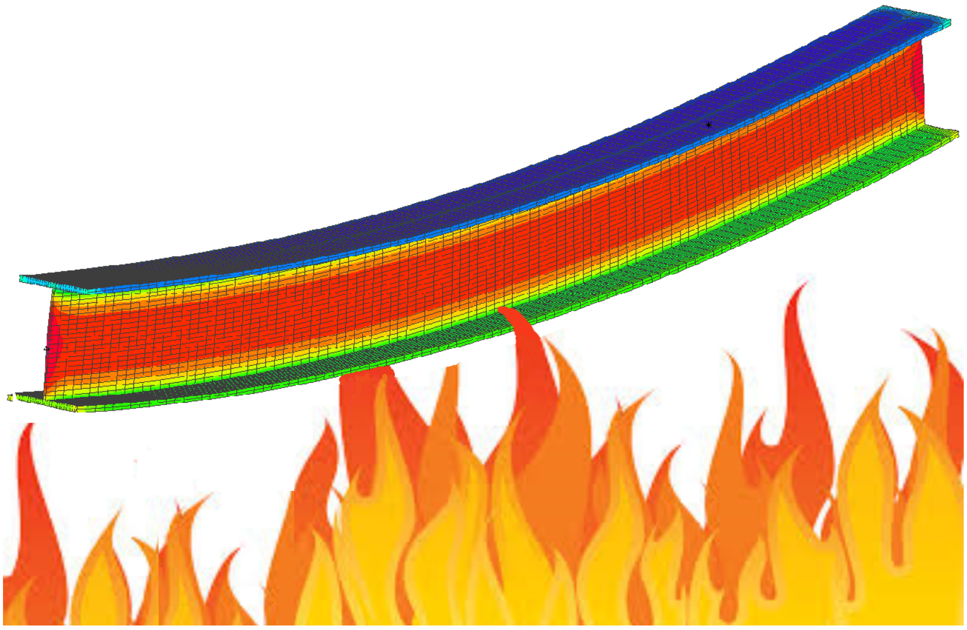

Structural integrity of steel structures subjected to fire

A comparison between Eurocode and FE modelling

Master's Thesis in the Master's Programme Structural Engineering and
Building Technology

FELICIA CARLANDER-REUTERFELT
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Cover: Steal beam and fire, with colours of the beam describing the temperature distribution of a steel beam subjected to elevated temperatures analyzed in ADINA.

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Abstract

Traditionally in Sweden, the fire resistance design of buildings is based on tabulated values specifying the required amount of a specific fire protection material. Alternatively, simplified calculation models from Eurocode may be used. Because fire resistance design is complicated, the design standards are conservative and this naturally results in more expensive designs. Provided that certain criteria are met, the current building codes also allow for more advanced methods to be used in the design of fire resistance. One possibility is to use numerical analyses with e.g. FE modelling to get a more realistic heat propagation scenario. Such a refined analysis can give less conservative results and may potentially provide more economical solutions.

To be able to answer the question whether a costlier and more time-consuming FE analysis in the design process helps to save material resources and time in the construction stage, the aim of this study was to investigate the extent of the advantages of using more advanced assessment methods for fire resistance design of steel structures. The first step of the study consisted of a literature study of the behaviour of structural steel subjected to increased temperatures and a review of current FE-modelling applications. In the second step analytical and numerical analyses of a representative structural element subjected to fire was made in order to compare analytical calculations to FE modelling. This structural element was first studied in a two-phased parametric study that investigated the influence of different parameters. The subsequent Main study was based on the influence of the different parameters. The Main study investigated a fire exposed steel beam with an axially applied normal force. The data obtained from the FE analyses and hand calculations consisted of numerous failure temperatures for beams with different boundary conditions, load effects and geometries. By comparing these values, several conclusions could be drawn.

The main conclusion was that the magnitude of the temperature gains when using FE analysis, and thus possible economical gains, depends on the geometry of and the loads on the structure in question. The gains increase with increasing thickness of the structural member and if lateral torsional buckling needs to be included. The slenderness' influence on the gains is most important for beams subjected to axial loads. Finally, due to the temperature lag between the air and the beam, there will always be gains in performing a FE analysis.

Keywords: Steel, Steel structures, Fire, Eurocode, FE-modelling, Standard fire, ISO 834, EN 1993-1-2, EN 1991-1-2, Fire resistance.

Strukturell integritet av stålkonstruktioner utsatta för brand
En jämförelse mellan Eurocode och FE modellering
Examensarbete inom masterprogrammet för Konstruktionsteknik och byggnadsteknologi
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Sammanfattning

I Sverige används traditionellt tabulerade värden för att specificera mängden brandskyddsmaterial som krävs vid dimensionering av en konstruktionsdel vid brandlastfall. Alternativt kan förenklade beräkningsmetoder i Eurocode användas. På grund av komplexiteten av dimensionering i brandlastfall, är dimensioneringsstandarderna konservativa vilket leder till dyrare konstruktioner. Förutsatt att vissa kriterier är uppfyllda tillåter Eurocode även användning av mer avancerade metoder för dimensionering i brandlastfall. En möjlighet är att använda numeriska analyser med FE modellering för att erhålla en mer realistisk approximation för värmespridningen. Sådana förfinade analyser skulle kunna ge mindre konservativa resultat och mer ekonomiska lösningar.

Syftet med den här studien var att undersöka hur stora fördelarna kan vara av att använda mer avancerade beräkningsmetoder för dimensionering av stålkonstruktioner i brandlastfall. Det gjordes för att svara på frågan om huruvida en mer kostsam och tidskrävande FE analys i dimensioneringsskedet kan bidra till besparingar av materiella resurser och tid i byggskedet. Det första steget i studien bestod av en litteraturstudie av konstruktionsståls beteende vid förhöjda temperaturer samt en genomgång av befintliga brandapplikationer av FE modellering. I det andra steget genomfördes först analytiska analyser och därefter numeriska analyser av en representativ konstruktionsdel utsatt för brand. Det gjordes för att kunna jämföra Eurocode-baserade beräkningar med FE analyser. Den representativa konstruktionsdelen studerades först i en tvåfasig parameterstudie som undersökte inflytandet av olika parametrar. I efterföljande huvudstudie beaktades sedan dessa parametrars påverkan. I huvudstudien undersöktes en stålbalk med en yttre axiell last i brandlastfallet. De resultat som erhölls från FE analyserna och handberäkningarna bestod av flertalet kollapstemperaturer för balkar med olika randvillkor, lasteffekter och geometrier. Genom att jämföra de olika värdena, kunde flera slutsatser dras.

Den huvudsakliga slutsatsen var att magnituden av temperaturvinningen, och således möjligheterna till besparingar, beror på geometrin av och lasten på konstruktionsdelen i fråga. Förtjänsterna ökar generellt med ökande tjocklek på konstruktionsdelens tvärsnitt samt om vippning beaktas. Slankhetens påverkan på vinningen är viktigast för axiellt lastade balkar. Slutligen, på grund av eftersläpningen av temperatur mellan luft och balk finns det alltid möjliga förtjänster med att genomföra en FE analys.

Nyckelord: Stål, stålkonstruktioner, brand, Eurokoderna, FE-modellering, Standard brand, ISO 834, EN1993-1-2, EN 1991-1-2, Fire resistance.

Contents

Preface

The study was carried out as a co-operation between ÅF and the Division of Structural Engineering at Chalmers University of Technology. The work was carried out at ÅF's office in Gothenburg, Sweden, between January and June 2018. Our supervisors at ÅF were David Wesley from Structural Engineering as well as Andreas Eliasson from Fire and Safety.

Firstly we would like to thank our main supervisor David Wesley for his engagement, positive spirit and many helpful suggestions to our work. He has contributed a lot to our understanding of the subject and helped us when the work seemed overwhelming.

We would also like to thank Mario Plos for his excellent work as an examiner and supervisor. His on-point comments and corrections of our report as well as his advice of improvements and simplifications of our study has been invaluable.

Additionally, we send our thanks to Andreas Eliasson and Mattias Carlsson. Andreas contributed a lot at the start of our thesis work by teaching us about the behaviour of fire and the directives for fire design. Mattias has been a great support with everything related to FE-modelling and he has never hesitated to help.
Finally, we would like to thank our opponents Victor Eryd and Anton Hellberg for their input and constructive criticism during our thesis work.

Felicia Carlander-Reuterfelt and Felicia Flink, Gothenburg, June 2018

Nomenclature

Latin capital letters

A	Element area of the cross section with a temperature θ
A_d	Design value of an accidental action
A_i	Element area of the cross section with a temperature θ_i
C_1	Coefficient depending on the loading and the end restraint conditions
C_2	Coefficient depending on the loading and the end restraint conditions
E	Modulus of elasticity
E_a	Modulus of elasticity of steel for normal temperature design
$E_{a,\theta}$	Slope of the linear elastic range for steel at elevated temperature θ_a
E_d	Design value of the relevant effects of actions from the fundamental combination according to EN 1990
$E_{fi,d}$	Design effect of actions for the fire situation determined in accordance with EN 1991-1-2
$E_{fi,d,t}$	Design value of the relevant effects of actions in the fire situation at time t
G	Shear modulus for steel
G_k	Characteristic value of a permanent action
$G_{k,j}$	Characteristic value of permanent action j
I_t	Torsion constant
I_w	Warping constant
I_z	Second moment of area about the weak axis
L	Unrestrained length of the beam
$M_{b,fi,t,Rd}$	Design buckling resistance moment at time t
M_{cr}	Elastic critical moment for lateral torsional buckling
$M_{fi,\theta,Rd}$	Design moment resistance of the cross section for a uniform temperature θ_a which is equal to the uniform temperature θ_a at time t in a cross section which is not thermally influenced by the supports
M_{Rd}	Plastic moment resistance of the gross cross section $M_{pl,Rd}$ for normal temperature design according to EN 1993-1-1
$M_{y,fi,Ed}$	Design bending moment, y-y axis, for the fire situation, determined in accordance with EN 1991-1-2
$M_{z,fi,Ed}$	Design bending moment, z-z axis, for the fire situation, determined in accordance with EN 1991-1-2
$N_{b,fi,t,Rd}$	Design buckling resistance at time t of a compression member
$N_{fi,Ed}$	Design value of the axial force for the fire situation, determined in accordance with EN 1991-1-2
$N_{fi,\theta,Rd}$	Design resistance of a tension member at uniform temperature θ_a
N_{Rd}	Design resistance of the cross section $N_{pl,Rd}$ for normal temperature design according to EN 1993-1-1
P	Relevant representative value of a prestressing action
Q_{fi}	Design load in fire scenario
$Q_{k,1}$	Characteristic value of the leading variable action one
$Q_{k,i}$	Characteristic value of variable action i
Q_{ULS}	Design load in ultimate limit state
$R_{fi,d,0}$	Value of $R_{fi,d,t}$ at time t=0
$R_{fi,d,t}$	Design value of the resistance of the member in the fire situation at time t

T_1	Temperature on surface one
T_2	Temperature on surface two
T_a	Air temperature
T_s	Temperature on the surface
$V_{fi,t,Rd}$	Design shear resistance at time t
V_{Rd}	Shear resistance of the gross cross section for normal temperature design according to EN 1993-1-1
$W_{pl,y}$	Plastic section modulus of the member about y-axis
$W_{pl,z}$	Plastic section modulus of the member about z-axis
$X_{d,fi}$	Design value of a strength or deformation property for fire design after time t
X_k	Characteristic value of a strength or deformation property for normal temperature design

Latin lowercase letters

d	Thickness of the material
$f_{p,\theta}$	Proportional limit for steel at elevated temperature θ_a
f_y	Yield strength at 20°C
$f_{y,i}$	Normal yield strength f_y for the elemental area A_i taken as positive on the compression side of the plastic neutral axis and negative on the tension side
$f_{y,\theta}$	Effective yield strength of steel at elevated temperature θ_a
$k_{E,\theta}$	Reduction factor for the slope of the linear elastic range at steel temperature θ_a reached at time t
k_{LT}	Interaction factor
$k_{p,\theta}$	Reduction factor for the proportional limit of steel at the steel temperature θ_a reached at time t
k_w	Factor for the warping conditions
k_y	Interaction factor
$k_{y,\theta}$	Reduction factor for the yield strength of steel at steel temperature θ_a reached at time t
$k_{y,\theta,com}$	Reduction factor for the yield strength of steel at the maximum temperature in the compression flange $\theta_{a,com}$ reached at time t
$k_{y,\theta,i}$	Reduction factor for the yield strength of steel at temperature θ_i
$k_{y,\theta,web}$	Reduction factor for the yield strength of steel at the steel temperature θ_{web}
k_z	Factor for the end rotation plan
k_z	Ineraction factor
k_θ	Reduction factor for a strength deformation property, dependent on the material temperature
q_c	Convection heat flow rate
q_{cd}	Conduction heat flow rate
q_r	Radiation heat flow rate
t	Time
$t_{fi,d}$	Design value of the fire resistance time
$t_{fi,requ}$	Required fire resistance time

z_i	Distance from the plastic neutral axis of the centroid of the elemental area A_i
z_g	Distance between the point of load application and the shear center

Greek capital letters

$\Theta_{cr,d}$	Design value of the critical material temperature
Θ_d	Design value of material temperature
Θ_g	Gas temperature on the fire compartment
Φ	Form factor

Greek lowercase letters

α	Imperfection factor
α	Imperfection factor for the fire design situation
α_c	Convective heat transfer coefficient
β_M	Equivalent moment factor
γ_G	Partial factor for permanent actions, also accounting for model uncertainties and dimensional variations
$\gamma_{g,j}$	Partial factor for permanent action j, which takes account of the possibility of unfavorable deviations of the action values from the representative values
$\gamma_{M,0}$	Partial factor for resistance of cross section whatever the class is
$\gamma_{M,fi}$	Partial factor for relevant material property for the fire situation found in EKS
γ_P	Partial factor for prestressing actions
γ_Q	Partial factor for variable actions, also accounting for model uncertainties and dimensional variations
$\gamma_{Q,1}$	Partial factor for variable action one
$\gamma_{q,1}$	Partial factor for the leading variable action one which takes account for the possibility of unfavorable deviations of the action values from the representative values
$\gamma_{q,i}$	Partial factor for the leading variable action i which takes account for the possibility of unfavorable deviations of the action values from the representative values
γ_{Sd}	Partial factor associated with the uncertainty of the action and/or action effect model
ϵ	Coefficient depending on f_y
ϵ_1	Emissivity constant for surface one
ϵ_2	Emissivity constant for surface two
η_{fi}	Reduction factor for design load level in the fire situation
θ_a	Steel temperature
$\theta_{a,cr}$	Critical temperature of steel
λ	Heat conductivity constant
λ	Non dimensional slenderness
λ_{LT}	Non dimensional slenderness for lateral torsional buckling

$\lambda_{LT,\theta_{com}}$	Non dimensional slenderness for lateral torsional buckling for the fire situation
λ_{θ}	Non dimensional slenderness for fire situation
μ_0	Degree of utilization at time t
μ_{LT}	Factor to determine the interaction factor k_{LT}
μ_y	Factor to determine the interaction factor k_y
μ_z	Factor to determine the interaction factor k_z
σ	Stephan Boltzmann's constant
$\phi_{LT,\theta,com}$	Value to determine reduction factor for lateral torsional buckling in the fire design situation
χ_{fi}	Reduction factor for flexural buckling in the fire design situation
$\chi_{LT,fi}$	Reduction factor for lateral torsional buckling in the fire design situation
$\chi_{min,fi}$	The minimum value of $\chi_{y,fi}$ and $\chi_{z,fi}$
$\chi_{y,fi}$	Reduction factor for flexural buckling around the y-axis in the fire design situation
$\chi_{z,fi}$	Reduction factor for flexural buckling around the z-axis in the fire design situation
$\psi_{0,i}$	Factor for combination value of variable action i
$\psi_{1,1}$	Factor for frequent value of leading variable action one
$\psi_{2,1}$	Factor for quasi-permanent value of leading variable action one
$\psi_{2,i}$	Factor for quasi-permanent value of variable action i
ψ_{fi}	Combination factor for frequent values given either by $\psi_{1,1}$ or $\psi_{2,1}$
φ_{θ}	Value to determine reduction factor

Codes and regulations

EN 1990	Basis of structural design: Principles and requirements for the structural safety, serviceability and maintenance.
EN 1991-1-2	Actions on structures - General actions on structures exposed to fire
EN 1993-1-1	Design of steel structures - General rules and rules for buildings
EN 1993-1-2	Design of steel structures - General rules for structural fire design
EKS	Directives from Boverket for application of Eurcode standards in Sweden: National parameters
BBR	Directives from Boverket for application of Eurcode standards in Sweden: Classification of buildings

1

Introduction

1.1 Background

In the event of fire and extreme temperatures in a building, most building materials' fundamental properties change (Bao et al., 2016). For steel, as for most other materials, the structural resistance decreases at high temperatures. The yield stress of steel as well as the stiffness is reduced at high temperatures leading to a reduced capacity to carry load. The heat and fire also creates additional restraining loads due to strains caused by the temperature differences (Liu et al., 2002). These strains may also result in significant second order effects.

Traditionally in Sweden, the design of fire resistance in buildings is based on tabulated values specifying required amount of a specific fire protection material. Alternatively, simplified calculation models from Eurocode, with additions of national parameters from Boverket (National Board of Housing, Building and Planning in Sweden) are used. There are different alternative calculation models, but none of them have the ability to fully describe the natural development of a fire.

Another issue when designing a building against fire, is to know how and where a potential fire may occur and how it develops with time. The possible variations are endless and this makes the design process even more complicated. To solve this, a commonly used design method is based on what is called a "standard fire" that follows the ISO 834 curve (CEN, 2009). The standard fire was introduced in EN 1991-1-2 Chapter 3 (CEN, 2009) to represent a plausible relationship between temperature and time in a fire scenario. The fire resistance, i.e. the time a building should be able to withstand this standard fire, is based on several different aspects. These aspects include, among other things, the size and use of the building as well as the characteristics of the building component concerned.

Because fire resistance design is complicated and fire propagation is hard to predict, the design standards are most likely conservative. This naturally results in more expensive design where as much as 30 % of the cost of the steel-work can be conventional fire protection (Qian et al., 2008). Costly protective sheets are often needed to fulfill the conservative requirements (Eliasson, 2018). A more economical alternative, to use isolating fire paint, is sometimes sufficient but cannot always be used.

To decrease the expenses for proper fire resistance, it is common to change the building structure to be classified in a different fire resistance safety class. This can be done, for example, by decreasing the span lengths or by using higher capacity structural members which results in a higher capacity in ultimate limit state and thus higher capacity when reduced in fire design. It is often cheaper to use more structural building material than to apply expensive fire protective sheets but increasing size is not always the best solution.

Provided that certain criteria are met, the current building codes (CEN, 2005) also allow for more advanced methods than the simplified calculation models in Eurocode, for the design of fire resistance. One possibility is to use numerical analyses with e.g. FE modelling to get a more realistic heat propagation scenario. Such a refined analysis can give less conservative results and may potentially provide more economical solutions.

1.2 Issue under investigation

Main question of interest:
“Will a costlier and more time-consuming FE analysis in the design process of steel structures help to save material resources and time in the construction stage?”

Hypothesis:
"The simplified method in Eurocode largely overestimates the needed material volume and a FE analysis will help in describing the actual need in a more accurate way, which will keep the use of material resources down."

1.3 Aim and objectives

The aim of this study was to investigate the extent of the advantages of using more advanced assessment methods for fire resistance design of steel structures. The objectives of this study was to

- increase the understanding how steel as a structural material is affected by high temperatures and how this is treated in Eurocode
- use FE analyses with temperature dependent material properties to assess the load carrying capacity of a structural steel beam in a postulated fire
- asses the load carrying capacity in the same postulated fire according to the hand calculation methods in EN 1993-1-2
- compare the results from the FE analyses to the hand calculation methods according to EN 1993-1-2 and assess the possible gains of using advanced FE analyses with regard to material resources.

1.4 Limitations

Firstly, the study was limited to a representative simply supported steel beam. The results may be transferable to a general case of a steel structural component to include also e.g. steel columns. However, the study itself was limited to, and treated only the case of, a standard steel beam placed in a roof structure. This means that possible failure modes for other structural components, such as buckling, has not been studied. Secondly, the research was also limited to steel components in cross section classes 1 and 2. Cross section classes 3 and 4 were not included due to their complex nature. Thirdly, the study was limited to structural carbon steel. Stainless steel and other high performance steel qualities were not studied. Fourthly, the fire models from Eurocode (CEN, 2009) that were studied were limited to the standard fire and the study did not include local fires or external fires. Fifthly, since the study is limited to simply supported beams, restraint stresses due to the restraint boundary conditions was not included. Stresses due to internal thermal gradients were not included in the hand calculations since it is time consuming and usually not included in the industry. Finally, the only FE modelling software used in this study was ADINA (ADINA R & D, n.d.). Other software are expected to give similar results but this was not verified in this study.

1.5 Method

To fulfill the objectives and answer the research question of whether FE analyses is worth the invested time in fire design of steel structures, the study was divided into three steps.

The first step consisted of a literature study where fire propagation and a review of current FE-modelling applications regarding fire was performed. Based on this, the general behaviour of structural steel subjected to increased temperatures were investigated.

The second step consisted of a comparison between Eurocode calculations and FE modelling. Analytical analyses as well as numerical analyses were made. A simply supported steel beam subjected to fire was studied. Initially this step consisted of a two-phased parametric study that investigated the influence of the type of cross section, length, slenderness and temperature distribution in the structural element. The results from the Parametric study were evaluated and the knowledge was afterwards applied to the Main study which investigated a fire exposed steel beam with an axially applied normal force combined with bending. This case was designed to resemble a case where the beam is partly axially restrained.

In the third step all the data from analytical analyses and numerical analyses, from both the Parametric study and the Main study, was compared, analyzed and evaluated. The results were compared to discover any possible patterns between the load magnitude and type, the slenderness and the beam type to see if any general conclusion could be drawn regarding if and when a FE analysis is worthwhile as well the extent of the benefits of performing a FE analyses compared to numerical analyses.

2

Fire propagation and its influence on steel structures

2.1 Fire propagation

As no fire is identical to another, describing a real or realistic fire propagation scenario is complicated. However, there are conditions that makes a fire more likely to propagate and conditions under which it cannot. In this chapter the conditions under which a fire thrives and under which it dies, as well as the different heat transport mechanisms, are described further.

2.1.1 Heat transport mechanisms

There are three different heat transport mechanisms (Burström, 2012). They are conduction, convection and radiation. All three mechanisms contribute to the propagation of a fire, more or less in the different stages of the fire (Drysdale, 2011). The basic concept of all three mechanisms are explained in the following subsections.

2.1.1.1 Heat conduction

Through heat conduction, the energy is transferred between the molecules by their internal vibrations (Hagentoft, 2003). The molecules' location does, however, not change. Heat conduction is thus a heat transfer mechanism that requires a medium for its heat transportation. The medium can be any out of three of the fundamental states of matter: gas, liquid or solid (Drysdale, 2011). Steady state heat conduction, q_{cd} $[W/m^2]$, is often described with *Fourier's law of heat conduction* which is shown in Equation 2.1.

$$q_{cd} = \lambda \cdot \frac{T_1 - T_2}{d} \tag{2.1}$$

where

λ is the material specific heat conductivity constant [W/mK]
T_1 is the temperature on surface one [K]
T_2 is the temperature on surface two [K]
d is the thickness of the material in [m]

Thus, the heat conduction here has the unit $[W/m^2]$. Since Equation 2.1 is only valid for steady state conditions, it cannot be applied in fire situations which is dependent on time. Analyses of fire propagation require more complex equations, applicable for transient problems.

In a fire, conduction has significant influence on the fire propagation in the combustible material. This is of particular interest when assessing the integrity and insulation properties of a structural component for fire resistance classification. These properties are further described in Section 2.3.1.

2.1.1.2 Heat convection

Just as conduction, convection also requires a medium for its heat transport. Convective heat transfer is the transfer of heat from a fluid medium, which can be either a gas or a liquid, to a solid matter (Drysdale, 2011). There is a distinction between natural and forced convection (Burström, 2012). Natural convection occurs when the density difference between e.g. cold air and hot air causes the air to flow. If the air flow originates from an outer source, it is called forced convection. An example of forced convection is mechanic ventilation. The convection heat flow rate, q_c $[W/m^2]$, is described by Equation 2.2

$$q_c = \alpha_c \cdot (T_s - T_a) \tag{2.2}$$

where

α_c is the convective heat transfer coefficient [W/m^2K]

T_a is the air temperature [K]

T_s is the temperature on the surface [K]

In a fire, heat convection has significant influence on the fire propagation at, especially, the early stages of the fire (Drysdale, 2011). Because the magnitude of the heat radiation is not yet large at a fire's early stages, convection is the most prevailing heat transfer mechanism that does not require direct contact between the different ignitable materials.

2.1.1.3 Heat radiation

Unlike conduction and convection, radiation is the only heat transfer mechanism that does not require a medium for the transportation of heat (Drysdale, 2011). The radiation from all bodies arises due to electron oscillations and is transported in the form of energy via electromagnetic waves. The radiation flow, in $[W/m^2]$, from a specific surface to another surface can be described by Equation 2.3 (Burström, 2012).

$$q_r = \Phi \cdot \epsilon_1 \cdot \epsilon_2 \cdot \sigma \cdot (T_1^4 - T_2^4) \tag{2.3}$$

where

Φ	is the form factor [-]
ϵ_1	is the emissivity constant for surface one [-]
ϵ_2	is the emissivity constant for surface two [-]
σ	is Stephan Boltzmann's constant [W/m^2K]
T_1	is the temperature on surface one [K]
T_2	is the temperature on surface two [K]

When the temperature increases, the electron oscillations also increase which results in increased radiation. However, since all bodies emit heat, all bodies are also exposed to heat radiation from surrounding bodies. The radiation magnitude of interest is most often the difference between emitted heat radiation and absorbed heat radiation.

In a fire, radiation is a very influential heat transfer mechanism. Since the temperatures are very high in a fire, the radiation from objects is higher than at room temperature. This can cause other objects to ignite and the fire to spread simply through the radiation from the already burning material. At the initial stages in a fire, radiation does not have as much influence on the fire propagation as the two other heat transport mechanisms. However, when the magnitude of the fire increases, the radiation part of the heat transfer becomes more and more significant. When the fire surpasses approximately 0.2-0.3 meters in diameter size, radiation becomes the principle heat transfer mechanism (Drysdale, 2011).

2.1.2 Real fire propagation

For a fire to subsist, three conditions must be fulfilled (Mourabit and Forsberg, 2014). The material itself must be combustible, it must be warm and it must have access to oxygen.

In buildings, the access to combustible material as well as heat is usually abundant. The oxygen is always there when the fire arises but can be fully consumed with time (Eliasson, 2018). Different fire scenarios are commonly described by using a curve with time on the x-axis and temperature on the y-axis, see Figure 2.1.

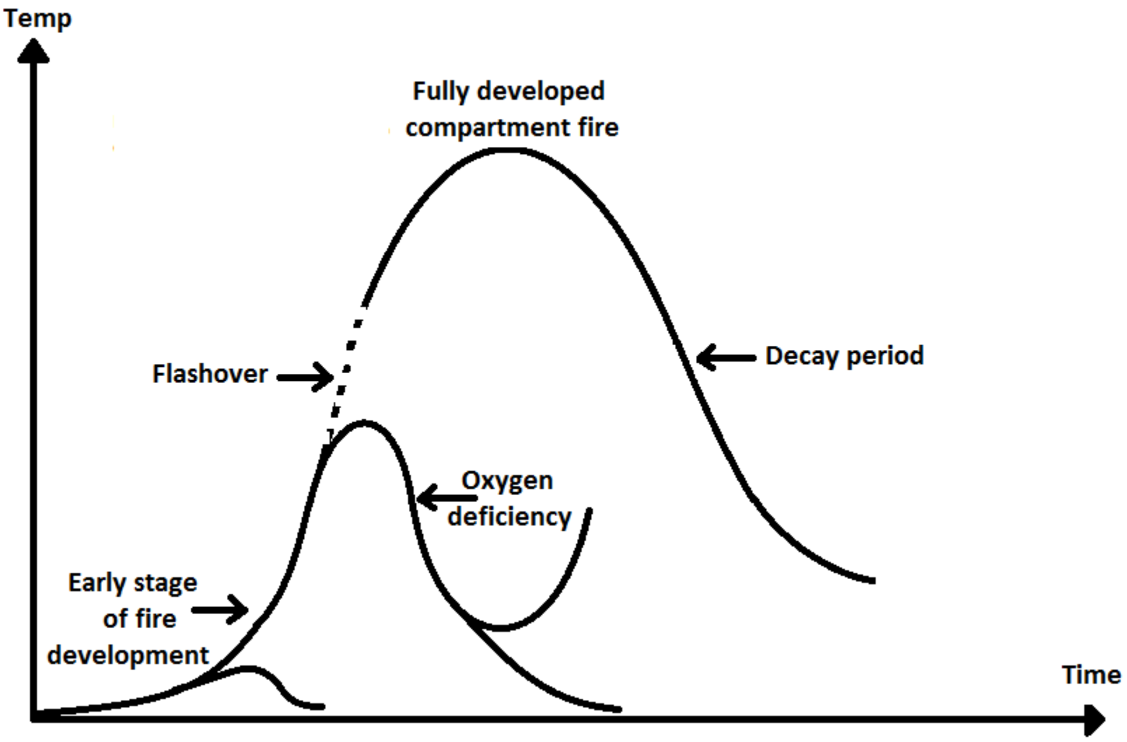


Figure 2.1: Fire diagram showing possible outcomes for a fire. Adapted from Bengtsson (2013).

The origin of the fire will influence the fire propagation (Bengtsson, 2013). Furthermore, the material available to the fire will influence the extent of the fire propagation. The geometry of the room/building, openings and ventilation systems as well as any sprinkler system will influence the heat and the oxygen levels.

As Figure 2.1 shows, several fire propagation scenarios can occur. The bottom left curve shows a fire with insufficient combustible material, quickly decreasing oxygen levels and/or insufficient heat which cause the fire to die out. The early fire that survive the initial phase, commonly called local fire, shows an exponential increase in heat. However, if the oxygen runs out, the fire will die down. If there instead is sufficient combustible material, heat and oxygen a flash-over can occur. A flash-over is defined in Marriam Webster Dictionary (Merriam-Webster, n.d.) as *"the sudden spread of flame over an area when it becomes heated to the flash point"*. It means that the fire spreads and propagates from a small to a large fire not by spreading through the combustible material, but by being ignited purely by the heat and radiation from the flames without actual contact to the flames themselves. If this happens, the fire will develop to a fully developed room fire. When either the material is burnt up and/or the oxygen runs out, the fire will enter the cooling phase and eventually die out.

A fire creates a great amount of toxic smoke which will rise towards the ceiling (MSB, 2013). This smoke is dark grey, almost black, and will increase in thickness as the fire continues and the smoke amount increases. Since the smoke becomes more concentrated with increasing height, it will soon after the fire has started be so dark in the ceiling that no direct radiation from the flames can pass through it.

In order to control a fire, the influencing conditions, namely the combustible material, the heat and the oxygen, must be controlled. The conditions easiest to influence is the heat and the oxygen. Since the amount of combustible material usually is unregulated in a building, it is not as easily influenced.

The heat can be influenced by, for example, installing sprinkler systems. This will not only cool down the room, but also make the combustible material less likely to catch fire (Eliasson, 2018). Ventilation however, does not only have the positive effect of cooling down the fire but it may also have the negative effect of adding oxygen that may help the fire propagate. Therefore it is important to be cautious with ventilation during a fire.

An often used preventive measure to contain a fire and hinder it from propagation, is to have fire compartments in the building. Fire compartments are areas in a building consisting of one or more rooms out of which the fire cannot, theoretically, spread (CEN, 2009). This is achieved by having the boundaries of the fire compartments made out of fire resistant material. For example, a fire-cell consisting of a room will have both all the walls as well as all windows and doors that leads out of the room, made of fire resistant material. The fire-resistance is not infinite but follows the same classifications of resistance, integrity and insulation as structural members in a building. This is further explained in Section 2.3.1.

It is impossible to know the exact characteristics of fire if it should occur (Boverket, 2015). When classifying the required resistance the probability is thus important. The consequences of the fire is also considered, in particular the risk of people getting injured. It is therefore also imperative to consider the probability and ease for any people in the building to evacuate in time. For example, the probability of a fire propagating without control is larger in a paint factory than it would be in a swimming pool facility. However, people in a paint factory most likely know the floor-plan and can evacuate quickly while people visiting a swimming-pool facility may not be as familiar with the nearest exit routes.

2.2 Influence of fire on structural steel

Steel is an important construction material that is used not only in pure steel structures but also together with concrete in reinforced concrete structures. When a steel component is subjected to fire, both the material properties and the geometry will change (Bao et al., 2016). These changes will reduce the load carrying capacity of the member. Exactly how the material properties will change depend on different parameters and this makes the design process especially difficult. For instance, the properties can change differently depending on if the material is at a steady state, i.e. the elevated temperature is constant, or if the structure is subjected to a transient state, i.e. the temperature is changing over time (Chen et al., 2006).

Furthermore, the relative change in strength and elasticity may vary depending on steel quality and strength. High-strength steel, mild steel and stainless steel have different content and production methods which may influence the performance at elevated temperatures differently. While it is interesting to see the differences between steel qualities, the scope of this study is focused on commonly used structural steel. Therefore, only regular strength carbon structural steel will be covered in the following sections.

The material properties described in the following sections, and used in this study, follow the EN 1993-1-2 Chapter 3.2 and 3.4 (CEN, 2005) recommendations. EN 1993-1-2 only provides material properties for every 100°C and allows for interpolation between those values. This is not totally analogous with the real steel properties (Franssen et al., 1998). In a study by Takagi and Deierlein (2006) it was shown that the material properties according to EN 1993-1-2 do not completely agree with experimental results. However, as further shown un the study, the material properties according to EN 1993-1-2 do not give results that differs with more than 10-20 % from experimental results. The material properties given in EN 1993-1-2 are also generally conservative and yield the smallest errors when comparing four different building codes, EN 1993-1-2, AISC 360, AS4100 and CECS200 (Bao et al., 2016).

2.2.1 Heat conduction

At room temperature, structural steel is a good heat conductor. Due to the high thermal conductivity of steel, it will increase in temperature very fast in a fire situation (Bailey, 2005). When the temperature increases, the change in conductivity depends on the type of steel. For carbon steel the conductivity decreases until the temperature reaches approximately 800°C, after which the conductivity is constant (CEN, 2005). In Figure 2.2 the conductivity as a function of temperature is shown for carbon steel.

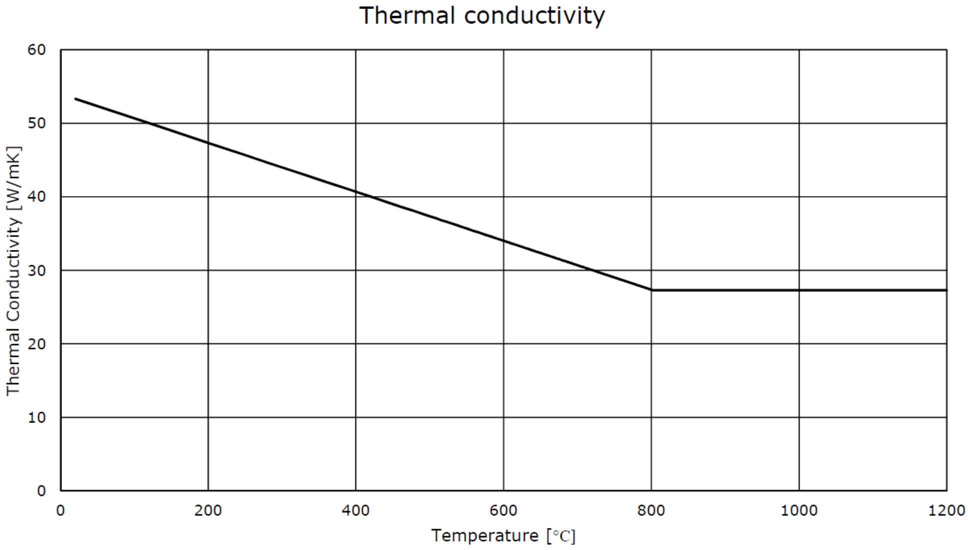


Figure 2.2: Conductivity for structural carbon steel. Based on equations from CEN (2005).

2.2.2 Specific heat capacity

The specific heat capacity for steel is almost linear, with a magnitude below 1000 J/kgK, for temperatures between 0°C and 700°C, see Figure 2.3. For temperatures between 800°C and 1200°C the specific heat capacity is almost constant at approximately 700 J/kgK. For the temperature span in between, the specific heat capacity is drastically increased to about 5000 J/kgK. This means that for these temperatures, the steel requires significantly more energy to increase its own temperature (Franssen and Real, 2012). In Figure 2.4, the specific heat capacity for carbon steel is shown for different temperatures.

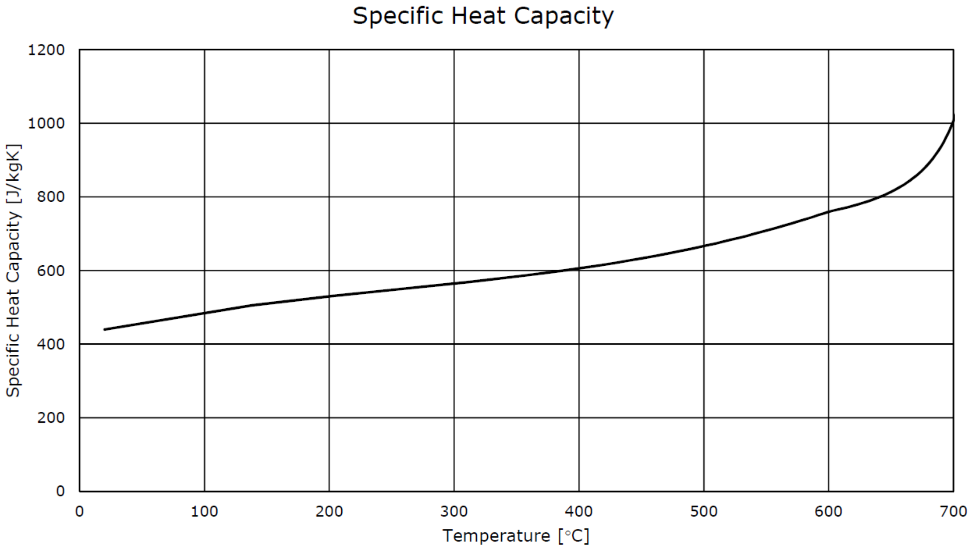


Figure 2.3: The specific heat capacity for carbon steel, zoomed in for temperatures between 0 ° C and 700 ° C. Based on equations from CEN (2005).

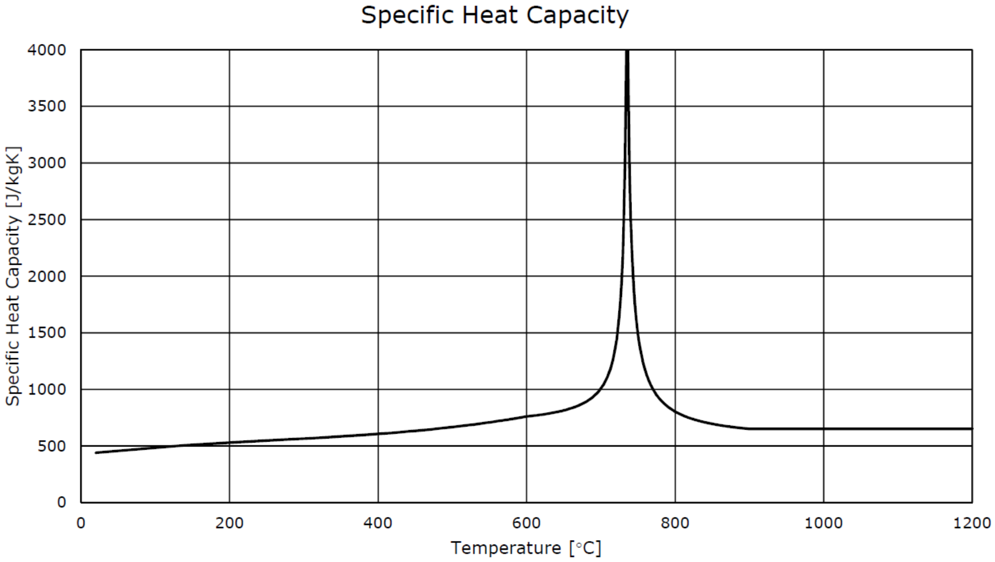


Figure 2.4: The specific heat capacity for carbon steel. Based on equations from CEN (2005).

2.2.3 Strength

An important material property in structural design is the yield strength. Up to approximately 400°C the yield strength for steel is more or less unchanged. When the temperatures surpasses 400°C however, the yield strength starts to decrease drastically (Franssen and Real, 2012). The ultimate strength on the other hand, starts to decrease at lower temperatures and already above 100°C the ultimate strength decreases more and more with increasing temperature. Since fires often have temperatures up to 1000°C and beyond, the reduced steel strength must be taken into account in fire resistance design. In Figure 2.5 the yield strength variation with temperature for steel class S355 is shown.

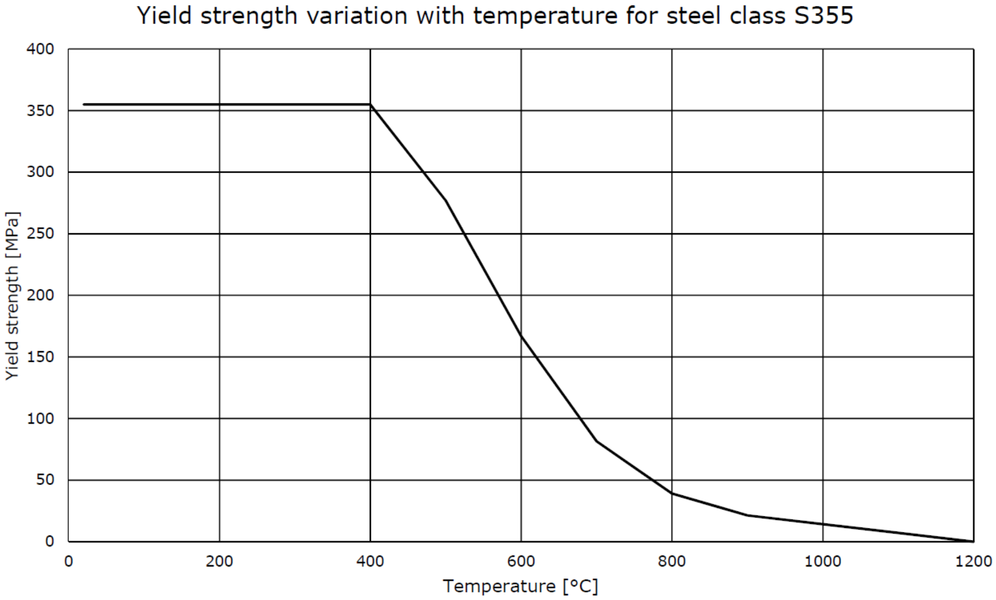


Figure 2.5: Yield stress variation with temperature for steel class S355. Based on data from CEN (2005).

2.2.4 Elasticity

Just as the strength of structural steel, the elasticity modulus, E, of structural steel also decreases with increasing temperature. The decrease starts already at, from a fire perspective, relatively low temperatures and continues to decrease more drastically with elevated temperatures (Chen et al., 2006). See Figure 2.6 for an illustration of this.

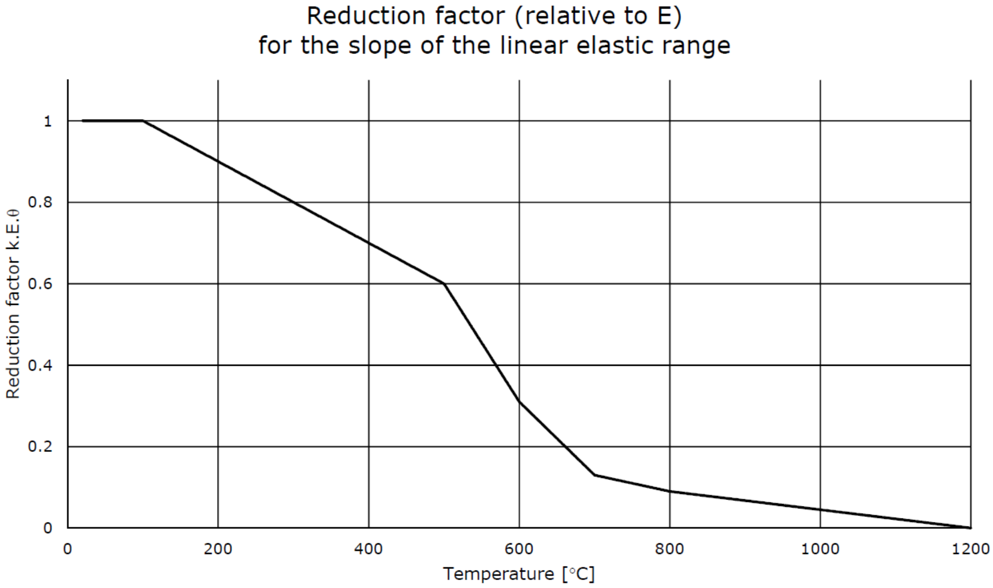


Figure 2.6: The reduction factor (relative to Young's modulus, E) for the slope of the linear elastic range. Based on equations from CEN (2005).

2.3 Fire requirements

When it concerns designing and protecting buildings against fire, there are five main functional requirements that must be fulfilled (Boverket, 2015; Eliasson, 2018). They regard the

- escape routes
- safety of the fire brigade
- protection against fire propagation within the building
- protection against fire propagation in between buildings
- structural integrity during the fire.

The last point, the structural integrity during the fire, is the main point of interest in this study.

In this section, the approach to determine the actions of fire on a building and its structural parts according to the Swedish standards is explained.

2.3.1 Classification of standard fire resistance: R E I

In order to systematize the process of ensuring proper fire protection, there are certain definitions to describe a building's resistance as well as the requirements on a building's resistance against fire. The resistance classification refers to the resistance to the standard fire, the ISO 834 curve which is further described in Section 2.3.6. The letters R, E and I are used to describe the resistance, the integrity and the insulation abilities, respectively, of the building. The definitions are given in the bullet-point list below (Eliasson, 2018; Träguiden, 2015) and shown in Figure 2.7.

- R - Resistance: describes the building's structural resistance.
- E - Integrity: describes the building's ability to keep the fire from propagating through building members, e.g. walls.
- I - Insulation: describes the building's ability to keep the heat from spreading through building members, e.g. walls.

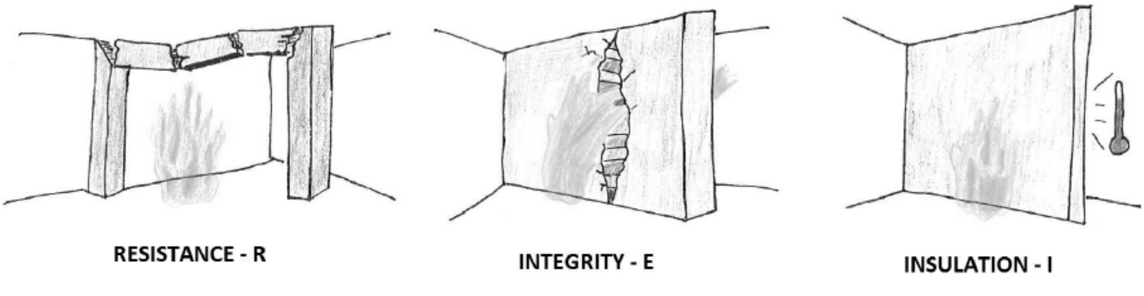


Figure 2.7: Graphic description of the fire design requirements' classification. Adapted from Träguiden (2003).

These letters can be combined to describe different requirements for different buildings (Eliasson, 2018). For example, R 30 means that the building should keep its structural resistance during 30 minutes if a fire occurs. REI 60, on the other hand, means that the building should keep its structural resistance as well as its integrity and insulation properties for 60 minutes in the event of a fire.

However, despite using the same standard fire for basis of fire protection design in many European countries, the requirements of the resistance vary considerably between countries (Schleich, 2005). Most countries have national regulations to determine the requirements of buildings with regard to fire. In Sweden, the regulations in EKS, Boverket Mandatory Provisions and General Recommendations on the Application of European Design Standards (Boverket, 2015), describes how the fire safety should be fulfilled.

2.3.2 Operation class

Initially all buildings are classified according to an operation class (Swedish: verksamhetsklass). The classification process is described by Boverket in their building regulations, BBR Section 5:2 (Boverket, 2017). There are six different operation classes. In addition to the use of the building, the residents expected knowledge of the building floor-plan is taken into account. For example, an employee will probably be familiar with the escape routs of his, or hers, office building while he or she may not be familiar with the escape routes of a shopping mall. Since the knowledge of the building and its escape routes is essential to shorten the evacuation time, this must be accounted for when determining the required resistance class of the building. In the bullet-point list below the operation classes are described briefly.

- Operation class 1: Buildings where people with good knowledge of the building floor-plans are residing, e.g. industry and office buildings.
- Operation class 2: Buildings where large groups of people, with poor knowledge of the building floor-plan but with good possibility to evacuate themselves, reside at the same time, e.g. shopping malls.
- Operation class 3: Private residence where people with good knowledge of the building floor-plan and good possibility to evacuate themselves reside, but where they cannot be expected to be awake, e.g. private residence.
- Operation class 4: Residence where people with poor knowledge of the building floor-plan and good possibility to evacuate themselves reside, but where they cannot be expected to be awake, e.g. hotels, hostels.
- Operation class 5: Residence where people with poor or no capability to evacuate the building themselves reside, e.g. hospitals, prisons.
- Operation class 6: Buildings with elevated risk of fire or where a fire could propagate very extensively and quickly, e.g. a paint-factory.

2.3.3 Building class

Based on the operation class as well as the structural appearance of the building, the building class (Swedish: Byggnadsklass, Br) is determined (Boverket, 2017). The building classes range from Br0 to Br3, where an increased number means a decreased fire protection need. Figure 2.8 shows a rule of thumb for the building classes based on structural appearance. The bullet-points below list the building classes as described in Boverkets building regulations, BBR (Boverket, 2017), in Section 5:2.

- Br0: Buildings with a *very large* fire protection need.
- Br1: Buildings with a *large* fire protection need.
- Br2: Buildings with an *average* fire protection need.
- Br3: Buildings with a *small* fire protection need.

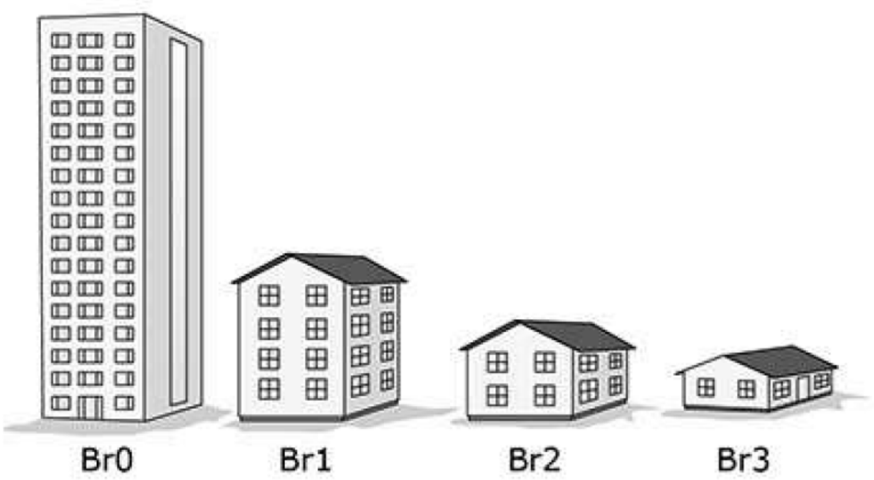


Figure 2.8: General rule of thumb for building classification, Br, based on the structural appearance. Reproduced with permission from Träguiden (2003).

2.3.4 Fire safety class

When the operation class and building class has been determined, the different building parts in a building can be classified in different fire safety classes (Swedish: brandsäkerhetsklass) (Boverket, 2015). Depending on the the building class (Br0 to Br3) the fire safety class for a certain building detail can be found in tables in EKS in Chapter 1.1.2 (Boverket, 2015). The bullet-point list below describes the different fire safety classes as described in EKS.

- Fire safety class 1: *Slight* risk of person injury if the building part collapses.
- Fire safety class 2: *Small* risk of person injury if the building part collapses.
- Fire safety class 3: *Average* risk of person injury if the building part collapses.
- Fire safety class 4: *Large* risk of person injury if the building part collapses.
- Fire safety class 5: *Very large* risk of person injury if the building part collapses.

2.3.5 Requirements on building parts

The conversion from fire safety class to fire safety requirements on specific building parts is done by tables provided by Boveket in EKS in Chapter 1.1.2 (Boverket, 2015). There are two different tables available depending on which design model that is used. If the standard fire, the ISO curve described in Section 2.3.6, is used, the fire load is already included in the requirements. These requirements follow the classification of standard fire resistance, R E I, as described in Section 2.3.1. If a natural fire propagation model is used, the requirements on the building parts are defined differently. These requirements do not include the fire load. The fire load together with the requirements must therefore be included in the natural fire propagation modeled used in the design. In Figure 2.9 a flowchart is presented describing the design process to obtain a temperature to use when designing individual structural members.

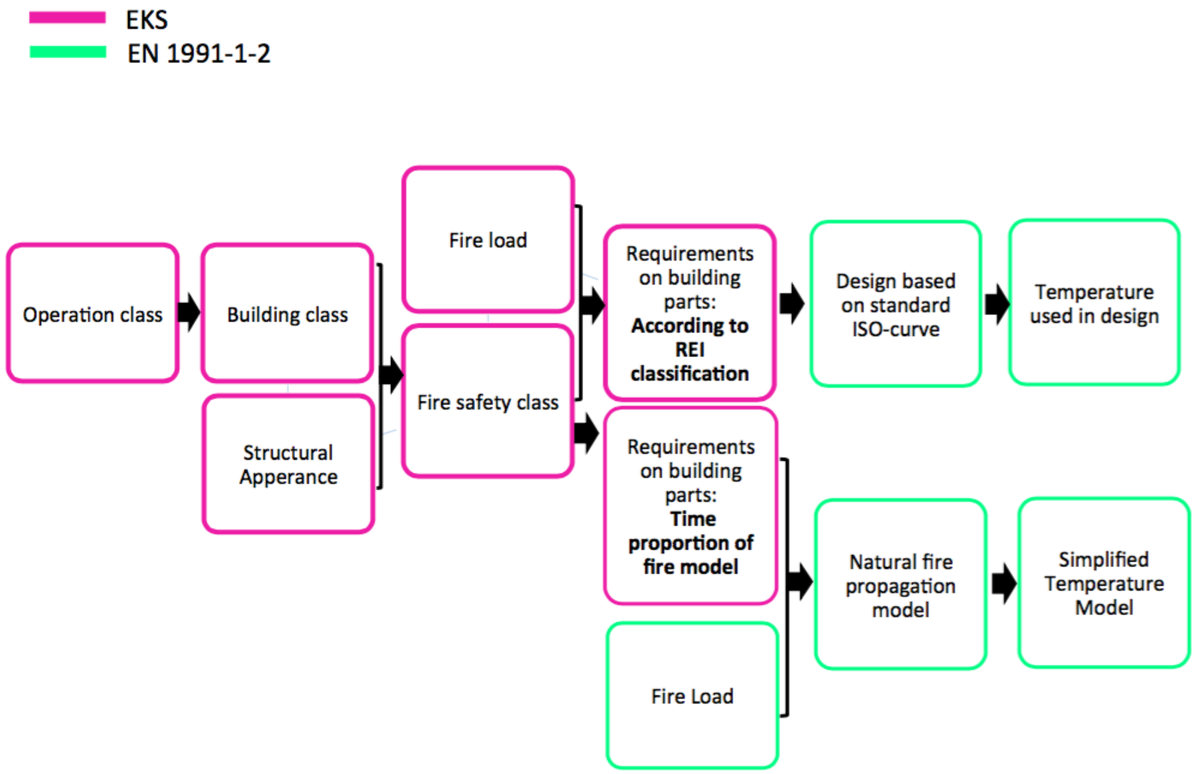


Figure 2.9: Flowchart showing the fire resistance requirement assessment process.

2.3.6 ISO curve

The ISO curve, or more specifically the standard fire curve according to ISO 834, is a theoretical nominal time-temperature curve used in fire resistance design (Schleich, 2005). The curve is used either graphically or analytically since the formula defining the curve is well defined in EN 1991-1-2 Chapter 3 (CEN, 2009), see Equation 2.4 and Figure 2.10 below. The temperature is given in [°C].

$$\Theta_g = 20 + 345 \cdot log_{10}(8t + 1) \tag{2.4}$$

where
t is the time [min]

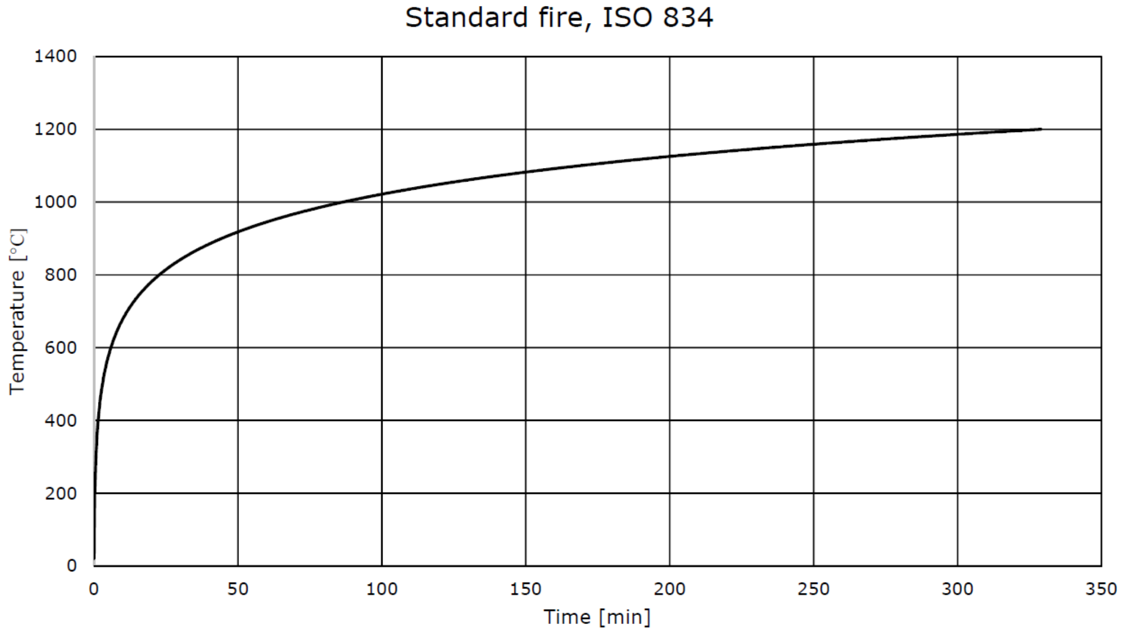


Figure 2.10: The standard fire curve according to ISO 834. Based on an equation, see Equation 2.4 from CEN (2009).

There are two other types of nominal time-temperature curves as well, the external fire curve and the hydrocarbon fire curve (Schleich, 2005). They are used for slightly different applications and are not used in this study. They are however presented in Equations 3.1 and 3.2. The standard fire, which is the most commonly used temperature curve, depends solely on the passed time, as Figure 2.10 and Equation 2.3.6 show. The curve looks the same regardless of room or building size. It is also constantly increasing and will not consider when, or if, the combustible material is consumed or if the oxygen supply is diminished. These factors are important to be aware of when choosing to use the standard fire for design.

The curve is used as a reference when specifying fire safety requirements. However, the prescribed time with respect to the standard fire curve is not always equivalent with fire evacuation time since it is a reference system and does not give actual fire temperatures (Franssen and Real, 2012).

2.4 Previous research on fire design

Previously made research on steel in elevated temperatures and fire is often in consensus when stating that more research is needed on the subject. With more and more advanced and crowded structures the fire safety is of increasing importance. Even though a lot of research is made within the subject of structural engineering and fire, and more specifically steel structures in fire (Choe et al., 2011; Mahmoud et al., 2015), there are still a great deal of further research that needs to be made according to Liu et al. (2002).

Early research within the field was done mainly by experiments of short, slender, simply supported beams in elevated temperatures (Mahmoud et al., 2015). As of the late 90's it was found that more research was needed on high rise buildings with compartment fires and this demand is still present today. Steel functions as a very good material in high rise buildings. However, since the steel capacity is remarkably reduced at high temperatures, problem arises for structural engineers when designing for fire safety (Sun et al., 2011). In the research concerning high rise steel buildings, it can be seen that the different standards used for fire design always gave conservative results, since the calculated resistance usually was lower than the actual resistance (Mahmoud et al., 2015). Impact of the composite interactions between different materials have a major impact on the fire resistance. For example, a ceiling beam supporting a concrete slab will have a lower temperature in the top because of the low conductivity of concrete compared to steel (Kodur et al., 2013). Many research projects such as Agarwal et al. (2014), Mahmoud et al. (2015), Huang et al. (2000) and Kodur et al. (2013) recommends further research within the field and emphasizes the importance of considering the whole structural system when designing for fire safety.

Another popular research topic is the study of fire resistance of more complex structures by the creation of Finite Element, FE, models. Much research, for example Choe et al. (2011) and Mahmoud et al. (2015), concludes that FE modelling can be very useful thanks to being an accurate but conservative design tool while still being less conservative than current design codes. As the structures becomes more complex and consists of many components and materials, it can be seen that FE models are necessary (Mahmoud et al., 2015). This is because experiments for such complex structures would be very hard and expensive to perform. During the years, many different FE programs have been developed in order to be more specified for different analyses on structures in fire. For example, a FE program called ANSYS can be used for thermomecanical problems (Kodur et al., 2013), Vulcan is a FE program for three dimensional modelling of steel (Sun et al., 2011), FEMFAN was developed by the fire engineering groups at Nanyang Technological University to be used for frames in fire, SAFIR is used a lot in research and ABAQUS is often used to do structural analyses.

Additionally, many studies are actual experiments with staged fires to study the material and structural responses (Chen et al., 2006; Franssen et al., 1998; Takagi and Deierlein, 2006). These are often compared to FE modelling for validation of the FE model. The influence of thermal gradients on fire resistance is also studied where, for example, Liu et al. (2002), Selamet (2017) and Choe et al. (2016) confirms that the influence is as important to consider as the actual temperature when it regards FE models.

Overall, the currently available research is foremost of the qualitative kind. That is, it presents specific topics and situations which have influence on the fire design. There is less research regarding the quantitative fire design research and the possibility to categorize the advantages of FE modelling as opposed to generic design in the terms of material and resource savings for specific structures and/or categories of structural elements. This study aims to start with that.

2.5 FE modelling for elevated temperatures

Research comparing FE models and experiments have shown that FE analyses can work as an accurate but conservative tool in fire safety design (Bao et al., 2016; Choe et al., 2011; Mahmoud et al., 2015). This conclusion has been made through several comparisons between FE models and experiments for basic cases. These basic cases have later worked as a verification of the FE modelling methods so that it can be used for more complex cases that are harder to study in experiments. When using FE models, non-linear material response, geometric non-linearities and temperature gradients in the steel can be taken into account (Liu et al., 2002).

In order to base design with respect to fire on FE models for elevated temperatures, it is of great importance to fulfill all requirements stated in EN 1993-1-2 Section 4.3 (CEN, 2005) for advanced calculation models as presented in Section 3.2.2.2. Several research studies, such as Lim et al. (2003), Bao et al. (2016), Huang et al. (2000) and Mahmoud et al. (2015), have been made within this field and properly describes how a FE model should be implemented. Bao et al. (2016) and Mahmoud et al. (2015) describes the modelling procedure in order to obtain an accurate result:

1. The first step should decide the thermal response, separate from the mechanical response with proper thermal conductivity, radiation and convection properties, in order to get the temperature distribution within the member.
2. In the second step, the temperatures from the previous step should be applied to the member, with properly specified temperature dependent material properties, in order to get the thermal expansions.
3. The results in terms of temperature distribution and thermal expansion should then be used in a structural analysis with temperature dependent material properties. In this analysis, the loads are applied and initial imperfections are included so that the result will be the response of the member in the fire scenario.

In the FE model it is important to know the temperature in the air during different time steps of the fire and also the material properties at these times. For the study described in this report, the standard temperature curve, ISO 834 see Section 2.3.6, was used to describe the temperature propagation in the air. The material properties described in Section 3.2 and 3.4 in EN 1993-1-2 (CEN, 2005) were used to describe the material behavior of steel at elevated temperatures, see Section 2.2.

3

Fire design of steel structures according to Eurocode

3.1 Temperature calculations according to EN 1991-1-2

In EN 1991-1-2 (CEN, 2009), the mechanical- and temperature induced loads, for the design of structures subjected to fire, are presented with regard to safety requirements and design methods. In order to use EN 1991-1-2, the relevant fire scenario, the design fire load caused by this fire scenario, the analysis of temperature propagation in the structure subjected to the fire and the mechanical behaviour of the structure subjected to the fire, must be determined. They are described in the following subsections.

3.1.1 Fire scenario

In order to decide where the fire may start, the essential fire scenario should be decided by an evaluation of the risk of fire (CEN, 2009). This risk evaluation should be done by a well qualified person or by national regulations.

3.1.2 Fire load

Every relevant fire scenario generates a unique fire, further explained in Section 2.1.2. In order to decide the design fire in the fire compartment, for the relevant fire scenario, it must be decided whether the fire should be described with a nominal temperature propagation model or with a natural temperature propagation model (CEN, 2009).

The decision process from fire scenario to design fire load is summarized in Figure 3.1. Within each temperature propagation description the fire can be further specified (CEN, 2009). A nominal temperature propagation can either be described by the standard curve, by the external fire curve or by the hydrocarbon curve (CEN, 2009). A natural fire temperature propagation can be described either by a simplified fire propagation model or by a more advanced fire propagation model. The simplified models are dependent on specific physical parameters and they can be regarded as either compartment fires or as local fires depending on the likelihood of a flash-over to occur. More advanced fire propagation models, on the other hand, are more complex and must also consider gas properties, mass exchange and energy exchange. The models that may be used as advanced fire temperature propagation models are one zone models, two zone models or computational fluid dynamics-models, CFD-models.

If the requirements on the fire resistance comes from national authorities, the design fire can be described by the nominal temperature propagation, unless directed otherwise (CEN, 2009).

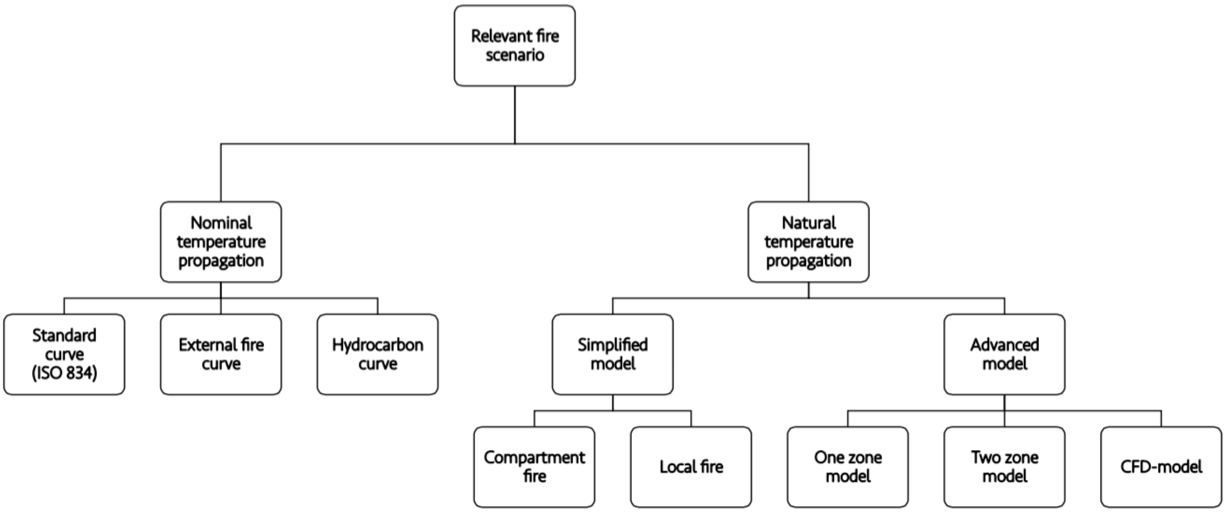


Figure 3.1: Flow-chart describing the process of deciding temperature calculation according to EN 1991-1-2.

