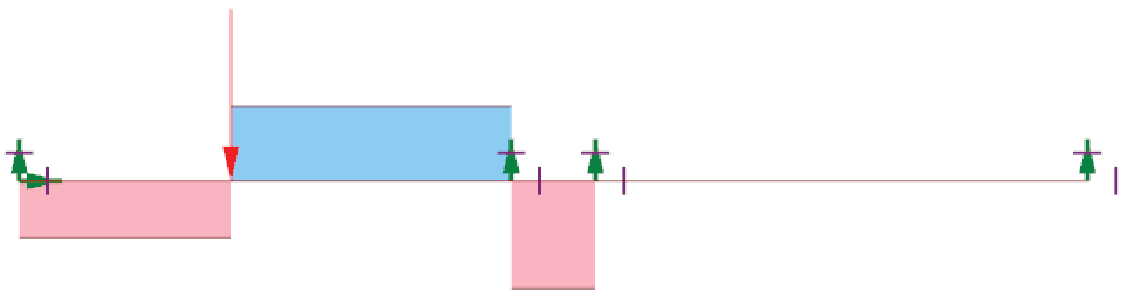


Figure 9. *The shape of the shear force diagram.*

The maximum moments occur at the load application point and close to the second support from the left. There are great shear forces in the second and the third supports from left which causes great shear deformations to the beam and reveals the differences between the theories. The first phase's results where the cross-section is HEB300 are presented in Figure 10 and the second phase results where the cross-section is HEB800 in Figure 11.

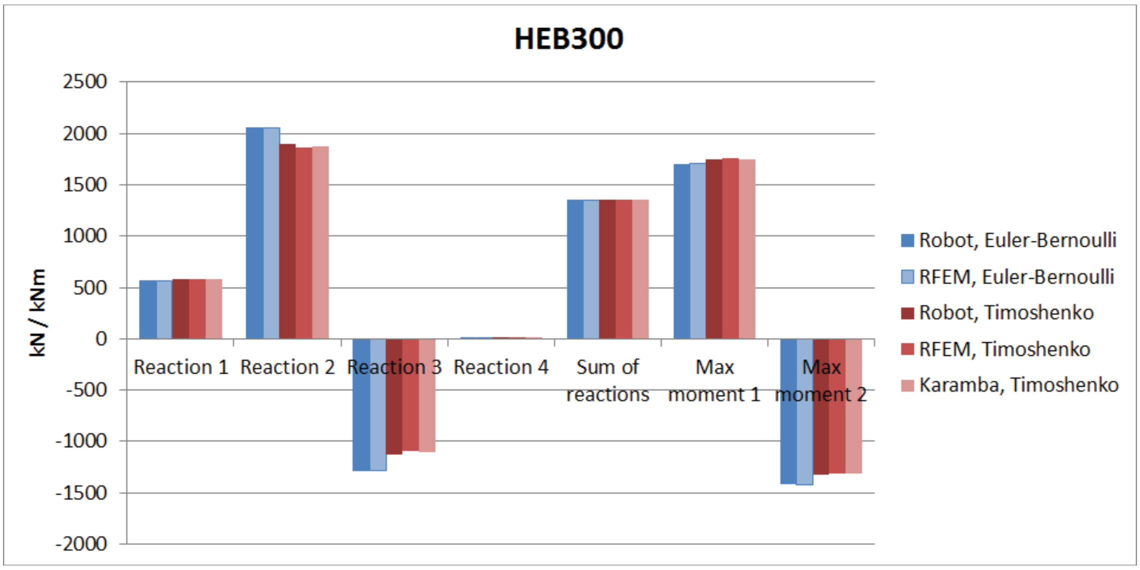


Figure 10. *Difference between Euler-Bernoulli and Timoshenko beam theory for cross-section HEB300.*

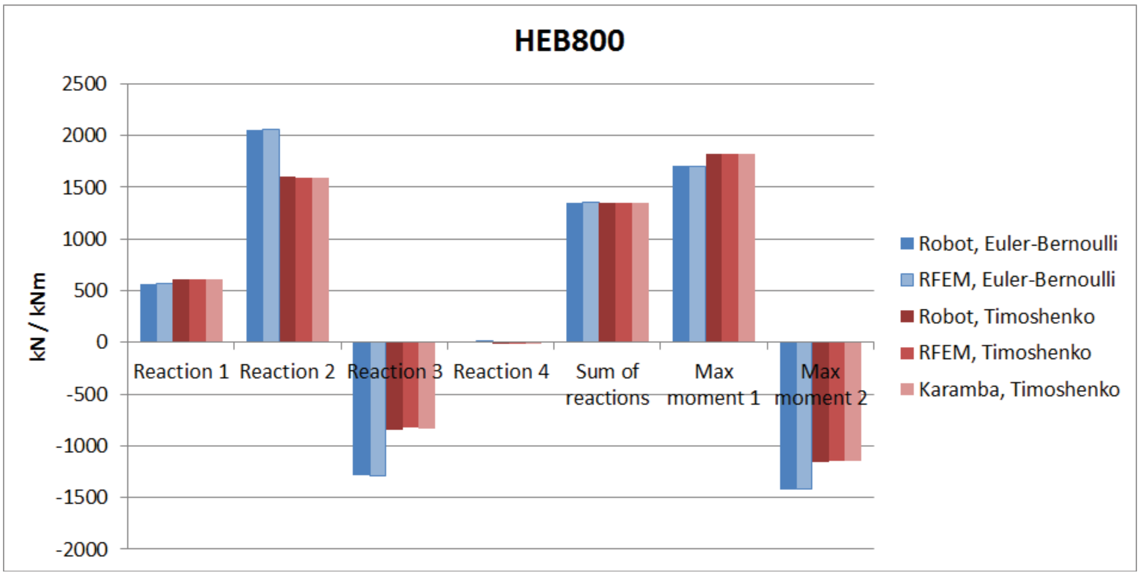


Figure 11. *Difference between Euler-Bernoulli and Timoshenko beam theory for cross-section HEB800.*

No major deviations are apparent when the same theory is applied, meaning the differences are mostly the result of different theories being applied. Since HEB300 has a bigger length to thickness ratio its results are closer to each other amongst the theories which was to be expected. For HEB800 the differences are significantly higher especially in light of the comparison of Euler-Bernoulli's and Timoshenko's theories. As an absolute value in supports 2 and 3, Euler-Bernoulli gives about

500 kN greater reaction force, meaning about 30% and 55% greater absolute value compared to Timoshenko. The second maximum moment differs about 300 kNm, meaning about 25% greater absolute value in Euler-Bernoulli than in Timoshenko. However, the first maximum moment is 100 kN smaller in Euler-Bernoulli theory which means that Euler-Bernoulli does not always give higher values than Timoshenko. These observations lead to the conclusion that the utilization rates will vary between the two theories. It is not researched here if the beam theory at all is suitable for this case or if the plate theory should be used in this case.

3.4 Summary

Karamba is capable to design steel structures well. If factors that uses moment diagram are used it can cause differences compared to more accurate design. These factors are used when critical design criteria is lateral torsional buckling or bending and compression. FEM analysis is also well handled in Karamba especially in the cases that were researched.

4 CASE STUDY: MODELLING OF STEEL-FRAMED WAREHOUSE

In order to study the benefits of the algorithm-aided design and the reliability of the results, a complete building frame will be modelled and analysed. The framework needs to be simple enough to enable convenient and realistic programming of the algorithm. A warehouse for steel and paper rolls seemed appropriate for this purpose. The warehouse is approximately 122 meters long, 43 meters wide and 35 meters high. Figure 12 presents the warehouse's long side, Figure 13 its short side. Due to numerous overlapping lines the 3D image of the building is obscure and therefore not enclosed in the thesis. The figures are obtained from already existing RFEM models. During the course of the study, the same warehouse is being remodelled and redesigned, this time using algorithms.

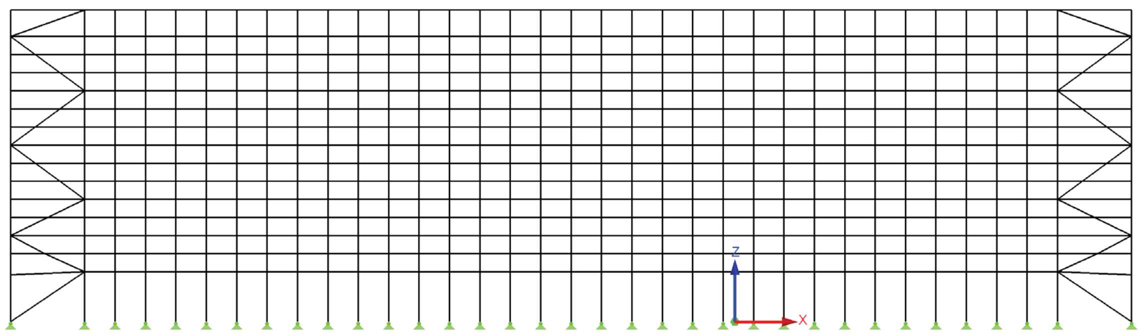


Figure 12. *Long side of the warehouse.*

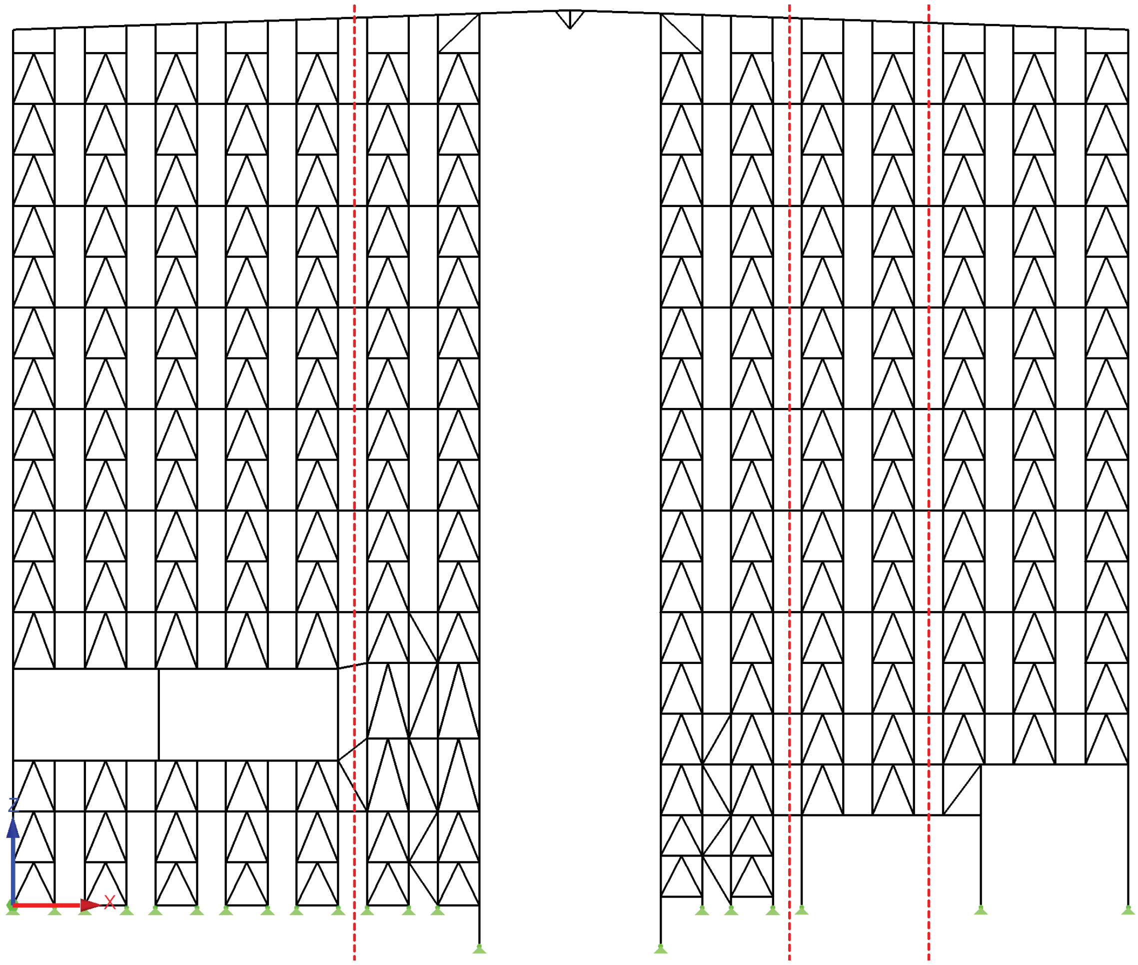


Figure 13. *Short side of the warehouse. Red dash line divides building into blocks.*

4.1 Algorithm-aided modelling

Algorithm-based results can be achieved in various ways, the following procedure being one of them. The modelling begins with programming an algorithm in Grasshopper. This model can fulfil numerous purposes, such as 3D visualizations, exporting it to other modelling programs for further application or, as in this case for structural design. The modelling part contains the geometry such as points and lines using the visual programming in Grasshopper. The algorithm has options to construct 2D model or 3D model of the warehouse. The algorithm modelling the warehouse of the case study is presented in Figure 14.

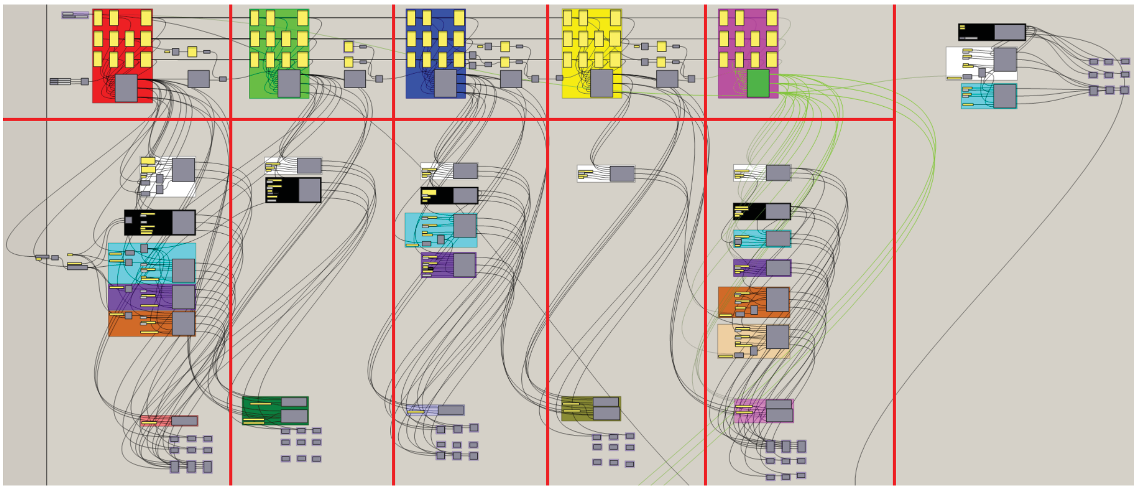


Figure 14. *Algorithm in Grasshopper to model the warehouse. The colors of the groups corresponds to the colors of the elements in the model.*

The algorithm is divided into five main blocks and one roof by red vertical lines. The same division of the main blocks can also be seen as a 2D model in Figure 13. The code is grouped with different colours which respond to the colors of the elements in Figure 15. Each main block has one main colour which is used in most of the elements. These elements are modelled by the main cluster located to the top of the code. They are separated with red horizontal line from the exceptions. The exceptions involves elements that cannot be modelled by the main cluster but requires extra code. The code of the exceptions of each main block is located below the main cluster. As can be seen the exceptions require more effort than the main cluster since they need to be programmed one by one or in small set of elements which is slow whereas the main cluster can model a big amount of elements.

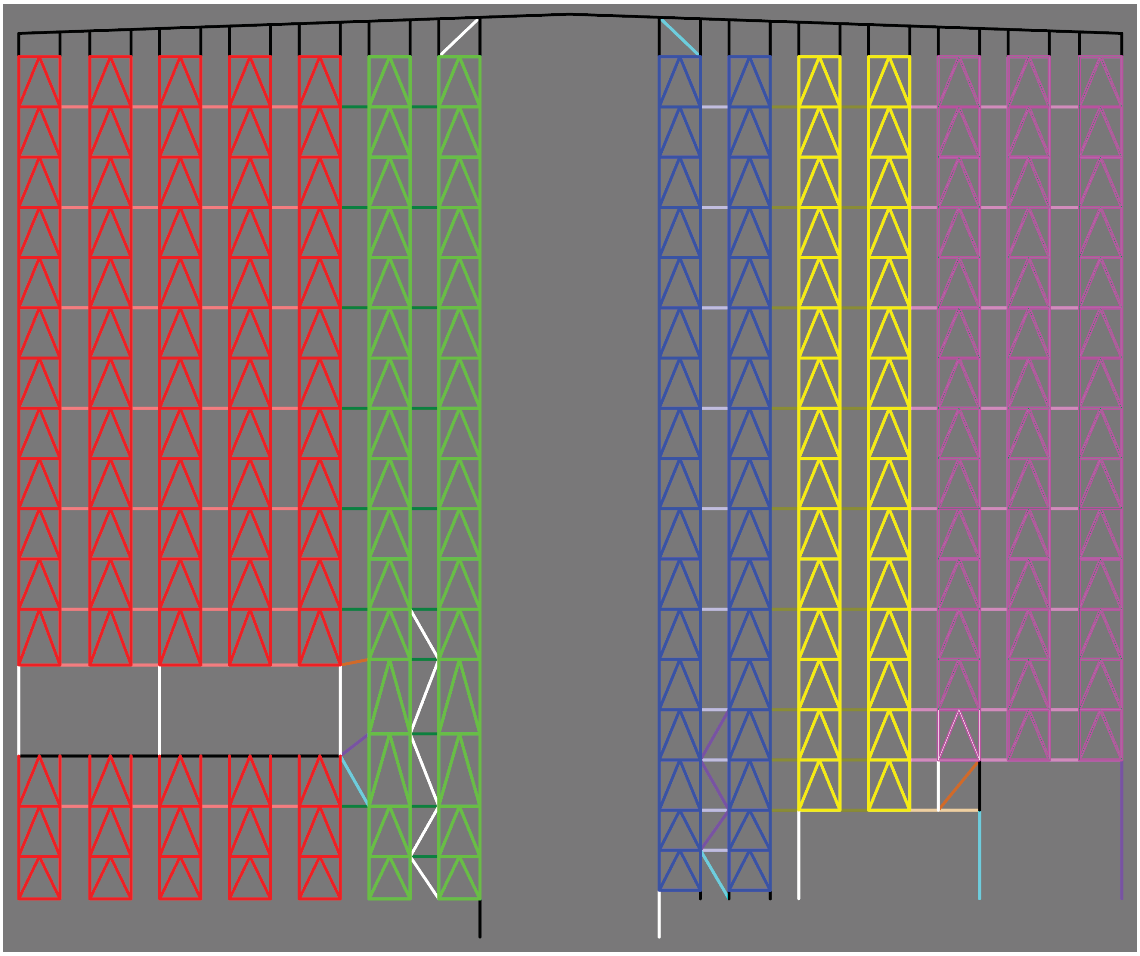


Figure 15. *Short side of the warehouse. The elements are coloured according to the colours in the code of the algorithm.*

Every main block has the respective input data located on top of the code within the yellow panels. Input data consists of dimensions, spacings and amounts of the rack block. Furthermore useful are the column lengths and block numbers. The column lengths are measured based on the number of rack blocks. The numbering of the blocks helps identify a block and individualize each element. Figure 16 demonstrates the first main block's input data. It corresponds with the first main block shown in Figure 17.

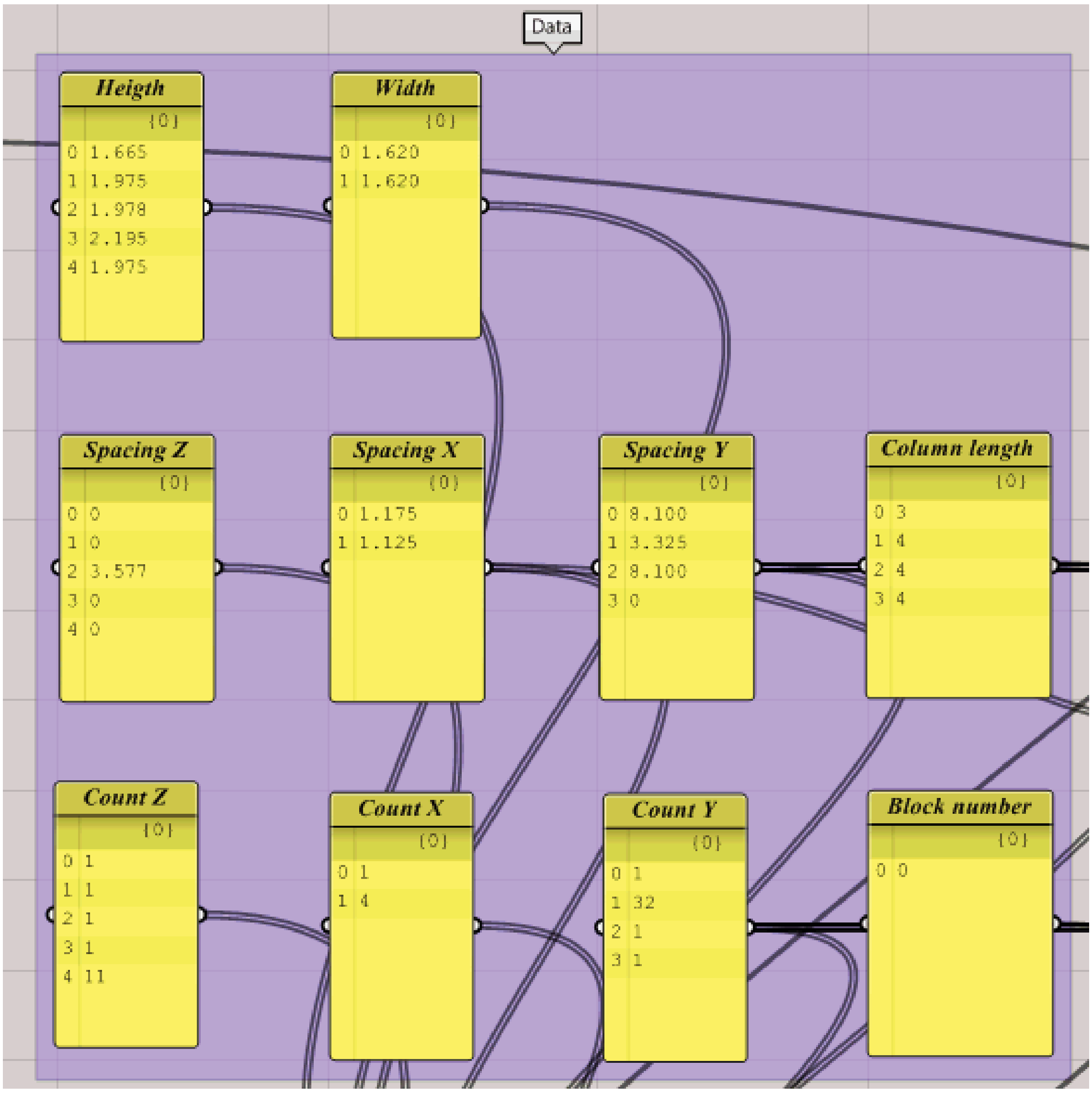


Figure 16. *Input values of the first main block.*

All five main clusters have the same content of code but varying inputs and consequently varying outputs. The main cluster is able to model differently sized racks with different spacing that are copied along x-, y- and z-axes according to the input values. The idea of the first main block being modelled by the main cluster's algorithm is presented in Figure 17. The main block consists of numerous smaller rack blocks, one of them marked red in the figure. This small rack block consists of several lines based on points. The main cluster also generates elements' identification and defines an initial cross-section for them. If necessary, these can be changed during an advanced stage of the algorithm.

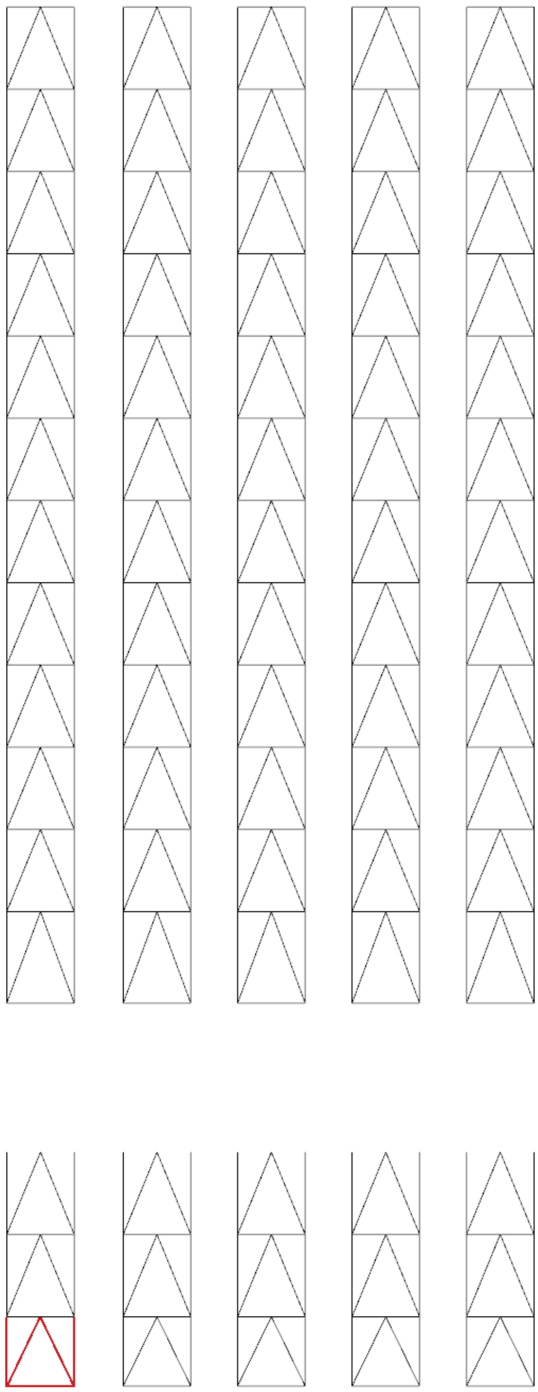


Figure 17. *The first main block of the warehouse.*

4.2 Results

Visualized programming, like programming in general depends on thorough organising and planning. Comprehensible codes enable other, potentially inexperienced, users to successfully apply them. Clear coding also allows modifications to be done subsequently. Visualized programming has the option to gather certain parts of the algorithm in one place on a canvas and save the other parts in a different section, easing the process of retrieving the required code.

4.2.1 Implementation

At first, the code's structure did not meet the expectations set, but repeated reconstruction led to the desired result. The greatest task of the modelling was to identify each element in order to easily gain access to them so that specific points can be found to create new elements which were not modeled by the main cluster. The points cannot be selected with the computer mouse from the model in order to maintain dynamism.

The element needs to be divided into individual elements at those points that are subjected to point loads. Furthermore, elements which intersect must be split at these points to be able to connect them to each other. This can be done at the beginning while constructing the lines or at the end, when the lines are defined. If it is done in the beginning it creates a clearer picture of the algorithm's structure, yet in some cases it is more convenient to split them in the end. It is advisable to identify the elements identification and define the cross-sections while constructing the lines, because it is easier to connect them to the correct element.

4.2.2 Improvements

Modelling turned into an iterative process since the algorithm occasionally worked at an unnecessarily slow pace. Nevertheless, using the correct component and efficiently taking care of the programming, the procedure became less time-consuming. Reading .csv files also requires time, doing so repeatedly significantly slows down the algorithm. Initially all the main blocks and the roof read the files of material properties and cross-section separately resulting dozen of readings, later it was done only once at the end of the algorithm. The amount of time spent on the reading is presented in Figure 18.

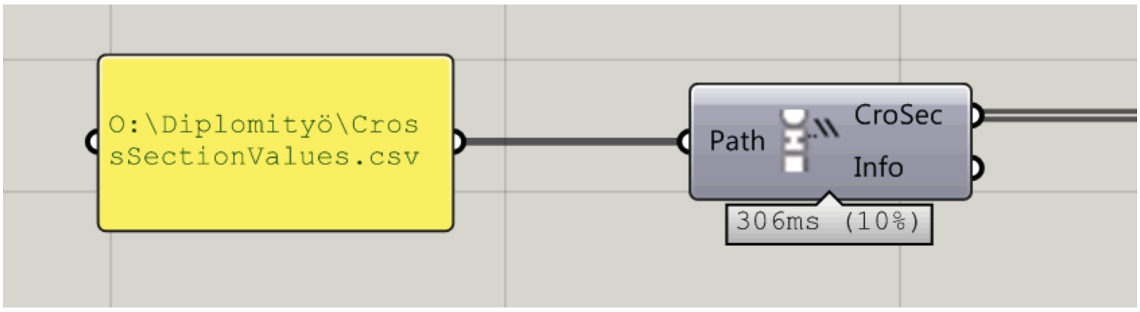


Figure 18. Reading .csv file takes time.

Using concentrated data turned out to have a time-saving influence on the process. Figure 19 shows a top beam from the first main block which needs to be divided into two elements to connect the diagonals to the beam. The beam is only located at the top of the main block and repeated 175 times in the first block in 3D model.

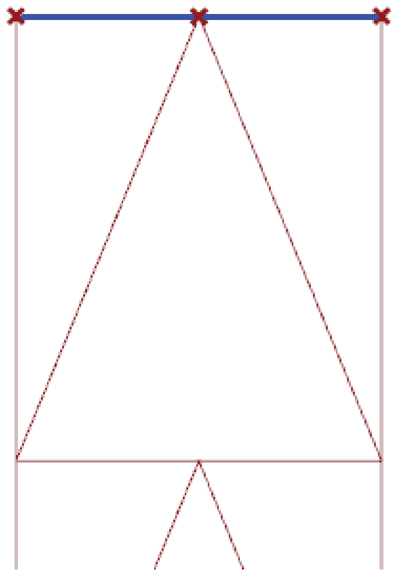


Figure 19. Beam to be divided. The top beam is marked in blue.

Originally, all the diagonal's top points were used to divide the beam, totaling in 2625 points. Every point was used for every top beam, resulting in 459 375 dividing parameters. It took 1.4 seconds for one block and 7 seconds for all of them. The first version is visible in a Figure 20.

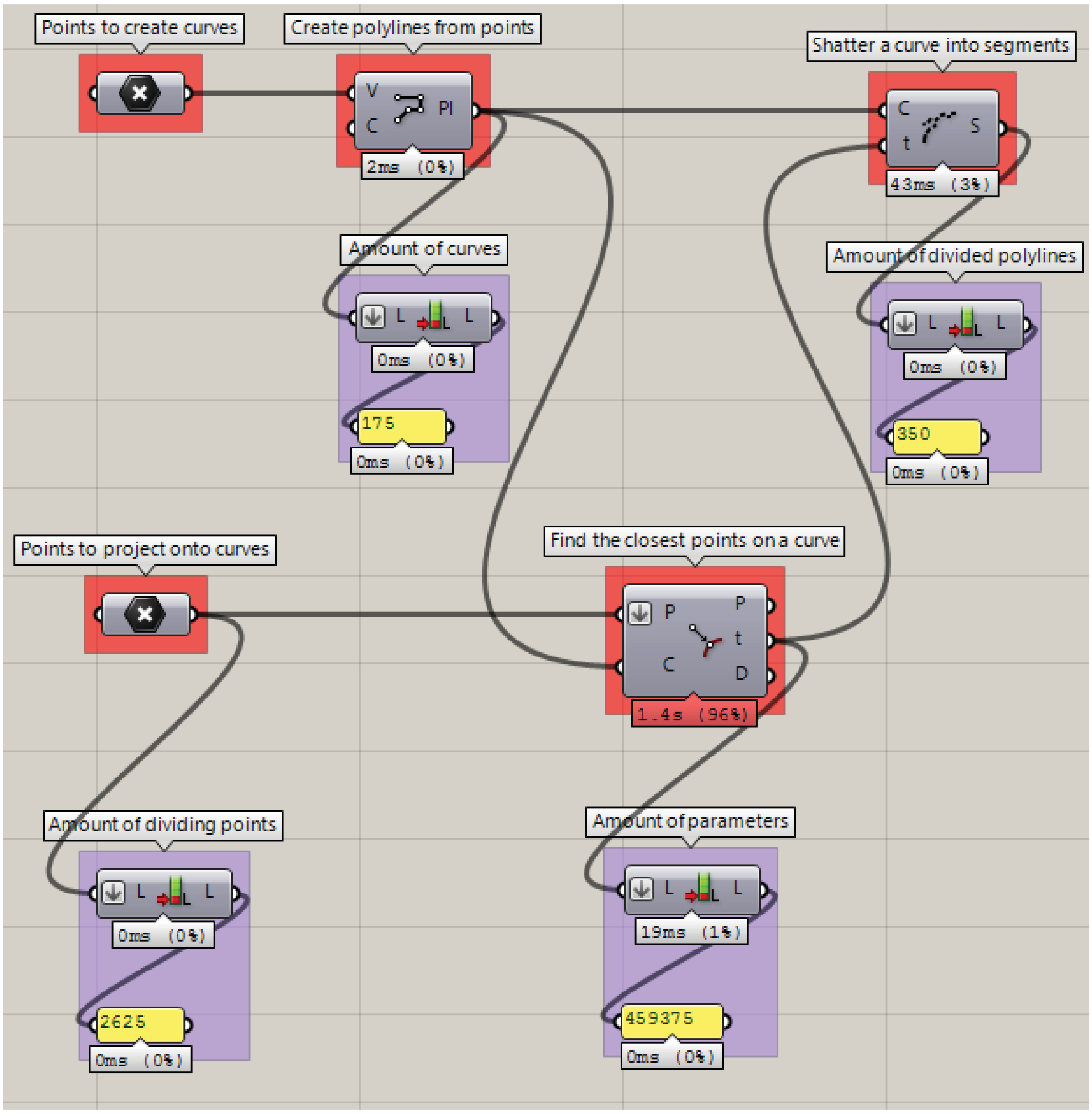


Figure 20. *Original version of dividing the top beam.*

The enhanced version used concentrated data and used only the diagonals' points that are located on the beam so the amount of points was reduced to 175. Consequently, every beam had only one dividing point and time was saved. Both of the versions delivered the same result, the latter quicker than the other. The second version is presented in Figure 21.

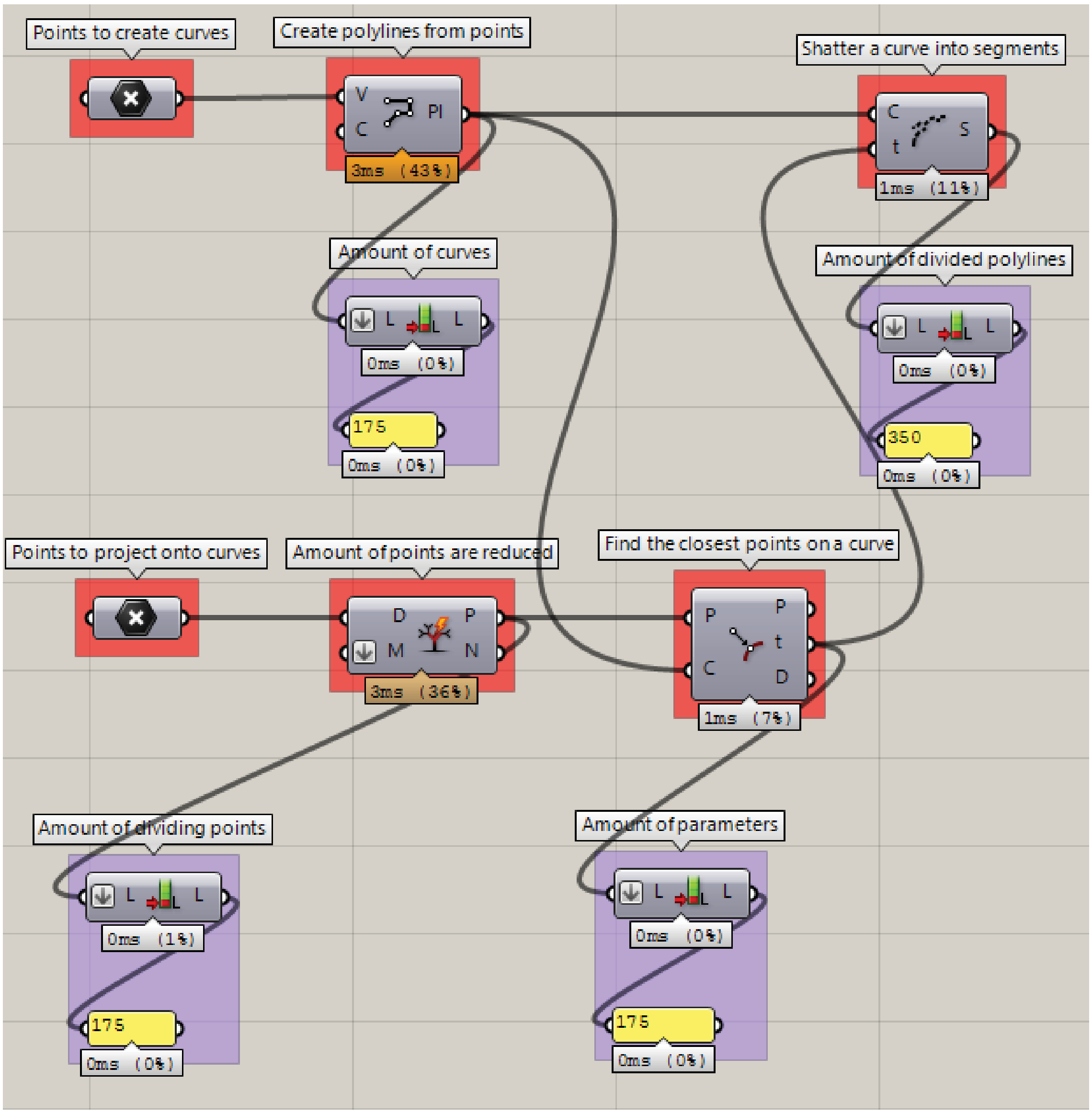


Figure 21. *Enhanced version of dividing the top beam.*

If the components of Grasshopper and Karamba do not suffice, Food4Rhino has an abundant collection of plug-ins and components for convenient programming. There are also handy components for scripting in Python, C# or Visual Basic. There is also the option of creating own components for Grasshopper or Rhino.

4.3 Summary

It takes a lot of time to create an algorithm from scratch that fits the building. The programmer must consider numerable preconditions and plan his work systematically. The algorithms need to be readable and easy to modify for other programmers to use them. The user needs to become acquainted with the new program and the algorithm in order to be able to successfully use them.

Modelling with an algorithm is a slow process if the elements need to be modeled one by one and the structure is not repetitive. In algorithm-aided design drawing a line for an element cannot be done using the mouse and drawing from one point to another. Instead, it needs to be done by programming in order to maintain dynamism. In this study the modelling took approximately 200 hours.

5 CASE STUDY: STRUCTURAL DESIGN OF STEEL-FRAMED WAREHOUSE

The structures of the warehouse have formerly been designed by structural engineers in Ramboll according to Eurocode 3 with RFEM. They designed it in two separated 2D models one concerning the short side and the other the long side.

5.1 Prerequisites and assumptions

The prerequisites and assumptions are the same as used in the pre-study. In addition, the beams carrying the imposed load are not included to the model. They have a sigma-shaped profile and diverse point of load application. All their loads are acting at the columns because the beams are designed separately. The used cross-sections are rectangular hollow sections from the manufacturer Ruukki and I-profiles from the Euronorm standards.

Although imperfections are not included in the analysis of this thesis, Karamba has components available to take these into account. Designing the long side was not part of the thesis either, since it has long columns which are susceptible to buckle and it requires a closer analysis which is not the main aim of the thesis. Karamba has components for buckling modes and eigen modes which could help.

5.2 Procedure

All the requisite data is taken from the prior RFEM models created by Ramboll. The design is done for 2D models as is done formerly by Ramboll. The definitions of the analysis model are carried out by Karamba including modelling, loads and supports. This data is exported to DStV file and then imported to RFEM for analysis and comparison. The DStV file includes all the necessary data except buckling lengths which need to be exported manually.

