lateral buckling restraint – attaches – steel check – creep – charges climatiques – dynamic analysis – lateral buckling – brandweerstandsanalyse – timber – 1st order – verstijvers – buisverbinding – diseño de planos de armaduras – pandeo lateral – verbindingen – shear connection – verificación – armatures longitudinales – pórtico – unión base columna – voorontwerp – unión tubular – haunch – connexion moment – cimbras – vérification acier – unity check – Eurocode 2 – mesh – retaining wall – raidisseur – Eurocode 3 – longitudes de pandeo – connections – ACI 138 – acero – 2nd ordre – portal frame – Eurocode 8 – andamios – kip – dwarskrachtverbinding – BS 8110 – dalle de fondation – seismische analyse – armaduras longitudinales – BIM – gelaste verbinding – 2de orde – buckling – funderingszool – poutre sur plusieurs appuis – maillage – malla – uniones – 2D raamwerken – fire resistance analysis – voiles – cracked deformation – gescheurde doorbuiging – longueurs de flambement – pandeo – reinforcement – unity check – cantonera – dynamische analyse – hout – ossatures 3D – koudgevormde profielen – placa de extreme – 1er orden – continuous beam – connexion soudée – momentverbinding – praktische wapening – renforts au déversement – fluencia – estribos – déformation fissurée – EHE – beugels – Eurocódigo 3 – platine de bout – análisis dinámico – column base plate – kruip – rigid link – welded connection – charpente métallique – moment connections – estructuras 2D – kniestuk – assemblage métallique – 3D raamwerken – second ordre – beam grid – cargas climáticas – Eurocode 2 – Eurocode 5 – wall – deformación fisurada – lien rigide – enlace rígido – 2D frames – estructuras 3D – éléments finis – vloerplaat – steel connection – scheurvorming – integrated connection design – armatures pratiques – analyse sismique – nieve y viento – practical reinforcement – charges mobiles – dalle – wapening – perfiles conformados en frío – Eurocode 3 – connexion tubulaire – unión a momento – 3D frames – treillis de poutres – roof truss – practical reinforcement design – portique – kipsteunen – análisis sísmico – Eurocode 8 – seismic analysis – B.A.E.L 91 – uniones atornilladas – bolts – ossatures 2D – eindige elementen – losa de cimentación – restricciones para el pandeo lateral – optimisation – wand – kniklengtes – end plate – dakspanten – kolomvoetverbinding – stirrups – acier – staalcontrole – cálculo de uniones integrado – paroi – dessin du plan de ferraillage – stiffeners – mobiele lasten – Eurocódigo 8 – Eurocódigo 5 – longitudinal reinorcement – doorlopende liggers – rigidizador – beton

Fire Design

in Diamonds

armé – fluage – CTE – connexion pied de poteau – langswapening – connexions – hormigón – neige et vent – elementos finitos – armaduras – cold formed steel – jarret – uittekenen wapening – puente grúa – analyse dynamique – flambement – keerwanden – optimisation – steel – cercha – 2º orden – slab on grade foundation – entramado de vigas – Eurocode 5 – prédimensionnement – multi span beam – bouten – armatures – floor slab – poutre continue – pared – staal – 1er ordre – NEN 6770-6771 – connexion cisaillement – losa – déversement – viga continua – predimensionering – 1ste orde – unión metálica – CM 66 – madera – análisis resistencia al fuego – verbindingen – 2nd order – bois – Eurocode 2 – profilés formés à froid – verificación acero – predesign – unión soldada – fisuración – beton – muro de contención – optimalisatie – foundation pads – fissuration – concrete – AISC-LRFD – HCSS – assemblage métallique – Eurocode 3 – viga con varios apoyos – armaduras prácticas – balkenroosters – unión a cortante – buckling length – boulons – cracking – Eurocode 8 – knik – Eurocode 2 – radier – eindplaat – Eurocódigo 2 – FEM – tornillos – NEN 6720 – sísmico – Eurocode 8 – seismic analysis – B.A.E.L 91 – uniones atornilladas – bolts – ossatures 2D – eindige elementen – losa de cimentación

Content

1. Introduction

In the calculation and detailing of structures, verifications must be carried out both in the ultimate limit state and in service limit state. The loads taken into account are the that are charged are the normal permanent (dead loads) and the variable (life) loads.

Next to the dead and life loads, there are also '**accidental loads'**. Accidental loads have major consequences for the construction and a small chance of occurrence. Fire is an **accidental loads.**

Constructions must be able to resist fire. This means that the construction must resist the fire for a certain period of time and may not collapse during that time. The size of the deformations is not relevant at that moment, so the verification of the fire resistance is always one in the ultimate limit state.