3.1.3 Temperature propagation

When the design fire is chosen, the temperature propagation can be determined. If a nominal temperature propagation is used, the temperature analysis should be done for the member during the required fire safety time. If a natural fire temperate propagation model is used, the temperature analysis should instead be done during the entire fire period, from the start of the fire to the end of the cooling phase. The models to use for the different design fires are described in EN 1991-1-2 Chapter 3 (CEN, 2009), and summarized below.

The standard temperature curve, the ISO 834 described in Section 2.3.6, can be described by Equation 2.4. The external fire temperature curve can be described by Equation 3.1. The hydrocarbon fire temperature curve can be described by Equation 3.2.

$$\Theta_g = 660 \cdot (1 - 0,687 \cdot e^{-0,32t} - 0,313 \cdot e^{-3,8t}) + 20 \tag{3.1}$$

$$\Theta_g = 1080 \cdot (1 - 0,325 \cdot e^{-0,167t} - 0,675 \cdot e^{-2,5t}) + 20 \tag{3.2}$$

where

Θ_g is the gas temperature in the fire compartment [°C]
t is the time [min]

For a natural fire temperature propagation with simplified models, the gas temperature must be decided from physical parameters that considers, at least, the fire intensity and the ventilation circumstances (CEN, 2009).

For a natural fire temperature propagation with advanced models, a one zone model, a two zone model or a CFD-model should be used. In a one zone model, the temperature is assumed to be uniform and time dependent in the fire compartment (CEN, 2009). In a two zone model, the temperature is assumed to be divided into two layers, one upper layer and one lower layer. The temperature in each layer in the two zone model is assumed to be uniform and time dependent and the thickness of each layer should also be time dependent. The lower layer is assumed to have a lower temperature than the upper layer. The CFD-model is a computational fluid dynamic model that gives the temperature development in the fire compartment depending on the time and the room properties.

3.1.4 Mechanical behavior of the structure

The mechanical analyses should be done using the same time as in the temperature calculations. In order to decide if the fire requirement is fulfilled, one of three checks must be made. If one is fulfilled, the other two are automatically fulfilled. These checks are described by Equations 3.3, 3.4 and 3.5.

$$t_{fi,d} \geq t_{fi,requ} \tag{3.3}$$

$$R_{fi,d,t} \geq E_{fi,d,t} \tag{3.4}$$

$$\Theta_{cr,d} \geq \Theta_d \tag{3.5}$$

where

$t_{fi,d}$ is the design value of the fire resistance time
$t_{fi,requ}$ is the required fire resistance time
$R_{fi,d,t}$ is the design value of the resistance of the member in the fire situation
$E_{fi,d,t}$ is the design value of the relevant effects of actions in the fire situation
$\Theta_{cr,d}$ is the design value of the critical material temperature
Θ_d is the design value of material temperature due to fire

When designing for fire resistance, the combination of actions used for the design loads should be decided according to EN 1990 (CEN, 2010) for an accidental load case. Since fire is considered as an accident load, other accidental loads can be assumed to not occur at the same time when deciding the design combination of actions. The variable load should be considered as quasi permanent. Loads caused by deformations due to the temperature changes, in case of fire, should be considered if they are not negligible or favorable. Alternatively they can be accounted for by conservatively chosen support conditions or conservatively chosen fire safety requirements.

3.2 Design of fire resistance for steel structures according to Eurocode

In this section the different parts of Eurocode, which are used in the design process for a steel structure exposed to fire, are explained. Furthermore this section describes how the different parts of Eurocode, with its national Annexes, should be combined in order to determine the requirements on the steel structure and design the structure in order to fulfill this requirement.

3.2.1 EN 1990 - Basis of structural design

EN 1990 (CEN, 2010) presents principles and requirements for the structural safety, serviceability and maintenance and it describes the fundamental principles for the design of structures. It is meant to be used in combination with EN 1991 to EN 1999 in order to design buildings, facilities and structural components in situations including fire exposure and earthquakes as well as the construction process for temporary structures.

EN 1990 (CEN, 2010) states that a structure must be designed and constructed in a way that will maintain required resistance in an economical way during the entire service life. In order to fulfill this requirement, the structure must be able to resist all loads and effects that are likely to occur on the structure and it must fulfill the maintenance requirement for the structure itself or its structural members.

Different design situations are presented in EN 1990 and are listed below (CEN, 2010).

- Design for a permanent situation, which relates to structures in normal use.
- Design for a temporary situation, which relates to structures in temporary circumstances.
- Design for an accidental situation, which relates to structures under accidental circumstances such as fire, explosion or local collapse.
- Design for a seismic situation, which relates to structures exposed to seismic loads.

Within each design situation, different loads are present. According to EN 1990 (CEN, 2010) these loads can be categorized depending on their maintenance time. Within the category permanent loads, called G, the self weight, any permanent equipment, any wall coating and any indirect loads belong. The variable loads, called Q, include imposed loads on floors, beams and roofs as well as wind loads and snow loads. Accidental loads, called A, are for example explosions or fires. A seismic load can be either a variable load or an accidental load.

In order to design for the ultimate limit state according to EN 1990 (CEN, 2010), the combination of actions can be evaluated according to Equation 3.6.

$$E_d = \gamma_{Sd} E\{\gamma_{g,j} G_{k,j}; \gamma_p P; \gamma_{q,1} Q_{k,1}; \gamma_{q,i} \psi_{0,i} Q_{k,i}\} \quad \text{and} \quad j \geq 1; i > 1 \tag{3.6}$$

where

E$_d$	is the design value of the relevant effects of actions from the fundamental combination according to EN 1990
γ_{Sd}	is the partial factor associated with the uncertainty of the action and/or action effect model
$\gamma_{g,j}$	is the partial factor for permanent action j, which takes account of the possibility of unfavorable deviations of the action values from the representative values
G$_{k,j}$	is the characteristic value of permanent action j
γ_P	is the partial factor for prestressing actions
P	is the relevant representative value of a prestressing action
$\gamma_{q,1}$	is the partial factor for the leading variable action one which takes account for the possibility of unfavorable deviations of the action values from the representative values
Q$_{k,1}$	is the characteristic value of the leading variable action one
$\gamma_{q,i}$	is a partial factor for variable action i whihch takes account of the possibility of unfavorable deviations of the action value from the representative value
$\psi_{0,i}$	is the factor for combination value of variable action i
Q$_{k,i}$	is the characteristic value of variable action i

The ψ factors for buildings can be found in Annex A in EN 1990 (CEN, 2010). γ_G and γ_Q can be found in Annex A in EN 1990 (CEN, 2010) or in EKS (Boverket, 2015) which both gives γ_G=1.35 and γ_Q=1.5 for the ultimate limit state.

In order to design for a fire scenario, EN 1990 (CEN, 2010) states that models for the temperature propagation within the structural member as well as models for the mechanical properties for the structural member should be used. This process is described in Section 3.2.2. The design should be based on a nominal fire exposure or a modelled fire exposure, as described in Section 3.1. The combination of actions for the fire situation is described in EN 1990 and it is categorized as an accidental design situation. The combination of actions for the fire situation can be evaluated according to Equation 3.7.

$$E_d = E\{G_{k,j}; P; A_d; (\psi_{1,1} or \psi_{2,1})Q_{k,1}; \psi_{2,i}Q_{k,i}\} \quad \text{and} \quad j \geq 1; i > 1 \tag{3.7}$$

where

E_d is the design value of the relevant effects of actions from the fundamental combination according to EN 1990

$G_{k,j}$ is the characteristic value of permanent action j

P is the relevant representative value of a prestressing action

A_d is the design value of an accidental action

$Q_{k,1}$ is the characteristic value of the leading variable action one

$\psi_{1,1}$ is the factor for frequent value of variable action one

$\psi_{2,1}$ is the factor for quasi-permanent value of variable action one

$\psi_{2,i}$ is the factor for quasi-permanent value of variable action i

$Q_{k,i}$ is the characteristic value of variable action i

In EKS (Boverket, 2015) it is written that for a fire load, ψ_1 should be used instead of $\psi_{1,1}$ and $\psi_{2,1}$. For design of congregation areas ψ_1 should be equal to 0.5.

For fire situations, A_d is the design value of the indirect effect of the thermal load caused by the fire.

3.2.2 EN 1993-1-2 - Reductions and capacities

In EN 1993-1-2 the general rules, principles and requirements for the structural design of steel structures exposed to fire is presented (CEN, 2005).

The basic requirement for the design and construction of fire exposed steel structures is that steel structures should maintain its load-carrying function during the relevant part of a fire (CEN, 2005). How the relevant fire characteristics and the required fire resistance time are determined is further explained in Section 2.3. In order to meet these requirements, the fire resistance for the load carrying structure must be determined. Eurocode allows three ways to do this. They are described further in the following subsections and are

- simplified calculation models
- advanced calculation models
- testing.

3.2.2.1 Simplified calculation models

The simplified calculation model in EN 1993-1-2 (CEN, 2005) is based on analytical expressions. These are used to calculate the resistance of single structural members where conservative assumptions are made during the calculations in order to account for the uncertainties of the simplifications made.

When using the simplified model, the calculations of resistance can be done in two alternative ways. It can be done by

- calculating the load carrying resistance for the member at time *t* to make sure it is larger than the load effect during the fire according to Equation 3.4 in Section 3.1.4.

  where specifically
  $E_{fi,d,t}$ is the design effect of actions for the fire design situation at time t according to EN 1991-1-2 (CEN, 2009)
  $R_{fi,d,t}$ is the corresponding design resistance of the steel member for the design situation at time *t* according to EN 1993-1-2 (CEN, 2005)

- calculating the critical temperature for the member, to make sure that it is larger than the design value of the material temperature due to the effect of fire, according to 3.8.

$$\theta_{a,cr} = 39.19 \cdot ln\left[\frac{1}{0.9674 \cdot {\mu_0}^{3,833}} - 1\right] + 482 \tag{3.8}$$

  where
  μ_0 is the degree of utilization at time t=0 in the fire scenario [-]

In order to calculate the design resistance of a steel member, the cross-section must be classified. This classification can be done at room temperature according to EN 1991-1-2 (CEN, 2009). However, when designing for fire exposure, both Young's modulus and the yield strength change. This means that the coefficient ϵ, depending on f_y, must be reduced (Franssen and Real, 2012). In this simplified calculation model (CEN, 2005), the coefficient can be calculated according to Equation 3.9.

$$\epsilon = 0.85 \cdot \left[\frac{235}{f_y}\right]^{0.5} \tag{3.9}$$

where
f_y is the yield strength at 20°C [MPa]

This reduction of ϵ may cause a change of cross section class when the temperature increases which could lead to changes in the design resistance calculations. The design resistance of the steel member for the design situation at time *t* during a fire must be calculated with respect to normal force, bending moment and shear force for both compression members and tension members (CEN, 2005).

The design resistance of a steel member at 20°C can be calculated according to EN 1993-1-1 (CEN, 2008) which requires a resistance of the member to handle the ultimate loads, deformations and vibrations. In case of a fire, the structural design requires the structure to withstand a specified period of time. When the temperature increases, the resistance will decrease due to changes of the material properties, see Section 2.2. This will be accounted for by using reduction factors depending on the stress-strain relationship for steel at elevated temperatures according to Equation 3.10.

$$X_{d,fi} = k_\theta \cdot X_k / \gamma_{M,fi} \tag{3.10}$$

where

X_k is the characteristic value of a strength or deformation property for normal temperature design

k_θ is the reduction factor for a strength or deformation property, dependent on the material temperature [-]

$\gamma_{M,fi}$ is the partial safety factor for the relevant material property, for the fire situation found in EKS (Boverket, 2015) [-]

The reduction factors are defined in EN 1993-1-2 Section 3.2 (CEN, 2005), as

- the effective yield strength, $f_{y,\theta}$, relative to yield strength, f_y, at 20°C according to Equation 3.11
$$k_{y,\theta} = f_{y,\theta} / f_y \tag{3.11}$$
- the proportional limit, $f_{p,\theta}$, relative to yield strength, f_y, at 20°C according to Equation 3.12
$$k_{p,\theta} = f_{p,\theta} / f_y \tag{3.12}$$
- the slope of linear elastic range, $E_{a,\theta}$, relative to slope, E_a, at 20°C according to Equation 3.13.
$$k_{E,\theta} = E_{a,\theta} / E_a \tag{3.13}$$

These reduction factors depend on the temperature and are described in Table 3.1 in EN 1993-1-2 (CEN, 2005). $k_{y,\theta}$ is the reduction factor for the yield strength of steel at the steel temperature θ_a, reached at time *t*. $k_{E,\theta}$ is the reduction factor for the slope of the linear elastic range at the steel temperature θ_a reached at time t.

The design resistance of the steel member in the fire situation can be calculated by reducing the design resistance at 20°C with the above described reduction factors.

For tension members exposed to fire, the design resistance at temperature θ_a can be calculated, according to EN 1993-1-2 Section 4.2.3.1 (CEN, 2005), with Equation 3.14.

$$N_{fi,\theta,Rd} = k_{y,\theta} \cdot N_{Rd} \cdot \left[\frac{\gamma_{M,0}}{\gamma_{M,fi}}\right] \tag{3.14}$$

where

N_{Rd} is the design resistance of the cross-section for 20°C calculated according to EN 1993-1-1 (CEN, 2008) [N]

If the temperature across the cross section is non-uniform the design resistance for a tension member could instead be calculated, according to EN 1993-1-2 Section 4.2.3.1 (CEN, 2005), with Equation 3.15.

$$N_{fi,\theta,Rd} = \sum_{i=1}^{n} A_i \cdot k_{y,\theta,i} \cdot \frac{f_y}{\gamma_{M,fi}} \tag{3.15}$$

For compression members in cross section classes 1 and 2, which is the scope of this study, the buckling resistance at a temperature θ_a should be calculated, according to EN 1993-1-2 Section 4.2.3.2 (CEN, 2005), with Equation 3.16.

$$N_{b,fi,t,Rd} = \chi_{fi} \cdot A \cdot k_{y,\theta} \cdot \frac{f_y}{\gamma_{M,fi}} \tag{3.16}$$

where

χ_{fi} is the reduction factor for flexural buckling in the fire situation and are calculated according to Equation 3.17, 3.18, 3.19 and 3.20 [-]

$$\chi_{fi} = \frac{1}{\varphi_\theta + \sqrt{\varphi_\theta^2 - \lambda_\theta^2}} \tag{3.17}$$

$$\varphi_\theta = \frac{1}{2} \cdot [1 + \alpha\lambda_\theta + \lambda_\theta^2] \tag{3.18}$$

$$\alpha = 0.65 \cdot \sqrt{235/f_y} \tag{3.19}$$

$$\lambda_\theta = \lambda \cdot [k_{y,\theta}/k_{E,\theta}]^{0,5} \tag{3.20}$$

where

φ_θ is the value to determine reduction factor

λ_θ is the non dimensional slenderness for fire situation

α is the imperfection factor for the fire design situation

λ is the non dimensional slenderness according to EN 1993-1-1

The bending resistance for members in cross section classes 1 and 2 at a temperature θ_a should be calculated, according to EN 1993-1-2 Section 4.2.3.3 (CEN, 2005), with Equation 3.21.

$$M_{b,fi,t,Rd} = k_{y,\theta} \cdot M_{Rd} \cdot \left[\frac{\gamma_{M,0}}{\gamma_{M,fi}}\right] \tag{3.21}$$

where

M_{Rd} is the plastic moment resistance of the cross-section for 20°C calculated according to EN 1993-1-1 (CEN, 2008) [Nm]

If the temperate across the cross-section is non-uniform, Equation 3.22 should be used instead (CEN, 2005).

$$M_{fi,\theta,Rd} = \sum_{i=1}^{n} A_i \cdot z_i \cdot k_{y,\theta,i} \cdot \frac{f_{y,i}}{\gamma_{M,fi}} \tag{3.22}$$

where

z_i is the distance from the plastic neutral axis to the centroid of the elemental area A_i [m]

If the structural element has a tendency to fail by buckling, which includes both twisting and lateral deflection, it is assumed that the member can fail by lateral torsional buckling (CEN, 2005). The lateral torsional resistance for members in cross section classes 1 and 2 at a temperature θ_a should be calculated, according to EN 1993-1-2 Section 4.2.3.3 (CEN, 2005), with Equation 3.23.

$$M_{b,fi,t,Rd} = \chi_{LT,fi} \cdot W_{pl,y} \cdot k_{y,\theta,com} \cdot \frac{\gamma_{M,0}}{\gamma_{M,fi}} \tag{3.23}$$

where

$\chi_{LT,fi}$ is the reduction factor for lateral torsional buckling in the fire design situation calculated by Equation 3.24, 3.25, 3.26, 3.27 and 3.28 [-]

$$\chi_{LT,fi} = \frac{1}{\phi_{LT,\theta,com} + \sqrt{\phi^2_{LT,\theta,com} - \lambda^2_{LT,\theta,com}}} \tag{3.24}$$

$$\phi_{LT,\theta,com} = \frac{1}{2} \cdot [1 + \alpha\lambda_{LT,\theta,com} + \lambda^2_{LT,\theta,com}] \tag{3.25}$$

$$\alpha = 0.65 \cdot \sqrt{235/f_y} \tag{3.26}$$

$$\lambda_{LT,\theta,com} = \lambda_{LT} \cdot [k_{y,\theta}/k_{E,\theta}]^{0.5} \tag{3.27}$$

$$\lambda_{LT} = \sqrt{\frac{W_{pl,y}}{M_{cr}}} \tag{3.28}$$

where

$\phi_{LT,\theta,com}$ is the value to determine reduction factor for lateral torsional buckling in the fire design situation

$\lambda_{LT,\theta,com}$ is the on dimensional slenderness for lateral torsional buckling for the fire situation

α is the imperfection factor for the fire design situation

λ_{LT} is the non dimensional slenderness for lateral torsional buckling

$W_{pl,y}$ is the plastic section modulus of the member

M_{cr} is the elastic critical moment for lateral torsional buckling of a double symmetric cross section and it can be described by Equation 3.29.

$$M_{cr} = C_1 \frac{\pi^2 E I_z}{(k_z L)^2} \sqrt{\left(\frac{k_z}{k_w}\right)^2 \frac{I_w}{I_z} + \frac{(k_z L)^2 G I_t}{\pi^2 E I_z} + (C_2 z_g)^2} - C_2 z_g \tag{3.29}$$

where

I_t	is the torsional constant [m^4]
I_w	is the warping constant [m^6]
I_z	is the second moment of area about the minor axis [m^4]
L	is the unrestrained length of the beam [m]
E	is Young's modulus for steel [Pa]
G	is shear modulus for steel [Pa]
z_g	is the distance between the point of loads application and the shear centre [m]
k_w	is a factor for the warping conditions [-]
k_z	is a factor for the end rotation on plan [-]

In order to calculate the reduction factor for lateral-torsional buckling, the section shape, the lateral restraint, the loading type, the residual stresses and the initial imperfections must be taken into account (Franssen and Real, 2012). This is done by the different coefficients in Equation 3.29.

The shear resistance for members in cross section classes 1 and 2 at a temperature θ_a should be calculated, according to EN 1993-1-2 Section 4.2.3.3 (CEN, 2005), with Equation 3.30.

$$V_{fi,t,Rd} = V_{Rd} \cdot k_{y,\theta,web} \cdot \frac{\gamma_{M,0}}{\gamma_{M,fi}} \tag{3.30}$$

where

V_{Rd}	is the plastic shear resistance of the cross-section for 20°C calculated according to EN 1993-1-1 (CEN, 2008) and EN 1993-1-5 (CEN, 2006) [N]

In order to check whether the capacity of the member is enough to fulfill the maintenance requirement, the calculated resistances can be compared to the design loads during fire according to EN 1990 (CEN, 2010).

If the structure is subjected to both bending and normal force, an interaction control must be made. For members in cross section class 1 or 2, at a temperature θ_a after time t in the fire scenario, two interaction equations should be checked according to EN 1993-1-2 Section 4.2.3.5 (CEN, 2005). The Equations to use are described by Equations 3.31 and 3.32. Both must be fulfilled in order for the member to be designed for a combination of bending moment and normal force.

$$\frac{N_{fi,Ed}}{\chi_{min,fi} A k_{y,\theta} \frac{f_y}{\gamma_{M,fi}}} + \frac{k_y M_{y,fi,Ed}}{W_{pl,y} k_{y,\theta} \frac{f_y}{\gamma_{M,fi}}} + \frac{k_z M_{z,fi,Ed}}{W_{pl,z} k_{y,\theta} \frac{f_y}{\gamma_{M,fi}}} \leq 1 \tag{3.31}$$

$$\frac{N_{fi,Ed}}{\chi_{z,fi} A k_{y,\theta} \frac{f_y}{\gamma_{M,fi}}} + \frac{k_{LT} M_{y,fi,Ed}}{\chi_{LT,fi} W_{pl,y} k_{y,\theta} \frac{f_y}{\gamma_{M,fi}}} + \frac{k_z M_{z,fi,Ed}}{W_{pl,z} k_{y,\theta} \frac{f_y}{\gamma_{M,fi}}} \leq 1 \tag{3.32}$$

where

$\chi_{min,fi}$	is the lowest value of the reduction factors for flextural buckling in the fire design situation in the y and z direction, $\chi_{y,fi}$ and $\chi_{z,fi}$ according to Equations 3.17 to 3.20
$\chi_{z,fi}$	is the value of the reduction factor for flextural buckling about the z-axis in the fire design situation, $\chi_{z,fi}$, according to Equations 3.17 to 3.20
$\chi_{LT,fi}$	is the value of the reduction factor for lateral torsional buckling in the fire design situation, $\chi_{LT,fi}$, according to Equations 3.24 to 3.28
k_{LT}	is the interaction factor from Equation 3.33
k_y	is the interaction factor from Equation 3.34
k_z	is the interaction factor from Equation 3.35

$$k_{LT} = 1 - \frac{\mu_{LT} N_{fi,Ed}}{\chi_{z,fi} A k_{y,\theta} \frac{f_y}{\gamma_{M,fi}}} \leq 1 \tag{3.33}$$

$$k_y = 1 - \frac{\mu_y N_{fi,Ed}}{\chi_{y,fi} A k_{y,\theta} \frac{f_y}{\gamma_{M,fi}}} \leq 3 \tag{3.34}$$

$$k_z = 1 - \frac{\mu_z N_{fi,Ed}}{\chi_{z,fi} A k_{y,\theta} \frac{f_y}{\gamma_{M,fi}}} \leq 3 \tag{3.35}$$

where

$\mu_{LT} = 0.15\lambda_{z,\theta}\beta_{M,LT} - 0.15 \leq 0.9$

$\mu_y = (2\beta_{M,y} - 5)\lambda_{y,\theta} + 0.44\beta_{M,y} + 0.29 \leq 0.8 \quad \text{and} \quad \lambda_{y,20°C} \leq 1.1$

$\mu_z = (1.2\beta_{M,z} - 3)\lambda_{z,\theta} + 0.71\beta_{M,z} - 0.29 \leq 0.8$

where

β_M is the equivalent moment factor that can be decided from figure 4.2 in EN 1993-1-2 Section 4.2.3.5 (CEN, 2005)

The other advocated alternative, given by EN 1993-1-2 Section 4.2.4 (CEN, 2005), is to calculate the utilization of the member at time *t=0* of the fire exposure in order to find the critical temperature θ_a, described in Equation 3.8. This method can only be used if the analysis is limited to one member of the structure. The degree of utilization is given by the Equation 3.36 (CEN, 2005).

$$\mu_0 = \frac{E_{fi,d}}{R_{fi,d,0}} \tag{3.36}$$

where

$R_{fi,d,0}$	is the resistance for the member at time t=0
$E_{fi,d}$	is the design effect of actions for the fire situation

Alternatively, EN 1993-1-2 Section 4.2.4 (CEN, 2005) gives another expression to calculate μ_0 provided that the member is in tension and that there is no risk for lateral torsional buckling. Equation 3.37 may then be used to calculate μ_0.

$$\mu_0 = \eta_{fi} \cdot [\gamma_{M,fi}/\gamma_{M0}] \tag{3.37}$$

where
η_{fi} is the reduction factor defined by Equation 3.38

$$\eta_{fi} = \frac{G_k + \psi_{fi} \cdot Q_{k,1}}{\gamma_G \cdot G_k + \gamma_{Q,1} \cdot Q_{k,1}} \tag{3.38}$$

where
$Q_{k,1}$ is the caracteristic value for the variable load
G_k is the caracteristic value for the permanent load
γ_G is the partial coefficient for permanent load defined in EN 1990 (CEN, 2010) to 1.35 for the ultimate limit state [-]
$\gamma_{Q,1}$ is the partial coefficient for the variable load defined in EN 1990 (CEN, 2010) to 1.5 for the ultimate limit state [-]
ψ_{fi} is the combination factor for values given by either $\psi_{1,1}$ or $\psi_{2,1}$ [-]

3.2.2.2 Advanced calculation models

EN 1993-1-2 (CEN, 2005) permits the use of advanced calculation models if they lead to trustworthy approximations of the expected behavior. This can be achieved by using methods that are established on fundamental physical behavior and provides a realistic analysis of the structure.

In order to fulfill this requirement, EN 1993-1-2 (CEN, 2005) specifies a list of prerequisites within the topics: General, thermal response, mechanical response and validation of advanced calculation models. The prerequisites from EN 1993-1-2 specifies what the model should include and how the material response should be analyzed. The entire list of these requirements can be found in Section 4.3 in EN 1993-1-2 (CEN, 2005). Below follows some examples.

- Every failure mode possible for the model must be analyzed and if any failure mode is excluded, it must be proven to be irrelevant for the model.
- The model must have separate calculations for the temperature development and for the temperature distribution in the structural member.
- If the temperature dependent material behaviour is known, predefined temperature standard curves may be used.
- The temperature development in the material must be included in the analysis.
- Moisture in the enclosed environment and on surfaces can be conservatively neglected.

- The thermal response must be based on known principles and assumptions within structural mechanics.
- The model must include the strains originated by the temperature change and the difference of temperature within the material.
- The model must include temperature dependent mechanical actions, geometrical non-linearities and imperfections, the effect of non-linear material response and thermal actions as well as the interaction between them.
- The results must be compared with trustworthy test results.

3.2.3 Combining EN 1991-2-1, EN 1990 and EN 1993-2-1

In order to evaluate if a structural member's resistance to fire is high enough compared to the actions, several parts of Eurocode must be combined. Section 2.3 describes how the actions pf fire on a structural member exposed to fire should be decided. More specifically, Section 2.3.5 describes the process to decide the required temperature a structure must sustain its structural stability according to EKS (Boverket, 2015). Furthermore, Section 3.1 describes how the required temperature should be calculated according to EN 1991-1-2 (CEN, 2009).

Section 3.2.1 describes how the design effect of actions for the fire situation, and thus the required resistance of the member, should be calculated. Additionally, Section 3.2.2 describes how to calculate the resistance of a steel member exposed to fire.

By combining these sections, a verification of a steel member's fire resistance can be made. As mentioned in Section 3.1.4 with Equations 3.3 to 3.5, there are three ways to check whether a structural steel member is properly designed for a fire scenario.

- Check to see if the member can withstand the fire during a long enough time period, with sufficient resistance.
- Check to see if the member have enough resistance, throughout the design period of the fire.
- Check to see if the member can handle the increased temperature caused by the fire.

Figure 3.2 to 3.9 summarizes how the parameters in Equations 3.3 to 3.5 can be calculated by using the different parts of Eurocode. The colors around the boxes in Figure 3.2 to 3.9 describes in which part of Eurocode the appropriate calculation methods can be found. The fill-in color in the end boxes of each figure is color coded to describe which requirement that should be compared to which resistance. Same colors should be compared.

Figure 3.2 describes how the required temperature, Θ_d, expressing how high temperature the structure must endure, should be decided. This temperature, colored with purple in Figure 3.2, must be lower than the maximum temperature that the steel member can resist, $\Theta_{cr,d}$, colored purple in Figure 3.3 and 3.4. Figure 3.3 and Figure 3.4 describes how the maximum resistable temperature can be calculated with two different methods: one method where the utilization ratio is used and another where the reduction factors are used.

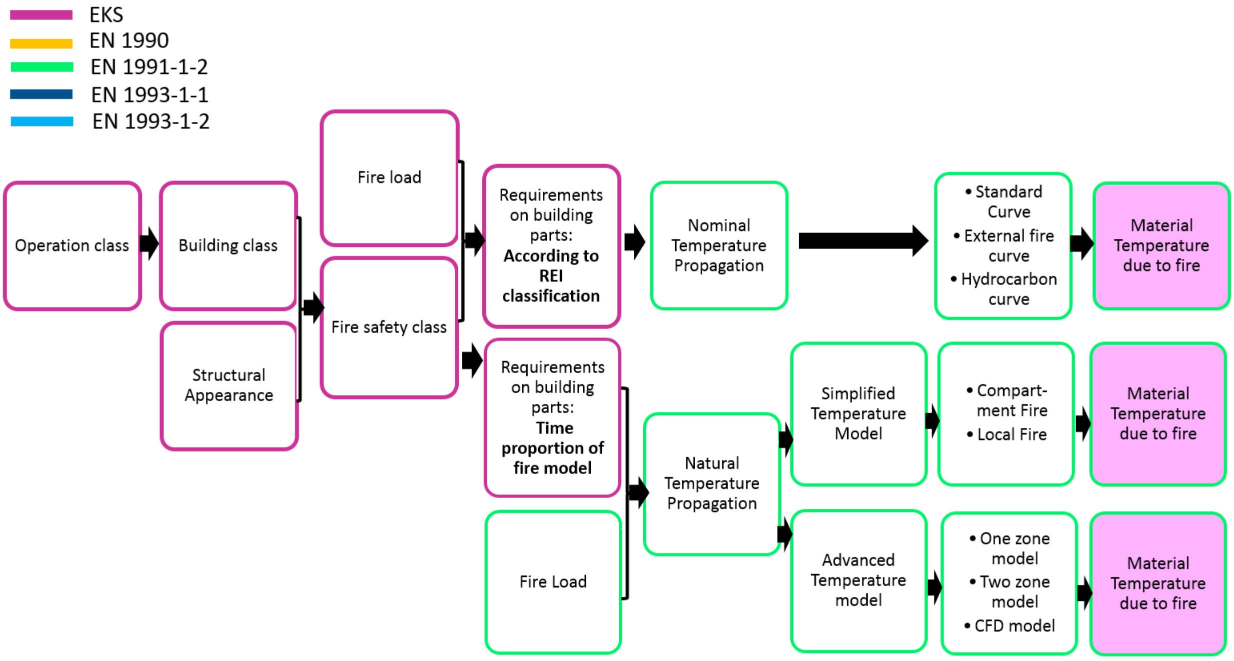


Figure 3.2: Flow-chart describing the process of deciding the required temperature, with color coding to describe which part of Eurocode to use for each step.

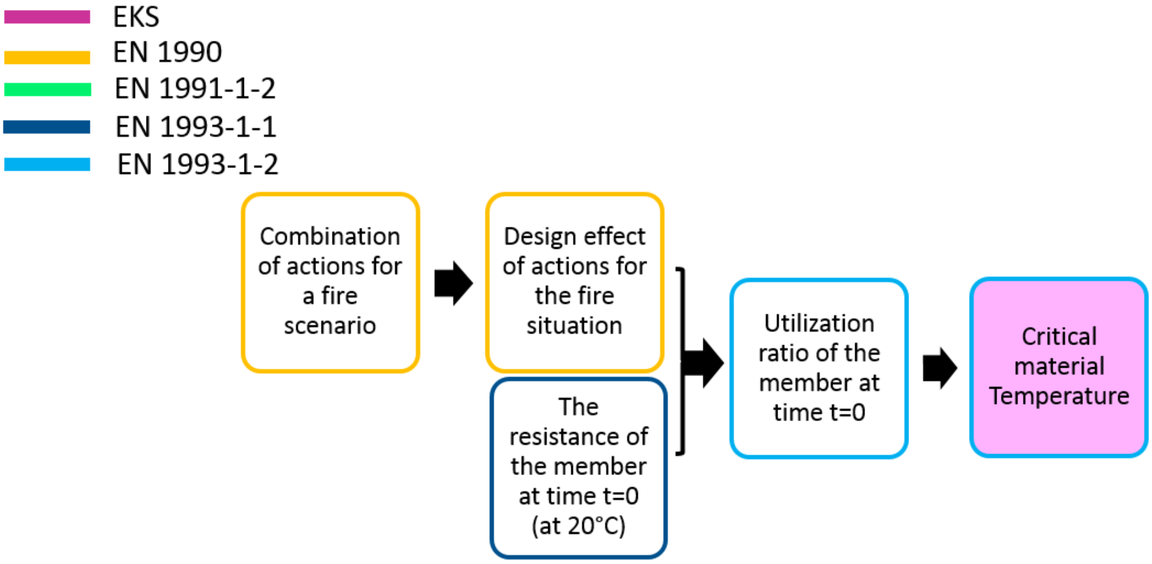


Figure 3.3: Flow-chart describing the process of deciding the maximum resistable temperature with utilization ratio, with color coding to describe which part of Eurocode to use for each step.

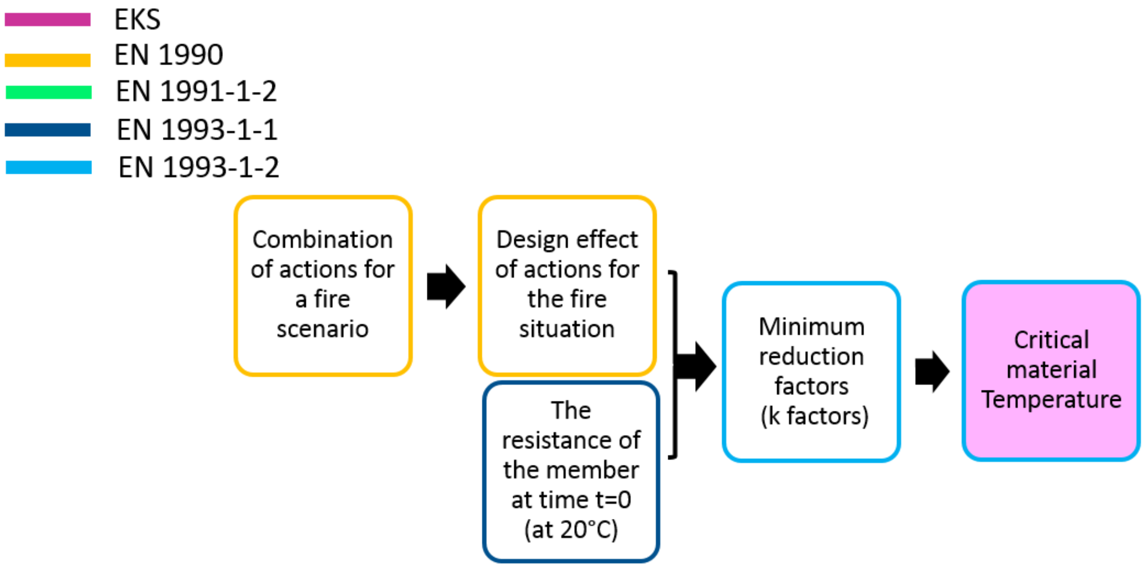


Figure 3.4: Flow-chart describing the process of deciding the maximum resistable temperature with k factors, with color coding to describe which part of Eurocode to use for each step.

Figure 3.5 describes how the required resistance, $E_{fi,d,t}$, expressing how much resistance the structure must maintain after time t in the fire scenario, should be decided. This resistance, colored with light blue in Figure 3.5, must be lower than the design resistance of the steel member at time t in the fire scenario, $R_{fi,d,t}$, colored light blue in Figure 3.6. Figure 3.6 describes how the design resistance in the steel member at time t in the fire situation should be calculated and what parts of Eurocode to use.

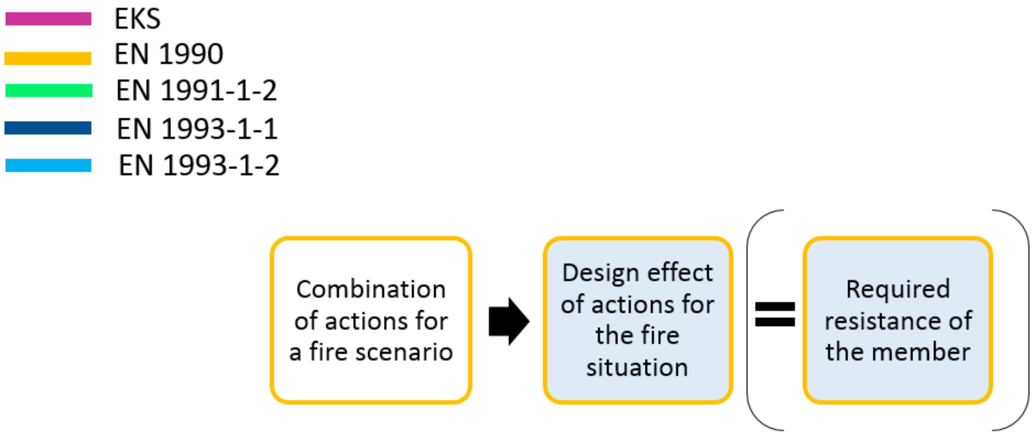


Figure 3.5: Flow-chart describing the process of deciding the required resistance of a structural member, with color coding to describe which part of Eurocode to use for each step.

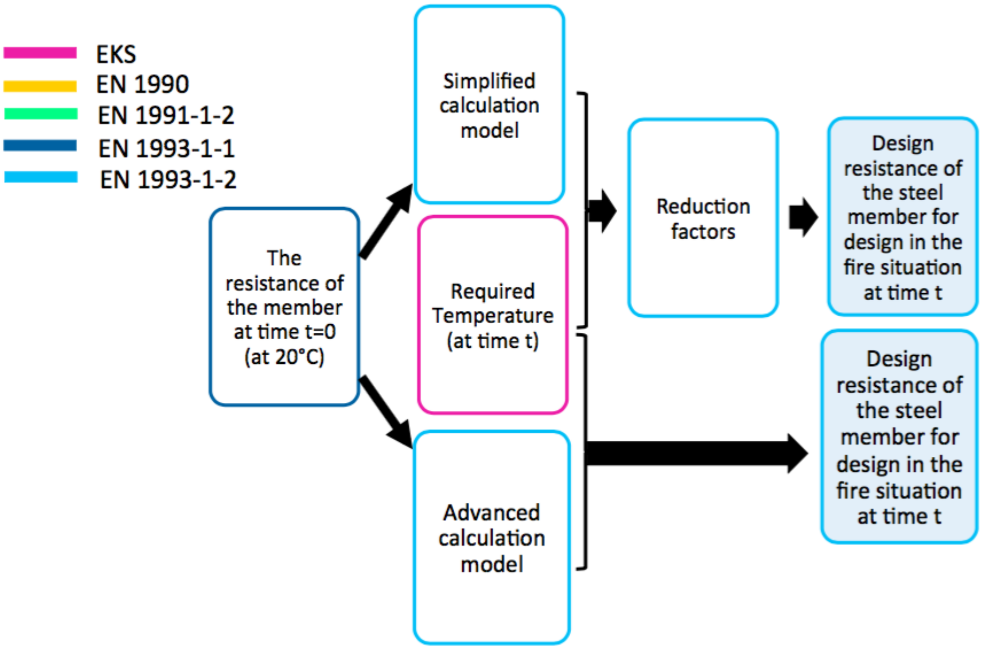


Figure 3.6: Flow-chart describing the process of deciding the design resistance of a steel member exposed to fire, with color coding to describe which part of Eurocode to use for each step.

Figure 3.7 describes how the required time that the structure must sustain its structural stability, $t_{fi,d}$, should be decided. This time is either according to REI classification, described in Section 2.3.1, or according to time proportion of fire model. Figure 3.8 and 3.9 describes how the resistance time, $t_{fi,d}$ which is the time that the structure will sustain its structural stability, should be calculated. The difference between Figure 3.8 and 3.9 is that Figure 3.8 shows calculations based on reduction factors and 3.9 shows calculations based on the utilization ratio. Depending on which of the methods that is used to decide the required time, according to REI or according to time proportion, the time needs to be compared to different resistance times. A time according to REI classification should be compared with a resistance time calculated from nominal temperature propagation. A time according to time proportion of fire model should instead be compared to resistance time calculated from natural temperature propagation. To highlight this, the different times are colored with different colors in Figure 3.7 to 3.9. The required time highlighted in light green or yellow in Figure 3.7 should, respectively, be lower than the resistance time colored in light green or yellow in Figure 3.4 and 3.9.

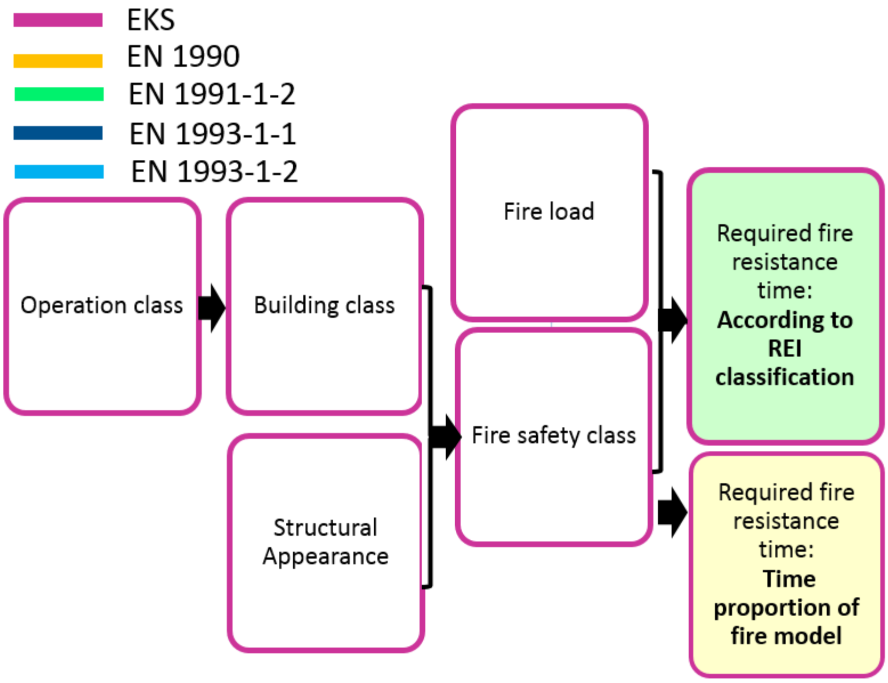


Figure 3.7: Flow-chart describing the process of deciding the required resistance time, with color coding to describe which part of Eurocode to use for each step.

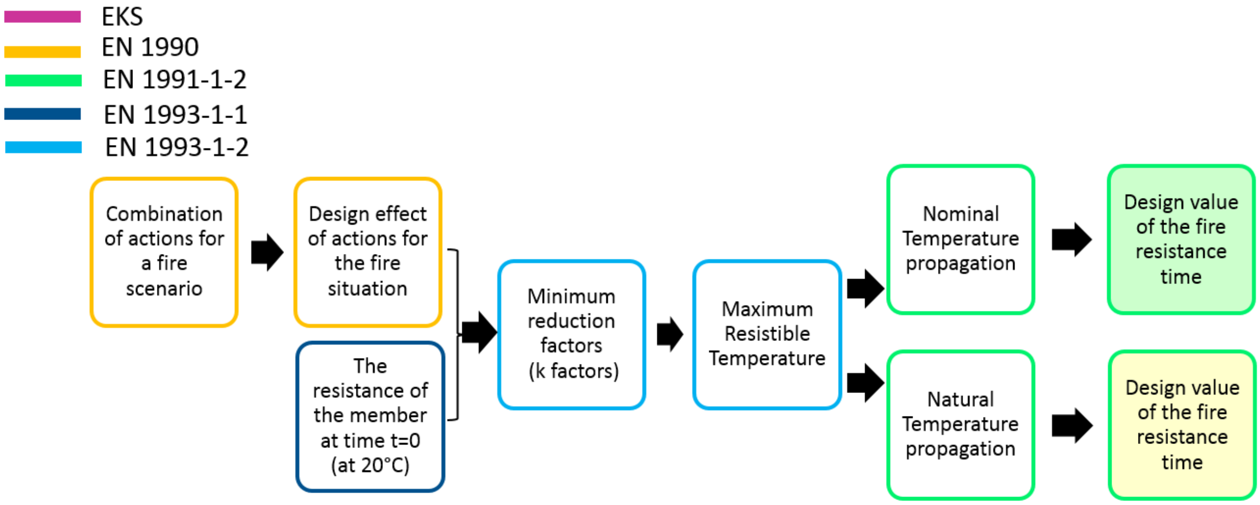


Figure 3.8: Flow-chart describing the process of deciding the resistance time with k factors, with color coding to describe which part of Eurocode to use for each step.

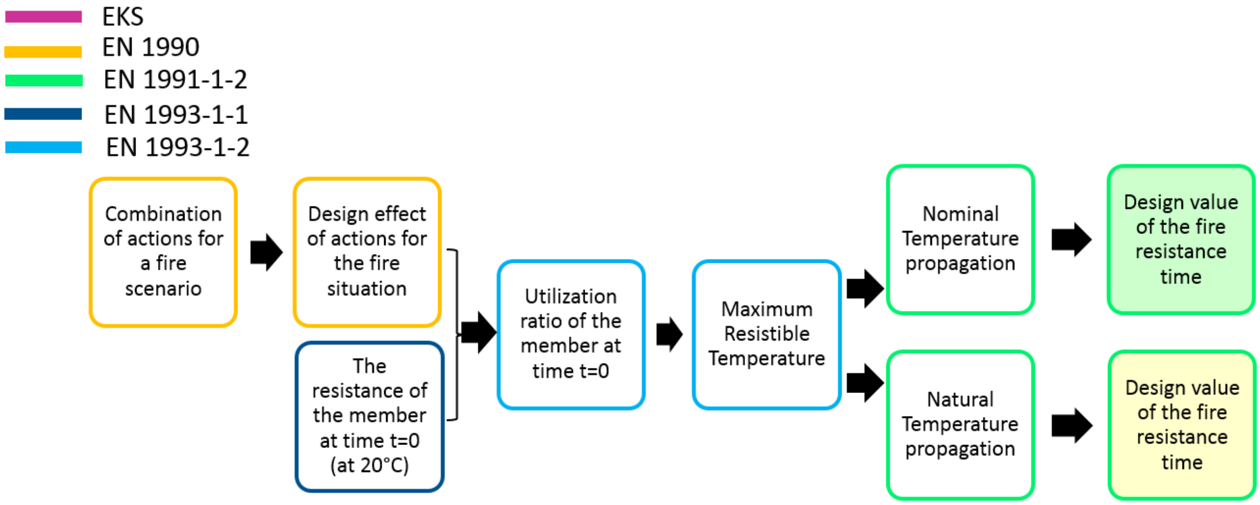


Figure 3.9: Flow-chart describing the process of deciding the resistance time with utilization ratio, with color coding to describe which part of Eurocode to use for each step.

4

FE modelling

4.1 Conditions for FE model

The study described in this report is concentrated on steel beams subjected to fire with an increased air temperature, during the fire, according to the ISO 834 curve. Furthermore, the study is made for a simply supported roof beam that is placed in the top layer of the compartment. This means that the beam should be analyzed for an air temperature that is uniform all around the beam and has boundary conditions corresponding to a simply supported beam.

In a fire scenario a gray smoke cloud is created. This smoke cloud will increase in thickness with increasing height and this will prevent any direct radiation from the fire to reach the beam in the ceiling, see Section 2.1.2. This means that no radiation from the fire will directly reach the beam since it is entirely surrounded by the smoke cloud. Instead, only radiation from the smoke cloud will reach the beam.

Heat can be transferred by three mechanisms as described in Section 2.1.1: heat conduction, heat convection and heat radiation. The heat in the air can be transferred to the beam surface by heat convection and heat radiation where the convection origins from the temperature in the air surrounding the beam and the heat radiation origins from the cloud surrounding the beam. The radiation and convection temperatures were assumed to be the same in this study. When the heat is transferred to the beam it will afterwards be distributed within the beam by conduction.

The FE model used for this study had to be able to describe these circumstances and relations in order to lead to trustworthy approximations of the expected beam behavior. Additionally, it needed to describe the proper material properties, described in Section 2.2, which for steel are both temperature dependent and elastic-plastic.

In order to analyze the behavior of a beam in fire, an analysis of increasing temperature with temperature dependent material properties, must be combined with a structural analysis. ADINA, as other FE programs, provides the opportunity to couple a thermal analysis with a structural analysis (ADINA R & D, n.d.), which is a way to incorporate calculated temperatures in different time steps into a structural analysis.

4.1.1 FE Thermal model

In order to analyze the temperature distribution in a beam, solid elements must be used in the Thermal model. In the FE analysis, two-dimensional and three-dimensional conduction, convection and radiation can be included and the heat transfer can be analyzed in either steady state or in transient state conditions (ADINA R & D, n.d.). The material properties for conductivity and specific heat capacity can be specified as temperature dependent or constant. In order to enable the analysis of the radiation induced adoption of heat, radiation elements must be created on the beam surfaces that are exposed to the radiation. The same applies for convection. These convection and radiation elements can be described with convection- and radiation material properties for steel. If the design is based on Eurocode, these material properties can be described according to guidelines in EN 1991-1-2 Chapter 3 (CEN, 2009). This would imply a convection coefficient of 25 $W/(m^2K)$, Stefan Boltzmann's constant of 5.6696*10^{-8} $W/(m^2K^4)$ and an emissivity coefficient of 0.8. The volume of the beam must be described with temperature dependent conduction material properties, described in Section 2.2.1, in order to analyze the conduction within the element.

If the aim is to obtain a uniform temperature within the beam, the thermal conductivity of the material can be highly exaggerated. This will make the heat transfer in the beam higher, which results in little or no difference in temperature within the beam. If the aim instead is to obtain a realistic temperature distribution in the beam, the correct, non exaggerated, values for thermal conductivity can be used. The analysis of the model can then be made with the ISO 834 curve for different temperatures in the air at different times. The results from this analysis specifies the temperature distribution in the beam at different times during the fire.

4.1.2 FE Structures model

In order to analyze the structural behaviour of the beam with prescribed temperature distribution, the structural FE model must be created with solid elements too. The thermal analysis results can be coupled with the structural analysis if the exact same geometry and time steps are used for both analyses. In the FE program, material properties for Young's modulus, Poisson's ratio, yield stress, strain hardening modulus, mean coefficient of thermal expansion and maximum effective plastic strain can be specified for different temperatures. If the material properties are temperature dependent in accordance with EN 1993-1-2 Section 3.2 and 3.4 (CEN, 2005), they must be specified in the FE model for different temperatures.

Load can be given either in several time steps, by a time function, or all at once in one single step in the FE model. If the FE model was created to identify the failure temperature and not the failure load, the mechanical load can be applied as time independent. This means that the temperature would be time dependent but that the mechanical load would be time independent. If a normal force on the edge of the beam is include in the model, it can be applied as a pressure on the beam's end surface.

The temperatures in the beam must be mapped from the thermal analysis for the different air temperatures. The structural analysis must be able to use the material properties for each temperature, in each step, in order to analyze the thermal expansions for each step and to do a structural analysis with these expansions and material properties. This method can be used in order to know the maximum temperature at which the beam still manages to carry the mechanical load.

Initial imperfections can be applied based on buckling mode shapes obtained from a linearized buckling analysis. The linearized buckling analysis generates the buckling mode shapes. Thereafter, the initial imperfection may be applied in accordance to a specific mode shape in the Structural model. If the initial imperfection is specified at a certain node with the desired mode shape, magnitude and direction, ADINA will scale that buckling mode in order to give the same shape but with the corresponding magnitude and direction in all other nodes as well. In this way, the initial imperfections can be given as a specific magnitude and applied in the most unfavourable direction.

The boundary conditions in the structural analysis for some parts of this study should correspond to simply supported conditions. One way to fulfill this is presented in a study by Snijder et al. (2008), where stiff beam elements along the edges at the supports were used, see Figure 4.1 for the location. These stiff beam elements prevent twisting of the beam but allows for warping by having high moment of inertia in both directions. In order to permit Poisson's contraction, a small cross section area was used. Furthermore, a small torsional stiffness was assigned to the beam elements in order to make sure that the beam studied did not obtain extra torsional stiffness by using beam elements along the edges. This kind of beam elements make it possible to introduce boundary conditions in edge points on the beam without any risk for high stress concentrations at the edge. Snijder et al. (2008) applied fix boundary conditions in the center of the beam, at mid height, on both edges of the beam. One point on one edge was given fixed x-,y- and z-translation, which represents a hinged support, while the other edge was given fixed y- and z-translations to represent a roller support. The center points of the top and bottom flange on both edges of the beam were given fixed z-translation as well. These boundary conditions could, according to Snijder et al. (2008), properly describe simply supported boundary conditions.

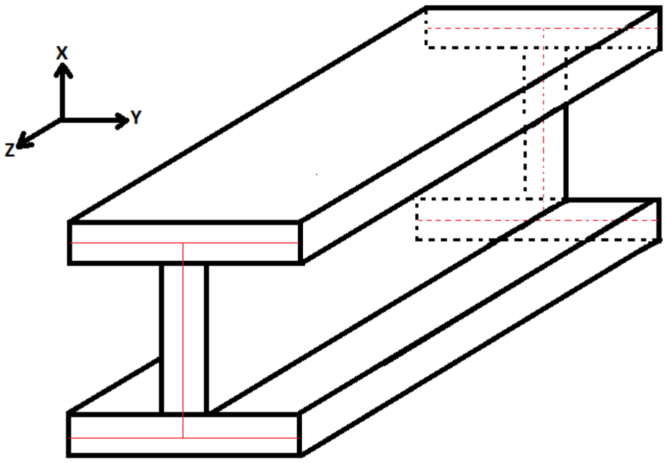


Figure 4.1: Beam with red lines which represent the locations of the stiff beam elements along the edges at the supports.

The three-dimensional beam elements used to apply the boundary conditions was defined with rectangular cross sections with small cross section areas but high second moments of area. It is impossible with rectangular cross sections, however, to achieve a high second moment of area in both directions while the cross section area remains small. Instead, one direction must be prioritized to have high second moment of area. In order to get a rectangular cross section with high second moment of area in one direction and a low cross section area, the beam must have a cross section with one very short edge and one very long edge. It is important to be aware of the importance of specifying the long edges in the plane of the main beam and the short edges along the main beam in order to get the high moment of area in the right direction, see Figure 4.2. With these beam elements on the edges of the main beam, the actual boundary conditions can be specified for specific nodes on the edges.

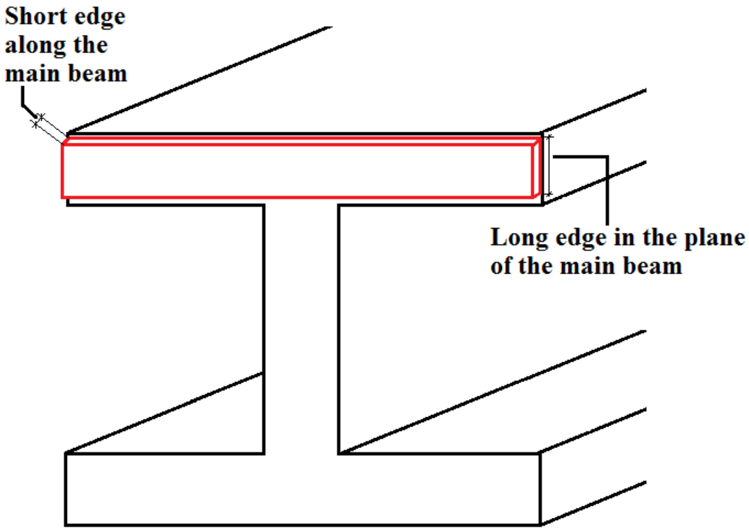


Figure 4.2: Showing the direction of short and long edges of the rectangular cross section of the three-dimensional beam elements in relation to the main beam.

5

Methodology

5.1 Comparison study

A comparison study was made to evaluate the difference between the two methods to calculate the factor μ_0 used in the simplified method, see Section 3.2.2.1, for calculation of critical temperature according to EN 1993-1-2, Section 4.2.4. The aim was also to determine if and when they may coincide in order to determine which method should be used in the Parametric and in the Main study. The comparison study was made in three steps:

1. μ_0 was calculated according to Equation 3.36 in Section 3.2.2.1.
2. μ_0 was calculated according to Equations 3.37 and 3.38 in Section 3.2.2.1.
3. The comparison of the two methods was made by deriving the circumstances during which the two methods gave the same value for μ_0. The derivation is presented in Appendix A.

5.2 Parametric study

The first part of the study consisted of a two phased parametric study of a steel beam exposed to fire. The Parametric study aimed to study the influence of different parameters for a simply supported beam on the temperature gains when performing a FE analysis instead of hand calculation. The first phase of the Parametric study was on a beam with no initial imperfections and no risk for lateral torsional buckling. The parameters studied in the first phase were varying thickness of web and flanges, different application of temperature loads in the FE model and mechanical loads based on utilization ratio in the ultimate limit state versus the fire scenario.

In phase two a simply supported beam with risk for lateral torsional buckling was studied, where the hand calculations and the FE analyses both included initial imperfections.

The second phase of the Parametric study was based on the results from the first phase in order to decrease the number of analyses. Based on the results, one temperature load case was chosen and the utilization ratio was based only on one of the scenarios. However, in the second phase, lateral torsional buckling as failure mode was included and varying slenderness as well as varying web and flange thicknesses were studied.

The Parametric study consisted of twelve steps which are listed below. In the first phase step one to seven was used. In phase two step three to five and eight to twelve were followed. A more detailed description of each step follows. Hand calculations for one of the beam cases for step two and nine can be found in Appendices B and C and the .in-files to ADINA used in step six and eleven for one of the beam cases can be found in Appendices D and E.

1. Based on simple hand calculations and reasoning the applicable beams and lengths for the first phase of the Parametric study were chosen.
2. Hand calculations according to Eurocode for fire design without lateral torsional buckling as a failure mode were made for the beams chosen in step one.
3. The Thermal model was created.
4. The Structural model was created.
5. The Thermal and Structural models were verified.
6. The chosen beams in step one were analyzed in the Thermal model from step three followed by the Structural model from step four with boundary conditions not allowing for lateral torsional buckling and without initial imperfections.
7. The results from steps two and six were compared and evaluated.
8. Based on the results from step six, new beams with varying slendernesses and loads were chosen for the second phase of the Parametric study.
9. Hand calculations according to Eurocode for fire design with initial imperfections and lateral torsional buckling as a failure mode were made for the beams chosen in step eight.
10. The linearized buckling model was created.
11. The chosen beams in step eight were analyzed in the Thermal model from step three followed by the Linearized buckling model from step ten and finally the Structural model from step four with boundary conditions allowing lateral torsional buckling and including initial imperfections obtained from the linearized buckling analysis in step ten.
12. The results from steps nine and eleven were compared and evaluated.

5.2.1 Choice of beams for the Parametric study phase one

The beam cross sections, lengths, design loads, temperature distributions within the beam and considered temperature loads in this phase were chosen based on several different criteria.

Firstly, the cross section height was chosen between the commonly used beam sizes 100-600 of the type HEA, HEB and HEM. Cross sections HEA 100, HEB 100 and HEM 100 were considered as too small to make a fair and general case. The remaining beams' cross section classes were calculated to check which ones were in cross section class 1 or 2 for both the ultimate limit state and the fire design scenario. The smallest height possible, not considering size 100 mm height, for these standard HEA, HEB and HEM beams were chosen in order to decrease computation times but to still yield representative results. Thus beams of size 400 were chosen.

Secondly, the length of the beams was chosen to have a reasonable ratio between the beam height and beam length. Lengths commonly used in actual buildings were also considered in this step. A length of 12 m was chosen.

Thirdly, the mechanical loads, which vary between the different studied beams, were chosen. The loads were chosen so that all beams would have, to the extent possible, the same utilization ratio. The used utilization ratio was chosen to represent a reasonable value that is within the range of what is commonly used in the industry. The utilization ratio was firstly based on the ultimate limit state, approximately 80 %, and then on the fire scenario, appropriately 70 % in a temperature corresponding to 6 min of the ISO 834 curve. This was done in order to see whether one of them affected the results more than the other.

Lastly, in the hand calculations according to EN 1993-1-2, the critical temperature can be based on either calculations with reduction factors or calculation based on utilization ratios after time t=0 in the fire scenario. Both these calculations were made for a uniform temperature in the beam. In the Thermal model, radiation and convection could be either included or excluded on the surfaces. Also, the steel conduction properties in the beam cause a, more or less pronounced, non-uniform temperature distribution within the beam in the FE model. In order to compare and evaluate the hand calculations and the results from the FE model, the considered temperature load and gradient had to be specified. Therefore, the FE models for all these beams, were meant to be studied for three different scenarios. Uniform temperature within the beam, non-uniform temperature within the beam with radiation on the top of the top flange as well as non-uniform temperature within the beam without radiation on the top of the top flange. In summation, this led to five different critical temperatures for each beam, which were compared and evaluated, see Table 5.1.

Table 5.1: A table showing the the different beams analyzed in the Parametric study phase one.

S355	12 m	Hand calculations with reduction factors	Hand calculations with utilization ratio	Uniform temperature Distribution	Non-uniform temperature Distribution w/ radiation on top	Non-uniform temperature Distribution w/o radiation on top
ULS, η=0.8	HEA400	Yes	Yes	Yes	Yes	Yes
ULS, η=0.8	HEB400	Yes	Yes	Yes	Yes	Yes
ULS, η=0.8	HEM400	Yes	Yes	Yes	Yes	Yes
Fi, η=0.7	HEA400	Yes	Yes	Yes	Yes	Yes
Fi, η=0.7	HEB400	Yes	Yes	Yes	Yes	Yes
Fi, η=0.7	HEM400	Yes	Yes	Yes	Yes	Yes

5.2.2 Hand calculations for the Parametric study phase one

The beam capacity, not considering lateral torsional buckling, was initially calculated without reduction for the fire scenario. Since the bending moment capacity was the most critical, this capacity was used in the following calculations.

The first calculation was made according to the process shown in Figure 3.6. This method used the reduction factors specified in EN 1993-1-2 Section 3.2 (CEN, 2005) in order to give the utilization ratio after time t in the fire scenario. These calculations were iterated for an increasing temperature until the utilization ratio exceeded 100 %.

The second calculation was made according to the processes shown in Figure 3.3 which uses the utilization ratio after time t=0 in the fire scenario. This simplified method instantly gave the critical temperature for a specific load case on the evaluated beam based on the non-reduced beam capacity.

The hand calculations resulted in two critical temperatures, one for each method, for each of the evaluated beams with their corresponding load cases. The second, simplified calculation was done in order to make sure that it for all cases gave a lower critical temperature than the first, more advanced, calculation. See Section 6.1 for more details on why this is the case. It was included as an additional verification method in order to make sure that the calculations were done correctly. Since this simplified calculation must be lower than, or equal to, the more advanced calculation according to EN 1993-1-2 Section 4.2.4 (CEN, 2009), a potential error could be identified if it was not. Hand calculations for one of the beam cases can be found in Appendix B and the final results of these calculations can be found in Chapter 6.

5.2.3 Thermal model

The input data for the thermal analysis was imported to ADINA by so-called .in-files. These were created in excel to facilitate changes and to generate a larger quantity of files for multiple simultaneous analyses. Once all .in-files were imported to ADINA, the analysis was performed. The .in-files for the thermal analysis of one of the beam cases are found in Appendices D and E together with the structural and linearized buckling .in-files. The .in-files consisted of six different sections as listed below.

1. Beam geometry
    - I Cross section
    - II Length
2. Material parameters
    - I Thermal conductivity
    - II Specific heat capacity
    - III Material parameter for Boundary convective elements
        - i. Convective coefficient
    - IV Material parameters for Boundary radiation elements
        - i. Emissivity coefficient
        - ii. Stefan Boltzmann's constant
    - V Material and cross sectional properties for rectangular 3-D beam elements
        - i. Dimensions (width and height)
        - ii. Yield strength (Isotropic Linear Elastic material)
        - iii. Poisson's ratio
        - iv. Density
        - v. Coefficient of thermal expansion
3. Mesh and element groups
    - I Size of mesh
    - II Number of integration points
4. Time step
    - I Length of analysis
    - II Number of time steps for the analysis
5. Temperature load
    - I Convection
    - II Radiation
6. Saving results for import to the structural analysis

5.2.3.1 Beam geometry - Thermal model

The chosen beam geometry, including the cross section and length of the beam, see Section 5.2.1, were incorporated into the analysis. This was done by defining points between which seven surfaces were created. These surfaces were afterwards extruded to volumes which together composed the entire beam. The surfaces and their numbering are shown in Figure 5.1 for the seven different volumes that created the studied beam. The flanges were divided in three sections in order to make sure the flange parts' and the web parts' meshing nodes coincided.

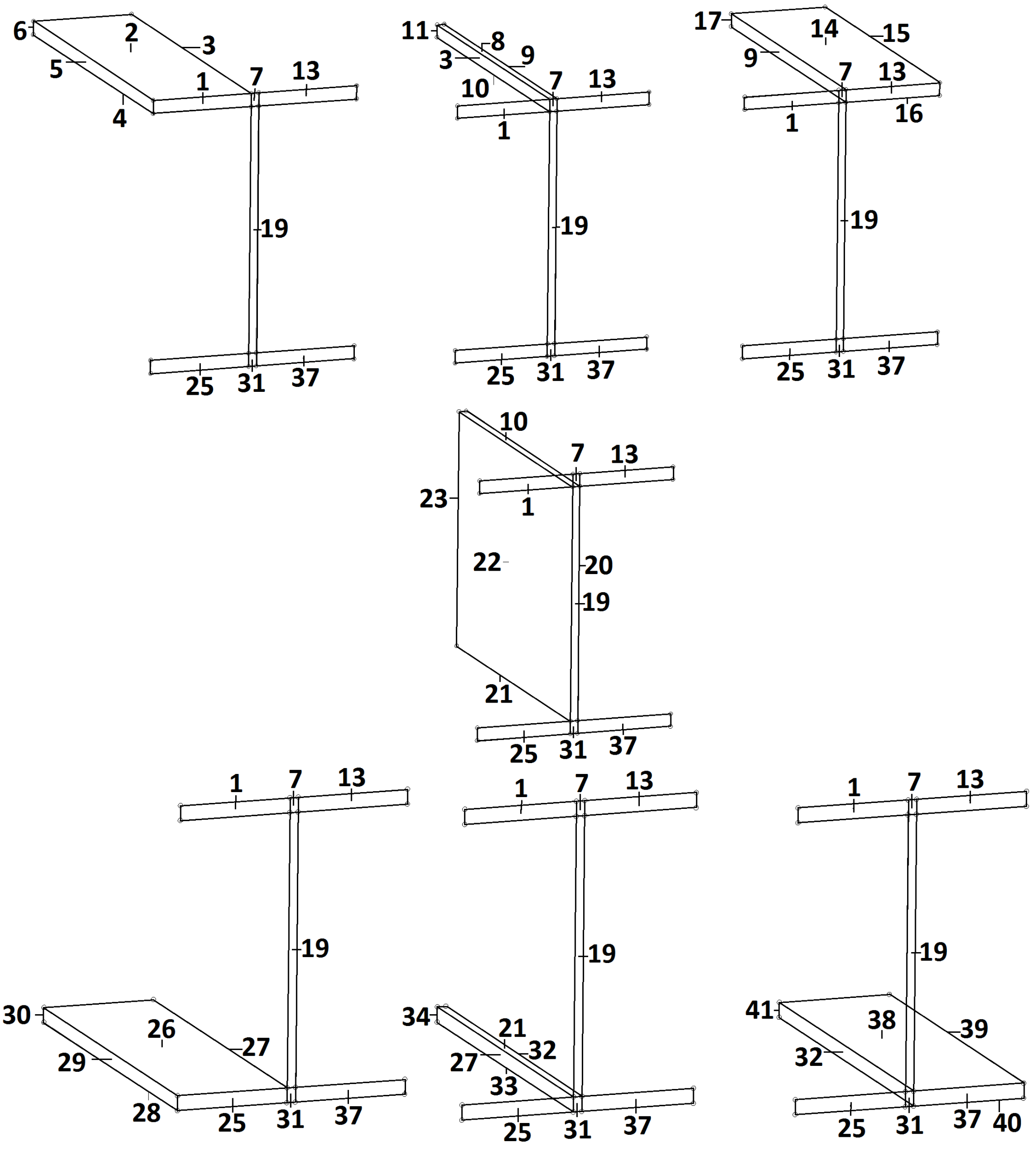


Figure 5.1: Numbering of surfaces for the seven volumes creating the studied beam.