The structural design's algorithm is presented in Figure 22. First part consists of the data: lines, element identifications and cross-sections collected from the modelling part. Sections 2, 3 and 4 are for the short side of the model and 5, 6 and 7 are for the long side. Sections 2 and 5 redefine desired cross-sections and element identifications, select location for the supports and create Karamba's elements. 3 and 6 defines the joints. By default all the connections are fixed. 4 and 7 defines loads. Section 8 does FEM-calculation and defines material and cross-section files. It also includes optimization of the cross-sections according to Eurocode 3. Section 9 visualize the model and the results. Several results can be visualized in Rhino, for example the deformation of elements, diagrams and values of the normal force, the shear force and the moment. Section 10 exports model to DStV file and it also exports results to Excel sheets.

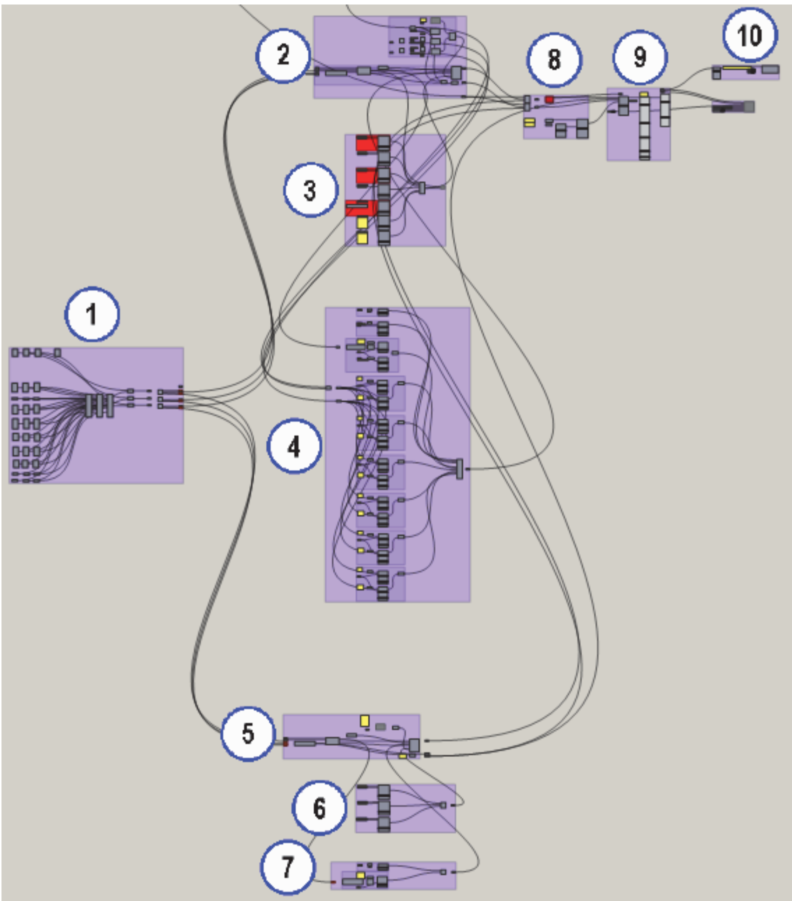


Figure 22. *Algorithm in Grasshopper to design steel structures.*

5.3 Results

Karamba is equipped with load cases, yet no load combinations or result combinations. The load values in the load cases need to be multiplied with the adequate coefficient before using them for designing. Also, the number of load cases need to be the same in order to use them as a combination. In order to go through all the load combinations, which could possibly amount to hundreds, the coefficients should be arranged for every load combination and the planned load cases for the combination need to be reselected if they are not the same. Going through the entire amount of load combinations and to obtain the suitable cross-section for all the elements to ensure that they are strong enough for all the combinations would be a highly time-consuming endeavour. Therefore only one load combination was calculated and it is following: $1.15DL + 1.5LL + 1.5SL + 0.9WL$ where DL stands for the dead load, LL is the live load, SL is the snow load and WL is the wind load. The combination is from the formerly designed RFEM model. The coefficient for the snow load in the combination is a simplification since the coefficients for both the snow load and the wind load don't need to be 1.5 at the same time. By taking snow load at 1.5-fold it reduces the amount of the combinations. Since the snow load is not significant compared to the imposed load it does not make a great difference in the results.

In the case study the simplifications of Karamba are not taken into consideration, and the actual differences will be seen. In RFEM the following applies: the elements are not combined to the set of members, buckling lengths $L_{cr,y}$, $L_{cr,z}$, L_w, L_T are copied from Karamba, the elastic critical moment M_{cr} is defined automatically by the eigenvalue method, the equivalent uniform moment factors C_{my}, C_{mz}, C_{mLT} are calculated by RFEM.

The utilization rates of Karamba and RFEM are shown in Appendix D. The frequency distribution of differences according to the appendix can be seen in Figure 23. The values are aggregated into bins which encompasses one percentage range. Some of the elements have a utilization rate above 1.0 in Karamba due to the used cross-sections not being big enough.

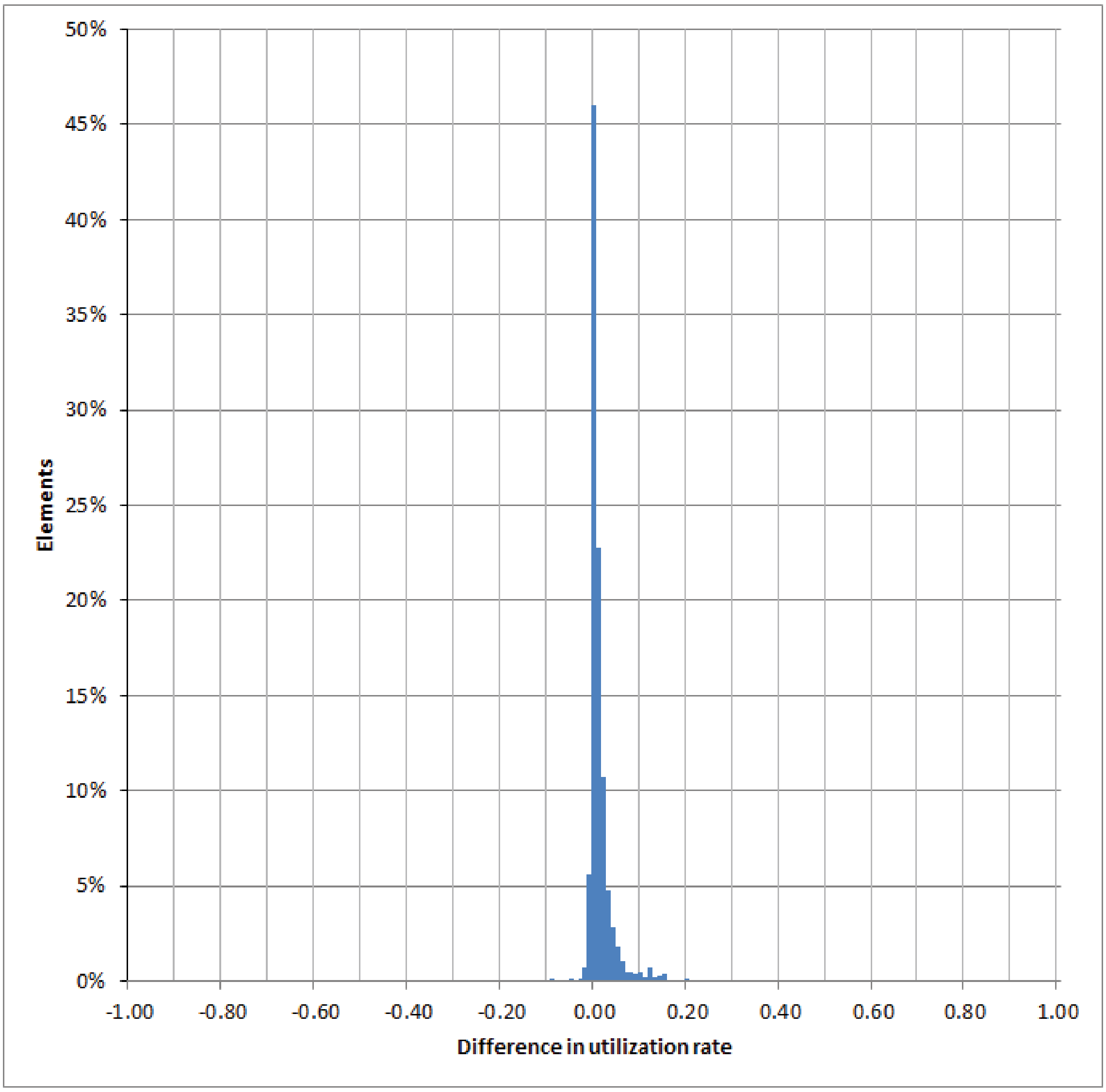


Figure 23. *Frequency distribution of Karamba's utilization rates compared to RFEM. Results of the short side of the warehouse.*

As seen in the Figure 23, Karamba's and RFEM's results are considerably similar. The y-axis shows the percentile amount of elements and the x-axis shows the difference in utilization rate while comparing Karamba's results to RFEM's results. The short side model comprises 1507 elements in total, 95% of which has a difference between -0.02 and 0.06. Only 0.3% of the elements has smaller than -0.02 difference which means that Karamba's design is mostly on the safe side. Other statistical numbers of the differences are shown in Table 6.

Table 6. *Statistical numbers of the results.*

	Value	RFEM Element number
Minimum	-0.09	1133
Maximum	0.20	1309
Average	0.01	
Median	0.00	
Standard deviation	0.02	

As the table shows, the differences vary between -0.09 and 0.20, while the average is 0.01, the median is 0.00 and the standard deviation is 0.02. The element numbers for the smallest and largest differences are also visible in the table. The comparison of the intermediate values of these and four other elements are presented in Appendix E. The highest differential value was discovered in element 1309. Its cross-section is SHS300x300x12.5 and for reasons that could not be established only the utilization rate differs. The critical design criteria is simultaneous bending, shear and axial force. The reason might potentially be due to the moment factors C_m since the element is subjected to compression and bending.

The highest negative difference is in element 1133. Its cross-section is HEB700. The difference is based on the cross-section classification. According to RFEM the cross-section is allocated to class 4, whereas in Karamba it is class 1. The class has been defined by hand calculations in Mathcad and the result was the same as in RFEM, class 4. Although Karamba does not have the necessary functions to design class 4, the difference may be smaller if it is designed as class 3.

In element 1053 the difference is -0.03. Its cross-section is SHS60x60x2.5. There are differences within the FEM results, meaning the design internal forces differs. Additionally, the moment resistance deviates as Karamba has not reduced the moment resistance due to the normal force like RFEM has done.

In element 727 the discrepancy is 0.15 and its cross-sections is SHS150x150x5. It is caused by the cross-section class. In RFEM the cross-section is classed at 1, in Karamba in class 3. The square hollow section is manufactured by Ruukki and according to its brochure the cross-section is class 2 (Ongelin & Valkonen 2012). Ruukki uses the class that is on the safe side assuming all the internal forces are compression, this being the worst case for the classification.

The element 939 has tension and a minor moment and therefore should be easy to design. However, the difference is 0.15 and the cross-section is SHS60x60x2.

The last element of closer comparison is element 1139 which cross-section is SHS90x90x3. The class of the cross-section varies: RFEM offers class 1, Karamba class 3 and Ruukki's brochure class 2 as simplification. The design requires now the moment factors C_m which also causes the difference. The difference is 0.12.

The differences of the utilization rates in the pre-study vary between -0.03 and 1.38, whereas in the case study the numbers lie between -0.09 and 0.20. Also, the differences of the utilization rates in the case study do not deviate significantly, meaning that Karamba designs quite close compared to RFEM. As seen in the pre-study, Karamba's structural design reliability depends on the forces and moments that the element is subjected to. The pre-study concerned I profiles so the following aspects apply only to them. If the critical design criteria is any of the following

- tension
- shear force
- bending about weaker axis
- flexural buckling

the results of Karamba are the same as in RFEM and in the hand calculations. The differences are due to

- lateral torsional buckling
- bending and compression
- bending and shear force
- bending, shear and axial force.

The differences in the results, when the members were subject to shear, bending moments and axial force acting simultaneously, can be explained by the simplification of the reduction factor ρ which reduces the moment resistance due to the shear force. Also, differences occur in the reduction factors χ_y, χ_z, $\chi_{LT.mod}$ for whom the difference is inexplicable. For the last two, the difference is due to the calculations where factors depend on the moment diagram. In the occurrence of bending, lateral torsional buckling might be a side effect. The lateral torsional buckling involves the moment factor C_1. When having axial force and bending there are moment factors C_{my}, C_{mz} and C_{mLT} that are used in calculations. The last listed moment factors are further treated and outlined in the following chapters.

5.3.1 Lateral torsional buckling

Karamba simplifies the moment diagram for the moment factor C_1 so that the moment diagram is uniform with the value of the greatest moment which always equals to $C_1 = 1.0$. The factor is used for the elastic critical moment M_{cr} for lateral torsional buckling which can be calculated using formula

$$M_{cr} = C_1 \frac{\pi^2 E I_z}{(k_z L)^2} \left[\sqrt{\left(\frac{k_z}{k_\omega}\right)^2 \frac{I_\omega}{I_z} + \frac{(k_z L)^2 G I_t}{\pi^2 E I_z} + (C_2 z_g - C_3 z_j)^2} - (C_2 z_g - C_3 z_j) \right], \tag{2}$$

where C_1, C_2 and C_3 are the moment diagram factors, I_z is the moment of inertia about the weak axis, I_ω is the warping constant, I_t is the torsional constant, E is the modulus of elasticity, G is the shear modulus, L is the length between the lateral restraints, k_z and k_ω are the effective length factors related to the restrain against lateral bending and warping at the boundaries respectively, z_g is the distance between the point of load application z_a and the shear centre z_s which equals to the $z_g = z_a - z_s$, z_j is the distance related to the effects of the asymmetry about the y-axis and $z_j = z_s - \frac{0.5 \int (y^2+z^2) z dA}{I_y}$. (Andrade et al. 2007)

Figure 24 shows the distances for z_g, z_s and z_a used in formula 2. The distance z_g between the point of load application and the shear centre is positive when the load direction is towards the shear centre as seen from the direction of the point of load application. The distance z_j is positive when the flange with the bigger moment of inertia I_z about the weaker axis is under compression at the location of the greatest moment. (SFS-ENV 1993-1-1 1993)

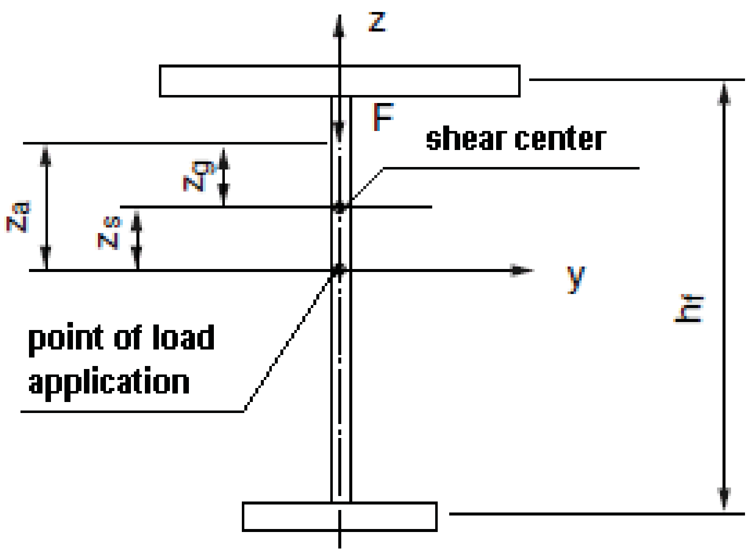


Figure 24. *Dimensions for elastic critical moment M_{cr}, adapted from an original source (Ongelin & Valkonen 2010).*

Specialized literature (Ahnlén & Westlund 2013; Dlubal Software GmbH 2014; Ongelin & Valkonen 2010; SFS-ENV 1993-1-1 1993) either applies the symbols k_z or k for effective length factor related to the restrain against lateral bending at the boundaries. For the thesis the symbol k_z was chosen since the symbol k can be used for both of the factors k_z and k_ω when these are equal $k = k_z = k_\omega$. Therefore the symbol k is changed to k_z for the formula (2).

Formula (2) is shown in the ENV 1993-1-1 which was abrogated in 2010 and replaced with the standard EN 1993-1-1. ENV serves as a provisional application but does not carry the status of an European Standard. The substituting standard does not have an analytic formula for the elastic critical moment M_{cr}, nor a manual how to calculate it. According to Andrade (2007) the formula (2) is one of the frequently used formulas to estimate the elastic critical moment.

Ahnlén and Westlund (2013) have done extensive researched on the subject of lateral torsional buckling in their thesis. They have incorrectly not marked the multiplication $C_3 z_j$ inside the square root for the formula of the elastic critical moment but it does not influence to the results since their thesis focused on double-symmetric sections when $z_j = 0$ and the term is not necessary. They have compared several programs and discovered that LTBeam offers highly accurate values for the elastic critical moment. According to them many trusted sources such as Access Steel and ECCS (European Convention for Constructional Steelwork) consider LTBeam a useful software.

A beam element may have 7 degrees of freedom in each node: three for translation, three for rotation and one for warping, all of which which are shown in Figure 25. The symbol φ'_x for warping in the figure is sometimes replaced with symbol ω. Factors k_z ja k_ω depend on the degree of freedoms of the ends of an element. Translation u_y in the y-axis and the rotation φ_z about the z-axis impact on the factor k_z. The rotation φ_x about the x-axis and the warping ω influence on the factor k_ω. (Dlubal Software GmbH 2014)

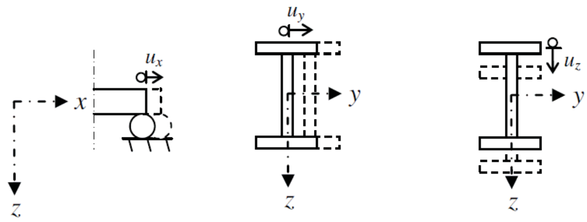
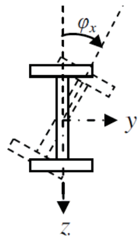
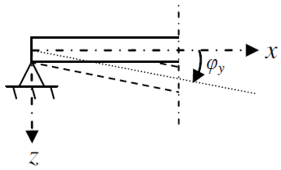
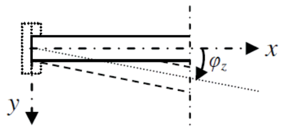
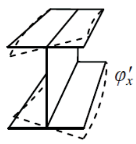
Translation in x, y and z	
Rotation about x-axis	
Rotation about y-axis (Major axis bending)	
Rotation about z-axis (Minor axis bending, lateral bending)	
Warping (see chapter 2.1.10)	

Figure 25. *Degrees of freedom of the end of an element (Ahnlén & Westlund 2013).*

The values of the effective length factors k_z ja k_ω may be 0.5, 0.7 or 1.0, depending on the degree of freedoms of the element (Ongelin & Valkonen 2010). Table 7 shows the degree of freedoms and the effective length factors for both ends of an element. Symbol x describes that the degree of freedom as being fixed and the empty cell means it is freed. The table has symbols from LTBeam following the equality sign.

Table 7. *Effective length factors for lateral torsional buckling, adapted from an original source (Ongelin & Valkonen 2010).*

k_z	$u_y = v$		$\varphi_z = v'$	
0.5	x	x	x	x
0.7	x	x	x	
1.0	x	x		

k_ω	$\varphi_x = \theta$		$\omega = \theta'$	
0.5	x	x	x	x
0.7	x	x	x	
1.0	x	x		

5.3.2 Bending and axial force

Karamba simplifies the moment diagram for the moment factors C_{my}, C_{mz}, C_{mLT} leading the variations to lie between 0.9 and 1.0. According to Eurocode 3 (2005), Annex B these factors should be used $C_{my} = 0.9$ or $C_{mz} = 0.9$ for members with sway buckling mode. No requirements are stated the factor C_{mLT}. These exact values are for the second order analysis where the change of structural behaviour caused by deformations need to be taken into account according to the chapter 5.2.1 in Eurocode 3. If the impact of deformations can be disregarded, the first order analysis may be used. This condition may apply, if the following criterion is fulfilled

$$\alpha_{cr} = \frac{F_{cr}}{F_{Ed}} \geq 10 \text{ for elastic analysis} \tag{3}$$

$$\alpha_{cr} = \frac{F_{cr}}{F_{Ed}} \geq 15 \text{ for plastic analysis} \tag{4}$$

where α_{cr} is the factor by which the design loading would have to be increased to cause elastic instability in a global mode, F_{Ed} is the design loading on the structure, F_{cr} is the elastic critical buckling load for global instability mode based on initial elastic stiffnesses. When the first order analysis is used the moment diagram factors C_{my}, C_{mz}, C_{mLT} are calculated according to the Annex A or B in Eurocode 3 and in Annex B their values varies from 0.4 to 1.0. (SFS-EN 1993-1-1 2005)

5.3.3 Buckling length

Buckling lengths can be defined so that the effective length equals to $L_e = KL$ where K is the effective length factor and L is the length of the beam. The buckling lengths defined by Karamba are colorfully presented in Figure 26. The color code is as follows: black means $K = 1.0$, green means $K = 2.0$ and red means $K = 6.0$. The buckling lengths are the same for the y-axis, z-axis and lateral torsional buckling.

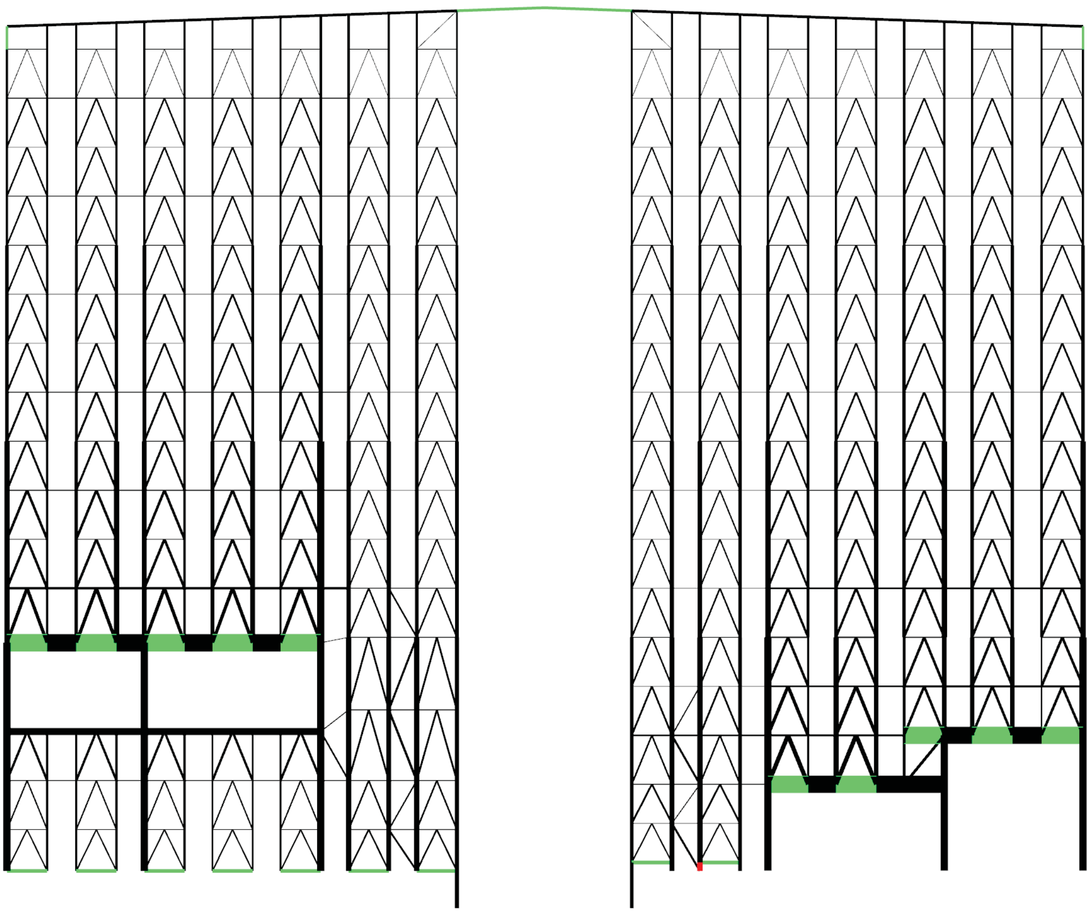


Figure 26. *Buckling lengths according to Karamba. Effective length factor K for buckling lengths is defined so that black means $K = 1.0$, green means $K = 2.0$ and the red one means $K = 6.0$.*

Almost all the buckling length factors are $K = 1.0$. The green ones where the factor is $K = 2.0$ should be combined to set of members in RFEM but it has not been done in the case study. There is one element which has factor $K = 6.0$.

Karamba's definition of buckling length does not consider the stiffness of the bracing. The correct approach would be to take the effective length as the distance between two adjacent point of contraflexure which equals to the distance between two adjacent point of zero moment. The distance is measured taken only the compressive force into account and excluding the transverse load since the buckling length does not depend on it. (Hibbeler 2003; Jalkanen & Mikkola 2011)

An example of buckling lengths is given in Figure 27. The column is braced about the weaker axis y-y in its midheight by struts which are assumed to be pin-connected. The ends of the column have fixed supports. The buckling length about the x-x axis is now $L_e = 0.5L$ and about the y-y axis $L_e = 0.7\frac{L}{2}$, where L equals to the total length of the column.

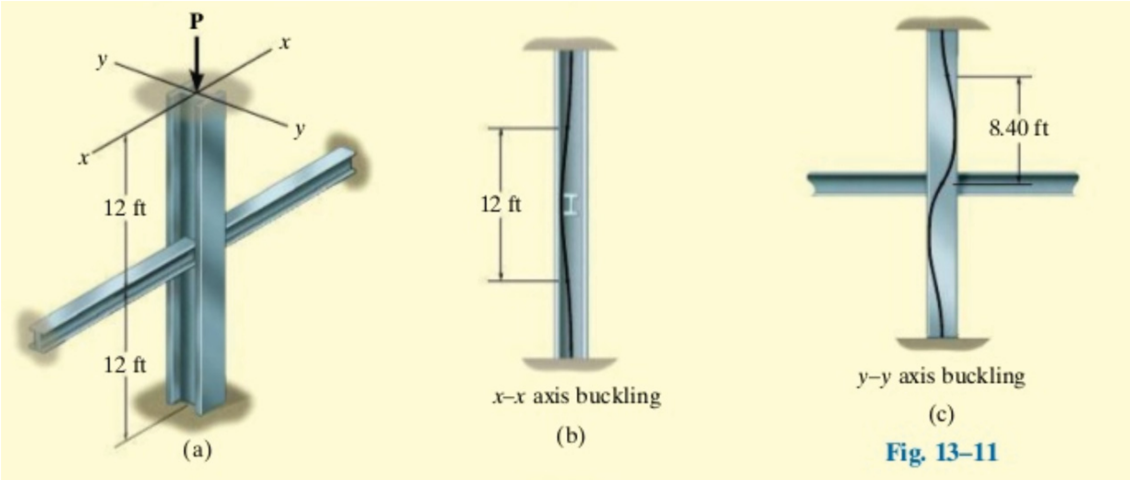


Figure 27. *Buckling lengths under axial compression, adapted from an original source (Hibbeler 2003).*

The theoretical buckling lengths are shown in Figure 28.

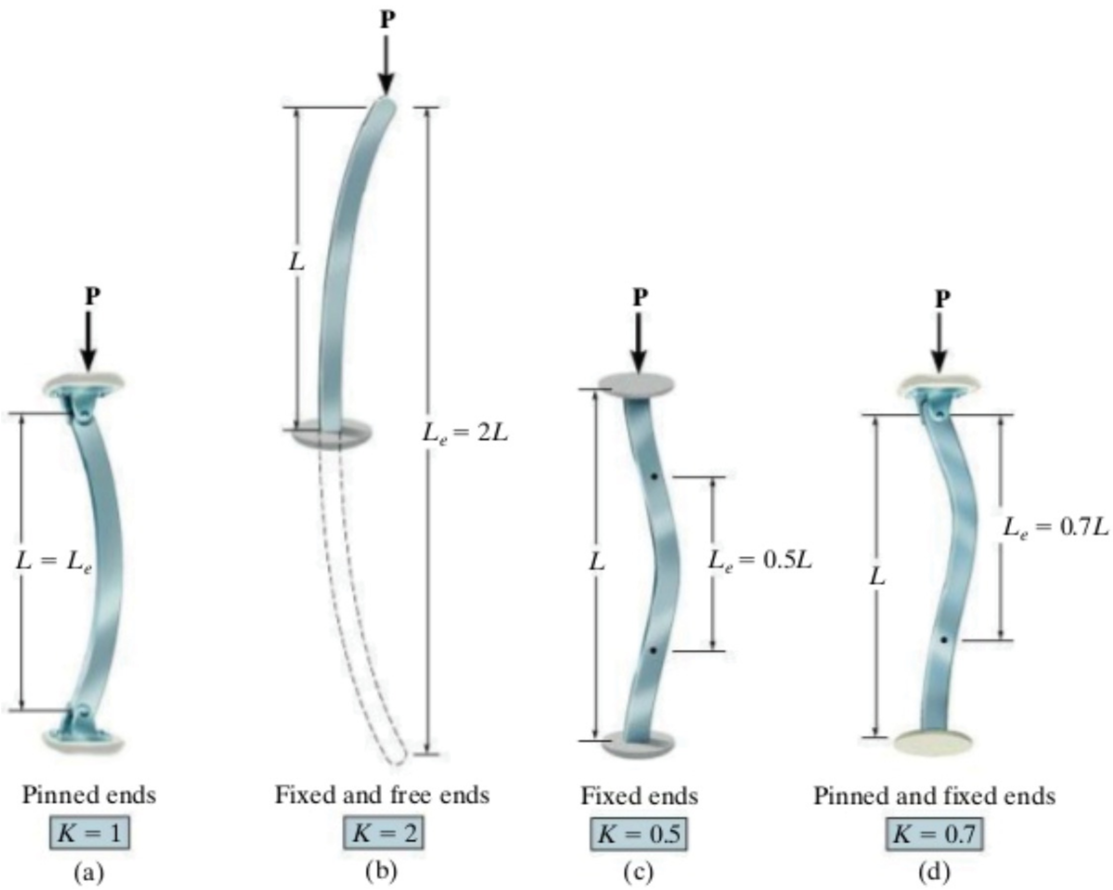


Figure 28. *Theoretical buckling lengths, adapted from an original source (Hibbeler 2003).*

The buckling lengths can be defined by stability analysis which defines the buckling lengths. RF-STABILITY is a module for RFEM that performs eigenvalue analysis and gives the effective lengths.

5.4 Summary

The limitations and simplifications of Karamba has were identified during the pre-study which helped understanding the differences in the utilization rates of the warehouse building. The results of Karamba in structural design of steel are promising since the design was so close to RFEM. However, it need to be take into consideration that the design was done using first order theory and the system length was used as a buckling length for the elements.

The actual model was designed with a result combination which goes through all the load combinations while in Karamba only one combination was calculated. Therefore the results between actual design and algorithm-aided design cannot be compared directly, nevertheless, the results of the selected load combination can be compared between the programs.

6 CONCLUSIONS

The main aims of the thesis were to examine the possibilities of algorithm-aided structural design in steel-framed warehouses and to examine the reliability of Karamba's components in structural design. Further, the parametrization of a particular type of building was to be ascertained in order to program an algorithm which can automatically create a customised structure for analysis. The thesis showed that it is possible to have the modelling and the structural design done by an algorithm. The thesis also proved that the more repetitive the structure is, the faster the model can be created. Elements that are not repeated in the model are exceptions for the code and require extra effort which consequently slows down the entire programming.

The programmed algorithm can create automatically a customised structure for analysis according to the input data and it can be used for other similar warehouses. For simple warehouses algorithm-aided modelling and structural design works well, yet for other type of buildings more research is needed since the modelling might be the stumbling block. The modeling part is the most time-consuming task in the process, whereas the structural design requires less time to do regardless of the structure. Albeit, this requires that the model's elements are constructed to be easily accessible by identifying them for structural design.

Most of the time was needed to create the model by the algorithm. In this study it took approximately 200 hours. The used method turned out to be not the most efficient way by planning massive steps to finish the model. It would have been wiser to begin with creating a small functioning model and thereupon take smaller steps to ultimately reach the planned result. The used method cannot be tested easily until the entire model is ready, whereas the more efficient method can be tested at any given moment of the progress which helps to find mistakes faster and improve the algorithm. Also, the author's inexperience in creating the model with an algorithm was another time-adding factor. The most important and time-consuming task of the entire process was to identify the elements in order to easily access them, especially when individual elements are added to main code. Since the modelling of the warehouse and verification of Karamba took a lot of time and effort, the long side of the warehouse was not designed but modelled. The long side consists of elements that are susceptible to buckling. The structural design of the long side would have been an intricate task, therefore it was excluded from the thesis. The model created for the case study is not ready for professional use since only the short side of the warehouse was designed. Also, the utilization rate of several elements is too big seeing as the cross-section was not big enough. This problem could be solved for example by adding some extra support against the shear force or to exchange the cross-section with a different one.

Karamba's components are good for the first stage of structural design and, depending on the structures, the results may turn out very close to the actual design. The case study revealed the difference of the utilization rate lying between -0.02 and 0.06 for 95% of the elements when comparing Karamba to RFEM. During the course of this case study Karamba has proven to be an exceedingly reliable tool. It would have been fairly interesting to compare the cross-sections optimized by Karamba with the realized model which was priorly designed, but was impossible to exercise since Karamba does neither have load nor result combinations.

Karamba has close to endless project possibilities since algorithm-aided design can be extended to unlimited dimensions. It is regularly updated and there were more than twenty work in process releases within the last six months. The creator of Karamba is fast to react to repair bugs and errors that have been detected. Karamba's verification for the pre-study required a lot of time and effort and will presumably continue to do so in the future. The pre- and the case study were designed repeatedly due to the new releases that fixed the existing bugs. Some problems still remain in Karamba but many of them have already been fixed. Karamba's simplifications require detailed observation. However, it is a magnificent tool for algorithm-aided design. It offers efficient tools for first stage design, to what it has been designed. It also includes many features that were not used in the thesis but can be useful for structural design.

6.1 Further studies

The thesis was a facile research of algorithm-aided design. Despite its enormous potential, several changes and improvements need to be conducted before algorithm-aided structural design is suitable as an efficient everyday tool. The use of it has to happen gradually.

Karamba simplifies the design of lateral torsional buckling by using constant values for certain factors and it is not verified if its choices are on the safe side in every case. The fundamental moment factor C_1 is selected to be 1.0 in Karamba but can be less or more in reality. There are also the length factors k_z and k_ω which are chosen to be 1.0 in Karamba but can vary in reality. They influence the elastic critical moment, therefore lateral torsional buckling should be investigated more detailed. How should the length factors be selected when a beam is divided in multiple elements? Does the condition change in different parts of the beam so that it has an impact on these factors?

When a member is subjected to bending and compression moment factors C_{my}, C_{mz}, C_{mLT} are needed. According to Annex B in Eurocode 3 the values may vary from 0.4 to 1.0 and for sway buckling modes the factors C_{my} and C_{mz} should be 0.9. Karamba uses values from 0.9 to 1.0 for all the factors. Is Karamba's way correct or should it always use the value 0.9 to be on the safe side? Why does Eurocode 3 not state that C_{mLT} should also be 0.9 too? Is the value 0.9 enough for the swaying buckling modes such as Eurocode 3 instructs or should it vary from 0.9 to 1.0 like Karamba calculates?

It is interesting to learn about the ways how a beam can be divided into smaller elements since there are factors such as C_1 and C_{my}, C_{mz}, C_{mLT} that depend on the moment diagram and there are buckling lengths that are a fundamental part of the design. As an example there is a beam which has pinned supports at both ends and is subjected to bending and compression. If the beam consists of one element the buckling length is the length of the entire beam and the used moment diagram is the diagram of the entire beam. If the beam is divided into smaller elements, the buckling length still needs to be the length of the entire beam for every element. Also, the whole beam's moment diagram needs to be used for all the elements which have to be taken into account by creating set of members in RFEM. How should the moment diagram be taken into account if the beam has a pinned strut in its mid-length? Now the buckling length is half of the whole beam's length, so should the moment diagram consequently be taken only from half of the beam? Should the beam be divided in two elements or can it be designed as one? If it is divided in two elements, should them construct a set of members?

For the pre-study only the cross-section IPE200 was studied. Many more cross-sections need examining since the classification of the cross-sections was not quite correct for square hollow sections and HEB profiles in the case study.

The elements of the long side are susceptible to buckling and the determination of the buckling lengths was not done. How well will Karamba design these kind of structures?

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APPENDIX A: I-section design according to Eurocode 3

Prerequisites
- double symmetric I-profile
- cross-section classes 1, 2 and 3
- hot rolled profile
- materials S235, S275, S355

Limitations
- axial force is always in the shear centre
- no 6.2.7 Torsion
- no 6.2.8 (6) Bending, shear and transverse loads

Safety factors

$\gamma_{M0} := 1.0$ — Partial safety factor, resistance of cross-sections whatever the class is

$\gamma_{M1} := 1.0$ — Partial safety factor, resistance of members to instability assessed by member checks

Loads

$N_{Ed} := 40 \cdot kN$ — Design normal force (compression positive)

$M_{y.Ed} := 18.75 \cdot kN \cdot m$ — Design bending moment, stronger axis

$M_{z.Ed} := 0 \cdot kN \cdot m$ — Design bending moment, weaker axis

$F_{Ed.y} := 0\ kN$ — Design transverse force, weaker axis

$F_{Ed.z} := 0\ kN$ — Design transverse force, stronger axis

$V_{y.Ed} := 0 \cdot kN$ — Design shear force, weaker axis

$V_{z.Ed} := 7.5 \cdot kN$ — Design shear force, stronger axis

$T_{w.Ed} := 0\ kN \cdot m$ — Design value of internal warping torsion (estetty vääntö).