Verifying the fire resistance of a construction is done in 3 steps:

1. Determine the thermal load
2. Determine the thermal response
3. Determine the mechanical response

The theory associated with these steps can be read in §2. In §3 the elaboration of these steps in examined in Diamonds. §4 contains worked examples. §5 contains the thermal properties of common fire protectors.

2. Theoretical approach

2.1. Thermal loading

2.1.1. Required fire resistance

When a fire breaks out in a building, it may not collapse after a few seconds. Those present, must be able to leave the building and the fire brigade must be given the opportunity to extinguish the fire. This makes it necessary to design constructions taking into account fire.

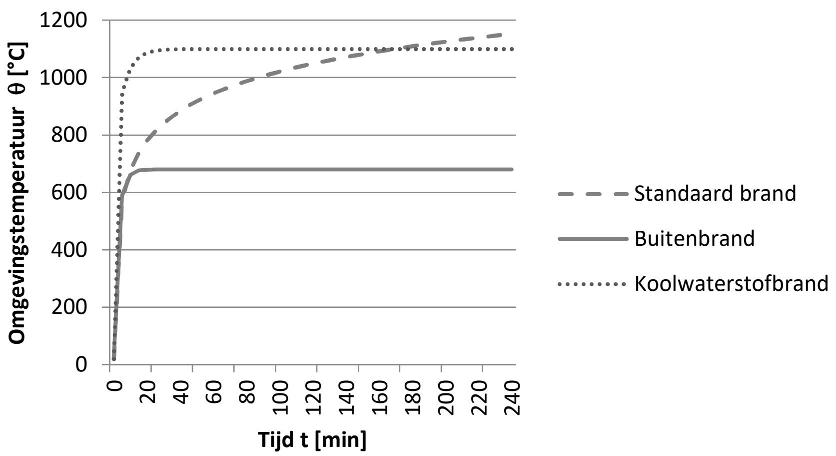
Depending on the size, height and destination of the construction, other **required fire resistances** apply. The required fire resistance is the minimum time during which the construction must fulfil its function during fire. This time varies for buildings from 0, 30, 60, 90 to 120min.

2.1.2. The temperature development during fire

If a fire occurs in a room, the temperature in the room will rise. But how much exactly? Theoretically, the temperature development in each room will be different. However, it is impossible to describe the temperature development in every possible room with every possible fire. For this reason, (nominal) **fire curves** are used in which the ambient temperature θ [°C] in relation to the time t [min] is fixed.

There are 3 nominal fire curves (EN 1991-1-2 §3.2):

- Standard curve ISO 834:for when no additional information on the fire is known
- External fire: for fire hazards developing outside (for example fire under a bridge)
- Hydrocarbon fire: for fire hazards which are caused by the ignition of hydrocarbons (fuel, diesel, …)



Notes:

- The method of the nominal fire curves requires little knowledge about the behaviour of a fire in a compartment due to the many assumptions. With stricter requirements (fire resistance of 60 to 120 minutes) this comes out very conservatively.
- There are alternatives for the nominal fire curves, like the local fire (EN 1991-1-2 Annex C) and parametric fire curves (EN 1991-1-2 Annex A). But they are not discussed in this document.

With §2.1.1 and §2.1.2 the **thermal loading** is known.

2.2. Thermal response

2.2.1. Fourier differential equation

With increasing gas temperature θ, the strucutre's temperature will raise as well with a certain delay. The next step is to calculate the temperature of the structure during the time it is exposed to fire. This is called the **thermal response of the structure**.

The description of a two-dimensional non-linear heat transport in materials can be done with the differential equation of Fourier:

$$\frac{\delta}{\delta x}\left(\lambda\frac{\delta\theta}{\delta x}\right)+\frac{\delta}{\delta y}\left(\lambda\frac{\delta\theta}{\delta y}\right)=\rho\cdot c\cdot\frac{\delta\theta}{\delta t}$$

In which

- θ the temperature [°C] in point x on time t [s]
- ρ the density [kg/m³]
- c the specific heat [J/kgK]
- λ the thermal conductivity [W/mK]

Depending on the material used (steel or concrete), further assumptions can be formulated to solve this differential equation.

2.2.2. Solution Fourier differential equation for steel

Steel has good heat conductivity and the cross-sections are not very solid. As a result, the cross section will heat up in a fairly uniform way. Because a constant temperature is assumed over the steel section, the prevented deformations will be limited to longitudinal deformations and analytical formulas can be used to determine the steel temperature.