In addition to the points, surfaces and volumes created for the three-dimensional solid elements, 22 lines, 11 on each end side of the studied beam, were created as well. They were created for the proper implementation of the necessary mechanical boundary conditions by the use of 22 3-dimensional beam elements, see Section 5.2.4.2 and 5.2.4.6.

5.2.3.2 Material parameters and element groups - Thermal model

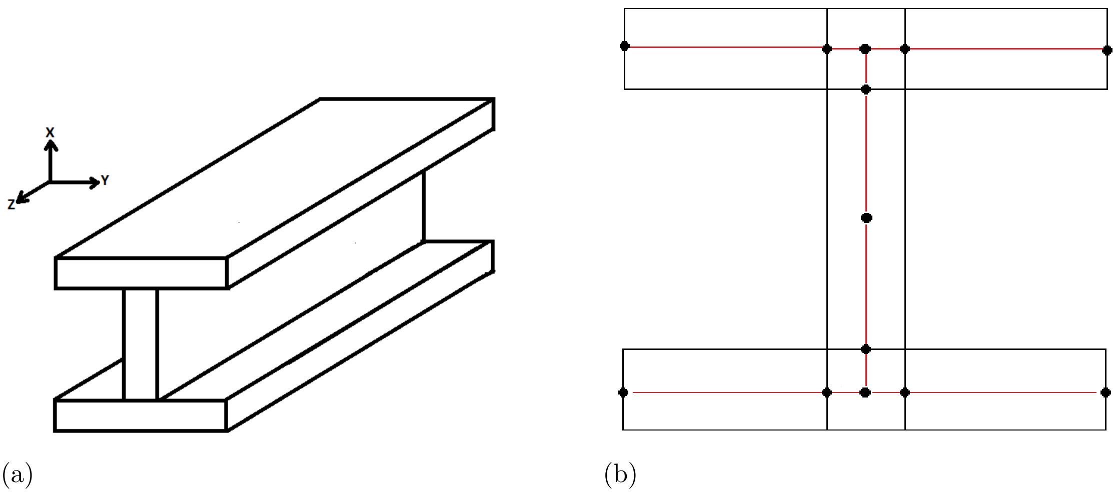
The temperature dependent material properties, as described in Section 2.2, were included in the analysis by choosing the conductivity and specific heat capacity as temperature dependent. The temperature dependent conductivity and specific heat capacity data that was included is shown in Figures 2.2 and 2.4 in Section 2.2. Values between given data points are automatically interpolated in ADINA. The radiation and convective material properties were set to be temperature independent.

Four different element groups were also introduced to the Thermal model. Three of them correspond to the thermal analysis and one of them is present to assure geometry identical to the structural analysis. They were "threedconduction", "beam", "convection" and "radiation". Element groups "convection" and "radiation" were created on the beam surface and element group "threedconduction" was created in the beam volume. The element group "beam" was not directly used in the Thermal model but was included to assure an identical geometry compared to the Structural model, see more in Section 5.2.4.2.

The material parameters for the 22 three-dimensional beam elements, used for proper implementation of boundary conditions, were specified as well. The three-dimensional beam elements' material parameters were set for a rectangular beam cross section where the cross section parameters were calculated based on the given width and height, see Section 4.1.2 for more details of how the dimensions were chosen. The manually specified non-temperature dependent material parameters were the yield strength, Poisson's ratio, the density and the coefficient of thermal expansion.

5.2.3.3 Mesh - Thermal model

The mesh size in all three directions, as well as the number of integration points, were specified manually. The mesh had a maximum length of 5 mm in y-direction and a maximum length of 7.5 mm in z-direction. See Figure 5.2 (a) for the direction of the coordinate system. Since the number of elements in the mesh had to be equally divided by two in order to achieve compatibility between the different volumes and surfaces and three-dimensional beam elements, see Figure 5.2 (b), the mesh size was closer to 5 mm for both y- and z- direction. The mesh length in x-direction was five times as long as the mesh length in y-direction. This mesh size, in addition to being compatible with the defined points and the three-dimensional beam elements, was carefully chosen to be fine enough to ensure quality results but increased in size where possible (along the beam in x-direction) to slightly shorten the computer processing time for the analysis. These guidelines for meshing were carefully investigated and chosen with the help of experienced engineers.



(a) (b)

Figure 5.2: (a) Graphic showing the direction of the coordinate system of the beam. (b) Graphic of how the mesh must be equally divided by two due to the placement of three-dimensional beam elements. The red lines show the placement of the three dimensional beam elements.

5.2.3.4 Time step - Thermal model

The length of the analysis, with the appropriate time stepping, was imported to the FE model. For each time step, the corresponding temperature, based on the ISO 834 standard fire curve, was imported as well. The time increments were equal to 30/100 minutes or 18 seconds.

5.2.3.5 Temperature load - Thermal model

The temperature load, convection and radiation, was imported to the FE model for the appropriate surfaces. For the first phase of the Parametric study, convection was added on all outward surfaces while the radiation was added on all outward surfaces or on all outward surfaces except for the top. The case with no top radiation was created to represent a steel beam whose top flange's upper surface is protected from radiation by a ceiling. For the second phase in the Parametric study, only the case of no radiation on the top of the top flange was studied, the reason for this is described in Section 5.2.8. In the second phase of the Parametric study, convection was added on all outward surfaces while the radiation was added on all outward surfaces except for the top of the top flange. The temperature load for both the convection and the radiation corresponded to the ISO 834 standard fire curve. This was done by setting the temperature load magnitude to unity and coupling it with a magnification factor following the time stepping described in Section 5.2.3.4.

5.2.3.6 Saving of results - Temperature mapping of the beam

The results, meaning the temperature at all nodes in the beam at all the different time steps, were saved to a .map-file to be available for import to the structural analysis later on, see Section 5.2.4.7.

5.2.4 Structural model

The structural analysis, in conformity with the thermal, was imported to ADINA by .in-files. The content of the .in-files for the structural analysis resembles the content of the thermal analysis but includes some different and additional steps as shown in the list below. The .in-files used for the ADINA structrual analysis of one of the beam cases are found in Appendix D for phase one and Appendix E for phase two together with .in-files for the thermal and linearized buckling analyses.

1. Beam geometry
    I Cross section
    II Length
2. Material parameters
    I Young's modulus
    II Poisson's ratio
    III Yield stress
    IV Strain hardening constant
    V Mean coefficient of thermal expansion
    VI Maximum effective plastic strain
    VII Material and cross sectional properties for rectangular 3-D beam elements
        i. Dimensions (width and height)
        ii. Yield strength (Isotropic Linear Elastic material)
        iii. Poisson's ratio
        iv. Density
        v. Coefficient of thermal expansion
3. Mesh
    I Size of mesh
    II Number of integration points
4. Time step
    I Length of analysis
    II Number of time steps for the analysis
5. Mechanical load
6. Boundary conditions
7. Import of thermal mapping (results) from thermal analysis

5.2.4.1 Beam geometry - Structural model

To ensure proper incorporation of the results from the thermal analysis, the geometries had to be identical. Therefore, the geometry for the structural analysis was created identically to the thermal analysis, see Section 5.2.3.1.

5.2.4.2 Material parameters and element groups - Structural model

The temperature dependent as well as the non-temperature dependent material parameters for the structural analysis were added to the FE model based mainly on data from EN 1993-1-2. The elasticity modulus and yield stress, both temperature dependent parameters, were based on EN 1993-1-2 Section 3.2 (CEN, 2005) and can be seen in Figure 2.6 in Section 2.2.4 and in Figure 2.5 in Section 2.2.3. Poisson's ratio and the strain hardening modulus were considered as temperature independent while the mean coefficient of thermal expansion and maximum effective plastic strain varied with temperature according to Eurocode standards (CEN, 2005). Exact values are found in the appended samples of .in-files, see Appendices D and E.

The temperature dependent material properties were incorporated into the analysis by choosing a thermo-plastic material and adding values for every 100 °C in accordance to the values given in EN 1993-1-2 Section 3.2 (CEN, 2005). Values in between directly given input data were automatically interpolated in the FE model which follows the Eurocode standard.

The material parameters for the structural analysis also included the material parameters for the 3-D beam elements by the method described in Section 4.1.2. The three-dimensional beam elements' material parameters were set for a rectangular beam cross section where the cross section parameters were calculated based on the given width and height. The manually specified non-temperature dependent material parameters for the isotropic linear elastic material that was used for the beam elements were the yield strength, Poisson's ratio, the density and the coefficient of thermal expansion.

The material parameters for the 22 three-dimensional beam elements, were specified as well. The three-dimensional beam elements' material parameters were set for a rectangular beam cross section where the cross section parameters were calculated based on the chosen width and height, see Section 4.1.2 for more details. The manually specified non-temperature dependent material parameters were the yield strength, Poisson's ratio, the density and the coefficient of thermal expansion.

Two element groups, "threedsolid" and "beam", were also created in the Structural model. The "threedsolid" elements correspond to the solid steel beam and enabling stress and strain calculations and were assigned to the beam volumes described in Section 5.2.3.1 and shown in Figure 5.1. The "beam" elements were assigned to the 22 lines created for proper application of boundary conditions, see Section 5.2.4.6.

5.2.4.3 Mesh - Structural model

The mesh for the structural analysis was identical to the mesh of the thermal analysis, see Section 5.2.3.3.

5.2.4.4 Time step - Structural model

The time stepping for the structural analysis was imported identically to the time stepping in the thermal analysis, see Section 5.2.3.4.

5.2.4.5 Mechanical load - Structural model

The line load corresponding to the specific case, see Section 5.2.1, was added to the Structural model in the first time step. The total load was divided in two in order to apply half of the load along line 6 and the other half of the load along line 16. See Figure 5.3 for a visualization of the placement of these lines. For the Parametric study phase one, the load was applied in negative z-direction by orienting the load towards two reference point, number 11 and 13 in Figure 5.3. The magnitude of the loads for the different structural analyses in the different phases are presented with the results in Chapter 6.

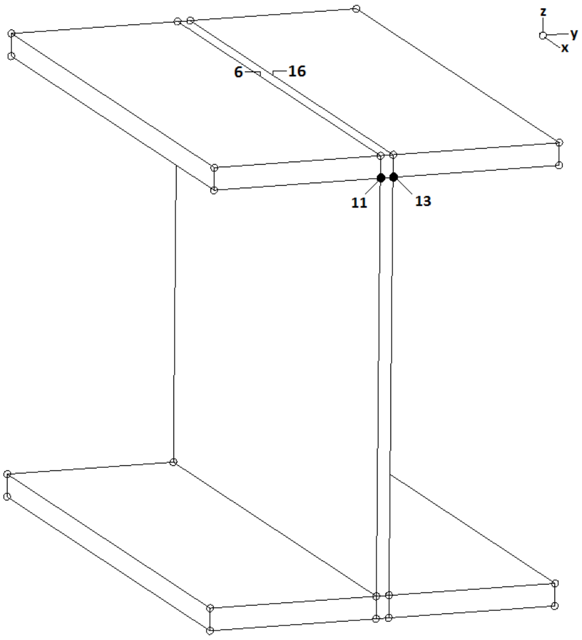


Figure 5.3: Load lines along which the mechanical load was applied in negative z-direction and the reference points 11 and 13.

5.2.4.6 Boundary conditions - Structural model

The boundary conditions relevant for a simply supported beam, in both phases, were applied to the Structural model by using beam elements on the edges of the beam according to the proposed method described in Section 4.1.2, a method originating from the article by Snijder et al. (2008). The actual fixity conditions are presented in the list below. See Figure 5.4 for location of points in the cross section.

1. Point 15 was fixed in x-,y- and z-translation (hinged support part 1).
2. Point 7 and 23 were fixed in z-direction (hinged support part 2).
3. Point 36 was fixed in y- and z-direction (roller support part 1).
4. Point 32 and 40 were fixed in z-direction (roller support part 2).

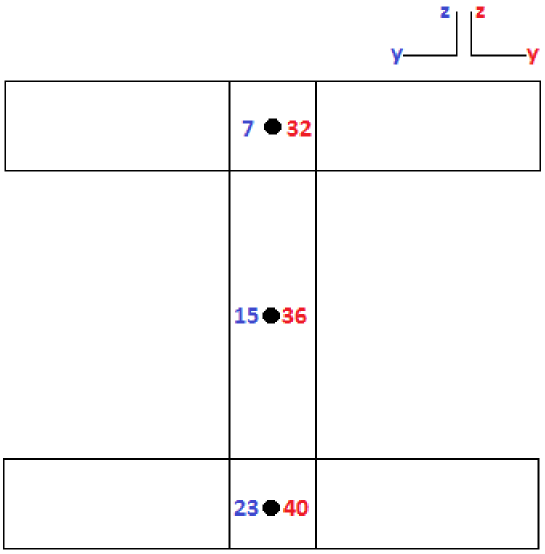


Figure 5.4: Fixation points for modelling of a simply supported beam with one hinged support and one roller support. Blue colored numbers and coordinate system views the beam from the front and red colored numbers and coordinate system views the beam, from the back.

In the Parametric study, two different phases for the beams were studied.

In the first phase lateral torsional buckling was excluded. The boundary conditions to exclude any lateral torsional buckling failure modes were applied by fixating two lines along the beam. The first line, centered along the beam on the top of the top flange, was fixed for translations in y-directions. The second line, centered along the beam on the bottom of the bottom flange, was also fixed for translations in y-direction. Figure 5.5 shows the location of the these lines.

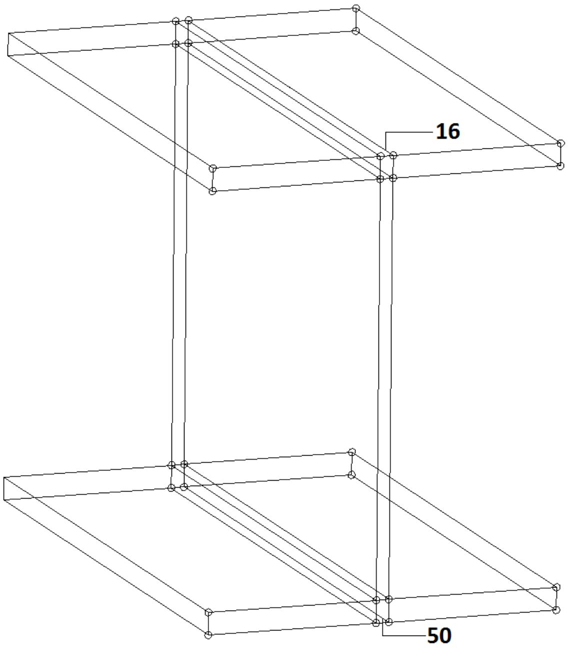


Figure 5.5: Location of lines fixed for translation in y-direction to prevent lateral torsional buckling.

In the second phase, lateral torsional buckling was included. Therefore, no lines were fixed in y-translation as opposed to the previous phase.

5.2.4.7 Import of temperature mapping from Thermal analysis

The temperature in all the nodes in the beam at all time steps were imported from the thermal analysis through the .map-file saved form the thermal analysis, see Section 5.2.3.6

5.2.5 Verification of Thermal and Structural models

In order to verify the FE model, several analyses were done. The analyses were performed on a HEA 100 beam in order to be able to have a fine mesh but still get reasonably short computational time for the FE analyses.

Firstly, the Thermal FE model was run in order to study how the temperature distribution varied over time. This was done in order to verify that the model with no radiation on the top of the beam resulted in a lower temperature in the top flange than the model with radiation on the top of the beam. Furthermore this study was done in order to make sure that the model meant to represent a uniform temperature distribution within the beam actually did so.

Secondly, an analysis of the critical mechanical load, without temperature load, for the beam was done on the FE model and compared with hand calculations. The critical load was compared for four different beam lengths, with the same cross sections, in order to make sure that the model was accurate for varying slendernesses ranging from thin to thick beams. A discrepancy between the FE model and hand calculations within a five percentage margin of error was considered acceptable.

Thirdly, an analysis of the elastic deflection for the beam was performed for the FE model and compared with hand calculations. The deflection was also verified for four different beam lengths, with the same cross section, in order to make sure that the model was accurate for different slendernesses. The hand calculations were made with the Timoshenko beam theory in order to take shear deformation and bending effects into account. Another alternative would have been to use FE models for small deflections but it was not considered suitable for a plastic analysis. As for the critical load, a discrepancy between the FE model and hand calculations within a five percentage margin of error was considered acceptable.

Fourthly, the beams chosen in the first phase were fully analyzed in the FE model in accordance with the method described in Sections 5.2.3 and 5.2.4 above. The beams were analyzed in order to see for which inner temperature the beam with uniform temperature would fail. This temperature was afterwards compared with hand calculations of the temperature at which the beam was fully utilized in the fire scenario. This was done in order to verify that the beam failed at approximately the same steel temperature within the beam.

Fifthly, the temperature difference between the air and the inner steel temperature in the FE model was evaluated. A verification was performed for one of the cases studied in the fourth step and was afterwards compared to hand calculations. The hand calculations calculated the required energy to heat the beam from 20 °C up to the air temperature in the last step. Furthermore, the heat flow from radiation and convection was calculated for each time step based on the temperature difference between the air temperature and the steel temperature, these temperatures were collected from the FE analysis. From the heat flow, the corresponding energy flow from both radiation and convection could be calculated for each time step. The amount of energy used in each time step was then summed up and compared to the required energy. Based on the difference between the calculated required energy and the actual energy use in the FE model, the temperature lag could be calculated and then compared to the time lag from the FE model results. This was done in order to verify that they were of, approximately, the same magnitude.

Lastly, a verification of the import and implementation of initial imperfections from the Linearized buckling model was done. This was done by checking that a larger initial imperfection yielded a lower capacity. Two additional magnitudes of initial imperfections for one of the beams were analyzed in the FE model in order to make sure that the model was accurate. The tested initial imperfections were L/300, which was used for the original study, as well as L/1000 and L/10000 in order to make sure that L/10000 showed highest capacity and L/300 showed the lowest capacity, but that the differences were not unreasonably high. The results from these additional analyses showed that the difference between using L/300 and L/1000 as initial imperfection was 10 °C, where L/1000 yielded the higher value. The difference between using L/1000 and L/10000 as initial imperfection was 5 °C, where L/10000 yielded the higher value. These results were seen as acceptable and the import and implementation was deemed accurate.

After these checks, the model was judged to give sufficiently correct results and to be valid for further analyses. The checks described above can be seen in more detail in Appendix H.

5.2.6 FE analysis for the Parametric study phase one

The beams chosen for phase one, described in Section 5.2.1 were first analyzed in the Thermal model described in Section 5.2.3. The results from the Thermal model were then mapped onto the Structural model described in Section 5.2.4 for the same beams.

5.2.7 Comparison between FE analyses and hand calculations for Parametric study phase one

The results from the structural analysis and the hand calculations as well as a comparison between the results can be seen in Section 6.2.

5.2.8 Choice of beams for the Parametric study phase two

The beam cross sections, lengths, design loads, temperature distribution within the beam and considered temperature loads in phase two of the Parametric study were chosen by evaluating the results from the first phase combined with an evaluation of interesting parameters to study further.

As previously mentioned, this phase took lateral torsional buckling and initial imperfections in consideration which were aspects not considered in phase one. Because of this, comparison between different thicknesses of webs and flanges was still deemed as interesting in the second phase. The same beam cross sections as in phase one were thus chosen.

In phase one, it could be seen that having radiation on top of the top flange versus not having radiation on top of the top flange caused no significant difference, see Section 6.2. Therefore only one of these cases was studied further in this phase. Furthermore, a uniform temperature within the beam is a scenario that lacks base in reality, and therefore uniform temperature within the beam was not studied further either.

It could also be seen in the results from phase one, see Section 6.2, that loads depending on a utilization ratio from the ultimate limit state versus a utilization ratio from the fire scenario, gave temperature differences relative to each other. Therefore, loads were only based on utilization ratio from ultimate limit state in the second phase.

One variable that was introduced for the first time in the second phase was a variation of the slenderness. It was considered interesting to see whether the slenderness made any difference in the results when lateral torsional buckling was included since the risk of lateral torsional buckling is strongly related to the slenderness. Three different slendernesses were analyzed. A summary of the different analyses in the Parametric study phase two is shown in Table 5.2.

Table 5.2: A table showing the the different beams analyzed in the Parametric study phase two, lengths vary according to the different slendernesses.

S355 ULS η=0.7	Hand calcs with reduction factor	Hand calcs with reduction factor	Hand calcs with reduction factor	Non-uniform Temperature distrib w/o top rad	Non-uniform Temperature distrib w/o top rad	Non-uniform Temperature distrib. w/o top rad
$\lambda =$	0.5	1	2	0.5	1	2
HEA400 L (m)	No -	Yes 13	No -	No -	Yes 13	No -
HEB400 L (m)	Yes 6.5	Yes 13	Yes 26	Yes 6.5	Yes 13	Yes 26
HEM400 L (m)	No -	Yes 14	No -	No -	Yes 14	No -

5.2.9 Hand calculations for the Parametric study phase two

The hand calculations for the Parametric study phase two were done in approximately the same manner as for phase one, described in Section 5.2.2. First the beam capacities were calculated, considering lateral torsional buckling, without reduction for the fire scenario. Since the lateral torsional buckling capacity was the most critical, it was used in the following calculations. In analytical expressions for lateral torsional buckling in Eurocode, initial imperfections are taken into account. Therefore no further consideration of initial imperfections were needed in the hand calculations.

In the hand calculations for phase two, the calculation method based on reduction factors was used. The process of the calculation is shown in Figure 3.6. In the calculation, reduction factors for the fire scenario, specified in EN 1993-1-2 Chapter 3 and 4 (CEN, 2005), were used in order to reduce the ultimate capacity and to see for which temperature the beam was fully utilized in the fire scenario. This calculation was done as an iteration process where the temperature was increased until full utilization was reached. This resulted in a critical temperature for each case. Hand calculations for one of the studied beam cases can be found in Appendix C and the result can be seen in Section 6.3.

5.2.10 FE linearized buckling model

A structural model appropriate for the linearized buckling section of ADINA Structures was created. The model had identical geometry, meshing and boundary conditions to the Structural model from Section 4.1.2. The material parameters were also identical to the previous Structural model with the exception of them being non-temperature dependent. Since the linearized buckling analysis did not consider the change in temperature, the time step for increase of temperature from the Structural model described in Section 4.1.2 was not included.

Furthermore, the magnitude of the load included in the linearized buckling analysis was adjusted to be within a range where ADINA could handle the scaling of the mechanical load to iterate the correct buckling load without too many iterations. In practice this meant that the applied mechanical load in the buckling analysis was lower than the mechanical load applied in the structural analysis described in Section 4.1.2.

In order for the results of the linearized buckling analysis to be used as input for the mode shape in the structural model, the number of buckling load/modes needed to be specified as a number larger than the number of used mode shapes. Since the Structural model was supposed to use mode number one, only two modes needed to be extracted and was therefore specified. The .in-files for the ADINA linearized buckling analysis of one of the studied beam cases are found in Appendix E together with the .in-files for the thermal and the structural analyses for the same beam case.

5.2.11 FE analysis for the Parametric study phase two

The chosen beams for phase two, described in Section 5.2.8, were, as for phase one, first analyzed in the Thermal model described in Section 5.2.3. The beams were also analyzed in the Linearized buckling model in order to retrieve the shape of the first buckling mode. The results from the Thermal model as well as from the linearized buckling analysis, see section 5.2.10, were then mapped onto the Structural model, described in Section 5.2.4, for the same beam.

The initial imperfections were assigned in the Structural model by mapping the result of the linearized buckling analysis, described in Section 5.2.10, onto the Structural model. Based on the mapped results, the initial conditions could be specified to follow the shape of buckling mode number one, but where the deflection of each node in the beam was scaled based on the manually specified magnitude of the deflection of one of the nodes. The deflections of the lateral torsional buckling mode was in the used model scaled based on the most deflected point, i.e. the mid point. The mid point was specified to have an initial imperfection as advocated by EN 1993-1-1 (CEN, 2008) and the other points followed according to the shape of the first buckling mode. The deflection of the mid-point was based on the value given in Table 5.1 in Section 5.3.2 in EN 1993-1-1.

5.2.12 Comparison between FE analyses and hand calculations for Parametric study phase two

The results from the structural analysis and the hand calculations as well as a comparison between the results can be seen in Section 6.3.

5.3 Main study

The second part of the study consisted in a Main study based on the findings from the Parametric study. In the Main study a normal force was included in the mechanical loads. The Main study aimed to study the influence of a normal force combined with a distributed line load on a simply supported beam. The beams studied in the Main study all included initial imperfections and lateral torsional buckling as a failure mode. Three main parameters were varied in order to study the influence of these same parameters. The parameters varied were the magnitude of the normal force, the magnitude of the distributed line load as well as the slenderness of the beam. The Main study consisted of seven steps which are listed below. Hand calculations for one of the studied beam cases in step two can be found in Appendix F and .in-files to ADINA used in step six for one of the studied beam cases can be found in Appendix G.

1. Based on the results from the Parametric study, the beams and corresponding load cases to evaluate in the Main study were chosen.
2. Hand calculations according to Eurocode for fire design with lateral torsional buckling as a failure mode were made for the beams from step one.
3. The Linearized buckling model was created.
4. The Thermal model was created.
5. The Structural model was created.
6. The beams from step five were analyzed in the Linearized buckling model from step three and the Thermal model from step four followed by the Structural model from step five including the buckling mapping from the linerarized buckling analysis as well as the temperature mapping from step four.
7. The results from steps two and six were compared and evaluated.

5.3.1 Choice of beams for the Main study

The beams chosen for the Main study were three out of five beams used in the Parametric study phase two. Since the difference between the different types of beams HEA, HEB and HEM was considered satisfactorily studied in the Parametric study, the beam type variable was excluded from the Main study. Throughout the Main study the beam type HEB400 was therefore used. However, since the Main study consisted of adding an axial force to the load case scenario, the slenderness was considered of great interest and was thus decided to be a variable also in the Main study. The same slendernesses as in the Parametric study, i.e. λ equal to 0.5, 1 and 2, were chosen.

To investigate the influence of the axial force, three different load scenarios were chosen. For a fire time equal to five minutes, corresponding to a durable temperature of 576 °C on the ISO 834 standard fire curve, different utilization ratios from the combined bending moment and normal force interaction check from EN 1993-1-2 were considered.

The factors in the interaction check, described in Equation 3.32 in Section 3.2.2.1, relevant to this case has one factor a depending solely on the normal force and one factor b depending on both the bending moment and the normal force, see Figure 5.6. The second of the two checks of Equations 3.31 and 3.32 was chosen because the second check was shown to be the most critical for this specific case.

$$\overset{a}{\frac{N_{fi,Ed}}{\chi_{z,fi}Ak_{y,\theta}\frac{f_y}{\gamma_{M,fi}}}} + \overset{b}{\frac{k_{LT}M_{y,fi,Ed}}{\chi_{LT,fi}W_{pl,y}k_{y,\theta}\frac{f_y}{\gamma_{M,fi}}}} + \overset{c=0}{\frac{k_zM_{z,fi,Ed}}{W_{pl,z}k_{y,\theta}\frac{f_y}{\gamma_{M,fi}}}} \leq 1$$

Figure 5.6: Figure of Equation 3.32 from Section 3.2.2.1 showing how the different contributions in the interaction check are referred to.

The chosen load cases correspond to a distributed load and an axial force that gives a utilization ratio of factor a and factor b as shown in Table 5.3 below. Since the studied beams are not loaded laterally, factor c will be zero. The loads are presented on the form x/y/z corresponding to a slenderness, λ, of 0.5/1/2 respectively.

Table 5.3: A table showing the contribution from each of the factors in the most critical interaction check as well as the distributed line load and normal force that corresponds to them for a HEB 400 beam with varying slenderness.

S355 HEB400	Contribution from factor a	Contribution from factor b	Q_{fi} (kN/m)	N_d (kN)
$\lambda =$	0.5/1/2	0.5/1/2	0.5/1/2	0.5/1/2
Load case 1	0.8	0.2	38.25/5.850/0.929	252.1/82.30/22.80
Load case 2	0.6	0.4	27.30/4.350/0.779	504.1/164.5/46.50
Load case 3	0.5	0.5	21.60/3.540/0.690	630.0/205.6/57.00
Load case 3	0.4	0.6	16.05/2.700/0.585	756.2/247.0/68.20

5.3.2 Hand calculations for the Main study

Hand calculations for fire design of a beam with lateral torsional buckling as a failure mode and with an added normal force were made for the beams chosen in Section 5.3.1. The hand calculations for the Main Study were done in the same manner as for the Parametric study phase two with the addition of a normal force and interaction checks described by Equation 3.31 and 3.32. The beam capacities in the ultimate limit state, considering lateral torsional buckling, were calculated according to EN 1991-1-1 (CEN, 2008) with additions from Al-Emrani et al. (2011) and Hauksson and Vilhjalmsson (2014).

With the intention of deciding the capacities of the beams in the fire scenario, calculations based on reduction factors were used in order to reduce the previously calculated capacity in ultimate limit state and see for which temperature the beam was fully utilized in the fire scenario. The process of the calculations is shown in Figure 3.6. The process of the hand calculations in the Main study was nearly identical to the hand calculations of Parametric study phase two but since a normal force was added in the Main study, interaction checks for bending and normal force had to be made as well in order to make sure that the beam could handle the combination of the loads. The calculations to find the temperature at which full utilization was reached was done as an iteration process where the temperature was increased in steps. It could be seen that the interaction checks were the critical checks. From the iteration process it could be seen for which temperature the interaction check reached full utilization and this temperature was seen as the critical temperature. Since the load cases were chosen based on the utilization ratio corresponding to 100 % after five minutes, all the load cases had the same failure temperature in the hand calculations. An example of these calculations can be found in Appendix F and the result can be seen in Section 6.4.

5.3.3 Linearized buckling model

A Linearized buckling model similar to the one used in the Parametric study phase two, described in Section 5.2.10, was created. The only difference between the buckling analysis from the Parametric study and the Main study, was that the Main study only modelled half of the beam in the FE analyses. This was done primarily to shorten the calculation time as well as to avoid stress concentrations in the node fixating the beam in the axial direction. Due to the applied normal force, the same type of boundary conditions as for the Parametric study, that did not have axial loading, could not be used in the Main study. Instead, a symmetry line was used at the mid length of the beam by fixating the surfaces for displacements in the axial direction. On the other side of the beam, the edge of the beam, the same boundary conditions as in the Parametric study was used. The surfaces that were locked in axial direction for implementation of the new boundary conditions are shown in Figure 5.7.

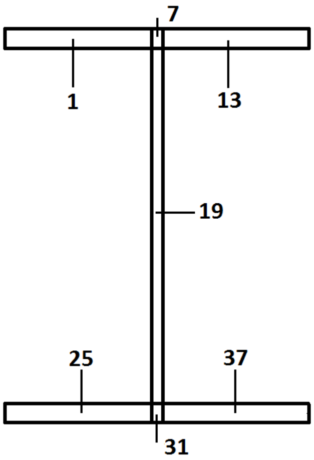


Figure 5.7: Surfaces that are fixed in x-direction (axial direction) to create the appropriate boundary conditions for the symmetry line of the beam used in the Main study.

The normal force was neglected in the linearized buckling model for the Main study. To have two different loads that the linearized buckling analysis should scale could be a problem and therefore the normal force was neglected in the linearized buckling analysis. Even though the normal force may have had a small influence on the buckling mode shape, this influence was considered negligible. The shape of the buckling mode from one beam in the Main study could not be reused for several load cases since ADINA overwrites the file in the subsequent structural analysis and the linearized buckling analysis was therefore remade for each load case. The same method as described in Section 5.2.10 was used for the linearized buckling analysis in the Main study but with new boundary conditions and new geometry describing only half of the beam. The .in-files for the linearized buckling analysis of one of the studied beam cases in the Main study can be found together with the .in-files for the thermal and structural analyses in Appendix G.

5.3.4 Thermal model

A Thermal model, similar to the one used in the Parametric study in Section 5.2.3, was created. In the same manner as the Linearized buckling model, the Thermal model for the Main study also modelled half of the beam. The applied thermal loads remained the same as in the Parametric study except for one end side of the model, the side representing the symmetry line of the beam, which had no thermal loads applied.

Unlike the linearized buckling analysis, the thermal analysis in the Main study was only necessary to be performed three times instead of one time for each load case. This could be done since the only difference between the different cases with the same slenderness was the mechanical load, which is not included in the thermal analysis. Since the thermal mapping is not overwritten when included in a structural analysis, the same thermal mapping for each beam with the same length and slenderness, i.e geometry, in the Main study could be reused for all its different load cases shown in Table 5.3 in Section 5.3.1. The .in-files for the thermal analysis of one of the studied beam cases in the Main study can be found together with the .in-files for the linearized buckling and structural analyses in Appendix G.

5.3.5 Structural model

A structural model, based on the structural model for the Parametric study in Section 5.2.4, was created. In the same manner as the Linearized buckling model, the Structural model for the Main study also modelled half of the beam. All the specifications and methods from the structural model in the Parametric study phase two applies except for the changed boundary conditions which are the same as described in Section 5.3.3. An axial normal force was also added to the model which was the only additional difference in terms of loads between the Main study and the Parametric study phase two that is described in Section 5.2.11. The normal force was applied as a surface pressure on one side, the non-symmetry side, of the beam. However, the magnitude of the distributed line load as well as the normal force was different and they are presented together with the results in Section 6.4. The .in-files for the structural analysis of one of the studied beam cases in the Main study can be found together with the .in-files for the thermal and linearized buckling analyses in Appendix G.

5.3.6 FE analysis for the Main study

The chosen beams from Section 5.3.1 were analyzed in the Linearized buckling model described in Section 5.3.3 and in the Thermal model described in Section 5.3.4. The results from the linearized buckling analysis as well as the temperature mapping were both included in the structural analysis that followed. Boundary conditions allowing lateral torsional buckling, thermal mapping as well initial imperfections scaled from the mode obtained in the linearized buckling analysis were thus all included. The initial imperfections were mapped in the same manner as for the Parametric study phase two which is described in more detail in Section 5.2.11.

5.3.7 Comparison between the FE analyses and hand calculations for Main study

The results from the structural analysis and the hand calculations as well as a comparison between the results can be seen in Section 6.4.

6

Results

6.1 Result from the Comparison study

The derivation proved that the two methods only coincide when a beam or structure is fully utilized in the ultimate limit state. For all other occasions, the method using Equations 3.37 and 3.38 gives a lower critical temperature than the method using Equation 3.36. For the full derivation, see Appendix A.

6.2 Results from the Parametric study phase one

The hand calculations in the Parametric study phase one were made for three different 12 meter long simply supported beams and for two different load cases, described in Section 5.2.1. The corresponding load for each beam in order to have the same utilization ratio, 80 % in the case based on utilization in the ultimate limit state and 70 % after six minutes in the case based on utilization in the fire scenario, is presented in Table 6.1 together with the results from the hand calculations.

Hand calculation results of the temperature that a specific beam can sustain, according to calculations done based on reduction factors, are presented in the column named "Durable temperature". The corresponding time, to that temperature, according to the ISO 834 curve is presented in the column named "Time". The results of the critical temperature based on utilization ratio after time t=0 in the fire scenario, described in Section 3.2.2.1, are presented in column "Critical temperature". The temperatures presented in the table refers to the maximum temperature in the air that the beam can sustain. However, the air temperature and the steel temperature are the same for the hand calculations.

Table 6.1: A table showing results from hand calculations of three different beam cross sections, all with length 12m and steel class S355.

S355	12 m	G_k (kN/m)	Q_k (kN/m)	Q_{ULS} (kN/m)	Q_{fi} (kN/m)	Durable temperature (°C)	Time (min)	Critical temperature (°C)
ULS, η=0.8	HEA400	14.0	13.2	38.7	20.6	619	6.67	610
ULS, η=0.8	HEB400	17.7	17.0	49.4	26.6	619	6.67	610
ULS, η=0.8	HEM400	30.5	30.0	86.2	45.5	620	6.73	611
Fi, η=0.7	HEA400	10.7	10.1	29.6	15.8	660	8.85	652
Fi, η=0.7	HEB400	13.5	13.0	37.7	20.0	661	8.87	652
Fi, η=0.7	HEM400	123.5	23.0	66.2	35.0	661	8.86	652

The ADINA analyses in the Parametric study phase one were made for the same cases as the hand calculations. The same temperatures and mechanical loads were applied. The results from the ADINA analyses are presented in Table 6.2. The temperatures in the table are the air temperature at which the beams failed in the ADINA analysis, the actual steel temperatures are lower. The results are presented for modified material properties for steel in order to get a beam with uniform temperature distribution within the beam as well as for proper material properties for the steel beam resulting in a non-uniform temperature distribution. The case for non-uniform temperature distribution was analyzed in two parts. One including radiation on top of the top flange and one excluding radiation in top of the top flange. Both parts are presented in Table 6.2.

Table 6.2: A table showing results from ADINA FE analyses of three different beam cross sections, all with length 12m and steel class S355.

S355	12 m	G_k (kN/m)	Q_k (kN/m)	Q_{ULS} (kN/m)	Q_{fi} (kN/m)	Uniform temperature Distribution (°C)	Non-uniform temperature Distribution w/ radiation on top (°C)	Non-uniform temperature Distribution w/o radiation on top (°C)
ULS, η=0.8	HEA400	14.0	13.2	38.7	20.6	732	737	742
ULS, η=0.8	HEB400	17.7	17.0	49.4	26.6	749	756	761
ULS, η=0.8	HEM400	30.5	30.0	86.2	45.5	787	781	789
Fi, η=0.7	HEA400	10.7	10.1	29.6	15.8	750	754	759
Fi, η=0.7	HEB400	13.5	13.0	37.7	20.0	766	773	778
Fi, η=0.7	HEM400	123.5	23.0	66.2	35.0	802	796	805

6.2.1 Comparison of results from the Parametric study phase one

Table 6.3 shows the difference between the different ADINA analyses and the durable temperature based on hand calculations according to EN 1993-1-2. It also shows the difference between the durable temperature and the critical temperature from the simplified calculations. As Table 6.3 shows, the critical temperature is always lower than the durable temperature. The temperature gains corresponding to the time gains on the ISO 834 curve as well as graphically presented temperatures are shown in Appendix I.

Table 6.3: A table showing the difference between Durable temperature by hand calculations and the Critical temperature by hand calculations as well as the ADINA analyses.

					Difference	Difference	Difference	Difference
S355	12 m	G_k (kN/m)	Q_k (kN/m)	Q_{fi} (kN/m)	Critical Temperature (°C)	Uniform temperature Distribution (°C)	Non-uniform temperature Distribution w/ radiation on top (°C)	Non-uniform temperature Distribution w/o radiation on top (°C)
ULS, η=0.8	HEA400	14.0	13.2	20.6	-9	113	118	123
ULS, η=0.8	HEB400	17.7	17.0	26.2	-8	130	137	142
ULS, η=0.8	HEM400	30.5	30.0	45.5	-9	167	161	169
Fi, η=0.7	HEA400	10.7	10.1	15.8	-9	90	94	99
Fi, η=0.7	HEB400	13.5	13.0	20.0	-9	105	112	117
Fi, η=0.7	HEM400	23.5	23.0	35.0	-9	142	136	145

Table 6.3 also shows that the ADINA analyses always result in higher critical capacity than the durable temperature calculations according to EN 1993-1-2. This difference is the largest for the HEM beams and the smallest for the HEA beams.

In Table 6.3, it can be seen that the difference between "no radiation on the top of the top flange" versus "radiation on the top flange" for all cases is small, around 5-10 °C. A similar, small difference is present between the cases of "radiation on top flange" versus the cases of uniform temperate distribution. It can also be seen in Table 6.3, that the different cases of non-uniform temperature distribution and the cases of uniform temperature distribution in the beam give similar results with the highest difference being 12 °C. For the HEA and HEB beams it can be seen that the difference between hand calculations and FE analysis is the largest for the non-uniform temperature distribution with radiation on top and the lowest for the uniform temperature distribution. For the HEM beams, the difference between hand calculations and FE analysis is the largest for the non-uniform temperature distribution with radiation on top but the lowest for the non-uniform temperature distribution with radiation on top.

A comparison between the case where the load is based on the utilization in the ultimate limit state versus the case where the load is based on the utilization in the fire scenario, see Table 6.3, shows that the differences are of the same magnitude for the different beams. The cases based on the ultimate limit state is all respectively around 20 °C higher than the cases based on the utilization in the fire scenario.

6.3 Results from the Parametric study phase two

The hand calculations in the Parametric study phase two were made for beams with different cross sections and slendernesses as described in Section 5.2.8. The corresponding loads for each beam in order to have the same utilization ratio in the ultimate limit state are presented in Table 6.4 together with the results from the hand calculations. The loads are presented on the form x/y/z corresponding to a slenderness, λ, of 0.5/1/2 respectively

The results from the hand calculations, i.e. the temperature that the beam can sustain according to calculations made based on reduction factors, are presented for the different slendernesses in the columns named "Durable temperature". The presented temperature is the critical air temperature which, for hand calculations, is the same as the steel temperature.

Table 6.4: A table showing results from hand calculations for HEA, HEB and HEM 400 beams with different slendernesses.

S355 ULS η=0.7	G_k (kN/m)	Q_k (kN/m)	Q_{fi} (kN/m)	Durable temperature (°C)	Durable temperature (°C)	Durable temperature (°C)
$\lambda =$	0.5/1/2	0.5/1/2	0.5/1/2	0.5	1	2
HEA400	-/3.600/-	-/3.600/-	-/5.400/-	-	560	-
HEB400	34.50/5.500/0.800	34.00/5.300/0.730	51.50/8.150/1.165	569	560	561
HEM400	-/11.00/-	-/10.70/-	-/16.35/-	-	564	-

The ADINA analyses in the parametric study were made for the same cases as the hand calculations. The same temperature and mechanical loads were applied. The results from the ADINA analyses with initial imperfections are presented in Table 6.5. The temperatures in the table represents the air temperature at which the beam in the ADINA analysis fails. The temperatures within the beams are lower than the presented temperatures.

Table 6.5: A table showing results from ADINA FE analyses with initial imperfections for HEA, HEB and HEM 400 beams with different slendernesses.

S355 ULS η=0.7	G_k (kN/m)	Q_k (kN/m)	Q_{fi} (kN/m)	ADINA temperature (°C)	ADINA temperature (°C)	ADINA temperature (°C)
$\lambda =$	0.5/1/2	0.5/1/2	0.5/1/2	0.5	1	2
HEA400	-/3.600/-	-/3.600/-	-/5.400/-	-	755	-
HEB400	34.50/5.500/0.800	34.00/5.300/0.730	51.5/8.15/1.165	761	775	786
HEM400	-/11.00/-	-/10.70/-	-/16.35/-	-	836	-

6.3.1 Comparison of results from the Parametric study phase two

Table 6.6 shows the difference between the different ADINA analyses in phase two, see Table 6.5, and the durable temperatures calculated by EN 1993-1-2 in phase two, see Table 6.4. The temperature gains corresponding to the time gains on the ISO 834 curve as well as graphically presented temperatures are shown in Appendix I.

Table 6.6 shows that the ADINA analyses give a higher critical temperature than the hand calculations according to EN 1993-1-2 for every studied case. The difference is higher than 190 °C for all the investigated cases. The difference depends on the slenderness and on the beam thickness and it can be seen in Table 6.6 that the difference increases with increased slenderness. It can also be seen in Table 6.6 that the HEM beam gives the highest difference and the HEA gives the lowest difference between the HEA, HEB and HEM beams.

Table 6.6: A table showing difference between the results from ADINA FE analyses with initial imperfections and hand calculations for HEA, HEB and HEM 400 beams with different slendernesses.

				Difference	Difference	Difference
S355 ULS η=0.7	G_k (kN/m)	Q_k (kN/m)	Q_{fi} (kN/m)	ADINA temperature (°C)	ADINA temperature (°C)	ADINA temperature (°C)
$\lambda =$	0.5/1/2	0.5/1/2	0.5/1/2	0.5	1	2
HEA400	-/3.600/-	-/3.600/-	-/5.400/-	-	195	-
HEB400	34.50/5.500/0.800	34.00/5.300/0.730	51.5/8.15/1.165	192	215	225
HEM400	-/11.00/-	-/10.70/-	-/16.35/-	-	272	-

6.4 Results from the Main study

The results from the, in the Main study, studied cases described in Section 5.3.1 are shown in Tables 6.7 and 6.8 below. A comparison between the results presented in these two table are summarized in Table 6.9 in Section 6.4.1. The results are presented according to the utilization ratio of normal force and bending moment as well as according to the beams' slendernesses. The applied distributed line load as well as the applied axial force for the different load cases with varying slenderness are also shown in all three tables. How these loads were chosen based on the utilization ratios is described in Section 5.3.1. The loads are presented on the form x/y/z corresponding to a slenderness, λ, of 0.5/1/2 respectively.

The results from the hand calculation part of the Main study are shown in Table 6.7. The studied load cases could all endure a temperature of 576 °C, equivalent to the five minute mark of the ISO 834 standard fire curve. The durable temperature refers to the air temperature calculated according to the method based on Eurocode standards described in Section 5.3.2. However, in the hand calculations the air temperature and the steel temperature are the same.

Table 6.7: A table showing results from hand calculations in the Main study for a HEB 400 beam with different slendernesses and load cases.

S355	η Bending Moment	η Normal Force	Q_{fi} (kN/m)	N_d (kN)	Durable temperature (°C)	Durable temperature (°C)	Durable temperature (°C)
$\lambda =$	0.5/1/2	0.5/1/2	0.5/1/2	0.5/1/2	0.5	1	2
HEB400	0.8	0.2	38.25/5.850/0.929	252.1/82.30/22.80	576	576	576
HEB400	0.6	0.4	27.30/4.350/0.779	504.1/164.5/46.50	576	576	576
HEB400	0.5	0.5	21.60/3.540/0.690	630.0/205.6/57.00	576	576	576
HEB400	0.4	0.6	16.05/2.700/0.585	756.2/247.0/68.20	576	576	576

In Table 6.8, the temperatures that the studied beams in the Main study could endure according to the FE analysis in ADINA are shown. The ADINA temperature refers to the air temperature at which the beams with different slendernesses and loads failed in the ADINA analysis. The actual temperature in the beam is thus different (lower). As the table shows, the failure temperatures varies with the different load cases and the different slendernesses.

For the different ratios of utilization ratio of normal force and bending moment, it can be seen for all cases except one that the capacity increases from slenderness 0.5 to 1 and then decreases again from slenderness 1 to 2. For the second load case, when the capacity also is the highest, the capacity increase from both slenderness 0.5 to 1 and form slenderness 1 to 2.

Table 6.8: A table showing results from ADINA analyses in the Main study for a HEB 400 beam with different slendernesses and load cases.

S355	η Bending Moment	η Normal Force	Q_{fi} (kN/m)	N$_d$ (kN)	ADINA temperature (°C)	ADINA temperature (°C)	ADINA temperature (°C)
$\lambda =$	0.5/1/2	0.5/1/2	0.5/1/2	0.5/1/2	0.5	1	2
HEB400	0.8	0.2	38.25/5.850/0.929	252.1/82.30/22.80	775	798	681
HEB400	0.6	0.4	27.30/4.350/0.779	504.1/164.5/46.50	785	791	793
HEB400	0.5	0.5	21.60/3.540/0.690	630.0/205.6/57.00	783	786	690
HEB400	0.4	0.6	16.05/2.700/0.585	756.2/247.0/68.20	781	782	686

6.4.1 Comparison of the results from the Main study

In Table 6.9 the difference between the temperature the studied beams could endure according to the FE analysis in ADINA and the temperature they could endure according to the hand calculations are shown. The temperature gains corresponding to the time gains on the ISO 834 curve as well as graphically presented temperatures are shown in Appendix I. As Table 6.3 shows, the differences range from 100 °C up to over 200 °C. The results show that the difference is around 200 °C for beams with slendernesses 0.5 and 1 and around 100 °C for all beams with slenderness 2 except for one. The results also show that for slendernesses 0.5 and 2, the capacity increases when the utilization ratio of the normal force increases, and the utilization ratio of the bending moment decreases, up until just before the two utilization ratios are equal, after which the capacity begins to decrease again. For beams with slenderness 1, the capacity decreases with increasing utilization ratio of normal force without exception.

For the different ratios of utilization ratio of normal force and bending moment, it can be seen for all cases except one that the difference between hand calculations and the FE analysis is the highest for slenderness 1 and lowest for slenderness 2, where the difference for slenderness 2 is almost half the difference for slendernesses 1 and 0.5. For the second load case, when the capacity is also the highest, the difference is the largest for slenderness 2 and the lowest for slenderness 0.5. It can be seen for all cases that the difference between slenderness 0.5 and 1 is small, where the difference decreases with increased normal force.

Table 6.9: A table showing difference between the results from the hand calculations and the ADINA analyses in the Main study for a HEB 400 beam with different slendernesses and load cases.

S355	η Bending Moment	η Normal Force	Q_{fi} (kN/m)	N$_d$ (kN)	Difference ADINA temperature (°C)	Difference ADINA temperature (°C)	Difference ADINA temperature (°C)
$\lambda =$	0.5/1/2	0.5/1/2	0.5/1/2	0.5/1/2	0.5	1	2
HEB400	0.8	0.2	38.25/5.850/0.929	252.1/82.30/22.80	199	222	105
HEB400	0.6	0.4	27.30/4.350/0.779	504.1/164.5/46.50	209	215	217
HEB400	0.5	0.5	21.6/03.540/0.690	630.0/205.6/57.00	207	210	114
HEB400	0.4	0.6	16.05/2.700/0.585	756.2/247.0/68.20	205	206	110

7

Discussion

7.1 General discussion

Since any previous research comparable to this study was not found, a validation by direct comparison between the results in this study and previous research was not possible. A lot of previous research has been focused on the comparison between FE modelling and real experiments which does not offer any direct comparison opportunities. Therefore, the extensive validation process of the FE model in this study, see Section 5.2.5, is of even greater importance. Furthermore, the validation process mention in Section 5.2.5 was only a part of the whole validation of the study itself. Throughout the study, continuous validations and checks for reasonable results have been conducted as well. The results of this study are therefore judged to be trustworthy. Moreover, further research on the topic is encouraged and the results from this study may then be used as comparison.

When relating this study to sustainability, there are a few aspects that can be mentioned. The implications for the ecological sustainability is favorable since savings of material resources equals savings of the earth's natural resources. These potential savings also implicates the benefits from an economical point of view since less money may be spent on materials. Regarding the social and ethical aspects, the implications are not as straightforward. It could be claimed that exclusion of additional fire protection material is to put peoples lives at risk to a higher extent, but this is not true. Using more detailed design methods for fire resistance probably leads to less use of fire protection material, but this does not mean that more detailed evaluation methods put peoples lives at risk. It is instead the uncertainties with simplified methods that leads to the need of more fire protection materials, to prove that they are safe, but both simplified and advanced methods fulfills the requirements for fire safety when used correctly.

7.2 Discussion of the results from the Parametric study phase one

The results from the Parametric study phase one yielded many results that are worth discussing.

Firstly, the results related to the variation of beam type were very reasonable. As expected, the HEM beams were the beams that, in the FE analyses, could endure the highest temperatures and thus yielded the largest gains in terms of temperature when performing a FE analysis as opposed to hand calculations. This was an expected result since the HEM beams also has the most mass to heat up. The temperature lag between the air temperature and the beam temperature is larger for the HEM beams than for the HEA and the HEB beams due to this extra mass. While the HEA 400 beams weigh about 120 kg/meter, the HEB 400 beams weigh 30 kg/meter more and the HEM 400 beams weigh 130 kg/meter more than the HEA beams.

The second aspect of the results is the difference between the different temperature distributions in the beams in the FE analyses. For the specific cases in the Parametric study phase one, the failure air temperature varied very little between the uniform temperature distribution cases, the cases with top radiation and the cases without top radiation. The uniform temperature distribution cases failed at the lowest temperature but the difference was small, only 5 °C, between the non-uniform temperature cases' failure temperatures. The non-top radiation cases could endure the highest temperatures, approximately 5 °C more than the cases with top radiation and 10 °C more than the cases with uniform temperature distribution. This result is in contrast to Selamet (2017), where it is concluded that thermal gradients significantly affect the structural response of perimeter columns. The results in this study are, however, for a simply supported beams where restraint stresses are not included whereas Selamet (2017) studies perimeter columns that have other boundary conditions and thus other restraint stresses. If other boundary conditions would have been applied in this study, the results of the difference between including or not including radiation on top of the beam might have given more a significant temperature difference.

The fact that all three temperature distribution variations of the FE analyses cases yielded around a 100 °C temperature gain confirms, at least for these specific cases, the hypothesis that the hand calculation methods provided by Eurocode are excessively conservative. Theoretically, the results from the different FE analyses methods are so similar that it almost does not matter which method to analyze. However, the similarity between the cases provides us with some other indications as well. The conservative approach of assuming an instant uniform (and thus higher average temperature) in the beam makes the failure temperature decrease approximately as much as the added bending moment load resulting from the temperature gradient in the beams with non-uniform temperature distribution. The two different load effects are thus almost of the same magnitude in the FE analyses.

Furthermore, the previous reasoning is even more relevant when looking at the difference between the top radiation and the non-top radiation cases. The added heat from the top radiation causes a decrease in capacity almost of the same magnitude as the added temperature gradient in the beam caused by the lack of top radiation in the non-top radiation cases and the result is an almost insignificant difference of 5 °C.

However, it is worth mentioning that while this is an interesting observation, the temperature gradients in the cases studied were not as high as they could be in reality. If, for example, a cool concrete floor was placed on top of the beam, the temperature gradient would be larger and the correlation between loss of capacity due to average temperature and temperature gradient is not necessarily linear. The presence of larger temperature gradients is therefore something worth studying further in order to model fire scenarios safely.

The third point worth mentioning is the actual validity of the hand calculation and FE analysis comparison and whether it is even fair to compare them in the presented way. In phase one of the Parametric study the hand calculations results assuming uniform temperature in the beam, were compared with results from both non-uniform and uniform temperature distribution in the FE models. It is not inaccurate to say that the different assumptions regarding the temperature distribution makes the comparison slightly misleading. However, the point of doing a FE analysis is, almost always, to have a better model to describe the reality. Hand calculations are somewhat more limited when doing this whereas when performing a FE analysis the aim is to make as many accurate decisions in the modelling of the structural behaviour that are justifiable while keeping the time of the analysis short. Since both these methods are in fact permitted by Eurocode standards to design the very same type of structure, the comparison between hand calculations with uniform temperature distribution and FE analyses with non-uniform temperature distribution, which is the only comparison made in Parametric study phase two as well as in the Main study, actually is not unjust.

Furthermore, the reason for doing the three versions of the FE analyses in phase one of the Parametric study was also to investigate the impact of the assumed temperature distributions. The results showed, as mentioned previously, that the difference was rather small, but it also confirmed the conservativeness of the hand calculation method when assuming a uniform temperature. It may also indicate that this conservativeness when calculating with a uniform temperature is needed in the hand calculations since the added moment from the temperature gradient is not accounted for in any other way when calculating by hand.

Another aspect regarding the conservativeness is the conservativeness of the FE analysis itself. While the FE analyses are less conservative, and hopefully more accurate, than the hand calculations they too have certain safety factors incorporated into the analyses. Since the material parameters and their temperature dependency are all according to Eurocode standards, all safety and partial factors that are included in these descriptions of material behaviour are also included in the FE analyses. The FE analyses can thus also be said to be on the safe side, provided the structural member is modelled accurately.

Fourthly, one reason for actually doing a FE analysis instead of hand calculations is to potentially save resources in the design and construction process. When it comes down to the specific examples provided in the Parametric study phase one, these savings seem to be rather significant, with a failure air temperature gain ranging from roughly 100 up to 169 °C. The temperatures from the results corresponds to between 7 and 14 minutes extra on the ISO 834 curve. More specifically, for the cases in the Parametric study phase one based on utilization ratio of 80 % in the ultimate limit state, this study shows that a structure can be shown to endure between 14 and 21 minutes with FE analysis instead of just 7 minutes with hand calculations. Thus, if the fire requirement is, e.g., R15, these extra minutes could make a big difference. For illustration of the maximum and minimum gains of the cases studied in the Parametric study phase one in accordance with the ISO 834 curve, see Figure 7.1. For a zoom in on the relevant parts of Figure 7.1, see Figure 7.2.

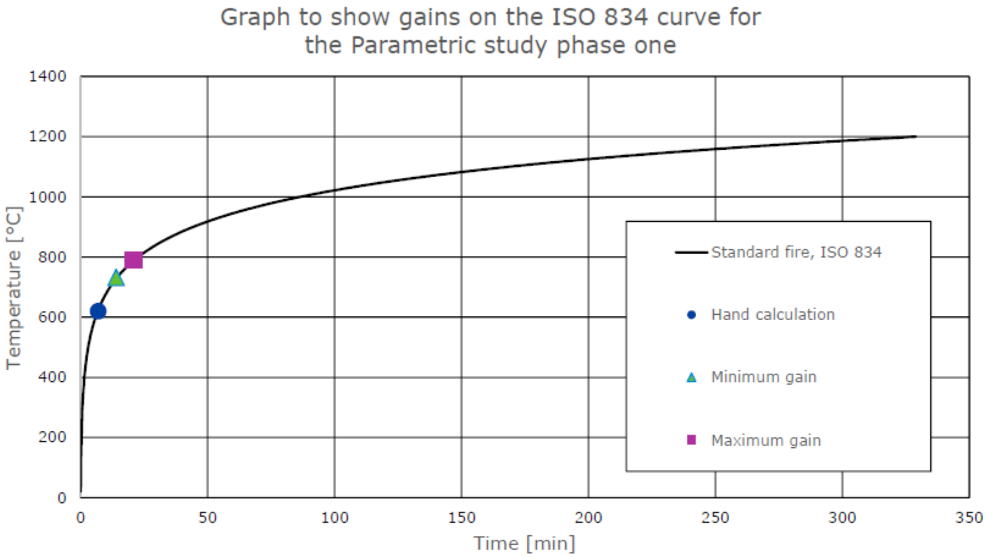


Figure 7.1: Temperature and corresponding time on the ISO 834 curve for the hand calculation and FE analyses for the cases with the smallest and largest gains in the Parametric study phase one.

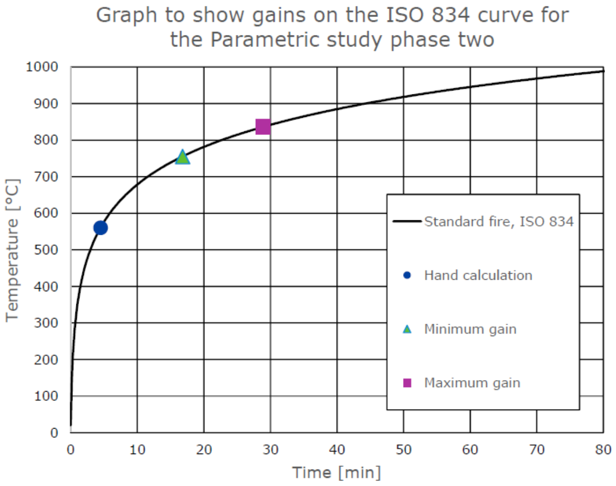


Figure 7.2: Zoom in of Figure 7.1.

Nonetheless, it is important to note that this is only proven for these specific cases, for beams assumed to be braced laterally and thus not subjected to lateral torsional buckling in the fire scenario. Observe however, while the assumption that the structure is braced from lateral torsional buckling may be true in the ultimate limit state, this may not be the case in the fire scenario if the structural component bracing the structure in question collapses.

Lastly, the comparison between the different hand calculations also gave some valuable results. The critical temperature was for all cases lower than the durable temperate but the difference was very small and only amounted to a few degrees Celsius. Thus, if the structure in question without doubt will need fire protection and only hand calculations are to be made, the time savings of using the critical temperature method instead of the durable temperature calculations may be justifiable.

Should one decide to go forward with a FE analysis, it is also important to note that the savings that can be made are not general throughout the standard fire curve. Due to the different slopes of the ISO 834 curve, this is clearly visibly in Figure 7.1, the time and temperature relation in savings are different depending on how much the fire has advanced. In the early stages, large temperature gains only save small amounts of time but further along the curve, large temperatures give large time spans, see Figure 7.3. But as the Parametric study phase one proves, even in the early stages the savings could be significant.

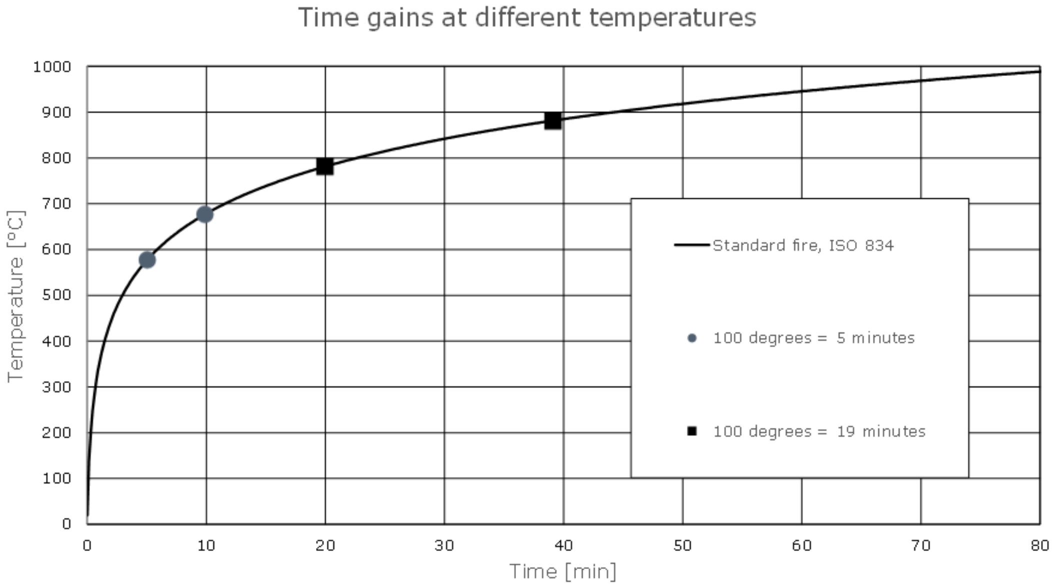


Figure 7.3: Showing how much time is gained for a temperature saving of 200 degrees at different stages on the Standard fire curve.

7.3 Discussion of the results from the Parametric study phase two

The results from the Parametric study phase two was mostly as expected with some exceptions. As in the Parametric study phase one, the critical temperatures varied with the beam studied. The critical temperatures according to the FE analyses were the highest for the HEM beams and the lowest for the HEA beams. The thickness of the web and the flanges of the beams varies between the HEA, HEB and HEM beams where the HEA beams have the smallest thickness for both flanges and webs and the HEM beams have the thickest flanges and webs. The difference between the flange thicknesses is small, less than one centimeter, but the difference between the web thicknesses is larger. The HEM 400 beam have a twice as thick web compared to the HEA 400 beam. Since steel takes time to heat up, a change in thickness will influence the inner temperature of the beam. These differences in geometry are most likely the reasons for the differences in critical temperatures and since the geometries were known beforehand, these differences were expected.

The results showed that the critical temperature varied reasonably with the slenderness, where the critical temperature increased with increasing slenderness. The slenderness highly affects the normal force capacity and slenderness around 1 yields the maximum capacity reduction for a beam or a column due to initial imperfections and residual stresses which is also taken into account in the hand calculations by the use of reduction factors. When calculating the bending capacity of the beam, the slenderness will not contribute to as much conservative reduction factors. Since the beams in the Parametric study phase two is subjected to pure bending, this can be seen as one explanation to why the difference between numerical and analytical analyses does not show the biggest difference for a slenderness around 1 but rather increases with increased slenderness. However, the difference is rather small. Comparison between a beam with slenderness 0.5 utilized at 70 % and a beam with slenderness 1 utilized the same, shows that the difference is only 23 °C. Comparison of a beam with slenderness 1 with a beam with slenderness 2 shows a difference of 10 °C instead. 23 °C may seem much but in relation to 775 °C, which is the critical temperature for a HEB 400 beam with slenderness 1 and utilization ratio in ultimate limit state of 70 %, it is not. It is reasonable to say that for a simply supported beam in pure bending, including lateral torsional buckling, the slenderness do influence the magnitude of the temperature gains from doing a FE analysis compared to hand calculations, but the differences are small.

Yet another thing worth noting is that the hand calculations show smaller difference between beam type and slenderness than the FE analyses do. This may also be a result of the very simplified way of calculating the capacity that is offered in Eurocode. For the different beams in the Parametric study phase two, the hand calculations vary no more than 9 °C while the results from the FE analyses for the same beams vary up to 81 °C.

Even though the beams in the Parametric study phase one have a utilization ratio in the ultimate limit state of 80 % and the beams in the Parametric study phase two have an utilization ratio in the ultimate limit state of 70 %, it can be seen that the gains of doing FE analyses for beams including lateral torsional buckling is larger than for beams excluding lateral torsional buckling. This is could be a consequence of the uncertainty and conservativeness of the method to calculate the capacities for lateral torsional buckling according to EN 1993-1-1. When not including lateral torsional buckling, a less conservative capacity of the beam can be calculated by hand than if lateral torsional buckling is included.

The results from the Parametric study part two all showed a difference between FE analysis and hand calculations of approximately 200 °C, except for the HEM beam which resulted in a difference of approximately 270 °C. This indicates that if a beam which is 80 % utilized in ultimate limit state were designed for fire by using a FE model instead of hand calculations, a gain of approximately 200 °C could be expected. This temperature gain correspond to an addition of 15 minutes according to the ISO 834 curve. This means that the beam can handle a temperature corresponding to around 5 min on the ISO 834 curve according to hand calculations while it can handle a temperature corresponding to around 19 min on the ISO 843 curve according to a FE analysis. This gain may influence the design of the beam and indicates that it is wise to do a FE analysis for this type of beam. For illustration of the maximum and minimum gains of the cases studied in the Parametric study phase two in accordance with the ISO 834 curve, see Figure 7.4. For a zoom in on the relevant parts of Figure 7.4, see Figure 7.5.

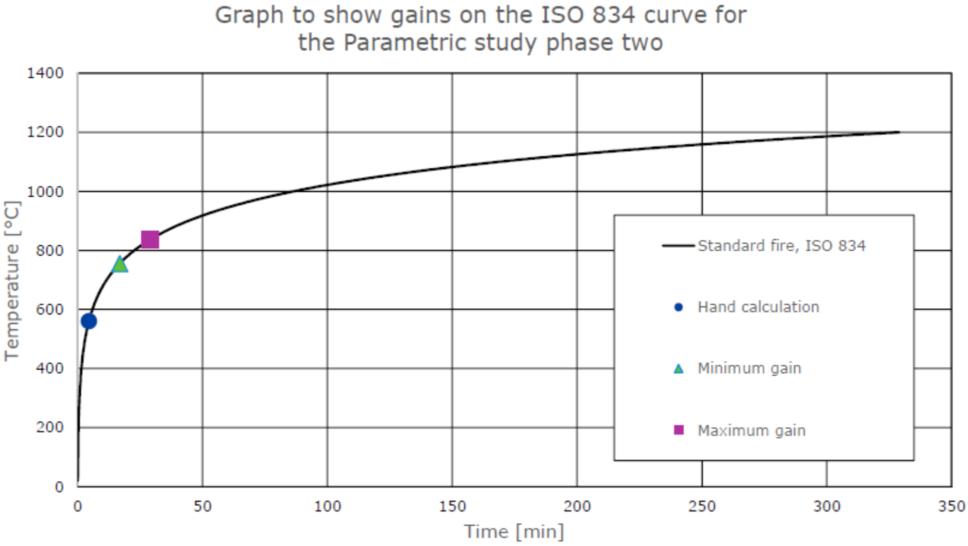


Figure 7.4: The temperature and corresponding time on the ISO 834 curve for the hand calculation and FE analyses for the cases with the smallest and largest gains in the Parametric study phase two.