$T_{t.Ed} := 0\ kN \cdot m$ — Design value of internal St. Venant torsion (vapaa vääntö). As a simplification in the case of I or H section this can be neglected. 6.2.7 (7)

Material

$material := \text{"S355"}$ — Material name

$E = 21000.000\ \frac{kN}{cm^2}$ — Modulus of elasticity

$G = 8076.000\ \frac{kN}{cm^2}$ — Shear modulus

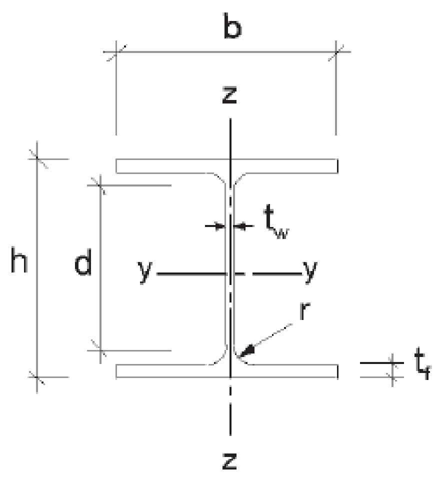
$\gamma = 78.500\ \frac{kN}{m^3}$ — Specific weight

$\alpha_T = \left(1.20 \cdot 10^{-5}\right)\ \frac{m}{m \cdot \Delta°C}$ — Coefficient of thermal expansion

$f_y = 35.500\ \frac{kN}{cm^2}$ — Yield strength

Cross-section

$profile := \text{“IPE200”}$	Profile name
$h = 200.000\ mm$	Section height
$b = 100.000\ mm$	Section width
$t_w = 5.600\ mm$	Web thickness
$t_f = 8.500\ mm$	Flange thickness
$r = 12.000\ mm$	Root radius
$z_s = 10.000\ cm$	Position of centroid
$A = 28.500\ cm^2$	Cross-sectional area
$A_{v.y} = 17.990\ cm^2$	Effective shear area
$A_{v.z} = 14.020\ cm^2$	Effective shear area
$I_y = 1940.000\ cm^4$	Moment of inertia
$W_{el.y} = 194.000\ cm^3$	Elastic section modulus
$W_{pl.y} = 220.000\ cm^3$	Plastic section modulus
$i_y = 8.260\ cm$	Radius of gyration
$I_z = 142.000\ cm^4$	Moment of inertia
$W_{el.z} = 28.500\ cm^3$	Elastic section modulus
$W_{pl.z} = 44.610\ cm^3$	Plastic section modulus
$i_z = 2.240\ cm$	Radius of gyration
$I_t = 7.020\ cm^4$	Torsional constant
$W_t = 8.260\ cm^3$	Elastic modulus of torsion
$I_w = 12990.000\ cm^6$	Warping constant of cross-section
$\alpha_y = 0.210$	Imperfection value for buckling (strong axis)
$\alpha_z = 0.340$	Imperfection value for buckling (weak axis)
$\alpha_{LT} = 0.340$	Imperfection value for lateral torsional buckling
$product = \text{“Rolled”}$	Type of product



Effective lengths

$L:=5\ m=5.000\ m$ Length

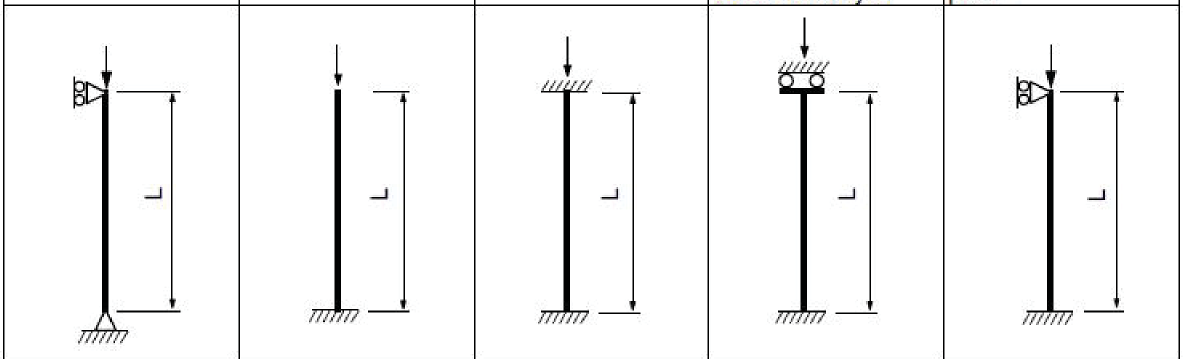
$L_{cr.y}:=5\ m=5.000\ m$ Effective buckling length axis Y

$L_{cr.z}:=5\ m=5.000\ m$ Effective buckling length axis Z

$L_{cr.LT}:=5\ m=5.000\ m$ Effective length, lateral torsional buckling

$L_{cr.T}:=5\ m=5.000\ m$ Effective length, torsional buckling

Taulukko 7.3 Pilareiden teoreettisia nurjahduspituuksia perustapauksille

Molemmista päistä nivelöity pilari	Toisesta päästä jäykästi kiinnitetty pilari	Molemmista päistä jäykästi kiinnitetty pilari	Molemmista päistä jäykästi kiinnitetty pilari, toinen kiinnityskohta sivusiirtyvä	Toisesta päästä jäykästi kiinnitetty ja toisesta päästä nivelöity pilari
				
L_{cr} = 1,0 L	L_{cr} = 2,0 L	L_{cr} = 0,5 L	L_{cr} = 1,0 L	L_{cr} = 0,7 L

Ruukki Hitsatut profiilit käsikirja 2010: 7.3.2.4 Kehän kimmoteprian mukainen mitoitus, Taulukko 7.3

Class of cross-section

3.2.3 Fracture toughness

$$f_y(t) := \begin{array}{l} \text{if } t > 40\ mm \\ \quad f_{y\_modified} \leftarrow 1\ MPa \\ \text{else} \\ \quad f_{y\_modified} \leftarrow f_y \\ \text{return } f_{y\_modified} \end{array}$$

$f_y(t_w) = 355.000\ MPa$ — Yield Strength of web, modified according to nominal thickness, $t > 40\ mm$ is not supported here.

$f_y(t_f) = 355.000\ MPa$ — Yield Strength of flange, modified according to nominal thickness, $t > 40\ mm$ is not supported here.

5.6 Cross-section requirements for plastic global analysis

Web

$$\varepsilon(t) := \sqrt{\frac{235}{f_y(t) \cdot \frac{1}{MPa}}}$$ Coefficient depending on f_y

$c_w := h - 2\ t_f - 2\ r = 159.000\ mm$ — Web specific width

$\varepsilon(t_w) = 0.814$ — Coefficient depending on f_y

$ct_w := \frac{c_w}{t_w} = 28.393$ — $\frac{c}{t}$ ratio

$\sigma_{1.w} := \frac{N_{Ed}}{A} + \frac{M_{y.Ed}}{I_y} \cdot (z_s - t_f - r) = 90.871\ MPa$ — Stress at web 1. end

$\sigma_{2.w} := \frac{N_{Ed}}{A} - \frac{M_{y.Ed}}{I_y} \cdot (h - t_f - r - z_s) = -62.801\ MPa$ — Stress at web 2. end

$\sigma_{max.w} := \max(\sigma_{1.w}, \sigma_{2.w}) = 90.871\ MPa$ — Web's maximum stress

$\sigma_{min.w} := min(\sigma_{1.w}, \sigma_{2.w}) = -62.801\ MPa$ — Web's minimum stress

$$stress_w := \begin{array}{l} \text{if } \sigma_{1.w} \le 0\ MPa \land \sigma_{2.w} \le 0 \\ \quad \text{"Tension"} \\ \text{else} \\ \quad \text{"Compression"} \end{array} = \text{"Compression"}$$ Stress

$$\alpha_w := \begin{array}{l} \text{if } stress_w = \text{"Tension"} \\ \quad \text{"Tension"} \\ \text{else if } \sigma_{1.w} \ne \sigma_{2.w} \\ \quad min\left(\frac{\sigma_{max.w}}{\sigma_{max.w} - \sigma_{min.w}}, 1\right) \\ \text{else} \\ \quad 1 \end{array} = 0.591$$ Compression ratio

$$\psi_w := \begin{array}{l} \text{if } stress_w = \text{"Tension"} \\ \quad \text{"Tension"} \\ \text{else} \\ \quad \frac{\sigma_{min.w}}{\sigma_{max.w}} \end{array} = -0.691$$ Stress ratio

$$\begin{bmatrix}\lambda_{1.w}\\ \lambda_{2.w}\\ \lambda_{3.w}\end{bmatrix} := \text{if } stress_w = \text{"Tension"}$$

$$\quad \begin{bmatrix}\text{"Tension"}\\ \text{"Tension"}\\ \text{"Tension"}\end{bmatrix}$$

$$\text{else if } \alpha_w > 0.5$$

$$\quad \text{if } \psi_w > -1$$

$$\quad\quad \lambda_{3.w} \leftarrow \frac{42\ \varepsilon\left(t_w\right)}{0.67 + 0.33\ \psi_w}$$

$$\quad \text{else if } \psi_w \le -1$$

$$\quad\quad \lambda_{3.w} \leftarrow 62\ \varepsilon\left(t_w\right) \cdot \left(1 - \psi_w\right) \cdot \sqrt{-\psi_w}$$

$$\quad \begin{bmatrix}\dfrac{396\ \varepsilon\left(t_w\right)}{13\ \alpha_w - 1}\\ \dfrac{456\ \varepsilon\left(t_w\right)}{13\ \alpha_w - 1}\\ \lambda_{3.w}\end{bmatrix}$$

$$\text{else}$$

$$\quad \text{if } \psi_w > -1$$

$$\quad\quad \lambda_{3.w} \leftarrow \frac{42\ \varepsilon\left(t_w\right)}{0.67 + 0.33\ \psi_w}$$

$$\quad \text{else if } \psi_w \le -1$$

$$\quad\quad \lambda_{3.w} \leftarrow 62\ \varepsilon\left(t_w\right) \cdot \left(1 - \psi_w\right) \cdot \sqrt{-\psi_w}$$

$$\quad \begin{bmatrix}\dfrac{36\ \varepsilon\left(t_w\right)}{\alpha_w}\\ \dfrac{41.5\ \varepsilon\left(t_w\right)}{\alpha_w}\\ \lambda_{3.w}\end{bmatrix}$$

$$\begin{bmatrix}\lambda_{1.w}\\ \lambda_{2.w}\\ \lambda_{3.w}\end{bmatrix} = \begin{bmatrix}48.180\\ 55.480\\ 77.323\end{bmatrix}$$

$\dfrac{c}{t}$ ratio limits

$$Class\_Web := \text{if } stress_w = \text{"Tension"} \quad = 1.000$$

$$\quad 0$$

$$\text{else if } ct_w \le \lambda_{1.w}$$

$$\quad 1$$

$$\text{else if } ct_w \le \lambda_{2.w}$$

$$\quad 2$$

$$\text{else if } ct_w \le \lambda_{3.w}$$

$$\quad 3$$

$$\text{else}$$

$$\quad 4$$

Class of web

Flange

$$c_f := \frac{b - t_w - 2\ r}{2} = 35.200\ mm$$ Flange specific width

$$\varepsilon\left(t_f\right) = 0.814$$ Coefficient depending on f_y

$$ct_f := \frac{\frac{b}{2} - \frac{t_w}{2} - r}{t_f} = 4.141$$ $\frac{c}{t}$ ratio

$$\sigma_{1.f} := \frac{N_{Ed}}{A} + \frac{\left|M_{y.Ed}\right|}{I_y} \cdot \left(z_s - \frac{t_f}{2}\right) + \frac{\left|M_{z.Ed}\right|}{I_z} \cdot \frac{b}{2} = 106.577\ MPa$$ Stress at flange's outermost point

$$\sigma_{2.f} := \frac{N_{Ed}}{A} + \frac{\left|M_{y.Ed}\right|}{I_y} \cdot \left(z_s - \frac{t_f}{2}\right) + \frac{\left|M_{z.Ed}\right|}{I_z} \cdot \left(\frac{t_w}{2} + r\right) = 106.577\ MPa$$ Stress at flange near web

$$\sigma_{max.f} := \max\left(\sigma_{1.f}, \sigma_{2.f}\right) = 106.577\ MPa$$ Flange's maximum stress

$$\sigma_{min.f} := min\left(\sigma_{1.f}, \sigma_{2.f}\right) = 106.577\ MPa$$ Flange's minimum stress

$$stress_f := \begin{array}{l} \text{if } \sigma_{1.f} \le 0\ MPa \wedge \sigma_{2.f} \le 0 \\ \quad \| \text{"Tension"} \\ \text{else} \\ \quad \| \text{"Compression"} \end{array} = \text{"Compression"}$$ Stress

$$\alpha_f := \begin{array}{l} \text{if } stress_f = \text{"Tension"} \\ \quad \| \text{"Tension"} \\ \text{else if } \sigma_{1.f} \ne \sigma_{2.f} \\ \quad \| min\left(\frac{\sigma_{max.f}}{\sigma_{max.f} - \sigma_{min.f}}, 1\right) \\ \text{else} \\ \quad \| 1 \end{array} = 1.000$$ Compression ratio

$$\begin{bmatrix} \lambda_{1.f} \\ \lambda_{2.f} \\ \lambda_{3.f} \end{bmatrix} := \begin{array}{l} \text{if } stress_f = \text{"Tension"} \\ \quad \left\| \begin{bmatrix} \text{"Tension"} \\ \text{"Tension"} \\ \text{"Tension"} \end{bmatrix} \right. \\ \text{else} \\ \quad \left\| \begin{bmatrix} \frac{9\ \varepsilon\left(t_f\right)}{\alpha_f} \\ \frac{10\ \varepsilon\left(t_f\right)}{\alpha_f} \\ \frac{14\ \varepsilon\left(t_f\right)}{\alpha_f} \end{bmatrix} \right. \end{array} = \begin{bmatrix} 7.323 \\ 8.136 \\ 11.391 \end{bmatrix}$$ $\frac{c}{t}$ ratio limits

$Class\_Flange := \text{if } stress_f = \text{"Tension"}$ $= 1.000$ Class of flange

$\quad 0$

$\text{else if } ct_f \le \lambda_{1.f}$

$\quad 1$

$\text{else if } ct_f \le \lambda_{2.f}$

$\quad 2$

$\text{else if } ct_f \le \lambda_{3.f}$

$\quad 3$

else

$\quad 4$

$Class\_Web = 1.000$

$Class\_Flange = 1.000$

$Class := \max\left(Class\_Web, Class\_Flange\right) = 1$

$W_y :=$ $\text{if } Class \le 2$ $= 220.000\ cm^3$ Section modulus

$\quad W_{pl.y}$

$\text{else if } Class = 3$

$\quad W_{el.y}$

else

$\quad \text{"Class 4"}$

$W_z :=$ $\text{if } Class \le 2$ $= 44.610\ cm^3$ Section modulus

$\quad W_{pl.z}$

$\text{else if } Class = 3$

$\quad W_{el.z}$

else

$\quad \text{"Class 4"}$

Design resistances

6.2.3 Tension

$$N_{pl.Rd} := \frac{A \cdot f_y\left(\max\left(t_w, t_f\right)\right)}{\gamma_{M0}} = 1011.750\ kN$$

Design plastic resistance to normal force

$$N_{t.Rd} := N_{pl.Rd} = 1011.750\ kN$$

Design tension resistance

6.2.4 Compression

$$N_{c.Rd} := N_{pl.Rd} = 1011.750\ kN$$

Design compression resistance for class 1, 2 or 3

6.2.5 Bending moment

$$M_{pl.y.Rd} := \frac{W_{pl.y} \cdot f_y\left(\max\left(t_w, t_f\right)\right)}{\gamma_{M0}} = 78.100\ kN \cdot m$$

Design plastic resistance for bending for class 1 or 2

$$M_{pl.z.Rd} := \frac{W_{pl.z} \cdot f_y\left(\max\left(t_w, t_f\right)\right)}{\gamma_{M0}} = 15.837\ kN \cdot m$$

Design plastic resistance for bending for class 1 or 2

$$M_{el.y.Rd} := \frac{W_{el.y} \cdot f_y\left(\max\left(t_w, t_f\right)\right)}{\gamma_{M0}} = 68.870\ kN \cdot m$$

Design elastic resistance for bending for class 3

$$M_{el.z.Rd} := \frac{W_{el.z} \cdot f_y\left(\max\left(t_w, t_f\right)\right)}{\gamma_{M0}} = 10.118\ kN \cdot m$$

Design elastic resistance for bending for class 3

$$M_{c.y.Rd} := \begin{array}{l} \text{if } Class \le 2 \\ \quad M_{pl.y.Rd} \\ \text{else if } Class = 3 \\ \quad M_{el.y.Rd} \\ \text{else} \\ \quad \text{“Class 4”} \end{array} = 78.100\ kN \cdot m$$

Design resistance for bending

$$M_{c.z.Rd} := \begin{array}{l} \text{if } Class \le 2 \\ \quad M_{pl.z.Rd} \\ \text{else if } Class = 3 \\ \quad M_{el.z.Rd} \\ \text{else} \\ \quad \text{“Class 4”} \end{array} = 15.837\ kN \cdot m$$

Design resistance for bending

6.2.6 Shear

$$V_{pl.y.Rd} := \frac{A_{v.y} \cdot \left(\frac{f_y\left(\max\left(t_w, t_f\right)\right)}{\sqrt{3}}\right)}{\gamma_{M0}} = 368.722\ kN$$

Design plastic shear resistance

$$V_{pl.z.Rd} := \frac{A_{v.z} \cdot \left(\frac{f_y\left(\max\left(t_w, t_f\right)\right)}{\sqrt{3}}\right)}{\gamma_{M0}} = 287.353\ kN$$

Design plastic shear resistance

$$V_{c.y.Rd} := V_{pl.y.Rd} = 368.722\ kN$$

Design shear resistance

$$V_{c.z.Rd} := V_{pl.z.Rd} = 287.353\ kN$$

Design shear resistance

6.2.7 Torsion, not implemented

6.2.7 (7) The effects of shear stresses (vapaa vääntö) $\tau_{t.Ed}$ due to St. Venant torsion $T_{t.Ed}$ can be neglected. Torsional warping $T_{w.Ed}$ (estetty vääntö) is used.

Formulas below are from Ruukki Hitsatut profiilit käsikirja 2010.
http://software.ruukki.com/Handbooks+and+Guides/Ruukki-Hitsatut-Profiilit-Kasikirja-2010_PDF-versio.pdf

$$kL := L \cdot \sqrt{\frac{G \cdot I_t}{E \cdot I_w}} = 7.208$$

```
torsion := if kL > 15
               "St. Venant torsion"
           else if kL ≤ 0.7
               "Warping torsion"
           else if 0.7 < kL ≤ 15
               "St. Venant torsion and Warping torsion"
```

$torsion =$ "St. Venant torsion and Warping torsion"

$$r_t := \frac{(h - t_f)}{2} = 95.750\ mm$$ Length

$$s := \frac{b}{2} = 50.000\ mm$$ Length

$$\omega := r_t \cdot \frac{s}{2} \cdot 2 = 47.875\ cm^2$$ Sectoral coordinate

$$S_\omega := \frac{1}{2} \cdot r_t \cdot s^2 \cdot t_f = 101.734\ cm^4$$ Sectoral statical moment

$$\tau_{t.Ed} := \frac{T_{t.Ed}}{I_t} \cdot t_f = 0.000\ \frac{kN}{cm^2}$$ Design shear stress due to St. Venant torsion (vapaa vääntö).

$$\tau_{w.Ed} := \frac{T_{w.Ed}}{I_w \cdot t_f} \cdot S_\omega = 0.000\ \frac{kN}{cm^2}$$ Design shear stress due to warping torsion (estetty vääntö).

$$\tau_{Rd} := \frac{\frac{f_y(\max(t_w, t_f))}{\sqrt{3}}}{\gamma_{M0}} = 20.496\ \frac{kN}{cm^2}$$ Design shear stress resistance

$$V_{pl.y.T.Rd} := \sqrt{1 - \frac{\tau_{t.Ed}}{1.25 \cdot \tau_{Rd}}} \cdot V_{pl.y.Rd} = 368.722\ kN$$ Reduced design plastic shear resistance making allowance for the presence of a torsional moment

$$V_{pl.z.T.Rd} := \sqrt{1 - \frac{\tau_{t.Ed}}{1.25 \cdot \tau_{Rd}}} \cdot V_{pl.z.Rd} = 287.353\ kN$$ Reduced design plastic shear resistance making allowance for the presence of a torsional moment

6.2.8 Bending and shear

EC-1-5: 5.1 Resistance to shear (leikkauslommahduskestävyys)

This apllies for unstiffened web

$h_w := h - 2\ t_f = 183.000\ mm$ Clear web depth between flanges

$t_w = 5.600\ mm$ Thickness of the plate

$\eta_w := 1.2$ Coefficient

$\varepsilon_w := \sqrt{\dfrac{235\ MPa}{f_y\left(\max\left(t_w, t_f\right)\right)}} = 0.814$ Coefficient

$$\frac{h_w}{t_w} = 32.679$$

$$\frac{72}{\eta_w}\ \varepsilon_w = 48.817$$

$$\frac{h_w}{t_w} < \frac{72}{\eta_w}\ \varepsilon_w = 1.000$$

$$Check\_Shear\_Buckling := \begin{array}{l} \text{if } \dfrac{h_w}{t_w} < \dfrac{72}{\eta_w}\ \varepsilon_w \\ \quad \| \ result \leftarrow \text{“False”} \\ \text{else} \\ \quad \| \ result \leftarrow \text{“True”} \end{array} = \text{“False”}$$

$$\rho_y := \left(\frac{2\ V_{y.Ed}}{V_{pl.y.Rd}} - 1\right)^2 = 1.000$$

Reduction factor to determine reduced design values of the resistance to bending moments making allowance for the presence of shear forces.

$$\rho_z := \left(\frac{2\ V_{z.Ed}}{V_{pl.z.Rd}} - 1\right)^2 = 0.898$$

$$\rho_y := \begin{array}{l} \text{if } T_{w.Ed} \neq 0 \lor T_{t.Ed} \neq 0 \\ \quad \| \ \text{if } V_{y.Ed} \leq V_{pl.y.T.Rd} \\ \quad \| \quad \| \ \rho \leftarrow 0 \\ \quad \| \ \text{else if } V_{y.Ed} > V_{pl.y.T.Rd} \\ \quad \| \quad \| \ \rho \leftarrow \left(\dfrac{2\ V_{y.Ed}}{V_{pl.y.T.Rd}} - 1\right)^2 \\ \text{else} \\ \quad \| \ \rho_y \end{array} = 1.000$$

Reduction factor taking torsion into account.

$$\rho_z := \text{if } T_{w.Ed} \neq 0 \lor T_{t.Ed} \neq 0 \; \begin{cases} \text{if } V_{z.Ed} \leq V_{pl.z.T.Rd} \\ \quad \rho \leftarrow 0 \\ \text{else if } V_{z.Ed} > V_{pl.z.T.Rd} \\ \quad \rho \leftarrow \left(\frac{2\, V_{z.Ed}}{V_{pl.z.T.Rd}} - 1 \right)^2 \end{cases} \text{ else } \rho_z \; = 0.898$$

Reduction factor taking torsion into account.

$A_w := h_w \cdot t_w = 10.248\ cm^2$ — Web area

$A_f := 2\ b \cdot t_f = 17.000\ cm^2$ — Flanges area

$$M_{V.y.Rd} := \text{if } Check\_Shear\_Buckling = \text{"False"} \; \begin{cases} \text{if } \frac{V_{z.Ed}}{V_{pl.z.Rd}} < 0.5 \\ \quad \text{return } M_{c.y.Rd} \\ \text{else} \\ \quad \text{return } \frac{\left(W_{pl.y} - \frac{\rho_z \cdot {A_w}^2}{4\, t_w} \right) \cdot f_y\left(\max\left(t_w, t_f\right)\right)}{\gamma_{M0}} \end{cases} \text{ else return "ERROR"}$$

$M_{V.y.Rd} = 78.100\ kN \cdot m$ — Reduced design value of the resistance to bending moments making allowance for the presence of shear forces

$$M_{V.z.Rd} := \text{if } Check\_Shear\_Buckling = \text{"False"} \; \begin{cases} \text{if } \frac{V_{y.Ed}}{V_{pl.y.Rd}} < 0.5 \\ \quad \text{return } M_{c.z.Rd} \\ \text{else} \\ \quad \text{return } \frac{\left(W_{pl.z} - \frac{\rho_y \cdot \left(b \cdot t_f\right)^2}{2\, t_f} \right) \cdot f_y\left(\max\left(t_w, t_f\right)\right)}{\gamma_{M0}} \end{cases} \text{ else return "ERROR"}$$

$M_{V.z.Rd} = 15.837\ kN \cdot m$ — Reduced design value of the resistance to bending moments making allowance for the presence of shear forces

$\alpha := 2$ — Parameter introducing the effect of biaxial bending, Ruukki Hitsatut profiilit käsikirja

$\beta := 1$ — Parameter introducing the effect of biaxial bending, Ruukki Hitsatut profiilit käsikirja

$$\left(\frac{M_{y.Ed}}{M_{V.y.Rd}} \right)^{\alpha} + \left(\frac{M_{z.Ed}}{M_{V.z.Rd}} \right)^{\beta} = 0.058$$

Utilization (design plastic) of bi-axial bending, Ruukki Hitsatut profiilit käsikirja

6.2.8 (6) Bending, shear and transverse loads EC3-1-5: 7, not implemented

6.2.9 Bending and axial force

Class 1 and 2 cross-sections

$n := \frac{|N_{Ed}|}{N_{pl.Rd}} = 0.040$ — Formula 6.38

$a := min\left(\frac{A - 2 \cdot b \cdot t_f}{A}, 0.5\right) = 0.404$ — Formula 6.38

$A_w := h_w \cdot t_w = 1024.800\ mm^2$

$$M_{N.y.Rd} := \text{if } |N_{Ed}| \le 0.25\ N_{pl.Rd} \wedge |N_{Ed}| \le \frac{0.5 \cdot A_w \cdot f_y(t_w)}{\gamma_{M0}}$$

$$\quad \text{return } M_{c.y.Rd}$$

$$\text{else}$$

$$\quad \text{return } min\left(M_{pl.y.Rd}, M_{pl.y.Rd} \cdot \frac{1-n}{1-0.5 \cdot a}\right)$$

$M_{N.y.Rd} = 78.100\ kN \cdot m$ — Design plastic moment resistance reduced due to the axial force N_{Ed}

$$M_{N.z.Rd} := \text{if } |N_{Ed}| \le \frac{A_w \cdot f_y(t_w)}{\gamma_{M0}}$$

$$\quad \text{return } M_{c.z.Rd}$$

$$\text{else}$$

$$\quad \text{if } n \le a$$

$$\qquad \text{return } M_{pl.z.Rd}$$

$$\quad \text{else if } n > a$$

$$\qquad \text{return } M_{pl.z.Rd} \cdot \left(1 - \left(\frac{n-a}{1-a}\right)^2\right)$$

$M_{N.z.Rd} = 15.837\ kN \cdot m$ — Design plastic moment resistance reduced due to the axial force N_{Ed}

$\alpha := 2$ — Parameter introducing the effect of biaxial bending

$\beta := \max(5\ n, 1) = 1.000$ — Parameter introducing the effect of biaxial bending

$\left(\frac{M_{y.Ed}}{M_{N.y.Rd}}\right)^{\alpha} + \left(\frac{M_{z.Ed}}{M_{N.z.Rd}}\right)^{\beta} = 0.058$ — Utilization (design plastic) of bi-axial bending, class 1 and 2

$\frac{M_{y.Ed}}{M_{N.y.Rd}} = 0.240$

$\frac{M_{z.Ed}}{M_{N.z.Rd}} = 0.000$

6.2.10 Bending, shear and axial force

$A_{tot.red.y} := A - 2\ \rho_z \cdot h_w \cdot t_w = 1008.796\ mm^2$

$A_{w.red} := 2 \cdot (1 - \rho_z) \cdot h_w \cdot t_w = 208.396\ mm^2$

$N_{V.Rd.y} := A_{tot.red.y} \cdot \frac{f_y(t_w)}{\gamma_{M0}} = 358.122\ kN$

Reduced normal force

$a_{V.y} := min\left(\frac{A_{w.red}}{A_{tot.red.y}}, 0.5\right) = 0.207$

$n_{V.y} := \frac{N_{Ed}}{N_{V.Rd.y}} = 0.112$

$M_{V.N.y.Rd} :=$ if $Check\_Shear\_Buckling =$ "False"

- if $\frac{V_{y.Ed}}{V_{pl.y.Rd}} < 0.5$
  - return $M_{N.y.Rd}$
- else
  - if $|N_{Ed}| \le 0.25\ N_{pl.Rd} \wedge |N_{Ed}| \le \frac{0.5 \cdot h_w \cdot t_w \cdot f_y(t_w)}{\gamma_{M0}}$
    - return $M_{V.y.Rd}$
  - else
    - return $min\left(M_{V.y.Rd}, M_{V.y.Rd} \cdot \frac{1 - n_{V.y}}{1 - 0.5\ a_{V.y}}\right)$

else

- return "ERROR"

$M_{V.N.y.Rd} = 78.100\ kN \cdot m$

Reduced design value of the resistance to bending moments making allowance for the presence of shear forces

$A_{tot.red.z} := A - 2\ \rho_y \cdot b \cdot t_f = 1150.000\ mm^2$

$A_{f.red} := 2 \cdot (1 - \rho_y) \cdot b \cdot t_f = 0.000\ mm^2$

$N_{V.Rd.z} := A_{tot.red.z} \cdot \frac{f_y(t_w)}{\gamma_{M0}} = 408.250\ kN$

Reduced normal force

$a_{V.z} := min\left(\frac{A_{f.red}}{A_{tot.red.z}}, 0.5\right) = 0.000$

$n_{V.z} := \frac{N_{Ed}}{N_{V.Rd.z}} = 0.098$

$M_{V.N.z.Rd} :=$ if $Check\_Shear\_Buckling =$ "False"

```
    if V_z.Ed / V_pl.z.Rd < 0.5
        return M_N.z.Rd
    else
        if |N_Ed| ≤ A_w · f_y(t_w) / γ_M0
            return M_V.z.Rd
        else
            return M_V.z.Rd · (1 − ((n_V.z − a_V.z) / (1 − a_V.z))^2)
else
    return "ERROR"
```

$M_{V.N.z.Rd} = 15.837\ kN \cdot m$

Reduced design value of the resistance to bending moments making allowance for the presence of shear forces

$\left(\frac{M_{y.Ed}}{M_{V.N.y.Rd}}\right)^{\alpha} + \left(\frac{M_{z.Ed}}{M_{V.N.z.Rd}}\right)^{\beta} = 0.058$

Utilization (design plastic) of bi-axial bending, class 1 and 2

$\frac{M_{y.Ed}}{M_{V.N.y.Rd}} = 0.240$

$\frac{M_{z.Ed}}{M_{V.N.z.Rd}} = 0.000$

6.3 Buckling resistance of members
6.3.1 Uniform members in compression

$$N_{cr.y} := \frac{E \cdot I_y \cdot \pi^2}{L_{cr.y}^{\ 2}} = 1608.351\ kN$$

Elastic critical force for the relevant buckling mode based on the gross cross sectional properties

$$N_{cr.z} := \frac{E \cdot I_z \cdot \pi^2}{L_{cr.z}^{\ 2}} = 117.725\ kN$$

Ruukki Hitsatut profiilit käsikirja 2010: 2.6.3 Nurjahduskestävyys, formula 2.38

$$\lambda_y := \sqrt{\frac{A \cdot f_y\left(\max\left(t_w, t_f\right)\right)}{N_{cr.y}}} = 0.793$$

Non-dimensional slenderness for flexural bending (taivutusnurjahdus)

$$\lambda_z := \sqrt{\frac{A \cdot f_y\left(\max\left(t_w, t_f\right)\right)}{N_{cr.z}}} = 2.932$$

Non-dimensional slenderness for flexural bending (taivutusnurjahdus)

Table 6.2: Selection of buckling curve for a cross section

```
[bc_yy; bc_zz] := if f_y(max(t_w, t_f)) ≤ 420 MPa
    if h/b > 1.2
        if t_f ≤ 40·mm
            bc_yy ← "a"
            bc_zz ← "b"
        else if 40·mm < t_f ≤ 100 mm
            bc_yy ← "b"
            bc_zz ← "c"
    else if h/b ≤ 1.2
        if t_f ≤ 100·mm
            bc_yy ← "b"
            bc_zz ← "c"
        else if t_f > 100 mm
            bc_yy ← "d"
            bc_zz ← "d"
    [bc_yy; bc_zz]
```

$bc_{yy} = \text{“a”}$ Buckling curve, stronger axis

$bc_{zz} = \text{“b”}$ Buckling curve, weaker axis

Table 6.1: Imperfection factors for buckling curves

$$\alpha_{imp}(bc) := \begin{cases} \text{if } bc = \text{"a0"} \\ \quad 0.13 \\ \text{else if } bc = \text{"a"} \\ \quad 0.21 \\ \text{else if } bc = \text{"b"} \\ \quad 0.34 \\ \text{else if } bc = \text{"c"} \\ \quad 0.49 \\ \text{else if } bc = \text{"d"} \\ \quad 0.76 \end{cases}$$

$\alpha_y := \alpha_{imp}(bc_{yy}) = 0.210$ Imperfection factor, stronger axis

$\alpha_z := \alpha_{imp}(bc_{zz}) = 0.340$ Imperfection factor, weaker axis

$\Phi_y := 0.5 \cdot \left(1 + \alpha_y \cdot (\lambda_y - 0.2) + {\lambda_y}^2\right) = 0.877$ Value to determine the reduction factor χ

$\Phi_z := 0.5 \cdot \left(1 + \alpha_z \cdot (\lambda_z - 0.2) + {\lambda_z}^2\right) = 5.261$ Value to determine the reduction factor χ

$\chi_y := min\left(1.0, \dfrac{1}{\Phi_y + \sqrt{{\Phi_y}^2 - {\lambda_y}^2}}\right) = 0.800$ Reduction factor for relevant buckling mode

$\chi_z := min\left(1.0, \dfrac{1}{\Phi_z + \sqrt{{\Phi_z}^2 - {\lambda_z}^2}}\right) = 0.104$ Reduction factor for relevant buckling mode

$N_{b.y.Rd} := \dfrac{\chi_y \cdot A \cdot f_y(\max(t_w, t_f))}{\gamma_{M1}} = 808.999\ kN$ The design buckling resistance of a compression member, class 1, 2 and 3

$N_{b.z.Rd} := \dfrac{\chi_z \cdot A \cdot f_y(\max(t_w, t_f))}{\gamma_{M1}} = 105.056\ kN$ The design buckling resistance of a compression member, class 1, 2 and 3

6.3.1.4 Slenderness for torsional and torsional-flexural buckling (vääntö- ja taivutusvääntönurjahdus)

Ruukki Hitsatut profiilit käsikirja 2010: 2.6.3 Nurjahduskestävyys, formulas 2.39 - 2.44

$y_0 := 0\ mm$ — Torsional center distance from neutral axis, Ruukki Hitsatut profiilit käsikirja

$z_0 := 0\ mm$ — Torsional center distance from neutral axis, Ruukki Hitsatut profiilit käsikirja

$i_0 := \sqrt{{i_y}^2 + {i_z}^2 + {y_0}^2 + {z_0}^2} = 85.583\ mm$ — Radius of gyration in relation to torsional center, Ruukki Hitsatut profiilit käsikirja

$N_{cr.T} := \frac{1}{{i_0}^2} \cdot \left(G \cdot I_t + \frac{\pi^2 \cdot E \cdot I_w}{{L_{cr.T}}^2} \right) = 921.055\ kN$ — Elastic torsional buckling force, Ruukki Hitsatut profiilit käsikirja

$\lambda_T := \sqrt{\frac{A \cdot f_y \left(\max \left(t_w , t_f \right) \right)}{N_{cr.T}}} = 1.048$ — The non-dimensional slenderness for torsional or torsional-flexural buckling (vääntö- ja taivutusvääntönurjahdus)

$\Phi_T := 0.5 \cdot \left(1 + \alpha_z \cdot \left(\lambda_T - 0.2 \right) + {\lambda_T}^2 \right) = 1.193$ — Value to determine the reduction factor χ

$\chi_T := min \left(1.0 , \frac{1}{\Phi_T + \sqrt{{\Phi_T}^2 - {\lambda_T}^2}} \right) = 0.567$ — Reduction factor for relevant buckling mode

$N_{T.Rd} := \frac{\chi_T \cdot A \cdot f_y \left(\max \left(t_w , t_f \right) \right)}{\gamma_{M1}} = 573.504\ kN$ — The design buckling resistance of a compression member, class 1, 2 and 3

6.3.2 Uniform members in bending

$k_z := 1$ Lateral bending coefficient (sauvan pään kiertyminen xy-tasossa)

$k_w := 1$ Warping coefficient (sauvan pään käyristyminen, sauvan akselin suuntaiset säikeet siirtyvät toistensa suhteen)

k_z and k_w values are 1 for free bending and free warping, and 0.5 for prevented bending and prevented warping.

Taulukko 2.16 Tehollisen pituuden kertoimet eri tuentatapauksille [37,38]

Tuentatapaukset sauvan päissä pystyakselin ympäri tapahtuvan kiertymän suhteen	Poikkipinnan käyristyminen estetty sauvan molemmissa päissä	Poikkipinta voi käyristyä sauvan molemmissa päissä	Poikkipinnan käyristyminen estetty sauvan toisessa päässä, toinen pää voi käyristyä
Kiertymä estetty sauvan molemmissa päissä	k = 0,5 k_ω = 0,5	k = 0,5 k_ω = 1,0	k = 0,5 k_ω = 0,7
Kiertymä vapaa sauvan molemmissa päissä	k = 1,0 k_ω = 0,5	k = 1,0 k_ω = 1,0	k = 1,0 k_ω = 0,7
Kiertymä estetty sauvan toisessa päässä, toinen pää voi kiertyä vapaasti	k = 0,7 k_ω = 0,5	k = 0,7 k_ω = 1,0	k = 0,7 k_ω = 0,7

Ruukki Hitsatut profiilit käsikirja

$C_1 := 1$ Moment coefficient

Elastic critical moment for lateral-torsional buckling for double symmetric beams loaded at section shear centre

$$M_{cr} := C_1 \cdot \frac{\pi^2 \cdot E \cdot I_z}{\left(k_z \cdot L_{cr.LT}\right)^2} \cdot \sqrt{\left(\frac{k_z}{k_w}\right)^2 \cdot \frac{I_w}{I_z} + \frac{\left(k_z \cdot L_{cr.LT}\right)^2 \cdot G \cdot I_t}{\pi^2 \cdot E \cdot I_z}} = 28.182\ kN \cdot m$$

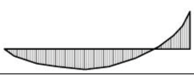
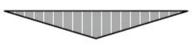
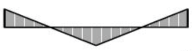
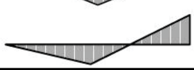
Elastic critical moment for lateral-torsional buckling for double symmetric beams loaded at section shear centre. A constant moment distribution.

$$M_{cr.0} := \frac{\pi^2 \cdot E \cdot I_z}{\left(k_z \cdot L_{cr.LT}\right)^2} \cdot \sqrt{\left(\frac{k_z}{k_w}\right)^2 \cdot \frac{I_w}{I_z} + \frac{\left(k_z \cdot L_{cr.LT}\right)^2 \cdot G \cdot I_t}{\pi^2 \cdot E \cdot I_z}} = 28.182\ kN \cdot m$$

$\psi_y := 1$ Ratio of end moments (y-y axis)

$k_c := \frac{1}{1.33 - 0.33 \cdot \psi_y} = 1.000$ Correction factor for moment distribution

Table 6.6: Correction factors k_c

Moment distribution	k_c
 $\psi = 1$	1,0
 $-1 \le \psi \le 1$	$\frac{1}{1,33 - 0,33\psi}$
	0,94
	0,90
	0,91
	0,86
	0,77
	0,82

6.3.3 Uniform members in bending and axial compression

Annex B – Method 2: Interaction factors k_{ij} for interaction formula in 6.3.3(4)

Table B.1: Interaction factors k_{ij} for members not susceptible to torsional deformations

$M_h := 18.75 \cdot kN \cdot m$

$M_s := 18.75 \cdot kN \cdot m$

$\psi_y = 1.000$

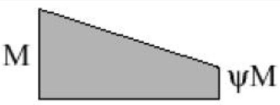
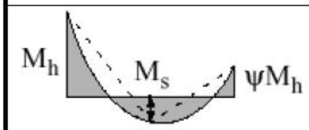
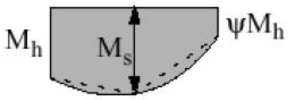
$\alpha_s := \dfrac{M_s}{M_h} = 1.000$

$\alpha_h := \dfrac{M_h}{M_s} = 1.000$

$Moment\_Diagram := 1$

$Loading := \text{"Concentrated"}$

Table B.3: Equivalent uniform moment factors C_m in Tables B.1 and B.2

Moment diagram	range		C_{my} and C_{mz} and C_{mLT} uniform loading	concentrated load
	$-1 \le \psi \le 1$		$0,6 + 0,4\psi \ge 0,4$	
	$0 \le \alpha_s \le 1$	$-1 \le \psi \le 1$	$0,2 + 0,8\alpha_s \ge 0,4$	$0,2 + 0,8\alpha_s \ge 0,4$
	$-1 \le \alpha_s < 0$	$0 \le \psi \le 1$	$0,1 - 0,8\alpha_s \ge 0,4$	$-0,8\alpha_s \ge 0,4$
$\alpha_s = M_s/M_h$		$-1 \le \psi < 0$	$0,1(1-\psi) - 0,8\alpha_s \ge 0,4$	$0,2(-\psi) - 0,8\alpha_s \ge 0,4$
	$0 \le \alpha_h \le 1$	$-1 \le \psi \le 1$	$0,95 + 0,05\alpha_h$	$0,90 + 0,10\alpha_h$
	$-1 \le \alpha_h < 0$	$0 \le \psi \le 1$	$0,95 + 0,05\alpha_h$	$0,90 + 0,10\alpha_h$
$\alpha_h = M_h/M_s$		$-1 \le \psi < 0$	$0,95 + 0,05\alpha_h(1+2\psi)$	$0,90 - 0,10\alpha_h(1+2\psi)$

For members with sway buckling mode the equivalent uniform moment factor should be taken $C_{my} = 0,9$ or $C_{Mz} = 0,9$ respectively.