For unprotected steel the Fourier differential equation becomes (EN 1993-1-2 §4.2.5.1):

$$\Delta\theta_a = k_{sh}\cdot\frac{A_m}{V}\frac{1}{\rho\cdot c}\cdot\dot{h}_{net}\cdot\Delta t$$

In which

- k_{sh} the shadow coefficient (see §2.2.2.3)
- $\frac{A_m}{V}$ the section factor (see §2.2.2.2)
- ρ the density of steel, namely 7850 kg/m³ (EN 1993-2-1 §3.2.3)
- c the specific heat of steel [J/kgK] (EN 1993-1-2 §3.4.1.2)
- $\dot{h}_{net}$ the net heat flux (see §2.2.2.1)
- Δt the time step [s] (EN 1993-1-2 §4.2.5.1 (4))

The above solution $\Delta\theta_a$ describes **the increase of the temperature** in a steel element during a time interval Δt (starting from an ambient temperature of 20°C).

The derivation for protected steel can be found in EN 1993-1-2 §4.2.5.2.

2.2.2.1. The net heat flux

The net heat flux $\dot{h}_{net}$ represents the energy per unity of time and surface, that is being absorbed by an element (EN 1991-1-2 §3.1).

The net heat flux $\dot{h}_{net}$ for unprotected steel is determined by (EN 1991-1-2 §3.1):

$$\dot{h}_{net} = 5{,}67 \cdot 10^{-8} \cdot \Phi \cdot \varepsilon_{res} \cdot [(\theta_r - 273)^4 - (\theta_a - 273)^4] + \alpha_c(\theta_g - \theta_a)$$

In which

- Φ the view factor, usually equal to 1
- ε_{res} the residual emissivity coefficient
- α_c the convection coefficient in W/m²K (EN 1990 §3.2 and §3.3.1.1)
- θ_r the radiation temperature = the gas temperature near the element exposed to fire [°C]

2.2.2.2. The section factor

The profile factor $\frac{A_m}{V}$ $[m^{-1}]$ (for unprotected steel) reflects geometric aspects of the cross section and the way it is exposed to fire. The profile factor is defined as the ratio of the section's circumference along which heat is injected into the cross section, to the section's surface.

- Sections with a large profile factor have a low massiveness and warm up fast.
- Sections with a small profile factor have a large massiveness and warm up slower.

Formula for the profile factor $\frac{A_m}{V}$ for unprotected steel elements are given in Table 4.2 of EN 1993-1-2. The profile factor is also often included in product catalogues.

2.2.2.3. The shadow coefficient

The shadow coefficient k_{sh} is the correction factor for the shadow effect (EN 1993-1-2 §4.2.5.1). The shadow effect is caused by the local protection of the heat radiation as a result of the shape of the cross section. This factor is important for open shapes (H, I-sections). This effect does not occur with closed shapes (- and O-sections).

- For I-sections subjected to a nominal fire: $k_{sh} = 0{,}9 \cdot \frac{\left[\frac{A_m}{V}\right]_b}{\frac{A_m}{V}}$
- In all other cases: $k_{sh} = \frac{\left[\frac{A_m}{V}\right]_b}{\frac{A_m}{V}}$

$\left[\frac{A_m}{V}\right]_b$ is the contour value of the profile factor, and it is defined as the ratio of the imaginary circumference encompassing the steel section, to the steel section area (thus , ).

2.2.3. Solution Fourier differential equation for concrete

Concrete has a heat conductivity an order smaller than that of steel and the cross-sections are solid. This will cause the cross-section to heat up anything but uniformly. The solution of the differential equation is not obtainable by analytical formulas. Diamonds contains a thermal calculation heart based on FEM to determine the temperature in each point of the cross-section.

2.3. Mechanical response

The **mechanical response** of a building structure exposed to a fire hazard, is understood to cover the complete set of mechanical actions to which the building is subjected during the duration of the hazard.

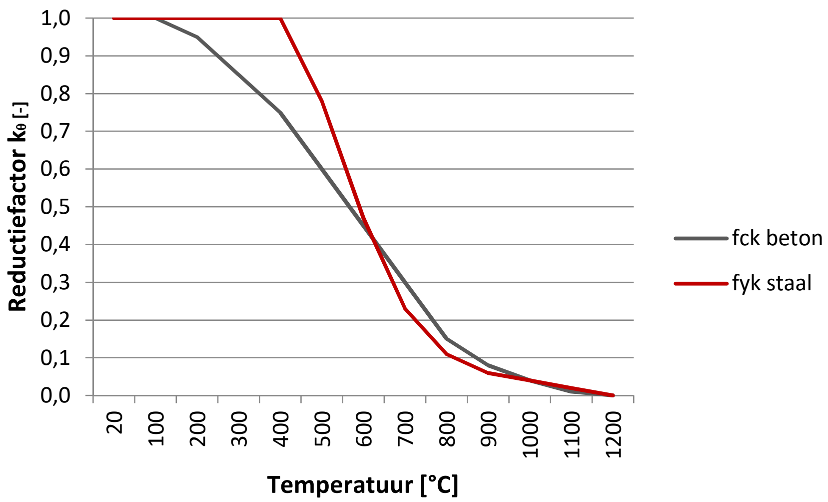
- the strength properties of the construction materials will deteriorate, such that the structure may not be able to resist the design actions any more (see §2.3.1).
- the stiffness properties of the construction materials will deteriorate, thus invoking additional deformations.
- the construction will expand.