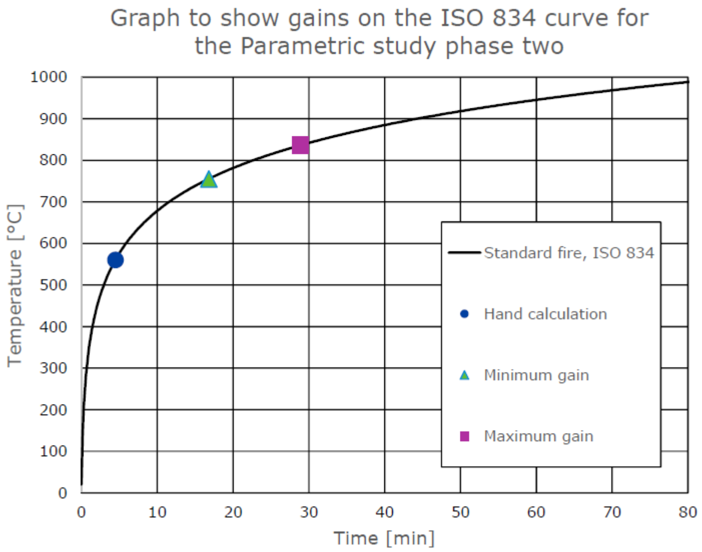


Figure 7.5: Zoom in of Figure 7.4.

7.4 Discussion of the results from the Main study

The results from the Main study was partly as expected, but also yielded some unexpected outcomes. By analyzing the results from the Main study, one temperature could be identified as a rather conspicuous value. The value seems to not follow the noted pattern of the other results from the Main study. The value that was identified as conspicuous is the result for the beam with slenderness 2 and load combination 2 (moment utilization of 0.6 and normal force utilization of 0.4). If compared with the other load combinations for the same slenderness it can be seen that this value is approximately 100 °C higher than all of the other load combinations' values. The FE model for this particular beam, with this particular load combination, was run two times in order to verify that nothing went wrong in the first run. The load values were also slightly changed, on the decimal level, in order to see whether it made any difference, but it did not. The source of this conspicuous temperature is unknown and will be disregarded in further discussion. However, the value must still be noted and if further studies are made, it could be wise to keep it in mind if the source can be identified.

As for the Parametric study phase two, the results from the Main study varies with the slenderness. An interesting observation when comparing the results from the Main study and the Parametric study phase two, is that the differences between the different slendernesses for the beams shows a different pattern. In the Main study it can be seen that the highest capacity in the FE analyses is for the beams with slenderness 1, closely followed by beams with slenderness 0.5. The lowest capacity in the FE analyses is seen to be for beams with slenderness 2, where the difference is approximately 100 °C. As mentioned in Section 7.3, the slenderness highly affect the normal force capacity and normal force is included in the Main study. In hand calculations, intermediate slendernesses are seen to be the most affected by initial imperfections and residual stresses, so the results for the hand calculations are known to be conservative due to the big uncertainties for intermediate slendernesses. This reasoning makes the results of the Main study reasonable. Intermediate slendernesses are slendernesses around 1 and that is most likely the reason why the gains of doing a FE analysis compared to hand calculations is the largest for beams with slenderness 1.

Slenderness 0.5 is also seen as an intermediate slenderness but is not as affected by initial imperfections and residual stresses as beams with slenderness 1. That is most likely why the results for beams with slenderness 0.5 are close to the result for the beam with slenderness 1 for each load case respectively. Beams with slenderness 2 on the other hand, are seen as very slender and the uncertainties are reduced remarkably. That is probably why the difference between the FE analyses and the hand calculations are also reduced remarkably compared to the other analyzed slendernesses. If the analyses had been made for beams with slenderness 0.2, which is regarded as a very low slenderness, the results might have shown a smaller difference between hand calculations and FE analyses as well.

Another thing to observe in the results from the Main study is how the different load cases affected the results. It can be seen that for the beams with slendernesses 0.5 and 2, the gained capacity by FE analysis compared to hand calculations is first increased for increased normal force and decreased bending moment. The peak capacity value is achieved when the normal force utilization and the bending utilization are as close as possible without the normal force utilization ratio exceeding the bending moment utilization ratio. When the normal force utilization is higher, or equal to, the bending moment utilization an increase in normal force will result in lower gains when making a FE analysis instead of hand calculations. However, it is notable that the differences are very small, only a few °C.

The results for beams with slenderness 1 showed a slightly different pattern. The gains of performing a FE analysis instead of hand calculations decreased with increased normal force. Yet, the small differences are notable here as well and they do not have a big influence on the actual result.

The Main study was performed for load cases where the beam is fully utilized in the hand calculations for a temperature corresponding to 5 minutes on the ISO 834 curve. The results showed that the gains of performing a FE analysis instead of hand calculations were approximately 200 °C for beams with slenderness 0.5 or 1 and approximately 100 °C for beams with slenderness 2.

To conclude, this study is quite narrow and only looks at the early stages of a fire. It might have resulted in other results if the study had been made for load cases were the beam was fully utilized for higher temperatures. Nonetheless, the studied load cases are not rare cases in practice and to gain 200 °C in the early stage of a fire will result in a gain in time of 12 minutes according to the ISO 834 curve. A 15 minute gain by making a FE analysis instead of hand calculation for this beam would result in the fulfillment of a fire requirement of R15 without the need of any fire protection even though this would not have been the case for hand calculation based design. For illustration of the maximum and minimum gains of the cases studied in the Main study in accordance with the ISO 834 curve, see Figure 7.6. For a zoom in on the relevant parts of Figure 7.6, see Figure 7.7.

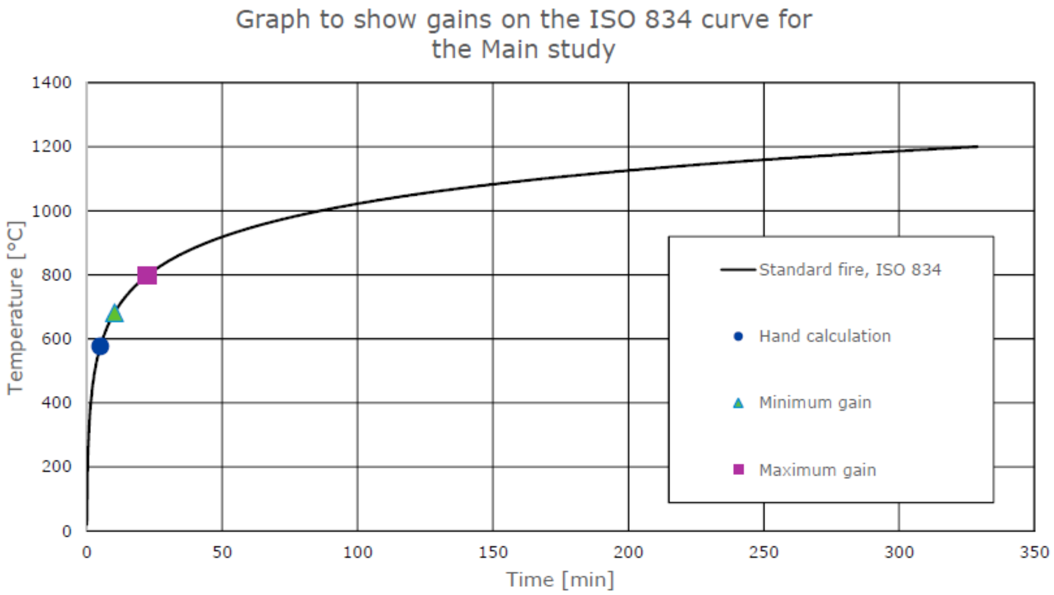


Figure 7.6: The temperature and corresponding time on the ISO 834 curve for the hand calculation and FE analyses for the cases with the smallest and largest gains in the Main study.

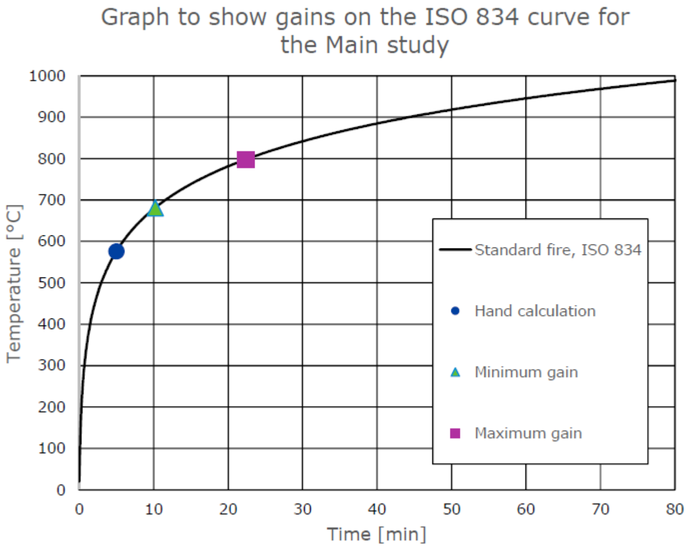


Figure 7.7: Zoom in of Figure 7.6.

8

Conclusion

8.1 General conclusions

The answer to the main question of interest, whether a costlier and more time-consuming FE analysis in the design process helps to save material resources and time in the construction stage, is yes. Due to the temperature lag between the air and the beam, there will always be gains in performing a FE analysis. Whether these gains are sufficient to save any substantial amount of resources in the construction stage is highly dependant on the specific boundary conditions and load type on the structure. Based on the cases studied, the conclusions from this study regrading the gains of doing a FE analysis instead of hand calculations were:

- The hand calculation methods advocated by Eurocode are conservative.
- The magnitude of the gains depends on the geometry of and load placed on the structure in question.
- The gains will be greater with increasing thickness of the structural member.
- The gains will be greater if lateral torsional buckling is included as a failure mode.
- The slenderness' influence on the gains is most important for beams subjected to axial loads
- If the beam is only subjected to bending moment, the gains become larger with increasing slenderness.
- If axial force is included, the gains are the greatest for intermediate slendernesses.
- The temperature gradient in the beam does not have any major influence of the temperature gains.
- The utilization ratio of bending moment compared to normal force has a small influence on the temperature gains.
- If performing only hand calculations, the gains of performing the lengthier calculations based on utilization ratios are few since the critical temperature method gives very similar results but takes significantly much less time.

Even though the extent of the influence in other cases has not been studied, the results show that the initial hypothesis had merit.

8.2 Specific temperature gains for the studied cases

The conclusions regarding the specific temperature gains, meaning the gains of doing a FE analysis instead of hand calculations, for the studied cases in this study are presented in the list below.

- For HEA 400, HEB 400 and HEM 400 beams, not subjected to lateral torsional buckling, with a utilization ratio of 80 % in the ultimate limit state, the gains are around 100 °C.
- For HEA 400, HEB 400 and HEM 400 beams, subjected to lateral torsional buckling, with a utilization ratio of 70 % in the ultimate limit state, the gains are around 200 °C.
- For HEB 400 beams with slenderness 0.5 to 1, subjected to axial force combined with bending moment as well as lateral torsional buckling, with a utilization ratio of 100 % in the fire scenario at t=5 min, the gains are around 200 °C.
- For HEB 400 beams with slenderness 2, subjected to axial force combined with bending moment as well as lateral torsional buckling, with a utilization ratio of 100 % in the fire scenario at t=5 min, the gains are around 100 °C.

8.3 Further research

This study had many limitations and new questions arose during the study, which opens up for the study of other parameters and questions. Some suggestions of further research topics regarding heat exposed steel structures and the gains of using FE analysis compared to hand calculations are the study of:

- Connections, e.g. joints.
- Beams with other boundary conditions, e.g. fixed supports.
- Other structural elements, e.g. columns.
- Other geometries of the beam cross section, e.g. VKR beams, I-beams with corrugated webs or beams in cross section classes 3 and 4.
- Structures consisting of several structural elements, e.g. frames or trusses.
- The influence of composite actions and increased temperature gradients, e.g. through a concrete floor on top of the steel beam.

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A

Comparison study: Hand calculations

μ.0 analyzis

$Q_{d.fi} = G_k + \psi_1 \cdot Q_k$	Desing load in fire scenario, definition by Eurocode
$Q_{d.ULS} = 1.35 \cdot G_k + 1.5 \cdot Q_k$	Design load in ULS, definition by Eurocode
$\eta_{fi} = \frac{Q_{d.fi}}{Q_{d.ULS}}$	Reduction factor, definition by Eurocode
$R_{fi.d.0} = M_{Rd}$	Design resistance in the fire scenario for the time t=0, definition by Eurocode
$E_{fi} = \frac{Q_{d.fi} \cdot L^2}{8}$	Design effect of action for the fire situation. For this example, for a simply supported beam
$\mu_{0u} = \frac{E_{fi.d}}{R_{fi.d.0}}$	Utilization ratio, defined by EN1993-1-2

Given by above equations

$$\frac{E_{fi.d}}{M_{Rd}} = \frac{\frac{Q_{d.fi} \cdot L^2}{8}}{M_{Rd}}$$

$\mu_{0\eta} = \eta_{fi} \cdot \frac{\gamma_{M.fi}}{\gamma_{M0}}$	Conservativley calcualted utilzation ratio according to EN1993-1-2

Since $\gamma_{M.fi} = \gamma_{M0} = 1$

$$\mu_{0\eta} = \eta_{fi}$$

To check when μ.0.u is equal to μ.0.η

$$\frac{\frac{Q_{d.fi} \cdot L^2}{8}}{M_{Rd}} = \frac{Q_{d.fi}}{Q_{d.ULS}}$$

Divide both sides by Q.d.fi

$$\frac{\frac{L^2}{8}}{M_{Rd}} = \frac{1}{Q_{d.ULS}}$$

Multiply both sides by Q.d.ULS

$$\frac{Q_{d.ULS} \cdot L^2}{8} = M_{Rd}$$

This means that, if the beam is fully utilized in the ultimate limit state,
the both methods to determine μ.0 will give the same result.

To check when μ.0.u is greater than μ.0.η

$$\frac{\frac{Q_{d.fi} \cdot L^2}{8}}{M_{Rd}} \geq \frac{Q_{d.fi}}{Q_{d.ULS}}$$

Divide both sides by Q.d.fi

$$\frac{\frac{L^2}{8}}{M_{Rd}} \geq \frac{1}{Q_{d.ULS}}$$

Multiply both sides by Q.d.ULS

$$\frac{Q_{d.ULS} \cdot L^2}{8} \geq M_{Rd}$$

This case will never happen if the structure is design according to approced design codes. This means that μ.0.η, will always be greater than μ.0.u if the beam is not fully utilized in the ultimate limit state. As a consquence, μ.0.η, will always give a conservative utilazation ratio (which is also indicated in Eurocode).

B

Parametric study: Hand calculations Phase one

Manual Input for Symmetric rolled HEA beam: uniform temperature without LT buckling

Example of hand calculations from Parametric Study Phase 1

All blue area data should be changed manually

.

Cross section:

$$A := \begin{pmatrix} \text{"HEA400"} & \text{"HEB400"} & \text{"HEM400"} \\ 0.3 & 0.3 & 0.307 \\ 0.019 & 0.024 & 0.04 \\ 0.39 & 0.4 & 0.432 \\ 0.011 & 0.0135 & 0.021 \\ 0.027 & 0.027 & 0.027 \end{pmatrix}$$

beam :=

● HEA400

○ HEB400

○ HEM400

$b_f := A_{1,\text{beam}-1} \cdot m = 300 \cdot mm$	Flange width
$t_f := A_{2,\text{beam}-1} \cdot m = 19 \cdot mm$	Flange thickness
$h_w := A_{3,\text{beam}-1} \cdot m - 2 \cdot t_f = 352 \cdot mm$	Web height
$t_w := A_{4,\text{beam}-1} \cdot m = 11 \cdot mm$	Web thickness
$r := A_{5,\text{beam}-1} \cdot m = 27 \cdot mm$	Radius of the rolled I section
$L := 12m$	Length of beam
$a_L := \infty \cdot m$	Distance betwen stiffeners
$I_{sl} := 0$	Second moment of area for longitudinal stiffeners
steel := ○ S235 ● S355	Steel class

$$f_y := \left| \begin{array}{l} 235MPa \quad \text{if steel} = 1 \\ (355MPa) \quad \text{if steel} = 2 \end{array} \right. = 355 \cdot MPa$$

Yield strength for structural steel, S235, S355.
[EN 1993-1-1, Section 3.2.3, Table 3.1]

Loads

$Q_k := 13.2 \frac{kN}{m}$ Variable imposed load

$g_k := 14 \frac{kN}{m}$ Selfweight from structural members above

Buckling

[EN 1993-1-1, Section 6.3.1.2, Table 6.2 and Table 6.4]

$$\text{Bucklingcurve}_y := \begin{cases} \text{"a"} & \text{if } \frac{h_w + 2 \cdot t_f}{b_f} > 1.2 \wedge t_f \le 40mm \\ \text{"b"} & \text{if } \frac{h_w + 2 \cdot t_f}{b_f} > 1.2 \wedge 40mm < t_f \le 100mm \\ \text{"b"} & \text{if } \frac{h_w + 2 \cdot t_f}{b_f} \le 1.2 \wedge t_f \le 100mm \\ \text{"d"} & \text{if } \frac{h_w + 2 \cdot t_f}{b_f} \le 1.2 \wedge t_f > 100mm \\ \text{"WARNING, INPUT NOT ACCURATE"} & \text{otherwise} \end{cases}$$

$\text{Bucklingcurve}_y = \text{"a"}$

$$\text{Bucklingcurve}_z := \begin{cases} \text{"b"} & \text{if } \frac{h_w + 2 \cdot t_f}{b_f} > 1.2 \wedge t_f \le 40mm \\ \text{"c"} & \text{if } \frac{h_w + 2 \cdot t_f}{b_f} > 1.2 \wedge 40mm < t_f \le 100mm \\ \text{"c"} & \text{if } \frac{h_w + 2 \cdot t_f}{b_f} \le 1.2 \wedge t_f \le 100mm \\ \text{"d"} & \text{if } \frac{h_w + 2 \cdot t_f}{b_f} \le 1.2 \wedge t_f > 100mm \\ \text{"WARNING, INPUT NOT ACCURATE"} & \text{otherwise} \end{cases}$$

$\text{Bucklingcurve}_z = \text{"b"}$

$$\text{Bucklingcurve\_LT} := \left| \begin{array}{l} \text{"a"} \quad \text{if } \dfrac{h_w + 2 \cdot t_f}{b_f} \leq 2 \\ \text{"b"} \quad \text{if } \dfrac{h_w + 2 \cdot t_f}{b_f} > 2 \\ \text{"WARNING, INPUT NOT ACCURATE"} \quad \text{otherwise} \end{array} \right.$$

$\text{Bucklingcurve\_LT} = \text{"a"}$ Lateral torisonal buckling curve

Support conditions

Simply supported = 1, Fixed = 0.5

$k_{l.cr} := 1$

Equivalent moment factors

[EN 1993-1-2, Section 4.2.3.5, Figure 4.2]

$\beta_{M.z} := 1.3$	The equivalent uniform moment factors in z direction
$\beta_{M.y} := 1.3$	The equivalent uniform moment factors in y direction

Required resistance time

$t_R := 6.67$ [min]

Constant variables

Required resistance time

$t_R = 6.67$ [min]

Input for EN 1993-1-2

$L_{cr} := k_{l.cr} \cdot L = 12\,m$	Critical buckling length of beam
$\gamma_{M.0} := 1.0$	Partial factor for resistance of cross-section [EN 1993-1-1, Section 6.1]
$\gamma_{M1} := 1.0$	Partial factor for resistance of members to instability assesed by member checks [EN 1993-1-1, Section 6.1]

$\gamma_{M.fi} := 1.0$

Partial factor for the relevant material property for the fire situation [EN 1993-1-2, Section 2.3]

$E := 210 \cdot 10^{9} Pa$

Elasticity modulus for structural steel [EN 1993-1-2, Section 3.2.6]

$G := 80770 MPa$

Shear modulus [EN 1993-1-2, Section 3.2.6]

$\alpha_{cT} := 12 \cdot 10^{-6} = 1.2 \times 10^{-5}$

Coeficient for thermal expansion [EN 1993-1-2, Section 3.2.6]

Cross section properties

$A := 2 \cdot t_f \cdot b_f + h_w \cdot t_w = 0.015 m^2$

Cross section area

$y_{TP} := t_f + \frac{h_w}{2} = 0.195 m$

Gravity center in y-direction

$$I_y := \frac{t_w \cdot h_w^{3}}{12} + \frac{2 \cdot b_f \cdot t_f^{3}}{12} + 2 \cdot b_f \cdot t_f \cdot \left(y_{TP} - \frac{t_f}{2} \right)^2$$

$I_y = 4.326 \times 10^{-4} m^4$

Second moment of area in y direction

$$I_z := \frac{h_w \cdot t_w^{3}}{12} + \frac{2 \cdot t_f \cdot b_f^{3}}{12} = 8.554 \times 10^{-5} m^4$$

Second moment of area in z direction

$$I_f := \frac{2 \cdot b_f \cdot t_f^{3}}{12} + 2 \cdot b_f \cdot t_f \cdot \left(y_{TP} - \frac{t_f}{2} \right)^2$$

Second moment of area flanges

$$W_{pl.y} := b_f \cdot t_f \cdot \left(h_w + t_f \right) + \frac{t_w \cdot h_w^{2}}{4} = 2.455 \times 10^{-3} \cdot m^3$$

Section modulus in y-direction

$$\varepsilon_{fi} := 0.85 \cdot \left(\frac{235 \cdot MPa}{f_y} \right)^{0.5} = 0.692$$

Fire reduced coefficient depending on fy. [EN 1993-1-2, Section 4.2.2, Eq. (4.2)]

$$\varepsilon := \left(\frac{235 \cdot MPa}{f_y} \right)^{0.5} = 0.814$$

Coefficient depending on fy. [EN 1993-1-1, Section 5.6, Table 5.2]

Eurocode 1991-1-2: Temperatures

Nominal temterapture-time curve

[EN 1991-1-2, Section 3.2.1, Eq. (3.4)]

$\Theta_{g.n} := 20 + 345 \cdot \log(8 \cdot t_R + 1) = 618.671$ [deg C]

$\theta_{a.n} := \Theta_{g.n} = 618.671$

Eurocode 1990: Design loads

Loads

$\rho_s := 7850 \frac{kg}{m^3}$ Steel density

$A := 2 \cdot t_f \cdot b_f + h_w \cdot t_w = 1.527 \times 10^4 \cdot mm^2$ Cross section area

$G_k := g_k = 14 \cdot \frac{kN}{m}$ Self weigth of the beam

$Q_k = 13.2 \cdot \frac{kN}{m}$ Variable imposed load

$\psi_1 := 0.5$ Factor for frequent value of a variable action.
[EN 1990, Section A1.2.2, Table A1.1]

Load combination ULS

$Q_{d.ULS} := 1.35 \cdot G_k + 1.5 \cdot Q_k = 38.7 \cdot \frac{kN}{m}$ Design load ULS
[EN 1990, Section A1.3.1, Table A1.2(B)]

$$M_{Ed.ULS} := \left| \begin{array}{ll} \frac{Q_{d.ULS} \cdot L^2}{8} & \text{if } k_{l.cr} = 1 \\ \frac{Q_{d.ULS} \cdot L^2}{12} & \text{if } k_{l.cr} = 0.5 \end{array} \right. = 696.6 \cdot kN \cdot m$$

Design moment ULS

$N_{Ed.ULS} := 0N$ Design normal force ULS

$V_{Ed.ULS} := Q_{d.ULS} \cdot \frac{L}{2} = 232.2 \cdot kN$ Design shear force ULS

Load combinations fire

Loads

$$Q_{d.fi} := G_k + \psi_1 \cdot Q_k = 20.6 \cdot \frac{kN}{m}$$

Load combination for fire
[EN 1990, Section A1.3.1, Table A1.3]

Design moment fire

$$M_{Ed.fi} := \left| \begin{array}{ll} \frac{Q_{d.fi} \cdot L^2}{8} & \text{if } k_{l.cr} = 1 \\ \frac{Q_{d.fi} \cdot L^2}{12} & \text{if } k_{l.cr} = 0.5 \end{array} \right. = 370.8 \cdot kN \cdot m$$

$$M_{Ed.fi.y.n} := \left| \begin{array}{ll} \frac{Q_{d.fi} \cdot L^2}{8} & \text{if } k_{l.cr} = 1 \\ \frac{Q_{d.fi} \cdot L^2}{12} & \text{if } k_{l.cr} = 0.5 \end{array} \right. = 370.8 \cdot kN \cdot m$$

$$M_{Ed.fi.z.n} := \left| \begin{array}{ll} 0kN \cdot m & \text{if } k_{l.cr} = 1 \\ 0kN \cdot m & \text{if } k_{l.cr} = 0.5 \end{array} \right. = 0 \cdot kN \cdot m$$

Design normal force fire

$$N_{Ed.fi} := 0kN$$

$$N_{Ed.fi.n} := \left| \begin{array}{ll} 0 & \text{if } k_{l.cr} = 1 \\ 0 & \text{if } k_{l.cr} = 0.5 \end{array} \right. = 0 \cdot kN$$

$$V_{Ed.fi} := Q_{d.fi} \cdot \frac{L}{2} = 123.6 \cdot kN$$

Design shear force fire

$$\eta_{fi} := \frac{Q_{d.fi}}{Q_{d.ULS}} = 0.532$$

Degree of Utilization at time t0 for fire

Eurocode 1993-1-1: Capacities without temperature load

Cross section class check [EN 1993-1-1, Section 5.6, Table 5.2]

$$c_{cs.f} := \frac{b_f - t_w}{2} - r = 0.117\,m$$

$$CSC_f := \begin{array}{|l} \text{"1"} \;\text{ if } \frac{c_{cs.f}}{t_f} \le 9\cdot\varepsilon_{fi} \\ \text{"2"} \;\text{ if } 9\cdot\varepsilon_{fi} < \frac{c_{cs.f}}{t_f} \le 10\cdot\varepsilon_{fi} \\ \text{"3"} \;\text{ if } 10\cdot\varepsilon_{fi} < \frac{c_{cs.f}}{t_f} \le 14\cdot\varepsilon_{fi} \\ \text{"4"} \;\text{ otherwise} \end{array} = \text{"1"}$$

$$c_{cs.w} := h_w - 2\cdot r = 0.298\,m$$

$$CSC_w := \begin{array}{|l} \text{"1"} \;\text{ if } \frac{c_{cs.w}}{t_w} \le 72\cdot\varepsilon_{fi} \\ \text{"2"} \;\text{ if } 72\cdot\varepsilon_{fi} < \frac{c_{cs.w}}{t_w} \le 83\cdot\varepsilon_{fi} \\ \text{"3"} \;\text{ if } 83\cdot\varepsilon_{fi} < \frac{c_{cs.w}}{t_w} \le 124\cdot\varepsilon_{fi} \\ \text{"4"} \;\text{ otherwise} \end{array} = \text{"1"}$$

Normal force, tension:

$$N_{Rd} := A\cdot\frac{f_y}{\gamma_{M.0}} = 5.422\times 10^3\cdot kN$$

Design values of the resistance to normal force [EN 1993-1-1, Section 6.2.3, Eq. (6.6)].

Normal force, compression:

$$N_{cr.y} := \pi^2 \cdot E \cdot \frac{I_y}{L_{cr}^{\;2}} = 6.226 \times 10^3 \cdot kN$$

Elastic critical force for the relvant buckling mode based on the gross cross section properties

$$\lambda_y := \sqrt{A \cdot \frac{f_y}{N_{cr.y}}} = 0.933$$

Non dimensional slenderness
[EN 1993-1-1, Section 6.3.1.2, Eq.(6.49)]

$$N_{cr.z} := \pi^2 \cdot E \cdot \frac{I_z}{L_{cr}^{\;2}} = 1.231 \times 10^3 \cdot kN$$

Elastic critical force for the relvant buckling mode based on the gross cross section properties

$$\lambda_z := \sqrt{A \cdot \frac{f_y}{N_{cr.z}}} = 2.098$$

Non dimensional slenderness
[EN 1993-1-1, Section 6.3.1.2, Eq.(6.49)]

Bending capacity without Lateral torsional buckling:

$$M_{Rd} := W_{pl.y} \cdot \frac{f_y}{\gamma_{M1}} = 871.68 \cdot kN \cdot m$$

Design value of the resistance to bending moment
[EN 1993-1-1, Section 6.2.5, Eq. (6.13)]

Shear capacity:

$$\eta := \left| \begin{array}{l} 1.2 \ \text{ if } f_y \le 460MPa \\ 1.0 \ \text{ otherwise} \end{array} \right. = 1.2$$

Factor
[EN 1993-1-5, Section 5.1, Note 2]

$$k_{\tau.sl} := \max\left[9 \cdot \left(\frac{h_w}{a_L}\right)^2 \cdot \left[\left(\frac{I_{sl}}{t_w^{\;3} \cdot h_w}\right)^3\right]^{\frac{1}{4}}, \frac{2.1}{t_w} \cdot \left(\frac{I_{sl}}{h_w}\right)^{\frac{1}{3}} \right] = 0$$

Coefficient to calculate the shear buckling coefficient
[EN 1993-1-5, Section A.3, Eq. (A.5)]

$$k_{\tau} := \left| \begin{array}{l} 5.34 + 4.0 \cdot \left(\frac{h_w}{a_L}\right)^2 + k_{\tau.sl} \ \text{ if } \frac{a_L}{h_w} \ge 1 \\ 4.0 + 5.34 \cdot \left(\frac{h_w}{a_L}\right)^2 + k_{\tau.sl} \ \text{ otherwise} \end{array} \right. = 5.34$$

Shear buckling coefficient
[EN 1993-1-5, Section A.3, Eq. (A.5)]

$$\lambda_w := \frac{\frac{h_w}{t_w}}{37.4 \cdot \varepsilon \cdot \sqrt{k_\tau}} = 0.455$$

The slenderness parameter
[EN 1993-1-5, Section 5.3, Eq. (5.6)]

$$\chi_w := \begin{vmatrix} \eta \text{ if } \lambda_w < \frac{0.83}{\eta} \\ \frac{0.83}{\lambda_w} \text{ if } \frac{0.83}{\eta} \le \lambda_w < 1.08 \\ \frac{0.83}{\lambda_w} \text{ otherwise} \end{vmatrix} = 1.2$$

The factor for the contribution of the web to the shear buckling resistance
[EN 1993-1-5, Section 5.3, Table 5.1]

$$V_{bw.Rd} := \chi_w \cdot h_w \cdot t_w \cdot \frac{f_y}{\sqrt{3} \cdot \gamma_{M1}} = 9.523 \times 10^5 \text{N}$$

Contribution from the web to the shear resistance
[EN 1993-1-5, Section 5.2, Eq. (5.2)]

$$V_{pl} := \eta \cdot h_w \cdot t_w \cdot \frac{f_y}{\sqrt{3} \cdot \gamma_{M1}} = 952.323 \cdot \text{kN}$$

Plastic shear resistance
[EN 1993-1-5, Section 5.2, Eq. (5.1)]

$$V_{Rd} := \min\left(V_{pl}, V_{bw.Rd}\right) = 952.323 \cdot \text{kN}$$

Shear resistance
[EN 1993-1-5, Section 5.2, Eq. (5.1)]

Eurocode 1993-1-2: Reduction factors, k

Nomínal temperature parameters

$\theta_{a.n} := \Theta_{g.n} = 618.671$

Reduction factor for the yield strength of steel at temperature θa
[EN 1993-1-2, Section 3.2.2 Table 3.1]

$$k_{y.\theta.n} := \left| \begin{array}{l} 1 \ \text{ if } \ 20 \le \theta_{a.n} \le 400 \\ 1 - \frac{(1 - 0.78)}{(500 - 400)} \cdot \left(\theta_{a.n} - 400\right) \ \text{ if } \ 400 < \theta_{a.n} \le 500 \\ 0.78 - \frac{(0.78 - 0.47)}{(600 - 500)} \cdot \left(\theta_{a.n} - 500\right) \ \text{ if } \ 500 < \theta_{a.n} \le 600 \\ 0.47 - \frac{(0.47 - 0.23)}{(700 - 600)} \cdot \left(\theta_{a.n} - 600\right) \ \text{ if } \ 600 < \theta_{a.n} \le 700 \\ 0.23 - \frac{(0.23 - 0.11)}{(800 - 700)} \cdot \left(\theta_{a.n} - 700\right) \ \text{ if } \ 700 < \theta_{a.n} \le 800 \\ 0.11 - \frac{(0.11 - 0.06)}{(900 - 800)} \cdot \left(\theta_{a.n} - 800\right) \ \text{ if } \ 800 < \theta_{a.n} \le 900 \\ 0.06 - \frac{(0.06 - 0.04)}{(1000 - 900)} \cdot \left(\theta_{a.n} - 900\right) \ \text{ if } \ 900 < \theta_{a.n} \le 1000 \\ 0.04 - \frac{(0.04 - 0.02)}{(1100 - 1000)} \cdot \left(\theta_{a.n} - 1000\right) \ \text{ if } \ 1000 < \theta_{a.n} \le 1100 \\ 0.02 - \frac{(0.02 - 0)}{(1200 - 1100)} \cdot \left(\theta_{a.n} - 1100\right) \ \text{ if } \ 1100 < \theta_{a.n} \le 1200 \\ 0 \ \text{ otherwise} \end{array} \right. = 0.425$$

Reduction factor for the slope for the linear elastic range at the steel temperature θa
[EN 1993-1-2, Section 3.2.2 Table 3.1]

$$k_{E.\theta.n} := \left| \begin{array}{l} 1 \text{ if } 20 \le \theta_{a.n} \le 100 \\ 1 - \frac{(1-0.9)}{(200-100)} \cdot \left(\theta_{a.n} - 100\right) \text{ if } 100 < \theta_{a.n} \le 200 \\ 0.9 - \frac{(0.9-0.8)}{(300-200)} \cdot \left(\theta_{a.n} - 200\right) \text{ if } 200 < \theta_{a.n} \le 300 \\ 0.8 - \frac{(0.8-0.7)}{(400-300)} \cdot \left(\theta_{a.n} - 300\right) \text{ if } 300 < \theta_{a.n} \le 400 \\ 0.7 - \frac{(0.7-0.6)}{(500-400)} \cdot \left(\theta_{a.n} - 400\right) \text{ if } 400 < \theta_{a.n} \le 500 \\ 0.6 - \frac{(0.6-0.31)}{(600-500)} \cdot \left(\theta_{a.n} - 500\right) \text{ if } 500 < \theta_{a.n} \le 600 \\ 0.31 - \frac{(0.31-0.13)}{(700-600)} \cdot \left(\theta_{a.n} - 600\right) \text{ if } 600 < \theta_{a.n} \le 700 \\ 0.13 - \frac{(0.13-0.09)}{(800-700)} \cdot \left(\theta_{a.n} - 700\right) \text{ if } 700 < \theta_{a.n} \le 800 \\ 0.09 - \frac{(0.09-0.0675)}{(900-800)} \cdot \left(\theta_{a.n} - 800\right) \text{ if } 800 < \theta_{a.n} \le 900 \\ 0.0675 - \frac{(0.0675-0.045)}{(1000-900)} \cdot \left(\theta_{a.n} - 900\right) \text{ if } 900 < \theta_{a.n} \le 1000 \\ 0.045 - \frac{(0.045-0.0225)}{(1100-1000)} \cdot \left(\theta_{a.n} - 1000\right) \text{ if } 1000 < \theta_{a.n} \le 1100 \\ 0.0225 - \frac{(0.0225-0)}{(1200-1100)} \cdot \left(\theta_{a.n} - 1100\right) \text{ if } 1100 < \theta_{a.n} \le 1200 \\ 0 \text{ otherwise} \end{array} \right. = 0.276$$

$$k_{z.\theta.n} := k_{y.\theta.n}$$

$$k_{y.\theta.com.n} := k_{y.\theta.n}$$

$$k_{E.\theta.com.n} := k_{E.\theta.n}$$

$$k_{y.\theta.web.n} := k_{y.\theta.n}$$

$$k_{E.\theta.web.n} := k_{E.\theta.n}$$

Eurocode 1993-1-2: Nominal temperature

Bending capacity without Lateral torsional buckling:

$$M_{fi.\theta.Rd} := k_{y.\theta.n} \cdot M_{Rd} \cdot \left(\frac{\gamma_{M.0}}{\gamma_{M.fi}} \right) = 370.628 \cdot kN \cdot m$$

Design moment resistance
with the uniform temperature θa
[EN 1993-1-2, Section 4.2.3.3, Eq. (4.8)]

Shear Capacity:

$$V_{fi.t.Rd} := k_{y.\theta.web.n} \cdot V_{Rd} \cdot \left(\frac{\gamma_{M.0}}{\gamma_{M.fi}} \right)$$

Design shear resistance at time t
of cross section class 1 or 2
[EN 1993-1-2, Section 4.2.3.3, Eq. (4.16)]

$$M_{fi.\theta.Rd.n} := M_{fi.\theta.Rd} = 370.628 \cdot kN \cdot m$$

Fire reduced capacities for nominal
temperature

$$V_{fi.t.Rd.n} := V_{fi.t.Rd} = 404.917 \cdot kN$$

Checks

ULS checks

$$Check := \begin{cases} \text{"Bending moment capacity w/o LT buckling OK"} & \text{if } \dfrac{M_{Ed.ULS}}{M_{Rd}} \leq 1 \\ \text{"Bending moment capacity w/o LT buckling NOT OK"} & \text{otherwise} \end{cases}$$

$$\frac{M_{Ed.ULS}}{M_{Rd}} = 0.799$$

$$Check = \text{"Bending moment capacity w/o LT buckling OK"}$$

$$Check := \begin{cases} \text{"Shear force capacity OK"} & \text{if } \dfrac{V_{Ed.ULS}}{V_{Rd}} \leq 1 \\ \text{"Shear force capacity NOT OK"} & \text{otherwise} \end{cases}$$

$$\frac{V_{Ed.ULS}}{V_{Rd}} = 0.244$$

$$Check = \text{"Shear force capacity OK"}$$

Fire check

$$C_M := \frac{M_{Ed.fi.y.n}}{M_{fi.\theta.Rd.n}}$$

$$Check := \begin{cases} \text{"Bending moment capacity w/o LT buckling OK, nominal temperature"} & \text{if } C_M \leq 1 \\ \text{"Bending moment capacity NOT OK w/o LT buckling, nominal temperature"} & \text{otherwise} \end{cases}$$

$$\frac{M_{Ed.fi.y.n}}{M_{fi.\theta.Rd.n}} = 1$$

$$Check = \text{"Bending moment capacity NOT OK w/o LT buckling, nominal temperature"}$$

Critical temperature

$\mu_0 := \eta_{fi} \cdot \left(\frac{\gamma_{M.fi}}{\gamma_{M.0}} \right) = 0.532$ [EN 1993-1-2, Section 4.2.4, Eq. (4.24)]

$\mu_0 := \max\left(\frac{M_{Ed.fi}}{M_{Rd}} \right) = 0.425$ [EN 1993-1-2, Section 4.2.4, Eq. (4.23)]

[EN 1993-1-2, Section 4.2.4, Eq. (4.22)]

$$\theta_{a.cr} := 39.19 \cdot \ln\left(\left(\frac{1}{0.9674 \cdot \mu_0^{3.833}} - 1 \right) \right) + 482 = 610.238$$

$$Check := \begin{array}{|l} \text{"Critical temperature is NOT OK wrt the nominal temperature"} \quad \text{if } \theta_{a.cr} \le \theta_{a.n} \\ \text{"Critical temperature is OK wrt the nominal temperature"} \quad \text{otherwise} \end{array}$$

$\frac{\theta_{a.n}}{\theta_{a.cr}} = 1.014$

Check = "Critical temperature is NOT OK wrt the nominal temperature"

Warnings

$CSC_w = \text{"1"}$

$CSC_f = \text{"1"}$

$$Loadcombinations := \begin{array}{|l} \text{"Load ratios probably OK"} \quad \text{if } 0.3 \cdot Q_k < G_k < 1.5Q_k \\ \text{"Look over chosen load ratios"} \quad \text{otherwise} \end{array}$$

Loadcombinations = "Load ratios probably OK"

C

Parametric study: Hand calculations Phase two

Manual Input for Symmetric rolled HEA beam: uniform temperature with LT buckling

Example of hand calculations from Parametric Study Phase 2.

All blue area data should be changed manually .

Cross section:

$$A := \begin{pmatrix} \text{"HEA400"} & \text{"HEB400"} & \text{"HEM400"} \\ 0.3 & 0.3 & 0.307 \\ 0.019 & 0.024 & 0.04 \\ 0.352 & 0.352 & 0.352 \\ 0.011 & 0.0135 & 0.021 \\ 0.027 & 0.027 & 0.027 \end{pmatrix}$$

beam :=

HEA400
HEB400
HEM400

$b_f := A_{1,beam-1} \cdot m = 300 \cdot mm$	Flange width
$t_f := A_{2,beam-1} \cdot m = 19 \cdot mm$	Flange thickness
$h_w := A_{3,beam-1} \cdot m = 352 \cdot mm$	Web height
$t_w := A_{4,beam-1} \cdot m = 11 \cdot mm$	Web thickness
$r := A_{5,beam-1} \cdot m = 27 \cdot mm$	Radius of the rolled I section
$L := 13m$	Length of beam
$a_L := \infty \cdot m$	Distance betwen stiffeners
$I_{sl} := 0$	Second moment of area for longitudinal stiffeners
steel := S235 S355	Steel class

$$f_y := \begin{cases} 235\text{MPa} & \text{if steel} = 1 \\ (355\text{MPa}) & \text{if steel} = 2 \end{cases} = 355 \cdot \text{MPa}$$

Yield strength for structural steel, S235,S355
[EN 1993-1-1, Section 3.2.3, Table 3.1]

Loads

$Q_k := 3.6 \frac{\text{kN}}{\text{m}}$ Variable imposed load

$g_k := 3.6 \frac{\text{kN}}{\text{m}}$ Selfweight from structural members above

Buckling

[EN 1993-1-1, Section 6.3.1.2, Table 6.2 and Table 6.4]

$$\text{Bucklingcurve}_y := \begin{cases} \text{"a"} & \text{if } \frac{h_w + 2 \cdot t_f}{b_f} > 1.2 \wedge t_f \leq 40\text{mm} \\ \text{"b"} & \text{if } \frac{h_w + 2 \cdot t_f}{b_f} > 1.2 \wedge 40\text{mm} < t_f \leq 100\text{mm} \\ \text{"b"} & \text{if } \frac{h_w + 2 \cdot t_f}{b_f} \leq 1.2 \wedge t_f \leq 100\text{mm} \\ \text{"d"} & \text{if } \frac{h_w + 2 \cdot t_f}{b_f} \leq 1.2 \wedge t_f > 100\text{mm} \\ \text{"WARNING, INPUT NOT ACCURATE"} & \text{otherwise} \end{cases}$$

$$\text{Bucklingcurve}_y = \text{"a"}$$

$$\text{Bucklingcurve}_z := \begin{cases} \text{"b"} & \text{if } \frac{h_w + 2 \cdot t_f}{b_f} > 1.2 \wedge t_f \leq 40\text{mm} \\ \text{"c"} & \text{if } \frac{h_w + 2 \cdot t_f}{b_f} > 1.2 \wedge 40\text{mm} < t_f \leq 100\text{mm} \\ \text{"c"} & \text{if } \frac{h_w + 2 \cdot t_f}{b_f} \leq 1.2 \wedge t_f \leq 100\text{mm} \\ \text{"d"} & \text{if } \frac{h_w + 2 \cdot t_f}{b_f} \leq 1.2 \wedge t_f > 100\text{mm} \\ \text{"WARNING, INPUT NOT ACCURATE"} & \text{otherwise} \end{cases}$$

$\text{Bucklingcurve}_z = \text{"b"}$

$$\text{Bucklingcurve\_LT} := \begin{cases} \text{"a"} & \text{if } \dfrac{h_w + 2 \cdot t_f}{b_f} \le 2 \\ \text{"b"} & \text{if } \dfrac{h_w + 2 \cdot t_f}{b_f} > 2 \\ \text{"WARNING, INPUT NOT ACCURATE"} & \text{otherwise} \end{cases}$$

$\text{Bucklingcurve\_LT} = \text{"a"}$ Lateral torisonal buckling curve

Support conditions

Simply supported = 1, Fixed = 0.5

$k_{l.cr} := 1$ Buckling length

Equivalent moment factors [EN 1993-1-2, Section 4.2.3.5, Figure 4.2]

$\beta_{M.z} := 1.3$ The equivalent uniform moment factors in z direction

$\beta_{M.y} := 1.3$ The equivalent uniform moment factors in y direction

Required resistance time

$t_R := 4.47$ [min]

Constant variables

Required resistance time

$t_R = 4.47$ [min]

Input for EN 1993-1-2

$L_{cr} := k_{l.cr} \cdot L = 13\,\mathrm{m}$ Critical buckling length of beam

$\gamma_{M.0} := 1.0$ Partial factor for resistance of cross-section [EN 1993-1-1, Section 6.1]

$\gamma_{M1} := 1.0$ Partial factor for resistance of members to instability assesed by member checks [EN 1993-1-1, Section 6.1]

$\gamma_{M.fi} := 1.0$ Partial factor for the relevant material property for the fire situation [EN 1993-1-2, Section 2.3]

$E := 210 \cdot 10^{9}\mathrm{Pa}$ Elasticity modulus for structural steel [EN 1993-1-2, Section 3.2.6]

$G := 80770\mathrm{MPa}$ Shear modulus [EN 1993-1-2, Section 3.2.6]

$\alpha_{cT} := 12 \cdot 10^{-6} = 1.2 \times 10^{-5}$ Coeficient for thermal expansion [EN 1993-1-2, Section 3.2.6]

Cross section properties

$A := 2 \cdot t_f \cdot b_f + h_w \cdot t_w = 0.015\,\mathrm{m}^2$ Cross section area

$y_{TP} := t_f + \frac{h_w}{2} = 0.195\,\mathrm{m}$ Gravity center in y-direction

$$I_y := \frac{t_w \cdot h_w^{\,3}}{12} + \frac{2 \cdot b_f \cdot t_f^{\,3}}{12} + 2 \cdot b_f \cdot t_f \cdot \left(y_{TP} - \frac{t_f}{2}\right)^2$$

$I_y = 4.326 \times 10^{-4}\,\mathrm{m}^4$ Second moment of area in y direction

$I_z := \frac{h_w \cdot t_w^{\,3}}{12} + \frac{2 \cdot t_f \cdot b_f^{\,3}}{12} = 8.554 \times 10^{-5}\,\mathrm{m}^4$ Second moment of area in z direction

$$I_f := \frac{2 \cdot b_f \cdot t_f^{\,3}}{12} + 2 \cdot b_f \cdot t_f \cdot \left(y_{TP} - \frac{t_f}{2} \right)^2$$ Second moment of area flanges

$$W_{pl.y} := b_f \cdot t_f \cdot \left(h_w + t_f \right) + \frac{t_w \cdot h_w^{\,2}}{4} = 2.455 \times 10^{-3} \cdot m^3$$ Section modulus in y-direction

$$\varepsilon_{fi} := 0.85 \cdot \left(\frac{235 \cdot MPa}{f_y} \right)^{0.5} = 0.692$$

Fire reduced coefficient depending on fy
[EN 1993-1-2, Section 4.2.2, Eq. (4.2)]

$$\varepsilon := \left(\frac{235 \cdot MPa}{f_y} \right)^{0.5} = 0.814$$

Coefficient depending on fy
[EN 1993-1-1, Section 5.6, Table 5.2]

Eurocode 1991-1-2: Temperatures

Nominal temterapture-time curve [EN 1991-1-2, Section 3.2.1, Eq. (3.4)]

$$\Theta_{g.n} := 20 + 345 \cdot \log\left(8 \cdot t_R + 1 \right) = 560.055$$ [deg C]

$$\theta_{a.n} := \Theta_{g.n} = 560.055$$

Eurocode 1990: Design loads

Loads

$\rho_s := 7850 \frac{kg}{m^3}$ Steel density

$A := 2 \cdot t_f \cdot b_f + h_w \cdot t_w = 1.527 \times 10^4 \cdot mm^2$ Cross section area

$G_k := g_k = 3.6 \cdot \frac{kN}{m}$ Self weigth of the beam

$Q_k = 3.6 \cdot \frac{kN}{m}$ Variable imposed load

$\psi_1 := 0.5$ Factor for frequent value of a variable action [EN 1990, Section A1.2.2, Table A1.1]

Load combination ULS

$Q_{d.ULS} := 1.35 \cdot G_k + 1.5 \cdot Q_k = 10.26 \cdot \frac{kN}{m}$ Design load ULS [EN 1990, Section A1.3.1, Table A1.2(B)]

$$M_{Ed.ULS} := \left| \begin{array}{ll} \frac{Q_{d.ULS} \cdot L^2}{8} & \text{if } k_{l.cr} = 1 \\ \frac{Q_{d.ULS} \cdot L^2}{12} & \text{if } k_{l.cr} = 0.5 \end{array} \right. = 216.743 \cdot kN \cdot m$$

Design moment ULS

$V_{Ed.ULS} := Q_{d.ULS} \cdot \frac{L}{2} = 66.69 \cdot kN$ Design shear force ULS

Load combinations fire

Loads

$Q_{d.fi} := G_k + \psi_1 \cdot Q_k = 5.4 \cdot \frac{kN}{m}$

Load combination for fire
[EN 1990, Section A1.3.1, Table A1.3]

Design moment fire

$$M_{Ed.fi} := \left| \begin{array}{ll} \frac{Q_{d.fi} \cdot L^2}{8} & \text{if } k_{l.cr} = 1 \\ \frac{Q_{d.fi} \cdot L^2}{12} & \text{if } k_{l.cr} = 0.5 \end{array} \right. = 114.075 \cdot kN \cdot m$$

$$M_{Ed.fi.y.n} := \left| \begin{array}{ll} \frac{Q_{d.fi} \cdot L^2}{8} & \text{if } k_{l.cr} = 1 \\ \frac{Q_{d.fi} \cdot L^2}{12} & \text{if } k_{l.cr} = 0.5 \end{array} \right. = 114.075 \cdot kN \cdot m$$

$V_{Ed.fi} := Q_{d.fi} \cdot \frac{L}{2} = 35.1 \cdot kN$

Design shear force fire

$\eta_{fi} := \frac{Q_{d.fi}}{Q_{d.ULS}} = 0.526$

Degree of Utilization at time t0 for fire

Eurocode 1993-1-1: Capacities without temperature load

Cross section class check [EN 1993-1-1, Section 5.6, Table 5.2]

$$c_{cs.f} := \frac{b_f - t_w}{2} - r = 0.117\,m$$

$$CSC_f := \begin{array}{|ll} "1" & \text{if } \frac{c_{cs.f}}{t_f} \le 9\cdot\varepsilon_{fi} \\ "2" & \text{if } 9\cdot\varepsilon_{fi} < \frac{c_{cs.f}}{t_f} \le 10\cdot\varepsilon_{fi} \\ "3" & \text{if } 10\cdot\varepsilon_{fi} < \frac{c_{cs.f}}{t_f} \le 14\cdot\varepsilon_{fi} \\ "4" & \text{otherwise} \end{array} = "1"$$

$$c_{cs.w} := h_w - 2\cdot r = 0.298\,m$$

$$CSC_w := \begin{array}{|ll} "1" & \text{if } \frac{c_{cs.w}}{t_w} \le 72\cdot\varepsilon_{fi} \\ "2" & \text{if } 72\cdot\varepsilon_{fi} < \frac{c_{cs.w}}{t_w} \le 83\cdot\varepsilon_{fi} \\ "3" & \text{if } 83\cdot\varepsilon_{fi} < \frac{c_{cs.w}}{t_w} \le 124\cdot\varepsilon_{fi} \\ "4" & \text{otherwise} \end{array} = "1"$$

Normal force, tension:

$$N_{Rd} := A \cdot \frac{f_y}{\gamma_{M.0}} = 5.422 \times 10^3 \cdot kN$$

Design values of the resistance to normal force
[EN 1993-1-1, Section 6.2.3, Eq. (6.6)].

Normal force, compression:

$$N_{cr.y} := \pi^2 \cdot E \cdot \frac{I_y}{L_{cr}^2} = 5.305 \times 10^3 \cdot kN$$

Elastic critical force for the relvant
buckling mode based on the gross
cross section properties

$$\lambda_y := \sqrt{A \cdot \frac{f_y}{N_{cr.y}}} = 1.011$$

Non dimensional slenderness
[EN 1993-1-1, Section 6.3.1.2, Eq.(6.49)]

$$N_{cr.z} := \pi^2 \cdot E \cdot \frac{I_z}{L_{cr}^2} = 1.049 \times 10^3 \cdot kN$$

Elastic critical force for the relvant
buckling mode based on the gross
cross section properties

$$\lambda_z := \sqrt{A \cdot \frac{f_y}{N_{cr.z}}} = 2.273$$

Non dimensional slenderness
[EN 1993-1-1, Section 6.3.1.2, Eq.(6.49)]

$$\alpha_{imp.y} := \left| \begin{array}{l} 0.13 \text{ if } Bucklingcurve_y = \text{"a.0"} \\ 0.21 \text{ if } Bucklingcurve_y = \text{"a"} \\ 0.34 \text{ if } Bucklingcurve_y = \text{"b"} \\ 0.49 \text{ if } Bucklingcurve_y = \text{"c"} \\ 0.76 \text{ if } Bucklingcurve_y = \text{"d"} \end{array} \right. = 0.21$$

Imperfection factor
[EN 1993-1-1, Section 6.3.1.2, Table 6.1]

$$\alpha_{imp.z} := \left| \begin{array}{l} 0.13 \text{ if } Bucklingcurve_z = \text{"a.0"} \\ 0.21 \text{ if } Bucklingcurve_z = \text{"a"} \\ 0.34 \text{ if } Bucklingcurve_z = \text{"b"} \\ 0.49 \text{ if } Bucklingcurve_z = \text{"c"} \\ 0.76 \text{ if } Bucklingcurve_z = \text{"d"} \end{array} \right. = 0.34$$

Imperfection factor
[EN 1993-1-1, Section 6.3.1.2, Table 6.1]

$$\Phi_y := 0.5 \cdot \left[1 + \alpha_{imp.y} \cdot \left(\lambda_y - 0.2 \right) + \lambda_y^{\,2} \right]$$

Value to determine the reduction factor χ
[EN 1993-1-1, Section 6.3.1.2, Eq. (6.49)]

$$\Phi_z := 0.5 \cdot \left[1 + \alpha_{imp.z} \cdot \left(\lambda_z - 0.2 \right) + \lambda_z^{\,2} \right]$$

$$\chi_y := \left| \begin{array}{ll} 1 \ \text{ if } \lambda_y \le 0.2 \\ \min\left(1, \dfrac{1}{\Phi_y + \sqrt{\Phi_y^{\,2} - \lambda_y^{\,2}}} \right) & \text{otherwise} \end{array} \right. = 0.658$$

Reduction factor
[EN 1993-1-1, Section 6.3.1.2, Eq. (6.49)]

$$\chi_z := \left| \begin{array}{ll} 1 \ \text{ if } \lambda_z \le 0.2 \\ \min\left(1, \dfrac{1}{\Phi_z + \sqrt{\Phi_z^{\,2} - \lambda_z^{\,2}}} \right) & \text{otherwise} \end{array} \right. = 0.166$$

$$N_{b.Rd.y} := \chi_y \cdot A \cdot \left(\frac{f_y}{\gamma_{M1}} \right) = 3.567 \times 10^3 \cdot kN$$

Design buckling resistance of a compression member in y-direction
[EN 1993-1-1, Section 6.3.1.1, Eq. (6.47)]

$$N_{b.Rd.z} := \chi_z \cdot A \cdot \left(\frac{f_y}{\gamma_{M1}} \right) = 901.55 \cdot kN$$

Design buckling resistance of a compression member in z-direction
[EN 1993-1-1, Section 6.3.1.1, Eq. (6.47)]

Bending capacity without Lateral torsional buckling:

$$M_{Rd} := W_{pl.y} \cdot \frac{f_y}{\gamma_{M1}} = 871.68 \cdot kN \cdot m$$

Design value of the resistance to bending moment
[EN 1993-1-1, Section 6.2.5, Eq. (6.13)]

Bending capacity with Lateral torsional buckling:

[NCCI: Elastic critical moment for lateral torsional buckling]

Coefficients depending on the loading and restraint condition

$$C_1 := \left| \begin{array}{l} 1.127 \ \text{ if } k_{l.cr} = 1 \\ 2.578 \ \text{ if } k_{l.cr} = 0.5 \\ \text{"WARNING, ERROR WITH LT FACTORS"} \ \text{ otherwise} \end{array} \right. = 1.127$$

$$C_2 := \left| \begin{array}{l} 0.454 \ \text{ if } k_{l.cr} = 1 \\ 1.554 \ \text{ if } k_{l.cr} = 0.5 \\ \text{"WARNING, ERRORWITH LT FACTORS"} \ \text{ otherwise} \end{array} \right. = 0.454$$

Warping constant

$$I_w := \frac{I_z \cdot \left(h_w + 2 \cdot t_f - t_f\right)^2}{4} = 2.943 \times 10^{12} \cdot mm^6$$

Torsion constant

$$I_t := \frac{\left[2 \cdot {t_f}^3 \cdot b_f + {t_w}^3 \cdot \left(h_w\right)\right]}{3} = 1.528 \times 10^6 \cdot mm^4$$

The beam length between points which have lateral retraint

$$L_{ef} := L = 13\,m$$

The distance between to point of load application and the shear center

$$z_g := \frac{h_w}{2} + t_f = 0.195\,m$$

Factor that refers to warping

$$k_w := 1$$

$$k := k_{l.cr} = 1$$

Elastic critical moment for lateral torsional buckling

$$M_{cr} := C_1 \cdot \frac{\pi^2 \cdot E \cdot I_z}{(k \cdot L)^2} \cdot \left[\left[\left(\frac{k}{k_w}\right)^2 \frac{I_w}{I_z} + \frac{(k \cdot L)^2 \cdot G \cdot I_t}{\pi^2 \cdot E \cdot I_z} + \left(C_2 \cdot z_g\right)^2 \right]^{0.5} - C_2 \cdot z_g \right]$$

$$M_{cr} = 368.085 \cdot kN \cdot m$$

$$\lambda_{LT} := \sqrt{W_{pl.y} \cdot \frac{f_y}{M_{cr}}}$$

Non dimensional slenderness
for lateral torsional buckling
[EN 1993-1-1, Section 6.3.2.2, Eq. (6.56)]

$$\alpha_{LT} := \left| \begin{array}{l} 0.21 \ \text{ if } \ \text{Bucklingcurve\_LT} = \text{"a"} \\ 0.34 \ \text{ if } \ \text{Bucklingcurve\_LT} = \text{"b"} \\ 0.49 \ \text{ if } \ \text{Bucklingcurve\_LT} = \text{"c"} \\ 0.76 \ \text{ if } \ \text{Bucklingcurve\_LT} = \text{"d"} \end{array} \right. = 0.21$$

Imperfection factor
[EN 1993-1-1, Section 6.3.2.2, Table 6.4]

$$\Phi_{LT} := 0.5 \cdot \left[1 + \alpha_{LT} \cdot \left(\lambda_{LT} - 0.2\right) + \lambda_{LT}^{\ 2} \right] = 1.825$$

Value to determine the
reduction factor χLT
[EN 1993-1-1, Section 6.3.2.2, Eq. (6.56)]

$$\chi_{LT} := \min\left(1 , \frac{1}{\Phi_{LT} + \sqrt{\Phi_{LT}^{\ 2} - \lambda_{LT}^{\ 2}}} \right) = 0.356$$

Reduction factor for lateral
torisonal buckling
[EN 1993-1-1, Section 6.3.2.2, Eq. (6.56)]

$$M_{b.Rd} := \chi_{LT} \cdot W_{pl.y} \cdot \frac{f_y}{\gamma_{M.fi}} = 310.751 \cdot kN \cdot m$$

Design buckling resistance
[EN 1993-1-1, Section 6.3.2.1, Eq. (6.55)]

Shear capacity:

$$\eta := \left| \begin{array}{l} 1.2 \ \text{ if } \ f_y \le 460MPa \\ 1.0 \ \text{ otherwise} \end{array} \right. = 1.2$$

Factor
[EN 1993-1-5, Section 5.1, Note 2]

$$k_{\tau.sl} := \max\left[9 \cdot \left(\frac{h_w}{a_L}\right)^2 \cdot \left[\left(\frac{I_{sl}}{t_w^{\ 3} \cdot h_w} \right)^3 \right]^{\frac{1}{4}} , \frac{2.1}{t_w} \cdot \left(\frac{I_{sl}}{h_w} \right)^{\frac{1}{3}} \right] = 0$$

Coefficient to calculate the
shear buckling coefficient
[EN 1993-1-5, Section A.3,
Eq. (A.5)]

$$k_\tau := \begin{cases} 5.34 + 4.0\cdot\left(\dfrac{h_w}{a_L}\right)^2 + k_{\tau.sl} & \text{if } \dfrac{a_L}{h_w} \geq 1 \\ 4.0 + 5.34\cdot\left(\dfrac{h_w}{a_L}\right)^2 + k_{\tau.sl} & \text{otherwise} \end{cases} = 5.34$$

Shear buckling coefficient
[EN 1993-1-5, Section A.3, Eq. (A.5)]

$$\lambda_w := \frac{\dfrac{h_w}{t_w}}{37.4\cdot\varepsilon\cdot\sqrt{k_\tau}} = 0.455$$

The slenderness parameter
[EN 1993-1-5, Section 5.3, Eq. (5.6)]

$$\chi_w := \begin{cases} \eta & \text{if } \lambda_w < \dfrac{0.83}{\eta} \\ \dfrac{0.83}{\lambda_w} & \text{if } \dfrac{0.83}{\eta} \leq \lambda_w < 1.08 \\ \dfrac{0.83}{\lambda_w} & \text{otherwise} \end{cases} = 1.2$$

The factor for the contribution of the web to the shear buckling resistance
[EN 1993-1-5, Section 5.3, Table 5.1]

$$V_{bw.Rd} := \chi_w\cdot h_w\cdot t_w\cdot\frac{f_y}{\sqrt{3}\cdot\gamma_{M1}} = 9.523\times10^5\,\text{N}$$

Contribution from the web to the shear resistance
[EN 1993-1-5, Section 5.2, Eq. (5.2)]

$$V_{pl} := \eta\cdot h_w\cdot t_w\cdot\frac{f_y}{\sqrt{3}\cdot\gamma_{M1}} = 952.323\cdot\text{kN}$$

Plastic shear resistance
[EN 1993-1-5, Section 5.2, Eq. (5.1)]

$$V_{Rd} := \min\left(V_{pl}, V_{bw.Rd}\right) = 952.323\cdot\text{kN}$$

Shear resistance
[EN 1993-1-5, Section 5.2, Eq. (5.1)]

Eurocode 1993-1-2: Reduction factors, k

Nomínal temperature parameters

$\theta_{a.n} := \Theta_{g.n} = 560.055$

Reduction factor for the yield strength of steel at temperature θa
[EN 1993-1-2, Section 3.2.2 Table 3.1]

$$k_{y.\theta.n} := \left| \begin{array}{l} 1 \ \text{ if } \ 20 \le \theta_{a.n} \le 400 \\ 1 - \dfrac{(1-0.78)}{(500-400)} \cdot \left(\theta_{a.n} - 400\right) \ \text{ if } \ 400 < \theta_{a.n} \le 500 \\ 0.78 - \dfrac{(0.78-0.47)}{(600-500)} \cdot \left(\theta_{a.n} - 500\right) \ \text{ if } \ 500 < \theta_{a.n} \le 600 \\ 0.47 - \dfrac{(0.47-0.23)}{(700-600)} \cdot \left(\theta_{a.n} - 600\right) \ \text{ if } \ 600 < \theta_{a.n} \le 700 \\ 0.23 - \dfrac{(0.23-0.11)}{(800-700)} \cdot \left(\theta_{a.n} - 700\right) \ \text{ if } \ 700 < \theta_{a.n} \le 800 \\ 0.11 - \dfrac{(0.11-0.06)}{(900-800)} \cdot \left(\theta_{a.n} - 800\right) \ \text{ if } \ 800 < \theta_{a.n} \le 900 \\ 0.06 - \dfrac{(0.06-0.04)}{(1000-900)} \cdot \left(\theta_{a.n} - 900\right) \ \text{ if } \ 900 < \theta_{a.n} \le 1000 \\ 0.04 - \dfrac{(0.04-0.02)}{(1100-1000)} \cdot \left(\theta_{a.n} - 1000\right) \ \text{ if } \ 1000 < \theta_{a.n} \le 1100 \\ 0.02 - \dfrac{(0.02-0)}{(1200-1100)} \cdot \left(\theta_{a.n} - 1100\right) \ \text{ if } \ 1100 < \theta_{a.n} \le 1200 \\ 0 \ \text{ otherwise} \end{array} \right. = 0.594$$

Reduction factor for the slope for the linear elastic range at the steel temperature θa
[EN 1993-1-2, Section 3.2.2 Table 3.1]

$$k_{E.\theta.n} := \begin{cases} 1 \text{ if } 20 \le \theta_{a.n} \le 100 \\ 1 - \frac{(1-0.9)}{(200-100)} \cdot (\theta_{a.n} - 100) \text{ if } 100 < \theta_{a.n} \le 200 \\ 0.9 - \frac{(0.9-0.8)}{(300-200)} \cdot (\theta_{a.n} - 200) \text{ if } 200 < \theta_{a.n} \le 300 \\ 0.8 - \frac{(0.8-0.7)}{(400-300)} \cdot (\theta_{a.n} - 300) \text{ if } 300 < \theta_{a.n} \le 400 \\ 0.7 - \frac{(0.7-0.6)}{(500-400)} \cdot (\theta_{a.n} - 400) \text{ if } 400 < \theta_{a.n} \le 500 \\ 0.6 - \frac{(0.6-0.31)}{(600-500)} \cdot (\theta_{a.n} - 500) \text{ if } 500 < \theta_{a.n} \le 600 \\ 0.31 - \frac{(0.31-0.13)}{(700-600)} \cdot (\theta_{a.n} - 600) \text{ if } 600 < \theta_{a.n} \le 700 \\ 0.13 - \frac{(0.13-0.09)}{(800-700)} \cdot (\theta_{a.n} - 700) \text{ if } 700 < \theta_{a.n} \le 800 \\ 0.09 - \frac{(0.09-0.0675)}{(900-800)} \cdot (\theta_{a.n} - 800) \text{ if } 800 < \theta_{a.n} \le 900 \\ 0.0675 - \frac{(0.0675-0.045)}{(1000-900)} \cdot (\theta_{a.n} - 900) \text{ if } 900 < \theta_{a.n} \le 1000 \\ 0.045 - \frac{(0.045-0.0225)}{(1100-1000)} \cdot (\theta_{a.n} - 1000) \text{ if } 1000 < \theta_{a.n} \le 1100 \\ 0.0225 - \frac{(0.0225-0)}{(1200-1100)} \cdot (\theta_{a.n} - 1100) \text{ if } 1100 < \theta_{a.n} \le 1200 \\ 0 \text{ otherwise} \end{cases} = 0.426$$

$$k_{z.\theta.n} := k_{y.\theta.n}$$

$$k_{y.\theta.com.n} := k_{y.\theta.n}$$

$$k_{E.\theta.com.n} := k_{E.\theta.n}$$

$$k_{y.\theta.web.n} := k_{y.\theta.n}$$

$$k_{E.\theta.web.n} := k_{E.\theta.n}$$

Eurocode 1993-1-2: Nominal temperature

$$\alpha := 0.65\cdot\left(235\,\frac{\mathrm{MPa}}{f_y}\right)^{0.5} = 0.529$$

Factor
[EN 1993-1-2, Section 4.2.3.3, Eq. (4.14)]

Bending capacity without Lateral torsional buckling:

$$M_{fi.\theta.Rd} := k_{y.\theta.n}\cdot M_{Rd}\cdot\left(\frac{\gamma_{M.0}}{\gamma_{M.fi}}\right) = 517.63\cdot\mathrm{kN\cdot m}$$

Design moment resistance
with the uniform temperature θa
[EN 1993-1-2, Section 4.2.3.3, Eq. (4.8)]

Bending capacity with Lateral torsional buckling:

$$\lambda_{LT.\theta.com} := \lambda_{LT}\cdot\left(\frac{k_{y.\theta.com.n}}{k_{E.\theta.com.n}}\right)^{0.5} = 1.817$$

Non dimensional slenderness for the
compression flange at temperature θa
[EN 1993-1-2, Section 4.2.3.3, Eq. (4.15)]

$$\phi_{LT.\theta.com} := \frac{1\cdot\left(1 + \alpha\cdot\lambda_{LT.\theta.com} + \lambda_{LT.\theta.com}^{\;2}\right)}{2} = 2.632$$

Value to determine
reduction factor
[EN 1993-1-2, Section 4.2.3.3,
Eq. (4.13)]

Reduction factor for lateral torsional buckling in the fire design situation
[EN 1993-1-2, Section 4.2.3.3, Eq. (4.12)]

$$\chi_{LT.fi} := \frac{1}{\phi_{LT.\theta.com} + \left(\phi_{LT.\theta.com}^{\;2} - \lambda_{LT.\theta.com}^{\;2}\right)^{0.5}} = 0.22$$

Design buckling resitance moment at time t of a lateral unrestrained member with cross section class 1 or 2. [EN 1993-1-2, Section 4.2.3.3, Eq. (4.11)]

$$M_{b.fi.t.Rd} := \chi_{LT.fi}\cdot W_{pl.y}\cdot k_{y.\theta.com.n}\cdot\frac{f_y}{\gamma_{M.fi}} = 114.135\cdot\mathrm{kN\cdot m}$$

Shear Capacity:

$$V_{fi.t.Rd} := k_{y.\theta.web.n} \cdot V_{Rd} \cdot \left(\frac{\gamma_{M.0}}{\gamma_{M.fi}} \right)$$

Design shear resistance at time t
of cross section class 1 or 2
[EN 1993-1-2, Section 4.2.3.3, Eq. (4.16)]

$$V_{fi.t.Rd} = 565.519 \cdot kN$$

Fire Capacities:

$$M_{fi.\theta.Rd.n} := M_{fi.\theta.Rd} = 517.63 \cdot kN \cdot m$$

Fire reduced capacities for nominal
temperature

$$M_{b.fi.t.Rd.n} := M_{b.fi.t.Rd} = 114.135 \cdot kN \cdot m$$

$$V_{fi.t.Rd.n} := V_{fi.t.Rd} = 565.519 \cdot kN$$

Checks

ULS checks

$$\text{Check} := \left| \begin{array}{ll} \text{"Bending moment capacity w/o LT buckling OK"} & \text{if } \dfrac{M_{Ed.ULS}}{M_{Rd}} \le 1 \\ \text{"Bending moment capacity w/o LT buckling NOT OK"} & \text{otherwise} \end{array} \right.$$

$$\frac{M_{Ed.ULS}}{M_{Rd}} = 0.249$$

Check = "Bending moment capacity w/o LT buckling OK"

$$\text{Check} := \left| \begin{array}{ll} \text{"Bending moment capacity w/ LT buckling OK"} & \text{if } \dfrac{M_{Ed.ULS}}{M_{b.Rd}} \le 1 \\ \text{"Bending moment capacity w/ LT buckling NOT OK"} & \text{otherwise} \end{array} \right.$$

$$\frac{M_{Ed.ULS}}{M_{b.Rd}} = 0.697$$

Check = "Bending moment capacity w/ LT buckling OK"

$$\text{Check} := \left| \begin{array}{ll} \text{"Shear force capacity OK"} & \text{if } \dfrac{V_{Ed.ULS}}{V_{Rd}} \le 1 \\ \text{"Shear force capacity NOT OK"} & \text{otherwise} \end{array} \right.$$

$$\frac{V_{Ed.ULS}}{V_{Rd}} = 0.07$$

Check = "Shear force capacity OK"

Fire check

$$C_M := \frac{M_{Ed.fi.y.n}}{M_{fi.\theta.Rd.n}}$$

$$Check := \begin{cases} \text{"Bending moment capacity w/o LT buckling OK, nominal temperature"} & \text{if } C_M \leq 1 \\ \text{"Bending moment capacity NOT OK w/o LT buckling, nominal temperature"} & \text{otherwise} \end{cases}$$

$$\frac{M_{Ed.fi.y.n}}{M_{fi.\theta.Rd.n}} = 0.22$$

Check = "Bending moment capacity w/o LT buckling OK, nominal temperature"

$$C_M := \frac{M_{Ed.fi.y.n}}{M_{b.fi.t.Rd.n}}$$

$$Check := \begin{cases} \text{"Bending moment capacity OK w/ LT buckling, nominal temperature"} & \text{if } C_M \leq 1 \\ \text{"Bending moment capacity NOT OK w/ LT buckling, nominal temperature"} & \text{otherwise} \end{cases}$$

$$\frac{M_{Ed.fi.y.n}}{M_{b.fi.t.Rd.n}} = 0.999$$

Check = "Bending moment capacity OK w/ LT buckling, nominal temperature"

$$Check := \begin{cases} \text{"Shear force OK, nominal temperature"} & \text{if } \frac{V_{Ed.fi}}{V_{fi.t.Rd.n}} \leq 1 \\ \text{"Shear force NOT OK, nominal temperature"} & \text{otherwise} \end{cases}$$

$$\frac{V_{Ed.fi}}{V_{fi.t.Rd.n}} = 0.062$$

Check = "Shear force OK, nominal temperature"

Warnings

$CSC_w = "1"$

$CSC_f = "1"$

$$\text{Loadcombinations} := \begin{cases} \text{"Load ratios probably OK"} & \text{if } 0.3 \cdot Q_k < G_k < 1.5Q_k \\ \text{"Look over chosen load ratios"} & \text{otherwise} \end{cases}$$

Loadcombinations = "Load ratios probably OK"

D

Parametric study: ADINA In-files Phase one

In figure D.1 the nomenclauture for the in files in the parametric study phase one is presented.