C_{my}, C_{mz} and C_{mLT} should be obtained according to the bending moment diagram between the relevant braced points as follows:

moment factor	bending axis	points braced in direction
C_{my}	y-y	z-z
C_{mz}	z-z	y-y
C_{mLT}	y-y	y-y

$C_{mi} :=$ if $Moment\_Diagram = 1$

- if $-1 \le \psi_y \le 1$
  - $\max(0.6 + 0.4\ \psi_y, 0.4)$

else if $Moment\_Diagram = 2$

- if $0 \le \alpha_s \le 1$
  - if $-1 \le \psi_y \le 1$
    - if $Loading =$ "Uniform"
      - $\max(0.2 + 0.8\ \alpha_s, 0.4)$
    - else if $Loading =$ "Concentrated"
      - $\max(0.2 + 0.8\ \alpha_s, 0.4)$
- else if $-1 \le \alpha_s < 0$
  - if $0 \le \psi_y \le 1$
    - if $Loading =$ "Uniform"
      - $\max(0.1 - 0.8\ \alpha_s, 0.4)$
    - else if $Loading =$ "Concentrated"
      - $\max(-0.8\ \alpha_s, 0.4)$
  - else if $-1 \le \psi_y < 0$
    - if $Loading =$ "Uniform"
      - $\max(0.1\ (1 - \psi_y) - 0.8\ \alpha_s, 0.4)$
    - else if $Loading =$ "Concentrated"
      - $\max(0.2\ (-\psi_y) - 0.8\ \alpha_s, 0.4)$

else if $Moment\_Diagram = 3$

- if $0 \le \alpha_h \le 1$
  - if $-1 \le \psi_y \le 1$
    - if $Loading =$ "Uniform"
      - $0.95 + 0.05\ \alpha_h$
    - else if $Loading =$ "Concentrated"
      - $0.90 + 0.10\ \alpha_h$
- else if $-1 \le \alpha_h < 0$
  - if $0 \le \psi_y \le 1$
    - if $Loading =$ "Uniform"
      - $0.95 + 0.05\ \alpha_h$
    - else if $Loading =$ "Concentrated"
      - $0.90 + 0.10\ \alpha_h$
  - else if $-1 \le \psi_y < 0$
    - if $Loading =$ "Uniform"
      - $0.95 + 0.05\ \alpha_h \cdot (1 + 2\ \psi_y)$
    - else if $Loading =$ "Concentrated"
      - $0.90 + 0.10\ \alpha_h \cdot (1 + 2\ \psi_y)$

$C_{mi} = 1.000$

$C_{my} := 0.9$ Equivalent uniform moment factor

$C_{mz} := 0.9$ Equivalent uniform moment factor

$C_{mLT} := 0.6$ Equivalent uniform moment factor

6.3.2.3 Lateral-torsional buckling curves for rolled sections or equivalent welded sections

$\lambda_{LT} := \sqrt{\dfrac{W_y \cdot f_y\left(\max\left(t_w, t_f\right)\right)}{M_{cr}}} = 1.665$

The non-dimensional slenderness for lateral torsional (kiepahdus)

$\lambda_{LT.0} := 0.4$

Plateau length of the lateral torsional buckling curves for rolled sections (myötötason pituus kiepahduskäyrällä valssatuille ja hitsatuille profiileille)

$\beta_{LT} := 0.75$

Correction factor for the lateral torsional buckling curves for rolled sections

$$bc_{LT} := \begin{array}{l} \text{if } \dfrac{h}{b} \le 2 \\ \quad bc \leftarrow \text{“b”} \\ \text{else if } \dfrac{h}{b} > 2 \\ \quad bc \leftarrow \text{“c”} \\ \text{return } bc \end{array} = \text{“b”}$$

Buckling curve for lateral-torsional buckling

$\alpha_{LT} := \alpha_{imp}\left(bc_{LT}\right) = 0.340$

Imperfection factor

$\Phi_{LT} := 0.5 \cdot \left(1 + \alpha_{LT} \cdot \left(\lambda_{LT} - \lambda_{LT.0}\right) + \beta_{LT} \cdot \lambda_{LT}^{2}\right) = 1.754$ Value to determine the reduction factor χ_{LT}

$\chi_{LT} := min\left(1.0, \dfrac{1}{\lambda_{LT}^{2}}, \dfrac{1}{\Phi_{LT} + \sqrt{\Phi_{LT}^{2} - \beta_{LT} \cdot \lambda_{LT}^{2}}}\right)$

Reduction factor for lateral-torsional buckling

$\chi_{LT} = 0.361$

$k_c = 1.000$

Correction factor for moment distribution

$f := min\left(1, 1 - 0.5 \cdot \left(1 - k_c\right) \cdot \left(1 - 2 \cdot \left(\lambda_{LT} - 0.8\right)^{2}\right)\right)$

Modification factor for χ_{LT}

$f = 1.000$

$\chi_{LT.mod} := min\left(1, \dfrac{\chi_{LT}}{f}\right) = 0.361$

Modified reduction factor for lateral-torsional buckling

$M_{b.Rd} := \chi_{LT.mod} \cdot W_y \cdot \dfrac{f_y\left(\max\left(t_w, t_f\right)\right)}{\gamma_{M1}} = 28.182\ kN \cdot m$ Design buckling resistance moment

6.3.3 Uniform members in bending and axial compression

Annex B - Method 2: Interaction factors k_{ij} for interaction formula in 6.3.3(4)

Table B.2: Interaction factors k_{ij} for members susceptible to torsional deformations

6.3.3 (2) NOTE 1 The interaction formulae are based on the modelling of simply supported single span members with end fork conditions and with or without continuous lateral restraints, which are subjected to compression forces, end moments and/or transverse loads.

$Susceptible\_To\_Torsional\_Deformations := \text{"yes"}$

$N_{Rk} := f_y\left(\max\left(t_w, t_f\right)\right) \cdot A = 1011.750\ kN$ Characteristic value of resistance to compression

$$k_{yy} := \text{if } N_{Ed} > 0 \\ \quad \text{if } Class \le 2 \\ \quad\quad \text{return } min\left(C_{my} \cdot \left(1 + \left(\lambda_y - 0.2\right) \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}}\right), C_{my} \cdot \left(1 + 0.8 \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}}\right)\right) \\ \quad \text{else} \\ \quad\quad \text{return } C_{my} \cdot min\left(1 + 0.6 \cdot \lambda_y \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}}, 1 + 0.6 \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}}\right) \\ \text{else} \\ \quad \text{return } 0$$

$$k_{zz} := \text{if } N_{Ed} > 0 \\ \quad \text{if } Class \le 2 \\ \quad\quad min\left(C_{mz} \cdot \left(1 + \left(2 \cdot \lambda_z - 0.6\right) \cdot \frac{N_{Ed}}{\chi_z \cdot \frac{N_{Rk}}{\gamma_{M1}}}\right), C_{mz} \cdot \left(1 + 1.4 \cdot \frac{N_{Ed}}{\chi_z \cdot \frac{N_{Rk}}{\gamma_{M1}}}\right)\right) \\ \quad \text{else} \\ \quad\quad min\left(C_{mz} \cdot \left(1 + 0.6 \cdot \lambda_y \cdot \frac{N_{Ed}}{\chi_z \cdot \frac{N_{Rk}}{\gamma_{M1}}}\right), C_{mz} \cdot \left(1 + 0.6 \cdot \frac{N_{Ed}}{\chi_z \cdot \frac{N_{Rk}}{\gamma_{M1}}}\right)\right) \\ \text{else} \\ \quad \text{return } 0$$

$$k_{yz} := \text{if } N_{Ed} > 0 \\ \quad \text{if } Class \le 2 \\ \quad\quad \text{return } 0.6\ k_{zz} \\ \quad \text{else} \\ \quad\quad \text{return } k_{zz} \\ \text{else} \\ \quad \text{return } 0$$

$k_{zy} :=$ if $N_{Ed} > 0$
  if *Susceptible_To_Torsional_Deformations* = "no"
    if $Class \le 2$
      $0.6\ k_{yy}$
    else
      $0.8\ k_{yy}$
  else if *Susceptible_To_Torsional_Deformations* = "yes"
    if $Class \le 2$
      if $\lambda_z < 0.4$

$$min\left(0.6 + \lambda_z, 1 - \frac{0.1\ \lambda_z}{C_{mLT} - 0.25} \cdot \frac{N_{Ed}}{\chi_z \cdot \frac{N_{Rk}}{\gamma_{M1}}}\right)$$

      else

$$\max\left(1 - \frac{0.1\ \lambda_z}{C_{mLT} - 0.25} \cdot \frac{N_{Ed}}{\chi_z \cdot \frac{N_{Rk}}{\gamma_{M1}}}, 1 - \frac{0.1}{C_{mLT} - 0.25} \cdot \frac{N_{Ed}}{\chi_z \cdot \frac{N_{Rk}}{\gamma_{M1}}}\right)$$

    else

$$\max\left(1 - \frac{0.05\ \lambda_z}{C_{mLT} - 0.25} \cdot \frac{N_{Ed}}{\chi_z \cdot \frac{N_{Rk}}{\gamma_{M1}}}, 1 - \frac{0.05}{C_{mLT} - 0.25} \cdot \frac{N_{Ed}}{\chi_z \cdot \frac{N_{Rk}}{\gamma_{M1}}}\right)$$

else
  return 0

$k_{yy} = 0.926$
$k_{yz} = 0.828$
$k_{zy} = 0.891$
$k_{zz} = 1.380$

$M_{y.Rk} := f_y\left(\max\left(t_w, t_f\right)\right) \cdot W_y = 78.100\ kN \cdot m$ — Characteristic value of resistance to bending moment

$M_{z.Rk} := f_y\left(\max\left(t_w, t_f\right)\right) \cdot W_z = 15.837\ kN \cdot m$ — Characteristic value of resistance to bending moment

$\Delta M_{y.Ed} := 0\ kN \cdot m$ — Moments due to the shift of the centroidal y-y axis

$\Delta M_{z.Ed} := 0\ kN \cdot m$ — Moments due to the shift of the centroidal z-z axis

Combined bending and axial compression

$$\frac{\left|N_{Ed}\right|}{\frac{\chi_y \cdot N_{Rk}}{\gamma_{M1}}} + k_{yy} \cdot \frac{M_{y.Ed} + \Delta M_{y.Ed}}{\chi_{LT.mod} \cdot \frac{M_{y.Rk}}{\gamma_{M1}}} + k_{yz} \cdot \frac{M_{z.Ed} + \Delta M_{z.Ed}}{\frac{M_{z.Rk}}{\gamma_{M1}}} = 0.666$$

$$\frac{\left|N_{Ed}\right|}{\frac{\chi_z \cdot N_{Rk}}{\gamma_{M1}}} + k_{zy} \cdot \frac{M_{y.Ed} + \Delta M_{y.Ed}}{\chi_{LT.mod} \cdot \frac{M_{y.Rk}}{\gamma_{M1}}} + k_{zz} \cdot \frac{M_{z.Ed} + \Delta M_{z.Ed}}{\frac{M_{z.Rk}}{\gamma_{M1}}} = 0.974$$

$$\frac{|N_{Ed}|}{\frac{\chi_y \cdot N_{Rk}}{\gamma_{M1}}} = 0.049$$

$$k_{yy} \cdot \frac{M_{y.Ed} + \Delta M_{y.Ed}}{\chi_{LT} \cdot \frac{M_{y.Rk}}{\gamma_{M1}}} = 0.616$$

$$k_{yz} \cdot \frac{M_{z.Ed} + \Delta M_{z.Ed}}{\frac{M_{z.Rk}}{\gamma_{M1}}} = 0.000$$

$$\frac{|N_{Ed}|}{\frac{\chi_z \cdot N_{Rk}}{\gamma_{M1}}} = 0.381$$

$$k_{zy} \cdot \frac{M_{y.Ed} + \Delta M_{y.Ed}}{\chi_{LT} \cdot \frac{M_{y.Rk}}{\gamma_{M1}}} = 0.593$$

$$k_{zz} \cdot \frac{M_{z.Ed} + \Delta M_{z.Ed}}{\frac{M_{z.Rk}}{\gamma_{M1}}} = 0.000$$

Utilization

$M_N := \left(\frac{M_{y.Ed}}{M_{N.y.Rd}}\right)^{\alpha} + \left(\frac{M_{z.Ed}}{M_{N.z.Rd}}\right)^{\beta} = 0.058$	6.2.1 (7) General, formula 6.2, class 1 and 2
$N_t := \frac{N_{Ed}}{N_{t.Rd}} = 0.040$	6.2.3 Tension
$N_c := \frac{N_{Ed}}{N_{c.Rd}} = 0.040$	6.2.4 Compression
$M_{c.y} := \frac{M_{y.Ed}}{M_{c.y.Rd}} = 0.240$	6.2.5 Bending moment, stronger axis
$M_{c.z} := \frac{M_{z.Ed}}{M_{c.z.Rd}} = 0.000$	6.2.5 Bending moment, weaker axis
$V_{c.y} := \frac{V_{y.Ed}}{V_{c.y.Rd}} = 0.000$	6.2.6 Shear, stronger axis
$V_{c.z} := \frac{V_{z.Ed}}{V_{c.z.Rd}} = 0.026$	6.2.6 Shear, weaker axis
$T = 1.000\ T$	6.2.7 Torsion
$T_{RFEM} := \frac{\tau_{t.Ed}}{\tau_{Rd}} = 0.000$	6.2.7 Torsion, St. Venant torsion (vapaa vääntö)
$V_{pl.T.y} := \frac{V_{y.Ed}}{V_{pl.y.T.Rd}} = 0.000$	6.2.7 Torsion, reduced shear force resistance by torsion
$V_{pl.T.z} := \frac{V_{z.Ed}}{V_{pl.z.T.Rd}} = 0.026$	6.2.7 Torsion, reduced shear force resistance by torsion
$M_{V.y} := \frac{M_{y.Ed}}{M_{V.y.Rd}} = 0.240$	6.2.8 Bending and shear
$M_{V.z} := \frac{M_{z.Ed}}{M_{V.z.Rd}} = 0.000$	6.2.8 Bending and shear
$M_{V}\_class\_1\_2 := \left(\frac{M_{y.Ed}}{M_{V.y.Rd}}\right)^{\alpha} + \left(\frac{M_{z.Ed}}{M_{V.z.Rd}}\right)^{\beta} = 0.058$	6.2.8 Bending and shear, Ruukki Hitsatut profiilit käsikirja
$M_{N.y}\_class\_1\_2 := \frac{M_{y.Ed}}{M_{N.y.Rd}} = 0.240$	6.2.9.1 Bending and axial force, class 1 and 2
$M_{N.z}\_class\_1\_2 := \frac{M_{z.Ed}}{M_{N.z.Rd}} = 0.000$	6.2.9.1 Bending and axial force, class 1 and 2
$M_{N}\_class\_1\_2 := \left(\frac{M_{y.Ed}}{M_{N.y.Rd}}\right)^{\alpha} + \left(\frac{M_{z.Ed}}{M_{N.z.Rd}}\right)^{\beta} = 0.058$	6.2.9.1 Bending and axial force, class 1 and 2
$M_{V.N.y} := \frac{M_{y.Ed}}{M_{V.N.y.Rd}} = 0.240$	6.2.10 Bending, shear and axial force
$M_{V.N.z} := \frac{M_{z.Ed}}{M_{V.N.z.Rd}} = 0.000$	6.2.10 Bending, shear and axial force
$M_{V.N}\_class\_1\_2 := \left(\frac{M_{y.Ed}}{M_{V.N.y.Rd}}\right)^{\alpha} + \left(\frac{M_{z.Ed}}{M_{V.N.z.Rd}}\right)^{\beta} = 0.058$	6.2.10 Bending, shear and axial force, Ruukki Hitsatut profiilit käsikirja

$N_{b.y} := \frac{N_{Ed}}{N_{b.y.Rd}} = 0.049$ 6.3.1.3 Flexural buckling, stronger axis (taivutusnurjahdus)

$N_{b.z} := \frac{N_{Ed}}{N_{b.z.Rd}} = 0.381$ 6.3.1.3 Flexural buckling, weaker axis (taivutusnurjahdus)

$N_T := \frac{N_{Ed}}{N_{T.Rd}} = 0.070$ 6.3.1.4 Torsional and torsional-flexural buckling (vääntö- ja taivutusvääntönurjahdus)

$M_b := \frac{M_{y.Ed}}{M_{b.Rd}} = 0.665$ 6.3.2.1 Buckling resistance (kiepahdus)

6.3.3 Uniform members in bending and axial compression (nurjahdus + kiepahdus?)

$$N_{b}\_M_{b}\_1 := \frac{N_{Ed}}{\frac{\chi_y \cdot N_{Rk}}{\gamma_{M1}}} + k_{yy} \cdot \frac{M_{y.Ed} + \Delta M_{y.Ed}}{\chi_{LT} \cdot \frac{M_{y.Rk}}{\gamma_{M1}}} + k_{yz} \cdot \frac{M_{z.Ed} + \Delta M_{z.Ed}}{\frac{M_{z.Rk}}{\gamma_{M1}}} = 0.666$$

$$N_{b}\_M_{b}\_2 := \frac{N_{Ed}}{\frac{\chi_z \cdot N_{Rk}}{\gamma_{M1}}} + k_{zy} \cdot \frac{M_{y.Ed} + \Delta M_{y.Ed}}{\chi_{LT} \cdot \frac{M_{y.Rk}}{\gamma_{M1}}} + k_{zz} \cdot \frac{M_{z.Ed} + \Delta M_{z.Ed}}{\frac{M_{z.Rk}}{\gamma_{M1}}} = 0.974$$

$Util\_name :=$ $\begin{bmatrix} \text{"M\_N"} \\ \vdots \end{bmatrix}$

$Util\_value := \begin{bmatrix} M_N \\ \vdots \end{bmatrix} = \begin{bmatrix} 0.058 \\ \vdots \end{bmatrix}$

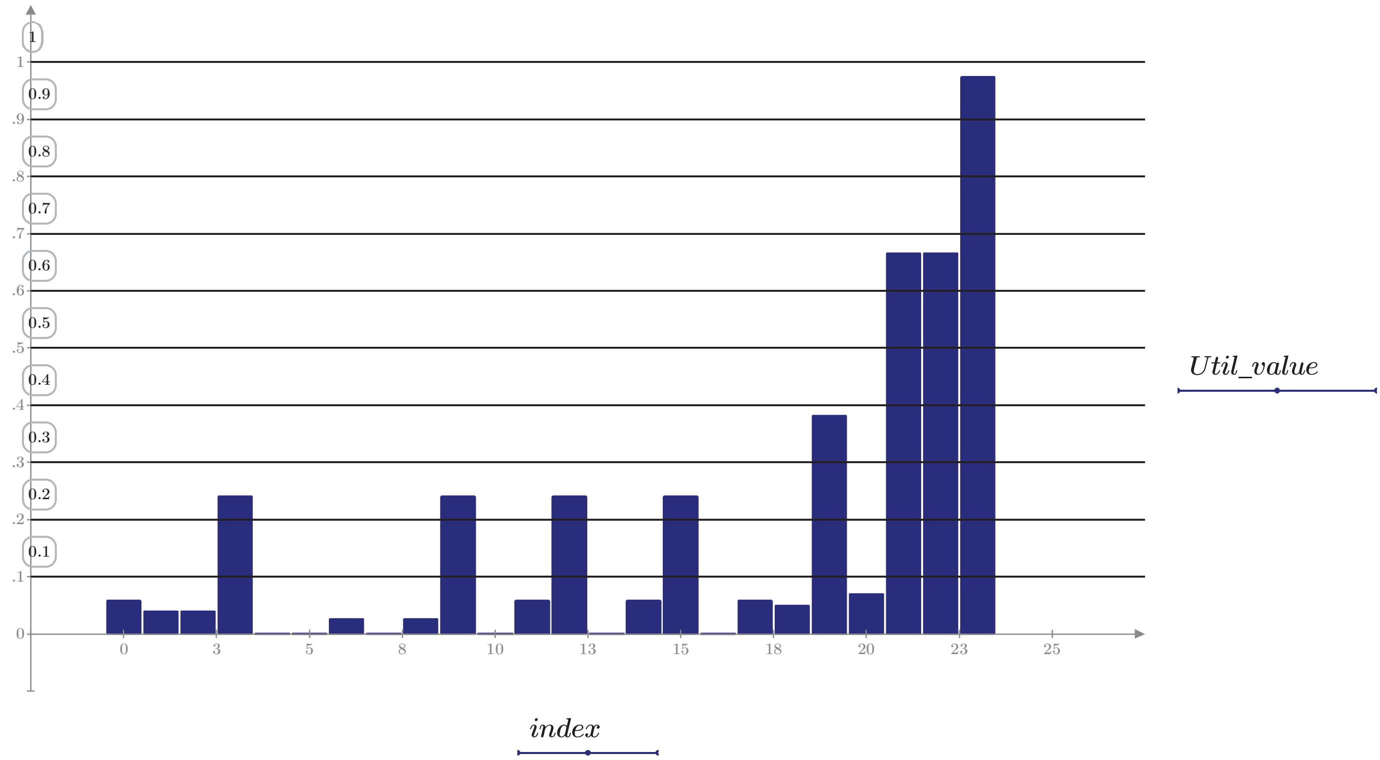
$\text{Utilization} := \text{augment}(Util\_name, Util\_value) = \begin{bmatrix} \text{"M\_N"} & 0.058 \\ & \vdots \end{bmatrix}$

```
max_util_name := || max_utils_index ← match(max(Util_value), Util_value)
                 || for i ∈ 0 .. length(max_utils_index) − 1
                 ||   || m_i ← Util_name_(max_utils_index_i)
                 || return m
```

$max\_util\_value := \text{vlookup}(\max(Util\_value), Util\_value, 0)$

$index := 0 \,..\, \text{length}(Util\_value) - 1 = \begin{bmatrix} 0.000 \\ \vdots \end{bmatrix}$

$max\_utilization := \text{augment}(max\_util\_name, max\_util\_value) = [\text{"N\_b\_M\_b\_2"} \;\; 0.974]$



$$Utilization = \begin{bmatrix} \text{“M\_N”} & 0.058 \\ \text{“N\_t”} & 0.040 \\ \text{“N\_c”} & 0.040 \\ \text{“M\_c.y”} & 0.240 \\ \text{“M\_c.z”} & 0.000 \\ \text{“V\_c.y”} & 0.000 \\ \text{“V\_c.z”} & 0.026 \\ \text{“V\_pl.T.y”} & 0.000 \\ \text{“V\_pl.T.z”} & 0.026 \\ \text{“M\_V.y”} & 0.240 \\ \text{“M\_V.z”} & 0.000 \\ \text{“M\_V\_class\_1\_2”} & 0.058 \\ \text{“M\_N.y\_class\_1\_2”} & 0.240 \\ \text{“M\_N.z\_class\_1\_2”} & 0.000 \\ \text{“M\_N\_class\_1\_2”} & 0.058 \\ \text{“M\_V.N.y”} & 0.240 \\ \text{“M\_V.N.z”} & 0.000 \\ \text{“M\_V.N\_class\_1\_2”} & 0.058 \\ \text{“N\_b.y”} & 0.049 \\ \text{“N\_b.z”} & 0.381 \\ \text{“N\_T”} & 0.070 \\ \text{“M\_b”} & 0.665 \\ \text{“N\_b\_M\_b\_1”} & 0.666 \\ \text{“N\_b\_M\_b\_2”} & 0.974 \end{bmatrix} \qquad max\_utilization = \begin{bmatrix} \text{“N\_b\_M\_b\_2”} & 0.974 \end{bmatrix}$$

$Class = 1.000$

APPENDIX B: Results of simplified design in pre-study

1	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	1000.0	1000.0	1000.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - No Compression	Class			1.0	-		
	Design Ratio							
	Tension Force	Nt,Ed	kN	1000.0	1000.0	1000.0	0 %	0 %
	Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Design plastic resistance to normal forces	Npl,Rd	kN	1011.75		1011.75		0 %
	Axial Force Resistance	Nt,Rd	kN	1011.75	1011.75	1011.75	0 %	0 %
	Design Ratio	<eta>		0.988	0.988	0.988	0 %	0 %
	Design Formula							
	Nt,Ed / Nt,Rd = 0.988 <le> 1 (6.5)							

2	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	1000.0	1000.0	1000.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - No Compression	Class			1.0	-		
	Design Ratio							
	Tension Force	Nt,Ed	kN	1000.0	1000.0	1000.0	0 %	0 %
	Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Design plastic resistance to normal forces	Npl,Rd	kN	1011.75		1011.75		0 %
	Axial Force Resistance	Nt,Rd	kN	1011.75	1011.75	1011.75	0 %	0 %
	Design Ratio	<eta>		0.988	0.988	0.988	0 %	0 %
	Design Formula							
	Nt,Ed / Nt,Rd = 0.988 <le> 1 (6.5)							

3	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	-100.0	-100.0	-100.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 2	Class		2.0	2.0	2.0	0 %	0 %
	Design Ratio							
	Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
	Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
	Effective Member Length	Lcr,z	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,z	kN	117.72	117.72	117.72	0 %	0 %
	Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_z		2.932		2.932		0 %
	Axial Force (Compression)	NEd	kN	100.0	100.0	100.0	0 %	0 %
	Criterion NEd / Ncr,z	<eta>N,cr		0.849		0.849		0 %
	Buckling Curve	BCz		b		b		0 %
	Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
	Auxiliary Factor	<phic>z		5.261		5.261		0 %
	Reduction Factor	<chi>z		0.104	0.104	0.104	0 %	0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Flexural Buckling Resistance	Nb,z,Rd	kN	105.06		105.06		0 %
	Design Ratio	<eta>		0.952	0.952	0.952	0 %	0 %
	Design Formula							
	NEd / Nb,z,Rd = 0.952 <le> 1 (6.46)							

4	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	-100.0	-100.0	-100.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 2	Class		2.0	2.0	2.0	0 %	0 %
	Design Ratio							
	Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
	Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
	Effective Member Length	Lcr,z	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,z	kN	117.72	117.72	117.72	0 %	0 %
	Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_z		2.932		2.932		0 %
	Axial Force (Compression)	NEd	kN	100.0	100.0	100.0	0 %	0 %
	Criterion NEd / Ncr,z	<eta>N,cr		0.849		0.849		0 %
	Buckling Curve	BCz		b		b		0 %
	Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
	Auxiliary Factor	<phic>z		5.261		5.261		0 %
	Reduction Factor	<chi>z		0.104	0.104	0.104	0 %	0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Flexural Buckling Resistance	Nb,z,Rd	kN	105.06		105.06		0 %
	Design Ratio	<eta>		0.952	0.952	0.952	0 %	0 %
	Design Formula NEd / Nb,z,Rd = 0.952 <le> 1 (6.46)							

5	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	279.44	279.44	279.44	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	2.79	2.794	2.79	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - No compression	Class			1.0	1.0		
	Design Ratio							
	Shear Force	Vz,Ed	kN	279.44	279.44	279.44	0 %	0 %
	Effective Shear Area	Av,z	cm^2	14.02	14.02	14.02	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Shear Force Resistance	Vpl,z,Rd	kN	287.27	287.35	287.35	0 %	0 %
	Design Ratio	<eta>		0.973	0.972	0.972	0 %	0 %
	Design Formula Vz,Ed / Vpl,z,Rd = 0.973 <le> 1 (6.17)							

6	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | British Steel							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	-0.56	-0.56	-0.56	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	2.79	2.794	2.79	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Section Height	h	mm	200.0	200.0	200.0	0 %	0 %
	Section Width	b	mm	100.0	100.0	100.0	0 %	0 %
	Criterion	h/b		2.0		2.0		0 %
	Buckling Curve	BCLT		b		b		0 %
	Imperfection Factor	<alfa>LT		0.34	0.34	0.34	0 %	0 %
	Elastic Critical Moment for Lateral-Torsional Buckling	Mcr	kNm	28.18	28.18	28.18	0 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_LT		1.665		1.669		0 %
	Parameter	<lambda>_LT,0		0.4		0.4		0 %
	Parameter	<beta>		0.75		0.75		0 %
	Auxiliary Factor	<phic>LT		1.754		1.754		0 %
	Reduction Factor	<chi>LT		0.361		0.361		0 %
	Correction Factor	kc		0.752		0.752		0 %
	Modification Factor	f		1.0		1.0		0 %
	Reduction Factor	<chi>LT,mod		0.361	0.361	0.361	0 %	0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Lateral-Torsional Buckling Resistance Moment	Mb,Rd	kNm	28.18		28.18		0 %
	Moment	My,Ed	kNm	2.79	2.794	2.79	0 %	0 %
	Design Ratio	<eta>		0.099	0.099	0.099	0 %	0 %
	Design Formula My,Ed / Mb,Rd = 0.099 <le> 1 (6.54)							

				RFEM	Karamba	Mathcad	R and K	R and M
7	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	-349.3	-349.3	-349.3	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	3.49	3.493	3.49	0 %	0 %
	Cross-Section Classification - No Compression	Class			1.0			
	Design Ratio							
	Shear Force	Vy,Ed	kN	349.3	349.3	349.3	0 %	0 %
	Effective Shear Area	Av,y	cm^2	17.99	17.99	17.99	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Shear Force Resistance	Vpl,y,Rd	kN	368.63	368.72	368.72	0 %	0 %
	Design Ratio	<eta>		0.948	1.105	0.947	17 %	0 %
	Design Formula							
	Vy,Ed / Vpl,y,Rd = 0.948 <le> 1 (6.17)							

				RFEM	Karamba	Mathcad	R and K	R and M
8	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.7	0.7	0.7	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	3.49	3.493	3.49	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Moment	Mz,Ed	kNm	3.49	3.493	3.49	0 %	0 %
	Plastic Section Modulus	Wpl,z	cm^3	44.61	44.61	44.61	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Moment Resistance	Mpl,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Shear Force	Vy,Ed	kN	0.7	0.7	0.7	0 %	0 %
	Effective Shear Area	Av,y	cm^2	17.99	17.99	17.99	0 %	0 %
	Shear Force Resistance	Vpl,y,Rd	kN	368.63	368.72	368.72	0 %	0 %
	Criterion Vy,Ed / Vpl,y,Rd	vy		0.002		0.002		0 %
	Moment Resistance	Mc,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Design Ratio	<eta>		0.221	0.221	0.22	0 %	0 %
	Design Formula							
	Mz,Ed / Mc,z,Rd = 0.221 <le> 1 (6.12)							

				RFEM	Karamba	Mathcad	R and K	R and M
9	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	11.0	11.0	11.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	27.5	27.5	27.5	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Section Height	h	mm	200.0	200.0	200.0	0 %	0 %
	Section Width	b	mm	100.0	100.0	100.0	0 %	0 %
	Criterion	h/b		2.0		2.0		0 %
	Buckling Curve	BCLT		b		b		0 %
	Imperfection Factor	<alfa>LT		0.34	0.34	0.34	0 %	0 %
	Elastic Critical Moment for Lateral-Torsional Buckling	Mcr	kNm	28.18	28.18	28.18	0 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_LT		1.665		1.665		0 %
	Parameter	<lambda>_LT,0		0.4		0.4		0 %
	Parameter	<beta>		0.75		0.75		0 %
	Auxiliary Factor	<phic>LT		1.754		1.76		0 %
	Reduction Factor	<chi>LT		0.361		0.361		0 %
	Correction Factor	kc		0.752		0.752		0 %
	Modification Factor	f		1.0		1.0		0 %
	Reduction Factor	<chi>LT,mod		0.361	0.361	0.361	0 %	0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Lateral-Torsional Buckling Resistance Moment	Mb,Rd	kNm	28.18		28.18		0 %
	Moment	My,Ed	kNm	27.5	27.5	27.5	0 %	0 %
	Design Ratio	<eta>		0.976	0.976	0.976	0 %	0 %
	Design Formula							
	My,Ed / Mb,Rd = 0.976 <le> 1 (6.54)							

				RFEM	Karamba	Mathcad	R and K	R and M
10	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							

	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	-11.0	-11.0	-11.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	27.5	27.5	27.5	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Section Height	h	mm	200.0	200.0	200.0	0 %	0 %
	Section Width	b	mm	100.0	100.0	100.0	0 %	0 %
	Criterion	h/b		2.0		2.0		0 %
	Buckling Curve	BCLT		b		b		0 %
	Imperfection Factor	<alfa>LT		0.34	0.34	0.34	0 %	0 %
	Elastic Critical Moment for Lateral-Torsional Buckling	Mcr	kNm	28.18	28.18	28.18	0 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_LT		1.665		1.665		0 %
	Parameter	<lambda>_LT,0		0.4		0.4		0 %
	Parameter	<beta>		0.75		0.75		0 %
	Auxiliary Factor	<phic>LT		1.754		1.76		0 %
	Reduction Factor	<chi>LT		0.361		0.361		0 %
	Correction Factor	kc		0.752		0.752		0 %
	Modification Factor	f		1.0		1.0		0 %
	Reduction Factor	<chi>LT,mod		0.361	0.361	0.361	0 %	0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Lateral-Torsional Buckling Resistance Moment	Mb,Rd	kNm	28.18		28.18		0 %
	Moment	My,Ed	kNm	27.5	27.5	27.5	0 %	0 %
	Design Ratio	<eta>		0.976	0.976	0.976	0 %	0 %
	Design Formula My,Ed / Mb,Rd = 0.976 <le> 1 (6.54)							

11	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	-6.0	-6.0	-6.0	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	15.0	15.0	15.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Moment	Mz,Ed	kNm	15.0	15.0	15.0	0 %	0 %
	Plastic Section Modulus	Wpl,z	cm^3	44.61	44.61	44.61	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Moment Resistance	Mpl,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Shear Force	Vy,Ed	kN	6.0	6.0	6.0	0 %	0 %
	Effective Shear Area	Av,y	cm^2	17.99	17.99	17.99	0 %	0 %
	Shear Force Resistance	Vpl,y,Rd	kN	368.63	368.72	368.72	0 %	0 %
	Criterion Vy,Ed / Vpl,y,Rd	vy		0.016		0.016		0 %
	Moment Resistance	Mc,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Design Ratio	<eta>		0.947	0.947	0.947	0 %	0 %
	Design Formula Mz,Ed / Mc,z,Rd = 0.947 <le> 1 (6.12)							

12	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	-6.0	-6.0	-6.0	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	15.0	15.0	15.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Moment	Mz,Ed	kNm	15.0	15.0	15.0	0 %	0 %
	Plastic Section Modulus	Wpl,z	cm^3	44.61	44.61	44.61	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Moment Resistance	Mpl,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Shear Force	Vy,Ed	kN	6.0	6.0	6.0	0 %	0 %
	Effective Shear Area	Av,y	cm^2	17.99	17.99	17.99	0 %	0 %
	Shear Force Resistance	Vpl,y,Rd	kN	368.63	368.72	368.72	0 %	0 %
	Criterion Vy,Ed / Vpl,y,Rd	vy		0.016		0.016		0 %
	Moment Resistance	Mc,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Design Ratio	<eta>		0.947	0.947	0.947	0 %	0 %
	Design Formula Mz,Ed / Mc,z,Rd = 0.947 <le> 1 (6.12)							

13	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | British Steel							

	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	28.13	28.125	28.13	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Section Height	h	mm	200.0	200.0	200.0	0 %	0 %
	Section Width	b	mm	100.0	100.0	100.0	0 %	0 %
	Criterion	h/b		2.0		2.0		0 %
	Buckling Curve	BCLT		b		b		0 %
	Imperfection Factor	<alfa>LT		0.34	0.34	0.34	0 %	0 %
	Elastic Critical Moment for Lateral-Torsional Buckling	Mcr	kNm	28.18	28.18	28.18	0 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_LT		1.665		1.665		0 %
	Parameter	<lambda>_LT,0		0.4		0.4		0 %
	Parameter	<beta>		0.75		0.75		0 %
	Auxiliary Factor	<phic>LT		1.754		1.754		0 %
	Reduction Factor	<chi>LT		0.361		0.361		0 %
	Correction Factor	kc		0.855		1.0		17 %
	Modification Factor	f		1.0		1.0		0 %
	Reduction Factor	<chi>LT,mod		0.361	0.361	0.361	0 %	0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Lateral-Torsional Buckling Resistance Moment	Mb,Rd	kNm	28.18		28.18		0 %
	Moment	My,Ed	kNm	28.13	28.125	28.13	0 %	0 %
	Design Ratio	<eta>		0.998	0.998	0.998	0 %	0 %
	Design Formula							
	My,Ed / Mb,Rd = 0.998 <le> 1 (6.54)							

14	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	28.13	28.125	28.13	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Section Height	h	mm	200.0	200.0	200.0	0 %	0 %
	Section Width	b	mm	100.0	100.0	100.0	0 %	0 %
	Criterion	h/b		2.0		2.0		0 %
	Buckling Curve	BCLT		b		b		0 %
	Imperfection Factor	<alfa>LT		0.34	0.34	0.34	0 %	0 %
	Elastic Critical Moment for Lateral-Torsional Buckling	Mcr	kNm	28.18	28.18	28.18	0 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_LT		1.665		1.665		0 %
	Parameter	<lambda>_LT,0		0.4		0.4		0 %
	Parameter	<beta>		0.75		0.75		0 %
	Auxiliary Factor	<phic>LT		1.754		1.754		0 %
	Reduction Factor	<chi>LT		0.361		0.361		0 %
	Correction Factor	kc		0.855		1.0		17 %
	Modification Factor	f		1.0		1.0		0 %
	Reduction Factor	<chi>LT,mod		0.361	0.361	0.361	0 %	0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Lateral-Torsional Buckling Resistance Moment	Mb,Rd	kNm	28.18		28.18		0 %
	Moment	My,Ed	kNm	28.13	28.125	28.13	0 %	0 %
	Design Ratio	<eta>		0.998	0.998	0.998	0 %	0 %
	Design Formula							
	My,Ed / Mb,Rd = 0.998 <le> 1 (6.54)							

15	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	15.63	15.625	15.63	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Moment	Mz,Ed	kNm	15.63	15.625	15.63	0 %	0 %
	Plastic Section Modulus	Wpl,z	cm^3	44.61	44.61	44.61	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Moment Resistance	Mpl,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %

	Effective Shear Area	Av,y	cm^2	17.99	17.99	17.99	0 %	0 %
	Shear Force Resistance	Vpl,y,Rd	kN	368.63	368.72	368.72	0 %	0 %
	Criterion Vy,Ed / Vpl,y,Rd	vy		0.007				
	Moment Resistance	Mc,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Design Ratio	<eta>		0.987	0.987	0.987	0 %	0 %
	Design Formula Mz,Ed / Mc,z,Rd = 0.987 <le> 1 (6.12)							

16	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	15.63	15.625	15.63	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Moment	Mz,Ed	kNm	15.63	15.625	15.63	0 %	0 %
	Plastic Section Modulus	Wpl,z	cm^3	44.61	44.61	44.61	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Moment Resistance	Mpl,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Effective Shear Area	Av,y	cm^2	17.99	17.99	17.99	0 %	0 %
	Shear Force Resistance	Vpl,y,Rd	kN	368.63	368.72	368.72	0 %	0 %
	Criterion Vy,Ed / Vpl,y,Rd	vy		0.0		0.0		0 %
	Moment Resistance	Mc,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Design Ratio	<eta>		0.987	0.987	0.987	0 %	0 %
	Design Formula Mz,Ed / Mc,z,Rd = 0.987 <le> 1 (6.12)							

17	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	-40.0	-40.0	-40.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	7.5	7.5	7.5	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	18.75	18.75	18.75	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Elastic Critical Load for Torsional Buckling	Ncr,T	kN	923.57		921.06		0 %
	Slenderness	<lambda>_T		1.047		1.048		0 %
	Buckling Curve	BCz		b		b		0 %
	Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
	Auxiliary Factor	<phic>T		1.192		1.193		0 %
	Reduction Factor	<chi>T		0.568		0.567		0 %
	Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
	Moment of Inertia	Iy	cm^4	1940.0	1940.0	1940.0	0 %	0 %
	Effective Member Length	Lcr,y	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,y	kN	1608.35	1608.35	1608.35	0 %	0 %
	Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_y		0.793		0.793		0 %
	Buckling Curve	BCy		a		a		0 %
	Imperfection Factor	<alfa>y		0.21	0.21	0.21	0 %	0 %
	Auxiliary Factor	<phic>y		0.877		0.877		0 %
	Reduction Factor	<chi>y		0.8	0.8	0.8	0 %	0 %
	Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
	Effective Member Length	Lcr,z	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,z	kN	117.72	117.72	117.72	0 %	0 %
	Slenderness	<lambda>_z		2.932		2.932		0 %
	Buckling Curve	BCz		b		b		0 %
	Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
	Auxiliary Factor	<phic>z		5.261		5.261		0 %
	Reduction Factor	<chi>z		0.104	0.104	0.104	0 %	0 %
	Section Height	h	mm	200.0	200.0	200.0	0 %	0 %
	Section Width	b	mm	100.0	100.0	100.0	0 %	0 %
	Criterion	h/b		2.0		2.0		0 %
	Buckling Curve	BCLT		b		b		0 %
	Imperfection Factor	<alfa>LT		0.34	0.34	0.34	0 %	0 %
	Elastic Critical Moment for Lateral-Torsional Buckling	Mcr	kNm	28.18	28.18	28.18	0 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Slenderness	<lambda>_LT		1.665		1.665		0 %
	Parameter	<lambda>_LT,0		0.4		0.4		0 %
	Parameter	<beta>		0.75		0.75		0 %
	Auxiliary Factor	<phic>LT		1.754		1.754		0 %
	Reduction Factor	<chi>LT		0.361		0.361		0 %
	Correction Factor	kc		0.752		0.752		0 %
	Modification Factor	f		1.0		1.0		0 %