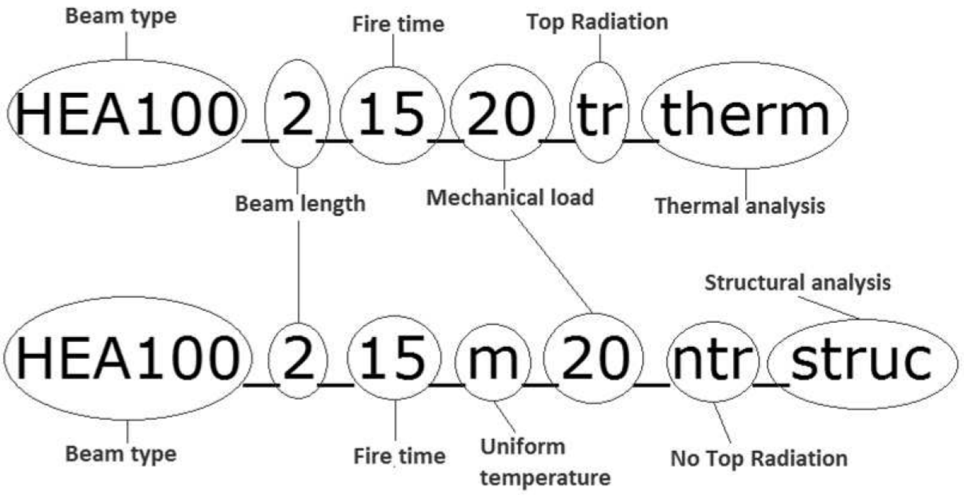

Figure D.1: Nomencalture for ADINA in files in Parametric study phase 1

```
FEPROGRAM PROGRAM=ADINA-T
*************** START READING FILES *****************

*Example of ADINA .in files for thermal analysis
*Parametric study phase 1

******************** GEOMETRY ********************

READ F='Geo_HEA400_12_30_20.6_tr_therm.in'

**************** MATERIALS&E GROUP ****************

READ F='Mtrl_HEA400_12_30_20.6_tr_therm.in'

********************** MESH **********************

READ F='Mesh_HEA400_12_30_20.6_tr_therm.in'

******************** TIME STEP ********************

READ F='Timestep_HEA400_12_30_20.6_tr_therm.in'

***************** TEMPERATURE LOAD ****************

READ F='Tempload_HEA400_12_30_20.6_tr_therm.in'

*************** SAVE THERMAL MAPPING ***************

READ F='Savemap_HEA400_12_30_20.6_tr_therm.in'

*************** END READING FILES *******************

*
*
```

```
******************** GEOMETRY ********************
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COORDINATES POINT SYSTEM=0
@CLEAR
1 0 0 0
2 0 0.1445 0
3 0 0.1555 0
4 0 0.3 0
5 0 0 -0.0095
6 0 0.1445 -0.0095
7 0 0.15 -0.0095
8 0 0.1555 -0.0095
9 0 0.3 -0.0095
10 0 0 -0.019
11 0 0.1445 -0.019
12 0 0.15 -0.019
13 0 0.1555 -0.019
14 0 0.3 -0.019
15 0 0.15 -0.195
16 0 0 -0.371
17 0 0.1445 -0.371
18 0 0.15 -0.371
19 0 0.1555 -0.371
20 0 0.3 -0.371
21 0 0 -0.3805
22 0 0.1445 -0.3805
23 0 0.15 -0.3805
24 0 0.1555 -0.3805
25 0 0.3 -0.3805
26 0 0 -0.39
27 0 0.1445 -0.39
28 0 0.1555 -0.39
29 0 0.3 -0.39
30 -12 0 -0.0095
31 -12 0.1445 -0.0095
32 -12 0.15 -0.0095
33 -12 0.1555 -0.0095
34 -12 0.3 -0.0095
35 -12 0.15 -0.019
36 -12 0.15 -0.195
37 -12 0.15 -0.371
38 -12 0 -0.3805
39 -12 0.1445 -0.3805
40 -12 0.15 -0.3805
41 -12 0.1555 -0.3805
42 -12 0.3 -0.3805
43 0.1 0.05 0
44 0 0 0.0905
45 -6.1 0.05 0
46 -6 0 0.0905
47 0 0.1445 0.1
48 0 0.1555 0.1
@
*
SURFACE VERTEX NAME=1 P1=1 P2=2 P3=11 P4=10
VOLUME EXTRUDED NAME=1 SURFACE=1 DX=-12,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=7 P1=2 P2=3 P3=13 P4=11
VOLUME EXTRUDED NAME=2 SURFACE=7 DX=-12,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
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```
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=13 P1=3 P2=4 P3=14 P4=13
VOLUME EXTRUDED NAME=3 SURFACE=13 DX=-12,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=19 P1=11 P2=13 P3=19 P4=17
VOLUME EXTRUDED NAME=4 SURFACE=19 DX=-12,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=25 P1=16 P2=17 P3=27 P4=26
VOLUME EXTRUDED NAME=5 SURFACE=25 DX=-12,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
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SURFACE VERTEX NAME=31 P1=17 P2=19 P3=28 P4=27
VOLUME EXTRUDED NAME=6 SURFACE=31 DX=-12,
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     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=37 P1=19 P2=20 P3=29 P4=28
VOLUME EXTRUDED NAME=7 SURFACE=37 DX=-12,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
*
LINE STRAIGHT NAME=61 P1=5 P2=6
*
LINE STRAIGHT NAME=62 P1=6 P2=7
*
LINE STRAIGHT NAME=63 P1=7 P2=8
*
LINE STRAIGHT NAME=64 P1=8 P2=9
*
LINE STRAIGHT NAME=65 P1=7 P2=12
*
LINE STRAIGHT NAME=66 P1=12 P2=15
*
LINE STRAIGHT NAME=67 P1=15 P2=18
*
LINE STRAIGHT NAME=68 P1=18 P2=23
*
*
LINE STRAIGHT NAME=69 P1=21 P2=22
*
LINE STRAIGHT NAME=70 P1=22 P2=23
*
LINE STRAIGHT NAME=71 P1=23 P2=24
*
LINE STRAIGHT NAME=72 P1=24 P2=25
*
LINE STRAIGHT NAME=73 P1=30 P2=31

LINE STRAIGHT NAME=74 P1=31 P2=32
*
LINE STRAIGHT NAME=75 P1=32 P2=33
*
```

```
LINE STRAIGHT NAME=76 P1=33 P2=34
*
LINE STRAIGHT NAME=77 P1=32 P2=35
*
LINE STRAIGHT NAME=78 P1=35 P2=36
*
LINE STRAIGHT NAME=79 P1=36 P2=37
*
LINE STRAIGHT NAME=80 P1=37 P2=40
*
LINE STRAIGHT NAME=81 P1=38 P2=39
*
LINE STRAIGHT NAME=82 P1=39 P2=40
*
LINE STRAIGHT NAME=83 P1=40 P2=41
*
LINE STRAIGHT NAME=84 P1=41 P2=42
```

```
*******************MATERIALS*******************
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     DENSITY=7850
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293 53.334 439.80176
622.213665756567 42.3711849303063 583.388761512031
717.504877875504 39.1979875667457 629.660953177154
775.289302991853 37.2737662103713 668.221020362955
816.887309257871 35.8885526017129 702.674163814492
849.410430568309 34.8055326620753 734.220631107051
876.117647609837 33.9161823345924 762.395115962911
898.77682520701 33.1616317206066 781.858422504833
918.455108041785 32.5063449022086 806.493977840188
935.846386741557 31.9272153215061 839.005653837134
951.427331513134 31.4083698606126 884.254450073302
965.539552292495 30.9384329086599 952.006862133333
978.436248321854 30.5089729308822 1065.27831806696
990.310308179129 30.113566737635 1294.42888683745
1001.31206300178 29.7472083020407 2008.08139487164
1011.56095275918 29.4059202731195 2901.84583247462
1021.15345005324 29.0864901132271 1583.85806905843
1030.16859566896 28.7862857642236 1225.96890736621
1038.67196077107 28.5031237063235 1058.95997237257
1046.71854363207 28.235172497052 962.149052493011
1054.35492723099 27.9808809232081 898.887910874265
1061.62091309172 27.7389235940458 854.262714591754
1068.55077689482 27.5081591294024 821.061743285216
1075.17424629904 27.3 795.371460557924
1081.51727160768 27.3 774.884251992095
1087.60263981007 27.3 758.151164131708
1093.45046870831 27.3 744.216396038222
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1109.73779275398 27.3 713.530092560778
1114.79587968833 27.3 705.836305917945
1119.68877474803 27.3 699.033959118437
1124.4269275493 27.3 692.97355012404
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1133.47611322906 27.3 682.631564275288
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1142.00975575101 27.3 674.121306700593
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1150.08344457464 27.3 666.985075392269
1153.96279645352 27.3 663.82947251869
1157.74423617968 27.3 660.90678416831
1161.43258479274 27.3 658.191306764479
1165.03231580061 27.3 655.661018016188
1168.54758780028 27.3 653.296938522302
1171.9822733588 27.3 651.082621955816
1175.33998465745 27.3 650
1178.62409632488 27.3 650
1181.837765821 27.3 650
1184.98395168043 27.3 650
1188.06542987952 27.3 650
1191.08480855396 27.3 650
1194.04454126253 27.3 650
1196.94693896595 27.3 650
1199.79418086736 27.3 650
1202.58832424191 27.3 650
@
*
MATERIAL CONSTH NAME=2 H=25.0 MDESCRIP='steel'
*
MATERIAL CONSTE NAME=3 E=0.8 ISIGMA=KELVIN,
```

```
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     DEGEN=NO DESCRIPT='NONE'
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EGROUP RADIATION NAME=4 SUBTYPE=SURFACE MATERIAL=3 DEGEN=NO,
     SHELLNOD=BOTTOM DESCRIPT='NONE' PROPERTY=1.00000000000000
*
EGROUP CONVECTION NAME=3 SUBTYPE=SURFACE MATERIAL=2 DEGEN=NO,
     SHELLNOD=BOTTOM DESCRIPT='NONE' PROPERTY=1.0
*
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     TORFAC=1.00000000000 SSHEARF=0.0000000000000000,
     TSHEARF=0.000000000000000 ISHEAR=NO SQUARE=NO
*
*
*
*
*
EGROUP BEAM NAME=2 SUBTYPE=THREE-D DISPLACE=DEFAULT MATERIAL=2 RINT=5,
     SINT=DEFAULT TINT=DEFAULT RESULTS=STRESSES INITIALS=NONE,
     CMASS=DEFAULT RIGIDEND=NONE MOMENT-C=NO RIGIDITY=1,
     MULTIPLY=1000000.00000000 RUPTURE=ADINA OPTION=NONE,
     BOLT-TOL=0.00000000000000 DESCRIPT='NONE' SECTION=1,
     PRINT=DEFAULT SAVE=DEFAULT TBIRTH=0.00000000000000,
     TDEATH=0.00000000000000 SPOINT=2 BOLTFORC=0.00000000000000,
     BOLTNCUR=0 TMC-MATE=1 BOLT-NUM=0 BOLT-LOA=0.00000000000000,
     WARP=NO ENDRELEA=ACCURATE
```

```
********************MESH********************
*****VOLUMES*****
SUBDIVIDE VOLUME NAME=1 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=655,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 1
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 1
@
*
SUBDIVIDE VOLUME NAME=2 MODE=DIVISIONS NDIV1=4 NDIV2=4 NDIV3=655,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 2
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 2
@
*
SUBDIVIDE VOLUME NAME=3 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=655,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 3
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 3
@
*
SUBDIVIDE VOLUME NAME=4 MODE=DIVISIONS NDIV1=4 NDIV2=48 NDIV3=655,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 4
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 4
```

```
@
*
SUBDIVIDE VOLUME NAME=5 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=655,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 5
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 5
@
*
SUBDIVIDE VOLUME NAME=6 MODE=DIVISIONS NDIV1=4 NDIV2=4 NDIV3=655,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 6
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 6
@
*
SUBDIVIDE VOLUME NAME=7 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=655,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 7
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 7
@
*****LINES*****
SUBDIVIDE LINE NAME=61 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 61
@
SUBDIVIDE LINE NAME=62 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 62
@
SUBDIVIDE LINE NAME=63 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 63
```

```
@
SUBDIVIDE LINE NAME=64 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 64
@
SUBDIVIDE LINE NAME=65 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 65
@
SUBDIVIDE LINE NAME=66 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 66
@
SUBDIVIDE LINE NAME=67 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 67
@
SUBDIVIDE LINE NAME=68 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 68
@
SUBDIVIDE LINE NAME=69 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 69
@
SUBDIVIDE LINE NAME=70 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 70
@
SUBDIVIDE LINE NAME=71 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 71
@
SUBDIVIDE LINE NAME=72 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 72
@
SUBDIVIDE LINE NAME=73 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 73
@
SUBDIVIDE LINE NAME=74 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 74
@
SUBDIVIDE LINE NAME=75 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 75
@
SUBDIVIDE LINE NAME=76 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
```

```
 76
@
SUBDIVIDE LINE NAME=77 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 77
@
SUBDIVIDE LINE NAME=78 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 78
@
SUBDIVIDE LINE NAME=79 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 79
@
SUBDIVIDE LINE NAME=80 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 80
@
SUBDIVIDE LINE NAME=81 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 81
@
SUBDIVIDE LINE NAME=82 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 82
@
SUBDIVIDE LINE NAME=83 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 83
@
SUBDIVIDE LINE NAME=84 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 84
@
GLINE NODES=2 AUXPOINT=30 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 61
@
GLINE NODES=2 AUXPOINT=31 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 62
@
GLINE NODES=2 AUXPOINT=32 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 63
@
GLINE NODES=2 AUXPOINT=33 NCOINCID=ENDS NCENDS=12,
```

```
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 64
@
GLINE NODES=2 AUXPOINT=32 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 65
@
GLINE NODES=2 AUXPOINT=35 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 66
@
GLINE NODES=2 AUXPOINT=36 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 67
@
GLINE NODES=2 AUXPOINT=37 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 68
@
GLINE NODES=2 AUXPOINT=38 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 69
@
GLINE NODES=2 AUXPOINT=39 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 70
@
GLINE NODES=2 AUXPOINT=40 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 71
@
GLINE NODES=2 AUXPOINT=41 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 72
@
GLINE NODES=2 AUXPOINT=5 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
```

```
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 73
@
GLINE NODES=2 AUXPOINT=6 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 74
@
GLINE NODES=2 AUXPOINT=7 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 75
@
GLINE NODES=2 AUXPOINT=8 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 76
@
GLINE NODES=2 AUXPOINT=7 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 77
@
GLINE NODES=2 AUXPOINT=12 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 78
@
GLINE NODES=2 AUXPOINT=15 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 79
@
GLINE NODES=2 AUXPOINT=18 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 80
@
GLINE NODES=2 AUXPOINT=21 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 81
@
GLINE NODES=2 AUXPOINT=22 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
```

```
     XYZOSYST=SKEW
@CLEAR
 82
@
GLINE NODES=2 AUXPOINT=23 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 83
@
GLINE NODES=2 AUXPOINT=24 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 84
@
*****SURFACES*****
*
GSURFACE NODES=4 PATTERN=AUTOMATIC NCOINCID=ALL,
     NCTOLERA=1.0E-05 SUBSTRUC=0 GROUP=3,
     PREFSHAP=AUTOMATIC MESHING=MAPPED SMOOTHIN=NO DEGENERA=NO,
     COLLAPSE=NO MIDNODES=CURVED METHOD=ADVFRONT FLIP=NO
@CLEAR
 1
 2
*
 4
 5
 6
 7
 8
*
*
 11
*
 13
 14
 15
 16
 17
*
 19
 20
*
 22
 23
*
 25
 26
*
 28
 29
 30
 31
*
 33
 34
*
*
 37
 38
 39
```

```
 40
 41
@
*
GSURFACE NODES=4 PATTERN=AUTOMATIC NCOINCID=ALL,
     NCTOLERA=1.0E-05 SUBSTRUC=0 GROUP=4,
     PREFSHAP=AUTOMATIC MESHING=MAPPED SMOOTHIN=NO DEGENERA=NO,
     COLLAPSE=NO MIDNODES=CURVED METHOD=ADVFRONT FLIP=NO
@CLEAR
 1
 2
*
 4
 5
 6
 7
 8
*
*
 11
*
 13
 14
 15
 16
 17
*
 19
 20
*
 22
 23
*
 25
 26
*
 28
 29
 30
 31
*
 33
 34
*
*
 37
 38
 39
 40
 41
@
*
```

```
******************** TIME STEP ********************
*
TIMESTEP NAME=TEMP
@CLEAR
100 18
@
*
TIMEFUNCTION NAME=1
@CLEAR
0 293
18 476.360226379578
36 556.382657779213
54 608.265779072382
72 646.730523516346
90 677.310456545859
108 702.69464868858
126 724.394900796568
144 743.346222459085
162 760.167411505853
180 775.289302991853
198 789.023944173034
216 801.604611106308
234 813.210275735062
252 823.981254083508
270 834.029594803113
288 843.446196529823
306 852.305817212387
324 860.670682925437
342 868.59314125805
360 876.117647609837
378 883.28227605337
396 890.119885104904
414 896.659028871326
432 902.924677526241
450 908.938793078715
468 914.720793969198
486 920.287933296815
504 925.655609256485
522 930.837621862872
540 935.846386741557
558 940.693114325072
576 945.387960961443
594 949.940157058036
612 954.358116325532
630 958.649529371431
648 962.821444258869
666 966.88033615022
684 970.832167763502
702 974.682442058619
720 978.436248321855
738 982.098302617073
756 985.672983410255
774.000000000001 989.164363042409
792.000000000001 992.576235618241
810.000000000001 995.912141789515
828.000000000001 999.17539083901
846.000000000001 1002.36908041037
864.000000000001 1005.49611417874
882.000000000001 1008.55921771474
900.000000000001 1011.56095275918
918.000000000001 1014.50373009554
936.000000000001 1017.38982118269
954.000000000001 1020.22136868807
972.000000000001 1023.00039604397
```

```
990.000000000001 1025.72881613364
1008 1028.40843920045
1026 1031.0409800622
1044 1033.62806470257
1062 1036.17123630297
1080 1038.67196077107
1098 1041.13163181545
1116 1043.55157561039
1134 1045.93305508992
1152 1048.2772739059
1170 1050.58538008119
1188 1052.85846938573
1206 1055.09758846031
1224 1057.30373771028
1242 1059.47787398942
1260 1061.62091309172
1278 1063.73373206758
1296 1065.81717137886
1314 1067.87203690623
1332 1069.89910182062
1350 1071.89910832987
1368 1073.87276931023
1386 1075.82076983188
1404 1077.74376858648
1422 1079.6423992243
1440 1081.51727160768
1458 1083.36897298705
1476 1085.1980691051
1494 1087.00510523444
1512 1088.79060715337
1530 1090.55508206424
1548 1092.29901945829
1566 1094.02289193085
1584 1095.72715595004
1602 1097.41225258233
1620 1099.07860817774
1638 1100.72663501735
1656 1102.35673192553
1674 1103.96928484934
1692 1105.56466740695
1710 1107.14324140726
1728 1108.70535734243
1746 1110.25135485491
1764 1111.78156318074
1782 1113.29630157034
1800 1114.79587968833
```

```
******************* TEMPERATURE LOAD ******************
INITIAL-COND NAME=IN
@CLEAR
'TEMPERATURE' 293
@
*
SET-INITCOND VOLUMES CONDITIO=IN
@CLEAR
1  'IN' 0
2  'IN' 0
3  'IN' 0
4  'IN' 0
5  'IN' 0
6  'IN' 0
7  'IN' 0
@
*
LOAD CONVECTION NAME=1 MAGNITUD=1.0 C-PROP=0
*
LOAD RADIATION NAME=1 MAGNITUD=1.0 R-PROP=0
*
APPLY-LOAD BODY=0
@CLEAR
1  'CONVECTION' 1  'SURFACE' 1  0  1  0   'TOP'  0  0
2  'CONVECTION' 1  'SURFACE' 2  0  1  0   'TOP'  0  0
*
3  'CONVECTION' 1  'SURFACE' 4  0  1  0   'TOP'  0  0
4  'CONVECTION' 1  'SURFACE' 5  0  1  0   'TOP'  0  0
5  'CONVECTION' 1  'SURFACE' 6  0  1  0   'TOP'  0  0
6  'CONVECTION' 1  'SURFACE' 7  0  1  0   'TOP'  0  0
7  'CONVECTION' 1  'SURFACE' 8  0  1  0   'TOP'  0  0
*
*
8  'CONVECTION' 1  'SURFACE' 11  0  1  0   'TOP'  0  0
*
9  'CONVECTION' 1  'SURFACE' 13  0  1  0   'TOP'  0  0
10  'CONVECTION' 1  'SURFACE' 14  0  1  0   'TOP'  0  0
11  'CONVECTION' 1  'SURFACE' 15  0  1  0   'TOP'  0  0
12  'CONVECTION' 1  'SURFACE' 16  0  1  0   'TOP'  0  0
13  'CONVECTION' 1  'SURFACE' 17  0  1  0   'TOP'  0  0
*
14  'CONVECTION' 1  'SURFACE' 19  0  1  0   'TOP'  0  0
15  'CONVECTION' 1  'SURFACE' 20  0  1  0   'TOP'  0  0
*
16  'CONVECTION' 1  'SURFACE' 22  0  1  0   'TOP'  0  0
17  'CONVECTION' 1  'SURFACE' 23  0  1  0   'TOP'  0  0
*
18  'CONVECTION' 1  'SURFACE' 25  0  1  0   'TOP'  0  0
19  'CONVECTION' 1  'SURFACE' 26  0  1  0   'TOP'  0  0
*
20  'CONVECTION' 1  'SURFACE' 28  0  1  0   'TOP'  0  0
21  'CONVECTION' 1  'SURFACE' 29  0  1  0   'TOP'  0  0
22  'CONVECTION' 1  'SURFACE' 30  0  1  0   'TOP'  0  0
23  'CONVECTION' 1  'SURFACE' 31  0  1  0   'TOP'  0  0
*
24  'CONVECTION' 1  'SURFACE' 33  0  1  0   'TOP'  0  0
25  'CONVECTION' 1  'SURFACE' 34  0  1  0   'TOP'  0  0
*
*
26  'CONVECTION' 1  'SURFACE' 37  0  1  0   'TOP'  0  0
27  'CONVECTION' 1  'SURFACE' 38  0  1  0   'TOP'  0  0
28  'CONVECTION' 1  'SURFACE' 39  0  1  0   'TOP'  0  0
29  'CONVECTION' 1  'SURFACE' 40  0  1  0   'TOP'  0  0
30  'CONVECTION' 1  'SURFACE' 41  0  1  0   'TOP'  0  0
```

```
31  'RADIATION' 1  'SURFACE' 1 0 1 0  'TOP' 0 0
32  'RADIATION' 1  'SURFACE' 2 0 1 0  'TOP' 0 0
*
33  'RADIATION' 1  'SURFACE' 4 0 1 0  'TOP' 0 0
34  'RADIATION' 1  'SURFACE' 5 0 1 0  'TOP' 0 0
35  'RADIATION' 1  'SURFACE' 6 0 1 0  'TOP' 0 0
36  'RADIATION' 1  'SURFACE' 7 0 1 0  'TOP' 0 0
37  'RADIATION' 1  'SURFACE' 8 0 1 0  'TOP' 0 0
*
*
38  'RADIATION' 1  'SURFACE' 11 0 1 0  'TOP' 0 0
*
39  'RADIATION' 1  'SURFACE' 13 0 1 0  'TOP' 0 0
40  'RADIATION' 1  'SURFACE' 14 0 1 0  'TOP' 0 0
41  'RADIATION' 1  'SURFACE' 15 0 1 0  'TOP' 0 0
42  'RADIATION' 1  'SURFACE' 16 0 1 0  'TOP' 0 0
43  'RADIATION' 1  'SURFACE' 17 0 1 0  'TOP' 0 0
*
44  'RADIATION' 1  'SURFACE' 19 0 1 0  'TOP' 0 0
45  'RADIATION' 1  'SURFACE' 20 0 1 0  'TOP' 0 0
*
46  'RADIATION' 1  'SURFACE' 22 0 1 0  'TOP' 0 0
47  'RADIATION' 1  'SURFACE' 23 0 1 0  'TOP' 0 0
*
48  'RADIATION' 1  'SURFACE' 25 0 1 0  'TOP' 0 0
49  'RADIATION' 1  'SURFACE' 26 0 1 0  'TOP' 0 0
*
50  'RADIATION' 1  'SURFACE' 28 0 1 0  'TOP' 0 0
51  'RADIATION' 1  'SURFACE' 29 0 1 0  'TOP' 0 0
52  'RADIATION' 1  'SURFACE' 30 0 1 0  'TOP' 0 0
53  'RADIATION' 1  'SURFACE' 31 0 1 0  'TOP' 0 0
*
54  'RADIATION' 1  'SURFACE' 33 0 1 0  'TOP' 0 0
55  'RADIATION' 1  'SURFACE' 34 0 1 0  'TOP' 0 0
*
*
56  'RADIATION' 1  'SURFACE' 37 0 1 0  'TOP' 0 0
57  'RADIATION' 1  'SURFACE' 38 0 1 0  'TOP' 0 0
58  'RADIATION' 1  'SURFACE' 39 0 1 0  'TOP' 0 0
59  'RADIATION' 1  'SURFACE' 40 0 1 0  'TOP' 0 0
60  'RADIATION' 1  'SURFACE' 41 0 1 0  'TOP' 0 0
*
```

```
********************SAVE MAP FILE ********************
MASTER ANALYSIS=TRANSIENT MODEX=EXECUTE TSTART=0.0,
     AUTOMATI=OFF IRINT=DEFAULT MAP-OUTP=YES MAP-FORM=NO,
     SOLVER=SPARSE MAXSOLME=0 MTOTM=2 RECL=3000 TMC-ITER=DEFAULT,
     RESULTS=PORTHOLE IPOSIT=STOP
```

```
FEPROGRAM PROGRAM=ADINA
*************** START READING FILES *****************

*Example of ADINA .in files for structural analysis
*Parametric study phase 1

******************** GEOMETRY ********************

READ F='Geo_HEA400_12_30_20.6_tr_struc.in'

**************** MATERIALS&E GROUP ****************

READ F='Mtrl_HEA400_12_30_20.6_tr_struc.in'

********************** MESH **********************

READ F='Mesh_HEA400_12_30_20.6_tr_struc.in'

******************** TIME STEP ********************

READ F='Timestep_HEA400_12_30_20.6_tr_struc.in'
READ F='Timestep2_HEA400_12_30_20.6_tr_struc.in'

***************** MECHANICAL LOAD *****************

READ F='Load_HEA400_12_30_20.6_tr_struc.in'

*************** BOUNDARY CONDITIONS ***************

READ F='BC_HEA400_12_30_20.6_tr_struc.in'

*************** IMPORT THERMAL MAPPING ************

READ F='Thermap_HEA400_12_30_20.6_tr_struc.in'

*************** END READING FILES ******************

*
*
```

```
******************* GEOMETRY *******************
*
COORDINATES POINT SYSTEM=0
@CLEAR
1 0 0 0
2 0 0.1445 0
3 0 0.1555 0
4 0 0.3 0
5 0 0 -0.0095
6 0 0.1445 -0.0095
7 0 0.15 -0.0095
8 0 0.1555 -0.0095
9 0 0.3 -0.0095
10 0 0 -0.019
11 0 0.1445 -0.019
12 0 0.15 -0.019
13 0 0.1555 -0.019
14 0 0.3 -0.019
15 0 0.15 -0.195
16 0 0 -0.371
17 0 0.1445 -0.371
18 0 0.15 -0.371
19 0 0.1555 -0.371
20 0 0.3 -0.371
21 0 0 -0.3805
22 0 0.1445 -0.3805
23 0 0.15 -0.3805
24 0 0.1555 -0.3805
25 0 0.3 -0.3805
26 0 0 -0.39
27 0 0.1445 -0.39
28 0 0.1555 -0.39
29 0 0.3 -0.39
30 -12 0 -0.0095
31 -12 0.1445 -0.0095
32 -12 0.15 -0.0095
33 -12 0.1555 -0.0095
34 -12 0.3 -0.0095
35 -12 0.15 -0.019
36 -12 0.15 -0.195
37 -12 0.15 -0.371
38 -12 0 -0.3805
39 -12 0.1445 -0.3805
40 -12 0.15 -0.3805
41 -12 0.1555 -0.3805
42 -12 0.3 -0.3805
43 0.1 0.05 0
44 0 0 0.0905
45 -6.1 0.05 0
46 -6 0 0.0905
47 0 0.1445 0.1
48 0 0.1555 0.1
@
*
SURFACE VERTEX NAME=1 P1=1 P2=2 P3=11 P4=10
VOLUME EXTRUDED NAME=1 SURFACE=1 DX=-12,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=7 P1=2 P2=3 P3=13 P4=11
VOLUME EXTRUDED NAME=2 SURFACE=7 DX=-12,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
```

```
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=13 P1=3 P2=4 P3=14 P4=13
VOLUME EXTRUDED NAME=3 SURFACE=13 DX=-12,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=19 P1=11 P2=13 P3=19 P4=17
VOLUME EXTRUDED NAME=4 SURFACE=19 DX=-12,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=25 P1=16 P2=17 P3=27 P4=26
VOLUME EXTRUDED NAME=5 SURFACE=25 DX=-12,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=31 P1=17 P2=19 P3=28 P4=27
VOLUME EXTRUDED NAME=6 SURFACE=31 DX=-12,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=37 P1=19 P2=20 P3=29 P4=28
VOLUME EXTRUDED NAME=7 SURFACE=37 DX=-12,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
*
LINE STRAIGHT NAME=61 P1=5 P2=6
*
LINE STRAIGHT NAME=62 P1=6 P2=7
*
LINE STRAIGHT NAME=63 P1=7 P2=8
*
LINE STRAIGHT NAME=64 P1=8 P2=9
*
LINE STRAIGHT NAME=65 P1=7 P2=12
*
LINE STRAIGHT NAME=66 P1=12 P2=15
*
LINE STRAIGHT NAME=67 P1=15 P2=18
*
LINE STRAIGHT NAME=68 P1=18 P2=23
*
*
LINE STRAIGHT NAME=69 P1=21 P2=22
*
LINE STRAIGHT NAME=70 P1=22 P2=23
*
LINE STRAIGHT NAME=71 P1=23 P2=24
*
LINE STRAIGHT NAME=72 P1=24 P2=25
*
LINE STRAIGHT NAME=73 P1=30 P2=31

LINE STRAIGHT NAME=74 P1=31 P2=32
*
LINE STRAIGHT NAME=75 P1=32 P2=33
*
```

```
LINE STRAIGHT NAME=76 P1=33 P2=34
*
LINE STRAIGHT NAME=77 P1=32 P2=35
*
LINE STRAIGHT NAME=78 P1=35 P2=36
*
LINE STRAIGHT NAME=79 P1=36 P2=37
*
LINE STRAIGHT NAME=80 P1=37 P2=40
*
LINE STRAIGHT NAME=81 P1=38 P2=39
*
LINE STRAIGHT NAME=82 P1=39 P2=40
*
LINE STRAIGHT NAME=83 P1=40 P2=41
*
LINE STRAIGHT NAME=84 P1=41 P2=42
```

```
*******************MATERIALS*******************
MATERIAL THERMO-PLASTIC NAME=1 HARDENIN=ISOTROPIC,
     TREF=293 TOLIL=1.0E-10,
     DENSITY=7850.0 MDESCRIP='STEEL' DEPENDEN=NO,
     TRANSITI=0.00010 BVALUE=0.0
@CLEAR
293 210e9 0.3 355e6 21000000 0.00001216 0.2 0
373 210e9 0.3 355e6 21000000 0.0000128 0.2 0
473 189e9 0.3 355e6 21000000 0.0000136 0.2 0
573 168e9 0.3 355e6 21000000 0.0000144 0.2 0
673 147e9 0.3 355e6 21000000 0.0000152 0.15 0
773 126e9 0.3 276.9e6 21000000 0.000016 0.15 0
873 65.1e9 0.3 166.85e6 21000000 0.0000168 0.15 0
973 27.3e9 0.3 81.65e6 21000000 0.0000176 0.15 0
1023 23.1e9 0.3 60.35e6 21000000 0.000018 0.15 0
1073 18.9e9 0.3 39.05e6 21000000 0 0.15 0
1133 16.065e9 0.3 28.4e6 21000000 0 0.15 0
1173 14.175e9 0.3 21.3e6 21000000 0.00002 0.15 0
1273 9.45e9 0.3 14.2e6 21000000 0.00002 0.15 0
1373 4.725e9 0.3 7.1e6 21000000 0.00002 0.15 0
1473 2.1E-28e9 0.3 3.55E-28e6 21000000 0.00002 0.15 0
@
*
*
MATERIAL ELASTIC NAME=2 E=210e9 NU=0.3,
     DENSITY=7850.00000000000 ALPHA=0.000015008 MDESCRIP=,
'NONE'
*
*******************EGROUP*******************
EGROUP THREEDSOLID NAME=1 DISPLACE=LARGE STRAINS=DEFAULT MATERIAL=1,
     RSINT=DEFAULT TINT=DEFAULT RESULTS=STRESSES DEGEN=DEFAUL,
     FORMULAT=0 STRESSRE=GLOBAL INITIALS=NONE FRACTUR=NO,
     CMASS=DEFAULT STRAIN-F=0 UL-FORMU=DEFAULT LVUS1=0 LVUS2=0 SED=NO,
     RUPTURE=ADINA INCOMPAT=DEFAULT TIME-OFF=0.0,
     POROUS=NO WTMC=1.0 OPTION=NONE DESCRIPT='NONE',
     PRINT=DEFAULT SAVE=DEFAULT TBIRTH=0.0,
     TDEATH=0.0 TMC-MATE=1 RUPTURE-=0 EM=NO JOULE=NO,
     BOLT-NUM=0 BOLT-PLA=0 BOLT-LOA=0.0,
     BOLT-TOL=0.0 TETINT=DEFAULT
*
CROSS-SECTIO RECTANGULAR NAME=1 WIDTH=3.425,
     HEIGHT=0.00685 SC=0.00000000000000 TC=0.0000000000000000000,
     TORFAC=1.00000000000 SSHEARF=0.000000000000000,
     TSHEARF=0.000000000000000 ISHEAR=NO SQUARE=NO
*
*
*
*
*
EGROUP BEAM NAME=2 SUBTYPE=THREE-D DISPLACE=DEFAULT MATERIAL=2 RINT=5,
     SINT=DEFAULT TINT=DEFAULT RESULTS=STRESSES INITIALS=NONE,
     CMASS=DEFAULT RIGIDEND=NONE MOMENT-C=NO RIGIDITY=1,
     MULTIPLY=1000000.00000000 RUPTURE=ADINA OPTION=NONE,
     BOLT-TOL=0.00000000000000 DESCRIPT='NONE' SECTION=1,
     PRINT=DEFAULT SAVE=DEFAULT TBIRTH=0.00000000000000,
     TDEATH=0.00000000000000 SPOINT=2 BOLTFORC=0.00000000000000,
     BOLTNCUR=0 TMC-MATE=1 BOLT-NUM=0 BOLT-LOA=0.00000000000000,
     WARP=NO ENDRELEA=ACCURATE
```

```
*******************MESH*******************
*****VOLUMES*****
SUBDIVIDE VOLUME NAME=1 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=655,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 1
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 1
@
*
SUBDIVIDE VOLUME NAME=2 MODE=DIVISIONS NDIV1=4 NDIV2=4 NDIV3=655,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 2
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 2
@
*
SUBDIVIDE VOLUME NAME=3 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=655,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 3
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 3
@
*
SUBDIVIDE VOLUME NAME=4 MODE=DIVISIONS NDIV1=4 NDIV2=48 NDIV3=655,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 4
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 4
```

```
@
*
SUBDIVIDE VOLUME NAME=5 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=655,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 5
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 5
@
*
SUBDIVIDE VOLUME NAME=6 MODE=DIVISIONS NDIV1=4 NDIV2=4 NDIV3=655,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 6
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 6
@
*
SUBDIVIDE VOLUME NAME=7 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=655,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 7
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 7
@
*****LINES*****
SUBDIVIDE LINE NAME=61 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 61
@
SUBDIVIDE LINE NAME=62 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 62
@
SUBDIVIDE LINE NAME=63 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 63
```

```
@
SUBDIVIDE LINE NAME=64 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 64
@
SUBDIVIDE LINE NAME=65 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 65
@
SUBDIVIDE LINE NAME=66 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 66
@
SUBDIVIDE LINE NAME=67 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 67
@
SUBDIVIDE LINE NAME=68 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 68
@
SUBDIVIDE LINE NAME=69 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 69
@
SUBDIVIDE LINE NAME=70 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 70
@
SUBDIVIDE LINE NAME=71 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 71
@
SUBDIVIDE LINE NAME=72 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 72
@
SUBDIVIDE LINE NAME=73 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 73
@
SUBDIVIDE LINE NAME=74 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 74
@
SUBDIVIDE LINE NAME=75 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 75
@
SUBDIVIDE LINE NAME=76 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
```

```
 76
@
SUBDIVIDE LINE NAME=77 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 77
@
SUBDIVIDE LINE NAME=78 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 78
@
SUBDIVIDE LINE NAME=79 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 79
@
SUBDIVIDE LINE NAME=80 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 80
@
SUBDIVIDE LINE NAME=81 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 81
@
SUBDIVIDE LINE NAME=82 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 82
@
SUBDIVIDE LINE NAME=83 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 83
@
SUBDIVIDE LINE NAME=84 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 84
@
GLINE NODES=2 AUXPOINT=30 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 61
@
GLINE NODES=2 AUXPOINT=31 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 62
@
GLINE NODES=2 AUXPOINT=32 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 63
@
GLINE NODES=2 AUXPOINT=33 NCOINCID=ENDS NCENDS=12,
```

```
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 64
@
GLINE NODES=2 AUXPOINT=32 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 65
@
GLINE NODES=2 AUXPOINT=35 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 66
@
GLINE NODES=2 AUXPOINT=36 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 67
@
GLINE NODES=2 AUXPOINT=37 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 68
@
GLINE NODES=2 AUXPOINT=38 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 69
@
GLINE NODES=2 AUXPOINT=39 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 70
@
GLINE NODES=2 AUXPOINT=40 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 71
@
GLINE NODES=2 AUXPOINT=41 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 72
@
GLINE NODES=2 AUXPOINT=5 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
```

```
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 73
@
GLINE NODES=2 AUXPOINT=6 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 74
@
GLINE NODES=2 AUXPOINT=7 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 75
@
GLINE NODES=2 AUXPOINT=8 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 76
@
GLINE NODES=2 AUXPOINT=7 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 77
@
GLINE NODES=2 AUXPOINT=12 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 78
@
GLINE NODES=2 AUXPOINT=15 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 79
@
GLINE NODES=2 AUXPOINT=18 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 80
@
GLINE NODES=2 AUXPOINT=21 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 81
@
GLINE NODES=2 AUXPOINT=22 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
```

```
     XYZOSYST=SKEW
@CLEAR
 82
@
GLINE NODES=2 AUXPOINT=23 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 83
@
GLINE NODES=2 AUXPOINT=24 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 84
@
```

```
******************* TIME STEP *******************
*
TIMESTEP NAME=TEMP
@CLEAR
100 18
@
*
TIMEFUNCTION NAME=1
@CLEAR
0 293
18 476.360226379578
36 556.382657779213
54 608.265779072382
72 646.730523516346
90 677.310456545859
108 702.69464868858
126 724.394900796568
144 743.346222459085
162 760.167411505853
180 775.289302991853
198 789.023944173034
216 801.604611106308
234 813.210275735062
252 823.981254083508
270 834.029594803113
288 843.446196529823
306 852.305817212387
324 860.670682925437
342 868.59314125805
360 876.117647609837
378 883.28227605337
396 890.119885104904
414 896.659028871326
432 902.924677526241
450 908.938793078715
468 914.720793969198
486 920.287933296815
504 925.655609256485
522 930.837621862872
540 935.846386741557
558 940.693114325072
576 945.387960961443
594 949.940157058036
612 954.358116325532
630 958.649529371431
648 962.821444258869
666 966.88033615022
684 970.832167763502
702 974.682442058619
720 978.436248321855
738 982.098302617073
756 985.672983410255
774.000000000001 989.164363042409
792.000000000001 992.576235618241
810.000000000001 995.912141789515
828.000000000001 999.17539083901
846.000000000001 1002.36908041037
864.000000000001 1005.49611417874
882.000000000001 1008.55921771474
900.000000000001 1011.56095275918
918.000000000001 1014.50373009554
936.000000000001 1017.38982118269
954.000000000001 1020.22136868807
972.000000000001 1023.00039604397
```

```
990.000000000001 1025.72881613364
1008 1028.40843920045
1026 1031.0409800622
1044 1033.62806470257
1062 1036.17123630297
1080 1038.67196077107
1098 1041.13163181545
1116 1043.55157561039
1134 1045.93305508992
1152 1048.2772739059
1170 1050.58538008119
1188 1052.85846938573
1206 1055.09758846031
1224 1057.30373771028
1242 1059.47787398942
1260 1061.62091309172
1278 1063.73373206758
1296 1065.81717137886
1314 1067.87203690623
1332 1069.89910182062
1350 1071.89910832987
1368 1073.87276931023
1386 1075.82076983188
1404 1077.74376858648
1422 1079.6423992243
1440 1081.51727160768
1458 1083.36897298705
1476 1085.1980691051
1494 1087.00510523444
1512 1088.79060715337
1530 1090.55508206424
1548 1092.29901945829
1566 1094.02289193085
1584 1095.72715595004
1602 1097.41225258233
1620 1099.07860817774
1638 1100.72663501735
1656 1102.35673192553
1674 1103.96928484934
1692 1105.56466740695
1710 1107.14324140726
1728 1108.70535734243
1746 1110.25135485491
1764 1111.78156318074
1782 1113.29630157034
1800 1114.79587968833
```

```
TIMEFUNCTION NAME=2 IFLIB=1 FPAR1=0.0,
     FPAR2=0.0 FPAR3=0.0,
     FPAR4=0.0 FPAR5=0.0,
     FPAR6=0.0
@CLEAR
0.0 1.0
1800 1.0
@
```

```
******************* TIME STEP LOAD *******************
*
LOAD LINE NAME=1 MAGNITUD=10300
*
*
APPLY-LOAD BODY=0
@CLEAR
1  'LINE' 1  'LINE' 6 0 2 0.00 0 -1 11 0 0  'NO',
     0.0 0.0 1 0  'MID'
2  'LINE' 1  'LINE' 16 0 2 0.0 0 -1 13 0 0  'NO',
     0.0 0.0 1 0  'MID'
@
```

```
******************** BOUNDARY CONDITIONS ********************
FIXITY NAME=Y
@CLEAR
 'Y-TRANSLATION'
 'OVALIZATION'
@
*
FIXITY NAME=XYZ
@CLEAR
 'X-TRANSLATION'
 'Y-TRANSLATION'
 'Z-TRANSLATION'
 'OVALIZATION'
@
FIXITY NAME=YZ
@CLEAR
 'Y-TRANSLATION'
 'Z-TRANSLATION'
 'OVALIZATION'
@
*
FIXBOUNDARY TWO-D FIXITY=ALL
@CLEAR
16 0  'Y'
50 0  'Y'
@
*
FIXBOUNDARY POINTS FIXITY=ALL
@CLEAR
7  'Y'
23  'Y'
32  'Y'
40  'Y'
15  'XYZ'
36  'YZ'
@
```

```
*******************THERMAL MAPPING *******************
THERMAL-MAPP FILENAME=,
'HEA400_12_30_20.6_tr_therm.map',
 EXTERNAL=ALL TIME=0.0 TOLERANC=1.0E-15
```