	Reduction Factor	<chi>LT,mod		0.361	0.361	0.361	0 %	0 %
	Structure type about y-axis	Type		Sway		Sway		0 %
	Moment Factor	Cmy		0.9	1.0	0.9	11 %	0 %
	Structure type about z-axis	Type		Sway		Sway		0 %
	Moment Factor	Cmz		0.9	1.0	0.9	11 %	0 %
	Moment Distribution	Diagr My,LT		1) Linear		1) Linear		0 %
	Moment Factor	<psi>y,LT		0.0	1.0	0.0	ERROR	0 %
	Moment Factor	CmLT		0.6	1.0	0.6	67 %	0 %
	Component Type	Component		rsion. Weak				0 %
	Interaction Factor	kyy		0.926	1.029	0.926	11 %	0 %
	Interaction Factor	kyz		0.828	0.92	0.828	11 %	0 %
	Interaction Factor	kzy		0.891	0.851	0.891	-4 %	0 %
	Interaction Factor	kzz		1.38	1.533	1.38	11 %	0 %
	Axial Force (Compression)	NEd	kN	40.0	40.0	40.0	0 %	0 %
	Governing Cross-Sectional Area	Ai	cm^2	28.5	28.5	28.5	0 %	0 %
	Compression Resistance	NRk	kN	1011.75		1011.75		0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Component for N	<eta>Ny		0.049		0.049		0 %
	Design Component for N	<eta>Nz		0.381		0.381		0 %
	Moment	My,Ed	kNm	18.75	18.75	18.75	0 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Moment Resistance	My,Rk	kNm	78.1		78.1		0 %
	Moment Component	<eta>My		0.665				
	Section Modulus	Wz	cm^3	44.61	44.61	44.61	0 %	0 %
	Moment Resistance	Mz,Rk	kNm	15.84		15.84		0 %
	Moment Component	<eta>Mz		0.0		0.0		0 %
	Design 1	<eta>1		0.666		0.666		0 %
	Design 2	<eta>2		0.974	0.947	0.974	-3 %	0 %
	Design Formula							
	NEd / (<chi>y NRk / <gamma>M1) + kyy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kyz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.666 <le> 1 (6.61)							
	NEd / (<chi>z NRk / <gamma>M1) + kzy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kzz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.974 <le> 1 (6.62)							

18	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | British Steel							
	Design Internal Forces							
	Axial Force	NEd	kN	-40.0	-40.0	-40.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	-7.5	-7.5	-7.5	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	18.75	18.75	18.75	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Elastic Critical Load for Torsional Buckling	Ncr,T	kN	911.32		921.06		1 %
	Slenderness	<lambda>_T		1.054		1.048		-1 %
	Buckling Curve	BCz		b		b		0 %
	Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
	Auxiliary Factor	<phic>T		1.2		1.193		-1 %
	Reduction Factor	<chi>T		0.563		0.567		1 %
	Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
	Moment of Inertia	Iy	cm^4	1940.0	1940.0	1940.0	0 %	0 %
	Effective Member Length	Lcr,y	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,y	kN	1610.84	1608.35	1608.35	0 %	0 %
	Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_y		0.793		0.793		0 %
	Buckling Curve	BCy		a		a		0 %
	Imperfection Factor	<alfa>y		0.21	0.21	0.21	0 %	0 %
	Auxiliary Factor	<phic>y		0.876		0.877		0 %
	Reduction Factor	<chi>y		0.8	0.8	0.8	0 %	0 %
	Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
	Effective Member Length	Lcr,z	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,z	kN	117.72	117.72	117.72	0 %	0 %
	Slenderness	<lambda>_z		2.932		2.932		0 %
	Buckling Curve	BCz		b		b		0 %
	Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
	Auxiliary Factor	<phic>z		5.261		5.261		0 %
	Reduction Factor	<chi>z		0.104	0.104	0.104	0 %	0 %
	Section Height	h	mm	200.0	200.0	200.0	0 %	0 %
	Section Width	b	mm	100.0	100.0	100.0	0 %	0 %
	Criterion	h/b		2.0		2.0		0 %
	Buckling Curve	BCLT		b		b		0 %
	Imperfection Factor	<alfa>LT		0.34	0.34	0.34	0 %	0 %
	Elastic Critical Moment for Lateral-Torsional Buckling	Mcr	kNm	28.18	28.18	28.18	0 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Slenderness	<lambda>_LT		1.669		1.665		0 %
	Parameter	<lambda>_LT,0		0.4		0.4		0 %
	Parameter	<beta>		0.75		0.75		0 %
	Auxiliary Factor	<phic>LT		1.76		1.754		0 %
	Reduction Factor	<chi>LT		0.359		0.361		1 %
	Correction Factor	kc		0.752		0.752		0 %
	Modification Factor	f		1.0		1.0		0 %
	Reduction Factor	<chi>LT,mod		0.359	0.361	0.361	1 %	1 %

	Structure type about y-axis	Type		Sway		Sway		0 %
	Moment Factor	Cmy		0.9	1.0	0.9	11 %	0 %
	Structure type about z-axis	Type		Sway		Sway		0 %
	Moment Factor	Cmz		0.9	1.0	0.9	11 %	0 %
	Moment Distribution	Diagr My,LT		1) Linear		1) Linear		0 %
	Moment Factor	<psi>y,LT		0.0	1.0	0.0	ERROR	0 %
	Moment Factor	CmLT		0.6	1.0	0.6	67 %	0 %
	Component Type	Component		rsion. Weak				
	Interaction Factor	kyy		0.926	1.029	0.926	11 %	0 %
	Interaction Factor	kyz		0.828	0.92	0.828	11 %	0 %
	Interaction Factor	kzy		0.891	0.851	0.891	-4 %	0 %
	Interaction Factor	kzz		1.38	1.533	1.38	11 %	0 %
	Axial Force (Compression)	NEd	kN	40.0	40.0	40.0	0 %	0 %
	Governing Cross-Sectional Area	Ai	cm^2	28.5	28.5	28.5	0 %	0 %
	Compression Resistance	NRk	kN	1011.75		1011.75		0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Component for N	<eta>Ny		0.049		0.049		0 %
	Design Component for N	<eta>Nz		0.381		0.381		0 %
	Moment	My,Ed	kNm	18.75	18.75	18.75	0 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Moment Resistance	My,Rk	kNm	78.46		78.1		0 %
	Moment Component	<eta>My		0.665				
	Section Modulus	Wz	cm^3	44.61	44.61	44.61	0 %	0 %
	Moment Resistance	Mz,Rk	kNm	15.84		15.84		0 %
	Moment Component	<eta>Mz		0.0		0.0		0 %
	Design 1	<eta>1		0.666		0.666		0 %
	Design 2	<eta>2		0.974	0.947	0.974	-3 %	0 %
	Design Formula							
	NEd / (<chi>y NRk / <gamma>M1) + kyy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kyz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.666 <le> 1 (6.61)							
	NEd / (<chi>z NRk / <gamma>M1) + kzy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kzz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.974 <le> 1 (6.62)							

19	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | British Steel							
	Design Internal Forces							
	Axial Force	NEd	kN	-40.0	-40.0	-40.0	0 %	0 %
	Shear Force	Vy,Ed	kN	-2.5	-2.5	-2.5	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	6.25	6.25	6.25	0 %	0 %
	Cross-Section Classification - Class 2	Class		2.0	2.0	2.0	0 %	0 %
	Design Ratio							
	Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
	Moment of Inertia	Iy	cm^4	1940.0	1940.0	1940.0	0 %	0 %
	Effective Member Length	Lcr,y	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,y	kN	1610.84	1608.35	1608.35	0 %	0 %
	Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_y		0.793		0.793		0 %
	Buckling Curve	BCy		a		a		0 %
	Imperfection Factor	<alfa>y		0.21	0.21	0.21	0 %	0 %
	Auxiliary Factor	<phic>y		0.876		0.877		0 %
	Reduction Factor	<chi>y		0.8	0.8	0.8	0 %	0 %
	Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
	Effective Member Length	Lcr,z	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,z	kN	117.72	117.72	117.72	0 %	0 %
	Slenderness	<lambda>_z		2.932		2.932		0 %
	Buckling Curve	BCz		b		b		0 %
	Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
	Auxiliary Factor	<phic>z		5.261		5.261		0 %
	Reduction Factor	<chi>z		0.104	0.104	0.104	0 %	0 %
	Structure type about y-axis	Type		Sway		Sway		0 %
	Moment Factor	Cmy		0.9	1.0	0.9	11 %	0 %
	Structure type about z-axis	Type		Sway		Sway		0 %
	Moment Factor	Cmz		0.9	1.0	0.9	11 %	0 %
	Component Type	Component		orsion. Rigid				
	Interaction Factor	kyy		0.926	1.029	0.926	11 %	0 %
	Interaction Factor	kyz		0.828	0.92	0.828	11 %	0 %
	Interaction Factor	kzy		0.556	0.851	0.556	53 %	0 %
	Interaction Factor	kzz		1.38	1.533	1.38	11 %	0 %
	Axial Force (Compression)	NEd	kN	40.0	40.0	40.0	0 %	0 %
	Governing Cross-Sectional Area	Ai	cm^2	28.5	28.5	28.5	0 %	0 %
	Compression Resistance	NRk	kN	1011.75		1011.75		0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Component for N	<eta>Ny		0.049		0.049		0 %
	Design Component for N	<eta>Nz		0.381		0.381		0 %
	Moment	Mz,Ed	kNm	6.25	6.25	6.25	0 %	0 %
	Section Modulus	Wz	cm^3	44.61	44.61	44.61	0 %	0 %
	Moment Resistance	Mz,Rk	kNm	15.84		15.84		0 %
	Moment Component	<eta>Mz		0.395				
	Design 1	<eta>1		0.376		0.376		0 %
	Design 2	<eta>2		0.925	0.986	0.925	7 %	0 %
	Design Formula							

	NEd / (<chi>y NRk / <gamma>M1) + kyy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kyz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.376 <le> 1						(6.61)	
	NEd / (<chi>z NRk / <gamma>M1) + kzy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kzz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.925 <le> 1						(6.62)	

20	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	-40.0	-40.0	-40.0	0 %	0 %
	Shear Force	Vy,Ed	kN	2.5	2.5	2.5	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	6.25	6.25	6.25	0 %	0 %
	Cross-Section Classification - Class 2	Class		2.0	2.0	2.0	0 %	0 %
	Design Ratio							
	Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
	Moment of Inertia	Iy	cm^4	1940.0	1940.0	1940.0	0 %	0 %
	Effective Member Length	Lcr,y	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,y	kN	1610.84	1608.35	1608.35	0 %	0 %
	Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_y		0.793		0.793		0 %
	Buckling Curve	BCy		a		a		0 %
	Imperfection Factor	<alfa>y		0.21	0.21	0.21	0 %	0 %
	Auxiliary Factor	<phic>y		0.876		0.877		0 %
	Reduction Factor	<chi>y		0.8	0.8	0.8	0 %	0 %
	Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
	Effective Member Length	Lcr,z	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,z	kN	117.72	117.72	117.72	0 %	0 %
	Slenderness	<lambda>_z		2.932		2.932		0 %
	Buckling Curve	BCz		b		b		0 %
	Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
	Auxiliary Factor	<phic>z		5.261		5.261		0 %
	Reduction Factor	<chi>z		0.104	0.104	0.104	0 %	0 %
	Structure type about y-axis	Type		Sway		Sway		0 %
	Moment Factor	Cmy		0.9	1.0	0.9	11 %	0 %
	Structure type about z-axis	Type		Sway		Sway		0 %
	Moment Factor	Cmz		0.9	1.0	0.9	11 %	0 %
	Component Type	Component		orsion. Rigid				
	Interaction Factor	kyy		0.926	1.029	0.926	11 %	0 %
	Interaction Factor	kyz		0.828	0.92	0.828	11 %	0 %
	Interaction Factor	kzy		0.556	0.851	0.556	53 %	0 %
	Interaction Factor	kzz		1.38	1.533	1.38	11 %	0 %
	Axial Force (Compression)	NEd	kN	40.0	40.0	40.0	0 %	0 %
	Governing Cross-Sectional Area	Ai	cm^2	28.5	28.5	28.5	0 %	0 %
	Compression Resistance	NRk	kN	1011.75		1011.75		0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Component for N	<eta>Ny		0.049		0.049		0 %
	Design Component for N	<eta>Nz		0.381		0.381		0 %
	Moment	Mz,Ed	kNm	6.25	6.25	6.25	0 %	0 %
	Section Modulus	Wz	cm^3	44.61	44.61	44.61	0 %	0 %
	Moment Resistance	Mz,Rk	kNm	15.84		15.84		0 %
	Moment Component	<eta>Mz		0.395				
	Design 1	<eta>1		0.376		0.376		0 %
	Design 2	<eta>2		0.925	0.986	0.925	7 %	0 %
	Design Formula							
	NEd / (<chi>y NRk / <gamma>M1) + kyy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kyz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.376 <le> 1						(6.61)	
	NEd / (<chi>z NRk / <gamma>M1) + kzy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kzz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.925 <le> 1						(6.62)	

21	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	274.4	274.4	274.4	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	27.44	27.44	27.44	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Section Height	h	mm	200.0	200.0	200.0	0 %	0 %
	Section Width	b	mm	100.0	100.0	100.0	0 %	0 %
	Criterion	h/b		2.0		2.0		0 %
	Buckling Curve	BCLT		b		b		0 %
	Imperfection Factor	<alfa>LT		0.34	0.34	0.34	0 %	0 %
	Elastic Critical Moment for Lateral-Torsional Buckling	Mcr	kNm	28.18	28.18	28.18	0 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_LT		1.665		1.665		0 %
	Parameter	<lambda>_LT,0		0.4		0.4		0 %
	Parameter	<beta>		0.75		0.75		0 %
	Auxiliary Factor	<phic>LT		1.754		1.754		0 %
	Reduction Factor	<chi>LT		0.361		0.361		0 %
	Correction Factor	kc		0.752		0.752		0 %

	Modification Factor	f		1.0		1.0		0 %
	Reduction Factor	<chi>LT,mod		0.361	0.874	0.361	142 %	0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Lateral-Torsional Buckling Resistance Moment	Mb,Rd	kNm	28.18		28.18		0 %
	Moment	My,Ed	kNm	27.44	27.44	27.44	0 %	0 %
	Design Ratio	<eta>		0.974	2.334	0.974	140 %	0 %
	Design Formula My,Ed / Mb,Rd = 0.974 <le> 1 (6.54)							

22	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	-5.6	-5.6	-5.6	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	27.44	27.44	27.44	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Section Height	h	mm	200.0	200.0	200.0	0 %	0 %
	Section Width	b	mm	100.0	100.0	100.0	0 %	0 %
	Criterion	h/b		2.0		2.0		0 %
	Buckling Curve	BCLT		b		b		0 %
	Imperfection Factor	<alfa>LT		0.34	0.34	0.34	0 %	0 %
	Elastic Critical Moment for Lateral-Torsional Buckling	Mcr	kNm	28.18	28.18	28.18	0 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_LT		1.665		1.665		0 %
	Parameter	<lambda>_LT,0		0.4		0.4		0 %
	Parameter	<beta>		0.75		0.75		0 %
	Auxiliary Factor	<phic>LT		1.754		1.754		0 %
	Reduction Factor	<chi>LT		0.361		0.361		0 %
	Correction Factor	kc		0.752		0.752		0 %
	Modification Factor	f		1.0		1.0		0 %
	Reduction Factor	<chi>LT,mod		0.361	0.361	0.361	0 %	0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Lateral-Torsional Buckling Resistance Moment	Mb,Rd	kNm	28.18		28.18		0 %
	Moment	My,Ed	kNm	27.44	27.44	27.44	0 %	0 %
	Design Ratio	<eta>		0.974	0.974	0.974	0 %	0 %
	Design Formula My,Ed / Mb,Rd = 0.974 <le> 1 (6.54)							

23	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	-257.4	-257.4	-257.4	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	12.87	12.87	12.87	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Moment	Mz,Ed	kNm	12.87	12.87	12.87	0 %	0 %
	Plastic Section Modulus	Wpl,z	cm^3	44.61	44.61	44.61	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Moment Resistance	Mpl,z,Rd	kNm	15.84		15.84		0 %
	Shear Force	Vy,Ed	kN	257.4	257.4	257.4	0 %	0 %
	Effective Shear Area	Av,y	cm^2	17.99	17.99	17.99	0 %	0 %
	Shear Force Resistance	Vpl,y,Rd	kN	368.63	368.72	368.72	0 %	0 %
	Criterion Vy,Ed / Vpl,y,Rd	vy		0.698		0.698		0 %
	Interaction Factor	<rho>		0.157		0.157		0 %
	Moment Resistance	Mpl,z,V,Rd	kNm	13.47	13.35	13.47	-1 %	0 %
	Design Ratio	<eta>		0.956	0.964	0.956	1 %	0 %
	Design Formula Mz,Ed / Mc,z,Rd = 0.956 <le> 1 (6.30)							

24	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	2.6	2.6	2.6	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	12.87	12.87	12.87	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Moment	Mz,Ed	kNm	12.87	12.87	12.87	0 %	0 %
	Plastic Section Modulus	Wpl,z	cm^3	44.61	44.61	44.61	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %

	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Moment Resistance	Mpl,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Shear Force	Vy,Ed	kN	2.6	2.6	2.6	0 %	0 %
	Effective Shear Area	Av,y	cm^2	17.99	17.99	17.99	0 %	0 %
	Shear Force Resistance	Vpl,y,Rd	kN	368.63	368.72	368.72	0 %	0 %
	Criterion Vy,Ed / Vpl,y,Rd	vy		0.007		0.007		0 %
	Design Ratio	<eta>		0.813	0.813	0.813	0 %	0 %
	Design Formula Mz,Ed / Mc,z,Rd = 0.813 <le> 1 (6.30)							

25	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	-20.0	-20.0	-20.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	235.2	235.2	235.2	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	23.52	23.52	23.52	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Elastic Critical Load for Torsional Buckling	Ncr,T	kN	923.57		921.0		0 %
	Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
	Moment of Inertia	Iy	cm^4	1940.0	1940.0	1940.0	0 %	0 %
	Effective Member Length	Lcr,y	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,y	kN	1608.35	1608.35	1608.35	0 %	0 %
	Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_y		0.793		0.793		0 %
	Buckling Curve	BCy		a		a		0 %
	Imperfection Factor	<alfa>y		0.21	0.21	0.21	0 %	0 %
	Auxiliary Factor	<phic>y		0.877		0.877		0 %
	Reduction Factor	<chi>y		0.8	0.886	0.8	11 %	0 %
	Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
	Effective Member Length	Lcr,z	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,z	kN	117.72	117.72	117.72	0 %	0 %
	Slenderness	<lambda>_z		2.932		2.932		0 %
	Buckling Curve	BCz		b		b		0 %
	Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
	Auxiliary Factor	<phic>z		5.261		5.261		0 %
	Reduction Factor	<chi>z		0.104	0.168	0.104	62 %	0 %
	Section Height	h	mm	200.0	200.0	200.0	0 %	0 %
	Section Width	b	mm	100.0	100.0	100.0	0 %	0 %
	Criterion	h/b		2.0		2.0		0 %
	Buckling Curve	BCLT		b		b		0 %
	Imperfection Factor	<alfa>LT		0.34	0.34	0.34	0 %	0 %
	Elastic Critical Moment for Lateral-Torsional Buckling	Mcr	kNm	28.18	28.18	28.18	0 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Slenderness	<lambda>_LT		1.665		1.665		0 %
	Parameter	<lambda>_LT,0		0.4		0.4		0 %
	Parameter	<beta>		0.75		0.75		0 %
	Auxiliary Factor	<phic>LT		1.754		1.754		0 %
	Reduction Factor	<chi>LT		0.361		0.361		0 %
	Correction Factor	kc		0.752		0.752		0 %
	Modification Factor	f		1.0		1.0		0 %
	Reduction Factor	<chi>LT,mod		0.361	0.533	0.361	48 %	0 %
	Structure type about y-axis	Type		Sway		Sway		0 %
	Moment Factor	Cmy		0.9	1.0	0.9	11 %	0 %
	Structure type about z-axis	Type		Sway		Sway		0 %
	Moment Factor	Cmz		0.9	1.0	0.9	11 %	0 %
	Moment Distribution	Diagr My,LT		1) Linear		1) Linear		0 %
	Moment Factor	<psi>y,LT		0.0	1.0	0.0	ERROR	0 %
	Moment Factor	CmLT		0.6	1.0	0.6	67 %	0 %
	Component Type	Component		rsion. Weak		Torsion. Weak		0 %
	Interaction Factor	kyy		0.913	1.016	0.913	11 %	0 %
	Interaction Factor	kyz		0.684	0.766	0.684	12 %	0 %
	Interaction Factor	kzy		0.946	0.94	0.946	-1 %	0 %
	Interaction Factor	kzz		1.14	1.277	1.14	12 %	0 %
	Axial Force (Compression)	NEd	kN	20.0	20.0	20.0	0 %	0 %
	Governing Cross-Sectional Area	Ai	cm^2	28.5	28.5	28.5	0 %	0 %
	Compression Resistance	NRk	kN	1011.75		1011.75		0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Component for N	<eta>Ny		0.025		0.025		0 %
	Design Component for N	<eta>Nz		0.19		0.19		0 %
	Moment	My,Ed	kNm	23.52	23.52	23.52	0 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Moment Resistance	My,Rk	kNm	78.1		78.1		0 %
	Moment Component	<eta>My		0.835				0 %
	Section Modulus	Wz	cm^3	44.61	44.61	44.61	0 %	0 %
	Moment Resistance	Mz,Rk	kNm	15.84		15.84		0 %
	Moment Component	<eta>Mz		0.0		0.0		0 %
	Design 1	<eta>1		0.787		0.787		0 %
	Design 2	<eta>2		0.98	1.093	0.98	11 %	0 %

	Design Formula							
	NEd / (<chi>y NRk / <gamma>M1) + kyy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kyz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.787 <le> 1 (6.61)							
	NEd / (<chi>z NRk / <gamma>M1) + kzy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kzz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.980 <le> 1 (6.62)							

26	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	-20.0	-20.0	-20.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	-4.8	-4.8	-4.8	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	23.52	23.52	23.52	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Elastic Critical Load for Torsional Buckling	Ncr,T	kN	923.57		921.0		0 %
	Slenderness	<lambda>_T		1.043		1.048		0 %
	Buckling Curve	BCz		b		b		0 %
	Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
	Auxiliary Factor	<phic>T		1.188		1.193		0 %
	Reduction Factor	<chi>T		0.57		0.567		-1 %
	Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
	Moment of Inertia	Iy	cm^4	1940.0	1940.0	1940.0	0 %	0 %
	Effective Member Length	Lcr,y	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,y	kN	1608.35	1608.35	1608.35	0 %	0 %
	Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_y		0.793		0.793		0 %
	Buckling Curve	BCy		a		a		0 %
	Imperfection Factor	<alfa>y		0.21	0.21	0.21	0 %	0 %
	Auxiliary Factor	<phic>y		0.877		0.877		0 %
	Reduction Factor	<chi>y		0.8	0.8	0.8	0 %	0 %
	Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
	Effective Member Length	Lcr,z	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,z	kN	117.72	117.72	117.72	0 %	0 %
	Slenderness	<lambda>_z		2.932		2.932		0 %
	Buckling Curve	BCz		b		b		0 %
	Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
	Auxiliary Factor	<phic>z		5.261		5.261		0 %
	Reduction Factor	<chi>z		0.104	0.104	0.104	0 %	0 %
	Section Height	h	mm	200.0	200.0	200.0	0 %	0 %
	Section Width	b	mm	100.0	100.0	100.0	0 %	0 %
	Criterion	h/b		2.0		2.0		0 %
	Buckling Curve	BCLT		b		b		0 %
	Imperfection Factor	<alfa>LT		0.34	0.34	0.34	0 %	0 %
	Elastic Critical Moment for Lateral-Torsional Buckling	Mcr	kNm	28.18	28.18	28.18	0 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Slenderness	<lambda>_LT		1.665		1.665		0 %
	Parameter	<lambda>_LT,0		0.4		0.4		0 %
	Parameter	<beta>		0.75		0.75		0 %
	Auxiliary Factor	<phic>LT		1.754		1.754		0 %
	Reduction Factor	<chi>LT		0.361		0.361		0 %
	Correction Factor	kc		0.752		0.752		0 %
	Modification Factor	f		1.0		1.0		0 %
	Reduction Factor	<chi>LT,mod		0.361	0.361	0.361	0 %	0 %
	Structure type about y-axis	Type		Sway		Sway		0 %
	Moment Factor	Cmy		0.9	1.0	0.9	11 %	0 %
	Structure type about z-axis	Type		Sway		Sway		0 %
	Moment Factor	Cmz		0.9	1.0	0.9	11 %	0 %
	Moment Distribution	Diagr My,LT		1) Linear		1) Linear		0 %
	Moment Factor	<psi>y,LT		0.0	1.0	0.0	ERROR	0 %
	Moment Factor	CmLT		0.6	1.0	0.6	67 %	0 %
	Component Type	Component		rsion. Weak				
	Interaction Factor	kyy		0.913	1.015	0.913	11 %	0 %
	Interaction Factor	kyz		0.684	0.76	0.684	11 %	0 %
	Interaction Factor	kzy		0.946	0.926	0.946	-2 %	0 %
	Interaction Factor	kzz		1.14	1.267	1.14	11 %	0 %
	Axial Force (Compression)	NEd	kN	20.0	20.0	20.0	0 %	0 %
	Governing Cross-Sectional Area	Ai	cm^2	28.5	28.5	28.5	0 %	0 %
	Compression Resistance	NRk	kN	1011.75		1011.75		0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Component for N	<eta>Ny		0.025		0.025		0 %
	Design Component for N	<eta>Nz		0.19		0.19		0 %
	Moment	My,Ed	kNm	23.52	23.52	23.52	0 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Moment Resistance	My,Rk	kNm	78.1		78.1		0 %
	Moment Component	<eta>My		0.835				0 %
	Section Modulus	Wz	cm^3	44.61	44.61	44.61	0 %	0 %
	Moment Resistance	Mz,Rk	kNm	15.84		15.84		0 %
	Moment Component	<eta>Mz		0.0		0.0		0 %
	Design 1	<eta>1		0.787		0.787		0 %
	Design 2	<eta>2		0.98	0.963	0.98	-2 %	0 %
	Design Formula							

	NEd / (<chi>y NRk / <gamma>M1) + kyy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kyz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.787 <le> 1 (6.61)							
	NEd / (<chi>z NRk / <gamma>M1) + kzy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kzz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.980 <le> 1 (6.62)							

27	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	-10.0	-10.0	-10.0	0 %	0 %
	Shear Force	Vy,Ed	kN	-257.4	-257.4	-257.4	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	12.87	12.87	12.87	0 %	0 %
	Cross-Section Classification - Class 2	Class		2.0	2.0	2.0	0 %	0 %
	Design Ratio							
	Moment	Mz,Ed	kNm	12.87	12.87	12.87	0 %	0 %
	Plastic Section Modulus	Wpl,z	cm^3	44.61	44.61	44.61	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Moment Resistance	Mpl,z,Rd	kNm	15.84		15.84		0 %
	Shear Force	Vy,Ed	kN	257.4	257.4	257.4	0 %	0 %
	Effective Shear Area	Av,y	cm^2	17.99	17.99	17.99	0 %	0 %
	Shear Force Resistance	Vpl,y,Rd	kN	368.63	368.72	368.72	0 %	0 %
	Criterion Vy,Ed / Vpl,y,Rd	vy		0.698		0.698		0 %
	Interaction Factor	<rho>		0.157		0.157		0 %
	Moment Resistance	Mpl,z,V,Rd	kNm	13.47	13.35	13.47	-1 %	0 %
	Axial Force	NEd	kN	-10.0	-10.0	-10.0	0 %	0 %
	Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
	Design plastic resistance to normal forces	Npl,Rd	kN	1011.75		1011.75		0 %
	Axial Force Resistance Reduced due to Shear	NV,Rd	kN	911.36		917.03		1 %
	Criterion	nw		0.027				
	Design Component for Mz	<eta>Mz		0.956		0.956		0 %
	Design Ratio	<eta>		0.956	1.19	0.956	24 %	0 %
	Design Formula							
	Mz,Ed / MN,z,Rd = 0.956 <le> 1 (6.31)							

28	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	-10.0	-10.0	-10.0	0 %	0 %
	Shear Force	Vy,Ed	kN	2.6	2.6	2.6	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	12.87	12.87	12.87	0 %	0 %
	Cross-Section Classification - Class 2	Class	2.0	2.0	2.0	2.0	0 %	0 %
	Design Ratio							
	Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
	Moment of Inertia	Iy	cm^4	1940.0	1940.0	1940.0	0 %	0 %
	Effective Member Length	Lcr,y	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,y	kN	1608.35	1608.35	1608.35	0 %	0 %
	Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_y		0.793		0.793		0 %
	Buckling Curve	BCy		a		a		0 %
	Imperfection Factor	<alfa>y		0.21	0.21	0.21	0 %	0 %
	Auxiliary Factor	<phic>y		0.877		0.877		0 %
	Reduction Factor	<chi>y		0.8	0.8	0.8	0 %	0 %
	Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
	Effective Member Length	Lcr,z	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,z	kN	117.72	117.72	117.72	0 %	0 %
	Slenderness	<lambda>_z		2.932		2.932		0 %
	Buckling Curve	BCz		b		b		0 %
	Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
	Auxiliary Factor	<phic>z		5.261		5.261		0 %
	Reduction Factor	<chi>z		0.104	0.104	0.104	0 %	0 %
	Structure type about y-axis	Type		Sway		Sway		0 %
	Moment Factor	Cmy		0.9	1.0	0.9	11 %	0 %
	Structure type about z-axis	Type		Sway		Sway		0 %
	Moment Factor	Cmz		0.9	1.0	0.9	11 %	0 %
	Component Type	Component		orsion. Rigid		Torsion. Rigid		0 %
	Interaction Factor	kyy		0.907	1.007	0.907	11 %	0 %
	Interaction Factor	kyz		0.612	0.68	0.612	11 %	0 %
	Interaction Factor	kzy		0.544	0.963	0.544	77 %	0 %
	Interaction Factor	kzz		1.02	1.133	1.02	11 %	0 %
	Axial Force (Compression)	NEd	kN	10.0	10.0	10.0	0 %	0 %
	Governing Cross-Sectional Area	Ai	cm^2	28.5	28.5	28.5	0 %	0 %
	Compression Resistance	NRk	kN	1011.75		1011.75		0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Component for N	<eta>Ny		0.012				
	Design Component for N	<eta>Nz		0.095				
	Moment	Mz,Ed	kNm	12.87	12.87	12.87	0 %	0 %
	Section Modulus	Wz	cm^3	44.61	44.61	44.61	0 %	0 %
	Moment Resistance	Mz,Rk	kNm	15.84		15.84		0 %

Moment Component	<eta>Mz		0.813				
Design 1	<eta>1		0.51		0.51		0 %
Design 2	<eta>2		0.924	1.016	0.924	10 %	0 %
Design Formula							
NEd / (<chi>y NRk / <gamma>M1) + kyy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kyz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.510 <le> 1 (6.61)							
NEd / (<chi>z NRk / <gamma>M1) + kzy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kzz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.924 <le> 1 (6.62)							

APPENDIX C: Results of non-simplified design in pre-study

1	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	1000.0	1000.0	1000.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - No Compression	Class			1.0			
	Design Ratio							
	Tension Force	Nt,Ed	kN	1000.0	1000.0	1000.0	0 %	0 %
	Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Design plastic resistance to normal forces	Npl,Rd	kN	1011.75		1011.75		0 %
	Axial Force Resistance	Nt,Rd	kN	1011.75	1011.75	1011.75	0 %	0 %
	Design Ratio	<eta>		0.988	0.988	0.988	0 %	0 %
	Design Formula							
	Nt,Ed / Nt,Rd = 0.988 <le> 1 (6.5)							

2	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	1000.0	1000.0	1000.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - No Compression	Class			1.0	-		
	Design Ratio							
	Tension Force	Nt,Ed	kN	1000.0	1000.0	1000.0	0 %	0 %
	Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Design plastic resistance to normal forces	Npl,Rd	kN	1011.75		1011.75		0 %
	Axial Force Resistance	Nt,Rd	kN	1011.75	1011.75	1011.75	0 %	0 %
	Design Ratio	<eta>		0.988	0.988	0.988	0 %	0 %
	Design Formula							
	Nt,Ed / Nt,Rd = 0.988 <le> 1 (6.5)							

3	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	-100.0	-100.0	-100.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 2	Class		2.0	2.0	2.0	0 %	0 %
	Design Ratio							
	Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
	Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
	Effective Member Length	Lcr,z	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,z	kN	117.72	117.72	117.72	0 %	0 %
	Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_z		2.932		2.932		0 %
	Axial Force (Compression)	NEd	kN	100.0	100.0	100.0	0 %	0 %
	Criterion NEd / Ncr,z	<eta>N,cr		0.849		0.849		0 %
	Buckling Curve	BCz		b		b		0 %
	Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
	Auxiliary Factor	<phic>z		5.261		5.261		0 %
	Reduction Factor	<chi>z		0.104	0.104	0.104	0 %	0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Flexural Buckling Resistance	Nb,z,Rd	kN	105.06		105.06		0 %
	Design Ratio	<eta>		0.952	0.952	0.952	0 %	0 %
	Design Formula							
	NEd / Nb,z,Rd = 0.952 <le> 1 (6.46)							

4	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	-100.0	-100.0	-100.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 2	Class		2.0	2.0	2.0	0 %	0 %
	Design Ratio							
	Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
	Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
	Effective Member Length	Lcr,z	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,z	kN	117.72	117.72	117.72	0 %	0 %
	Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_z		2.932		2.932		0 %
	Axial Force (Compression)	NEd	kN	100.0	100.0	100.0	0 %	0 %
	Criterion NEd / Ncr,z	<eta>N,cr		0.849		0.849		0 %
	Buckling Curve	BCz		b		b		0 %
	Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
	Auxiliary Factor	<phic>z		5.261		5.261		0 %
	Reduction Factor	<chi>z		0.104	0.104	0.104	0 %	0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Flexural Buckling Resistance	Nb,z,Rd	kN	105.06		105.06		0 %
	Design Ratio	<eta>		0.952	0.952	0.952	0 %	0 %
	Design Formula NEd / Nb,z,Rd = 0.952 <le> 1 (6.46)							

5	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	279.44	279.44	279.44	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	2.79	2.794	2.79	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - No compression	Class			1.0	1.0		
	Design Ratio							
	Shear Force	Vz,Ed	kN	279.44	279.44	279.44	0 %	0 %
	Effective Shear Area	Av,z	cm^2	14.02	14.02	14.02	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Shear Force Resistance	Vpl,z,Rd	kN	287.27	287.35	287.35	0 %	0 %
	Design Ratio	<eta>		0.973	0.972	0.972	0 %	0 %
	Design Formula Vz,Ed / Vpl,z,Rd = 0.973 <le> 1 (6.17)							

6	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | British Steel							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	-0.56	-0.56	-0.56	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	2.79	2.794	2.79	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Section Height	h	mm	200.0	200.0	200.0	0 %	0 %
	Section Width	b	mm	100.0	100.0	100.0	0 %	0 %
	Criterion	h/b		2.0		2.0		0 %
	Buckling Curve	BCLT		b		b		0 %
	Imperfection Factor	<alfa>LT		0.34	0.34	0.34	0 %	0 %
	Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
	Shear Modulus	G	kN/cm^2	8076.92	8076.92	8076.92	0 %	0 %
	Length Factor	kz		1.0	1.0	1.0	0 %	0 %
	Length Factor	kw		1.0	1.0	1.0	0 %	0 %
	Length	L	m	5.0	5.0	5.0	0 %	0 %
	Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
	Warping Constant of Cross-Section	Iw	cm^6	12990.0	12990.0	12990.0	0 %	0 %
	Torsional Constant	It	cm^4	7.02	7.02	7.02	0 %	0 %
	Moment Factor	C1		1.806	1.0	1.806	-45 %	0 %
	Elastic Critical Moment for Lateral-Torsional Buckling	Mcr	kNm	50.91	28.18	50.9	-45 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_LT		1.239		1.239		0 %
	Parameter	<lambda>_LT,0		0.4		0.4		0 %
	Parameter	<beta>		0.75		0.75		0 %
	Auxiliary Factor	<phic>LT		1.218		1.218		0 %
	Reduction Factor	<chi>LT		0.557		0.557		0 %

	Correction Factor	kc		0.86		0.86		0 %
	Modification Factor	f		0.957		0.957		0 %
	Reduction Factor	<chi>LT,mod		0.582	0.361	0.582	-38 %	0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Lateral-Torsional Buckling Resistance Moment	Mb,Rd	kNm	45.48		45.47		0 %
	Moment	My,Ed	kNm	2.79	2.794	2.79	0 %	0 %
	Design Ratio	<eta>	0.059	0.061	0.099	0.061	63 %	0 %
	Design Formula My,Ed / Mb,Rd = 0.061 <le> 1 (6.54)							

7	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	-349.3	-349.3	-349.3	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	3.49	3.493	3.49	0 %	0 %
	Cross-Section Classification - No Compression	Class			1.0			
	Design Ratio							
	Shear Force	Vy,Ed	kN	349.3	349.3	349.3	0 %	0 %
	Effective Shear Area	Av,y	cm^2	17.99	17.99	17.99	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Shear Force Resistance	Vpl,y,Rd	kN	368.63	368.72	368.72	0 %	0 %
	Design Ratio	<eta>		0.948	1.105	0.947	17 %	0 %
	Design Formula Vy,Ed / Vpl,y,Rd = 0.948 <le> 1 (6.17)							

8	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.7	0.7	0.7	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	3.49	3.493	3.49	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Moment	Mz,Ed	kNm	3.49	3.493	3.49	0 %	0 %
	Plastic Section Modulus	Wpl,z	cm^3	44.61	44.61	44.61	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Moment Resistance	Mpl,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Shear Force	Vy,Ed	kN	0.7	0.7	0.7	0 %	0 %
	Effective Shear Area	Av,y	cm^2	17.99	17.99	17.99	0 %	0 %
	Shear Force Resistance	Vpl,y,Rd	kN	368.63	368.72	368.72	0 %	0 %
	Criterion Vy,Ed / Vpl,y,Rd	vy		0.002		0.002		0 %
	Moment Resistance	Mc,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Design Ratio	<eta>		0.221	0.221	0.22	0 %	0 %
	Design Formula Mz,Ed / Mc,z,Rd = 0.221 <le> 1 (6.12)							

9	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	11.0	11.0	11.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	27.5	27.5	27.5	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Section Height	h	mm	200.0	200.0	200.0	0 %	0 %
	Section Width	b	mm	100.0	100.0	100.0	0 %	0 %
	Criterion	h/b		2.0		2.0		0 %
	Buckling Curve	BCLT		b		b		0 %
	Imperfection Factor	<alfa>LT		0.34	0.34	0.34	0 %	0 %
	Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
	Shear Modulus	G	kN/cm^2	8076.92	8076.92	8076.92	0 %	0 %
	Length Factor	kz		1.0	1.0	1.0	0 %	0 %
	Length Factor	kw		1.0	1.0	1.0	0 %	0 %
	Length	L	m	5.0	5.0	5.0	0 %	0 %
	Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
	Warping Constant of Cross-Section	Iw	cm^6	12990.0	12990.0	12990.0	0 %	0 %
	Torsional Constant	It	cm^4	7.02	7.02	7.02	0 %	0 %
	Moment Factor	C1		1.358	1.0	1.358	-26 %	0 %
	Elastic Critical Moment for Lateral-Torsional Buckling	Mcr	kNm	38.28	28.18	38.27	-26 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %

	Slenderness	<lambda>_LT		1.428		1.429		0 %
	Parameter	<lambda>_LT,0		0.4		0.4		0 %
	Parameter	<beta>		0.75		0.75		0 %
	Auxiliary Factor	<phic>LT		1.44		1.44		0 %
	Reduction Factor	<chi>LT		0.459		0.459		0 %
	Correction Factor	kc		0.86		0.86		0 %
	Modification Factor	f		0.985		0.985		0 %
	Reduction Factor	<chi>LT,mod		0.466	0.361	0.466	-23 %	0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Lateral-Torsional Buckling Resistance Moment	Mb,Rd	kNm	36.41		36.41		0 %
	Moment	My,Ed	kNm	27.5	27.5	27.5	0 %	0 %
	Design Ratio	<eta>		0.755	0.976	0.755	29 %	0 %
	Design Formula My,Ed / Mb,Rd = 0.755 <le> 1 (6.54)							

10	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	-11.0	-11.0	-11.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	27.5	27.5	27.5	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Section Height	h	mm	200.0	200.0	200.0	0 %	0 %
	Section Width	b	mm	100.0	100.0	100.0	0 %	0 %
	Criterion	h/b		2.0		2.0		0 %
	Buckling Curve	BCLT		b		b		0 %
	Imperfection Factor	<alfa>LT		0.34	0.34	0.34	0 %	0 %
	Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
	Shear Modulus	G	kN/cm^2	8076.92	8076.92	8076.92	0 %	0 %
	Length Factor	kz		1.0	1.0	1.0	0 %	0 %
	Length Factor	kw		1.0	1.0	1.0	0 %	0 %
	Length	L	m	5.0	5.0	5.0	0 %	0 %
	Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
	Warping Constant of Cross-Section	Iw	cm^6	12990.0	12990.0	12990.0	0 %	0 %
	Torsional Constant	It	cm^4	7.02	7.02	7.02	0 %	0 %
	Moment Factor	C1		1.358	1.0	1.358	-26 %	0 %
	Elastic Critical Moment for Lateral-Torsional Buckling	Mcr	kNm	38.28	28.18	38.27	-26 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_LT		1.428		1.429		0 %
	Parameter	<lambda>_LT,0		0.4		0.4		0 %
	Parameter	<beta>		0.75		0.75		0 %
	Auxiliary Factor	<phic>LT		1.44		1.44		0 %
	Reduction Factor	<chi>LT		0.459		0.459		0 %
	Correction Factor	kc		0.86		0.86		0 %
	Modification Factor	f		0.985		0.985		0 %
	Reduction Factor	<chi>LT,mod		0.466	0.361	0.466	-23 %	0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Lateral-Torsional Buckling Resistance Moment	Mb,Rd	kNm	36.41		36.41		0 %
	Moment	My,Ed	kNm	27.5	27.5	27.5	0 %	0 %
	Design Ratio	<eta>		0.755	0.976	0.755	29 %	0 %
	Design Formula My,Ed / Mb,Rd = 0.755 <le> 1 (6.54)							

11	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	-6.0	-6.0	-6.0	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	15.0	15.0	15.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Moment	Mz,Ed	kNm	15.0	15.0	15.0	0 %	0 %
	Plastic Section Modulus	Wpl,z	cm^3	44.61	44.61	44.61	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Moment Resistance	Mpl,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Shear Force	Vy,Ed	kN	6.0	6.0	6.0	0 %	0 %
	Effective Shear Area	Av,y	cm^2	17.99	17.99	17.99	0 %	0 %
	Shear Force Resistance	Vpl,y,Rd	kN	368.63	368.72	368.72	0 %	0 %
	Criterion Vy,Ed / Vpl,y,Rd	vy		0.016		0.016		0 %
	Moment Resistance	Mc,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Design Ratio	<eta>		0.947	0.947	0.947	0 %	0 %
	Design Formula Mz,Ed / Mc,z,Rd = 0.947 <le> 1 (6.12)							

12	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	-6.0	-6.0	-6.0	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	15.0	15.0	15.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Moment	Mz,Ed	kNm	15.0	15.0	15.0	0 %	0 %
	Plastic Section Modulus	Wpl,z	cm^3	44.61	44.61	44.61	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Moment Resistance	Mpl,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Shear Force	Vy,Ed	kN	6.0	6.0	6.0	0 %	0 %
	Effective Shear Area	Av,y	cm^2	17.99	17.99	17.99	0 %	0 %
	Shear Force Resistance	Vpl,y,Rd	kN	368.63	368.72	368.72	0 %	0 %
	Criterion Vy,Ed / Vpl,y,Rd	vy		0.016		0.016		0 %
	Moment Resistance	Mc,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Design Ratio	<eta>		0.947	0.947	0.947	0 %	0 %
	Design Formula							
	Mz,Ed / Mc,z,Rd = 0.947 <le> 1 (6.12)							

13	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | British Steel							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	28.13	28.125	28.13	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Section Height	h	mm	200.0	200.0	200.0	0 %	0 %
	Section Width	b	mm	100.0	100.0	100.0	0 %	0 %
	Criterion	h/b		2.0		2.0		0 %
	Buckling Curve	BCLT		b		b		0 %
	Imperfection Factor	<alfa>LT		0.34	0.34	0.34	0 %	0 %
	Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
	Shear Modulus	G	kN/cm^2	8076.92	8076.92	8076.92	0 %	0 %
	Length Factor	kz		1.0	1.0	1.0	0 %	0 %
	Length Factor	kw		1.0	1.0	1.0	0 %	0 %
	Length	L	m	5.0	5.0	5.0	0 %	0 %
	Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
	Warping Constant of Cross-Section	Iw	cm^6	12990.0	12990.0	12990.0	0 %	0 %
	Torsional Constant	It	cm^4	7.02	7.02	7.02	0 %	0 %
	Moment Factor	C1		1.13	1.0	1.13	-12 %	0 %
	Elastic Critical Moment for Lateral-Torsional Buckling	Mcr	kNm	31.85	28.18	31.85	-12 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_LT		1.566		1.566		0 %
	Parameter	<lambda>_LT,0		0.4		0.4		0 %
	Parameter	<beta>		0.75		0.75		0 %
	Auxiliary Factor	<phic>LT		1.618		1.618		0 %
	Reduction Factor	<chi>LT		0.4		0.4		0 %
	Correction Factor	kc		0.94		0.94		0 %
	Modification Factor	f		1.0		1.0		0 %
	Reduction Factor	<chi>LT,mod		0.4	0.361	0.4	-10 %	0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Lateral-Torsional Buckling Resistance Moment	Mb,Rd	kNm	31.24		31.24		0 %
	Moment	My,Ed	kNm	28.13	28.125	28.13	0 %	0 %
	Design Ratio	<eta>		0.9	0.998	0.9	11 %	0 %
	Design Formula							
	My,Ed / Mb,Rd = 0.900 <le> 1 (6.54)							

14	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	28.13	28.125	28.13	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Section Height	h	mm	200.0	200.0	200.0	0 %	0 %
	Section Width	b	mm	100.0	100.0	100.0	0 %	0 %
	Criterion	h/b		2.0		2.0		0 %
	Buckling Curve	BCLT		b		b		0 %

	Imperfection Factor	<alfa>LT		0.34	0.34	0.34	0 %	0 %
	Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
	Shear Modulus	G	kN/cm^2	8076.92	8076.92	8076.92	0 %	0 %
	Length Factor	kz		1.0	1.0	1.0	0 %	0 %
	Length Factor	kw		1.0	1.0	1.0	0 %	0 %
	Length	L	m	5.0	5.0	5.0	0 %	0 %
	Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
	Warping Constant of Cross-Section	Iw	cm^6	12990.0	12990.0	12990.0	0 %	0 %
	Torsional Constant	It	cm^4	7.02	7.02	7.02	0 %	0 %
	Moment Factor	C1		1.13	1.0	1.13	-12 %	0 %
	Elastic Critical Moment for Lateral-Torsional Buckling	Mcr	kNm	31.85	28.18	31.85	-12 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_LT		1.566		1.566		0 %
	Parameter	<lambda>_LT,0		0.4		0.4		0 %
	Parameter	<beta>		0.75		0.75		0 %
	Auxiliary Factor	<phic>LT		1.618		1.618		0 %
	Reduction Factor	<chi>LT		0.4		0.4		0 %
	Correction Factor	kc		0.94		0.94		0 %
	Modification Factor	f		1.0		1.0		0 %
	Reduction Factor	<chi>LT,mod		0.4	0.361	0.4	-10 %	0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Lateral-Torsional Buckling Resistance Moment	Mb,Rd	kNm	31.24		31.24		0 %
	Moment	My,Ed	kNm	28.13	28.125	28.13	0 %	0 %
	Design Ratio	<eta>		0.9	0.998	0.9	11 %	0 %
	Design Formula							
	My,Ed / Mb,Rd = 0.900 <le> 1 (6.54)							

15	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	15.63	15.625	15.63	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Moment	Mz,Ed	kNm	15.63	15.625	15.63	0 %	0 %
	Plastic Section Modulus	Wpl,z	cm^3	44.61	44.61	44.61	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Moment Resistance	Mpl,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Effective Shear Area	Av,y	cm^2	17.99	17.99	17.99	0 %	0 %
	Shear Force Resistance	Vpl,y,Rd	kN	368.63	368.72	368.72	0 %	0 %
	Criterion Vy,Ed / Vpl,y,Rd	vy		0.007				
	Moment Resistance	Mc,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Design Ratio	<eta>		0.987	0.987	0.987	0 %	0 %
	Design Formula							
	Mz,Ed / Mc,z,Rd = 0.987 <le> 1 (6.12)							

16	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	15.63	15.625	15.63	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Moment	Mz,Ed	kNm	15.63	15.625	15.63	0 %	0 %
	Plastic Section Modulus	Wpl,z	cm^3	44.61	44.61	44.61	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Moment Resistance	Mpl,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Effective Shear Area	Av,y	cm^2	17.99	17.99	17.99	0 %	0 %
	Shear Force Resistance	Vpl,y,Rd	kN	368.63	368.72	368.72	0 %	0 %
	Criterion Vy,Ed / Vpl,y,Rd	vy		0.0		0.0		0 %
	Moment Resistance	Mc,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Design Ratio	<eta>		0.987	0.987	0.987	0 %	0 %
	Design Formula							
	Mz,Ed / Mc,z,Rd = 0.987 <le> 1 (6.12)							

17	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	-40.0	-40.0	-40.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %

Shear Force	Vz,Ed	kN	7.5	7.5	7.5	0 %	0 %
Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
Moment	My,Ed	kNm	18.75	18.75	18.75	0 %	0 %
Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
Design Ratio							
Elastic Critical Load for Torsional Buckling	Ncr,T	kN	923.57		921.06		0 %
Slenderness	<lambda>_T		1.047		1.048		0 %
Buckling Curve	BCz		b		b		0 %
Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
Auxiliary Factor	<phic>T		1.192		1.193		0 %
Reduction Factor	<chi>T		0.568		0.567		0 %
Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
Moment of Inertia	Iy	cm^4	1940.0	1940.0	1940.0	0 %	0 %
Effective Member Length	Lcr,y	m	5.0	5.0	5.0	0 %	0 %
Elastic Flexural Buckling Force	Ncr,y	kN	1608.35	1608.35	1608.35	0 %	0 %
Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
Slenderness	<lambda>_y		0.793		0.793		0 %
Buckling Curve	BCy		a		a		0 %
Imperfection Factor	<alfa>y		0.21	0.21	0.21	0 %	0 %
Auxiliary Factor	<phic>y		0.877		0.877		0 %
Reduction Factor	<chi>y		0.8	0.8	0.8	0 %	0 %
Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
Effective Member Length	Lcr,z	m	5.0	5.0	5.0	0 %	0 %
Elastic Flexural Buckling Force	Ncr,z	kN	117.72	117.72	117.72	0 %	0 %
Slenderness	<lambda>_z		2.932		2.932		0 %
Buckling Curve	BCz		b		b		0 %
Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
Auxiliary Factor	<phic>z		5.261		5.261		0 %
Reduction Factor	<chi>z		0.104	0.104	0.104	0 %	0 %
Section Height	h	mm	200.0	200.0	200.0	0 %	0 %
Section Width	b	mm	100.0	100.0	100.0	0 %	0 %
Criterion	h/b		2.0		2.0		0 %
Buckling Curve	BCLT		b		b		0 %
Imperfection Factor	<alfa>LT		0.34	0.34	0.34	0 %	0 %
Shear Modulus	G	kN/cm^2	8076.92	8076.92	8076.92	0 %	0 %
Length Factor	kz		1.0	1.0	1.0	0 %	0 %
Length Factor	kw		1.0	1.0	1.0	0 %	0 %
Length	L	m	5.0	5.0	5.0	0 %	0 %
Warping Constant of Cross-Section	Iw	cm^6	12990.0	12990.0	12990.0	0 %	0 %
Torsional Constant	It	cm^4	7.02	7.02	7.02	0 %	0 %
Moment Factor	C1		1.358	1.0	1.358	-26 %	0 %
Elastic Critical Moment for Lateral-Torsional Buckling	Mcr	kNm	38.28	28.18	38.28	-26 %	0 %
Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
Slenderness	<lambda>_LT		1.428		1.429		0 %
Parameter	<lambda>_LT,0		0.4		0.4		0 %
Parameter	<beta>		0.75		0.75		0 %
Auxiliary Factor	<phic>LT		1.44		1.44		0 %
Reduction Factor	<chi>LT		0.459		0.459		0 %
Correction Factor	kc		0.86		0.86		0 %
Modification Factor	f		0.985		0.985		0 %
Reduction Factor	<chi>LT,mod		0.466	0.361	0.466	-23 %	0 %
Structure type about y-axis	Type		Non-sway		Non-sway		0 %
Moment Distribution	Diagr My		Max in Span		3) Max in Span		0 %
Moment Factor	<psi>y		0.0		0.0		0 %
Moment	Mh,y	kNm	0.0		0.0		0 %
Moment	Ms,y	kNm	18.75		18.75		0 %
Ratio Mh,y / Ms,y	<alfa>h,y		0.0		0.0		0 %
Load Type	Load z		Sing. Load		Sing. Load		0 %
Moment Factor	Cmy		0.9	1.0	0.9	11 %	0 %
Structure type about z-axis	Type		Non-sway		Non-sway		0 %
Moment Distribution	Diagr Mz		1) Linear		1) Linear		0 %
Moment Factor	<psi>z		0.0		0.0		0 %
Moment Factor	Cmz		0.6	1.0	0.6	67 %	0 %
Moment Distribution	Diagr My,LT		Max in Span		3) Max in Span		0 %
Moment Factor	<psi>y,LT		0.0	1.0	0.0	ERROR	0 %
Moment	Mh,y,LT	kNm	0.0		0.0		0 %
Moment	Ms,y,LT	kNm	18.75		18.75		0 %
Ratio Mh,y / Ms,y	<alfa>h,y.LT		0.0		0.0		0 %
Load Type	Load z		Sing. Load		Sing. Load		0 %
Moment Factor	CmLT		0.9	1.0	0.9	11 %	0 %
Component Type	Component		rsion. Weak		Torsion. Weak		0 %
Interaction Factor	kyy		0.926	1.029	0.926	11 %	0 %
Interaction Factor	kyz		0.552	0.92	0.552	67 %	0 %
Interaction Factor	kzy		0.941	0.851	0.941	-10 %	0 %
Interaction Factor	kzz		0.92	1.533	0.92	67 %	0 %
Axial Force (Compression)	NEd	kN	40.0	40.0	40.0	0 %	0 %
Governing Cross-Sectional Area	Ai	cm^2	28.5	28.5	28.5	0 %	0 %
Compression Resistance	NRk	kN	1011.75		1011.75		0 %
Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
Design Component for N	<eta>Ny		0.049		0.049		0 %
Design Component for N	<eta>Nz		0.381		0.381		0 %

	Moment	My,Ed	kNm	18.75	18.75	18.75	0 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Moment Resistance	My,Rk	kNm	78.1		78.1		0 %
	Moment Component	<eta>My		0.515				
	Section Modulus	Wz	cm^3	44.61	44.61	44.61	0 %	0 %
	Moment Resistance	Mz,Rk	kNm	15.84		15.84		0 %
	Moment Component	<eta>Mz		0.0		0.0		0 %
	Design 1	<eta>1		0.526		0.527		0 %
	Design 2	<eta>2		0.866	0.947	0.866	9 %	0 %
	Design Formula							
	NEd / (<chi>y NRk / <gamma>M1) + kyy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kyz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.526 <le> 1						(6.61)	
	NEd / (<chi>z NRk / <gamma>M1) + kzy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kzz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.866 <le> 1						(6.62)	

18	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | British Steel							
	Design Internal Forces							
	Axial Force	NEd	kN	-40.0	-40.0	-40.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	-7.5	-7.5	-7.5	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	18.75	18.75	18.75	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Elastic Critical Load for Torsional Buckling	Ncr,T	kN	923.57		921.06		0 %
	Slenderness	<lambda>_T		1.047		1.048		0 %
	Buckling Curve	BCz		b		b		0 %
	Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
	Auxiliary Factor	<phic>T		1.192		1.193		0 %
	Reduction Factor	<chi>T		0.568		0.567		0 %
	Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
	Moment of Inertia	Iy	cm^4	1940.0	1940.0	1940.0	0 %	0 %
	Effective Member Length	Lcr,y	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,y	kN	1608.35	1608.35	1608.35	0 %	0 %
	Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_y		0.793		0.793		0 %
	Buckling Curve	BCy		a		a		0 %
	Imperfection Factor	<alfa>y		0.21	0.21	0.21	0 %	0 %
	Auxiliary Factor	<phic>y		0.877		0.877		0 %
	Reduction Factor	<chi>y		0.8	0.8	0.8	0 %	0 %
	Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
	Effective Member Length	Lcr,z	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,z	kN	117.72	117.72	117.72	0 %	0 %
	Slenderness	<lambda>_z		2.932		2.932		0 %
	Buckling Curve	BCz		b		b		0 %
	Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
	Auxiliary Factor	<phic>z		5.261		5.261		0 %
	Reduction Factor	<chi>z		0.104	0.104	0.104	0 %	0 %
	Section Height	h	mm	200.0	200.0	200.0	0 %	0 %
	Section Width	b	mm	100.0	100.0	100.0	0 %	0 %
	Criterion	h/b		2.0		2.0		0 %
	Buckling Curve	BCLT		b		b		0 %
	Imperfection Factor	<alfa>LT		0.34	0.34	0.34	0 %	0 %
	Shear Modulus	G	kN/cm^2	8076.92	8076.92	8076.92	0 %	0 %
	Length Factor	kz		1.0	1.0	1.0	0 %	0 %
	Length Factor	kw		1.0	1.0	1.0	0 %	0 %
	Length	L	m	5.0	5.0	5.0	0 %	0 %
	Warping Constant of Cross-Section	Iw	cm^6	12990.0	12990.0	12990.0	0 %	0 %
	Torsional Constant	It	cm^4	7.02	7.02	7.02	0 %	0 %
	Moment Factor	C1		1.358	1.0	1.358	-26 %	0 %
	Elastic Critical Moment for Lateral-Torsional Buckling	Mcr	kNm	38.28	28.18	38.28	-26 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Slenderness	<lambda>_LT		1.428		1.429		0 %
	Parameter	<lambda>_LT,0		0.4		0.4		0 %
	Parameter	<beta>		0.75		0.75		0 %
	Auxiliary Factor	<phic>LT		1.44		1.44		0 %
	Reduction Factor	<chi>LT		0.459		0.459		0 %
	Correction Factor	kc		0.86		0.86		0 %
	Modification Factor	f		0.985		0.985		0 %
	Reduction Factor	<chi>LT,mod		0.466	0.361	0.466	-23 %	0 %
	Structure type about y-axis	Type		Non-sway		Non-sway		0 %
	Moment Distribution	Diagr My		Max in Span	3)	Max in Span		0 %
	Moment Factor	<psi>y		0.0		0.0		0 %
	Moment	Mh,y	kNm	0.0		0.0		0 %
	Moment	Ms,y	kNm	18.75		18.75		0 %
	Ratio Mh,y / Ms,y	<alfa>h,y		0.0		0.0		0 %
	Load Type	Load z		Sing. Load		Sing. Load		0 %
	Moment Factor	Cmy		0.9	1.0	0.9	11 %	0 %
	Structure type about z-axis	Type		Non-sway		Non-sway		0 %
	Moment Distribution	Diagr Mz		1) Linear		1) Linear		0 %
	Moment Factor	<psi>z		0.0		0.0		0 %
	Moment Factor	Cmz		0.6	1.0	0.6	67 %	0 %

	Moment Distribution	Diagr My,LT		Max in Span		3) Max in Span		0 %
	Moment Factor	<psi>y,LT		0.0	1.0	0.0	ERROR	0 %
	Moment	Mh,y,LT	kNm	0.0		0.0		0 %
	Moment	Ms,y,LT	kNm	18.75		18.75		0 %
	Ratio Mh,y / Ms,y	<alfa>h,y.LT		0.0		0.0		0 %
	Load Type	Load z		Sing. Load		Sing. Load		0 %
	Moment Factor	CmLT		0.9	1.0	0.9	11 %	0 %
	Component Type	Component		rsion. Weak		Torsion. Weak		0 %
	Interaction Factor	kyy		0.926	1.029	0.926	11 %	0 %
	Interaction Factor	kyz		0.552	0.92	0.552	67 %	0 %
	Interaction Factor	kzy		0.941	0.851	0.941	-10 %	0 %
	Interaction Factor	kzz		0.92	1.533	0.92	67 %	0 %
	Axial Force (Compression)	NEd	kN	40.0	40.0	40.0	0 %	0 %
	Governing Cross-Sectional Area	Ai	cm^2	28.5	28.5	28.5	0 %	0 %
	Compression Resistance	NRk	kN	1011.75		1011.75		0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Component for N	<eta>Ny		0.049		0.049		0 %
	Design Component for N	<eta>Nz		0.381		0.381		0 %
	Moment	My,Ed	kNm	18.75	18.75	18.75	0 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Moment Resistance	My,Rk	kNm	78.1		78.1		0 %
	Moment Component	<eta>My		0.515				
	Section Modulus	Wz	cm^3	44.61	44.61	44.61	0 %	0 %
	Moment Resistance	Mz,Rk	kNm	15.84		15.84		0 %
	Moment Component	<eta>Mz		0.0		0.0		0 %
	Design 1	<eta>1		0.526		0.527		0 %
	Design 2	<eta>2		0.866	0.947	0.866	9 %	0 %
	Design Formula							

NEd / (<chi>y NRk / <gamma>M1) + kyy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kyz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.526 <le> 1 (6.61)
NEd / (<chi>z NRk / <gamma>M1) + kzy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kzz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.866 <le> 1 (6.62)

19	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | British Steel							
	Design Internal Forces							
	Axial Force	NEd	kN	-40.0	-40.0	-40.0	0 %	0 %
	Shear Force	Vy,Ed	kN	-2.5	-2.5	-2.5	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	6.25	6.25	6.25	0 %	0 %
	Cross-Section Classification - Class 2	Class		2.0	2.0	2.0	0 %	0 %
	Design Ratio							
	Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
	Moment of Inertia	Iy	cm^4	1940.0	1940.0	1940.0	0 %	0 %
	Effective Member Length	Lcr,y	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,y	kN	1608.35	1608.35	1608.35	0 %	0 %
	Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_y		0.793		0.793		0 %
	Buckling Curve	BCy		a		a		0 %
	Imperfection Factor	<alfa>y		0.21	0.21	0.21	0 %	0 %
	Auxiliary Factor	<phic>y		0.877		0.877		0 %
	Reduction Factor	<chi>y		0.8	0.8	0.8	0 %	0 %
	Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
	Effective Member Length	Lcr,z	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,z	kN	117.72	117.72	117.72	0 %	0 %
	Slenderness	<lambda>_z		2.932		2.932		0 %
	Buckling Curve	BCz		b		b		0 %
	Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
	Auxiliary Factor	<phic>z		5.261		5.261		0 %
	Reduction Factor	<chi>z		0.104	0.104	0.104	0 %	0 %
	Structure type about y-axis	Type		Non-sway		Non-sway		0 %
	Moment Distribution	Diagr My		1) Linear		1) Linear		0 %
	Moment Factor	<psi>y		0.0		0.0		0 %
	Moment Factor	Cmy		0.6	1.0	0.6	67 %	0 %
	Structure type about z-axis	Type		Non-sway		Non-sway		0 %
	Moment Distribution	Diagr Mz		Max in Span		3) Max in Span		0 %
	Moment Factor	<psi>z		0.0		0.0		0 %
	Moment	Mh,z	kNm	0.0		0.0		0 %
	Moment	Ms,z	kNm	6.25		6.25		0 %
	Ratio Mh,z / Ms,z	<alfa>h,z		0.0		0.0		0 %
	Load Type	Load y		Sing. Load		Sing. Load		0 %
	Moment Factor	Cmz		0.9	1.0	0.9	11 %	0 %
	Component Type	Component		orsion. Rigid		Torsion. Rigid		0 %
	Interaction Factor	kyy		0.618	1.029	0.618	67 %	0 %
	Interaction Factor	kyz		0.828	0.92	0.828	11 %	0 %
	Interaction Factor	kzy		0.371	0.851	0.371	129 %	0 %
	Interaction Factor	kzz		1.38	1.533	1.38	11 %	0 %
	Axial Force (Compression)	NEd	kN	40.0	40.0	40.0	0 %	0 %
	Governing Cross-Sectional Area	Ai	cm^2	28.5	28.5	28.5	0 %	0 %
	Compression Resistance	NRk	kN	1011.75		1011.75		0 %
	Partial Factor	<gamma>M1	kN	1.0	1.0	1.0	0 %	0 %
	Design Component for N	<eta>Ny		0.049		0.049		0 %

	Design Component for N	<eta>Nz		0.381		0.381		0 %
	Moment	Mz,Ed	kNm	6.25	6.25	6.25	0 %	0 %
	Section Modulus	Wz	cm^3	44.61	44.61	44.61	0 %	0 %
	Moment Resistance	Mz,Rk	kNm	15.84		15.84		0 %
	Moment Component	<eta>Mz		0.395				
	Design 1	<eta>1		0.376		0.376		0 %
	Design 2	<eta>2		0.925	0.986	0.925	7 %	0 %
	Design Formula							
	NEd / (<chi>y NRk / <gamma>M1) + kyy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kyz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.376 <le> 1 (6.61)							
	NEd / (<chi>z NRk / <gamma>M1) + kzy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kzz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.925 <le> 1 (6.62)							

20	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	-40.0	-40.0	-40.0	0 %	0 %
	Shear Force	Vy,Ed	kN	2.5	2.5	2.5	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	6.25	6.25	6.25	0 %	0 %
	Cross-Section Classification - Class 2	Class		2.0	2.0	2.0	0 %	0 %
	Design Ratio							
	Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
	Moment of Inertia	Iy	cm^4	1940.0	1940.0	1940.0	0 %	0 %
	Effective Member Length	Lcr,y	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,y	kN	1608.35	1608.35	1608.35	0 %	0 %
	Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_y		0.793		0.793		0 %
	Buckling Curve	BCy		a		a		0 %
	Imperfection Factor	<alfa>y		0.21	0.21	0.21	0 %	0 %
	Auxiliary Factor	<phic>y		0.877		0.877		0 %
	Reduction Factor	<chi>y		0.8	0.8	0.8	0 %	0 %
	Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
	Effective Member Length	Lcr,z	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,z	kN	117.72	117.72	117.72	0 %	0 %
	Slenderness	<lambda>_z		2.932		2.932		0 %
	Buckling Curve	BCz		b		b		0 %
	Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
	Auxiliary Factor	<phic>z		5.261		5.261		0 %
	Reduction Factor	<chi>z		0.104	0.104	0.104	0 %	0 %
	Structure type about y-axis	Type		Non-sway		Non-sway		0 %
	Moment Distribution	Diagr My		1) Linear		1) Linear		0 %
	Moment Factor	<psi>y		0.0		0.0		0 %
	Moment Factor	Cmy		0.6	1.0	0.6	67 %	0 %
	Structure type about z-axis	Type		Non-sway		Non-sway		0 %
	Moment Distribution	Diagr Mz		Max in Span		3) Max in Span		0 %
	Moment Factor	<psi>z		0.0		0.0		0 %
	Moment	Mh,z	kNm	0.0		0.0		0 %
	Moment	Ms,z	kNm	6.25		6.25		0 %
	Ratio Mh,z / Ms,z	<alfa>h,z		0.0		0.0		0 %
	Load Type	Load y		Sing. Load		Sing. Load		0 %
	Moment Factor	Cmz		0.9	1.0	0.9	11 %	0 %
	Component Type	Component		orsion. Rigid		Torsion. Rigid		0 %
	Interaction Factor	kyy		0.618	1.029	0.618	67 %	0 %
	Interaction Factor	kyz		0.828	0.92	0.828	11 %	0 %
	Interaction Factor	kzy		0.371	0.851	0.371	129 %	0 %
	Interaction Factor	kzz		1.38	1.533	1.38	11 %	0 %
	Axial Force (Compression)	NEd	kN	40.0	40.0	40.0	0 %	0 %
	Governing Cross-Sectional Area	Ai	cm^2	28.5	28.5	28.5	0 %	0 %
	Compression Resistance	NRk	kN	1011.75		1011.75		0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Component for N	<eta>Ny		0.049		0.049		0 %
	Design Component for N	<eta>Nz		0.381		0.381		0 %
	Moment	Mz,Ed	kNm	6.25	6.25	6.25	0 %	0 %
	Section Modulus	Wz	cm^3	44.61	44.61	44.61	0 %	0 %
	Moment Resistance	Mz,Rk	kNm	15.84		15.84		0 %
	Moment Component	<eta>Mz		0.395				
	Design 1	<eta>1		0.376		0.376		0 %
	Design 2	<eta>2		0.925	0.986	0.925	7 %	0 %
	Design Formula							
	NEd / (<chi>y NRk / <gamma>M1) + kyy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kyz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.376 <le> 1 (6.61)							
	NEd / (<chi>z NRk / <gamma>M1) + kzy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kzz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.925 <le> 1 (6.62)							

21	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	274.4	274.4	274.4	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	27.44	27.44	27.44	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %

	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Shear Force	Vz,Ed	kN	274.4	274.4	274.4	0 %	0 %
	Effective Shear Area	Av,z	cm^2	14.02	14.02	14.02	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Shear Force Resistance	Vpl,z,Rd	kN	287.27	287.35	287.35	0 %	0 %
	Design Ratio	<eta>		0.955	2.334	0.955	144 %	0 %
	Design Formula Vz,Ed / Vpl,z,Rd = 0.955 <le> 1 (6.17)							

22	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	-5.6	-5.6	-5.6	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	27.44	27.44	27.44	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Section Height	h	mm	200.0	200.0	200.0	0 %	0 %
	Section Width	b	mm	100.0	100.0	100.0	0 %	0 %
	Criterion	h/b		2.0		2.0		0 %
	Buckling Curve	BCLT		b		b		0 %
	Imperfection Factor	<alfa>LT		0.34	0.34	0.34	0 %	0 %
	Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
	Shear Modulus	G	kN/cm^2	8076.92	8076.92	8076.92	0 %	0 %
	Length Factor	kz		1.0	1.0	1.0	0 %	0 %
	Length Factor	kw		1.0	1.0	1.0	0 %	0 %
	Length	L	m	5.0	5.0	5.0	0 %	0 %
	Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
	Warping Constant of Cross-Section	Iw	cm^6	12990.0	12990.0	12990.0	0 %	0 %
	Torsional Constant	It	cm^4	7.02	7.02	7.02	0 %	0 %
	Moment Factor	C1		1.774	1.0	1.774	-44 %	0 %
	Elastic Critical Moment for Lateral-Torsional Buckling	Mcr	kNm	50.0	28.18	50.0	-44 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_LT		1.25		1.25		0 %
	Parameter	<lambda>_LT,0		0.4		0.4		0 %
	Parameter	<beta>		0.75		0.75		0 %
	Auxiliary Factor	<phic>LT		1.23		1.23		0 %
	Reduction Factor	<chi>LT		0.551		0.551		0 %
	Correction Factor	kc		0.86		0.86		0 %
	Modification Factor	f		0.958		0.958		0 %
	Reduction Factor	<chi>LT,mod		0.575	0.361	0.575	-37 %	0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Lateral-Torsional Buckling Resistance Moment	Mb,Rd	kNm	44.9		44.9		0 %
	Moment	My,Ed	kNm	27.44	27.44	27.44	0 %	0 %
	Design Ratio	<eta>		0.611	0.974	0.611	59 %	0 %
	Design Formula My,Ed / Mb,Rd = 0.611 <le> 1 (6.54)							

23	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	-257.4	-257.4	-257.4	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	12.87	12.87	12.87	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Moment	Mz,Ed	kNm	12.87	12.87	12.87	0 %	0 %
	Plastic Section Modulus	Wpl,z	cm^3	44.61	44.61	44.61	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Moment Resistance	Mpl,z,Rd	kNm	15.84		15.84		0 %
	Shear Force	Vy,Ed	kN	257.4	257.4	257.4	0 %	0 %
	Effective Shear Area	Av,y	cm^2	17.99	17.99	17.99	0 %	0 %
	Shear Force Resistance	Vpl,y,Rd	kN	368.63	368.72	368.72	0 %	0 %
	Criterion Vy,Ed / Vpl,y,Rd	vy		0.698		0.698		0 %
	Interaction Factor	<rho>		0.157		0.157		0 %
	Moment Resistance	Mpl,z,V,Rd	kNm	13.47	13.35	13.47	-1 %	0 %
	Design Ratio	<eta>		0.956	0.964	0.956	1 %	0 %
	Design Formula Mz,Ed / Mc,z,Rd = 0.956 <le> 1 (6.30)							

24	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							

	Axial Force	NEd	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vy,Ed	kN	2.6	2.6	2.6	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	12.87	12.87	12.87	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Moment	Mz,Ed	kNm	12.87	12.87	12.87	0 %	0 %
	Plastic Section Modulus	Wpl,z	cm^3	44.61	44.61	44.61	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Moment Resistance	Mpl,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Shear Force	Vy,Ed	kN	2.6	2.6	2.6	0 %	0 %
	Effective Shear Area	Av,y	cm^2	17.99	17.99	17.99	0 %	0 %
	Shear Force Resistance	Vpl,y,Rd	kN	368.63	368.72	368.72	0 %	0 %
	Criterion Vy,Ed / Vpl,y,Rd	vy		0.007		0.007		0 %
	Moment Resistance	Mc,z,Rd	kNm	15.84	15.84	15.84	0 %	0 %
	Design Ratio	<eta>		0.813	0.813	0.813	0 %	0 %
	Design Formula							
	Mz,Ed / Mc,z,Rd = 0.813 <le> 1 (6.12)							

25	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	-20.0	-20.0	-20.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	235.2	235.2	235.2	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	23.52	23.52	23.52	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Shear Force	Vz,Ed	kN	235.2	235.2	235.2	0 %	0 %
	Effective Shear Area	Av,z	cm^2	14.02	14.02	14.02	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Shear Force Resistance	Vpl,z,Rd	kN	287.27	287.35	287.35	0 %	0 %
	Design Ratio	<eta>		0.819	1.093	0.819	33 %	0 %
	Design Formula							
	Vz,Ed / Vpl,z,Rd = 0.819 <le> 1 (6.17)							

26	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	-20.0	-20.0	-20.0	0 %	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Shear Force	Vz,Ed	kN	-4.8	-4.8	-4.8	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	23.52	23.52	23.52	0 %	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	1.0	0 %	0 %
	Design Ratio							
	Elastic Critical Load for Torsional Buckling	Ncr,T	kN	923.57		921.1		0 %
	Slenderness	<lambda>_T		1.047		1.048		0 %
	Buckling Curve	BCz		b		b		0 %
	Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
	Auxiliary Factor	<phic>T		1.192		1.193		0 %
	Reduction Factor	<chi>T		0.568		0.567		0 %
	Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
	Moment of Inertia	Iy	cm^4	1940.0	1940.0	1940.0	0 %	0 %
	Effective Member Length	Lcr,y	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,y	kN	1608.35	1608.35	1608.35	0 %	0 %
	Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_y		0.793		0.793		0 %
	Buckling Curve	BCy		a		a		0 %
	Imperfection Factor	<alfa>y		0.21	0.21	0.21	0 %	0 %
	Auxiliary Factor	<phic>y		0.877		0.877		0 %
	Reduction Factor	<chi>y		0.8	0.8	0.8	0 %	0 %
	Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
	Effective Member Length	Lcr,z	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,z	kN	117.72	117.72	117.72	0 %	0 %
	Slenderness	<lambda>_z		2.932		2.932		0 %
	Buckling Curve	BCz		b		b		0 %
	Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
	Auxiliary Factor	<phic>z		5.261		5.261		0 %
	Reduction Factor	<chi>z		0.104	0.104	0.104	0 %	0 %
	Section Height	h	mm	200.0	200.0	200.0	0 %	0 %
	Section Width	b	mm	100.0	100.0	100.0	0 %	0 %
	Criterion	h/b		2.0		2.0		0 %
	Buckling Curve	BCLT		b		b		0 %
	Imperfection Factor	<alfa>LT		0.34	0.34	0.34	0 %	0 %

	Shear Modulus	G	kN/cm^2	8076.92	8076.92	8076.92	0 %	0 %
	Length Factor	kz		1.0	1.0	1.0	0 %	0 %
	Length Factor	kw		1.0	1.0	1.0	0 %	0 %
	Length	L	m	5.0	5.0	5.0	0 %	0 %
	Warping Constant of Cross-Section	Iw	cm^6	12990.0	12990.0	12990.0	0 %	0 %
	Torsional Constant	It	cm^4	7.02	7.02	7.02	0 %	0 %
	Moment Factor	C1		1.774	1.0	1.774	-44 %	0 %
	Elastic Critical Moment for Lateral-Torsional Buckling	Mcr	kNm	50.0	28.18	50.0	-44 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Slenderness	<lambda>_LT		1.25		1.25		0 %
	Parameter	<lambda>_LT,0		0.4		0.4		0 %
	Parameter	<beta>		0.75		0.75		0 %
	Auxiliary Factor	<phic>LT		1.23		1.23		0 %
	Reduction Factor	<chi>LT		0.551		0.551		0 %
	Correction Factor	kc		0.86		0.86		0 %
	Modification Factor	f		0.958		0.958		0 %
	Reduction Factor	<chi>LT,mod		0.575	0.361	0.575	-37 %	0 %
	Structure type about y-axis	Type		Non-sway		Non-sway		0 %
	Moment Distribution	Diagr My		Max in Span		3) Max in Span		0 %
	Moment Factor	<psi>y		0.0		0.0		0 %
	Moment	Mh,y	kNm	0.0		0.0		0 %
	Moment	Ms,y	kNm	12.0		12.0		0 %
	Ratio Mh,y / Ms,y	<alfa>h,y		0.0		0.0		0 %
	Load Type	Load z		Sing. Load		Sing. Load		0 %
	Moment Factor	Cmy		0.9	1.0	0.9	11 %	0 %
	Structure type about z-axis	Type		Non-sway		Non-sway		0 %
	Moment Distribution	Diagr Mz		1) Linear		1) Linear		0 %
	Moment Factor	<psi>z		0.0		0.0		0 %
	Moment Factor	Cmz		0.6	1.0	0.6	67 %	0 %
	Moment Distribution	Diagr My,LT		Max in Span		3) Max in Span		0 %
	Moment Factor	<psi>y,LT		0.0	1.0	0.0	ERROR	0 %
	Moment	Mh,y,LT	kNm	0.0		0.0		0 %
	Moment	Ms,y,LT	kNm	12.0		12.0		0 %
	Ratio Mh,y,LT / Ms,y,LT	<alfa>h,y.LT		0.0		0.0		0 %
	Load Type	Load z		Sing. Load		Sing. Load		0 %
	Moment Factor	CmLT		0.9	1.0	0.9	11 %	0 %
	Component Type	Component		rsion. Weak		Torsion. Weak		0 %
	Interaction Factor	kyy		0.913	1.015	0.913	11 %	0 %
	Interaction Factor	kyz		0.456	0.76	0.456	67 %	0 %
	Interaction Factor	kzy		0.971	0.926	0.971	-5 %	0 %
	Interaction Factor	kzz		0.76	1.267	0.76	67 %	0 %
	Axial Force (Compression)	NEd	kN	20.0	20.0	20.0	0 %	0 %
	Governing Cross-Sectional Area	Ai	cm^2	28.5	28.5	28.5	0 %	0 %
	Compression Resistance	NRk	kN	1011.75		1011.75		0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Component for N	<eta>Ny		0.025		0.025		0 %
	Design Component for N	<eta>Nz		0.19		0.19		0 %
	Moment	My,Ed	kNm	23.52	23.52	23.52	0 %	0 %
	Section Modulus	Wy	cm^3	220.0	220.0	220.0	0 %	0 %
	Moment Resistance	My,Rk	kNm	78.1		78.1		0 %
	Moment Component	<eta>My		0.524				
	Section Modulus	Wz	cm^3	44.61	44.61	44.61	0 %	0 %
	Moment Resistance	Mz,Rk	kNm	15.84		15.84		0 %
	Moment Component	<eta>Mz		0.0		0.0		0 %
	Design 1	<eta>1		0.503		0.503		0 %
	Design 2	<eta>2		0.699	0.963	0.699	38 %	0 %
	Design Formula							
	NEd / (<chi>y NRk / <gamma>M1) + kyy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kyz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.503 <le> 1 (6.61)							
	NEd / (<chi>z NRk / <gamma>M1) + kzy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kzz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.699 <le> 1 (6.62)							