E

Parametric study: ADINA In-files Phase two

```
FEPROGRAM PROGRAM=ADINA-T
*************** START READING FILES ****************

* Example of ADINA in files for thermal analysis
* Parametric study Phase 2 with initial imperfections

******************** GEOMETRY ********************

READ F='Geo_HEA400_13_30_5.4_ntr_therm_LTb.in'

**************** MATERIALS&E GROUP ****************

READ F='Mtrl_HEA400_13_30_5.4_ntr_therm_LTb.in'

********************** MESH **********************

READ F='Mesh_HEA400_13_30_5.4_ntr_therm_LTb.in'

******************** TIME STEP ********************

READ F='Timestep_HEA400_13_30_5.4_ntr_therm_LTb.in'

***************** TEMPERATURE LOAD ****************

READ F='Tempload_HEA400_13_30_5.4_ntr_therm_LTb.in'

*************** SAVE THERMAL MAPPING ***************

READ F='Savemap_HEA400_13_30_5.4_ntr_therm_LTb.in'

*************** END READING FILES *******************
```

```
*******************MATERIALS*******************
MATERIAL TEMPDEP-C-K NAME=1 JOULE-HE=NO MDESCRIP='steel',
     DENSITY=7850
@CLEAR
293 53.334 439.80176
622.213665756567 42.3711849303063 583.388761512031
717.504877875504 39.1979875667457 629.660953177154
775.289302991853 37.2737662103713 668.221020362955
816.887309257871 35.8885526017129 702.674163814492
849.410430568309 34.8055326620753 734.220631107051
876.117647609837 33.9161823345924 762.395115962911
898.77682520701 33.1616317206066 781.858422504833
918.455108041785 32.5063449022086 806.493977840188
935.846386741557 31.9272153215061 839.005653837134
951.427331513134 31.4083698606126 884.254450073302
965.539552292495 30.9384329086599 952.006862133333
978.436248321854 30.5089729308822 1065.27831806696
990.310308179129 30.113566737635 1294.42888683745
1001.31206300178 29.7472083020407 2008.08139487164
1011.56095275918 29.4059202731195 2901.84583247462
1021.15345005324 29.0864901132271 1583.85806905843
1030.16859566896 28.7862857642236 1225.96890736621
1038.67196077107 28.5031237063235 1058.95997237257
1046.71854363207 28.235172497052 962.149052493011
1054.35492723099 27.9808809232081 898.887910874265
1061.62091309172 27.7389235940458 854.262714591754
1068.55077689482 27.5081591294024 821.061743285216
1075.17424629904 27.3 795.371460557924
1081.51727160768 27.3 774.884251992095
1087.60263981007 27.3 758.151164131708
1093.45046870831 27.3 744.216396038222
1099.07860817774 27.3 732.423862649386
1104.50296874842 27.3 722.308195189808
1109.73779275398 27.3 713.530092560778
1114.79587968833 27.3 705.836305917945
1119.68877474803 27.3 699.033959118437
1124.4269275493 27.3 692.97355012404
1129.0198265082 27.3 687.537391849855
1133.47611322906 27.3 682.631564275288
1137.80368036725 27.3 678.180193183694
1142.00975575101 27.3 674.121306700593
1146.10097501444 27.3 670.40378416256
1150.08344457464 27.3 666.985075392269
1153.96279645352 27.3 663.82947251869
1157.74423617968 27.3 660.90678416831
1161.43258479274 27.3 658.191306764479
1165.03231580061 27.3 655.661018016188
1168.54758780028 27.3 653.296938522302
1171.9822733588 27.3 651.082621955816
1175.33998465745 27.3 650
1178.62409632488 27.3 650
1181.837765821 27.3 650
1184.98395168043 27.3 650
1188.06542987952 27.3 650
1191.08480855396 27.3 650
1194.04454126253 27.3 650
1196.94693896595 27.3 650
1199.79418086736 27.3 650
1202.58832424191 27.3 650
@
*
MATERIAL CONSTH NAME=2 H=25.0 MDESCRIP='steel'
*
MATERIAL CONSTE NAME=3 E=0.8 ISIGMA=KELVIN,
```

```
     SIGMA=5.66960E-08 MDESCRIP='steel'
*
********************EGROUP********************
EGROUP THREEDCONDUCTION NAME=1 MATERIAL=1 RSINT=DEFAULT TINT=DEFAULT,
     DEGEN=NO DESCRIPT='NONE'
*
EGROUP RADIATION NAME=4 SUBTYPE=SURFACE MATERIAL=3 DEGEN=NO,
     SHELLNOD=BOTTOM DESCRIPT='NONE' PROPERTY=1.00000000000000
*
EGROUP CONVECTION NAME=3 SUBTYPE=SURFACE MATERIAL=2 DEGEN=NO,
     SHELLNOD=BOTTOM DESCRIPT='NONE' PROPERTY=1.0
*
CROSS-SECTIO RECTANGULAR NAME=1 WIDTH=3.425,
     HEIGHT=0.00685 SC=0.00000000000000 TC=0.0000000000000000000,
     TORFAC=1.00000000000 SSHEARF=0.000000000000000,
     TSHEARF=0.000000000000000 ISHEAR=NO SQUARE=NO
*
*
*
*
*
EGROUP BEAM NAME=2 SUBTYPE=THREE-D DISPLACE=DEFAULT MATERIAL=2 RINT=5,
     SINT=DEFAULT TINT=DEFAULT RESULTS=STRESSES INITIALS=NONE,
     CMASS=DEFAULT RIGIDEND=NONE MOMENT-C=NO RIGIDITY=1,
     MULTIPLY=1000000.00000000 RUPTURE=ADINA OPTION=NONE,
     BOLT-TOL=0.00000000000000 DESCRIPT='NONE' SECTION=1,
     PRINT=DEFAULT SAVE=DEFAULT TBIRTH=0.00000000000000,
     TDEATH=0.00000000000000 SPOINT=2 BOLTFORC=0.00000000000000,
     BOLTNCUR=0 TMC-MATE=1 BOLT-NUM=0 BOLT-LOA=0.00000000000000,
     WARP=NO ENDRELEA=ACCURATE
```

```
*******************MESH*******************
*****VOLUMES*****
SUBDIVIDE VOLUME NAME=1 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=710,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 1
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 1
@
*
SUBDIVIDE VOLUME NAME=2 MODE=DIVISIONS NDIV1=4 NDIV2=4 NDIV3=710,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 2
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 2
@
*
SUBDIVIDE VOLUME NAME=3 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=710,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 3
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 3
@
*
SUBDIVIDE VOLUME NAME=4 MODE=DIVISIONS NDIV1=4 NDIV2=48 NDIV3=710,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 4
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 4
```

```
@
*
SUBDIVIDE VOLUME NAME=5 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=710,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 5
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 5
@
*
SUBDIVIDE VOLUME NAME=6 MODE=DIVISIONS NDIV1=4 NDIV2=4 NDIV3=710,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 6
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 6
@
*
SUBDIVIDE VOLUME NAME=7 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=710,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 7
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 7
@
*****LINES*****
SUBDIVIDE LINE NAME=61 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 61
@
SUBDIVIDE LINE NAME=62 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 62
@
SUBDIVIDE LINE NAME=63 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 63
```

```
@
SUBDIVIDE LINE NAME=64 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 64
@
SUBDIVIDE LINE NAME=65 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 65
@
SUBDIVIDE LINE NAME=66 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 66
@
SUBDIVIDE LINE NAME=67 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 67
@
SUBDIVIDE LINE NAME=68 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 68
@
SUBDIVIDE LINE NAME=69 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 69
@
SUBDIVIDE LINE NAME=70 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 70
@
SUBDIVIDE LINE NAME=71 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 71
@
SUBDIVIDE LINE NAME=72 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 72
@
SUBDIVIDE LINE NAME=73 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 73
@
SUBDIVIDE LINE NAME=74 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 74
@
SUBDIVIDE LINE NAME=75 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 75
@
SUBDIVIDE LINE NAME=76 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
```

```
 76
@
SUBDIVIDE LINE NAME=77 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 77
@
SUBDIVIDE LINE NAME=78 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 78
@
SUBDIVIDE LINE NAME=79 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 79
@
SUBDIVIDE LINE NAME=80 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 80
@
SUBDIVIDE LINE NAME=81 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 81
@
SUBDIVIDE LINE NAME=82 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 82
@
SUBDIVIDE LINE NAME=83 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 83
@
SUBDIVIDE LINE NAME=84 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 84
@
GLINE NODES=2 AUXPOINT=30 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 61
@
GLINE NODES=2 AUXPOINT=31 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 62
@
GLINE NODES=2 AUXPOINT=32 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 63
@
GLINE NODES=2 AUXPOINT=33 NCOINCID=ENDS NCENDS=12,
```

```
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 64
@
GLINE NODES=2 AUXPOINT=32 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 65
@
GLINE NODES=2 AUXPOINT=35 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 66
@
GLINE NODES=2 AUXPOINT=36 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 67
@
GLINE NODES=2 AUXPOINT=37 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 68
@
GLINE NODES=2 AUXPOINT=38 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 69
@
GLINE NODES=2 AUXPOINT=39 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 70
@
GLINE NODES=2 AUXPOINT=40 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 71
@
GLINE NODES=2 AUXPOINT=41 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 72
@
GLINE NODES=2 AUXPOINT=5 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
```

```
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 73
@
GLINE NODES=2 AUXPOINT=6 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 74
@
GLINE NODES=2 AUXPOINT=7 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 75
@
GLINE NODES=2 AUXPOINT=8 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 76
@
GLINE NODES=2 AUXPOINT=7 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 77
@
GLINE NODES=2 AUXPOINT=12 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 78
@
GLINE NODES=2 AUXPOINT=15 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 79
@
GLINE NODES=2 AUXPOINT=18 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 80
@
GLINE NODES=2 AUXPOINT=21 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 81
@
GLINE NODES=2 AUXPOINT=22 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
```

```
     XYZOSYST=SKEW
@CLEAR
 82
@
GLINE NODES=2 AUXPOINT=23 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 83
@
GLINE NODES=2 AUXPOINT=24 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 84
@
*****SURFACES*****
*
GSURFACE NODES=4 PATTERN=AUTOMATIC NCOINCID=ALL,
     NCTOLERA=1.0E-05 SUBSTRUC=0 GROUP=3,
     PREFSHAP=AUTOMATIC MESHING=MAPPED SMOOTHIN=NO DEGENERA=NO,
     COLLAPSE=NO MIDNODES=CURVED METHOD=ADVFRONT FLIP=NO
@CLEAR
 1
 2
*
 4
 5
 6
 7
 8
*
*
 11
*
 13
 14
 15
 16
 17
*
 19
 20
*
 22
 23
*
 25
 26
*
 28
 29
 30
 31
*
 33
 34
*
*
 37
 38
 39
```

```
 40
 41
@
*
GSURFACE NODES=4 PATTERN=AUTOMATIC NCOINCID=ALL,
     NCTOLERA=1.0E-05 SUBSTRUC=0 GROUP=4,
     PREFSHAP=AUTOMATIC MESHING=MAPPED SMOOTHIN=NO DEGENERA=NO,
     COLLAPSE=NO MIDNODES=CURVED METHOD=ADVFRONT FLIP=NO
@CLEAR
 1
*
*
 4
 5
 6
 7
*
*
*
 11
*
 13
*
 15
 16
 17
*
 19
 20
*
 22
 23
*
 25
 26
*
 28
 29
 30
 31
*
 33
 34
*
*
 37
 38
 39
 40
 41
@
*
```

```
******************** TIME STEP ********************
*
TIMESTEP NAME=TEMP
@CLEAR
100 18
@
*
TIMEFUNCTION NAME=1
@CLEAR
0 293
18 476.360226379578
36 556.382657779213
54 608.265779072382
72 646.730523516346
90 677.310456545859
108 702.69464868858
126 724.394900796568
144 743.346222459085
162 760.167411505853
180 775.289302991853
198 789.023944173034
216 801.604611106308
234 813.210275735062
252 823.981254083508
270 834.029594803113
288 843.446196529823
306 852.305817212387
324 860.670682925437
342 868.59314125805
360 876.117647609837
378 883.28227605337
396 890.119885104904
414 896.659028871326
432 902.924677526241
450 908.938793078715
468 914.720793969198
486 920.287933296815
504 925.655609256485
522 930.837621862872
540 935.846386741557
558 940.693114325072
576 945.387960961443
594 949.940157058036
612 954.358116325532
630 958.649529371431
648 962.821444258869
666 966.88033615022
684 970.832167763502
702 974.682442058619
720 978.436248321855
738 982.098302617073
756 985.672983410255
774.000000000001 989.164363042409
792.000000000001 992.576235618241
810.000000000001 995.912141789515
828.000000000001 999.17539083901
846.000000000001 1002.36908041037
864.000000000001 1005.49611417874
882.000000000001 1008.55921771474
900.000000000001 1011.56095275918
918.000000000001 1014.50373009554
936.000000000001 1017.38982118269
954.000000000001 1020.22136868807
972.000000000001 1023.00039604397
```

```
990.000000000001 1025.72881613364
1008 1028.40843920045
1026 1031.0409800622
1044 1033.62806470257
1062 1036.17123630297
1080 1038.67196077107
1098 1041.13163181545
1116 1043.55157561039
1134 1045.93305508992
1152 1048.2772739059
1170 1050.58538008119
1188 1052.85846938573
1206 1055.09758846031
1224 1057.30373771028
1242 1059.47787398942
1260 1061.62091309172
1278 1063.73373206758
1296 1065.81717137886
1314 1067.87203690623
1332 1069.89910182062
1350 1071.89910832987
1368 1073.87276931023
1386 1075.82076983188
1404 1077.74376858648
1422 1079.6423992243
1440 1081.51727160768
1458 1083.36897298705
1476 1085.1980691051
1494 1087.00510523444
1512 1088.79060715337
1530 1090.55508206424
1548 1092.29901945829
1566 1094.02289193085
1584 1095.72715595004
1602 1097.41225258233
1620 1099.07860817774
1638 1100.72663501735
1656 1102.35673192553
1674 1103.96928484934
1692 1105.56466740695
1710 1107.14324140726
1728 1108.70535734243
1746 1110.25135485491
1764 1111.78156318074
1782 1113.29630157034
1800 1114.79587968833
```

```
******************* TEMPERATURE LOAD ******************
INITIAL-COND NAME=IN
@CLEAR
'TEMPERATURE' 293
@
*
SET-INITCOND VOLUMES CONDITIO=IN
@CLEAR
1  'IN' 0
2  'IN' 0
3  'IN' 0
4  'IN' 0
5  'IN' 0
6  'IN' 0
7  'IN' 0
@
*
LOAD CONVECTION NAME=1 MAGNITUD=1.0 C-PROP=0
*
LOAD RADIATION NAME=1 MAGNITUD=1.0 R-PROP=0
*
APPLY-LOAD BODY=0
@CLEAR
1  'CONVECTION' 1  'SURFACE' 1  0  1  0   'TOP'  0  0
2  'CONVECTION' 1  'SURFACE' 2  0  1  0   'TOP'  0  0
*
3  'CONVECTION' 1  'SURFACE' 4  0  1  0   'TOP'  0  0
4  'CONVECTION' 1  'SURFACE' 5  0  1  0   'TOP'  0  0
5  'CONVECTION' 1  'SURFACE' 6  0  1  0   'TOP'  0  0
6  'CONVECTION' 1  'SURFACE' 7  0  1  0   'TOP'  0  0
7  'CONVECTION' 1  'SURFACE' 8  0  1  0   'TOP'  0  0
*
*
8  'CONVECTION' 1  'SURFACE' 11  0  1  0   'TOP'  0  0
*
9  'CONVECTION' 1  'SURFACE' 13  0  1  0   'TOP'  0  0
10  'CONVECTION' 1  'SURFACE' 14  0  1  0   'TOP'  0  0
11  'CONVECTION' 1  'SURFACE' 15  0  1  0   'TOP'  0  0
12  'CONVECTION' 1  'SURFACE' 16  0  1  0   'TOP'  0  0
13  'CONVECTION' 1  'SURFACE' 17  0  1  0   'TOP'  0  0
*
14  'CONVECTION' 1  'SURFACE' 19  0  1  0   'TOP'  0  0
15  'CONVECTION' 1  'SURFACE' 20  0  1  0   'TOP'  0  0
*
16  'CONVECTION' 1  'SURFACE' 22  0  1  0   'TOP'  0  0
17  'CONVECTION' 1  'SURFACE' 23  0  1  0   'TOP'  0  0
*
18  'CONVECTION' 1  'SURFACE' 25  0  1  0   'TOP'  0  0
19  'CONVECTION' 1  'SURFACE' 26  0  1  0   'TOP'  0  0
*
20  'CONVECTION' 1  'SURFACE' 28  0  1  0   'TOP'  0  0
21  'CONVECTION' 1  'SURFACE' 29  0  1  0   'TOP'  0  0
22  'CONVECTION' 1  'SURFACE' 30  0  1  0   'TOP'  0  0
23  'CONVECTION' 1  'SURFACE' 31  0  1  0   'TOP'  0  0
*
24  'CONVECTION' 1  'SURFACE' 33  0  1  0   'TOP'  0  0
25  'CONVECTION' 1  'SURFACE' 34  0  1  0   'TOP'  0  0
*
*
26  'CONVECTION' 1  'SURFACE' 37  0  1  0   'TOP'  0  0
27  'CONVECTION' 1  'SURFACE' 38  0  1  0   'TOP'  0  0
28  'CONVECTION' 1  'SURFACE' 39  0  1  0   'TOP'  0  0
29  'CONVECTION' 1  'SURFACE' 40  0  1  0   'TOP'  0  0
30  'CONVECTION' 1  'SURFACE' 41  0  1  0   'TOP'  0  0
```

```
31  'RADIATION' 1  'SURFACE' 1 0 1 0  'TOP' 0 0
*
*
32  'RADIATION' 1  'SURFACE' 4 0 1 0  'TOP' 0 0
33  'RADIATION' 1  'SURFACE' 5 0 1 0  'TOP' 0 0
34  'RADIATION' 1  'SURFACE' 6 0 1 0  'TOP' 0 0
35  'RADIATION' 1  'SURFACE' 7 0 1 0  'TOP' 0 0
*
*
*
36  'RADIATION' 1  'SURFACE' 11 0 1 0  'TOP' 0 0
*
37  'RADIATION' 1  'SURFACE' 13 0 1 0  'TOP' 0 0
*
38  'RADIATION' 1  'SURFACE' 15 0 1 0  'TOP' 0 0
39  'RADIATION' 1  'SURFACE' 16 0 1 0  'TOP' 0 0
40  'RADIATION' 1  'SURFACE' 17 0 1 0  'TOP' 0 0
*
41  'RADIATION' 1  'SURFACE' 19 0 1 0  'TOP' 0 0
42  'RADIATION' 1  'SURFACE' 20 0 1 0  'TOP' 0 0
*
43  'RADIATION' 1  'SURFACE' 22 0 1 0  'TOP' 0 0
44  'RADIATION' 1  'SURFACE' 23 0 1 0  'TOP' 0 0
*
45  'RADIATION' 1  'SURFACE' 25 0 1 0  'TOP' 0 0
46  'RADIATION' 1  'SURFACE' 26 0 1 0  'TOP' 0 0
*
47  'RADIATION' 1  'SURFACE' 28 0 1 0  'TOP' 0 0
48  'RADIATION' 1  'SURFACE' 29 0 1 0  'TOP' 0 0
49  'RADIATION' 1  'SURFACE' 30 0 1 0  'TOP' 0 0
50  'RADIATION' 1  'SURFACE' 31 0 1 0  'TOP' 0 0
*
51  'RADIATION' 1  'SURFACE' 33 0 1 0  'TOP' 0 0
52  'RADIATION' 1  'SURFACE' 34 0 1 0  'TOP' 0 0
*
*
53  'RADIATION' 1  'SURFACE' 37 0 1 0  'TOP' 0 0
54  'RADIATION' 1  'SURFACE' 38 0 1 0  'TOP' 0 0
55  'RADIATION' 1  'SURFACE' 39 0 1 0  'TOP' 0 0
56  'RADIATION' 1  'SURFACE' 40 0 1 0  'TOP' 0 0
57  'RADIATION' 1  'SURFACE' 41 0 1 0  'TOP' 0 0
*
```

```
********************SAVE MAP FILE ********************
MASTER ANALYSIS=TRANSIENT MODEX=EXECUTE TSTART=0.0,
     AUTOMATI=OFF IRINT=DEFAULT MAP-OUTP=YES MAP-FORM=NO,
     SOLVER=SPARSE MAXSOLME=0 MTOTM=2 RECL=3000 TMC-ITER=DEFAULT,
     RESULTS=PORTHOLE IPOSIT=STOP
```

```
FEPROGRAM PROGRAM=ADINA
*************** START READING FILES **************

* Example of ADINA in files for linearized buckling analysis
* Parametric study Phase 2 with initial imperfections

******************** SETTINGS ********************

MASTER ANALYSIS=BUCKLING-LOADS MODEX=EXECUTE TSTART=0.00000000000000,
     IDOF=0 OVALIZAT=NONE FLUIDPOT=AUTOMATIC CYCLICPA=1 IPOSIT=STOP,
     REACTION=YES INITIALS=NO FSINTERA=NO IRINT=DEFAULT CMASS=NO,
     SHELLNDO=AUTOMATIC AUTOMATI=ATS SOLVER=SPARSE,
     CONTACT-=CONSTRAINT-FUNCTION TRELEASE=0.00000000000000,
     RESTART-=NO FRACTURE=NO LOAD-CAS=NO LOAD-PEN=NO SINGULAR=YES,
     STIFFNES=0.000100000000000000 MAP-OUTP=NONE MAP-FORM=NO,
     NODAL-DE='' POROUS-C=NO ADAPTIVE=0 ZOOM-LAB=1 AXIS-CYC=0,
     PERIODIC=NO VECTOR-S=GEOMETRY EPSI-FIR=NO STABILIZ=NO,

******************** GEOMETRY ********************

READ F='Geo_HEA400_13_30_5.4_ntr_struc_LTb.in'

**************** MATERIALS&E GROUP ***************

READ F='Mtrl_buck_HEA400_13_30_5.4_ntr_struc_LTb.in'

********************** MESH **********************

READ F='Mesh_HEA400_13_30_5.4_ntr_struc_LTb.in'

******************** TIME STEP *******************

*
READ F='Timestep2_HEA400_13_30_5.4_ntr_struc_LTb.in'

***************** MECHANICAL LOAD ***************

READ F='Load_buck_HEA400_13_30_5.4_ntr_struc_LTb.in'

*************** BOUNDARY CONDITIONS *************

READ F='BC_HEA400_13_30_5.4_ntr_struc_LTb.in'

*************** MODE SHAPES *********************

BUCKLING-LOA NEIGEN=2 NMODE=0 IPRINT=NO NITEMM=40 NVECTOR=DEFAULT,
     TOLERANC=DEFAULT STARTTYP=LANCZOS NSTVECTO=0 METHOD=CLASSICAL


*************** END READING FILES ****************
```

```
******************* GEOMETRY *******************
*
COORDINATES POINT SYSTEM=0
@CLEAR
1 0 0 0
2 0 0.1445 0
3 0 0.1555 0
4 0 0.3 0
5 0 0 -0.0095
6 0 0.1445 -0.0095
7 0 0.15 -0.0095
8 0 0.1555 -0.0095
9 0 0.3 -0.0095
10 0 0 -0.019
11 0 0.1445 -0.019
12 0 0.15 -0.019
13 0 0.1555 -0.019
14 0 0.3 -0.019
15 0 0.15 -0.195
16 0 0 -0.371
17 0 0.1445 -0.371
18 0 0.15 -0.371
19 0 0.1555 -0.371
20 0 0.3 -0.371
21 0 0 -0.3805
22 0 0.1445 -0.3805
23 0 0.15 -0.3805
24 0 0.1555 -0.3805
25 0 0.3 -0.3805
26 0 0 -0.39
27 0 0.1445 -0.39
28 0 0.1555 -0.39
29 0 0.3 -0.39
30 -13 0 -0.0095
31 -13 0.1445 -0.0095
32 -13 0.15 -0.0095
33 -13 0.1555 -0.0095
34 -13 0.3 -0.0095
35 -13 0.15 -0.019
36 -13 0.15 -0.195
37 -13 0.15 -0.371
38 -13 0 -0.3805
39 -13 0.1445 -0.3805
40 -13 0.15 -0.3805
41 -13 0.1555 -0.3805
42 -13 0.3 -0.3805
43 0.1 0.05 0
44 0 0 0.0905
45 -13.1 0.05 0
46 -13 0 0.0905
47 0 0.1445 0.1
48 0 0.1555 0.1
49 -6.5 0.1555 -0.195
@
*
SURFACE VERTEX NAME=1 P1=1 P2=2 P3=11 P4=10
VOLUME EXTRUDED NAME=1 SURFACE=1 DX=-13,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=7 P1=2 P2=3 P3=13 P4=11
VOLUME EXTRUDED NAME=2 SURFACE=7 DX=-13,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
```

```
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=13 P1=3 P2=4 P3=14 P4=13
VOLUME EXTRUDED NAME=3 SURFACE=13 DX=-13,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=19 P1=11 P2=13 P3=19 P4=17
VOLUME EXTRUDED NAME=4 SURFACE=19 DX=-13,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=25 P1=16 P2=17 P3=27 P4=26
VOLUME EXTRUDED NAME=5 SURFACE=25 DX=-13,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=31 P1=17 P2=19 P3=28 P4=27
VOLUME EXTRUDED NAME=6 SURFACE=31 DX=-13,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=37 P1=19 P2=20 P3=29 P4=28
VOLUME EXTRUDED NAME=7 SURFACE=37 DX=-13,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
*
LINE STRAIGHT NAME=61 P1=5 P2=6
*
LINE STRAIGHT NAME=62 P1=6 P2=7
*
LINE STRAIGHT NAME=63 P1=7 P2=8
*
LINE STRAIGHT NAME=64 P1=8 P2=9
*
LINE STRAIGHT NAME=65 P1=7 P2=12
*
LINE STRAIGHT NAME=66 P1=12 P2=15
*
LINE STRAIGHT NAME=67 P1=15 P2=18
*
LINE STRAIGHT NAME=68 P1=18 P2=23
*
*
LINE STRAIGHT NAME=69 P1=21 P2=22
*
LINE STRAIGHT NAME=70 P1=22 P2=23
*
LINE STRAIGHT NAME=71 P1=23 P2=24
*
LINE STRAIGHT NAME=72 P1=24 P2=25
*
LINE STRAIGHT NAME=73 P1=30 P2=31

LINE STRAIGHT NAME=74 P1=31 P2=32
*
LINE STRAIGHT NAME=75 P1=32 P2=33
```

```
*
LINE STRAIGHT NAME=76 P1=33 P2=34
*
LINE STRAIGHT NAME=77 P1=32 P2=35
*
LINE STRAIGHT NAME=78 P1=35 P2=36
*
LINE STRAIGHT NAME=79 P1=36 P2=37
*
LINE STRAIGHT NAME=80 P1=37 P2=40
*
LINE STRAIGHT NAME=81 P1=38 P2=39
*
LINE STRAIGHT NAME=82 P1=39 P2=40
*
LINE STRAIGHT NAME=83 P1=40 P2=41
*
LINE STRAIGHT NAME=84 P1=41 P2=42
```

```
********************MATERIALS********************
MATERIAL THERMO-PLASTIC NAME=1 HARDENIN=ISOTROPIC,
     TREF=0 TOLIL=1.0E-10,
     DENSITY=7850.0 MDESCRIP='STEEL' DEPENDEN=NO,
     TRANSITI=0.00010 BVALUE=0.0
@CLEAR
0 210e9 0.3 355e6 21000000 0.00001216 0.2 0
373 210e9 0.3 355e6 21000000 0.0000128 0.2 0
473 189e9 0.3 355e6 21000000 0.0000136 0.2 0
573 168e9 0.3 355e6 21000000 0.0000144 0.2 0
673 147e9 0.3 355e6 21000000 0.0000152 0.15 0
773 126e9 0.3 276.9e6 21000000 0.000016 0.15 0
873 65.1e9 0.3 166.85e6 21000000 0.0000168 0.15 0
973 27.3e9 0.3 81.65e6 21000000 0.0000176 0.15 0
1023 23.1e9 0.3 60.35e6 21000000 0.000018 0.15 0
1073 18.9e9 0.3 39.05e6 21000000 0 0.15 0
1133 16.065e9 0.3 28.4e6 21000000 0 0.15 0
1173 14.175e9 0.3 21.3e6 21000000 0.00002 0.15 0
1273 9.45e9 0.3 14.2e6 21000000 0.00002 0.15 0
1373 4.725e9 0.3 7.1e6 21000000 0.00002 0.15 0
1473 2.1E-28e9 0.3 3.55E-28e6 21000000 0.00002 0.15 0
@
*
*
MATERIAL ELASTIC NAME=2 E=210e9 NU=0.3,
     DENSITY=7850.00000000000 ALPHA=0.000015172 MDESCRIP=,
'NONE'
*
********************EGROUP********************
EGROUP THREEDSOLID NAME=1 DISPLACE=LARGE STRAINS=DEFAULT MATERIAL=1,
     RSINT=DEFAULT TINT=DEFAULT RESULTS=STRESSES DEGEN=DEFAUL,
     FORMULAT=0 STRESSRE=GLOBAL INITIALS=NONE FRACTUR=NO,
     CMASS=DEFAULT STRAIN-F=0 UL-FORMU=DEFAULT LVUS1=0 LVUS2=0 SED=NO,
     RUPTURE=ADINA INCOMPAT=DEFAULT TIME-OFF=0.0,
     POROUS=NO WTMC=1.0 OPTION=NONE DESCRIPT='NONE',
     PRINT=DEFAULT SAVE=DEFAULT TBIRTH=0.0,
     TDEATH=0.0 TMC-MATE=1 RUPTURE-=0 EM=NO JOULE=NO,
     BOLT-NUM=0 BOLT-PLA=0 BOLT-LOA=0.0,
     BOLT-TOL=0.0 TETINT=DEFAULT
*
CROSS-SECTIO RECTANGULAR NAME=1 WIDTH=3.425,
     HEIGHT=0.00685 SC=0.00000000000000 TC=0.0000000000000000000,
     TORFAC=1.00000000000 SSHEARF=0.000000000000000,
     TSHEARF=0.000000000000000 ISHEAR=NO SQUARE=NO
*
*
*
*
*
EGROUP BEAM NAME=2 SUBTYPE=THREE-D DISPLACE=DEFAULT MATERIAL=2 RINT=5,
     SINT=DEFAULT TINT=DEFAULT RESULTS=STRESSES INITIALS=NONE,
     CMASS=DEFAULT RIGIDEND=NONE MOMENT-C=NO RIGIDITY=1,
     MULTIPLY=1000000.00000000 RUPTURE=ADINA OPTION=NONE,
     BOLT-TOL=0.00000000000000 DESCRIPT='NONE' SECTION=1,
     PRINT=DEFAULT SAVE=DEFAULT TBIRTH=0.00000000000000,
     TDEATH=0.00000000000000 SPOINT=2 BOLTFORC=0.00000000000000,
     BOLTNCUR=0 TMC-MATE=1 BOLT-NUM=0 BOLT-LOA=0.00000000000000,
     WARP=NO ENDRELEA=ACCURATE
```

```
******************MESH******************
*****VOLUMES*****
SUBDIVIDE VOLUME NAME=1 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=710,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 1
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 1
@
*
SUBDIVIDE VOLUME NAME=2 MODE=DIVISIONS NDIV1=4 NDIV2=4 NDIV3=710,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 2
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 2
@
*
SUBDIVIDE VOLUME NAME=3 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=710,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 3
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 3
@
*
SUBDIVIDE VOLUME NAME=4 MODE=DIVISIONS NDIV1=4 NDIV2=48 NDIV3=710,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 4
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 4
```

```
@
*
SUBDIVIDE VOLUME NAME=5 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=710,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 5
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 5
@
*
SUBDIVIDE VOLUME NAME=6 MODE=DIVISIONS NDIV1=4 NDIV2=4 NDIV3=710,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 6
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 6
@
*
SUBDIVIDE VOLUME NAME=7 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=710,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 7
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 7
@
*****LINES*****
SUBDIVIDE LINE NAME=61 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 61
@
SUBDIVIDE LINE NAME=62 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 62
@
SUBDIVIDE LINE NAME=63 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 63
```

```
@
SUBDIVIDE LINE NAME=64 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 64
@
SUBDIVIDE LINE NAME=65 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 65
@
SUBDIVIDE LINE NAME=66 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 66
@
SUBDIVIDE LINE NAME=67 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 67
@
SUBDIVIDE LINE NAME=68 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 68
@
SUBDIVIDE LINE NAME=69 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 69
@
SUBDIVIDE LINE NAME=70 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 70
@
SUBDIVIDE LINE NAME=71 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 71
@
SUBDIVIDE LINE NAME=72 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 72
@
SUBDIVIDE LINE NAME=73 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 73
@
SUBDIVIDE LINE NAME=74 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 74
@
SUBDIVIDE LINE NAME=75 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 75
@
SUBDIVIDE LINE NAME=76 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
```

```
 76
@
SUBDIVIDE LINE NAME=77 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 77
@
SUBDIVIDE LINE NAME=78 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 78
@
SUBDIVIDE LINE NAME=79 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 79
@
SUBDIVIDE LINE NAME=80 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 80
@
SUBDIVIDE LINE NAME=81 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 81
@
SUBDIVIDE LINE NAME=82 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 82
@
SUBDIVIDE LINE NAME=83 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 83
@
SUBDIVIDE LINE NAME=84 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 84
@
GLINE NODES=2 AUXPOINT=30 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 61
@
GLINE NODES=2 AUXPOINT=31 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 62
@
GLINE NODES=2 AUXPOINT=32 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 63
@
GLINE NODES=2 AUXPOINT=33 NCOINCID=ENDS NCENDS=12,
```

```
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 64
@
GLINE NODES=2 AUXPOINT=32 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 65
@
GLINE NODES=2 AUXPOINT=35 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 66
@
GLINE NODES=2 AUXPOINT=36 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 67
@
GLINE NODES=2 AUXPOINT=37 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 68
@
GLINE NODES=2 AUXPOINT=38 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 69
@
GLINE NODES=2 AUXPOINT=39 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 70
@
GLINE NODES=2 AUXPOINT=40 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 71
@
GLINE NODES=2 AUXPOINT=41 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 72
@
GLINE NODES=2 AUXPOINT=5 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
```

```
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 73
@
GLINE NODES=2 AUXPOINT=6 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 74
@
GLINE NODES=2 AUXPOINT=7 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 75
@
GLINE NODES=2 AUXPOINT=8 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 76
@
GLINE NODES=2 AUXPOINT=7 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 77
@
GLINE NODES=2 AUXPOINT=12 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 78
@
GLINE NODES=2 AUXPOINT=15 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 79
@
GLINE NODES=2 AUXPOINT=18 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 80
@
GLINE NODES=2 AUXPOINT=21 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 81
@
GLINE NODES=2 AUXPOINT=22 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
```

```
     XYZOSYST=SKEW
@CLEAR
 82
@
GLINE NODES=2 AUXPOINT=23 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 83
@
GLINE NODES=2 AUXPOINT=24 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 84
@
```

```
TIMEFUNCTION NAME=2 IFLIB=1 FPAR1=0.0,
     FPAR2=0.0 FPAR3=0.0,
     FPAR4=0.0 FPAR5=0.0,
     FPAR6=0.0
@CLEAR
0.0 1.0
1800 1.0
@
```

```
******************** TIME STEP LOAD ********************
*
*
LOAD LINE NAME=1 MAGNITUD=-500
*
*
APPLY-LOAD BODY=0
@CLEAR
1  'LINE' 1  'LINE' 6 0 2 0.00 13 -1 11 0 0  'NO',
     0.0 0.0 1 0  'MID'
2  'LINE' 1  'LINE' 16 0 2 0.0 13 -1 13 0 0  'NO',
     0.0 0.0 1 0  'MID'
*
*
*
*
*
*
*
*
*
*
*
*
*
*
@
```

```
******************** BOUNDARY CONDITIONS ********************
FIXITY NAME=Y
@CLEAR
 'Y-TRANSLATION'
 'OVALIZATION'
@
*
FIXITY NAME=XYZ
@CLEAR
 'X-TRANSLATION'
 'Y-TRANSLATION'
 'Z-TRANSLATION'
 'OVALIZATION'
@
FIXITY NAME=YZ
@CLEAR
 'Y-TRANSLATION'
 'Z-TRANSLATION'
 'OVALIZATION'
@





FIXBOUNDARY POINTS FIXITY=ALL
@CLEAR
7  'Y'
23  'Y'
32  'Y'
40  'Y'
15  'XYZ'
36  'YZ'
@
```

```
FEPROGRAM PROGRAM=ADINA
*************** START READING FILES *****************

* Example of ADINA in files for structural analysis
* Parametric study Phase 2 with initial imperfections

******************** GEOMETRY ********************

READ F='Geo_HEA400_13_30_5.4_ntr_struc_LTb.in'

**************** MATERIALS&E GROUP *****************

READ F='Mtrl_HEA400_13_30_5.4_ntr_struc_LTb.in'

********************** MESH **********************

READ F='Mesh_HEA400_13_30_5.4_ntr_struc_LTb.in'

******************** TIME STEP *********************

READ F='Timestep_HEA400_13_30_5.4_ntr_struc_LTb.in'
READ F='Timestep2_HEA400_13_30_5.4_ntr_struc_LTb.in'

***************** MECHANICAL LOAD ******************

READ F='Load_HEA400_13_30_5.4_ntr_struc_LTb.in'

*************** BOUNDARY CONDITIONS ****************

READ F='BC_HEA400_13_30_5.4_ntr_struc_LTb.in'

*************** IMPORT THERMAL MAPPING **************

READ F='Thermap_HEA400_13_30_5.4_ntr_struc_LTb.in'

*************** END READING FILES ********************

*********** IMPORT INITIAL IMPERFECTIONS **************

IMPERFECTION POINTS
@CLEAR
1 49 2 0.052
@
ADINA OPTIMIZE=SOLVER FILE='HEA400_13_30_5.4_ntr_struc_LTb.dat' FIXBOUND=YES
OVERWRIT=YES
EXIT PROMPT=NO IMMEDIAT=NO
```

```
******************** GEOMETRY *******************
*
COORDINATES POINT SYSTEM=0
@CLEAR
1 0 0 0
2 0 0.1445 0
3 0 0.1555 0
4 0 0.3 0
5 0 0 -0.0095
6 0 0.1445 -0.0095
7 0 0.15 -0.0095
8 0 0.1555 -0.0095
9 0 0.3 -0.0095
10 0 0 -0.019
11 0 0.1445 -0.019
12 0 0.15 -0.019
13 0 0.1555 -0.019
14 0 0.3 -0.019
15 0 0.15 -0.195
16 0 0 -0.371
17 0 0.1445 -0.371
18 0 0.15 -0.371
19 0 0.1555 -0.371
20 0 0.3 -0.371
21 0 0 -0.3805
22 0 0.1445 -0.3805
23 0 0.15 -0.3805
24 0 0.1555 -0.3805
25 0 0.3 -0.3805
26 0 0 -0.39
27 0 0.1445 -0.39
28 0 0.1555 -0.39
29 0 0.3 -0.39
30 -13 0 -0.0095
31 -13 0.1445 -0.0095
32 -13 0.15 -0.0095
33 -13 0.1555 -0.0095
34 -13 0.3 -0.0095
35 -13 0.15 -0.019
36 -13 0.15 -0.195
37 -13 0.15 -0.371
38 -13 0 -0.3805
39 -13 0.1445 -0.3805
40 -13 0.15 -0.3805
41 -13 0.1555 -0.3805
42 -13 0.3 -0.3805
43 0.1 0.05 0
44 0 0 0.0905
45 -13.1 0.05 0
46 -13 0 0.0905
47 0 0.1445 0.1
48 0 0.1555 0.1
49 -6.5 0.1555 -0.195
@
*
SURFACE VERTEX NAME=1 P1=1 P2=2 P3=11 P4=10
VOLUME EXTRUDED NAME=1 SURFACE=1 DX=-13,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=7 P1=2 P2=3 P3=13 P4=11
VOLUME EXTRUDED NAME=2 SURFACE=7 DX=-13,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
```

```
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=13 P1=3 P2=4 P3=14 P4=13
VOLUME EXTRUDED NAME=3 SURFACE=13 DX=-13,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=19 P1=11 P2=13 P3=19 P4=17
VOLUME EXTRUDED NAME=4 SURFACE=19 DX=-13,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=25 P1=16 P2=17 P3=27 P4=26
VOLUME EXTRUDED NAME=5 SURFACE=25 DX=-13,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=31 P1=17 P2=19 P3=28 P4=27
VOLUME EXTRUDED NAME=6 SURFACE=31 DX=-13,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=37 P1=19 P2=20 P3=29 P4=28
VOLUME EXTRUDED NAME=7 SURFACE=37 DX=-13,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
*
LINE STRAIGHT NAME=61 P1=5 P2=6
*
LINE STRAIGHT NAME=62 P1=6 P2=7
*
LINE STRAIGHT NAME=63 P1=7 P2=8
*
LINE STRAIGHT NAME=64 P1=8 P2=9
*
LINE STRAIGHT NAME=65 P1=7 P2=12
*
LINE STRAIGHT NAME=66 P1=12 P2=15
*
LINE STRAIGHT NAME=67 P1=15 P2=18
*
LINE STRAIGHT NAME=68 P1=18 P2=23
*
*
LINE STRAIGHT NAME=69 P1=21 P2=22
*
LINE STRAIGHT NAME=70 P1=22 P2=23
*
LINE STRAIGHT NAME=71 P1=23 P2=24
*
LINE STRAIGHT NAME=72 P1=24 P2=25
*
LINE STRAIGHT NAME=73 P1=30 P2=31

LINE STRAIGHT NAME=74 P1=31 P2=32
*
LINE STRAIGHT NAME=75 P1=32 P2=33
```

```
*
LINE STRAIGHT NAME=76 P1=33 P2=34
*
LINE STRAIGHT NAME=77 P1=32 P2=35
*
LINE STRAIGHT NAME=78 P1=35 P2=36
*
LINE STRAIGHT NAME=79 P1=36 P2=37
*
LINE STRAIGHT NAME=80 P1=37 P2=40
*
LINE STRAIGHT NAME=81 P1=38 P2=39
*
LINE STRAIGHT NAME=82 P1=39 P2=40
*
LINE STRAIGHT NAME=83 P1=40 P2=41
*
LINE STRAIGHT NAME=84 P1=41 P2=42
```

```
********************MATERIALS********************
MATERIAL THERMO-PLASTIC NAME=1 HARDENIN=ISOTROPIC,
     TREF=293 TOLIL=1.0E-10,
     DENSITY=7850.0 MDESCRIP='STEEL' DEPENDEN=NO,
     TRANSITI=0.00010 BVALUE=0.0
@CLEAR
293 210e9 0.3 355e6 21000000 0.00001216 0.2 0
373 210e9 0.3 355e6 21000000 0.0000128 0.2 0
473 189e9 0.3 355e6 21000000 0.0000136 0.2 0
573 168e9 0.3 355e6 21000000 0.0000144 0.2 0
673 147e9 0.3 355e6 21000000 0.0000152 0.15 0
773 126e9 0.3 276.9e6 21000000 0.000016 0.15 0
873 65.1e9 0.3 166.85e6 21000000 0.0000168 0.15 0
973 27.3e9 0.3 81.65e6 21000000 0.0000176 0.15 0
1023 23.1e9 0.3 60.35e6 21000000 0.000018 0.15 0
1073 18.9e9 0.3 39.05e6 21000000 0 0.15 0
1133 16.065e9 0.3 28.4e6 21000000 0 0.15 0
1173 14.175e9 0.3 21.3e6 21000000 0.00002 0.15 0
1273 9.45e9 0.3 14.2e6 21000000 0.00002 0.15 0
1373 4.725e9 0.3 7.1e6 21000000 0.00002 0.15 0
1473 2.1E-28e9 0.3 3.55E-28e6 21000000 0.00002 0.15 0
@
*
*
MATERIAL ELASTIC NAME=2 E=210e9 NU=0.3,
     DENSITY=7850.00000000000 ALPHA=0.000015172 MDESCRIP=,
'NONE'
*
********************EGROUP********************
EGROUP THREEDSOLID NAME=1 DISPLACE=LARGE STRAINS=DEFAULT MATERIAL=1,
     RSINT=DEFAULT TINT=DEFAULT RESULTS=STRESSES DEGEN=DEFAUL,
     FORMULAT=0 STRESSRE=GLOBAL INITIALS=NONE FRACTUR=NO,
     CMASS=DEFAULT STRAIN-F=0 UL-FORMU=DEFAULT LVUS1=0 LVUS2=0 SED=NO,
     RUPTURE=ADINA INCOMPAT=DEFAULT TIME-OFF=0.0,
     POROUS=NO WTMC=1.0 OPTION=NONE DESCRIPT='NONE',
     PRINT=DEFAULT SAVE=DEFAULT TBIRTH=0.0,
     TDEATH=0.0 TMC-MATE=1 RUPTURE-=0 EM=NO JOULE=NO,
     BOLT-NUM=0 BOLT-PLA=0 BOLT-LOA=0.0,
     BOLT-TOL=0.0 TETINT=DEFAULT
*
CROSS-SECTIO RECTANGULAR NAME=1 WIDTH=3.425,
     HEIGHT=0.00685 SC=0.00000000000000 TC=0.0000000000000000000,
     TORFAC=1.00000000000 SSHEARF=0.000000000000000,
     TSHEARF=0.000000000000000 ISHEAR=NO SQUARE=NO
*
*
*
*
*
EGROUP BEAM NAME=2 SUBTYPE=THREE-D DISPLACE=DEFAULT MATERIAL=2 RINT=5,
     SINT=DEFAULT TINT=DEFAULT RESULTS=STRESSES INITIALS=NONE,
     CMASS=DEFAULT RIGIDEND=NONE MOMENT-C=NO RIGIDITY=1,
     MULTIPLY=1000000.00000000 RUPTURE=ADINA OPTION=NONE,
     BOLT-TOL=0.00000000000000 DESCRIPT='NONE' SECTION=1,
     PRINT=DEFAULT SAVE=DEFAULT TBIRTH=0.00000000000000,
     TDEATH=0.00000000000000 SPOINT=2 BOLTFORC=0.00000000000000,
     BOLTNCUR=0 TMC-MATE=1 BOLT-NUM=0 BOLT-LOA=0.00000000000000,
     WARP=NO ENDRELEA=ACCURATE
```

```
*******************MESH*******************
*****VOLUMES*****
SUBDIVIDE VOLUME NAME=1 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=710,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 1
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 1
@
*
SUBDIVIDE VOLUME NAME=2 MODE=DIVISIONS NDIV1=4 NDIV2=4 NDIV3=710,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 2
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 2
@
*
SUBDIVIDE VOLUME NAME=3 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=710,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 3
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 3
@
*
SUBDIVIDE VOLUME NAME=4 MODE=DIVISIONS NDIV1=4 NDIV2=48 NDIV3=710,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 4
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 4
```

```
@
*
SUBDIVIDE VOLUME NAME=5 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=710,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 5
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 5
@
*
SUBDIVIDE VOLUME NAME=6 MODE=DIVISIONS NDIV1=4 NDIV2=4 NDIV3=710,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 6
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 6
@
*
SUBDIVIDE VOLUME NAME=7 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=710,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 7
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 7
@
*****LINES*****
SUBDIVIDE LINE NAME=61 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 61
@
SUBDIVIDE LINE NAME=62 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 62
@
SUBDIVIDE LINE NAME=63 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 63
```

```
@
SUBDIVIDE LINE NAME=64 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 64
@
SUBDIVIDE LINE NAME=65 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 65
@
SUBDIVIDE LINE NAME=66 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 66
@
SUBDIVIDE LINE NAME=67 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 67
@
SUBDIVIDE LINE NAME=68 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 68
@
SUBDIVIDE LINE NAME=69 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 69
@
SUBDIVIDE LINE NAME=70 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 70
@
SUBDIVIDE LINE NAME=71 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 71
@
SUBDIVIDE LINE NAME=72 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 72
@
SUBDIVIDE LINE NAME=73 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 73
@
SUBDIVIDE LINE NAME=74 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 74
@
SUBDIVIDE LINE NAME=75 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 75
@
SUBDIVIDE LINE NAME=76 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
```

```
 76
@
SUBDIVIDE LINE NAME=77 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 77
@
SUBDIVIDE LINE NAME=78 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 78
@
SUBDIVIDE LINE NAME=79 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 79
@
SUBDIVIDE LINE NAME=80 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 80
@
SUBDIVIDE LINE NAME=81 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 81
@
SUBDIVIDE LINE NAME=82 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 82
@
SUBDIVIDE LINE NAME=83 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 83
@
SUBDIVIDE LINE NAME=84 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 84
@
GLINE NODES=2 AUXPOINT=30 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 61
@
GLINE NODES=2 AUXPOINT=31 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 62
@
GLINE NODES=2 AUXPOINT=32 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 63
@
GLINE NODES=2 AUXPOINT=33 NCOINCID=ENDS NCENDS=12,
```

```
      NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
      XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
      XYZOSYST=SKEW
@CLEAR
 64
@
GLINE NODES=2 AUXPOINT=32 NCOINCID=ENDS NCENDS=12,
      NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
      XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
      XYZOSYST=SKEW
@CLEAR
 65
@
GLINE NODES=2 AUXPOINT=35 NCOINCID=ENDS NCENDS=12,
      NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
      XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
      XYZOSYST=SKEW
@CLEAR
 66
@
GLINE NODES=2 AUXPOINT=36 NCOINCID=ENDS NCENDS=12,
      NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
      XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
      XYZOSYST=SKEW
@CLEAR
 67
@
GLINE NODES=2 AUXPOINT=37 NCOINCID=ENDS NCENDS=12,
      NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
      XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
      XYZOSYST=SKEW
@CLEAR
 68
@
GLINE NODES=2 AUXPOINT=38 NCOINCID=ENDS NCENDS=12,
      NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
      XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
      XYZOSYST=SKEW
@CLEAR
 69
@
GLINE NODES=2 AUXPOINT=39 NCOINCID=ENDS NCENDS=12,
      NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
      XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
      XYZOSYST=SKEW
@CLEAR
 70
@
GLINE NODES=2 AUXPOINT=40 NCOINCID=ENDS NCENDS=12,
      NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
      XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
      XYZOSYST=SKEW
@CLEAR
 71
@
GLINE NODES=2 AUXPOINT=41 NCOINCID=ENDS NCENDS=12,
      NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
      XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
      XYZOSYST=SKEW
@CLEAR
 72
@
GLINE NODES=2 AUXPOINT=5 NCOINCID=ENDS NCENDS=12,
      NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
```

```
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 73
@
GLINE NODES=2 AUXPOINT=6 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 74
@
GLINE NODES=2 AUXPOINT=7 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 75
@
GLINE NODES=2 AUXPOINT=8 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 76
@
GLINE NODES=2 AUXPOINT=7 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 77
@
GLINE NODES=2 AUXPOINT=12 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 78
@
GLINE NODES=2 AUXPOINT=15 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 79
@
GLINE NODES=2 AUXPOINT=18 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 80
@
GLINE NODES=2 AUXPOINT=21 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 81
@
GLINE NODES=2 AUXPOINT=22 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
```

```
     XYZOSYST=SKEW
@CLEAR
 82
@
GLINE NODES=2 AUXPOINT=23 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 83
@
GLINE NODES=2 AUXPOINT=24 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 84
@
```

```
******************** TIME STEP ********************
*
TIMESTEP NAME=TEMP
@CLEAR
100 18
@
*
TIMEFUNCTION NAME=1
@CLEAR
0 293
18 476.360226379578
36 556.382657779213
54 608.265779072382
72 646.730523516346
90 677.310456545859
108 702.69464868858
126 724.394900796568
144 743.346222459085
162 760.167411505853
180 775.289302991853
198 789.023944173034
216 801.604611106308
234 813.210275735062
252 823.981254083508
270 834.029594803113
288 843.446196529823
306 852.305817212387
324 860.670682925437
342 868.59314125805
360 876.117647609837
378 883.28227605337
396 890.119885104904
414 896.659028871326
432 902.924677526241
450 908.938793078715
468 914.720793969198
486 920.287933296815
504 925.655609256485
522 930.837621862872
540 935.846386741557
558 940.693114325072
576 945.387960961443
594 949.940157058036
612 954.358116325532
630 958.649529371431
648 962.821444258869
666 966.88033615022
684 970.832167763502
702 974.682442058619
720 978.436248321855
738 982.098302617073
756 985.672983410255
774.000000000001 989.164363042409
792.000000000001 992.576235618241
810.000000000001 995.912141789515
828.000000000001 999.17539083901
846.000000000001 1002.36908041037
864.000000000001 1005.49611417874
882.000000000001 1008.55921771474
900.000000000001 1011.56095275918
918.000000000001 1014.50373009554
936.000000000001 1017.38982118269
954.000000000001 1020.22136868807
972.000000000001 1023.00039604397
```

```
990.000000000001 1025.72881613364
1008 1028.40843920045
1026 1031.0409800622
1044 1033.62806470257
1062 1036.17123630297
1080 1038.67196077107
1098 1041.13163181545
1116 1043.55157561039
1134 1045.93305508992
1152 1048.2772739059
1170 1050.58538008119
1188 1052.85846938573
1206 1055.09758846031
1224 1057.30373771028
1242 1059.47787398942
1260 1061.62091309172
1278 1063.73373206758
1296 1065.81717137886
1314 1067.87203690623
1332 1069.89910182062
1350 1071.89910832987
1368 1073.87276931023
1386 1075.82076983188
1404 1077.74376858648
1422 1079.6423992243
1440 1081.51727160768
1458 1083.36897298705
1476 1085.1980691051
1494 1087.00510523444
1512 1088.79060715337
1530 1090.55508206424
1548 1092.29901945829
1566 1094.02289193085
1584 1095.72715595004
1602 1097.41225258233
1620 1099.07860817774
1638 1100.72663501735
1656 1102.35673192553
1674 1103.96928484934
1692 1105.56466740695
1710 1107.14324140726
1728 1108.70535734243
1746 1110.25135485491
1764 1111.78156318074
1782 1113.29630157034
1800 1114.79587968833
```

```
TIMEFUNCTION NAME=2 IFLIB=1 FPAR1=0.0,
     FPAR2=0.0 FPAR3=0.0,
     FPAR4=0.0 FPAR5=0.0,
     FPAR6=0.0
@CLEAR
0.0 1.0
1800 1.0
@
```

```
******************** TIME STEP LOAD ********************
*
*
LOAD LINE NAME=1 MAGNITUD=-2700
*
*
APPLY-LOAD BODY=0
@CLEAR
1  'LINE' 1  'LINE' 6 0 2 0.00 13 -1 11 0 0  'NO',
     0.0 0.0 1 0  'MID'
2  'LINE' 1  'LINE' 16 0 2 0.0 13 -1 13 0 0  'NO',
     0.0 0.0 1 0  'MID'
*
*
*
*
*
*
*
*
*
*
*
*
*
*
@
```

```
******************** BOUNDARY CONDITIONS ********************
FIXITY NAME=Y
@CLEAR
 'Y-TRANSLATION'
 'OVALIZATION'
@
*
FIXITY NAME=XYZ
@CLEAR
 'X-TRANSLATION'
 'Y-TRANSLATION'
 'Z-TRANSLATION'
 'OVALIZATION'
@
FIXITY NAME=YZ
@CLEAR
 'Y-TRANSLATION'
 'Z-TRANSLATION'
 'OVALIZATION'
@





FIXBOUNDARY POINTS FIXITY=ALL
@CLEAR
7  'Y'
23  'Y'
32  'Y'
40  'Y'
15  'XYZ'
36  'YZ'
@
```

```
*******************THERMAL MAPPING *******************
THERMAL-MAPP FILENAME=,
'HEA400_13_30_5.4_ntr_therm_LTb.map',
 EXTERNAL=ALL TIME=0.0 TOLERANC=1.0E-15
```

F

Main study: Hand calculations

Manual Input for Symmetric rolled HEA beam: uniform temperature with LT buckling and normal force

---

Example of hand calculations from Main Study.

All blue area data should be changed manually .

Cross section:

$$A := \begin{pmatrix} \text{"HEA400"} & \text{"HEB400"} & \text{"HEM400"} \\ 0.3 & 0.3 & 0.307 \\ 0.019 & 0.024 & 0.04 \\ 0.352 & 0.352 & 0.352 \\ 0.011 & 0.0135 & 0.021 \\ 0.027 & 0.027 & 0.027 \end{pmatrix}$$

beam :=

HEA400
[✓ HEB400]
HEM400

$b_f := A_{1,\text{beam}-1} \cdot m = 300 \cdot mm$ Flange width

$t_f := A_{2,\text{beam}-1} \cdot m = 24 \cdot mm$ Flange thickness

$h_w := A_{3,\text{beam}-1} \cdot m = 352 \cdot mm$ Web height

$t_w := A_{4,\text{beam}-1} \cdot m = 13.5 \cdot mm$ Web thickness

$r := A_{5,\text{beam}-1} \cdot m = 27 \cdot mm$ Radius of the rolled I section

$L := 6.5m$ Length of beam

$a_L := \infty \cdot m$ Distance betwen stiffeners

$I_{sl} := 0$ Second moment of area for longitudinal stiffeners

steel := Steel class

S235
[✓ S355]

$$f_y := \begin{cases} 235\text{MPa} & \text{if steel} = 1 \\ (355\text{MPa}) & \text{if steel} = 2 \end{cases} = 355\cdot\text{MPa}$$

Yield strength for structural steel, S235,S355
[EN 1993-1-1, Section 3.2.3, Table 3.1]

Loads

$Q_k := 25.5\dfrac{\text{kN}}{\text{m}}$ Variable imposed load

$g_k := Q_k = 25.5\cdot\dfrac{\text{kN}}{\text{m}}$ Selfweight from structural members above

$N_k := 252.1\text{kN}$ Applied normal force

Buckling

[EN 1993-1-1, Section 6.3.1.2, Table 6.2 and Table 6.4]

$$\text{Bucklingcurve}_y := \begin{cases} \text{"a"} & \text{if } \dfrac{h_w + 2\cdot t_f}{b_f} > 1.2 \wedge t_f \le 40\text{mm} \\ \text{"b"} & \text{if } \dfrac{h_w + 2\cdot t_f}{b_f} > 1.2 \wedge 40\text{mm} < t_f \le 100\text{mm} \\ \text{"b"} & \text{if } \dfrac{h_w + 2\cdot t_f}{b_f} \le 1.2 \wedge t_f \le 100\text{mm} \\ \text{"d"} & \text{if } \dfrac{h_w + 2\cdot t_f}{b_f} \le 1.2 \wedge t_f > 100\text{mm} \\ \text{"WARNING, INPUT NOT ACCURATE"} & \text{otherwise} \end{cases}$$

$\text{Bucklingcurve}_y = \text{"a"}$

$$\text{Bucklingcurve}_z := \begin{cases} \text{"b"} & \text{if } \dfrac{h_w + 2\cdot t_f}{b_f} > 1.2 \wedge t_f \le 40\text{mm} \\ \text{"c"} & \text{if } \dfrac{h_w + 2\cdot t_f}{b_f} > 1.2 \wedge 40\text{mm} < t_f \le 100\text{mm} \\ \text{"c"} & \text{if } \dfrac{h_w + 2\cdot t_f}{b_f} \le 1.2 \wedge t_f \le 100\text{mm} \\ \text{"d"} & \text{if } \dfrac{h_w + 2\cdot t_f}{b_f} \le 1.2 \wedge t_f > 100\text{mm} \\ \text{"WARNING, INPUT NOT ACCURATE"} & \text{otherwise} \end{cases}$$

$\text{Bucklingcurve}_z = \text{"b"}$

$$\text{Bucklingcurve\_LT} := \begin{vmatrix} \text{"a"} \quad \text{if } \dfrac{h_w + 2 \cdot t_f}{b_f} \leq 2 \\ \text{"b"} \quad \text{if } \dfrac{h_w + 2 \cdot t_f}{b_f} > 2 \\ \text{"WARNING, INPUT NOT ACCURATE"} \quad \text{otherwise} \end{vmatrix}$$

$\text{Bucklingcurve\_LT} = \text{"a"}$ Lateral torisonal buckling curve

Support conditions

Simply supported = 1, Fixed = 0.5

$k_{l.cr} := 1$ Buckling length

Equivalent moment factors [EN 1993-1-2, Section 4.2.3.5, Figure 4.2]

$\beta_{M.z} := 1.3$ The equivalent uniform moment factors in z direction

$\beta_{M.y} := 1.3$ The equivalent uniform moment factors in y direction

$\beta_{M.LT} := 1$ The equivalent uniform moment factors for LT buckling

Required resistance time

$t_R := 5$ [min]

Constant variables

Required resistance time

$t_R = 5$ [min]

Input for EN 1993-1-2

$L_{cr} := k_{l.cr} \cdot L = 6.5\,\mathrm{m}$ Critical buckling length of beam

$\gamma_{M.0} := 1.0$ Partial factor for resistance of cross-section [EN 1993-1-1, Section 6.1]

$\gamma_{M1} := 1.0$ Partial factor for resistance of members to instability assesed by member checks [EN 1993-1-1, Section 6.1]

$\gamma_{M.fi} := 1.0$ Partial factor for the relevant material property for the fire situation [EN 1993-1-2, Section 2.3]

$E := 210 \cdot 10^{9}\mathrm{Pa}$ Elasticity modulus for structural steel [EN 1993-1-2, Section 3.2.6]

$G := 80770\mathrm{MPa}$ Shear modulus [EN 1993-1-2, Section 3.2.6]

$\alpha_{cT} := 12 \cdot 10^{-6} = 1.2 \times 10^{-5}$ Coeficient for thermal expansion [EN 1993-1-2, Section 3.2.6]

Cross section properties

$A := 2 \cdot t_f \cdot b_f + h_w \cdot t_w = 0.019\,\mathrm{m}^2$ Cross section area

$y_{TP} := t_f + \frac{h_w}{2} = 0.2\,\mathrm{m}$ Gravity center in y-direction

$$I_y := \frac{t_w \cdot h_w^{\,3}}{12} + \frac{2 \cdot b_f \cdot t_f^{\,3}}{12} + 2 \cdot b_f \cdot t_f \cdot \left(y_{TP} - \frac{t_f}{2}\right)^2$$

$I_y = 5.587 \times 10^{-4}\,\mathrm{m}^4$ Second moment of area in y direction

$I_z := \frac{h_w \cdot t_w^{\,3}}{12} + \frac{2 \cdot t_f \cdot b_f^{\,3}}{12} = 1.081 \times 10^{-4}\,\mathrm{m}^4$ Second moment of area in z direction

$$I_f := \frac{2 \cdot b_f \cdot t_f^{\,3}}{12} + 2 \cdot b_f \cdot t_f \cdot \left(y_{TP} - \frac{t_f}{2}\right)^2$$ Second moment of area flanges

$$W_{pl.y} := b_f \cdot t_f \cdot \left(h_w + t_f\right) + \frac{t_w \cdot h_w^{\,2}}{4} = 3.125 \times 10^{-3} \cdot m^3$$ Section modulus in y-direction

$$\varepsilon_{fi} := 0.85 \cdot \left(\frac{235 \cdot MPa}{f_y}\right)^{0.5} = 0.692$$

Fire reduced coefficient depending on fy
[EN 1993-1-2, Section 4.2.2, Eq. (4.2)]

$$\varepsilon := \left(\frac{235 \cdot MPa}{f_y}\right)^{0.5} = 0.814$$

Coefficient depending on fy
[EN 1993-1-1, Section 5.6, Table 5.2]

Eurocode 1991-1-2: Temperatures

Nominal temterapture-time curve

[EN 1991-1-2, Section 3.2.1, Eq. (3.4)]

$$\Theta_{g.n} := 20 + 345 \cdot \log\left(8 \cdot t_R + 1\right) = 576.41$$ [deg C]

$$\theta_{a.n} := \Theta_{g.n} = 576.41$$

Eurocode 1990: Design loads

Loads

$\rho_s := 7850 \dfrac{kg}{m^3}$	Steel density
$A := 2 \cdot t_f \cdot b_f + h_w \cdot t_w = 1.915 \times 10^4 \cdot mm^2$	Cross section area
$G_k := g_k = 25.5 \cdot \dfrac{kN}{m}$	Self weigth of the beam
$Q_k = 25.5 \cdot \dfrac{kN}{m}$	Variable imposed load
$\psi_1 := 0.5$	Factor for frequent value of a variable action [EN 1990, Section A1.2.2, Table A1.1]

Buckling load

$N_{cr.y} := \pi^2 \cdot E \cdot \dfrac{I_y}{L_{cr}^2} = 2.741 \times 10^4 \cdot kN$	Elastic critical force for the relvant buckling mode based on the gross cross section properties
$\lambda_y := \sqrt{A \cdot \dfrac{f_y}{N_{cr.y}}} = 0.498$	Non dimensional slenderness [EN 1993-1-1, Section 6.3.1.2, Eq. (6.49)]

Load combination ULS

$N_{Ed.ULS} := N_k = 252.1 \cdot kN$ Design normal force ULS

$Q_{d.ULS} := 1.35 \cdot G_k + 1.5 \cdot Q_k = 72.675 \cdot \frac{kN}{m}$ Design load ULS
[EN 1990, Section A1.3.1, Table A1.2(B)]

$M_q := \frac{Q_{d.ULS} \cdot L^2}{8} = 383.815 \cdot kN \cdot m$

[EN 1993-1-1, Section 5.3.2
"Konstruktionsteknik" from Chalmers
course litterature pages s94 to S101]

$v_1 := \frac{5 \cdot Q_{d.ULS} \cdot L^4}{384 \cdot E \cdot I_y} = 0.014 m$

$$\alpha_{bow} := \left(\begin{array}{|l} 300 \text{ if } Bucklingcurve_y = \text{"a.0"} \\ 250 \text{ if } Bucklingcurve_y = \text{"a"} \\ 200 \text{ if } Bucklingcurve_y = \text{"b"} \\ 150 \text{ if } Bucklingcurve_y = \text{"c"} \\ 100 \text{ if } Bucklingcurve_y = \text{"d"} \end{array} \right) = 250$$

[EN 1993-1-1, Section 5.3.2, Table 5.1]

$e_0 := \frac{L}{\alpha_{bow}} = 0.026 m$

[EN 1993-1-1, Section 5.3.2, Table 5.1]

$$M_{Ed.ULS} := \begin{array}{|l} M_q \text{ if } \lambda_y \le 0.5 \cdot \sqrt{A \cdot \frac{f_y}{N_{Ed.ULS}}} \\ M_q + N_{Ed.ULS} \cdot \left[\frac{N_{cr.y}}{N_{cr.y} - N_{Ed.ULS}} \cdot \left(e_0 + v_1\right) \right] \end{array} = 394.093 \cdot kN \cdot m$$

Design moment ULS

$M_{Ed.ULS.z} := 0 kN \cdot m$

$V_{Ed.ULS} := Q_{d.ULS} \cdot \frac{L}{2} = 236.194 \cdot kN$ Design shear force ULS

Load combinations fire

Loads

$N_{Ed.fi} := N_k = 252.1 \cdot kN$

$Q_{d.fi} := G_k + \psi_1 \cdot Q_k = 38.25 \cdot \frac{kN}{m}$

Load combination for fire
[EN 1990, Section A1.3.1, Table A1.3]

$M_q := \frac{Q_{d.fi} \cdot L^2}{8} = 202.008 \cdot kN \cdot m$

$v_1 := \frac{5 \cdot Q_{d.fi} \cdot L^4}{384 \cdot E \cdot I_y} = 7.577 \times 10^{-3} m$

Design moment fire

$$M_{Ed.fi} := \left| \begin{array}{l} M_q \;\; \text{if} \;\; \lambda_y \le 0.5 \cdot \sqrt{A \cdot \frac{f_y}{N_{Ed.ULS}}} \\ M_q + N_{Ed.ULS} \cdot \left[\frac{N_{cr.y}}{N_{cr.y} - N_{Ed.ULS}} \cdot \left(e_0 + v_1 \right) \right] \end{array} \right. = 210.551 \cdot kN \cdot m$$

Design moment fire

$M_{Ed.fi.y.n} := M_{Ed.fi}$

$M_{Ed.fi.z.n} := 0kN \cdot m = 0 \cdot kN \cdot m$

$V_{Ed.fi} := Q_{d.fi} \cdot \frac{L}{2} = 124.313 \cdot kN$ Design shear force fire

$\eta_{fi} := \frac{Q_{d.fi}}{Q_{d.ULS}} = 0.526$ Degree of Utilization at time t0 for fire

Eurocode 1993-1-1: Capacities without temperature load

Cross section class check [EN 1993-1-1, Section 5.6, Table 5.2]

$$c_{cs.f} := \frac{b_f - t_w}{2} - r = 0.116\,\mathrm{m}$$

$$CSC_f := \left| \begin{array}{ll} \text{"1"} & \text{if } \frac{c_{cs.f}}{t_f} \le 9 \cdot \varepsilon_{fi} \\ \text{"2"} & \text{if } 9 \cdot \varepsilon_{fi} < \frac{c_{cs.f}}{t_f} \le 10 \cdot \varepsilon_{fi} \\ \text{"3"} & \text{if } 10 \cdot \varepsilon_{fi} < \frac{c_{cs.f}}{t_f} \le 14 \cdot \varepsilon_{fi} \\ \text{"4"} & \text{otherwise} \end{array} \right. = \text{"1"}$$

$$c_{cs.w} := h_w - 2 \cdot r = 0.298\,\mathrm{m}$$

$$CSC_w := \left| \begin{array}{ll} \text{"1"} & \text{if } \frac{c_{cs.w}}{t_w} \le 72 \cdot \varepsilon_{fi} \\ \text{"2"} & \text{if } 72 \cdot \varepsilon_{fi} < \frac{c_{cs.w}}{t_w} \le 83 \cdot \varepsilon_{fi} \\ \text{"3"} & \text{if } 83 \cdot \varepsilon_{fi} < \frac{c_{cs.w}}{t_w} \le 124 \cdot \varepsilon_{fi} \\ \text{"4"} & \text{otherwise} \end{array} \right. = \text{"1"}$$

Normal force, tension:

$$N_{Rd} := A \cdot \frac{f_y}{\gamma_{M.0}} = 6.799 \times 10^3 \cdot kN$$

Design values of the resistance to normal force
[EN 1993-1-1, Section 6.2.3, Eq. (6.6)].

Normal force, compression:

$$N_{cr.y} := \pi^2 \cdot E \cdot \frac{I_y}{L_{cr}^{\;2}} = 2.741 \times 10^4 \cdot kN$$

Elastic critical force for the relvant buckling mode based on the gross cross section properties

$$\lambda_y := \sqrt{A \cdot \frac{f_y}{N_{cr.y}}} = 0.498$$

Non dimensional slenderness
[EN 1993-1-1, Section 6.3.1.2, Eq.(6.49)]

$$N_{cr.z} := \pi^2 \cdot E \cdot \frac{I_z}{L_{cr}^{\;2}} = 5.302 \times 10^3 \cdot kN$$

Elastic critical force for the relvant buckling mode based on the gross cross section properties

$$\lambda_z := \sqrt{A \cdot \frac{f_y}{N_{cr.z}}} = 1.132$$

Non dimensional slenderness
[EN 1993-1-1, Section 6.3.1.2, Eq.(6.49)]

$$\alpha_{imp.y} := \left| \begin{array}{l} 0.13 \text{ if } \mathrm{Bucklingcurve}_y = \text{"a.0"} \\ 0.21 \text{ if } \mathrm{Bucklingcurve}_y = \text{"a"} \\ 0.34 \text{ if } \mathrm{Bucklingcurve}_y = \text{"b"} \\ 0.49 \text{ if } \mathrm{Bucklingcurve}_y = \text{"c"} \\ 0.76 \text{ if } \mathrm{Bucklingcurve}_y = \text{"d"} \end{array} \right. = 0.21$$

Imperfection factor
[EN 1993-1-1, Section 6.3.1.2, Table 6.1]

$$\alpha_{imp.z} := \left| \begin{array}{l} 0.13 \text{ if } \mathrm{Bucklingcurve}_z = \text{"a.0"} \\ 0.21 \text{ if } \mathrm{Bucklingcurve}_z = \text{"a"} \\ 0.34 \text{ if } \mathrm{Bucklingcurve}_z = \text{"b"} \\ 0.49 \text{ if } \mathrm{Bucklingcurve}_z = \text{"c"} \\ 0.76 \text{ if } \mathrm{Bucklingcurve}_z = \text{"d"} \end{array} \right. = 0.34$$

Imperfection factor
[EN 1993-1-1, Section 6.3.1.2, Table 6.1]

$$\Phi_y := 0.5\cdot\left[1 + \alpha_{imp.y}\cdot\left(\lambda_y - 0.2\right) + \lambda_y^{\,2}\right]$$

Value to determine the reduction factor χ
[EN 1993-1-1, Section 6.3.1.2, Eq. (6.49)]

$$\Phi_z := 0.5\cdot\left[1 + \alpha_{imp.z}\cdot\left(\lambda_z - 0.2\right) + \lambda_z^{\,2}\right]$$

$$\chi_y := \left|\begin{array}{l} 1 \ \text{ if } \lambda_y \le 0.2 \\ \min\left(1, \dfrac{1}{\Phi_y + \sqrt{\Phi_y^{\,2} - \lambda_y^{\,2}}}\right) \ \text{ otherwise} \end{array}\right. = 0.925$$

Reduction factor
[EN 1993-1-1, Section 6.3.1.2, Eq. (6.49)]

$$\chi_z := \left|\begin{array}{l} 1 \ \text{ if } \lambda_z \le 0.2 \\ \min\left(1, \dfrac{1}{\Phi_z + \sqrt{\Phi_z^{\,2} - \lambda_z^{\,2}}}\right) \ \text{ otherwise} \end{array}\right. = 0.516$$

$$N_{b.Rd.y} := \chi_y\cdot A\cdot\left(\frac{f_y}{\gamma_{M1}}\right) = 6.288\times10^3\cdot kN$$

Design buckling resistance of a compression member in y-direction
[EN 1993-1-1, Section 6.3.1.1, Eq. (6.47)]

$$N_{b.Rd.z} := \chi_z\cdot A\cdot\left(\frac{f_y}{\gamma_{M1}}\right) = 3.509\times10^3\cdot kN$$

Design buckling resistance of a compression member in z-direction
[EN 1993-1-1, Section 6.3.1.1, Eq. (6.47)]

Bending capacity without Lateral torsional buckling:

$$M_{Rd} := W_{pl.y}\cdot\frac{f_y}{\gamma_{M1}} = 1.11\times10^3\cdot kN\cdot m$$

Design value of the resistance to bending moment
[EN 1993-1-1, Section 6.2.5, Eq. (6.13)]

Bending capacity with Lateral torsional buckling:

[NCCI: Elastic critical moment for lateral torsional buckling]

Coefficients depending on the loading and restraint condition

$$C_1 := \left| \begin{array}{l} 1.127 \;\text{ if } k_{1.cr} = 1 \\ 2.578 \;\text{ if } k_{1.cr} = 0.5 \\ \text{"WARNING, ERROR WITH LT FACTORS"} \;\text{ otherwise} \end{array} \right. = 1.127$$

$$C_2 := \left| \begin{array}{l} 0.454 \;\text{ if } k_{1.cr} = 1 \\ 1.554 \;\text{ if } k_{1.cr} = 0.5 \\ \text{"WARNING, ERRORWITH LT FACTORS"} \;\text{ otherwise} \end{array} \right. = 0.454$$

Warping constant

$$I_w := \frac{I_z \cdot \left(h_w + 2 \cdot t_f - t_f\right)^2}{4} = 3.82 \times 10^{12} \cdot mm^6$$

Torsion constant

$$I_t := \frac{\left[2 \cdot t_f^{\,3} \cdot b_f + t_w^{\,3} \cdot \left(h_w\right)\right]}{3} = 3.053 \times 10^6 \cdot mm^4$$

The beam length between points which have lateral retraint

$$L_{ef} := L = 6.5\,m$$

The distance between to point of load application and the shear center

$$z_g := \frac{h_w}{2} + t_f = 0.2\,m$$

Factor that refers to warping

$$k_w := 1$$

$$k := k_{1.cr} = 1$$

Elastic critical moment for lateral torsional buckling

$$M_{cr} := C_1 \cdot \frac{\pi^2 \cdot E \cdot I_z}{(k \cdot L)^2} \cdot \left[\left[\left(\frac{k}{k_w} \right)^2 \frac{I_w}{I_z} + \frac{(k \cdot L)^2 \cdot G \cdot I_t}{\pi^2 \cdot E \cdot I_z} + \left(C_2 \cdot z_g \right)^2 \right]^{0.5} - C_2 \cdot z_g \right]$$

$$M_{cr} = 1.251 \times 10^3 \cdot kN \cdot m$$

$$\lambda_{LT} := \sqrt{W_{pl.y} \cdot \frac{f_y}{M_{cr}}}$$

Non dimensional slenderness
for lateral torsional buckling
[EN 1993-1-1, Section 6.3.2.2, Eq. (6.56)]

$$\alpha_{LT} := \left| \begin{array}{l} 0.21 \text{ if } Bucklingcurve\_LT = \text{"a"} \\ 0.34 \text{ if } Bucklingcurve\_LT = \text{"b"} \\ 0.49 \text{ if } Bucklingcurve\_LT = \text{"c"} \\ 0.76 \text{ if } Bucklingcurve\_LT = \text{"d"} \end{array} \right. = 0.21$$

Imperfection factor
[EN 1993-1-1, Section 6.3.2.2, Table 6.4]

$$\Phi_{LT} := 0.5 \cdot \left[1 + \alpha_{LT} \cdot \left(\lambda_{LT} - 0.2 \right) + \lambda_{LT}^2 \right] = 1.021$$

Value to determine the
reduction factor χLT
[EN 1993-1-1, Section 6.3.2.2, Eq. (6.56)]

$$\chi_{LT} := \min \left(1, \frac{1}{\Phi_{LT} + \sqrt{\Phi_{LT}^2 - \lambda_{LT}^2}} \right) = 0.706$$

Reduction factor for lateral
torisonal buckling
[EN 1993-1-1, Section 6.3.2.2, Eq. (6.56)]

$$M_{b.Rd} := \chi_{LT} \cdot W_{pl.y} \cdot \frac{f_y}{\gamma_{M.fi}} = 783.237 \cdot kN \cdot m$$

Design buckling resistance
[EN 1993-1-1, Section 6.3.2.1, Eq. (6.55)]

Shear capacity:

$$\eta := \left| \begin{array}{l} 1.2 \text{ if } f_y \le 460 MPa \\ 1.0 \text{ otherwise} \end{array} \right. = 1.2$$

Factor
[EN 1993-1-5, Section 5.1, Note 2]

$$k_{\tau.sl} := \max \left[9 \cdot \left(\frac{h_w}{a_L} \right)^2 \cdot \left[\left(\frac{I_{sl}}{t_w^{\,3} \cdot h_w} \right)^3 \right]^{\frac{1}{4}}, \frac{2.1}{t_w} \cdot \left(\frac{I_{sl}}{h_w} \right)^{\frac{1}{3}} \right] = 0$$

Coefficient to calculate the
shear buckling coefficient
[EN 1993-1-5, Section A.3,
Eq. (A.5)]

$$k_\tau := \begin{cases} 5.34 + 4.0\cdot\left(\dfrac{h_w}{a_L}\right)^2 + k_{\tau.sl} & \text{if } \dfrac{a_L}{h_w} \geq 1 \\ 4.0 + 5.34\cdot\left(\dfrac{h_w}{a_L}\right)^2 + k_{\tau.sl} & \text{otherwise} \end{cases} = 5.34$$

Shear buckling coefficient
[EN 1993-1-5, Section A.3, Eq. (A.5)]

$$\lambda_w := \frac{\dfrac{h_w}{t_w}}{37.4\cdot\varepsilon\cdot\sqrt{k_\tau}} = 0.371$$

The slenderness parameter
[EN 1993-1-5, Section 5.3, Eq. (5.6)]

$$\chi_w := \begin{cases} \eta & \text{if } \lambda_w < \dfrac{0.8}{\eta} \\ \dfrac{0.83}{\lambda_w} & \text{if } \dfrac{0.8}{\eta} \leq \lambda_w < 1.08 \\ \dfrac{0.83}{\lambda_w} & \text{otherwise} \end{cases} = 1.2$$

The factor for the contribution of the web to the shear buckling resistance
[EN 1993-1-5, Section 5.3, Table 5.1]

$$V_{bw.Rd} := \chi_w\cdot h_w\cdot t_w\cdot\frac{f_y}{\sqrt{3}\cdot\gamma_{M1}} = 1.169\times 10^6 N$$

Contribution from the web to the shear resistance
[EN 1993-1-5, Section 5.2, Eq. (5.2)]

$$V_{pl} := \eta\cdot h_w\cdot t_w\cdot\frac{f_y}{\sqrt{3}\cdot\gamma_{M1}} = 1.169\times 10^3\cdot kN$$

Plastic shear resistance
[EN 1993-1-5, Section 5.2, Eq. (5.1)]

$$V_{Rd} := \min\left(V_{pl}, V_{bw.Rd}\right) = 1.169\times 10^3\cdot kN$$

Shear resistance
[EN 1993-1-5, Section 5.2, Eq. (5.1)]

Eurocode 1993-1-2: Reduction factors, k

Nomínal temperature parameters

$$\theta_{a.n} := \Theta_{g.n} = 576.41$$

Reduction factor for the yield strength of steel at temperature θa
[EN 1993-1-2, Section 3.2.2 Table 3.1]

$$k_{y.\theta.n} := \left|\begin{array}{l}
1 \ \text{ if } \ 20 \le \theta_{a.n} \le 400 \\
1 - \dfrac{(1 - 0.78)}{(500 - 400)} \cdot \left(\theta_{a.n} - 400\right) \ \text{ if } \ 400 < \theta_{a.n} \le 500 \\
0.78 - \dfrac{(0.78 - 0.47)}{(600 - 500)} \cdot \left(\theta_{a.n} - 500\right) \ \text{ if } \ 500 < \theta_{a.n} \le 600 \\
0.47 - \dfrac{(0.47 - 0.23)}{(700 - 600)} \cdot \left(\theta_{a.n} - 600\right) \ \text{ if } \ 600 < \theta_{a.n} \le 700 \\
0.23 - \dfrac{(0.23 - 0.11)}{(800 - 700)} \cdot \left(\theta_{a.n} - 700\right) \ \text{ if } \ 700 < \theta_{a.n} \le 800 \\
0.11 - \dfrac{(0.11 - 0.06)}{(900 - 800)} \cdot \left(\theta_{a.n} - 800\right) \ \text{ if } \ 800 < \theta_{a.n} \le 900 \\
0.06 - \dfrac{(0.06 - 0.04)}{(1000 - 900)} \cdot \left(\theta_{a.n} - 900\right) \ \text{ if } \ 900 < \theta_{a.n} \le 1000 \\
0.04 - \dfrac{(0.04 - 0.02)}{(1100 - 1000)} \cdot \left(\theta_{a.n} - 1000\right) \ \text{ if } \ 1000 < \theta_{a.n} \le 1100 \\
0.02 - \dfrac{(0.02 - 0)}{(1200 - 1100)} \cdot \left(\theta_{a.n} - 1100\right) \ \text{ if } \ 1100 < \theta_{a.n} \le 1200 \\
0 \ \text{ otherwise}
\end{array}\right. \qquad = 0.543$$

Reduction factor for the slope for the linear elastic range at the steel temperature θa
[EN 1993-1-2, Section 3.2.2 Table 3.1]

$$k_{E.\theta.n} := \left| \begin{array}{l} 1 \ \text{ if } 20 \le \theta_{a.n} \le 100 \\ 1 - \frac{(1-0.9)}{(200-100)} \cdot \left(\theta_{a.n} - 100\right) \ \text{ if } 100 < \theta_{a.n} \le 200 \\ 0.9 - \frac{(0.9-0.8)}{(300-200)} \cdot \left(\theta_{a.n} - 200\right) \ \text{ if } 200 < \theta_{a.n} \le 300 \\ 0.8 - \frac{(0.8-0.7)}{(400-300)} \cdot \left(\theta_{a.n} - 300\right) \ \text{ if } 300 < \theta_{a.n} \le 400 \\ 0.7 - \frac{(0.7-0.6)}{(500-400)} \cdot \left(\theta_{a.n} - 400\right) \ \text{ if } 400 < \theta_{a.n} \le 500 \\ 0.6 - \frac{(0.6-0.31)}{(600-500)} \cdot \left(\theta_{a.n} - 500\right) \ \text{ if } 500 < \theta_{a.n} \le 600 \\ 0.31 - \frac{(0.31-0.13)}{(700-600)} \cdot \left(\theta_{a.n} - 600\right) \ \text{ if } 600 < \theta_{a.n} \le 700 \\ 0.13 - \frac{(0.13-0.09)}{(800-700)} \cdot \left(\theta_{a.n} - 700\right) \ \text{ if } 700 < \theta_{a.n} \le 800 \\ 0.09 - \frac{(0.09-0.0675)}{(900-800)} \cdot \left(\theta_{a.n} - 800\right) \ \text{ if } 800 < \theta_{a.n} \le 900 \\ 0.0675 - \frac{(0.0675-0.045)}{(1000-900)} \cdot \left(\theta_{a.n} - 900\right) \ \text{ if } 900 < \theta_{a.n} \le 1000 \\ 0.045 - \frac{(0.045-0.0225)}{(1100-1000)} \cdot \left(\theta_{a.n} - 1000\right) \ \text{ if } 1000 < \theta_{a.n} \le 1100 \\ 0.0225 - \frac{(0.0225-0)}{(1200-1100)} \cdot \left(\theta_{a.n} - 1100\right) \ \text{ if } 1100 < \theta_{a.n} \le 1200 \\ 0 \ \text{ otherwise} \end{array} \right. \qquad = 0.378$$

$$k_{z.\theta.n} := k_{y.\theta.n}$$

$$k_{y.\theta.com.n} := k_{y.\theta.n}$$

$$k_{E.\theta.com.n} := k_{E.\theta.n}$$

$$k_{y.\theta.web.n} := k_{y.\theta.n}$$

$$k_{E.\theta.web.n} := k_{E.\theta.n}$$

Eurocode 1993-1-2: Nominal temperature

Normal force, compression:

$$\lambda_{\theta.y} := \lambda_y \cdot \left(\frac{k_{y.\theta.n}}{k_{E.\theta.n}}\right)^{0.5} = 0.597$$