27	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	-10.0	-10.0	-10.0	0 %	0 %
	Shear Force	Vy,Ed	kN	-257.4	-257.4	-257.4	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	12.87	12.87	12.87	0 %	0 %
	Cross-Section Classification - Class 2	Class		2.0	2.0	2.0	0 %	0 %
	Design Ratio							
	Moment	Mz,Ed	kNm	12.87	12.87	12.87	0 %	0 %
	Plastic Section Modulus	Wpl,z	cm^3	44.61	44.61	44.61	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Partial Factor	<gamma>M0		1.0	1.0	1.0	0 %	0 %
	Moment Resistance	Mpl,z,Rd	kNm	15.84		15.84		0 %
	Shear Force	Vy,Ed	kN	257.4	257.4	257.4	0 %	0 %
	Effective Shear Area	Av,y	cm^2	17.99	17.99	17.99	0 %	0 %
	Shear Force Resistance	Vpl,y,Rd	kN	368.63	368.72	368.72	0 %	0 %
	Criterion Vy,Ed / Vpl,y,Rd	vy		0.698		0.698		0 %
	Interaction Factor	<rho>		0.157		0.157		0 %
	Moment Resistance	Mpl,z,V,Rd	kNm	13.47	13.35	13.47	-1 %	0 %
	Axial Force	NEd	kN	-10.0	-10.0	-10.0	0 %	0 %

	Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
	Design plastic resistance to normal forces	Npl,Rd	kN	1011.75		1011.75		0 %
	Axial Force Resistance Reduced due to Shear	NV,Rd	kN	911.36	852.95	917.03	-6 %	1 %
	Criterion	nw		0.027				
	Design Component for Mz	<eta>Mz		0.956		0.956		0 %
	Design Ratio	<eta>		0.956	1.19	0.956	24 %	0 %
	Design Formula Mz,Ed / MN,z,Rd = 0.956 <le> 1 (6.31)							

28	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	Mathcad	R and K	R and M
LC1	Cross-Section Properties - IPE 200 | Euronorm 19-57							
	Design Internal Forces							
	Axial Force	NEd	kN	-10.0	-10.0	-10.0	0 %	0 %
	Shear Force	Vy,Ed	kN	2.6	2.6	2.6	0 %	0 %
	Shear Force	Vz,Ed	kN	0.0	0.0	0.0	0 %	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	My,Ed	kNm	0.0	0.0	0.0	0 %	0 %
	Moment	Mz,Ed	kNm	12.87	12.87	12.87	0 %	0 %
	Cross-Section Classification - Class 2	Class	2.0	2.0	2.0	2.0	0 %	0 %
	Design Ratio							
	Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	21000.0	0 %	0 %
	Moment of Inertia	Iy	cm^4	1940.0	1940.0	1940.0	0 %	0 %
	Effective Member Length	Lcr,y	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,y	kN	1608.35	1608.35	1608.35	0 %	0 %
	Cross-Sectional Area	A	cm^2	28.5	28.5	28.5	0 %	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	35.5	0 %	0 %
	Slenderness	<lambda>_y		0.793		0.793		0 %
	Buckling Curve	BCy		a		a		0 %
	Imperfection Factor	<alfa>y		0.21	0.21	0.21	0 %	0 %
	Auxiliary Factor	<phic>y		0.877		0.877		0 %
	Reduction Factor	<chi>y		0.8	0.8	0.8	0 %	0 %
	Moment of Inertia	Iz	cm^4	142.0	142.0	142.0	0 %	0 %
	Effective Member Length	Lcr,z	m	5.0	5.0	5.0	0 %	0 %
	Elastic Flexural Buckling Force	Ncr,z	kN	117.72	117.72	117.72	0 %	0 %
	Slenderness	<lambda>_z		2.932		2.932		0 %
	Buckling Curve	BCz		b		b		0 %
	Imperfection Factor	<alfa>z		0.34	0.34	0.34	0 %	0 %
	Auxiliary Factor	<phic>z		5.261		5.261		0 %
	Reduction Factor	<chi>z		0.104	0.104	0.104	0 %	0 %
	Structure type about y-axis	Type		Sway		Sway		0 %
	Moment Factor	Cmy		0.9	1.0	0.9	11 %	0 %
	Structure type about z-axis	Type		Sway		Sway		0 %
	Moment Factor	Cmz		0.9	1.0	0.9	11 %	0 %
	Component Type	Component		orsion. Rigid		Torsion. Rigid		0 %
	Interaction Factor	kyy		0.907	1.007	0.907	11 %	0 %
	Interaction Factor	kyz		0.612	0.68	0.612	11 %	0 %
	Interaction Factor	kzy		0.544	0.963	0.544	77 %	0 %
	Interaction Factor	kzz		1.02	1.133	1.02	11 %	0 %
	Axial Force (Compression)	NEd	kN	10.0	10.0	10.0	0 %	0 %
	Governing Cross-Sectional Area	Ai	cm^2	28.5	28.5	28.5	0 %	0 %
	Compression Resistance	NRk	kN	1011.75		1011.75		0 %
	Partial Factor	<gamma>M1		1.0	1.0	1.0	0 %	0 %
	Design Component for N	<eta>Ny		0.012				
	Design Component for N	<eta>Nz		0.095				
	Moment	Mz,Ed	kNm	12.87	12.87	12.87	0 %	0 %
	Section Modulus	Wz	cm^3	44.61	44.61	44.61	0 %	0 %
	Moment Resistance	Mz,Rk	kNm	15.84		15.84		0 %
	Moment Component	<eta>Mz		0.813				
	Design 1	<eta>1		0.51		0.51		0 %
	Design 2	<eta>2		0.924	1.016	0.924	10 %	0 %
	Design Formula NEd / (<chi>y NRk / <gamma>M1) + kyy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kyz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.510 <le> 1 NEd / (<chi>z NRk / <gamma>M1) + kzy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kzz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.924 <le> 1						(6.61) (6.62)	

APPENDIX D: Case study results of short side of the warehouse

RFEM		Karamba		Diff.
Beam	Util.	Beam	Util.	
1	0.686	0	0.683	0.00
2	0.761	1	0.775	0.01
3	0.773	2	0.797	0.02
4	0.808	3	0.853	0.04
5	1.007	4	1.002	0.00
6	0.811	5	0.841	0.03
7	0.860	6	0.856	0.00
8	0.778	7	0.779	0.00
9	0.836	8	0.841	0.01
10	0.773	9	0.773	0.00
11	0.689	10	0.692	0.00
12	0.464	11	0.477	0.01
13	0.438	12	0.464	0.03
14	0.648	13	0.699	0.05
15	1.009	14	1.001	-0.01
16	0.662	15	0.696	0.03
17	0.376	16	0.381	0.00
18	0.274	17	0.273	0.00
19	0.549	18	0.556	0.01
20	0.766	19	0.766	0.00
21	0.686	20	0.686	0.00
22	0.002	21	0.008	0.01
23	0.036	22	0.055	0.02
24	0.594	23	0.644	0.05
25	0.986	24	0.977	-0.01
26	0.176	25	0.194	0.02
27	0.065	26	0.083	0.02
28	0.008	27	0.022	0.01
29	0.009	28	0.016	0.01
30	0.832	29	0.859	0.03
31	0.922	30	0.976	0.05
32	0.583	31	0.636	0.05
33	0.854	32	0.865	0.01
34	0.878	33	0.934	0.06
35	0.993	34	0.997	0.00
36	0.675	35	0.774	0.10
37	0.854	36	0.930	0.08
38	0.892	37	0.939	0.05
39	0.593	38	0.601	0.01
40	0.849	39	0.986	0.14
41	0.721	40	0.718	0.00
42	0.686	41	0.712	0.03
43	0.774	42	0.787	0.01
44	0.711	43	0.719	0.01
45	0.843	44	0.848	0.01
46	0.710	45	0.756	0.05
47	0.740	46	0.746	0.01
48	0.714	47	0.740	0.03
49	0.074	48	0.061	-0.01
50	0.546	49	0.550	0.00
51	0.609	50	0.609	0.00
52	0.855	51	0.876	0.02
53	0.714	52	0.722	0.01
54	0.603	53	0.619	0.02
55	0.707	54	0.715	0.01
56	0.813	55	0.844	0.03
57	0.672	56	0.693	0.02
58	0.623	57	0.650	0.03
59	0.619	58	0.648	0.03
60	0.450	59	0.459	0.01
61	0.519	60	0.534	0.01
62	0.863	61	0.872	0.01
63	0.645	62	0.651	0.01
64	0.525	63	0.541	0.02
65	0.608	64	0.619	0.01
66	0.781	65	0.802	0.02
67	0.606	66	0.627	0.02
68	0.542	67	0.567	0.03
69	0.806	68	0.815	0.01
70	0.374	69	0.384	0.01
71	0.965	70	1.019	0.05
72	0.784	71	0.788	0.00
73	0.889	72	0.904	0.01
74	0.936	73	0.965	0.03
75	0.929	74	0.970	0.04
76	0.886	75	0.900	0.01
77	0.919	76	0.941	0.02
78	0.965	77	0.999	0.03
79	0.734	78	0.734	0.00
80	0.943	79	1.004	0.06
81	0.788	80	0.796	0.01
82	0.720	81	0.733	0.01
83	0.761	82	0.778	0.02
84	0.779	83	0.798	0.02
85	0.767	84	0.794	0.03
86	0.787	85	0.803	0.02
87	0.787	86	0.803	0.02
88	0.794	87	0.816	0.02
89	0.730	88	0.739	0.01
90	0.753	89	0.781	0.03
91	0.602	90	0.621	0.02
92	0.667	91	0.682	0.01
93	0.634	92	0.651	0.02
94	0.625	93	0.639	0.01
95	0.605	94	0.621	0.02
96	0.693	95	0.708	0.01
97	0.659	96	0.673	0.01
98	0.627	97	0.643	0.02
99	0.730	98	0.742	0.01
100	0.599	99	0.609	0.01
101	0.453	100	0.465	0.01
102	0.549	101	0.563	0.01
103	0.495	102	0.508	0.01
104	0.481	103	0.493	0.01
105	0.462	104	0.474	0.01
106	0.564	105	0.576	0.01
107	0.516	106	0.529	0.01
108	0.472	107	0.483	0.01
109	0.646	108	0.659	0.01
110	0.439	109	0.444	0.00
111	0.876	110	0.935	0.06
112	0.731	111	0.750	0.02
113	0.872	112	0.892	0.02
114	0.881	113	0.909	0.03
115	0.994	114	1.021	0.03
116	0.803	115	0.820	0.02
117	0.973	116	0.998	0.02
118	0.893	117	0.920	0.03

119	0.797	118	0.811	0.01
120	0.917	119	0.937	0.02
121	0.511	120	0.542	0.03
122	0.463	121	0.490	0.03
123	0.519	122	0.533	0.01
124	0.510	123	0.532	0.02
125	0.574	124	0.589	0.01
126	0.525	125	0.548	0.02
127	0.588	126	0.608	0.02
128	0.479	127	0.498	0.02
129	0.574	128	0.590	0.02
130	0.506	129	0.515	0.01
131	0.149	130	0.256	0.11
132	0.246	131	0.295	0.05
133	0.173	132	0.184	0.01
134	0.143	133	0.167	0.02
135	0.175	134	0.181	0.01
136	0.253	135	0.292	0.04
137	0.206	136	0.226	0.02
138	0.068	137	0.087	0.02
139	0.359	138	0.389	0.03
140	0.220	139	0.222	0.00
141	0.279	140	0.333	0.05
142	0.343	141	0.342	0.00
143	0.160	142	0.158	0.00
144	0.114	143	0.136	0.02
145	0.146	144	0.189	0.04
146	0.193	145	0.200	0.01
147	0.051	146	0.050	0.00
148	0.088	147	0.108	0.02
149	0.162	148	0.202	0.04
150	0.050	149	0.060	0.01
151	0.785	150	0.917	0.13
152	0.785	151	0.917	0.13
153	0.695	152	0.812	0.12
154	0.695	153	0.812	0.12
155	0.695	154	0.812	0.12
156	0.695	155	0.812	0.12
157	0.695	156	0.812	0.12
158	0.695	157	0.812	0.12
159	0.695	158	0.812	0.12
160	0.695	159	0.812	0.12
161	0.131	160	0.150	0.02
162	0.424	161	0.427	0.00
163	0.283	162	0.296	0.01
164	0.360	163	0.360	0.00
165	0.181	164	0.228	0.05
166	0.520	165	0.528	0.01
167	0.235	166	0.245	0.01
168	0.390	167	0.397	0.01
169	0.333	168	0.336	0.00
170	0.306	169	0.318	0.01
171	0.020	170	0.038	0.02
172	0.095	171	0.115	0.02
173	0.056	172	0.059	0.00
174	0.010	173	0.019	0.01
175	0.359	174	0.419	0.06
176	0.577	175	0.634	0.06
177	0.510	176	0.534	0.02
178	0.393	177	0.410	0.02
179	0.088	178	0.126	0.04
180	0.081	179	0.123	0.04
181	0.140	180	0.142	0.00
182	0.155	181	0.169	0.01
183	0.287	182	0.301	0.01
184	0.222	183	0.231	0.01
185	0.585	184	0.621	0.04
186	0.371	185	0.382	0.01
187	0.503	186	0.545	0.04
188	0.546	187	0.588	0.04
189	0.145	188	0.155	0.01
190	0.179	189	0.183	0.00
191	0.416	190	0.418	0.00
192	0.630	191	0.626	0.00
193	0.615	192	0.608	-0.01
194	0.357	193	0.359	0.00
195	0.463	194	0.464	0.00
196	0.902	195	0.894	-0.01
197	0.834	196	0.821	-0.01
198	0.873	197	0.869	0.00
199	0.808	198	0.792	-0.02
200	0.272	199	0.262	-0.01
201	0.567	200	0.576	0.01
202	0.428	201	0.445	0.02
203	0.080	202	0.099	0.02
204	0.319	203	0.335	0.02
205	0.558	204	0.568	0.01
206	0.442	205	0.461	0.02
207	0.089	206	0.091	0.00
208	0.190	207	0.276	0.09
209	0.736	208	0.738	0.00
210	0.800	209	0.800	0.00
211	0.383	210	0.400	0.02
212	0.459	211	0.477	0.02
213	0.299	212	0.318	0.02
214	0.081	213	0.093	0.01
215	0.096	214	0.189	0.09
216	0.703	215	0.717	0.01
217	0.545	216	0.556	0.01
218	0.315	217	0.331	0.02
219	0.778	218	0.784	0.01
220	0.437	219	0.450	0.01
221	0.798	220	0.803	0.00
222	0.608	221	0.620	0.01
223	0.040	222	0.045	0.01
224	0.456	223	0.466	0.01
225	0.682	224	0.687	0.01
226	0.433	225	0.444	0.01
227	0.047	226	0.092	0.05
228	0.400	227	0.408	0.01
229	0.963	228	0.978	0.01
230	0.934	229	0.937	0.00
231	0.536	230	0.552	0.02
232	0.629	231	0.652	0.02
233	0.392	232	0.419	0.03
234	0.094	233	0.183	0.09
235	0.220	234	0.304	0.08
236	0.700	235	0.719	0.02
237	0.512	236	0.532	0.02
238	0.152	237	0.175	0.02
239	0.794	238	0.817	0.02
240	0.669	239	0.689	0.02
241	0.808	240	0.813	0.01
242	0.465	241	0.477	0.01
243	0.112	242	0.153	0.04
244	0.486	243	0.496	0.01
245	0.663	244	0.669	0.01
246	0.193	245	0.203	0.01
247	0.143	246	0.185	0.04
248	0.456	247	0.465	0.01
249	0.728	248	0.746	0.02
250	0.906	249	0.912	0.01
251	0.459	250	0.464	0.01
252	0.531	251	0.541	0.01
253	0.289	252	0.300	0.01
254	0.089	253	0.121	0.03
255	0.190	254	0.221	0.03
256	0.577	255	0.583	0.01

257	0.335	256	0.341	0.01	303	0.021	302	0.025	0.00	349	0.676	348	0.664	-0.01
258	0.028	257	0.047	0.02	304	0.095	303	0.096	0.00	350	0.968	349	0.952	-0.02
259	0.663	258	0.674	0.01	305	0.052	304	0.059	0.01	351	0.625	350	0.617	-0.01
260	0.503	259	0.512	0.01	306	0.084	305	0.088	0.00	352	0.218	351	0.214	0.00
261	0.692	260	0.693	0.00	307	0.008	306	0.011	0.00	353	0.007	352	0.006	0.00
262	0.188	261	0.192	0.00	308	0.016	307	0.017	0.00	354	0.308	353	0.306	0.00
263	0.152	262	0.168	0.02	309	0.039	308	0.045	0.01	355	0.595	354	0.585	-0.01
264	0.453	263	0.457	0.00	310	0.028	309	0.038	0.01	356	0.225	355	0.218	-0.01
265	0.594	264	0.596	0.00	311	0.462	310	0.464	0.00	357	0.039	356	0.043	0.00
266	0.018	265	0.028	0.01	312	0.931	311	0.930	0.00	358	0.262	357	0.258	0.00
267	0.204	266	0.219	0.01	313	0.553	312	0.563	0.01	359	0.458	358	0.453	0.00
268	0.403	267	0.407	0.00	314	0.682	313	0.672	-0.01	360	0.901	359	0.893	-0.01
269	0.346	268	0.356	0.01	315	0.356	314	0.366	0.01	361	0.652	360	0.644	-0.01
270	0.762	269	0.766	0.00	316	0.878	315	0.870	-0.01	362	0.238	361	0.233	0.00
271	0.375	270	0.380	0.01	317	0.498	316	0.491	-0.01	363	0.004	362	0.004	0.00
272	0.403	271	0.414	0.01	318	0.737	317	0.745	0.01	364	0.305	363	0.303	0.00
273	0.289	272	0.304	0.02	319	0.640	318	0.633	-0.01	365	0.606	364	0.595	-0.01
274	0.050	273	0.089	0.04	320	0.595	319	0.603	0.01	366	0.232	365	0.225	-0.01
275	0.113	274	0.153	0.04	321	0.541	320	0.541	0.00	367	0.015	366	0.018	0.00
276	0.526	275	0.540	0.01	322	0.787	321	0.786	0.00	368	0.287	367	0.283	0.00
277	0.353	276	0.368	0.02	323	0.516	322	0.527	0.01	369	0.450	368	0.445	-0.01
278	0.126	277	0.137	0.01	324	0.661	323	0.649	-0.01	370	0.892	369	0.883	-0.01
279	0.578	278	0.595	0.02	325	0.241	324	0.245	0.00	371	0.818	370	0.813	0.00
280	0.335	279	0.344	0.01	326	0.938	325	0.933	0.00	372	0.174	371	0.173	0.00
281	0.572	280	0.573	0.00	327	0.452	326	0.444	-0.01	373	0.043	372	0.043	0.00
282	0.039	281	0.046	0.01	328	0.723	327	0.731	0.01	374	0.454	373	0.454	0.00
283	0.179	282	0.193	0.01	329	0.600	328	0.594	-0.01	375	0.676	374	0.670	-0.01
284	0.432	283	0.435	0.00	330	0.578	329	0.583	0.01	376	0.121	375	0.119	0.00
285	0.529	284	0.533	0.00	331	0.005	330	0.013	0.01	377	0.092	376	0.094	0.00
286	0.087	285	0.103	0.02	332	0.339	331	0.355	0.02	378	0.405	377	0.403	0.00
287	0.227	286	0.241	0.01	333	0.213	332	0.233	0.02	379	0.309	378	0.308	0.00
288	0.386	287	0.390	0.00	334	0.065	333	0.066	0.00	380	0.956	379	0.952	0.00
289	0.015	288	0.020	0.00	335	0.127	334	0.217	0.09	381	0.747	380	0.743	0.00
290	0.613	289	0.617	0.00	336	0.831	335	0.875	0.04	382	0.183	381	0.182	0.00
291	0.088	290	0.100	0.01	337	0.013	336	0.020	0.01	383	0.019	382	0.018	0.00
292	0.567	291	0.577	0.01	338	0.009	337	0.008	0.00	384	0.403	383	0.404	0.00
293	0.519	292	0.527	0.01	339	0.352	338	0.362	0.01	385	0.601	384	0.596	0.00
294	0.315	293	0.323	0.01	340	0.038	339	0.058	0.02	386	0.121	385	0.119	0.00
295	0.288	294	0.295	0.01	341	0.522	340	0.510	-0.01	387	0.065	386	0.066	0.00
296	0.630	295	0.638	0.01	342	0.290	341	0.281	-0.01	388	0.357	387	0.356	0.00
297	0.613	296	0.623	0.01	343	0.150	342	0.144	-0.01	389	0.296	388	0.296	0.00
298	0.492	297	0.500	0.01	344	0.336	343	0.328	-0.01	390	0.863	389	0.860	0.00
299	0.491	298	0.493	0.00	345	0.701	344	0.682	-0.02	391	0.839	390	0.837	0.00
300	0.014	299	0.015	0.00	346	0.446	345	0.431	-0.01	392	0.086	391	0.086	0.00
301	0.060	300	0.064	0.00	347	0.109	346	0.115	0.01	393	0.140	392	0.139	0.00
302	0.175	301	0.177	0.00	348	0.043	347	0.037	-0.01	394	0.480	393	0.481	0.00

395	0.662	394	0.660	0.00
396	0.027	395	0.027	0.00
397	0.170	396	0.171	0.00
398	0.450	397	0.450	0.00
399	0.174	398	0.176	0.00
400	0.906	399	0.905	0.00
401	0.889	400	0.887	0.00
402	0.116	401	0.117	0.00
403	0.132	402	0.131	0.00
404	0.489	403	0.490	0.00
405	0.683	404	0.680	0.00
406	0.039	405	0.039	0.00
407	0.166	406	0.166	0.00
408	0.454	407	0.454	0.00
409	0.189	408	0.191	0.00
410	0.930	409	0.930	0.00
411	0.968	410	0.966	0.00
412	0.024	411	0.025	0.00
413	0.220	412	0.219	0.00
414	0.600	413	0.601	0.00
415	0.787	414	0.785	0.00
416	0.034	415	0.036	0.00
417	0.287	416	0.286	0.00
418	0.534	417	0.534	0.00
419	0.098	418	0.100	0.00
420	1.005	419	1.005	0.00
421	1.023	420	1.021	0.00
422	0.052	421	0.053	0.00
423	0.215	422	0.215	0.00
424	0.606	423	0.606	0.00
425	0.796	424	0.794	0.00
426	0.026	425	0.027	0.00
427	0.287	426	0.286	0.00
428	0.535	427	0.535	0.00
429	0.103	428	0.105	0.00
430	1.013	429	1.013	0.00
431	0.812	430	0.810	0.00
432	0.114	431	0.115	0.00
433	0.251	432	0.251	0.00
434	0.570	433	0.570	0.00
435	0.694	434	0.693	0.00
436	0.127	435	0.127	0.00
437	0.313	436	0.311	0.00
438	0.507	437	0.509	0.00
439	0.017	438	0.016	0.00
440	0.804	439	0.804	0.00

441	0.849	440	0.847	0.00
442	0.076	441	0.077	0.00
443	0.245	442	0.245	0.00
444	0.574	443	0.574	0.00
445	0.687	444	0.686	0.00
446	0.133	445	0.133	0.00
447	0.313	446	0.311	0.00
448	0.507	447	0.508	0.00
449	0.021	448	0.021	0.00
450	0.799	449	0.799	0.00
451	0.961	450	0.948	-0.01
452	0.123	451	0.126	0.00
453	0.448	452	0.441	-0.01
454	0.057	453	0.061	0.00
455	0.622	454	0.615	-0.01
456	0.079	455	0.083	0.00
457	0.036	456	0.027	-0.01
458	0.005	457	0.007	0.00
459	0.039	458	0.045	0.01
460	0.310	459	0.317	0.01
461	0.920	460	0.937	0.02
462	0.918	461	0.960	0.04
463	0.973	462	0.997	0.02
464	0.838	463	0.852	0.01
465	0.900	464	0.929	0.03
466	0.885	465	0.950	0.07
467	0.939	466	0.988	0.05
468	0.808	467	0.821	0.01
469	0.822	468	0.850	0.03
470	0.899	469	0.967	0.07
471	0.838	470	0.898	0.06
472	0.853	471	0.878	0.02
473	0.814	472	0.859	0.05
474	0.855	473	0.913	0.06
475	0.770	474	0.819	0.05
476	0.789	475	0.812	0.02
477	0.873	476	0.952	0.08
478	0.845	477	0.913	0.07
479	0.909	478	0.965	0.06
480	0.851	479	0.876	0.02
481	0.788	480	0.846	0.06
482	0.813	481	0.842	0.03
483	0.805	482	0.829	0.02
484	0.775	483	0.780	0.00
485	0.696	484	0.706	0.01
486	0.686	485	0.690	0.00

487	0.691	486	0.698	0.01
488	0.691	487	0.691	0.00
489	0.597	488	0.597	0.00
490	0.599	489	0.603	0.00
491	0.606	490	0.610	0.00
492	0.609	491	0.610	0.00
493	0.898	492	0.898	0.00
494	0.945	493	0.948	0.00
495	0.955	494	0.958	0.00
496	0.884	495	0.886	0.00
497	0.745	496	0.744	0.00
498	0.789	497	0.791	0.00
499	0.810	498	0.812	0.00
500	0.741	499	0.741	0.00
501	0.654	500	0.657	0.00
502	0.636	501	0.638	0.00
503	0.666	502	0.666	0.00
504	0.595	503	0.596	0.00
505	0.494	504	0.498	0.00
506	0.489	505	0.491	0.00
507	0.517	506	0.517	0.00
508	0.448	507	0.450	0.00
509	0.889	508	0.899	0.01
510	0.947	509	0.948	0.00
511	0.949	510	0.949	0.00
512	0.904	511	0.908	0.00
513	0.501	512	0.511	0.01
514	0.570	513	0.572	0.00
515	0.559	514	0.562	0.00
516	0.491	515	0.495	0.00
517	0.242	516	0.249	0.01
518	0.193	517	0.196	0.00
519	0.171	518	0.172	0.00
520	0.071	519	0.079	0.01
521	0.023	520	0.035	0.01
522	0.007	521	0.008	0.00
523	0.003	522	0.007	0.00
524	0.039	523	0.046	0.01
525	0.695	524	0.812	0.12
526	0.695	525	0.812	0.12
527	0.785	526	0.930	0.14
528	0.785	527	0.930	0.14
529	0.127	528	0.161	0.03
530	0.209	529	0.233	0.02
531	0.544	530	0.557	0.01
532	0.179	531	0.248	0.07

533	0.133	532	0.214	0.08
534	0.452	533	0.470	0.02
535	0.066	534	0.104	0.04
536	0.066	535	0.071	0.01
537	0.450	536	0.500	0.05
538	0.459	537	0.505	0.05
539	0.487	538	0.509	0.02
540	0.170	539	0.275	0.10
541	0.117	540	0.214	0.10
542	0.347	541	0.372	0.03
543	0.090	542	0.122	0.03
544	0.090	543	0.118	0.03
545	0.777	544	0.785	0.01
546	0.413	545	0.423	0.01
547	0.709	546	0.719	0.01
548	0.292	547	0.302	0.01
549	0.226	548	0.252	0.03
550	0.474	549	0.477	0.00
551	0.451	550	0.457	0.01
552	0.320	551	0.323	0.00
553	0.168	552	0.197	0.03
554	0.549	553	0.553	0.00
555	0.435	554	0.442	0.01
556	0.357	555	0.360	0.00
557	0.162	556	0.184	0.02
558	0.483	557	0.485	0.00
559	0.373	558	0.377	0.00
560	0.355	559	0.357	0.00
561	0.187	560	0.233	0.05
562	0.519	561	0.528	0.01
563	0.412	562	0.423	0.01
564	0.402	563	0.409	0.01
565	0.191	564	0.214	0.02
566	0.443	565	0.447	0.00
567	0.339	566	0.344	0.01
568	0.390	567	0.393	0.00
569	0.164	568	0.180	0.02
570	0.401	569	0.405	0.00
571	0.330	570	0.333	0.00
572	0.384	571	0.385	0.00
573	0.226	572	0.228	0.00
574	0.385	573	0.387	0.00
575	0.322	574	0.324	0.00
576	0.381	575	0.383	0.00
577	0.129	576	0.156	0.03
578	0.299	577	0.306	0.01

579	0.308	578	0.312	0.00
580	0.366	579	0.369	0.00
581	0.284	580	0.285	0.00
582	0.326	581	0.328	0.00
583	0.350	582	0.352	0.00
584	0.357	583	0.359	0.00
585	0.022	584	0.023	0.00
586	0.032	585	0.055	0.02
587	0.033	586	0.047	0.01
588	0.033	587	0.054	0.02
589	0.007	588	0.009	0.00
590	0.001	589	0.002	0.00
591	0.079	590	0.087	0.01
592	0.001	591	0.005	0.00
593	0.416	592	0.411	0.00
594	0.317	593	0.322	0.00
595	0.676	594	0.672	0.00
596	0.151	595	0.155	0.00
597	0.069	596	0.063	-0.01
598	0.755	597	0.760	0.01
599	0.524	598	0.520	0.00
600	0.405	599	0.408	0.00
601	0.446	600	0.442	0.00
602	0.425	601	0.429	0.00
603	0.891	602	0.887	0.00
604	0.090	603	0.094	0.00
605	0.165	604	0.164	0.00
606	0.733	605	0.734	0.00
607	0.514	606	0.513	0.00
608	0.498	607	0.499	0.00
609	0.706	608	0.704	0.00
610	0.116	609	0.117	0.00
611	0.802	610	0.801	0.00
612	0.125	611	0.125	0.00
613	0.450	612	0.455	0.01
614	0.978	613	0.973	-0.01
615	0.956	614	0.960	0.00
616	0.655	615	0.651	0.00
617	0.248	616	0.252	0.00
618	0.929	617	0.924	0.00
619	0.737	618	0.740	0.00
620	0.590	619	0.586	0.00
621	0.299	620	0.303	0.00
622	0.877	621	0.873	0.00
623	0.680	622	0.683	0.00
624	0.647	623	0.644	0.00

625	0.305	624	0.308	0.00
626	0.872	625	0.868	0.00
627	0.673	626	0.676	0.00
628	0.654	627	0.651	0.00
629	0.443	628	0.445	0.00
630	0.985	629	0.983	0.00
631	0.747	630	0.750	0.00
632	0.864	631	0.861	0.00
633	0.453	632	0.455	0.00
634	0.974	633	0.973	0.00
635	0.744	634	0.746	0.00
636	0.867	635	0.865	0.00
637	0.530	636	0.530	0.00
638	0.897	637	0.897	0.00
639	0.737	638	0.738	0.00
640	0.874	639	0.873	0.00
641	0.542	640	0.542	0.00
642	0.886	641	0.886	0.00
643	0.739	642	0.740	0.00
644	0.872	643	0.871	0.00
645	0.666	644	0.665	0.00
646	0.762	645	0.763	0.00
647	0.797	646	0.797	0.00
648	0.813	647	0.813	0.00
649	0.673	648	0.672	0.00
650	0.754	649	0.754	0.00
651	0.797	650	0.797	0.00
652	0.813	651	0.813	0.00
653	0.007	652	0.011	0.00
654	0.049	653	0.060	0.01
655	0.046	654	0.056	0.01
656	0.508	655	0.548	0.04
657	0.822	656	0.840	0.02
658	0.904	657	0.944	0.04
659	0.863	658	0.904	0.04
660	0.963	659	0.982	0.02
661	0.838	660	0.848	0.01
662	0.879	661	0.920	0.04
663	0.826	662	0.866	0.04
664	0.914	663	0.945	0.03
665	0.852	664	0.860	0.01
666	0.809	665	0.835	0.03
667	0.724	666	0.757	0.03
668	0.869	667	0.902	0.03
669	0.839	668	0.846	0.01
670	0.798	669	0.815	0.02

671	0.663	670	0.676	0.01	717	0.082	716	0.091	0.01	763	0.402	762	0.406	0.00
672	0.794	671	0.804	0.01	718	0.143	717	0.142	0.00	764	0.247	763	0.267	0.02
673	0.797	672	0.799	0.00	719	0.186	718	0.187	0.00	765	0.351	764	0.357	0.01
674	0.721	673	0.730	0.01	720	0.251	719	0.259	0.01	766	0.466	765	0.473	0.01
675	0.619	674	0.625	0.01	721	0.032	720	0.040	0.01	767	0.465	766	0.473	0.01
676	0.700	675	0.705	0.00	722	0.023	721	0.027	0.00	768	0.337	767	0.346	0.01
677	0.940	676	0.942	0.00	723	0.033	722	0.042	0.01	769	0.343	768	0.348	0.00
678	0.991	677	0.995	0.00	724	0.033	723	0.035	0.00	770	0.390	769	0.395	0.00
679	0.976	678	0.982	0.01	725	0.785	724	0.930	0.15	771	0.390	770	0.395	0.00
680	0.972	679	0.980	0.01	726	0.785	725	0.930	0.15	772	0.268	771	0.273	0.00
681	0.863	680	0.864	0.00	727	0.695	726	0.850	0.15	773	0.347	772	0.349	0.00
682	0.885	681	0.892	0.01	728	0.695	727	0.850	0.15	774	0.389	773	0.390	0.00
683	0.877	682	0.884	0.01	729	0.586	728	0.601	0.01	775	0.384	774	0.387	0.00
684	0.870	683	0.876	0.01	730	0.239	729	0.273	0.03	776	0.268	775	0.271	0.00
685	0.787	684	0.788	0.00	731	0.290	730	0.296	0.01	777	0.342	776	0.344	0.00
686	0.780	685	0.787	0.01	732	0.397	731	0.403	0.01	778	0.360	777	0.362	0.00
687	0.777	686	0.785	0.01	733	0.062	732	0.082	0.02	779	0.351	778	0.353	0.00
688	0.803	687	0.804	0.00	734	0.677	733	0.690	0.01	780	0.266	779	0.267	0.00
689	0.697	688	0.698	0.00	735	0.379	734	0.401	0.02	781	0.345	780	0.348	0.00
690	0.680	689	0.685	0.00	736	0.192	735	0.214	0.02	782	0.364	781	0.367	0.00
691	0.685	690	0.691	0.01	737	0.106	736	0.114	0.01	783	0.343	782	0.349	0.01
692	0.693	691	0.693	0.00	738	0.197	737	0.302	0.10	784	0.245	783	0.269	0.02
693	0.941	692	0.941	0.00	739	0.587	738	0.613	0.03	785	0.338	784	0.340	0.00
694	0.997	693	1.003	0.01	740	0.666	739	0.693	0.03	786	0.371	785	0.373	0.00
695	0.923	694	0.929	0.01	741	0.057	740	0.109	0.05	787	0.337	786	0.340	0.00
696	0.932	695	0.933	0.00	742	0.735	741	0.748	0.01	788	0.275	787	0.277	0.00
697	0.793	696	0.794	0.00	743	0.544	742	0.553	0.01	789	0.033	788	0.053	0.02
698	0.838	697	0.841	0.00	744	0.531	743	0.544	0.01	790	0.051	789	0.086	0.03
699	0.779	698	0.784	0.00	745	0.099	744	0.129	0.03	791	0.072	790	0.095	0.02
700	0.769	699	0.769	0.00	746	0.664	745	0.673	0.01	792	0.020	791	0.038	0.02
701	0.643	700	0.644	0.00	747	0.472	746	0.475	0.00	793	0.001	792	0.005	0.00
702	0.682	701	0.684	0.00	748	0.190	747	0.220	0.03	794	0.074	793	0.082	0.01
703	0.634	702	0.637	0.00	749	0.180	748	0.225	0.04	795	0.004	794	0.006	0.00
704	0.666	703	0.666	0.00	750	0.641	749	0.653	0.01	796	0.018	795	0.020	0.00
705	0.488	704	0.489	0.00	751	0.604	750	0.615	0.01	797	0.240	796	0.240	0.00
706	0.523	705	0.522	0.00	752	0.357	751	0.372	0.02	798	0.863	797	0.863	0.00
707	0.495	706	0.498	0.00	753	0.228	752	0.261	0.03	799	0.421	798	0.422	0.00
708	0.499	707	0.500	0.00	754	0.519	753	0.528	0.01	800	0.556	799	0.556	0.00
709	0.879	708	0.882	0.00	755	0.480	754	0.487	0.01	801	0.113	800	0.114	0.00
710	0.943	709	0.942	0.00	756	0.204	755	0.245	0.04	802	0.789	801	0.789	0.00
711	0.827	710	0.829	0.00	757	0.308	756	0.314	0.01	803	0.181	802	0.182	0.00
712	0.885	711	0.889	0.00	758	0.547	757	0.555	0.01	804	0.377	803	0.377	0.00
713	0.484	712	0.489	0.00	759	0.517	758	0.525	0.01	805	0.023	804	0.025	0.00
714	0.542	713	0.543	0.00	760	0.284	759	0.295	0.01	806	0.980	805	0.980	0.00
715	0.507	714	0.507	0.00	761	0.301	760	0.304	0.00	807	0.220	806	0.220	0.00
716	0.501	715	0.506	0.01	762	0.428	761	0.431	0.00	808	0.617	807	0.617	0.00

809	0.026	808	0.028	0.00	855	0.784	854	0.786	0.00	901	0.658	900	0.659	0.00
810	0.740	809	0.741	0.00	856	0.643	855	0.641	0.00	902	0.712	901	0.720	0.01
811	0.318	810	0.316	0.00	857	0.767	856	0.767	0.00	903	0.631	902	0.639	0.01
812	0.302	811	0.305	0.00	858	0.843	857	0.843	0.00	904	0.674	903	0.683	0.01
813	0.107	812	0.104	0.00	859	0.778	858	0.779	0.00	905	0.484	904	0.484	0.00
814	0.819	813	0.822	0.00	860	0.649	859	0.647	0.00	906	0.602	905	0.610	0.01
815	0.583	814	0.579	0.00	861	0.473	860	0.511	0.04	907	0.472	906	0.476	0.00
816	0.238	815	0.242	0.00	862	0.043	861	0.053	0.01	908	0.501	907	0.509	0.01
817	0.127	816	0.124	0.00	863	0.177	862	0.192	0.01	909	0.926	908	0.934	0.01
818	0.800	817	0.802	0.00	864	0.015	863	0.023	0.01	910	0.739	909	0.747	0.01
819	0.607	818	0.603	0.00	865	0.764	864	0.789	0.03	911	1.046	910	1.063	0.02
820	0.215	819	0.218	0.00	866	0.887	865	0.884	0.00	912	0.919	911	0.934	0.01
821	0.413	820	0.411	0.00	867	0.936	866	0.949	0.01	913	0.506	912	0.509	0.00
822	0.914	821	0.916	0.00	868	0.985	867	0.993	0.01	914	0.521	913	0.534	0.01
823	0.820	822	0.817	0.00	869	0.640	868	0.663	0.02	915	0.549	914	0.559	0.01
824	0.356	823	0.359	0.00	870	0.238	869	0.261	0.02	916	0.505	915	0.523	0.02
825	0.438	824	0.435	0.00	871	0.878	870	0.882	0.00	917	0.213	916	0.213	0.00
826	0.890	825	0.891	0.00	872	0.898	871	0.908	0.01	918	0.305	917	0.332	0.03
827	0.808	826	0.806	0.00	873	0.481	872	0.489	0.01	919	0.057	918	0.065	0.01
828	0.368	827	0.370	0.00	874	0.796	873	0.797	0.00	920	0.244	919	0.269	0.03
829	0.660	828	0.659	0.00	875	0.770	874	0.786	0.02	921	0.031	920	0.064	0.03
830	0.951	829	0.952	0.00	876	0.829	875	0.847	0.02	922	0.162	921	0.199	0.04
831	0.874	830	0.873	0.00	877	0.990	876	1.045	0.05	923	0.122	922	0.128	0.01
832	0.553	831	0.554	0.00	878	0.709	877	0.711	0.00	924	0.057	923	0.092	0.03
833	0.673	832	0.672	0.00	879	0.984	878	1.014	0.03	925	0.099	924	0.110	0.01
834	0.939	833	0.939	0.00	880	0.939	879	0.959	0.02	926	0.125	925	0.161	0.04
835	0.860	834	0.860	0.00	881	0.852	880	0.873	0.02	927	0.736	926	0.808	0.07
836	0.568	835	0.568	0.00	882	0.763	881	0.776	0.01	928	0.736	927	0.808	0.07
837	0.751	836	0.751	0.00	883	0.877	882	0.901	0.02	929	0.757	928	0.759	0.00
838	0.860	837	0.860	0.00	884	0.840	883	0.860	0.02	930	1.005	929	1.013	0.01
839	0.853	838	0.854	0.00	885	0.725	884	0.727	0.00	931	0.774	930	0.856	0.08
840	0.574	839	0.574	0.00	886	0.811	885	0.827	0.02	932	0.574	931	0.635	0.06
841	0.757	840	0.757	0.00	887	0.771	886	0.788	0.02	933	0.405	932	0.421	0.02
842	0.854	841	0.853	0.00	888	0.779	887	0.798	0.02	934	0.839	933	0.859	0.02
843	0.847	842	0.848	0.00	889	0.616	888	0.619	0.00	935	0.565	934	0.629	0.06
844	0.581	843	0.580	0.00	890	0.791	889	0.806	0.01	936	0.631	935	0.690	0.06
845	0.784	844	0.784	0.00	891	0.668	890	0.680	0.01	937	0.747	936	0.768	0.02
846	0.827	845	0.826	0.00	892	0.674	891	0.689	0.02	938	0.691	937	0.740	0.05
847	0.812	846	0.813	0.00	893	0.997	892	1.010	0.01	939	0.187	938	0.339	0.15
848	0.616	847	0.615	0.00	894	0.874	893	0.879	0.01	940	0.154	939	0.187	0.03
849	0.784	848	0.784	0.00	895	0.958	894	0.977	0.02	941	0.518	940	0.557	0.04
850	0.827	849	0.827	0.00	896	0.950	895	0.966	0.02	942	0.690	941	0.740	0.05
851	0.805	850	0.807	0.00	897	0.804	896	0.808	0.00	943	0.393	942	0.456	0.06
852	0.622	851	0.621	0.00	898	0.794	897	0.800	0.01	944	0.557	943	0.611	0.05
853	0.767	852	0.767	0.00	899	0.793	898	0.805	0.01	945	0.754	944	0.765	0.01
854	0.844	853	0.844	0.00	900	0.779	899	0.790	0.01	946	0.646	945	0.672	0.03

947	0.341	946	0.355	0.01
948	0.069	947	0.103	0.03
949	0.582	948	0.600	0.02
950	0.614	949	0.638	0.02
951	0.071	950	0.105	0.03
952	0.305	951	0.325	0.02
953	0.871	952	0.879	0.01
954	0.594	953	0.613	0.02
955	0.467	954	0.475	0.01
956	0.110	955	0.147	0.04
957	0.667	956	0.682	0.02
958	0.542	957	0.565	0.02
959	0.138	958	0.198	0.06
960	0.258	959	0.276	0.02
961	0.704	960	0.712	0.01
962	0.173	961	0.189	0.02
963	0.454	962	0.462	0.01
964	0.158	963	0.194	0.04
965	0.598	964	0.605	0.01
966	0.368	965	0.380	0.01
967	0.241	966	0.266	0.03
968	0.061	967	0.069	0.01
969	0.601	968	0.606	0.00
970	0.022	969	0.038	0.02
971	0.429	970	0.433	0.00
972	0.183	971	0.195	0.01
973	0.474	972	0.482	0.01
974	0.265	973	0.280	0.01
975	0.148	974	0.190	0.04
976	0.206	975	0.221	0.01
977	0.482	976	0.485	0.00
978	0.131	977	0.137	0.01
979	0.397	978	0.400	0.00
980	0.212	979	0.220	0.01
981	0.018	980	0.036	0.02
982	0.459	981	0.464	0.01
983	0.456	982	0.463	0.01
984	0.699	983	0.710	0.01
985	0.014	984	0.022	0.01
986	0.043	985	0.049	0.01
987	0.001	986	0.004	0.00
988	0.025	987	0.029	0.00
989	1.002	988	0.998	0.00
990	0.832	989	0.829	0.00
991	0.066	990	0.069	0.00
992	0.162	991	0.164	0.00
993	0.869	992	0.864	0.00
994	0.593	993	0.590	0.00
995	0.128	994	0.124	0.00
996	0.041	995	0.045	0.00
997	0.914	996	0.911	0.00
998	0.466	997	0.465	0.00
999	0.274	998	0.271	0.00
1000	0.030	999	0.033	0.00
1001	0.886	1000	0.884	0.00
1002	0.436	1001	0.436	0.00
1003	0.257	1002	0.254	0.00
1004	0.021	1003	0.023	0.00
1005	0.867	1004	0.866	0.00
1006	0.250	1005	0.250	0.00
1007	0.399	1006	0.398	0.00
1008	0.099	1007	0.099	0.00
1009	0.882	1008	0.881	0.00
1010	0.259	1009	0.260	0.00
1011	0.397	1010	0.396	0.00
1012	0.101	1011	0.101	0.00
1013	0.858	1012	0.859	0.00
1014	0.146	1013	0.148	0.00
1015	0.473	1014	0.474	0.00
1016	0.147	1015	0.147	0.00
1017	0.867	1016	0.867	0.00
1018	0.151	1017	0.152	0.00
1019	0.473	1018	0.473	0.00
1020	0.148	1019	0.148	0.00
1021	0.901	1020	0.902	0.00
1022	0.044	1021	0.046	0.00
1023	0.587	1022	0.588	0.00
1024	0.234	1023	0.233	0.00
1025	0.898	1024	0.898	0.00
1026	0.042	1025	0.044	0.00
1027	0.584	1026	0.585	0.00
1028	0.236	1027	0.235	0.00
1029	0.784	1028	0.785	0.00
1030	0.037	1029	0.036	0.00
1031	0.566	1030	0.567	0.00
1032	0.255	1031	0.254	0.00
1033	0.781	1032	0.782	0.00
1034	0.040	1033	0.038	0.00
1035	0.563	1034	0.564	0.00
1036	0.258	1035	0.256	0.00
1037	0.915	1036	0.917	0.00
1038	0.261	1037	0.258	0.00
1039	0.756	1038	0.758	0.00
1040	0.420	1039	0.418	0.00
1041	0.906	1040	0.909	0.00
1042	0.269	1041	0.266	0.00
1043	0.748	1042	0.750	0.00
1044	0.427	1043	0.425	0.00
1045	0.464	1044	0.487	0.02
1046	0.042	1045	0.050	0.01
1047	0.154	1046	0.172	0.02
1048	0.013	1047	0.021	0.01
1049	0.871	1048	0.887	0.02
1050	0.989	1049	0.993	0.00
1051	0.962	1050	0.963	0.00
1052	0.955	1051	0.969	0.01
1053	0.296	1052	0.270	-0.03
1054	0.514	1053	0.527	0.01
1055	0.890	1054	0.908	0.02
1056	0.874	1055	0.890	0.02
1057	0.870	1056	0.881	0.01
1058	0.905	1057	0.926	0.02
1059	0.703	1058	0.753	0.05
1060	0.453	1059	0.466	0.01
1061	0.874	1060	0.889	0.02
1062	0.948	1061	0.972	0.02
1063	0.973	1062	0.991	0.02
1064	0.915	1063	0.932	0.02
1065	0.620	1064	0.626	0.01
1066	0.961	1065	1.000	0.04
1067	0.817	1066	0.835	0.02
1068	0.839	1067	0.859	0.02
1069	0.871	1068	0.882	0.01
1070	0.834	1069	0.851	0.02
1071	0.741	1070	0.750	0.01
1072	0.839	1071	0.868	0.03
1073	0.818	1072	0.835	0.02
1074	0.717	1073	0.725	0.01
1075	0.774	1074	0.783	0.01
1076	0.746	1075	0.759	0.01
1077	0.838	1076	0.851	0.01
1078	0.693	1077	0.699	0.01
1079	0.731	1078	0.745	0.01
1080	0.617	1079	0.624	0.01
1081	0.681	1080	0.689	0.01
1082	0.656	1081	0.664	0.01
1083	0.850	1082	0.855	0.01
1084	0.592	1083	0.596	0.00

1085	0.867	1084	0.880	0.01	1131	0.351	1130	0.378	0.03	1177	0.176	1176	0.228	0.05
1086	0.999	1085	1.017	0.02	1132	0.307	1131	0.367	0.06	1178	0.153	1177	0.205	0.05
1087	0.940	1086	0.950	0.01	1133	0.440	1132	0.348	-0.09	1179	0.706	1178	0.725	0.02
1088	0.907	1087	0.919	0.01	1134	0.545	1133	0.588	0.04	1180	0.884	1179	0.892	0.01
1089	0.841	1088	0.842	0.00	1135	0.331	1134	0.353	0.02	1181	0.165	1180	0.178	0.01
1090	0.950	1089	0.970	0.02	1136	0.433	1135	0.461	0.03	1182	0.683	1181	0.691	0.01
1091	0.736	1090	0.748	0.01	1137	0.177	1136	0.196	0.02	1183	0.315	1182	0.324	0.01
1092	0.828	1091	0.837	0.01	1138	0.131	1137	0.132	0.00	1184	0.351	1183	0.359	0.01
1093	0.798	1092	0.804	0.01	1139	0.759	1138	0.878	0.12	1185	0.357	1184	0.371	0.01
1094	0.757	1093	0.765	0.01	1140	0.242	1139	0.384	0.14	1186	0.968	1185	0.974	0.01
1095	0.786	1094	0.787	0.00	1141	0.260	1140	0.344	0.08	1187	0.424	1186	0.434	0.01
1096	0.773	1095	0.797	0.02	1142	0.519	1141	0.622	0.10	1188	0.544	1187	0.551	0.01
1097	0.674	1096	0.686	0.01	1143	0.565	1142	0.550	-0.02	1189	0.227	1188	0.255	0.03
1098	0.657	1097	0.660	0.00	1144	0.481	1143	0.475	-0.01	1190	0.287	1189	0.293	0.01
1099	0.659	1098	0.665	0.01	1145	0.524	1144	0.559	0.04	1191	0.308	1190	0.317	0.01
1100	0.609	1099	0.613	0.00	1146	0.668	1145	0.691	0.02	1192	0.902	1191	0.906	0.00
1101	0.714	1100	0.717	0.00	1147	0.364	1146	0.390	0.03	1193	0.017	1192	0.035	0.02
1102	0.605	1101	0.610	0.00	1148	0.134	1147	0.135	0.00	1194	0.595	1193	0.598	0.00
1103	0.522	1102	0.532	0.01	1149	0.816	1148	0.827	0.01	1195	0.306	1194	0.309	0.00
1104	0.502	1103	0.504	0.00	1150	0.817	1149	0.820	0.00	1196	0.327	1195	0.330	0.00
1105	0.519	1104	0.524	0.01	1151	0.611	1150	0.709	0.10	1197	0.073	1196	0.077	0.00
1106	0.458	1105	0.460	0.00	1152	0.205	1151	0.284	0.08	1198	0.843	1197	0.845	0.00
1107	0.613	1106	0.615	0.00	1153	0.238	1152	0.350	0.11	1199	0.480	1198	0.494	0.01
1108	0.449	1107	0.456	0.01	1154	0.379	1153	0.480	0.10	1200	0.377	1199	0.384	0.01
1109	0.818	1108	0.835	0.02	1155	0.573	1154	0.645	0.07	1201	0.165	1200	0.200	0.04
1110	0.875	1109	0.882	0.01	1156	0.476	1155	0.506	0.03	1202	0.183	1201	0.218	0.04
1111	0.960	1110	0.974	0.01	1157	0.345	1156	0.374	0.03	1203	0.082	1202	0.092	0.01
1112	0.949	1111	0.956	0.01	1158	0.573	1157	0.590	0.02	1204	0.769	1203	0.773	0.00
1113	0.809	1112	0.811	0.00	1159	0.192	1158	0.283	0.09	1205	0.080	1204	0.094	0.01
1114	0.894	1113	0.928	0.03	1160	0.132	1159	0.225	0.09	1206	0.529	1205	0.532	0.00
1115	0.520	1114	0.542	0.02	1161	0.523	1160	0.549	0.03	1207	0.350	1206	0.352	0.00
1116	0.513	1115	0.516	0.00	1162	0.830	1161	0.843	0.01	1208	0.279	1207	0.283	0.00
1117	0.575	1116	0.592	0.02	1163	0.596	1162	0.618	0.02	1209	0.102	1208	0.106	0.00
1118	0.538	1117	0.542	0.00	1164	0.404	1163	0.421	0.02	1210	0.707	1209	0.707	0.00
1119	0.555	1118	0.568	0.01	1165	0.072	1164	0.123	0.05	1211	0.963	1210	0.966	0.00
1120	0.499	1119	0.538	0.04	1166	0.072	1165	0.074	0.00	1212	0.186	1211	0.187	0.00
1121	0.363	1120	0.407	0.04	1167	0.598	1166	0.619	0.02	1213	0.287	1212	0.290	0.00
1122	0.185	1121	0.192	0.01	1168	0.749	1167	0.763	0.01	1214	0.434	1213	0.436	0.00
1123	0.192	1122	0.220	0.03	1169	0.412	1168	0.424	0.01	1215	0.670	1214	0.672	0.00
1124	0.141	1123	0.143	0.00	1170	0.665	1169	0.670	0.01	1216	0.138	1215	0.154	0.02
1125	0.296	1124	0.333	0.04	1171	0.286	1170	0.293	0.01	1217	0.167	1216	0.171	0.00
1126	0.161	1125	0.177	0.02	1172	0.229	1171	0.266	0.04	1218	0.068	1217	0.076	0.01
1127	0.261	1126	0.278	0.02	1173	0.658	1172	0.674	0.02	1219	0.075	1218	0.074	0.00
1128	0.184	1127	0.185	0.00	1174	0.938	1173	0.943	0.01	1220	0.027	1219	0.028	0.00
1129	0.111	1128	0.144	0.03	1175	0.765	1174	0.784	0.02	1221	0.147	1220	0.149	0.00
1130	0.202	1129	0.201	0.00	1176	0.543	1175	0.553	0.01	1222	0.180	1221	0.185	0.00

1223	0.372	1222	0.364	-0.01
1224	0.697	1223	0.685	-0.01
1225	0.354	1224	0.340	-0.01
1226	0.113	1225	0.104	-0.01
1227	0.569	1226	0.559	-0.01
1228	0.974	1227	0.958	-0.02
1229	0.249	1228	0.244	0.00
1230	0.628	1229	0.621	-0.01
1231	0.289	1230	0.283	-0.01
1232	0.013	1231	0.019	0.01
1233	0.412	1232	0.408	0.00
1234	0.883	1233	0.876	-0.01
1235	0.229	1234	0.226	0.00
1236	0.600	1235	0.594	-0.01
1237	0.261	1236	0.256	0.00
1238	0.020	1237	0.025	0.00
1239	0.407	1238	0.405	0.00
1240	0.886	1239	0.880	-0.01
1241	0.129	1240	0.128	0.00
1242	0.614	1241	0.610	0.00
1243	0.245	1242	0.244	0.00
1244	0.177	1243	0.178	0.00
1245	0.253	1244	0.252	0.00
1246	0.857	1245	0.855	0.00
1247	0.142	1246	0.141	0.00
1248	0.632	1247	0.628	0.00
1249	0.240	1248	0.239	0.00
1250	0.182	1249	0.183	0.00
1251	0.247	1250	0.247	0.00
1252	0.848	1251	0.847	0.00
1253	0.093	1252	0.093	0.00
1254	0.633	1253	0.630	0.00
1255	0.262	1254	0.261	0.00
1256	0.235	1255	0.235	0.00
1257	0.181	1256	0.182	0.00
1258	0.833	1257	0.832	0.00
1259	0.098	1258	0.098	0.00
1260	0.640	1259	0.638	0.00
1261	0.260	1260	0.259	0.00
1262	0.238	1261	0.238	0.00
1263	0.167	1262	0.168	0.00
1264	0.813	1263	0.812	0.00
1265	0.029	1264	0.030	0.00
1266	0.666	1265	0.664	0.00
1267	0.292	1266	0.293	0.00
1268	0.328	1267	0.328	0.00

1269	0.108	1268	0.110	0.00
1270	0.884	1269	0.883	0.00
1271	0.026	1270	0.027	0.00
1272	0.662	1271	0.660	0.00
1273	0.291	1272	0.291	0.00
1274	0.329	1273	0.329	0.00
1275	0.086	1274	0.088	0.00
1276	0.847	1275	0.846	0.00
1277	0.038	1276	0.039	0.00
1278	0.782	1277	0.782	0.00
1279	0.397	1278	0.397	0.00
1280	0.424	1279	0.424	0.00
1281	0.049	1280	0.051	0.00
1282	1.027	1281	1.026	0.00
1283	0.043	1282	0.043	0.00
1284	0.778	1283	0.777	0.00
1285	0.399	1284	0.399	0.00
1286	0.422	1285	0.422	0.00
1287	0.020	1286	0.022	0.00
1288	0.972	1287	0.971	0.00
1289	0.122	1288	0.121	0.00
1290	0.699	1289	0.699	0.00
1291	0.457	1290	0.456	0.00
1292	0.364	1291	0.364	0.00
1293	0.079	1292	0.080	0.00
1294	0.856	1293	0.855	0.00
1295	0.138	1294	0.138	0.00
1296	0.682	1295	0.683	0.00
1297	0.462	1296	0.461	0.00
1298	0.359	1297	0.359	0.00
1299	0.146	1298	0.147	0.00
1300	0.789	1299	0.788	0.00
1301	0.111	1300	0.114	0.00
1302	0.488	1301	0.485	0.00
1303	0.047	1302	0.050	0.00
1304	0.211	1303	0.209	0.00
1305	0.184	1304	0.186	0.00
1306	0.813	1305	0.807	-0.01
1307	0.864	1306	0.970	0.11
1308	1.238	1307	1.269	0.03
1309	1.067	1308	1.270	0.20
1310	0.490	1309	0.522	0.03
1311	0.102	1310	0.102	0.00
1312	0.610	1311	0.615	0.01
1313	0.506	1312	0.517	0.01
1314	0.287	1313	0.276	-0.01

1315	0.680	1314	0.684	0.00
1316	0.436	1315	0.432	0.00
1317	0.551	1316	0.536	-0.01
1318	0.308	1317	0.298	-0.01
1319	0.039	1318	0.039	0.00
1320	0.546	1319	0.530	-0.02
1321	0.663	1320	0.652	-0.01
1322	0.344	1321	0.333	-0.01
1323	0.304	1322	0.298	-0.01
1324	0.666	1323	0.644	-0.02
1325	0.615	1324	0.600	-0.02
1326	0.628	1325	0.621	-0.01
1327	0.390	1326	0.383	-0.01
1328	0.795	1327	0.780	-0.02
1329	0.654	1328	0.643	-0.01
1330	0.782	1329	0.778	0.00
1331	0.629	1330	0.623	-0.01
1332	0.901	1331	0.890	-0.01
1333	0.722	1332	0.714	-0.01
1334	0.800	1333	0.800	0.00
1335	0.663	1334	0.661	0.00
1336	0.934	1335	0.928	-0.01
1337	0.862	1336	0.858	0.00
1338	0.707	1337	0.706	0.00
1339	0.377	1338	0.376	0.00
1340	0.774	1339	0.774	0.00
1341	0.616	1340	0.614	0.00
1342	0.167	1341	0.151	-0.02
1343	0.151	1342	0.159	0.01
1344	0.109	1343	0.111	0.00
1345	0.084	1344	0.086	0.00
1346	0.104	1345	0.113	0.01
1347	0.139	1346	0.152	0.01
1348	0.161	1347	0.152	-0.01
1349	0.702	1348	0.650	-0.05
1350	0.598	1349	0.607	0.01
1351	0.142	1350	0.154	0.01
1352	0.151	1351	0.163	0.01
1353	0.121	1352	0.126	0.00
1354	0.142	1353	0.150	0.01
1355	0.165	1354	0.141	-0.02
1356	0.867	1355	0.871	0.00
1357	0.698	1356	0.713	0.01
1358	1.117	1357	1.122	0.01
1359	0.802	1358	0.808	0.01
1360	0.721	1359	0.715	-0.01

1361	0.823	1360	0.826	0.00
1362	0.785	1361	0.787	0.00
1363	0.707	1362	0.703	0.00
1364	0.079	1363	0.079	0.00
1365	0.156	1364	0.152	0.00
1366	0.158	1365	0.154	0.00
1367	0.027	1366	0.027	0.00
1368	0.131	1367	0.128	0.00
1369	0.138	1368	0.131	-0.01
1370	0.351	1369	0.350	0.00
1371	0.346	1370	0.346	0.00
1372	0.322	1371	0.321	0.00
1373	0.103	1372	0.106	0.00
1374	0.105	1373	0.108	0.00
1375	0.039	1374	0.041	0.00
1376	0.181	1375	0.181	0.00
1377	0.270	1376	0.417	0.15
1378	0.271	1377	0.400	0.13
1379	0.172	1378	0.172	0.00
1380	0.109	1379	0.111	0.00
1381	0.111	1380	0.113	0.00
1382	0.071	1381	0.076	0.01
1383	0.470	1382	0.475	0.01
1384	0.466	1383	0.471	0.01
1385	0.434	1384	0.442	0.01
1386	0.341	1385	0.343	0.00
1387	0.340	1386	0.340	0.00
1388	0.067	1387	0.056	-0.01
1389	0.279	1388	0.276	0.00
1390	0.277	1389	0.275	0.00
1391	0.240	1390	0.262	0.02
1392	0.904	1391	0.917	0.01
1393	0.412	1392	0.407	-0.01
1394	0.129	1393	0.129	0.00
1395	0.008	1394	0.011	0.00
1396	0.007	1395	0.003	0.00
1397	0.138	1396	0.133	-0.01
1398	0.304	1397	0.301	0.00
1399	0.011	1398	0.009	0.00
1400	0.411	1399	0.412	0.00
1401	0.410	1400	0.408	0.00
1402	0.394	1401	0.394	0.00
1403	0.328	1402	0.327	0.00
1404	0.433	1403	0.431	0.00
1405	0.078	1404	0.083	0.01
1406	0.064	1405	0.070	0.01

1407	0.005	1406	0.011	0.01
1408	0.187	1407	0.184	0.00
1409	0.029	1408	0.037	0.01
1410	0.957	1409	0.965	0.01
1411	0.976	1410	0.976	0.00
1412	0.938	1411	0.951	0.01
1413	0.968	1412	0.969	0.00
1414	0.320	1413	0.322	0.00
1415	0.394	1414	0.395	0.00
1416	0.440	1415	0.440	0.00
1417	0.263	1416	0.263	0.00
1418	0.219	1417	0.225	0.01
1419	0.133	1418	0.139	0.01
1420	0.075	1419	0.081	0.01
1421	0.025	1420	0.030	0.01
1422	0.058	1421	0.059	0.00
1423	0.067	1422	0.075	0.01
1424	0.856	1423	0.856	0.00
1425	0.497	1424	0.498	0.00
1426	0.878	1425	0.880	0.00
1427	0.583	1426	0.573	-0.01
1428	1.178	1427	1.214	0.04
1429	0.774	1428	0.776	0.00
1430	0.519	1429	0.517	0.00
1431	0.348	1430	0.351	0.00
1432	0.178	1431	0.188	0.01
1433	0.021	1432	0.029	0.01
1434	0.063	1433	0.070	0.01
1435	0.049	1434	0.046	0.00
1436	0.135	1435	0.135	0.00
1437	0.014	1436	0.020	0.01
1438	0.722	1437	0.731	0.01
1439	0.711	1438	0.708	0.00
1440	0.602	1439	0.597	0.00
1441	0.494	1440	0.488	-0.01
1442	0.497	1441	0.492	-0.01
1443	0.630	1442	0.625	-0.01
1444	0.693	1443	0.688	0.00
1445	0.902	1444	0.898	0.00
1446	0.668	1445	0.668	0.00
1447	0.553	1446	0.571	0.02
1448	1.323	1447	1.327	0.00
1449	1.506	1448	1.510	0.00
1450	0.868	1449	0.859	-0.01
1451	0.432	1450	0.428	0.00
1452	0.570	1451	0.561	-0.01

1453	0.544	1452	0.536	-0.01
1454	0.553	1453	0.545	-0.01
1455	0.753	1454	0.746	-0.01
1456	0.813	1455	0.806	-0.01
1457	1.106	1456	1.100	-0.01
1458	1.029	1457	1.032	0.00
1459	0.702	1458	0.705	0.00
1460	0.433	1459	0.420	-0.01
1461	0.159	1460	0.160	0.00
1462	0.379	1461	0.367	-0.01
1463	0.231	1462	0.229	0.00
1464	0.362	1463	0.355	-0.01
1465	0.281	1464	0.279	0.00
1466	0.361	1465	0.356	0.00
1467	0.278	1466	0.277	0.00
1468	0.524	1467	0.521	0.00
1469	0.280	1468	0.279	0.00
1470	0.226	1469	0.226	0.00
1471	0.653	1470	0.653	0.00
1472	0.356	1471	0.359	0.00
1473	0.415	1472	0.416	0.00
1474	0.804	1473	0.801	0.00
1475	1.035	1474	1.027	-0.01
1476	0.279	1475	0.333	0.05
1477	0.343	1476	0.340	0.00
1478	0.160	1477	0.158	0.00
1479	0.114	1478	0.136	0.02
1480	0.146	1479	0.189	0.04
1481	0.193	1480	0.193	0.00
1482	0.019	1481	0.023	0.00
1483	0.088	1482	0.108	0.02
1484	0.162	1483	0.179	0.02
1485	0.050	1484	0.060	0.01
1486	0.023	1485	0.028	0.00
1487	0.005	1486	0.006	0.00
1488	0.005	1487	0.007	0.00
1489	0.040	1488	0.043	0.00
1490	0.032	1489	0.035	0.00
1491	0.018	1490	0.021	0.00
1492	0.030	1491	0.039	0.01
1493	0.033	1492	0.035	0.00
1494	0.031	1493	0.064	0.03
1495	0.150	1494	0.178	0.03
1496	0.122	1495	0.124	0.00
1497	0.058	1496	0.080	0.02
1498	0.261	1497	0.265	0.00

1499	0.184	1498	0.185	0.00
1500	0.111	1499	0.141	0.03
1501	0.202	1500	0.201	0.00
1502	0.351	1501	0.352	0.00
1503	0.307	1502	0.368	0.06
1504	0.730	1503	0.730	0.00
1505	0.127	1504	0.115	-0.01
1506	0.051	1505	0.068	0.02
1507	0.048	1506	0.065	0.02

APPENDIX E: Case study intermediate results of certain elements

1309	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	R and K
LC5	Cross-Section Properties - SHS 300x300x12.5 | Ruukki					
	Design Internal Forces					
	Axial Force	NEd	kN	-3669.07	-3667.906	0 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0 %
	Shear Force	Vz,Ed	kN	77.67	78.178	1 %
	Torsional Moment	TEd	kNm	0.0	0.0	0 %
	Moment	My,Ed	kNm	208.04	209.238	1 %
	Moment	Mz,Ed	kNm	0.0	0.0	0 %
	Cross-Section Classification - Class 1	Class		1.0	1.0	0 %
	Design Ratio					
	Moment	My,Ed	kNm	208.04	209.238	1 %
	Plastic Section Modulus	Wpl,y	cm^3	1450.6	1451.0	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	0 %
	Partial Factor	<gamma>M0		1.0	1.0	0 %
	Moment Resistance	Mpl,y,Rd	kNm	514.96	515.11	0 %
	Shear Force	Vz,Ed	kN	77.67	78.178	1 %
	Effective Shear Area	Av,z	cm^2	68.52	68.5	0 %
	Shear Force Resistance	Vpl,z,Rd	kN	1404.38	1403.97	0 %
	Criterion Vz,Ed / Vpl,z,Rd	vz		0.055		
	Cross-Sectional Area	A	cm^2	137.04	137.0	0 %
	Section Width	b	mm	300.0	300.0	0 %
	Section Thickness	t	mm	12.5		
	Factor	aw		0.453		
	Axial Force	NEd	kN	-3669.07	-3667.906	0 %
	Design plastic resistance to normal forces	Npl,Rd	kN	4864.92	4863.5	0 %
	Ratio NEd / Npl,Rd	n		0.754		
	Moment Resistance	MN,pl,y,Rd	kNm	163.62		
	Design Component for My	<eta>My		1.271		
	Design Ratio	<eta>		1.067	1.27	19 %
	Design Formula					
	My,Ed / MN,y,Rd = 1.067 <gt> 1 (6.31)					

1133	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	R and K
LC5	Cross-Section Properties - HE B 700 | Euronorm 53-62					
	Design Internal Forces					
	Axial Force	NEd	kN	-322.69	-318.443	-1 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0 %
	Shear Force	Vz,Ed	kN	-945.82	-973.773	3 %
	Torsional Moment	TEd	kNm	0.0	0.0	0 %
	Moment	My,Ed	kNm	0.0	0.0	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0 %
	Cross-Section Classification - Class 4	Class		4.0	1.0	-75 %
	Effective Cross-Section Properties					
	Design Ratio					
	Shear Force	Vz,Ed	kN	945.82	976.01	3 %
	First Moment of Area	Qy	cm^3	4160.0		
	Moment of Inertia	Iy	cm^4	256900.0	256900.0	0 %
	Thickness	t	mm	17.0		
	Shear Stress	<tau>V,z,Ed	kN/cm^2	9.01		
	Yield Strength	fy	kN/cm^2	35.5	35.5	0 %
	Partial Factor	<gamma>M0		1.0	1.0	0 %
	Shear Stress Resistance	<tau>Rd	kN/cm^2	20.5		
	Design Ratio	<eta>		0.44	0.348	-21 %
	Design Formula					
	<tau>V,z,Ed / <tau>Rd = 0.440 <le> 1 (6.19)					

1053	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	R and K
LC5	Cross-Section Properties - SHS 60x60x2.5 | Ruukki					
	Design Internal Forces					
	Axial Force	NEd	kN	56.81	51.062	-10 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0 %
	Shear Force	Vz,Ed	kN	-0.03	-0.028	-6 %
	Torsional Moment	TEd	kNm	0.0	0.0	0 %
	Moment	My,Ed	kNm	-0.06	-0.056	-7 %
	Moment	Mz,Ed	kNm	0.0	0.0	0 %
	Cross-Section Classification - No Compression	Class			1.0	
	Design Ratio					

	Moment	My,Ed	kNm	0.06	0.056	-7 %
	Plastic Section Modulus	Wpl,y	cm^3	11.93	11.93	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	0 %
	Partial Factor	<gamma>M0		1.0	1.0	0 %
	Moment Resistance	Mpl,y,Rd	kNm	4.24	4.24	0 %
	Shear Force	Vz,Ed	kN	0.03	0.028	-6 %
	Effective Shear Area	Av,z	cm^2	2.8	2.795	0 %
	Shear Force Resistance	Vpl,z,Rd	kN	57.29	57.29	0 %
	Criterion Vz,Ed / Vpl,z,Rd	vz		0.0		
	Cross-Sectional Area	A	cm^2	5.59	5.59	0 %
	Section Width	b	mm	60.0	60.0	0 %
	Section Thickness	t	mm	2.5		
	Factor	aw		0.463		
	Axial Force	NEd	kN	56.81	51.062	-10 %
	Design plastic resistance to normal forces	Npl,Rd	kN	198.45	198.45	0 %
	Ratio NEd / Npl,Rd	n		0.286		
	Moment Resistance	MN,pl,y,Rd	kNm	3.93		
	Design Component for My	<eta>My		0.014		
	Design Ratio	<eta>		0.296	0.27	-9 %
	Design Formula					
	My,Ed / MN,y,Rd = 0.296 <le> 1 (6.31)					

727	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	R and K
LC5	Cross-Section Properties - SHS 150x150x5 | Ruukki					
	Design Internal Forces					
	Axial Force	NEd		37.64	37.877	1 %
	Shear Force	Vy,Ed		0.0	0.0	0 %
	Shear Force	Vz,Ed		46.5	46.707	0 %
	Torsional Moment	TEd		0.0	0.0	0 %
	Moment	My,Ed		37.75	37.749	0 %
	Moment	Mz,Ed		0.0	0.0	0 %
	Cross-Section Classification - Class 1	Class		1.0	3.0	200 %
	Design Ratio					
	Moment	My,Ed		37.75	37.749	0 %
	Plastic Section Modulus	Wpl,y		152.98	153.0	0 %
	Yield Strength	fy		35.5	35.5	0 %
	Partial Factor	<gamma>M0		1.0	1.0	0 %
	Moment Resistance	Mpl,y,Rd		54.31	46.47	-14 %
	Shear Force	Vz,Ed		46.5	46.707	0 %
	Effective Shear Area	Av,z		14.18	14.18	0 %
	Shear Force Resistance	Vpl,z,Rd		290.63	290.63	0 %
	Criterion Vz,Ed / Vpl,z,Rd	vz		0.16		
	Cross-Sectional Area	A		28.36	28.36	0 %
	Section Width	b		150.0	150.0	0 %
	Section Thickness	t		5.0		
	Factor	aw		0.471		
	Axial Force	NEd		37.64	37.877	1 %
	Design plastic resistance to normal forces	Npl,Rd		1006.78	1006.78	0 %
	Ratio NEd / Npl,Rd	n		0.037		
	Moment Resistance	MN,pl,y,Rd		54.31		
	Design Component for My	<eta>My		0.695		
	Design Ratio	<eta>		0.695	0.85	22 %
	Design Formula					
	My,Ed / MN,y,Rd = 0.695 <le> 1 (6.31)					

939	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	R and K
LC5	Cross-Section Properties - SHS 60x60x2 | Ruukki					
	Design Internal Forces					
	Axial Force	NEd	kN	30.1	29.787	-1 %
	Shear Force	Vy,Ed	kN	0.0	0.0	0 %
	Shear Force	Vz,Ed	kN	-0.64	0.644	0 %
	Torsional Moment	TEd	kNm	0.0	0.0	0 %
	Moment	My,Ed	kNm	0.0	0.0	0 %
	Moment	Mz,Ed	kNm	0.0	0.0	0 %
	Cross-Section Classification - No Compression	Class			1.0	
	Design Ratio					
	Tension Force	Nt,Ed	kN	30.1	29.787	-1 %
	Cross-Sectional Area	A	cm^2	4.54	4.54	0 %
	Yield Strength	fy	kN/cm^2	35.5	35.5	0 %
	Partial Factor	<gamma>M0		1.0	1.0	0 %
	Design plastic resistance to normal forces	Npl,Rd	kN	161.17	161.17	0 %
	Axial Force Resistance	Nt,Rd	kN	161.17	161.17	0 %
	Design Ratio	<eta>		0.187	0.339	81 %
	Design Formula					
	Nt,Ed / Nt,Rd = 0.187 <le> 1 (6.5)					

1139	Material Properties - Steel S 355 | DIN EN 1993-1-1:2010-12			RFEM	Karamba	R and K
LC5	Cross-Section Properties - SHS 90x90x3 | Ruukki					

Design Internal Forces					
Axial Force	NEd	kN	-207.98	-204.196	-2 %
Shear Force	Vy,Ed	kN	0.0	0.0	0 %
Shear Force	Vz,Ed	kN	-3.55	-3.576	1 %
Torsional Moment	TEd	kNm	0.0	0.0	0 %
Moment	My,Ed	kNm	-2.84	-2.867	1 %
Moment	Mz,Ed	kNm	0.0	0.0	0 %
Cross-Section Classification - Class 1	Class		1.0	3.0	200 %
Design Ratio					
Modulus of Elasticity	E	kN/cm^2	21000.0	21000.0	0 %
Moment of Inertia	Iy	cm^4	127.28	127.3	0 %
Effective Member Length	Lcr,y	m	0.81	0.81	0 %
Elastic Flexural Buckling Force	Ncr,y	kN	4020.77	4021.4	0 %
Cross-Sectional Area	A	cm^2	10.21	10.21	0 %
Yield Strength	fy	kN/cm^2	35.5	35.5	0 %
Slenderness	<lambda>_y		0.3		
Buckling Curve	BCy		c		
Imperfection Factor	<alfa>y		0.49	0.49	0 %
Auxiliary Factor	<phic>y		0.57		
Reduction Factor	<chi>y		0.949	0.949	0 %
Moment of Inertia	Iz	cm^4	127.28	127.3	0 %
Effective Member Length	Lcr,z	m	0.81	0.81	0 %
Elastic Flexural Buckling Force	Ncr,z	kN	4020.77	4021.4	0 %
Slenderness	<lambda>_z		0.3		
Buckling Curve	BCz		c		
Imperfection Factor	<alfa>z		0.49	0.49	0 %
Auxiliary Factor	<phic>z		0.57		
Reduction Factor	<chi>z		0.949	0.949	0 %
Structure type about y-axis	Type		Non-sway		
Moment Distribution	Diagr My		1) Linear		
Moment Factor	<psi>y		0.0		
Moment Factor	Cmy		0.6	0.9	50 %
Structure type about z-axis	Type		Non-sway		
Moment Distribution	Diagr Mz		1) Linear		
Moment Factor	<psi>z		0.0		
Moment Factor	Cmz		0.6	1.0	67 %
Component Type	Component		Torsion. Rigid		
Interaction Factor	kyy		0.636	0.996	57 %
Interaction Factor	kyz		0.382	0.996	161 %
Interaction Factor	kzy		0.382	0.954	150 %
Interaction Factor	kzz		0.636	0.996	57 %
Axial Force (Compression)	NEd	kN	207.98	204.196	-2 %
Governing Cross-Sectional Area	Ai	cm^2	10.21	10.21	0 %
Compression Resistance	NRk	kN	362.46	362.46	0 %
Partial Factor	<gamma>M1		1.0	1.0	0 %
Design Component for N	<eta>Ny		0.605		
Design Component for N	<eta>Nz		0.605		
Moment	My,Ed	kNm	2.84	2.867	1 %
Section Modulus	Wy	cm^3	33.04	33.04	0 %
Moment Resistance	My,Rk	kNm	11.73		
Moment Component	<eta>My		0.242		
Section Modulus	Wz	cm^3	33.04	33.04	0 %
Moment Resistance	Mz,Rk	kNm	11.73		
Moment Component	<eta>Mz		0.0		
Design 1	<eta>1		0.759	0.878	16 %
Design 2	<eta>2		0.697		
Design Formula					

NEd / (<chi>y NRk / <gamma>M1) + kyy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kyz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.759 <le> 1 (6.61)

NEd / (<chi>z NRk / <gamma>M1) + kzy My,Ed / (<chi>LT My,Rk / <gamma>M1) + kzz Mz,Ed / (Mz,Rk / <gamma>M1) = 0.697 <le> 1 (6.62)