Non dimensional slenderness
for temperature θa
[EN 1993-1-2, Section 4.2.3.2, Eq. (4.7)]

$$\lambda_{\theta.z} := \lambda_z \cdot \left(\frac{k_{z.\theta.n}}{k_{E.\theta.n}}\right)^{0.5} = 1.357$$

$$\alpha := 0.65 \cdot \left(\frac{235\text{MPa}}{f_y}\right)^{0.5} = 0.529$$

Factor
[EN 1993-1-2, Section 4.2.3.2, Eq. (4.6)]

$$\varphi_{\theta.y} := \frac{1}{2} \cdot \left(1 + \alpha \cdot \lambda_{\theta.y} + \lambda_{\theta.y}^{2}\right) = 0.836$$

Value to calculate the reduction factor χ
[EN 1993-1-2, Section 4.2.3.2, Eq. (4.6)]

$$\varphi_{\theta.z} := \frac{1}{2} \cdot \left(1 + \alpha \cdot \lambda_{\theta.z} + \lambda_{\theta.z}^{2}\right) = 1.779$$

$$\chi_{fi.y} := \frac{1}{\varphi_{\theta.y} + \left(\varphi_{\theta.y}^{2} - \lambda_{\theta.y}^{2}\right)^{0.5}} = 0.704$$

Reduction factor for flexural
buckling the fire design situation
[EN 1993-1-2, Section 4.2.3.2, Eq. (4.6)]

$$\chi_{fi.z} := \frac{1}{\varphi_{\theta.z} + \left(\varphi_{\theta.z}^{2} - \lambda_{\theta.z}^{2}\right)^{0.5}} = 0.341$$

$$\chi_{fi.min} := \min\left(\chi_{fi.y}, \chi_{fi.z}\right) = 0.341$$

$$N_{b.fi.t.Rd.y} := \chi_{fi.y} \cdot A \cdot k_{y.\theta.n} \cdot \left(\frac{f_y}{\gamma_{M.fi}}\right) = 2.599 \times 10^{3} \cdot \text{kN}$$

Design buckling resistance
at time t of a compression
member
[EN 1993-1-2, Section 4.2.3.2,
Eq. (4.5)]

$$N_{b.fi.t.Rd.z} := \chi_{fi.z} \cdot A \cdot k_{z.\theta.n} \cdot \left(\frac{f_y}{\gamma_{M.fi}}\right) = 1.26 \times 10^{3} \cdot \text{kN}$$

$$N_{b.fi.t.Rd} := \min\left(N_{b.fi.t.Rd.y}, N_{b.fi.t.Rd.z}\right) = 1.26 \times 10^{3} \cdot kN$$

Bending capacity without Lateral torsional buckling:

$$M_{fi.\theta.Rd} := k_{y.\theta.n} \cdot M_{Rd} \cdot \left(\frac{\gamma_{M.0}}{\gamma_{M.fi}}\right) = 602.605 \cdot kN \cdot m$$

Design moment resistance
with the uniform temperature θa
[EN 1993-1-2, Section 4.2.3.3, Eq. (4.8)]

Bending capacity with Lateral torsional buckling:

$$\lambda_{LT.\theta.com} := \lambda_{LT} \cdot \left(\frac{k_{y.\theta.com.n}}{k_{E.\theta.com.n}}\right)^{0.5} = 1.128$$

Non dimensional slenderness for the
compression flange at temperature θa
[EN 1993-1-2, Section 4.2.3.3, Eq. (4.15)]

$$\phi_{LT.\theta.com} := \frac{1 \cdot \left(1 + \alpha \cdot \lambda_{LT.\theta.com} + \lambda_{LT.\theta.com}^{2}\right)}{2} = 1.435$$

Value to determine
eduction factor
EN 1993-1-2, Section 4.2.3.3,
Eq. (4.13)]

Reduction factor for lateral torsional buckling in the fire design situation
[EN 1993-1-2, Section 4.2.3.3, Eq. (4.12)]

$$\chi_{LT.fi} := \frac{1}{\phi_{LT.\theta.com} + \left(\phi_{LT.\theta.com}^{2} - \lambda_{LT.\theta.com}^{2}\right)^{0.5}} = 0.431$$

Design buckling resitance moment at time t of a lateral unrestrained member with cross section class 1 or 2. [EN 1993-1-2, Section 4.2.3.3, Eq. (4.11)]

$$M_{b.fi.t.Rd} := \chi_{LT.fi} \cdot W_{pl.y} \cdot k_{y.\theta.com.n} \cdot \frac{f_y}{\gamma_{M.fi}} = 259.608 \cdot kN \cdot m$$

Shear Capacity:

$$V_{fi.t.Rd} := k_{y.\theta.web.n} \cdot V_{Rd} \cdot \left(\frac{\gamma_{M.0}}{\gamma_{M.fi}}\right)$$

Design shear resistance at time t
of cross section class 1 or 2
[EN 1993-1-2, Section 4.2.3.3, Eq. (4.16)]

$$V_{fi.t.Rd} = 634.786 \cdot kN$$

Fire Capacities:

$M_{fi.\theta.Rd.n} := M_{fi.\theta.Rd} = 602.605 \cdot kN \cdot m$

Fire reduced capacities for nominal temperature

$M_{b.fi.t.Rd.n} := M_{b.fi.t.Rd} = 259.608 \cdot kN \cdot m$

$N_{b.fi.t.Rd.n} := N_{b.fi.t.Rd} = 1.26 \times 10^{3} \cdot kN$

$V_{fi.t.Rd.n} := V_{fi.t.Rd} = 634.786 \cdot kN$

Checks

ULS checks

$$\text{Check} := \left| \begin{array}{ll} \text{"Bending moment capacity w/o LT buckling OK"} & \text{if } \dfrac{M_{Ed.ULS}}{M_{Rd}} \le 1 \\ \text{"Bending moment capacity w/o LT buckling NOT OK"} & \text{otherwise} \end{array} \right.$$

$$\frac{M_{Ed.ULS}}{M_{Rd}} = 0.355$$

$\text{Check} = \text{"Bending moment capacity w/o LT buckling OK"}$

$$\text{Check} := \left| \begin{array}{ll} \text{"Bending moment capacity w/ LT buckling OK"} & \text{if } \dfrac{M_{Ed.ULS}}{M_{b.Rd}} \le 1 \\ \text{"Bending moment capacity w/ LT buckling NOT OK"} & \text{otherwise} \end{array} \right.$$

$$\frac{M_{Ed.ULS}}{M_{b.Rd}} = 0.503$$

$\text{Check} = \text{"Bending moment capacity w/ LT buckling OK"}$

$$\text{Check} := \left| \begin{array}{ll} \text{"Shear force capacity OK"} & \text{if } \dfrac{V_{Ed.ULS}}{V_{Rd}} \le 1 \\ \text{"Shear force capacity NOT OK"} & \text{otherwise} \end{array} \right.$$

$$\frac{V_{Ed.ULS}}{V_{Rd}} = 0.202$$

$\text{Check} = \text{"Shear force capacity OK"}$

$$\text{Check} := \begin{cases} \text{"Normal force capacity OK"} & \text{if } \dfrac{N_{Ed.ULS}}{N_{b.Rd.z}} \le 1 \\ \text{"Normal force capacity NOT OK"} & \text{otherwise} \end{cases}$$

$$\frac{N_{Ed.ULS}}{N_{b.Rd.z}} = 0.072$$

Check = "Normal force capacity OK"

Fire check

$$C_M := \frac{M_{Ed.fi.y.n}}{M_{fi.\theta.Rd.n}}$$

$$\text{Check} := \begin{cases} \text{"Bending moment capacity w/o LT buckling OK, nominal temperature"} & \text{if } C_M \le 1 \\ \text{"Bending moment capacity NOT OK w/o LT buckling, nominal temperature"} & \text{otherwise} \end{cases}$$

$$\frac{M_{Ed.fi.y.n}}{M_{fi.\theta.Rd.n}} = 0.349$$

Check = "Bending moment capacity w/o LT buckling OK, nominal temperature"

$$C_M := \frac{M_{Ed.fi.y.n}}{M_{b.fi.t.Rd.n}}$$

$$\text{Check} := \begin{cases} \text{"Bending moment capacity OK w/ LT buckling, nominal temperature"} & \text{if } C_M \le 1 \\ \text{"Bending moment capacity NOT OK w/ LT buckling, nominal temperature"} & \text{otherwise} \end{cases}$$

$$\frac{M_{Ed.fi.y.n}}{M_{b.fi.t.Rd.n}} = 0.811$$

Check = "Bending moment capacity OK w/ LT buckling, nominal temperature"

$$\text{Check} := \begin{array}{|l} \text{"Shear force OK, nominal temperature"} \quad \text{if } \dfrac{V_{Ed.fi}}{V_{fi.t.Rd.n}} \le 1 \\ \text{"Shear force NOT OK, nominal temperature"} \quad \text{otherwise} \end{array}$$

$$\frac{V_{Ed.fi}}{V_{fi.t.Rd.n}} = 0.196$$

Check = "Shear force OK, nominal temperature"

$$\text{Check} := \begin{array}{|l} \text{"Normal force capacity OK"} \quad \text{if } \dfrac{N_{Ed.fi}}{N_{b.fi.t.Rd}} \le 1 \\ \text{"Normal force capacity NOT OK"} \quad \text{otherwise} \end{array}$$

$$\frac{N_{Ed.fi}}{N_{b.fi.t.Rd}} = 0.2$$

Check = "Normal force capacity OK"

Interaction check normal force bending moment ULS

Factors for interaction

$N_{Rk} := f_y \cdot A = 6.799 \times 10^3 \cdot kN$ [EN 1993-1-1, Section 6.3.3, Table 6.7]

$M_{y.Rk} := f_y \cdot W_{pl.y} = 1.11 \times 10^3 \cdot kN \cdot m$ [EN 1993-1-1, Section 6.3.3, Table 6.7]

$C_{mLT} := 0.95$ [EN 1993-1-1, Section B, Table B.3]

$C_{my} := 0.95$ [EN 1993-1-1, Section B, Table B.3]

$$v_a := C_{my} \cdot \left[1 + \left(\lambda_y - 0.2\right) \cdot \frac{N_{Ed.ULS}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right] = 0.961$$

[EN 1993-1-1, Section B, Table B.1]

$$v_b := C_{my} \cdot \left(1 + 0.8 \cdot \frac{N_{Ed.ULS}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right) = 0.98$$

[EN 1993-1-1, Section B, Table B.1]

$k_{yy} := \min\left(v_a, v_b\right) = 0.961$ [EN 1993-1-1, Section B, Table B.1]

$k_{zy} := 0.6 \cdot k_{yy} = 0.577$ [EN 1993-1-1, Section B, Table B.1]

Interaction check a

$$IC_1 := \frac{N_{Ed.ULS}}{\left(\frac{\chi_y \cdot N_{Rk}}{\gamma_{M1}}\right)} = 0.04$$

[EN 1993-1-1, Section 6.3.3, Eq. (6.61)]

$$IC_2 := \frac{M_{Ed.ULS}}{\chi_{LT} \cdot \frac{M_{y.Rk}}{\gamma_{M1}}} \cdot k_{yy} = 0.484$$

$$IC_3 := 0 = 0$$

$$IC_a := IC_1 + IC_2 + IC_3 = 0.524$$

Check := | "Normal force and bending moment interaction a for ULS OK" if $IC_a \leq 1$
| "Normal force and bending moment interaction a for ULS NOT OK" otherwise

Check = "Normal force and bending moment interaction a for ULS OK"

Interaction check b

$$IC_1 := \frac{N_{Ed.ULS}}{\left(\frac{\chi_z \cdot N_{Rk}}{\gamma_{M1}}\right)} = 0.072$$

[EN 1993-1-1, Section 6.3.3, Eq. (6.62)]

$$IC_2 := \frac{M_{Ed.ULS}}{\chi_{LT} \cdot \frac{M_{y.Rk}}{\gamma_{M1}}} \cdot k_{zy} = 0.29$$

$$IC_3 := 0 = 0$$

$$IC_a := IC_1 + IC_2 + IC_3 = 0.362$$

Check := | "Normal force and bending moment interaction b for ULS OK" if $IC_a \leq 1$
| "Normal force and bending moment interaction b for ULS NOT OK" otherwise

Check = "Normal force and bending moment interaction b for ULS OK"

Interaction check c

$$y_n := \begin{cases} N_{Ed.ULS} \cdot \dfrac{\gamma_{M1}}{2 \cdot f_y \cdot t_w} & \text{if } N_{Ed.ULS} \cdot \dfrac{\gamma_{M1}}{2 \cdot f_y \cdot t_w} < \dfrac{(h_w)}{2} \\ \left[\dfrac{N_{Ed.ULS}}{f_y \cdot 2 \cdot b_f} - t_f + \dfrac{h_w + 2 \cdot t_f}{2} - \dfrac{t_w}{2 \cdot b_f} \cdot (h_w)\right] & \text{otherwise} \end{cases} \quad = 0.026$$

$$M_{N.y} := \begin{cases} \left[f_y \cdot b_f \cdot t_f \cdot (h_w + t_f) + f_y \cdot t_w \cdot \left[\left(\dfrac{h_w}{2}\right)^2 - y_n^{\ 2}\right]\right] & \text{if } N_{Ed.ULS} \cdot \dfrac{\gamma_{M1}}{2 \cdot f_y \cdot t_w} < \dfrac{h_w}{2} \\ \left[f_y \cdot b_f \cdot \left[\dfrac{(h_w + 2 \cdot t_f)}{2} - y_n\right] \cdot \left[\dfrac{(h_w + 2 \cdot t_f)}{2} + y_n\right]\right] & \text{otherwise} \end{cases}$$

$$M_{N.y} = 1.106 \times 10^3 \cdot kN \cdot m$$

$$Check := \begin{cases} \text{"Normal force and bending moment interaction c for ULS OK"} & \text{if } M_{N.y} \geq M_{Ed.ULS} \\ \text{"Normal force and bending moment interaction c for ULS NOT OK"} & \text{otherwise} \end{cases}$$

Check = "Normal force and bending moment interaction c for ULS OK"

Interaction check normal force and bending moment fire

[EN 1993-1-2, Section 4.2.3.5, Eq. (4.21)]

$$\mu_y := \min\left[\left(1.2\cdot\beta_{M.y}-3\right)\cdot\lambda_{\theta.y}+0.44\cdot\beta_{M.y}-0.29, 0.8\right] = -0.577$$

$$k_y := \min\left(1-\frac{\mu_y\cdot N_{Ed.fi}}{\chi_{fi.y}\cdot A\cdot k_{y.\theta.n}\cdot\frac{f_y}{\gamma_{M.fi}}}, 3\right) = 1.056$$

$$\mu_z := \min\left[\left(2\cdot\beta_{M.z}-5\right)\cdot\lambda_{\theta.z}+0.44\cdot\beta_{M.z}-0.29, 0.8\right] = -2.974$$

$$k_z := \min\left(1-\frac{\mu_z\cdot N_{Ed.fi}}{\chi_{fi.z}\cdot A\cdot k_{y.\theta.n}\cdot\frac{f_y}{\gamma_{M.fi}}}, 3\right) = 1.595$$

[EN 1993-1-2, Section 4.2.3.5, Eq. (4.21a)]

$$IC_1 := \frac{N_{Ed.fi}}{\chi_{fi.min}\cdot A\cdot k_{y.\theta.n}\cdot\frac{f_y}{\gamma_{M.fi}}} = 0.2$$

$$IC_2 := \frac{k_y\cdot M_{Ed.fi.y.n}}{W_{pl.y}\cdot k_{y.\theta.n}\cdot\frac{f_y}{\gamma_{M.fi}}} = 0.369$$

$$IC_3 := 0 = 0$$

$$IC_a := IC_1 + IC_2 + IC_3 = 0.569$$

$$Check := \left| \begin{array}{ll} \text{"Normal force and bending moment interaction a for fire OK"} & \text{if } IC_a \le 1 \\ \text{"Normal force and bending moment interaction a for fire NOT OK"} & \text{otherwise} \end{array} \right.$$

Check = "Normal force and bending moment interaction a for fire OK"

[EN 1993-1-2, Section 4.2.3.5, Eq. (4.21)]

$$\mu_{LT} := \min\left(0.15\cdot\lambda_{\theta.z}\cdot\beta_{M.LT} - 0.15, 0.9\right) = 0.054$$

$$k_{LT} := \min\left(1 - \frac{\mu_{LT}\cdot N_{Ed.fi}}{\chi_{fi.z}\cdot A\cdot k_{y.\theta.n}\cdot\frac{f_y}{\gamma_{M.fi}}}, 3\right) = 0.989$$

[EN 1993-1-2, Section 4.2.3.5, Eq. (4.21b)]

$$IC_1 := \frac{N_{Ed.fi}}{\chi_{fi.z}\cdot A\cdot k_{y.\theta.n}\cdot\frac{f_y}{\gamma_{M.fi}}} = 0.2$$

$$IC_2 := \frac{k_{LT}\cdot M_{Ed.fi.y.n}}{\chi_{LT.fi}\cdot W_{pl.y}\cdot k_{y.\theta.n}\cdot\frac{f_y}{\gamma_{M.fi}}} = 0.802$$

$$IC_3 := 0 = 0$$

$$IC_b := IC_1 + IC_2 + IC_3 = 1.002$$

$$\text{Check} := \left|\begin{array}{ll} \text{"Normal force and bending moment interaction b for fire OK"} & \text{if } IC_b \le 1 \\ \text{"Normal force and bending moment interaction b for fire NOT OK"} & \text{otherwise} \end{array}\right.$$

Check = "Normal force and bending moment interaction b for fire NOT OK"

Warnings

CSC_w = "1"

CSC_f = "1"

$$\text{Loadcombinations} := \left| \begin{array}{ll} \text{"Load ratios probably OK"} & \text{if } 0.3 \cdot Q_k < G_k < 1.5Q_k \\ \text{"Look over chosen load ratios"} & \text{otherwise} \end{array} \right.$$

Loadcombinations = "Load ratios probably OK"

G

Main study: ADINA In-files

```
FEPROGRAM PROGRAM=ADINA-T
*************** START READING FILES **************

* Example of ADINA in files for thermal analysis
*Main study with initial imperfections and normal force

******************** GEOMETRY ********************

READ F='Geo_HEB400_6.5_30_ntr_therm_NF_half.in'

**************** MATERIALS&E GROUP ***************

READ F='Mtrl_HEB400_6.5_30_ntr_therm_NF_half.in'

********************** MESH **********************

READ F='Mesh_HEB400_6.5_30_ntr_therm_NF_half.in'

******************** TIME STEP *******************

READ F='Timestep_HEB400_6.5_30_ntr_therm_NF_half.in'

***************** TEMPERATURE LOAD ***************

READ F='Tempload_HEB400_6.5_30_ntr_therm_NF_half.in'

*************** SAVE THERMAL MAPPING *************

READ F='Savemap_HEB400_6.5_30_ntr_therm_NF_half.in'

*************** END READING FILES ****************
```

```
******************** GEOMETRY ********************
*
COORDINATES POINT SYSTEM=0
@CLEAR
1 0 0 0
2 0 0.14325 0
3 0 0.15675 0
4 0 0.3 0
5 0 0 -0.012
6 0 0.14325 -0.012
7 0 0.15 -0.012
8 0 0.15675 -0.012
9 0 0.3 -0.012
10 0 0 -0.024
11 0 0.14325 -0.024
12 0 0.15 -0.024
13 0 0.15675 -0.024
14 0 0.3 -0.024
15 0 0.15 -0.2
16 0 0 -0.376
17 0 0.14325 -0.376
18 0 0.15 -0.376
19 0 0.15675 -0.376
20 0 0.3 -0.376
21 0 0 -0.388
22 0 0.14325 -0.388
23 0 0.15 -0.388
24 0 0.15675 -0.388
25 0 0.3 -0.388
26 0 0 -0.4
27 0 0.14325 -0.4
28 0 0.15675 -0.4
29 0 0.3 -0.4
30 -3.25 0 -0.012
31 -3.25 0.14325 -0.012
32 -3.25 0.15 -0.012
33 -3.25 0.15675 -0.012
34 -3.25 0.3 -0.012
35 -3.25 0.15 -0.024
36 -3.25 0.15 -0.2
37 -3.25 0.15 -0.376
38 -3.25 0 -0.388
39 -3.25 0.14325 -0.388
40 -3.25 0.15 -0.388
41 -3.25 0.15675 -0.388
42 -3.25 0.3 -0.388
43 0.1 0.05 0
44 0 0 0.088
45 -3.35 0.05 0
46 -3.25 0 0.088
47 0 0.14325 0.1
48 0 0.15675 0.1
49 0 0.15675 -0.2
@
*
SURFACE VERTEX NAME=1 P1=1 P2=2 P3=11 P4=10
VOLUME EXTRUDED NAME=1 SURFACE=1 DX=-3.25,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=7 P1=2 P2=3 P3=13 P4=11
VOLUME EXTRUDED NAME=2 SURFACE=7 DX=-3.25,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
```

```
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=13 P1=3 P2=4 P3=14 P4=13
VOLUME EXTRUDED NAME=3 SURFACE=13 DX=-3.25,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=19 P1=11 P2=13 P3=19 P4=17
VOLUME EXTRUDED NAME=4 SURFACE=19 DX=-3.25,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=25 P1=16 P2=17 P3=27 P4=26
VOLUME EXTRUDED NAME=5 SURFACE=25 DX=-3.25,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=31 P1=17 P2=19 P3=28 P4=27
VOLUME EXTRUDED NAME=6 SURFACE=31 DX=-3.25,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=37 P1=19 P2=20 P3=29 P4=28
VOLUME EXTRUDED NAME=7 SURFACE=37 DX=-3.25,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
*
LINE STRAIGHT NAME=61 P1=5 P2=6
*
LINE STRAIGHT NAME=62 P1=6 P2=7
*
LINE STRAIGHT NAME=63 P1=7 P2=8
*
LINE STRAIGHT NAME=64 P1=8 P2=9
*
LINE STRAIGHT NAME=65 P1=7 P2=12
*
LINE STRAIGHT NAME=66 P1=12 P2=15
*
LINE STRAIGHT NAME=67 P1=15 P2=18
*
LINE STRAIGHT NAME=68 P1=18 P2=23
*
*
LINE STRAIGHT NAME=69 P1=21 P2=22
*
LINE STRAIGHT NAME=70 P1=22 P2=23
*
LINE STRAIGHT NAME=71 P1=23 P2=24
*
LINE STRAIGHT NAME=72 P1=24 P2=25
*
LINE STRAIGHT NAME=73 P1=30 P2=31

LINE STRAIGHT NAME=74 P1=31 P2=32
*
LINE STRAIGHT NAME=75 P1=32 P2=33
```

```
*
LINE STRAIGHT NAME=76 P1=33 P2=34
*
LINE STRAIGHT NAME=77 P1=32 P2=35
*
LINE STRAIGHT NAME=78 P1=35 P2=36
*
LINE STRAIGHT NAME=79 P1=36 P2=37
*
LINE STRAIGHT NAME=80 P1=37 P2=40
*
LINE STRAIGHT NAME=81 P1=38 P2=39
*
LINE STRAIGHT NAME=82 P1=39 P2=40
*
LINE STRAIGHT NAME=83 P1=40 P2=41
*
LINE STRAIGHT NAME=84 P1=41 P2=42
```

```
*******************MATERIALS*******************
MATERIAL TEMPDEP-C-K NAME=1 JOULE-HE=NO MDESCRIP='steel',
     DENSITY=7850
@CLEAR
293 53.334 439.80176
622.213665756567 42.3711849303063 583.388761512031
717.504877875504 39.1979875667457 629.660953177154
775.289302991853 37.2737662103713 668.221020362955
816.887309257871 35.8885526017129 702.674163814492
849.410430568309 34.8055326620753 734.220631107051
876.117647609837 33.9161823345924 762.395115962911
898.77682520701 33.1616317206066 781.858422504833
918.455108041785 32.5063449022086 806.493977840188
935.846386741557 31.9272153215061 839.005653837134
951.427331513134 31.4083698606126 884.254450073302
965.539552292495 30.9384329086599 952.006862133333
978.436248321854 30.5089729308822 1065.27831806696
990.310308179129 30.113566737635 1294.42888683745
1001.31206300178 29.7472083020407 2008.08139487164
1011.56095275918 29.4059202731195 2901.84583247462
1021.15345005324 29.0864901132271 1583.85806905843
1030.16859566896 28.7862857642236 1225.96890736621
1038.67196077107 28.5031237063235 1058.95997237257
1046.71854363207 28.235172497052 962.149052493011
1054.35492723099 27.9808809232081 898.887910874265
1061.62091309172 27.7389235940458 854.262714591754
1068.55077689482 27.5081591294024 821.061743285216
1075.17424629904 27.3 795.371460557924
1081.51727160768 27.3 774.884251992095
1087.60263981007 27.3 758.151164131708
1093.45046870831 27.3 744.216396038222
1099.07860817774 27.3 732.423862649386
1104.50296874842 27.3 722.308195189808
1109.73779275398 27.3 713.530092560778
1114.79587968833 27.3 705.836305917945
1119.68877474803 27.3 699.033959118437
1124.4269275493 27.3 692.97355012404
1129.0198265082 27.3 687.537391849855
1133.47611322906 27.3 682.631564275288
1137.80368036725 27.3 678.180193183694
1142.00975575101 27.3 674.121306700593
1146.10097501444 27.3 670.40378416256
1150.08344457464 27.3 666.985075392269
1153.96279645352 27.3 663.82947251869
1157.74423617968 27.3 660.90678416831
1161.43258479274 27.3 658.191306764479
1165.03231580061 27.3 655.661018016188
1168.54758780028 27.3 653.296938522302
1171.9822733588 27.3 651.082621955816
1175.33998465745 27.3 650
1178.62409632488 27.3 650
1181.837765821 27.3 650
1184.98395168043 27.3 650
1188.06542987952 27.3 650
1191.08480855396 27.3 650
1194.04454126253 27.3 650
1196.94693896595 27.3 650
1199.79418086736 27.3 650
1202.58832424191 27.3 650
@
*
MATERIAL CONSTH NAME=2 H=25.0 MDESCRIP='steel'
*
MATERIAL CONSTE NAME=3 E=0.8 ISIGMA=KELVIN,
```

```
     SIGMA=5.66960E-08 MDESCRIP='steel'
*
********************EGROUP********************
EGROUP THREEDCONDUCTION NAME=1 MATERIAL=1 RSINT=DEFAULT TINT=DEFAULT,
     DEGEN=NO DESCRIPT='NONE'
*
EGROUP RADIATION NAME=4 SUBTYPE=SURFACE MATERIAL=3 DEGEN=NO,
     SHELLNOD=BOTTOM DESCRIPT='NONE' PROPERTY=1.00000000000000
*
EGROUP CONVECTION NAME=3 SUBTYPE=SURFACE MATERIAL=2 DEGEN=NO,
     SHELLNOD=BOTTOM DESCRIPT='NONE' PROPERTY=1.0
*
CROSS-SECTIO RECTANGULAR NAME=1 WIDTH=3.425,
     HEIGHT=0.00685 SC=0.00000000000000 TC=0.0000000000000000000,
     TORFAC=1.00000000000 SSHEARF=0.0000000000000000,
     TSHEARF=0.000000000000000 ISHEAR=NO SQUARE=NO
*
*
*
*
*
EGROUP BEAM NAME=2 SUBTYPE=THREE-D DISPLACE=DEFAULT MATERIAL=2 RINT=5,
     SINT=DEFAULT TINT=DEFAULT RESULTS=STRESSES INITIALS=NONE,
     CMASS=DEFAULT RIGIDEND=NONE MOMENT-C=NO RIGIDITY=1,
     MULTIPLY=1000000.00000000 RUPTURE=ADINA OPTION=NONE,
     BOLT-TOL=0.00000000000000 DESCRIPT='NONE' SECTION=1,
     PRINT=DEFAULT SAVE=DEFAULT TBIRTH=0.00000000000000,
     TDEATH=0.00000000000000 SPOINT=2 BOLTFORC=0.00000000000000,
     BOLTNCUR=0 TMC-MATE=1 BOLT-NUM=0 BOLT-LOA=0.00000000000000,
     WARP=NO ENDRELEA=ACCURATE
```

```
********************MESH********************
*****VOLUMES*****
SUBDIVIDE VOLUME NAME=1 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=145,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 1
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 1
@
*
SUBDIVIDE VOLUME NAME=2 MODE=DIVISIONS NDIV1=4 NDIV2=4 NDIV3=145,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 2
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 2
@
*
SUBDIVIDE VOLUME NAME=3 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=145,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 3
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 3
@
*
SUBDIVIDE VOLUME NAME=4 MODE=DIVISIONS NDIV1=4 NDIV2=48 NDIV3=145,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 4
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 4
```

```
@
*
SUBDIVIDE VOLUME NAME=5 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=145,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 5
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 5
@
*
SUBDIVIDE VOLUME NAME=6 MODE=DIVISIONS NDIV1=4 NDIV2=4 NDIV3=145,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 6
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 6
@
*
SUBDIVIDE VOLUME NAME=7 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=145,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 7
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 7
@
*****LINES*****
SUBDIVIDE LINE NAME=61 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 61
@
SUBDIVIDE LINE NAME=62 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 62
@
SUBDIVIDE LINE NAME=63 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 63
```

```
@
SUBDIVIDE LINE NAME=64 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 64
@
SUBDIVIDE LINE NAME=65 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 65
@
SUBDIVIDE LINE NAME=66 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 66
@
SUBDIVIDE LINE NAME=67 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 67
@
SUBDIVIDE LINE NAME=68 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 68
@
SUBDIVIDE LINE NAME=69 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 69
@
SUBDIVIDE LINE NAME=70 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 70
@
SUBDIVIDE LINE NAME=71 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 71
@
SUBDIVIDE LINE NAME=72 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 72
@
SUBDIVIDE LINE NAME=73 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 73
@
SUBDIVIDE LINE NAME=74 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 74
@
SUBDIVIDE LINE NAME=75 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 75
@
SUBDIVIDE LINE NAME=76 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
```

```
 76
@
SUBDIVIDE LINE NAME=77 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 77
@
SUBDIVIDE LINE NAME=78 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 78
@
SUBDIVIDE LINE NAME=79 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 79
@
SUBDIVIDE LINE NAME=80 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 80
@
SUBDIVIDE LINE NAME=81 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 81
@
SUBDIVIDE LINE NAME=82 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 82
@
SUBDIVIDE LINE NAME=83 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 83
@
SUBDIVIDE LINE NAME=84 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 84
@
*
GLINE NODES=2 AUXPOINT=30 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 61
@
GLINE NODES=2 AUXPOINT=31 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 62
@
GLINE NODES=2 AUXPOINT=32 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 63
@
```

```
GLINE NODES=2 AUXPOINT=33 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 64
@
GLINE NODES=2 AUXPOINT=32 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 65
@
GLINE NODES=2 AUXPOINT=35 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 66
@
GLINE NODES=2 AUXPOINT=36 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 67
@
GLINE NODES=2 AUXPOINT=37 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 68
@
GLINE NODES=2 AUXPOINT=38 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 69
@
GLINE NODES=2 AUXPOINT=39 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 70
@
GLINE NODES=2 AUXPOINT=40 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 71
@
GLINE NODES=2 AUXPOINT=41 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 72
@
GLINE NODES=2 AUXPOINT=5 NCOINCID=ENDS NCENDS=12,
```

```
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 73
@
GLINE NODES=2 AUXPOINT=6 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 74
@
GLINE NODES=2 AUXPOINT=7 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 75
@
GLINE NODES=2 AUXPOINT=8 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 76
@
GLINE NODES=2 AUXPOINT=7 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 77
@
GLINE NODES=2 AUXPOINT=12 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 78
@
GLINE NODES=2 AUXPOINT=15 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 79
@
GLINE NODES=2 AUXPOINT=18 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 80
@
GLINE NODES=2 AUXPOINT=21 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 81
@
GLINE NODES=2 AUXPOINT=22 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
```

```
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 82
@
GLINE NODES=2 AUXPOINT=23 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 83
@
GLINE NODES=2 AUXPOINT=24 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 84
@
*****SURFACES*****
*
GSURFACE NODES=4 PATTERN=AUTOMATIC NCOINCID=ALL,
     NCTOLERA=1.0E-05 SUBSTRUC=0 GROUP=3,
     PREFSHAP=AUTOMATIC MESHING=MAPPED SMOOTHIN=NO DEGENERA=NO,
     COLLAPSE=NO MIDNODES=CURVED METHOD=ADVFRONT FLIP=NO
@CLEAR
*
 2
*
 4
 5
 6
*
 8
*
*
 11
*
*
 14
 15
 16
 17
*
*
 20
*
 22
 23
*
*
 26
*
 28
 29
 30
*
*
 33
 34
*
*
*
 38
```

```
 39
 40
 41
@
*
GSURFACE NODES=4 PATTERN=AUTOMATIC NCOINCID=ALL,
     NCTOLERA=1.0E-05 SUBSTRUC=0 GROUP=4,
     PREFSHAP=AUTOMATIC MESHING=MAPPED SMOOTHIN=NO DEGENERA=NO,
     COLLAPSE=NO MIDNODES=CURVED METHOD=ADVFRONT FLIP=NO
@CLEAR
*
*
*
 4
 5
 6
*
*
*
*
 11
*
*
*
 15
 16
 17
*
*
 20
*
 22
 23
*
*
 26
*
 28
 29
 30
*
*
 33
 34
*
*
*
 38
 39
 40
 41
@
*
```

```
******************** TIME STEP ********************
*
TIMESTEP NAME=TEMP
@CLEAR
100 18
@
*
TIMEFUNCTION NAME=1
@CLEAR
0 293
18 476.360226379578
36 556.382657779213
54 608.265779072382
72 646.730523516346
90 677.310456545859
108 702.69464868858
126 724.394900796568
144 743.346222459085
162 760.167411505853
180 775.289302991853
198 789.023944173034
216 801.604611106308
234 813.210275735062
252 823.981254083508
270 834.029594803113
288 843.446196529823
306 852.305817212387
324 860.670682925437
342 868.59314125805
360 876.117647609837
378 883.28227605337
396 890.119885104904
414 896.659028871326
432 902.924677526241
450 908.938793078715
468 914.720793969198
486 920.287933296815
504 925.655609256485
522 930.837621862872
540 935.846386741557
558 940.693114325072
576 945.387960961443
594 949.940157058036
612 954.358116325532
630 958.649529371431
648 962.821444258869
666 966.88033615022
684 970.832167763502
702 974.682442058619
720 978.436248321855
738 982.098302617073
756 985.672983410255
774.000000000001 989.164363042409
792.000000000001 992.576235618241
810.000000000001 995.912141789515
828.000000000001 999.17539083901
846.000000000001 1002.36908041037
864.000000000001 1005.49611417874
882.000000000001 1008.55921771474
900.000000000001 1011.56095275918
918.000000000001 1014.50373009554
936.000000000001 1017.38982118269
954.000000000001 1020.22136868807
972.000000000001 1023.00039604397
```

```
990.000000000001 1025.72881613364
1008 1028.40843920045
1026 1031.0409800622
1044 1033.62806470257
1062 1036.17123630297
1080 1038.67196077107
1098 1041.13163181545
1116 1043.55157561039
1134 1045.93305508992
1152 1048.2772739059
1170 1050.58538008119
1188 1052.85846938573
1206 1055.09758846031
1224 1057.30373771028
1242 1059.47787398942
1260 1061.62091309172
1278 1063.73373206758
1296 1065.81717137886
1314 1067.87203690623
1332 1069.89910182062
1350 1071.89910832987
1368 1073.87276931023
1386 1075.82076983188
1404 1077.74376858648
1422 1079.6423992243
1440 1081.51727160768
1458 1083.36897298705
1476 1085.1980691051
1494 1087.00510523444
1512 1088.79060715337
1530 1090.55508206424
1548 1092.29901945829
1566 1094.02289193085
1584 1095.72715595004
1602 1097.41225258233
1620 1099.07860817774
1638 1100.72663501735
1656 1102.35673192553
1674 1103.96928484934
1692 1105.56466740695
1710 1107.14324140726
1728 1108.70535734243
1746 1110.25135485491
1764 1111.78156318074
1782 1113.29630157034
1800 1114.79587968833
```

```
******************* TEMPERATURE LOAD ******************
INITIAL-COND NAME=IN
@CLEAR
'TEMPERATURE' 293
@
*
SET-INITCOND VOLUMES CONDITIO=IN
@CLEAR
1  'IN' 0
2  'IN' 0
3  'IN' 0
4  'IN' 0
5  'IN' 0
6  'IN' 0
7  'IN' 0
@
*
LOAD CONVECTION NAME=1 MAGNITUD=1.0 C-PROP=0
*
LOAD RADIATION NAME=1 MAGNITUD=1.0 R-PROP=0
*
APPLY-LOAD BODY=0
@CLEAR
*
1  'CONVECTION' 1  'SURFACE' 2  0  1  0  'TOP'  0  0
*
2  'CONVECTION' 1  'SURFACE' 4  0  1  0  'TOP'  0  0
3  'CONVECTION' 1  'SURFACE' 5  0  1  0  'TOP'  0  0
4  'CONVECTION' 1  'SURFACE' 6  0  1  0  'TOP'  0  0
*
5  'CONVECTION' 1  'SURFACE' 8  0  1  0  'TOP'  0  0
*
*
6  'CONVECTION' 1  'SURFACE' 11  0  1  0  'TOP'  0  0
*
*
7  'CONVECTION' 1  'SURFACE' 14  0  1  0  'TOP'  0  0
8  'CONVECTION' 1  'SURFACE' 15  0  1  0  'TOP'  0  0
9  'CONVECTION' 1  'SURFACE' 16  0  1  0  'TOP'  0  0
10  'CONVECTION' 1  'SURFACE' 17  0  1  0  'TOP'  0  0
*
*
11  'CONVECTION' 1  'SURFACE' 20  0  1  0  'TOP'  0  0
*
12  'CONVECTION' 1  'SURFACE' 22  0  1  0  'TOP'  0  0
13  'CONVECTION' 1  'SURFACE' 23  0  1  0  'TOP'  0  0
*
*
14  'CONVECTION' 1  'SURFACE' 26  0  1  0  'TOP'  0  0
*
15  'CONVECTION' 1  'SURFACE' 28  0  1  0  'TOP'  0  0
16  'CONVECTION' 1  'SURFACE' 29  0  1  0  'TOP'  0  0
17  'CONVECTION' 1  'SURFACE' 30  0  1  0  'TOP'  0  0
*
*
18  'CONVECTION' 1  'SURFACE' 33  0  1  0  'TOP'  0  0
19  'CONVECTION' 1  'SURFACE' 34  0  1  0  'TOP'  0  0
*
*
*
20  'CONVECTION' 1  'SURFACE' 38  0  1  0  'TOP'  0  0
21  'CONVECTION' 1  'SURFACE' 39  0  1  0  'TOP'  0  0
22  'CONVECTION' 1  'SURFACE' 40  0  1  0  'TOP'  0  0
23  'CONVECTION' 1  'SURFACE' 41  0  1  0  'TOP'  0  0
```

```
*
*
*
24  'RADIATION' 1  'SURFACE' 4 0 1 0  'TOP' 0 0
25  'RADIATION' 1  'SURFACE' 5 0 1 0  'TOP' 0 0
26  'RADIATION' 1  'SURFACE' 6 0 1 0  'TOP' 0 0
*
*
*
*
27  'RADIATION' 1  'SURFACE' 11 0 1 0  'TOP' 0 0
*
*
*
28  'RADIATION' 1  'SURFACE' 15 0 1 0  'TOP' 0 0
29  'RADIATION' 1  'SURFACE' 16 0 1 0  'TOP' 0 0
30  'RADIATION' 1  'SURFACE' 17 0 1 0  'TOP' 0 0
*
*
31  'RADIATION' 1  'SURFACE' 20 0 1 0  'TOP' 0 0
*
32  'RADIATION' 1  'SURFACE' 22 0 1 0  'TOP' 0 0
33  'RADIATION' 1  'SURFACE' 23 0 1 0  'TOP' 0 0
*
*
34  'RADIATION' 1  'SURFACE' 26 0 1 0  'TOP' 0 0
*
35  'RADIATION' 1  'SURFACE' 28 0 1 0  'TOP' 0 0
36  'RADIATION' 1  'SURFACE' 29 0 1 0  'TOP' 0 0
37  'RADIATION' 1  'SURFACE' 30 0 1 0  'TOP' 0 0
*
*
38  'RADIATION' 1  'SURFACE' 33 0 1 0  'TOP' 0 0
39  'RADIATION' 1  'SURFACE' 34 0 1 0  'TOP' 0 0
*
*
*
40  'RADIATION' 1  'SURFACE' 38 0 1 0  'TOP' 0 0
41  'RADIATION' 1  'SURFACE' 39 0 1 0  'TOP' 0 0
42  'RADIATION' 1  'SURFACE' 40 0 1 0  'TOP' 0 0
43  'RADIATION' 1  'SURFACE' 41 0 1 0  'TOP' 0 0
*
```

```
********************SAVE MAP FILE ********************
MASTER ANALYSIS=TRANSIENT MODEX=EXECUTE TSTART=0.0,
     AUTOMATI=OFF IRINT=DEFAULT MAP-OUTP=YES MAP-FORM=NO,
     SOLVER=SPARSE MAXSOLME=0 MTOTM=2 RECL=3000 TMC-ITER=DEFAULT,
     RESULTS=PORTHOLE IPOSIT=STOP
```

```
FEPROGRAM PROGRAM=ADINA
*************** START READING FILES **************

* Example of ADINA in files for linearized buckling analysis
*Main study with initial imperfections and normal force

******************** SETTINGS ********************

MASTER ANALYSIS=BUCKLING-LOADS MODEX=EXECUTE TSTART=0.00000000000000,
     IDOF=0 OVALIZAT=NONE FLUIDPOT=AUTOMATIC CYCLICPA=1 IPOSIT=STOP,
     REACTION=YES INITIALS=NO FSINTERA=NO IRINT=DEFAULT CMASS=NO,
     SHELLNDO=AUTOMATIC AUTOMATI=ATS SOLVER=SPARSE,
     CONTACT-=CONSTRAINT-FUNCTION TRELEASE=0.00000000000000,
     RESTART-=NO FRACTURE=NO LOAD-CAS=NO LOAD-PEN=NO SINGULAR=YES,
     STIFFNES=0.000100000000000000 MAP-OUTP=NONE MAP-FORM=NO,
     NODAL-DE='' POROUS-C=NO ADAPTIVE=0 ZOOM-LAB=1 AXIS-CYC=0,
     PERIODIC=NO VECTOR-S=GEOMETRY EPSI-FIR=NO STABILIZ=NO,

******************** GEOMETRY ********************

READ F='Geo_HEB400_6.5_30_38.25_252.1_ntr_struc_NF_half.in'

**************** MATERIALS&E GROUP ***************

READ F='Mtrl_buck_HEB400_6.5_30_38.25_252.1_ntr_struc_NF_half.in'

********************** MESH **********************

READ F='Mesh_HEB400_6.5_30_38.25_252.1_ntr_struc_NF_half.in'

******************** TIME STEP *******************

*
READ F='Timestep2_HEB400_6.5_30_38.25_252.1_ntr_struc_NF_half.in'

***************** MECHANICAL LOAD ***************

READ F='Load_buck_HEB400_6.5_30_38.25_252.1_ntr_struc_NF_half.in'

*************** BOUNDARY CONDITIONS *************

READ F='BC_HEB400_6.5_30_38.25_252.1_ntr_struc_NF_half.in'

*************** CREATE BUCKLING MODES *************

BUCKLING-LOA NEIGEN=2 NMODE=0 IPRINT=NO NITEMM=40 NVECTOR=DEFAULT,
     TOLERANC=DEFAULT STARTTYP=LANCZOS NSTVECTO=0 METHOD=CLASSICAL


*************** END READING FILES ****************
```

```
******************** GEOMETRY ********************
*
COORDINATES POINT SYSTEM=0
@CLEAR
1 0 0 0
2 0 0.14325 0
3 0 0.15675 0
4 0 0.3 0
5 0 0 -0.012
6 0 0.14325 -0.012
7 0 0.15 -0.012
8 0 0.15675 -0.012
9 0 0.3 -0.012
10 0 0 -0.024
11 0 0.14325 -0.024
12 0 0.15 -0.024
13 0 0.15675 -0.024
14 0 0.3 -0.024
15 0 0.15 -0.2
16 0 0 -0.376
17 0 0.14325 -0.376
18 0 0.15 -0.376
19 0 0.15675 -0.376
20 0 0.3 -0.376
21 0 0 -0.388
22 0 0.14325 -0.388
23 0 0.15 -0.388
24 0 0.15675 -0.388
25 0 0.3 -0.388
26 0 0 -0.4
27 0 0.14325 -0.4
28 0 0.15675 -0.4
29 0 0.3 -0.4
30 -3.25 0 -0.012
31 -3.25 0.14325 -0.012
32 -3.25 0.15 -0.012
33 -3.25 0.15675 -0.012
34 -3.25 0.3 -0.012
35 -3.25 0.15 -0.024
36 -3.25 0.15 -0.2
37 -3.25 0.15 -0.376
38 -3.25 0 -0.388
39 -3.25 0.14325 -0.388
40 -3.25 0.15 -0.388
41 -3.25 0.15675 -0.388
42 -3.25 0.3 -0.388
43 0.1 0.05 0
44 0 0 0.088
45 -3.35 0.05 0
46 -3.25 0 0.088
47 0 0.14325 0.1
48 0 0.15675 0.1
49 0 0.15675 -0.2
@
*
SURFACE VERTEX NAME=1 P1=1 P2=2 P3=11 P4=10
VOLUME EXTRUDED NAME=1 SURFACE=1 DX=-3.25,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=7 P1=2 P2=3 P3=13 P4=11
VOLUME EXTRUDED NAME=2 SURFACE=7 DX=-3.25,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
```

```
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=13 P1=3 P2=4 P3=14 P4=13
VOLUME EXTRUDED NAME=3 SURFACE=13 DX=-3.25,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=19 P1=11 P2=13 P3=19 P4=17
VOLUME EXTRUDED NAME=4 SURFACE=19 DX=-3.25,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=25 P1=16 P2=17 P3=27 P4=26
VOLUME EXTRUDED NAME=5 SURFACE=25 DX=-3.25,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=31 P1=17 P2=19 P3=28 P4=27
VOLUME EXTRUDED NAME=6 SURFACE=31 DX=-3.25,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=37 P1=19 P2=20 P3=29 P4=28
VOLUME EXTRUDED NAME=7 SURFACE=37 DX=-3.25,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
*
LINE STRAIGHT NAME=61 P1=5 P2=6
*
LINE STRAIGHT NAME=62 P1=6 P2=7
*
LINE STRAIGHT NAME=63 P1=7 P2=8
*
LINE STRAIGHT NAME=64 P1=8 P2=9
*
LINE STRAIGHT NAME=65 P1=7 P2=12
*
LINE STRAIGHT NAME=66 P1=12 P2=15
*
LINE STRAIGHT NAME=67 P1=15 P2=18
*
LINE STRAIGHT NAME=68 P1=18 P2=23
*
*
LINE STRAIGHT NAME=69 P1=21 P2=22
*
LINE STRAIGHT NAME=70 P1=22 P2=23
*
LINE STRAIGHT NAME=71 P1=23 P2=24
*
LINE STRAIGHT NAME=72 P1=24 P2=25
*
LINE STRAIGHT NAME=73 P1=30 P2=31

LINE STRAIGHT NAME=74 P1=31 P2=32
*
LINE STRAIGHT NAME=75 P1=32 P2=33
```

```
*
LINE STRAIGHT NAME=76 P1=33 P2=34
*
LINE STRAIGHT NAME=77 P1=32 P2=35
*
LINE STRAIGHT NAME=78 P1=35 P2=36
*
LINE STRAIGHT NAME=79 P1=36 P2=37
*
LINE STRAIGHT NAME=80 P1=37 P2=40
*
LINE STRAIGHT NAME=81 P1=38 P2=39
*
LINE STRAIGHT NAME=82 P1=39 P2=40
*
LINE STRAIGHT NAME=83 P1=40 P2=41
*
LINE STRAIGHT NAME=84 P1=41 P2=42
```

```
********************MATERIALS********************
MATERIAL THERMO-PLASTIC NAME=1 HARDENIN=ISOTROPIC,
     TREF=0 TOLIL=1.0E-10,
     DENSITY=7850.0 MDESCRIP='STEEL' DEPENDEN=NO,
     TRANSITI=0.00010 BVALUE=0.0
@CLEAR
0 210e9 0.3 355e6 21000000 0.00001216 0.2 0
373 210e9 0.3 355e6 21000000 0.0000128 0.2 0
473 189e9 0.3 355e6 21000000 0.0000136 0.2 0
573 168e9 0.3 355e6 21000000 0.0000144 0.2 0
673 147e9 0.3 355e6 21000000 0.0000152 0.15 0
773 126e9 0.3 276.9e6 21000000 0.000016 0.15 0
873 65.1e9 0.3 166.85e6 21000000 0.0000168 0.15 0
973 27.3e9 0.3 81.65e6 21000000 0.0000176 0.15 0
1023 23.1e9 0.3 60.35e6 21000000 0.000018 0.15 0
1073 18.9e9 0.3 39.05e6 21000000 0 0.15 0
1133 16.065e9 0.3 28.4e6 21000000 0 0.15 0
1173 14.175e9 0.3 21.3e6 21000000 0.00002 0.15 0
1273 9.45e9 0.3 14.2e6 21000000 0.00002 0.15 0
1373 4.725e9 0.3 7.1e6 21000000 0.00002 0.15 0
1473 2.1E-28e9 0.3 3.55E-28e6 21000000 0.00002 0.15 0
@
*
*
MATERIAL ELASTIC NAME=2 E=210e9 NU=0.3,
     DENSITY=7850.00000000000 ALPHA=0.000015172 MDESCRIP=,
'NONE'
*
********************EGROUP********************
EGROUP THREEDSOLID NAME=1 DISPLACE=LARGE STRAINS=DEFAULT MATERIAL=1,
     RSINT=DEFAULT TINT=DEFAULT RESULTS=STRESSES DEGEN=DEFAUL,
     FORMULAT=0 STRESSRE=GLOBAL INITIALS=NONE FRACTUR=NO,
     CMASS=DEFAULT STRAIN-F=0 UL-FORMU=DEFAULT LVUS1=0 LVUS2=0 SED=NO,
     RUPTURE=ADINA INCOMPAT=DEFAULT TIME-OFF=0.0,
     POROUS=NO WTMC=1.0 OPTION=NONE DESCRIPT='NONE',
     PRINT=DEFAULT SAVE=DEFAULT TBIRTH=0.0,
     TDEATH=0.0 TMC-MATE=1 RUPTURE-=0 EM=NO JOULE=NO,
     BOLT-NUM=0 BOLT-PLA=0 BOLT-LOA=0.0,
     BOLT-TOL=0.0 TETINT=DEFAULT
*
CROSS-SECTIO RECTANGULAR NAME=1 WIDTH=3.425,
     HEIGHT=0.00685 SC=0.00000000000000 TC=0.0000000000000000000,
     TORFAC=1.00000000000 SSHEARF=0.000000000000000,
     TSHEARF=0.000000000000000 ISHEAR=NO SQUARE=NO
*
*
*
*
*
EGROUP BEAM NAME=2 SUBTYPE=THREE-D DISPLACE=DEFAULT MATERIAL=2 RINT=5,
     SINT=DEFAULT TINT=DEFAULT RESULTS=STRESSES INITIALS=NONE,
     CMASS=DEFAULT RIGIDEND=NONE MOMENT-C=NO RIGIDITY=1,
     MULTIPLY=1000000.00000000 RUPTURE=ADINA OPTION=NONE,
     BOLT-TOL=0.00000000000000 DESCRIPT='NONE' SECTION=1,
     PRINT=DEFAULT SAVE=DEFAULT TBIRTH=0.00000000000000,
     TDEATH=0.00000000000000 SPOINT=2 BOLTFORC=0.00000000000000,
     BOLTNCUR=0 TMC-MATE=1 BOLT-NUM=0 BOLT-LOA=0.00000000000000,
     WARP=NO ENDRELEA=ACCURATE
```

```
******************MESH******************
*****VOLUMES*****
SUBDIVIDE VOLUME NAME=1 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=145,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 1
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 1
@
*
SUBDIVIDE VOLUME NAME=2 MODE=DIVISIONS NDIV1=4 NDIV2=4 NDIV3=145,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 2
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 2
@
*
SUBDIVIDE VOLUME NAME=3 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=145,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 3
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 3
@
*
SUBDIVIDE VOLUME NAME=4 MODE=DIVISIONS NDIV1=4 NDIV2=48 NDIV3=145,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 4
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 4
```

```
@
*
SUBDIVIDE VOLUME NAME=5 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=145,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 5
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 5
@
*
SUBDIVIDE VOLUME NAME=6 MODE=DIVISIONS NDIV1=4 NDIV2=4 NDIV3=145,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 6
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 6
@
*
SUBDIVIDE VOLUME NAME=7 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=145,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 7
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 7
@
*****LINES*****
SUBDIVIDE LINE NAME=61 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 61
@
SUBDIVIDE LINE NAME=62 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 62
@
SUBDIVIDE LINE NAME=63 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 63
```

```
@
SUBDIVIDE LINE NAME=64 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 64
@
SUBDIVIDE LINE NAME=65 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 65
@
SUBDIVIDE LINE NAME=66 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 66
@
SUBDIVIDE LINE NAME=67 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 67
@
SUBDIVIDE LINE NAME=68 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 68
@
SUBDIVIDE LINE NAME=69 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 69
@
SUBDIVIDE LINE NAME=70 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 70
@
SUBDIVIDE LINE NAME=71 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 71
@
SUBDIVIDE LINE NAME=72 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 72
@
SUBDIVIDE LINE NAME=73 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 73
@
SUBDIVIDE LINE NAME=74 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 74
@
SUBDIVIDE LINE NAME=75 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 75
@
SUBDIVIDE LINE NAME=76 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
```

```
 76
@
SUBDIVIDE LINE NAME=77 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 77
@
SUBDIVIDE LINE NAME=78 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 78
@
SUBDIVIDE LINE NAME=79 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 79
@
SUBDIVIDE LINE NAME=80 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 80
@
SUBDIVIDE LINE NAME=81 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 81
@
SUBDIVIDE LINE NAME=82 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 82
@
SUBDIVIDE LINE NAME=83 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 83
@
SUBDIVIDE LINE NAME=84 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 84
@
*
GLINE NODES=2 AUXPOINT=30 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 61
@
GLINE NODES=2 AUXPOINT=31 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 62
@
GLINE NODES=2 AUXPOINT=32 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 63
@
```

```
GLINE NODES=2 AUXPOINT=33 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 64
@
GLINE NODES=2 AUXPOINT=32 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 65
@
GLINE NODES=2 AUXPOINT=35 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 66
@
GLINE NODES=2 AUXPOINT=36 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 67
@
GLINE NODES=2 AUXPOINT=37 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 68
@
GLINE NODES=2 AUXPOINT=38 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 69
@
GLINE NODES=2 AUXPOINT=39 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 70
@
GLINE NODES=2 AUXPOINT=40 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 71
@
GLINE NODES=2 AUXPOINT=41 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 72
@
GLINE NODES=2 AUXPOINT=5 NCOINCID=ENDS NCENDS=12,
```

```
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 73
@
GLINE NODES=2 AUXPOINT=6 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 74
@
GLINE NODES=2 AUXPOINT=7 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 75
@
GLINE NODES=2 AUXPOINT=8 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 76
@
GLINE NODES=2 AUXPOINT=7 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 77
@
GLINE NODES=2 AUXPOINT=12 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 78
@
GLINE NODES=2 AUXPOINT=15 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 79
@
GLINE NODES=2 AUXPOINT=18 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 80
@
GLINE NODES=2 AUXPOINT=21 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 81
@
GLINE NODES=2 AUXPOINT=22 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
```

```
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 82
@
GLINE NODES=2 AUXPOINT=23 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 83
@
GLINE NODES=2 AUXPOINT=24 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 84
@
```

```
TIMEFUNCTION NAME=2 IFLIB=1 FPAR1=0.0,
     FPAR2=0.0 FPAR3=0.0,
     FPAR4=0.0 FPAR5=0.0,
     FPAR6=0.0
@CLEAR
0.0 1.0
1800 1.0
@
```

```
******************** TIME STEP LOAD ********************
*
*
LOAD LINE NAME=1 MAGNITUD=-7500
*
*
APPLY-LOAD BODY=0
@CLEAR
1  'LINE' 1  'LINE' 6 0 2 0.00 13 -1 11 0 0  'NO',
     0.0 0.0 1 0  'MID'
2  'LINE' 1  'LINE' 16 0 2 0.0 13 -1 13 0 0  'NO',
     0.0 0.0 1 0  'MID'
*
*
*
*
*
*
*
*
*
*
*
*
*
*
@
```

```
******************** BOUNDARY CONDITIONS ********************
FIXITY NAME=Y
@CLEAR
 'Y-TRANSLATION'
 'OVALIZATION'
@
*
FIXITY NAME=YZ
@CLEAR
*
 'Y-TRANSLATION'
 'Z-TRANSLATION'
 'OVALIZATION'
@
FIXITY NAME=X
@CLEAR
 'X-TRANSLATION'
 'OVALIZATION'
@

FIXBOUNDARY POINTS FIXITY=ALL
@CLEAR
32  'Y'
40  'Y'
36  'YZ'
*
@
FIXBOUNDARY THREE-D FIXITY=ALL
@CLEAR
1 0  'X'
7 0  'X'
13 0  'X'
19 0  'X'
25 0  'X'
31 0  'X'
37 0  'X'
@
*
```

```
FEPROGRAM PROGRAM=ADINA
*************** START READING FILES **************

* Example of ADINA in files for structural analysis
*Main study with initial imperfections and normal force

******************** GEOMETRY ********************

READ F='Geo_HEB400_6.5_30_38.25_252.1_ntr_struc_NF_half.in'

**************** MATERIALS&E GROUP ***************

READ F='Mtrl_HEB400_6.5_30_38.25_252.1_ntr_struc_NF_half.in'

********************** MESH **********************

READ F='Mesh_HEB400_6.5_30_38.25_252.1_ntr_struc_NF_half.in'

******************** TIME STEP *******************

READ F='Timestep_HEB400_6.5_30_38.25_252.1_ntr_struc_NF_half.in'
READ F='Timestep2_HEB400_6.5_30_38.25_252.1_ntr_struc_NF_half.in'

***************** MECHANICAL LOAD ***************

READ F='Load_HEB400_6.5_30_38.25_252.1_ntr_struc_NF_half.in'

*************** BOUNDARY CONDITIONS *************

READ F='BC_HEB400_6.5_30_38.25_252.1_ntr_struc_NF_half.in'

*************** IMPORT THERMAL MAPPING *************

READ F='Thermap_HEB400_6.5_30_38.25_252.1_ntr_struc_NF_half.in'

*************** END READING FILES ****************

IMPERFECTION POINTS
@CLEAR
1 49 2 0.026
@
```

```
******************** GEOMETRY ********************
*
COORDINATES POINT SYSTEM=0
@CLEAR
1 0 0 0
2 0 0.14325 0
3 0 0.15675 0
4 0 0.3 0
5 0 0 -0.012
6 0 0.14325 -0.012
7 0 0.15 -0.012
8 0 0.15675 -0.012
9 0 0.3 -0.012
10 0 0 -0.024
11 0 0.14325 -0.024
12 0 0.15 -0.024
13 0 0.15675 -0.024
14 0 0.3 -0.024
15 0 0.15 -0.2
16 0 0 -0.376
17 0 0.14325 -0.376
18 0 0.15 -0.376
19 0 0.15675 -0.376
20 0 0.3 -0.376
21 0 0 -0.388
22 0 0.14325 -0.388
23 0 0.15 -0.388
24 0 0.15675 -0.388
25 0 0.3 -0.388
26 0 0 -0.4
27 0 0.14325 -0.4
28 0 0.15675 -0.4
29 0 0.3 -0.4
30 -3.25 0 -0.012
31 -3.25 0.14325 -0.012
32 -3.25 0.15 -0.012
33 -3.25 0.15675 -0.012
34 -3.25 0.3 -0.012
35 -3.25 0.15 -0.024
36 -3.25 0.15 -0.2
37 -3.25 0.15 -0.376
38 -3.25 0 -0.388
39 -3.25 0.14325 -0.388
40 -3.25 0.15 -0.388
41 -3.25 0.15675 -0.388
42 -3.25 0.3 -0.388
43 0.1 0.05 0
44 0 0 0.088
45 -3.35 0.05 0
46 -3.25 0 0.088
47 0 0.14325 0.1
48 0 0.15675 0.1
49 0 0.15675 -0.2
@
*
SURFACE VERTEX NAME=1 P1=1 P2=2 P3=11 P4=10
VOLUME EXTRUDED NAME=1 SURFACE=1 DX=-3.25,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=7 P1=2 P2=3 P3=13 P4=11
VOLUME EXTRUDED NAME=2 SURFACE=7 DX=-3.25,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
```

```
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=13 P1=3 P2=4 P3=14 P4=13
VOLUME EXTRUDED NAME=3 SURFACE=13 DX=-3.25,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=19 P1=11 P2=13 P3=19 P4=17
VOLUME EXTRUDED NAME=4 SURFACE=19 DX=-3.25,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=25 P1=16 P2=17 P3=27 P4=26
VOLUME EXTRUDED NAME=5 SURFACE=25 DX=-3.25,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=31 P1=17 P2=19 P3=28 P4=27
VOLUME EXTRUDED NAME=6 SURFACE=31 DX=-3.25,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
SURFACE VERTEX NAME=37 P1=19 P2=20 P3=29 P4=28
VOLUME EXTRUDED NAME=7 SURFACE=37 DX=-3.25,
     DY=0.0 DZ=0.0  SYSTEM=0 PCOINCID=YES,
     PTOLERAN=1.0E-05 NDIV=1 OPTION=VECTOR,
     RATIO=1.0 PROGRESS=GEOMETRIC CBIAS=NO
*
*
LINE STRAIGHT NAME=61 P1=5 P2=6
*
LINE STRAIGHT NAME=62 P1=6 P2=7
*
LINE STRAIGHT NAME=63 P1=7 P2=8
*
LINE STRAIGHT NAME=64 P1=8 P2=9
*
LINE STRAIGHT NAME=65 P1=7 P2=12
*
LINE STRAIGHT NAME=66 P1=12 P2=15
*
LINE STRAIGHT NAME=67 P1=15 P2=18
*
LINE STRAIGHT NAME=68 P1=18 P2=23
*
*
LINE STRAIGHT NAME=69 P1=21 P2=22
*
LINE STRAIGHT NAME=70 P1=22 P2=23
*
LINE STRAIGHT NAME=71 P1=23 P2=24
*
LINE STRAIGHT NAME=72 P1=24 P2=25
*
LINE STRAIGHT NAME=73 P1=30 P2=31

LINE STRAIGHT NAME=74 P1=31 P2=32
*
LINE STRAIGHT NAME=75 P1=32 P2=33
```

```
*
LINE STRAIGHT NAME=76 P1=33 P2=34
*
LINE STRAIGHT NAME=77 P1=32 P2=35
*
LINE STRAIGHT NAME=78 P1=35 P2=36
*
LINE STRAIGHT NAME=79 P1=36 P2=37
*
LINE STRAIGHT NAME=80 P1=37 P2=40
*
LINE STRAIGHT NAME=81 P1=38 P2=39
*
LINE STRAIGHT NAME=82 P1=39 P2=40
*
LINE STRAIGHT NAME=83 P1=40 P2=41
*
LINE STRAIGHT NAME=84 P1=41 P2=42
```

```
*******************MATERIALS*******************
MATERIAL THERMO-PLASTIC NAME=1 HARDENIN=ISOTROPIC,
     TREF=293 TOLIL=1.0E-10,
     DENSITY=7850.0 MDESCRIP='STEEL' DEPENDEN=NO,
     TRANSITI=0.00010 BVALUE=0.0
@CLEAR
293 210e9 0.3 355e6 21000000 0.00001216 0.2 0
373 210e9 0.3 355e6 21000000 0.0000128 0.2 0
473 189e9 0.3 355e6 21000000 0.0000136 0.2 0
573 168e9 0.3 355e6 21000000 0.0000144 0.2 0
673 147e9 0.3 355e6 21000000 0.0000152 0.15 0
773 126e9 0.3 276.9e6 21000000 0.000016 0.15 0
873 65.1e9 0.3 166.85e6 21000000 0.0000168 0.15 0
973 27.3e9 0.3 81.65e6 21000000 0.0000176 0.15 0
1023 23.1e9 0.3 60.35e6 21000000 0.000018 0.15 0
1073 18.9e9 0.3 39.05e6 21000000 0 0.15 0
1133 16.065e9 0.3 28.4e6 21000000 0 0.15 0
1173 14.175e9 0.3 21.3e6 21000000 0.00002 0.15 0
1273 9.45e9 0.3 14.2e6 21000000 0.00002 0.15 0
1373 4.725e9 0.3 7.1e6 21000000 0.00002 0.15 0
1473 2.1E-28e9 0.3 3.55E-28e6 21000000 0.00002 0.15 0
@
*
*
MATERIAL ELASTIC NAME=2 E=210e9 NU=0.3,
     DENSITY=7850.00000000000 ALPHA=0.000015172 MDESCRIP=,
'NONE'
*
*******************EGROUP*******************
EGROUP THREEDSOLID NAME=1 DISPLACE=LARGE STRAINS=DEFAULT MATERIAL=1,
     RSINT=DEFAULT TINT=DEFAULT RESULTS=STRESSES DEGEN=DEFAUL,
     FORMULAT=0 STRESSRE=GLOBAL INITIALS=NONE FRACTUR=NO,
     CMASS=DEFAULT STRAIN-F=0 UL-FORMU=DEFAULT LVUS1=0 LVUS2=0 SED=NO,
     RUPTURE=ADINA INCOMPAT=DEFAULT TIME-OFF=0.0,
     POROUS=NO WTMC=1.0 OPTION=NONE DESCRIPT='NONE',
     PRINT=DEFAULT SAVE=DEFAULT TBIRTH=0.0,
     TDEATH=0.0 TMC-MATE=1 RUPTURE-=0 EM=NO JOULE=NO,
     BOLT-NUM=0 BOLT-PLA=0 BOLT-LOA=0.0,
     BOLT-TOL=0.0 TETINT=DEFAULT
*
CROSS-SECTIO RECTANGULAR NAME=1 WIDTH=3.425,
     HEIGHT=0.00685 SC=0.00000000000000 TC=0.0000000000000000000,
     TORFAC=1.00000000000 SSHEARF=0.0000000000000000,
     TSHEARF=0.000000000000000 ISHEAR=NO SQUARE=NO
*
*
*
*
*
EGROUP BEAM NAME=2 SUBTYPE=THREE-D DISPLACE=DEFAULT MATERIAL=2 RINT=5,
     SINT=DEFAULT TINT=DEFAULT RESULTS=STRESSES INITIALS=NONE,
     CMASS=DEFAULT RIGIDEND=NONE MOMENT-C=NO RIGIDITY=1,
     MULTIPLY=1000000.00000000 RUPTURE=ADINA OPTION=NONE,
     BOLT-TOL=0.00000000000000 DESCRIPT='NONE' SECTION=1,
     PRINT=DEFAULT SAVE=DEFAULT TBIRTH=0.00000000000000,
     TDEATH=0.00000000000000 SPOINT=2 BOLTFORC=0.00000000000000,
     BOLTNCUR=0 TMC-MATE=1 BOLT-NUM=0 BOLT-LOA=0.00000000000000,
     WARP=NO ENDRELEA=ACCURATE
```

```
*******************MESH*******************
*****VOLUMES*****
SUBDIVIDE VOLUME NAME=1 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=145,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 1
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 1
@
*
SUBDIVIDE VOLUME NAME=2 MODE=DIVISIONS NDIV1=4 NDIV2=4 NDIV3=145,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 2
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 2
@
*
SUBDIVIDE VOLUME NAME=3 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=145,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 3
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 3
@
*
SUBDIVIDE VOLUME NAME=4 MODE=DIVISIONS NDIV1=4 NDIV2=48 NDIV3=145,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 4
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 4
```

```
@
*
SUBDIVIDE VOLUME NAME=5 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=145,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 5
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 5
@
*
SUBDIVIDE VOLUME NAME=6 MODE=DIVISIONS NDIV1=4 NDIV2=4 NDIV3=145,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 6
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 6
@
*
SUBDIVIDE VOLUME NAME=7 MODE=DIVISIONS NDIV1=30 NDIV2=4 NDIV3=145,
     RATIO1=1.0 RATIO2=1.0,
     RATIO3=1.0 PROGRESS=GEOMETRIC EXTEND=NONE CBIAS1=NO,
     CBIAS2=NO CBIAS3=NO
@CLEAR
 7
@
GVOLUME NODES=8 PATTERN=0 NCOINCID=BOUNDARIES NCFACE=123456 NCEDGE=,
'123456789ABC' NCVERTEX=12345678 NCTOLERA=1.00000000000000E-05,
     SUBSTRUC=0 GROUP=1 MESHING=MAPPED PREFSHAP=AUTOMATIC,
     DEGENERA=YES COLLAPSE=NO MIDNODES=CURVED METHOD=DELAUNAY,
     BOUNDARY=ADVFRONT
@CLEAR
 7
@
*****LINES*****
SUBDIVIDE LINE NAME=61 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 61
@
SUBDIVIDE LINE NAME=62 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 62
@
SUBDIVIDE LINE NAME=63 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 63
```

```
@
SUBDIVIDE LINE NAME=64 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 64
@
SUBDIVIDE LINE NAME=65 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 65
@
SUBDIVIDE LINE NAME=66 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 66
@
SUBDIVIDE LINE NAME=67 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 67
@
SUBDIVIDE LINE NAME=68 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 68
@
SUBDIVIDE LINE NAME=69 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 69
@
SUBDIVIDE LINE NAME=70 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 70
@
SUBDIVIDE LINE NAME=71 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 71
@
SUBDIVIDE LINE NAME=72 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 72
@
SUBDIVIDE LINE NAME=73 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 73
@
SUBDIVIDE LINE NAME=74 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 74
@
SUBDIVIDE LINE NAME=75 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 75
@
SUBDIVIDE LINE NAME=76 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
```

```
 76
@
SUBDIVIDE LINE NAME=77 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 77
@
SUBDIVIDE LINE NAME=78 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 78
@
SUBDIVIDE LINE NAME=79 MODE=DIVISIONS NDIV=24 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 79
@
SUBDIVIDE LINE NAME=80 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 80
@
SUBDIVIDE LINE NAME=81 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 81
@
SUBDIVIDE LINE NAME=82 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 82
@
SUBDIVIDE LINE NAME=83 MODE=DIVISIONS NDIV=2 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 83
@
SUBDIVIDE LINE NAME=84 MODE=DIVISIONS NDIV=30 RATIO=1.00000000000000,
     PROGRESS=GEOMETRIC CBIAS=NO
@CLEAR
 84
@
*
GLINE NODES=2 AUXPOINT=30 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 61
@
GLINE NODES=2 AUXPOINT=31 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 62
@
GLINE NODES=2 AUXPOINT=32 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 63
@
```

```
GLINE NODES=2 AUXPOINT=33 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 64
@
GLINE NODES=2 AUXPOINT=32 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 65
@
GLINE NODES=2 AUXPOINT=35 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 66
@
GLINE NODES=2 AUXPOINT=36 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 67
@
GLINE NODES=2 AUXPOINT=37 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 68
@
GLINE NODES=2 AUXPOINT=38 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 69
@
GLINE NODES=2 AUXPOINT=39 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 70
@
GLINE NODES=2 AUXPOINT=40 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 71
@
GLINE NODES=2 AUXPOINT=41 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 72
@
GLINE NODES=2 AUXPOINT=5 NCOINCID=ENDS NCENDS=12,
```

```
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 73
@
GLINE NODES=2 AUXPOINT=6 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 74
@
GLINE NODES=2 AUXPOINT=7 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 75
@
GLINE NODES=2 AUXPOINT=8 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 76
@
GLINE NODES=2 AUXPOINT=7 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 77
@
GLINE NODES=2 AUXPOINT=12 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 78
@
GLINE NODES=2 AUXPOINT=15 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 79
@
GLINE NODES=2 AUXPOINT=18 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 80
@
GLINE NODES=2 AUXPOINT=21 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 81
@
GLINE NODES=2 AUXPOINT=22 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
```

```
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 82
@
GLINE NODES=2 AUXPOINT=23 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 83
@
GLINE NODES=2 AUXPOINT=24 NCOINCID=ENDS NCENDS=12,
     NCTOLERA=1.00000000000000E-05 SUBSTRUC=0 GROUP=2 MIDNODES=CURVED,
     XO=0.00000000000000 YO=0.00000000000000 ZO=0.00000000000000,
     XYZOSYST=SKEW
@CLEAR
 84
@
```

```
******************** TIME STEP ********************
*
TIMESTEP NAME=TEMP
@CLEAR
100 18
@
*
TIMEFUNCTION NAME=1
@CLEAR
0 293
18 476.360226379578
36 556.382657779213
54 608.265779072382
72 646.730523516346
90 677.310456545859
108 702.69464868858
126 724.394900796568
144 743.346222459085
162 760.167411505853
180 775.289302991853
198 789.023944173034
216 801.604611106308
234 813.210275735062
252 823.981254083508
270 834.029594803113
288 843.446196529823
306 852.305817212387
324 860.670682925437
342 868.59314125805
360 876.117647609837
378 883.28227605337
396 890.119885104904
414 896.659028871326
432 902.924677526241
450 908.938793078715
468 914.720793969198
486 920.287933296815
504 925.655609256485
522 930.837621862872
540 935.846386741557
558 940.693114325072
576 945.387960961443
594 949.940157058036
612 954.358116325532
630 958.649529371431
648 962.821444258869
666 966.88033615022
684 970.832167763502
702 974.682442058619
720 978.436248321855
738 982.098302617073
756 985.672983410255
774.000000000001 989.164363042409
792.000000000001 992.576235618241
810.000000000001 995.912141789515
828.000000000001 999.17539083901
846.000000000001 1002.36908041037
864.000000000001 1005.49611417874
882.000000000001 1008.55921771474
900.000000000001 1011.56095275918
918.000000000001 1014.50373009554
936.000000000001 1017.38982118269
954.000000000001 1020.22136868807
972.000000000001 1023.00039604397
```

```
990.000000000001 1025.72881613364
1008 1028.40843920045
1026 1031.0409800622
1044 1033.62806470257
1062 1036.17123630297
1080 1038.67196077107
1098 1041.13163181545
1116 1043.55157561039
1134 1045.93305508992
1152 1048.2772739059
1170 1050.58538008119
1188 1052.85846938573
1206 1055.09758846031
1224 1057.30373771028
1242 1059.47787398942
1260 1061.62091309172
1278 1063.73373206758
1296 1065.81717137886
1314 1067.87203690623
1332 1069.89910182062
1350 1071.89910832987
1368 1073.87276931023
1386 1075.82076983188
1404 1077.74376858648
1422 1079.6423992243
1440 1081.51727160768
1458 1083.36897298705
1476 1085.1980691051
1494 1087.00510523444
1512 1088.79060715337
1530 1090.55508206424
1548 1092.29901945829
1566 1094.02289193085
1584 1095.72715595004
1602 1097.41225258233
1620 1099.07860817774
1638 1100.72663501735
1656 1102.35673192553
1674 1103.96928484934
1692 1105.56466740695
1710 1107.14324140726
1728 1108.70535734243
1746 1110.25135485491
1764 1111.78156318074
1782 1113.29630157034
1800 1114.79587968833
```

```
TIMEFUNCTION NAME=2 IFLIB=1 FPAR1=0.0,
     FPAR2=0.0 FPAR3=0.0,
     FPAR4=0.0 FPAR5=0.0,
     FPAR6=0.0
@CLEAR
0.0 1.0
1800 1.0
@
```

```
******************* TIME STEP LOAD *******************
*
*
LOAD LINE NAME=1 MAGNITUD=-19125
LOAD PRESSURE NAME=1 MAGNITUD=13163116.1236424 BETA=0.00000000000000,
     LINE=0 SYSTEM=0 MAPPING=0
APPLY-LOAD BODY=0
@CLEAR
1  'LINE' 1  'LINE' 6 0 2 0.00 13 -1 11 0 0  'NO',
     0.0 0.0 1 0  'MID'
2  'LINE' 1  'LINE' 16 0 2 0.0 13 -1 13 0 0  'NO',
     0.0 0.0 1 0  'MID'
3  'PRESSURE' 1  'SURFACE' 6 0 2 0.00000000000000 0 -1 0 0 0  'NO',
     0.00000000000000 0.00000000000000 1 0  'MID'
4  'PRESSURE' 1  'SURFACE' 11 0 2 0.00000000000000 0 -1 0 0 0  'NO',
     0.00000000000000 0.00000000000000 1 0  'MID'
5  'PRESSURE' 1  'SURFACE' 17 0 2 0.00000000000000 0 -1 0 0 0  'NO',
     0.00000000000000 0.00000000000000 1 0  'MID'
6  'PRESSURE' 1  'SURFACE' 23 0 2 0.00000000000000 0 -1 0 0 0  'NO',
     0.00000000000000 0.00000000000000 1 0  'MID'
7  'PRESSURE' 1  'SURFACE' 30 0 2 0.00000000000000 0 -1 0 0 0  'NO',
     0.00000000000000 0.00000000000000 1 0  'MID'
8  'PRESSURE' 1  'SURFACE' 34 0 2 0.00000000000000 0 -1 0 0 0  'NO',
     0.00000000000000 0.00000000000000 1 0  'MID'
9  'PRESSURE' 1  'SURFACE' 41 0 2 0.00000000000000 0 -1 0 0 0  'NO',
     0.00000000000000 0.00000000000000 1 0  'MID'
@
```

```
******************** BOUNDARY CONDITIONS ********************
FIXITY NAME=Y
@CLEAR
 'Y-TRANSLATION'
 'OVALIZATION'
@
*
FIXITY NAME=YZ
@CLEAR
*
 'Y-TRANSLATION'
 'Z-TRANSLATION'
 'OVALIZATION'
@
FIXITY NAME=X
@CLEAR
 'X-TRANSLATION'
 'OVALIZATION'
@

FIXBOUNDARY POINTS FIXITY=ALL
@CLEAR
32  'Y'
40  'Y'
36  'YZ'
*
@
FIXBOUNDARY THREE-D FIXITY=ALL
@CLEAR
1 0  'X'
7 0  'X'
13 0  'X'
19 0  'X'
25 0  'X'
31 0  'X'
37 0  'X'
@
*
```

```
********************THERMAL MAPPING ********************
THERMAL-MAPP FILENAME=,
'HEB400_6.5_30_ntr_therm_NF_half.map',
 EXTERNAL=ALL TIME=0.0 TOLERANC=1.0E-15
```

H

FE model verification calculations

Calculations for FE model verification

Input data

All blue area data should be changed manually
.

Cross section:

$$A := \begin{pmatrix} \text{"HEA100"} & \text{"HEB400"} & \text{"HEM400"} \\ 0.1 & 0.3 & 0.307 \\ 0.008 & 0.024 & 0.04 \\ 0.096 & 0.4 & 0.432 \\ 0.005 & 0.0235 & 0.021 \\ 0.012 & 0.027 & 0.027 \end{pmatrix}$$

beam :=

- HEA100
- HEB400
- HEM400

$b_f := A_{1,\text{beam}-1} \cdot m = 100 \cdot mm$	Flange width
$t_f := A_{2,\text{beam}-1} \cdot m = 8 \cdot mm$	Flange thickness
$h_w := A_{3,\text{beam}-1} \cdot m - 2 \cdot t_f = 80 \cdot mm$	Web height
$t_w := A_{4,\text{beam}-1} \cdot m = 5 \cdot mm$	Web thickness
$r := A_{5,\text{beam}-1} \cdot m = 12 \cdot mm$	Radius of the rolled I section
$L := 1.5m$	Length of beam
$Q := 79.5 \dfrac{kN}{m}$	Load
steel :=	Steel class

- S235
- S355

$$f_y := \left| \begin{array}{l} 235MPa \quad \text{if } steel = 1 \\ (355MPa) \quad \text{if } steel = 2 \end{array} \right. = 355 \cdot MPa$$

Yield strength for structural steel, S235, S275, S355. S420

Buckling

$$\text{Bucklingcurve}_y := \begin{array}{|l} \text{"a"} \quad \text{if } \dfrac{h_w + 2 \cdot t_f}{b_f} > 1.2 \wedge t_f \le 40\text{mm} \\ \text{"b"} \quad \text{if } \dfrac{h_w + 2 \cdot t_f}{b_f} > 1.2 \wedge 40\text{mm} < t_f \le 100\text{mm} \\ \text{"b"} \quad \text{if } \dfrac{h_w + 2 \cdot t_f}{b_f} \le 1.2 \wedge t_f \le 100\text{mm} \\ \text{"d"} \quad \text{if } \dfrac{h_w + 2 \cdot t_f}{b_f} \le 1.2 \wedge t_f > 100\text{mm} \\ \text{"WARNING, INPUT NOT ACCURATE"} \quad \text{otherwise} \end{array}$$

$$\text{Bucklingcurve}_y = \text{"b"}$$

Support conditions

Simply supported = 1, Fixed = 0.5

$k_{l.cr} := 1$ Buckling length

Constant variables

Input for EN 1993-1-2

$L_{cr} := k_{l.cr} \cdot L = 1.5\,m$ Critical buckling length of beam

$\gamma_{M1} := 1.0$ Partial factor for resistance of members to instability assesed by member checks

$E := 210 \cdot 10^9 Pa$ Elasticity modulus for structural steel

Cross section properties

$A := 2 \cdot t_f \cdot b_f + h_w \cdot t_w = 2 \times 10^{-3} m^2$ Cross section area

$y_{TP} := t_f + \frac{h_w}{2} = 0.048\,m$ Gravity center in y-direction

$$I_y := \frac{t_w \cdot h_w^{\ 3}}{12} + \frac{2 \cdot b_f \cdot t_f^{\ 3}}{12} + 2 \cdot b_f \cdot t_f \cdot \left(y_{TP} - \frac{t_f}{2}\right)^2$$

$I_y = 3.319 \times 10^{-6} m^4$ Second moment of area in y direction

$W_{pl.y} := b_f \cdot t_f \cdot \left(h_w + t_f\right) + \frac{t_w \cdot h_w^{\ 2}}{4} = 7.84 \times 10^{-5} \cdot m^3$ Section modulus in y-direction

Eurocode 1993-1-1: Capacities

Normal force, compression:

$N_{cr.y} := \pi^2 \cdot E \cdot \frac{I_y}{L_{cr}^{\ 2}} = 3.058 \times 10^3 \cdot kN$ Elastic critical force for the relvant buckling mode based on the gross cross section properties

$\lambda_y := \sqrt{A \cdot \frac{f_y}{N_{cr.y}}} = 0.482$ Non dimensional slenderness

Bending capacity without Lateral torsional buckling:

$M_{Rd} := W_{pl.y} \cdot \frac{f_y}{\gamma_{M1}} = 27.832 \cdot kN \cdot m$ Design value of the resistance to bending moment

Results

Critical load

$$Q_{cr} := M_{Rd} \cdot \frac{8}{L^2} = 98.958 \cdot \frac{kN}{m}$$

Deflection Euler Bernouilli beam theory

$$Deflection_{EB} := \frac{5Q \cdot L^4}{384 \cdot E \cdot I_y} = 7.518 \cdot mm$$

Deflection Timishenko beam theory

$$variable := \frac{A}{8 \cdot I_y \cdot t_w} \cdot \left[b_f \cdot \left(h_w + 2 \cdot t_f \right)^2 - b_f \cdot h_w{}^2 + t_w \cdot h_w{}^2 \right] = 4.724$$

$$E_s := 12000000psi$$

$$Delta := \frac{Q \cdot L^2 \cdot variable}{8 \cdot A \cdot E_s} = 0.638 \cdot mm$$

$$Deflection_T := Deflection_{EB} + Delta = 8.156 \cdot mm$$

Critical load comparison					
BEAM			Critical load [kN/m]		
Beam	Length [m]	Slenderness	Handcalculations	ADINA	Difference
HEA100	1.5	0.482	98.96	99.75	1%
HEA100	2	0.624	55.66	56.1	1%
HEA100	3	0.964	24.74	24.975	1%
HEA100	6	1.927	6.19	6.4	3%

Deflection comparison					
BEAM			Deflection [m]		
Beam	Length [m]	Load [kN/m]	Handcalculations	ADINA	Difference
HEA100	1.5	79.5	0.007518	0.008169	8.7%
HEA100	2	54	0.016139	0.01687	4.5%
HEA100	3	23	0.034799	0.03533	1.5%
HEA100	6	4	0.09631	0.09683	0.5%
Beam	Length [m]	Load [kN/m]	Handcalculations with Timoshenko	ADINA	Difference
HEA100	1.5	79.5	0.008156	0.008169	0.2%
HEA100	2	54	0.016909	0.01687	-0.2%
HEA100	3	23	0.035537	0.03533	-0.6%
HEA100	6	4	0.097345	0.09683	-0.5%

Energy calculations for FE model verification

Time	Temp outside beam	P	Temperature difference	Alpha	Stefan Boltzmans constant	Kappa	Heat flow convection [kW/s]	Energy from convection [kJ]	Heat flow radiation [kW/s]	Energy from radiaton [kJ]	Total Energy [kJ]
0	293	293	0	25	5.6696E-08	5.704469627	0	0	0	0	0
7.2	393.8283446	293.5	100.3283446	25	5.6696E-08	9.400943042	61.86245729	445.4096925	23.2626175	167.490846	612.9005385
14.4	453.5570837	294.3	159.2570837	25	5.6696E-08	12.39479206	98.19791784	707.0250084	48.6857109	350.5371185	1057.562127
21.6	496.1469453	295.4	200.7469453	25	5.6696E-08	14.96320371	123.7805665	891.2200787	74.08615326	533.4203035	1424.640382
28.8	529.2716498	296.7	232.5716498	25	5.6696E-08	17.24064137	143.4036792	1032.506491	98.89485622	712.0429648	1744.549455
36	556.3826578	298.2	258.1826578	25	5.6696E-08	19.30715869	159.1954268	1146.207073	122.9444547	885.200074	2031.407147
43.2	579.3316101	299.9	279.4316101	25	5.6696E-08	21.21395987	172.2975308	1240.542222	146.2045162	1052.672516	2293.214738
50.4	599.2279686	301.8	297.4279686	25	5.6696E-08	22.99614741	183.3940854	1320.437415	168.694297	1214.598938	2535.036353
57.6	616.7893052	303.9	312.8893052	25	5.6696E-08	24.67905494	192.9275456	1389.078328	190.4507799	1371.245615	2760.323943
64.8	632.5065767	306.1	326.4065767	25	5.6696E-08	26.27565085	201.2622952	1449.088525	211.5319119	1523.029766	2972.118291
72	646.7305235	308.5	338.2305235	25	5.6696E-08	27.80635536	208.5529408	1501.581174	231.9638873	1670.139989	3171.721162
79.2	659.7204528	311	348.7204528	25	5.6696E-08	29.27649678	215.0210312	1548.151424	251.802501	1812.978007	3361.129432
86.4	671.6734935	313.6	358.0734935	25	5.6696E-08	30.69511066	220.7881161	1589.674436	271.0846262	1951.809308	3541.483744
93.6	682.7430128	316.3	366.4430128	25	5.6696E-08	32.06963208	225.9487617	1626.831084	289.8437463	2086.874973	3713.706058
100.8	693.0506817	319.1	373.9506817	25	5.6696E-08	33.40627563	230.5779903	1660.16153	308.110076	2218.392547	3878.554077
108	702.6946487	322.2	380.4946487	25	5.6696E-08	34.72456892	234.6130004	1689.213603	325.8734121	2346.288567	4035.50217
115.2	711.7552383	325.2	386.5552383	25	5.6696E-08	36.00083289	238.3499599	1716.119711	343.231883	2471.269558	4187.389269
122.4	720.2990213	328.4	391.8990213	25	5.6696E-08	37.26037354	241.6449365	1739.843543	360.151224	2593.088813	4332.932355
129.6	728.381786	331.6	396.781786	25	5.6696E-08	38.4918689	244.6556493	1761.520675	376.6901271	2712.168915	4473.68959
136.8	736.0507484	335	401.0507484	25	5.6696E-08	39.71342691	247.2878914	1780.472818	392.8259841	2828.347085	4608.819904
144	743.3462225	338.4	404.9462225	25	5.6696E-08	40.91236012	249.6898408	1797.766854	408.6160273	2942.035397	4739.80225
151.2	750.3029039	341.9	408.4029039	25	5.6696E-08	42.0987194	251.8212305	1813.11286	424.0540529	3053.189181	4866.302041
158.4	756.9508673	345.5	411.4508673	25	5.6696E-08	43.27470729	253.7006048	1826.644354	439.1527765	3161.899991	4988.544345
165.6	763.3163525	349.1	414.2163525	25	5.6696E-08	44.43393269	255.405803	1838.921781	453.9473703	3268.421066	5107.342848
172.8	769.4223898	352.9	416.5223898	25	5.6696E-08	45.59487997	256.8277056	1849.15948	468.4011364	3372.488182	5221.647662
180	775.289303	356.7	418.589303	25	5.6696E-08	46.74229776	258.1021642	1858.335582	482.5715285	3474.515005	5332.850588
187.2	780.9351174	360.5	420.4351174	25	5.6696E-08	47.87730136	259.2402934	1866.530112	496.4690261	3574.576988	5441.1071
194.4	786.3758942	364.5	421.8758942	25	5.6696E-08	49.01893097	260.1286763	1872.92647	510.0491852	3672.354133	5545.280603
201.6	791.6260055	368.4	423.2260055	25	5.6696E-08	50.1415209	260.961155	1878.920316	523.3995682	3768.476891	5647.397207
208.8	796.6983633	372.3	424.3983633	25	5.6696E-08	51.25477252	261.6840308	1884.125022	536.5022189	3862.815976	5746.940998
216	801.6046111	376.4	425.2046111	25	5.6696E-08	52.37839999	262.1811632	1887.704375	549.3051934	3954.997393	5842.701768
223.2	806.3552842	380.7	425.6552842	25	5.6696E-08	53.51403467	262.4590483	1889.705147	561.8097044	4045.029871	5934.735019
230.4	810.9599466	384.8	426.1599466	25	5.6696E-08	54.62411069	262.7702231	1891.945606	574.1435901	4133.833849	6025.779455
237.6	815.4273065	389.1	426.3273065	25	5.6696E-08	55.74806192	262.8734172	1892.688604	586.1873415	4220.548859	6113.237463
244.8	819.7653156	393.3	426.4653156	25	5.6696E-08	56.8570831	262.9585136	1893.301298	598.0421624	4305.903569	6199.204867
252	823.9812541	397.6	426.3812541	25	5.6696E-08	57.97172896	262.9066813	1892.928105	609.6461947	4389.452602	6282.380707
259.2	828.0818045	402	426.0818045	25	5.6696E-08	59.09294752	262.7220407	1891.598693	621.0007905	4471.205691	6362.804384
266.4	832.0731153	406.3	425.7731153	25	5.6696E-08	60.20052224	262.5317029	1890.228261	632.1818247	4551.709138	6441.937399
273.6	835.9608559	410.7	425.2608559	25	5.6696E-08	61.31584968	262.2158437	1887.954075	643.1194903	4630.46033	6518.414405
280.8	839.7502658	415.2	424.5502658	25	5.6696E-08	62.43979513	261.7776939	1884.799396	653.813823	4707.459526	6592.258921
288	843.4461965	419.7	423.7461965	25	5.6696E-08	63.56216181	261.2819048	1881.229714	664.3057084	4783.0011	6664.230815
295.2	847.0531494	424.2	422.8531494	25	5.6696E-08	64.68329694	260.7312519	1877.265014	674.5982795	4857.107612	6734.372626

Energy calculations for FE model verification

Time	Temp outside beam	P	Temperature difference	Alpha	Stefan Boltzmans constant	Kappa	Heat flow convection [kW/s]	Energy from convection [kJ]	Heat flow radiation [kW/s]	Energy from radiaton [kJ]	Total Energy [kJ]
302.4	850.5753079	428.7	421.8753079	25	5.6696E-08	65.80352815	260.1283149	1872.923867	684.6944356	4929.799937	6802.723804
309.6	854.0165676	433.3	420.7165676	25	5.6696E-08	66.93468838	259.4138356	1867.779616	694.5513699	5000.769864	6868.54948
316.8	857.3805614	437.8	419.5805614	25	5.6696E-08	68.0541838	258.7133742	1862.736294	704.2611007	5070.679925	6933.416219
324	860.6706829	442.4	418.2706829	25	5.6696E-08	69.18550104	257.9057031	1856.921062	713.7334116	5138.880564	6995.801626
331.2	863.890107	447.1	416.790107	25	5.6696E-08	70.32939083	256.99278	1850.348016	722.9658264	5205.35395	7055.701966
338.4	867.041808	451.7	415.341808	25	5.6696E-08	71.46224743	256.0997588	1843.918264	732.0585733	5270.821727	7114.739991
345.6	870.1285767	456.4	413.7285767	25	5.6696E-08	72.60849514	255.1050404	1836.756291	740.9117234	5334.564409	7171.320699
352.8	873.1530346	461.1	412.0530346	25	5.6696E-08	73.75635328	254.0719011	1829.317688	749.5766759	5396.952066	7226.269754
360	876.1176476	465.8	410.3176476	25	5.6696E-08	74.90604074	253.0018615	1821.613403	758.0547099	5457.993911	7279.607314
367.2	879.0247382	470.5	408.5247382	25	5.6696E-08	76.05776697	251.8963536	1813.653746	766.3469665	5517.698159	7331.351905
374.4	881.8764963	475.2	406.6764963	25	5.6696E-08	77.2117326	250.7567276	1805.448439	774.454456	5576.072083	7381.520522
381.6	884.6749888	479.9	404.7749888	25	5.6696E-08	78.36813006	249.5842581	1797.006658	782.3780639	5633.12206	7430.128718
388.8	887.4221691	484.7	402.7221691	25	5.6696E-08	79.54048102	248.3184895	1787.893124	790.0548839	5688.395164	7476.288288
396	890.1198851	489.4	400.7198851	25	5.6696E-08	80.7024566	247.0838812	1779.003944	797.6110478	5742.799544	7521.803489
403.2	892.7698866	494.2	398.5698866	25	5.6696E-08	81.88107225	245.7581921	1769.458983	804.9177713	5795.407953	7564.866936
410.4	895.3738322	499	396.3738322	25	5.6696E-08	83.06315691	244.4041049	1759.709555	812.0390606	5846.681237	7606.390792
417.6	897.9332953	503.7	394.2332953	25	5.6696E-08	84.23485395	243.0842499	1750.206599	819.0466515	5897.135891	7647.34249
424.8	900.4497704	508.5	391.9497704	25	5.6696E-08	85.42417947	241.6762284	1740.068845	825.7997404	5945.758131	7685.826975
432	902.9246775	513.3	389.6246775	25	5.6696E-08	86.61743744	240.2425762	1729.746548	832.3678525	5993.048538	7722.795086
439.2	905.3593677	518.1	387.2593677	25	5.6696E-08	87.81477239	238.7841261	1719.245708	838.7509475	6039.006822	7758.25253
446.4	907.7551272	522.9	384.8551272	25	5.6696E-08	89.01632428	237.3016714	1708.572034	844.9489014	6083.63209	7792.204124
453.6	910.1131813	527.7	382.4131813	25	5.6696E-08	90.22222875	235.7959676	1697.730967	850.9615091	6126.922865	7824.653832
460.8	912.4346986	532.5	379.9346986	25	5.6696E-08	91.43261743	234.2677351	1686.727693	856.7884881	6168.877114	7855.604807
468	914.720794	537.3	377.420794	25	5.6696E-08	92.64761808	232.7176616	1675.567163	862.4294812	6209.492264	7885.059428
475.2	916.9725322	542.1	374.8725322	25	5.6696E-08	93.86735485	231.1464034	1664.254104	867.8840587	6248.765223	7913.019327
482.4	919.1909307	546.9	372.2909307	25	5.6696E-08	95.09194848	229.5545879	1652.793033	873.1517218	6286.692397	7939.48543
489.6	921.3769624	551.7	369.6769624	25	5.6696E-08	96.32151645	227.942815	1641.188268	878.2319043	6323.269711	7964.457979
496.8	923.5315581	556.5	367.0315581	25	5.6696E-08	97.55617318	226.3116588	1629.443943	883.1239749	6358.492619	7987.936562
504	925.6556093	561.2	364.4556093	25	5.6696E-08	98.77992344	224.7233287	1618.007966	887.9261281	6393.068122	8011.076089
511.2	927.7499697	566	361.7499697	25	5.6696E-08	100.0249116	223.0550313	1605.996225	892.4423912	6425.585217	8031.581442
518.4	929.8154581	570.8	359.0154581	25	5.6696E-08	101.2753142	221.3689314	1593.856306	896.7683237	6456.731931	8050.588237
525.6	931.8528596	575.6	356.2528596	25	5.6696E-08	102.5312351	219.6655132	1581.591695	900.9030549	6486.501996	8068.093691
532.8	933.8629279	580.3	353.5629279	25	5.6696E-08	103.7759567	218.0069014	1569.64969	904.9549904	6515.675931	8085.325621
540	935.8463867	585.1	350.7463867	25	5.6696E-08	105.0430352	216.2702221	1557.145599	908.7072221	6542.691999	8099.837598
547.2	937.8039314	589.8	348.0039314	25	5.6696E-08	106.2987519	214.5792241	1544.970413	912.3801482	6569.137067	8114.10748
554.4	939.7362302	594.5	345.2362302	25	5.6696E-08	107.5600185	212.8726595	1532.683149	915.8634876	6594.217111	8126.90026
561.6	941.6439262	599.2	342.4439262	25	5.6696E-08	108.826926	211.1509249	1520.286659	919.1562427	6617.924947	8138.211606
568.8	943.5276379	603.9	339.6276379	25	5.6696E-08	110.0995636	209.4144015	1507.783691	922.2573687	6640.253055	8148.036746
576	945.387961	608.6	336.787961	25	5.6696E-08	111.3780188	207.6634567	1495.176888	925.1657754	6661.193583	8156.370471
583.2	947.2254691	613.3	333.9254691	25	5.6696E-08	112.6623772	205.8984442	1482.468798	927.8803279	6680.738361	8163.207159
590.4	949.0407151	618	331.0407151	25	5.6696E-08	113.952723	204.1197049	1469.661875	930.3998476	6698.878903	8168.540778
597.6	950.8342319	622.6	328.2342319	25	5.6696E-08	115.2307053	202.3892274	1457.202437	932.858137	6716.578586	8173.781024

Energy calculations for FE model verification

Time	Temp outside beam	P	Temperature difference	Alpha	Stefan Boltzmans constant	Kappa	Heat flow convection [kW/s]	Energy from convection [kJ]	Heat flow radiation [kW/s]	Energy from radiaton [kJ]	Total Energy [kJ]
604.8	952.6065336	627.3	325.3065336	25	5.6696E-08	116.5330894	200.5840086	1444.204862	934.9869683	6731.906172	8176.111034
612	954.3581163	631.9	322.4581163	25	5.6696E-08	117.8229079	198.8276745	1431.559257	937.0581916	6746.81898	8178.378236
619.2	956.0894588	636.5	319.5894588	25	5.6696E-08	119.1186706	197.0588603	1418.823794	938.9355791	6760.336169	8179.159964
626.4	957.8010235	641.1	316.7010235	25	5.6696E-08	120.4204526	195.2778511	1406.000528	940.6178885	6772.448797	8178.449325
633.6	959.4932572	645.7	313.7932572	25	5.6696E-08	121.7283277	193.4849224	1393.091441	942.1038411	6783.147656	8176.239097
640.8	961.1665916	650.2	310.9665916	25	5.6696E-08	123.0228519	191.7420004	1380.542403	943.5459082	6793.530539	8174.072942
648	962.8214443	654.7	308.1214443	25	5.6696E-08	124.3232513	189.9876825	1367.911314	944.795456	6802.527283	8170.438598
655.2	964.458219	659.3	305.158219	25	5.6696E-08	125.6494702	188.1605578	1354.756016	945.6909765	6808.975031	8163.731047
662.4	966.0773065	663.7	302.3773065	25	5.6696E-08	126.9419493	186.4458472	1342.4101	946.7119709	6816.326191	8158.73629
669.6	967.6790849	668.2	299.4790849	25	5.6696E-08	128.2603817	184.6588037	1329.543387	947.3763462	6821.109693	8150.65308
676.8	969.2639204	672.7	296.5639204	25	5.6696E-08	129.5849574	182.8613133	1316.601456	947.8430199	6824.469743	8141.071199
684	970.8321678	677.1	293.7321678	25	5.6696E-08	130.8951436	181.1152546	1304.029833	948.2842908	6827.646893	8131.676727
691.2	972.3841706	681.5	290.8841706	25	5.6696E-08	132.2112392	179.3591796	1291.386093	948.5319759	6829.430227	8120.81632
698.4	973.9202619	685.9	288.0202619	25	5.6696E-08	133.5333052	177.5932935	1278.671713	948.5847783	6829.810404	8108.482117
705.6	975.4407647	690.3	285.1407647	25	5.6696E-08	134.8614016	175.8177955	1265.888128	948.4413731	6828.777886	8094.666014
712.8	976.9459922	694.6	282.3459922	25	5.6696E-08	136.1742739	174.0945388	1253.480679	948.2878962	6827.672853	8081.153532
720	978.4362483	698.9	279.5362483	25	5.6696E-08	137.492935	172.3620507	1241.006765	947.9425694	6825.1865	8066.193265

SUM ENERGY [kJ]: 646808.7613

Required heat flow to heat the beam from 293K to 699K
Q=m*c*(T2-T1) [kJ]
m=mass of beam=V*dencity
c=specific heat capacity for steel=500 J/kgK
T2=end temperature=699K
T1=start temerature=293K

Q= 1031582

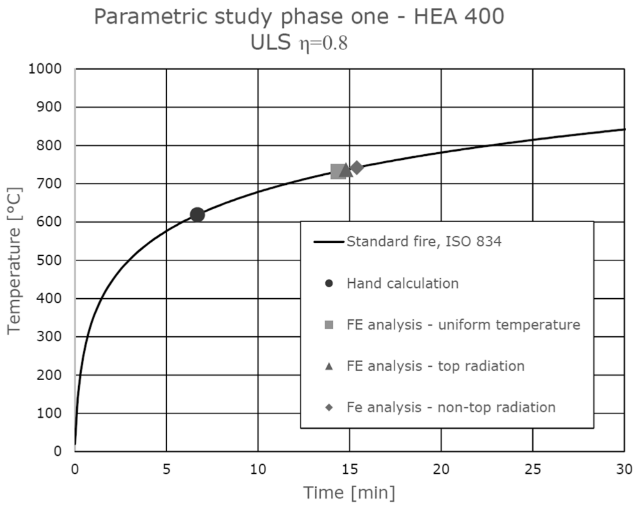
Difference [kJ]: -384773
onds to a temperature difference [K]: -255.7

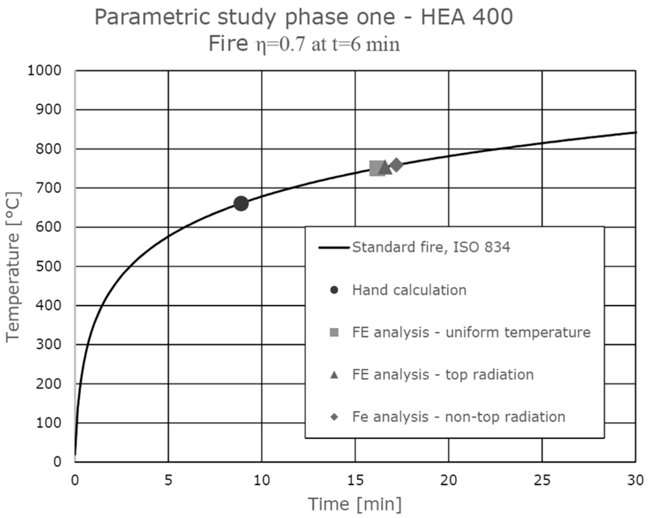
Difference from ADINA calculations [K]: 23.9

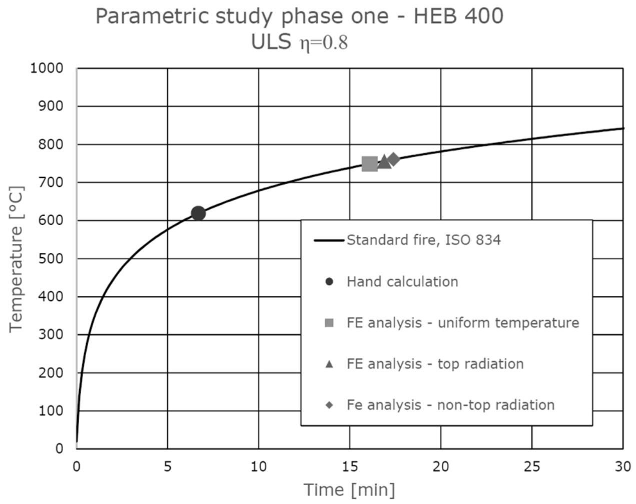
I

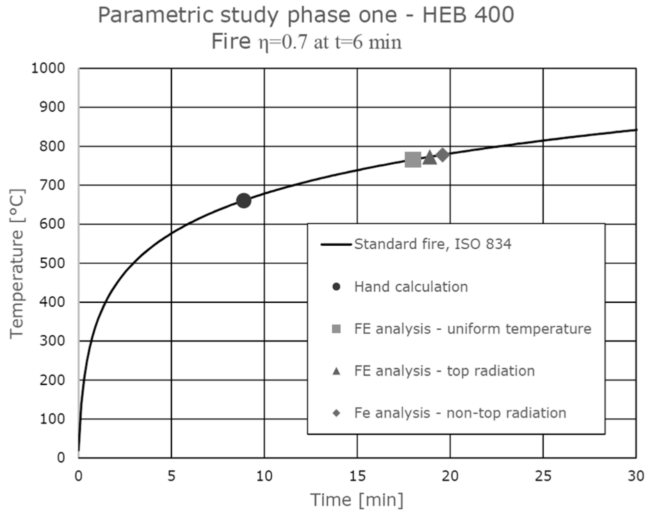
Graphically presented results

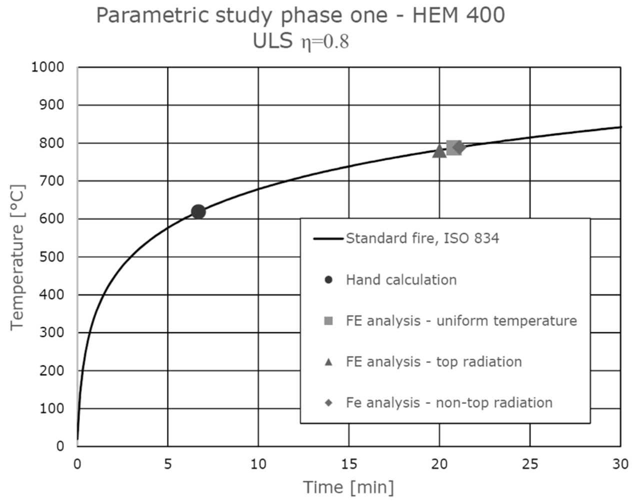
Figures showing the temperature and corresponding time on the ISO 834 curve for the Parametric study phase one to show the gains in time

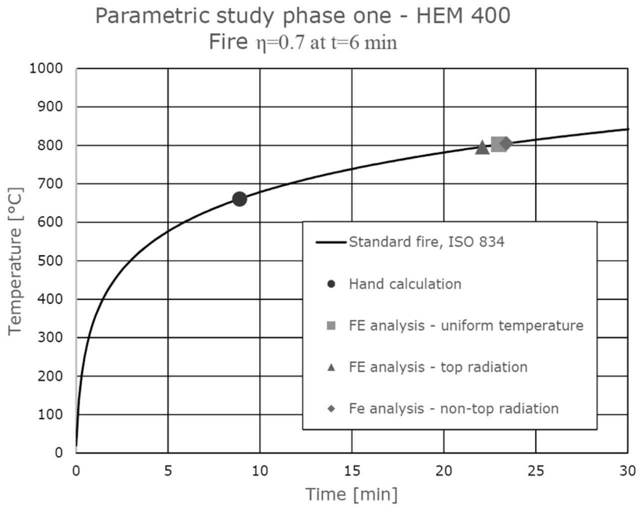






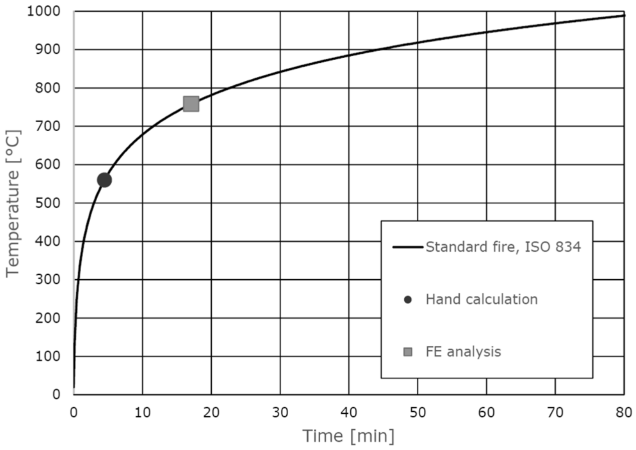




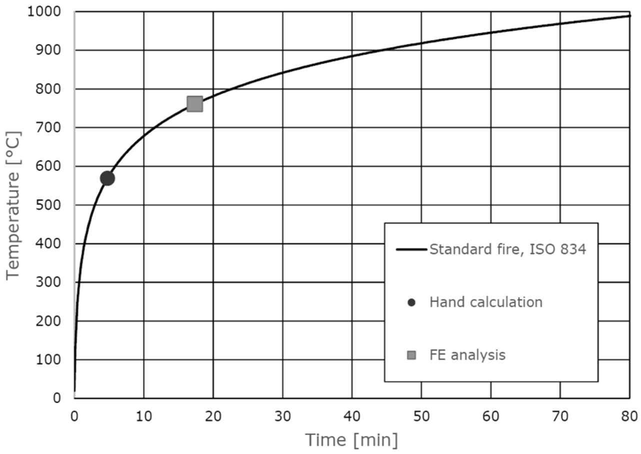


Figures showing the temperature and corresponding time on the ISO 834 curve for the Parametric study phase two to show the gains in time

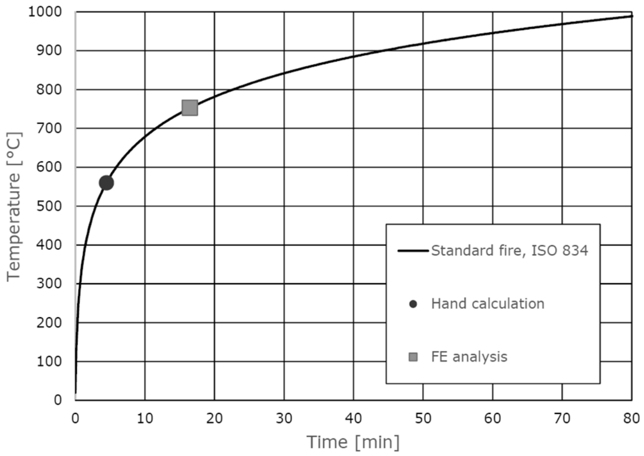
Parametric study phase two - HEA 400, λ=1



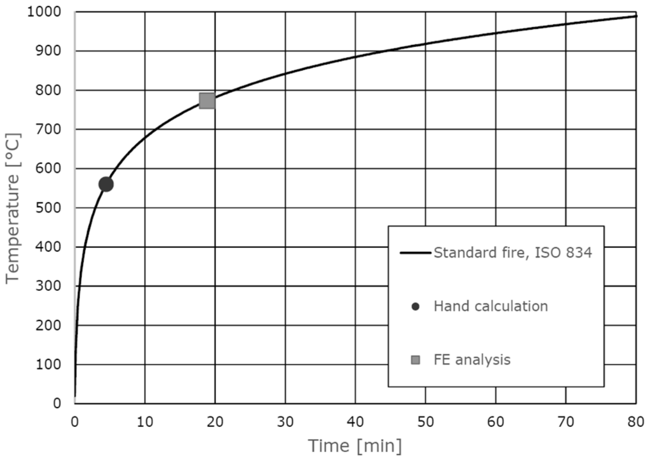
Parametric study phase two - HEB 400, λ=0.5



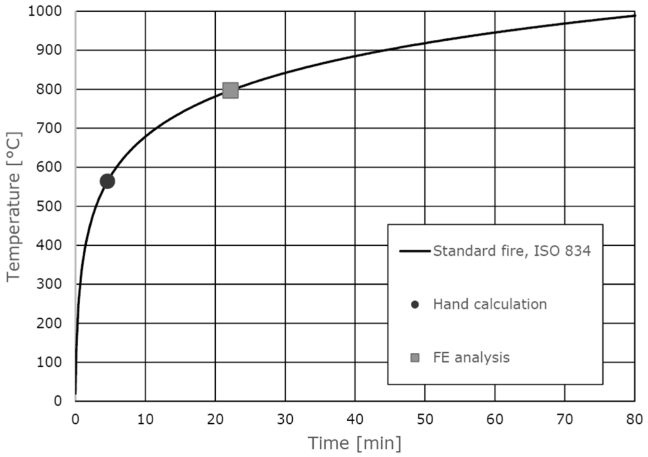
Parametric study phase two - HEB 400, λ=1



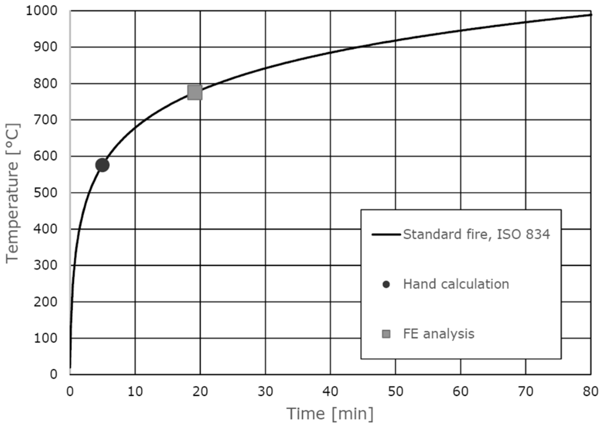
Parametric study phase two - HEB 400, λ=2

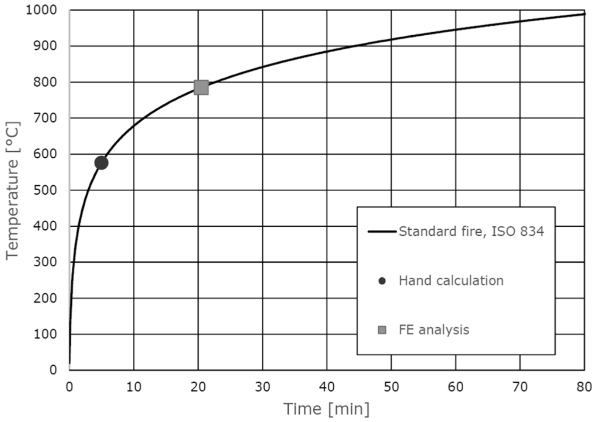


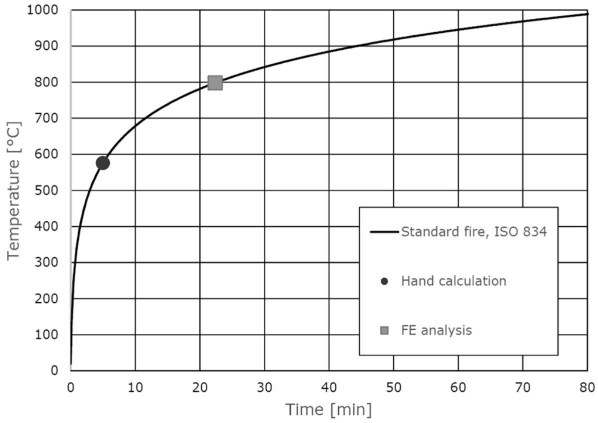
Parametric study phase two - HEM 400, λ=1

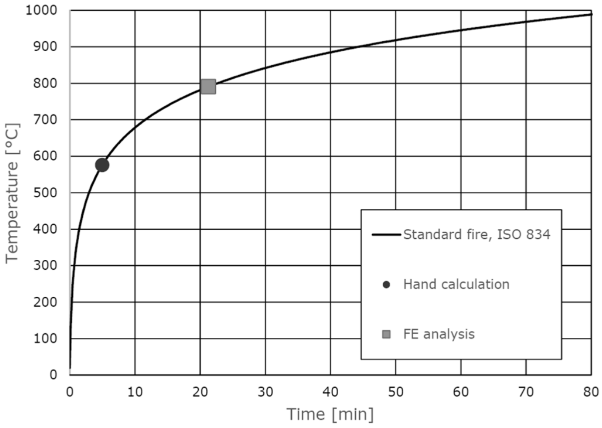


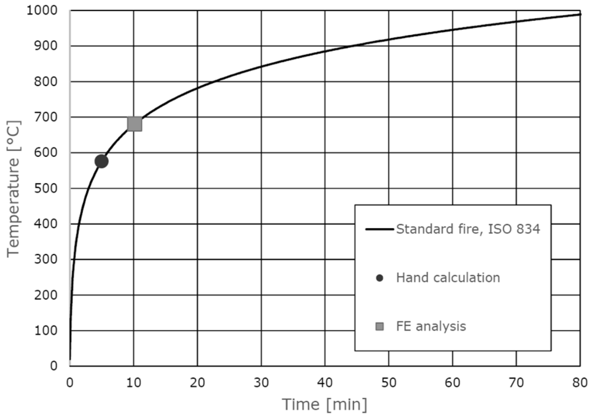
Figures showing the temperature and corresponding time on the ISO 834 curve for the Main study to show the gains in time

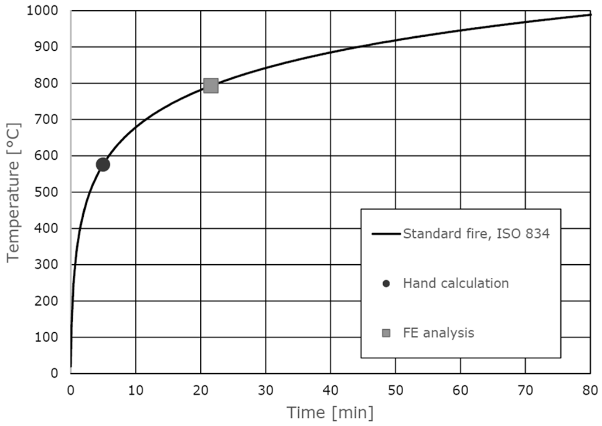

Main study - HEB 400, η.M=0.8, η.N=0.2 , λ=0.5

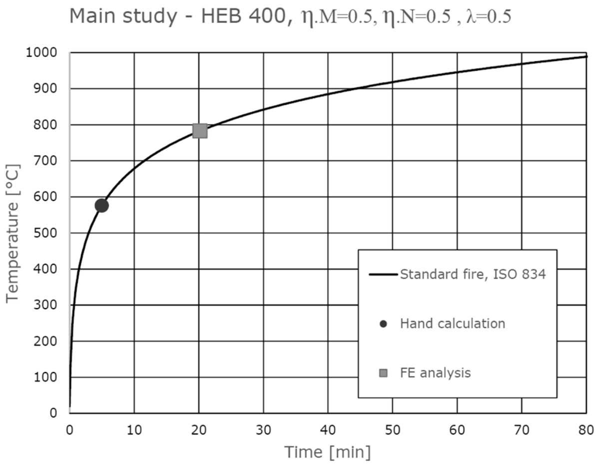

Main study - HEB 400, η.M=0.6, η.N=0.4 , λ=0.5


Main study - HEB 400, η.M=0.8, η.N=0.2 , λ=1

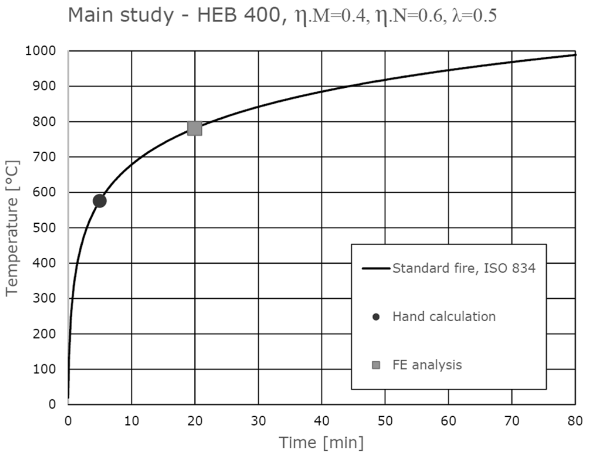

Main study - HEB 400, η.M=0.6, η.N=0.4 , λ=1


Main study - HEB 400, η.M=0.8, η.N=0.2 , λ=2

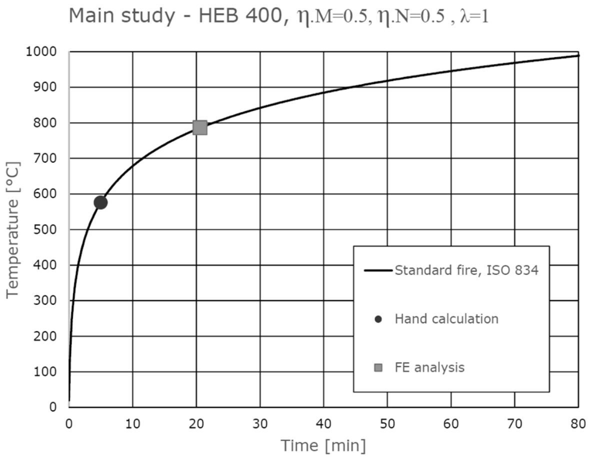

Main study - HEB 400, η.M=0.6, η.N=0.4 , λ=2



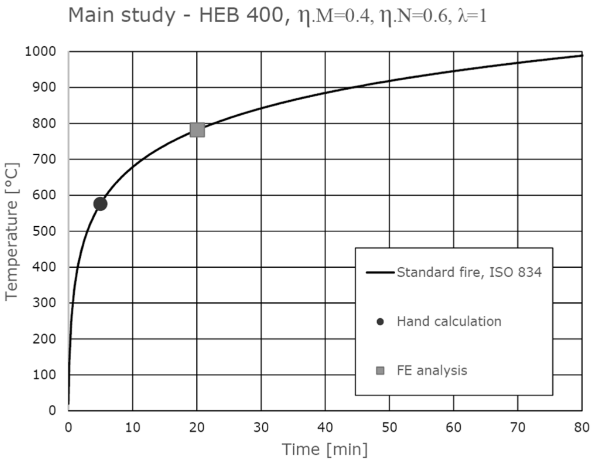
Main study - HEB 400, η.M=0.5, η.N=0.5 , λ=0.5



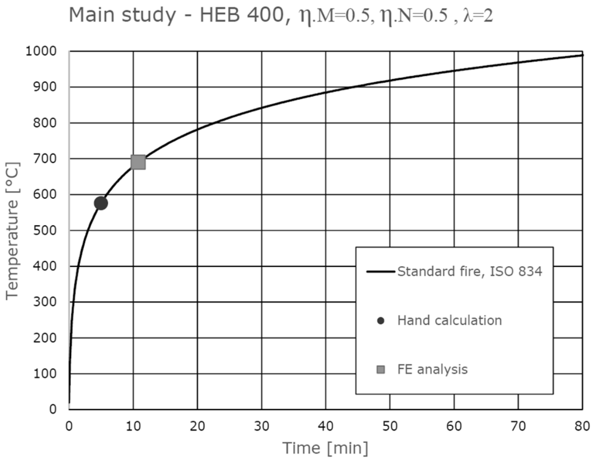
Main study - HEB 400, η.M=0.4, η.N=0.6, λ=0.5



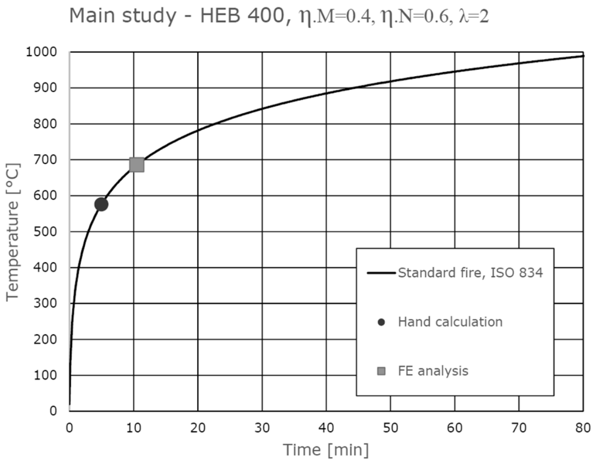
Main study - HEB 400, η.M=0.5, η.N=0.5 , λ=1



Main study - HEB 400, η.M=0.4, η.N=0.6, λ=1

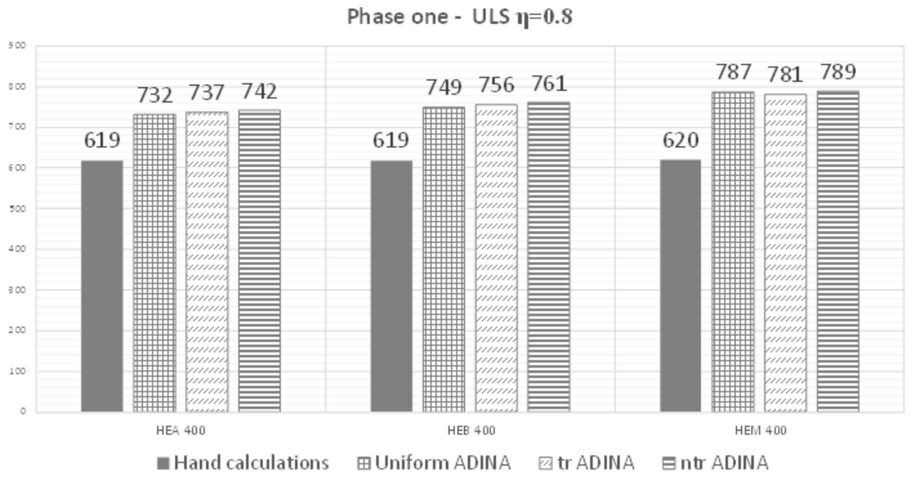


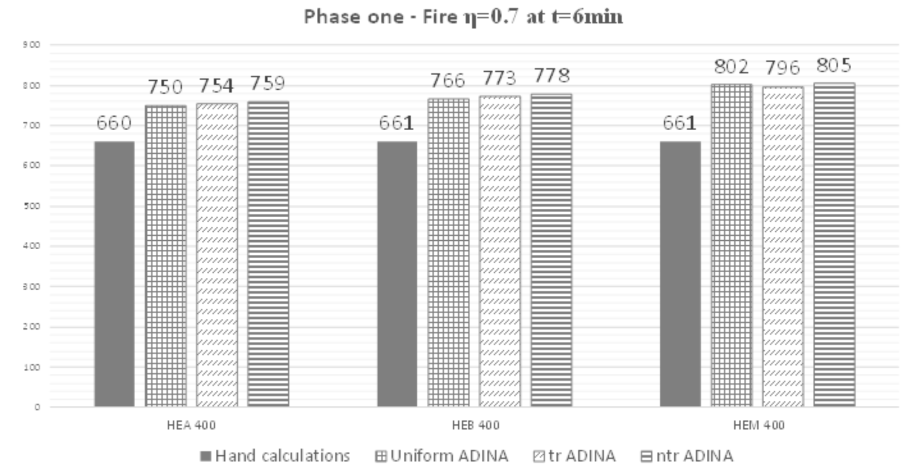
Main study - HEB 400, η.M=0.5, η.N=0.5 , λ=2

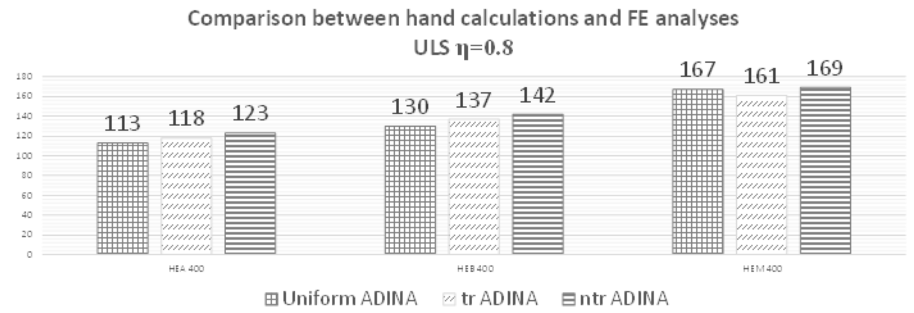


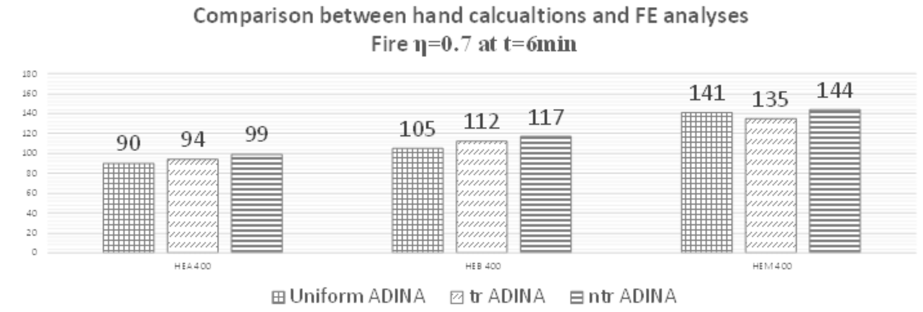
Main study - HEB 400, η.M=0.4, η.N=0.6, λ=2

Parametric study phase one – Graphically presented results

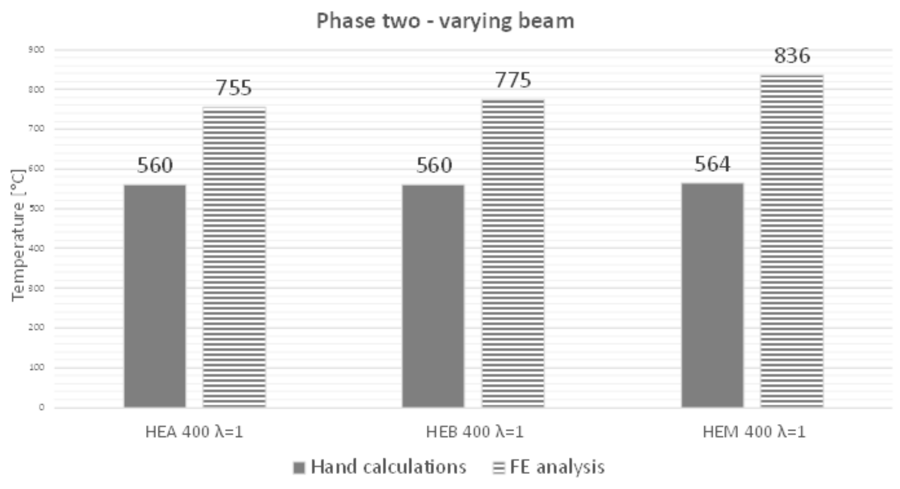


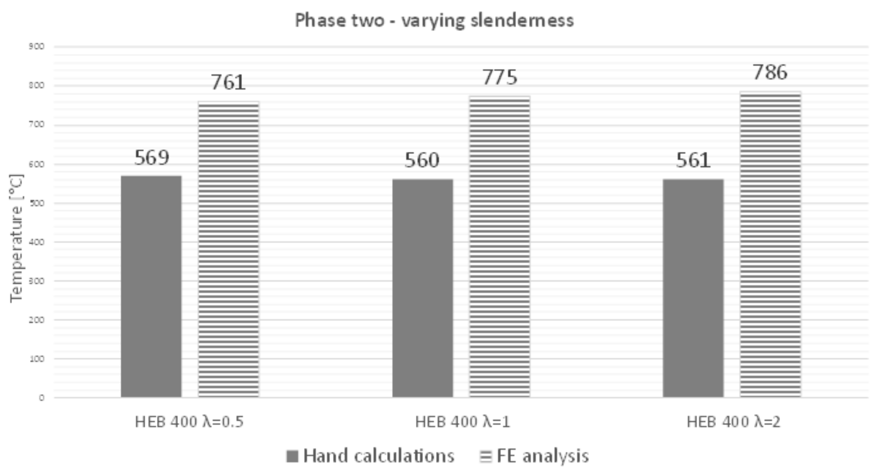


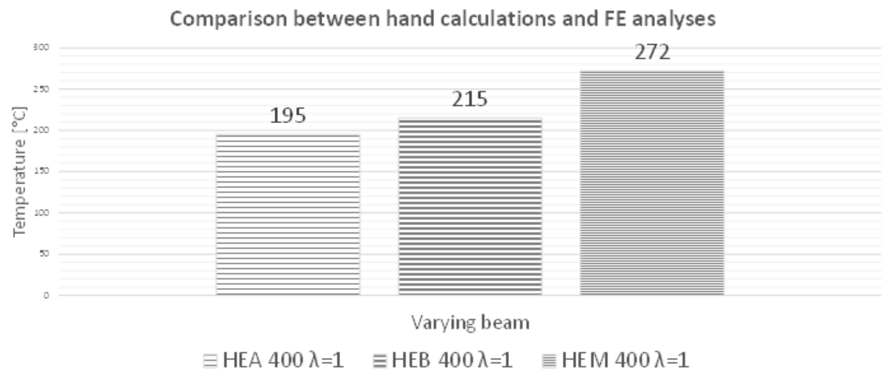


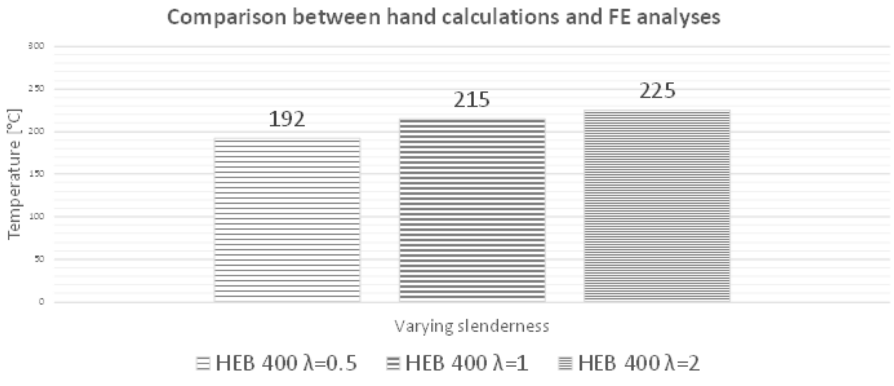


Parametric study phase two – Graphically presented results


Phase two - varying beam


Phase two - varying slenderness


Comparison between hand calculations and FE analyses


Comparison between hand calculations and FE analyses

Main study – Graphically presented results