2.3.1. Strength properties of construction materials in case of fire

With increasing temperature:

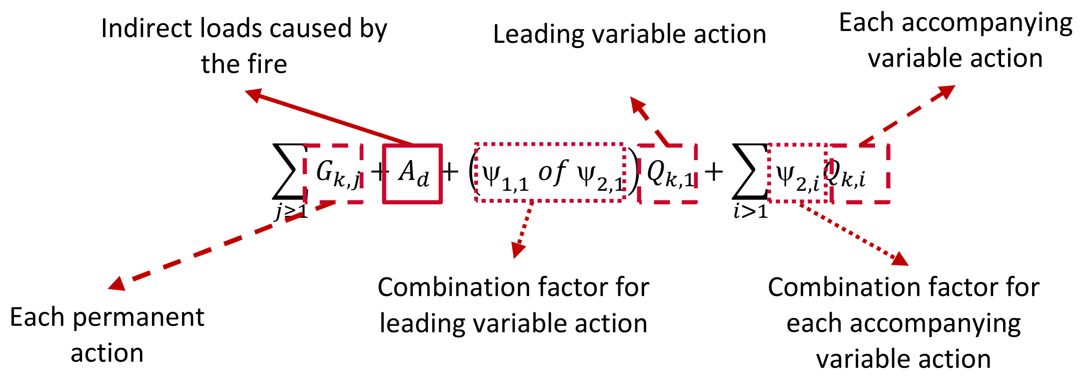
- The yielding strength f_{yk} of (structural) steel (EN 1993-1-2 Table 3.1).
- The compressive strength f_{ck} and the yielding strength f_{yk} of the (reinforcement) steel (EN 1992-1-2 Table 3.1 and 3.2).

The reduction k_θ of the yield strengthf_{yk} of steel (regardless of whether it is structural or reinforcing steel) and the concrete compressive strength f_{ck} are shown in the graph below.



2.3.2. Design load for fire

The design actions to which a structure in case of fire must resist, is obtained by combining the different mechanical loads and the possibly the indirect load by fire A_d by applying combination factors (partial safety coefficients are all equal to 1).
According to EN 1990, fire hazard should be considered as an accidental design action, implying that only ultimate limit states must be evaluated (EN 1990 §6.4.3.3).



The choice between $\psi_{1,1}Q_{k,1}$ of $\psi_{2,1}Q_{k,1}$ is nationally determined.

- [BE], [DE]: $\psi_{2,1}Q_{k,1}$, but for wind loads $\psi_{1,1}Q_{k,1}$
- [FR]: $\psi_{1,1}Q_{k,1}$

The indirect loads caused by fire are **the internal forces and bending moments caused by the thermal expansion** (EN 1991-1-2 §1.5.1.7). For steel and concrete, only the effects of a thermal deformation due to a **gradient** over the cross section must be considered. The effects of axial or in the plane occurring thermal displacements may be neglected (EN 1993-1-2 §2.4.2 (4) and EN 1992-1-2 §2.4.2 (4)).

2.3.3. Verification

In the last step it is verified if the structure load with the design load (see §2.3.2) can resist fire (see §2.1.2) during the imposed time (see §2.1.1) and thus not collapse.

For steel, this means that a steel verification is performed as in cold condition, but with the exception of the following points:

- The classification of the sections may be done using an adjusted ε (EN 1993-1-2 §4.2.2).
- For cross sections of class 1, 2 and 3 a reduced yielding strength $k_{y,\theta} \cdot f_y$ is used.
- The relative slenderness's $\overline{\lambda_y}$, $\overline{\lambda_z}$ and $\overline{\lambda_{LT}}$ are bases on the material properties of steel at 20°C. They are multiplied afterwards with a factor $\sqrt{k_{y,\theta}/k_{E,\theta}}$ (EN 1993-1-2 §4.2.3.2 and §4.2.3.3.).
- The imperfection factor α for buckling and lateral torsional buckling will be determined by $\alpha = 0{,}65\sqrt{235/f_y}$.
- If the temperature in a cross section of class 4 does not exceed 350°C, it may be assumed that the section has sufficient fire resistance (EN 1993-1-2 §4.2.3.6).
- For cross section of class 4, effective properties and a reduced yielding strength is used according to EN 1993-1-2 Annex E.

For concrete this means that the reinforcement will be increased if necessary. The reinforcement calculation is done with the following assumptions:

- The partial safety factor on the concrete and the reinforcement steel is taken equal to 1 (EN 1992-1-2 §2.3(2)).
- Concrete with a higher temperature than 500°C is neglected (EN 1992-1-2 §4.2.3). At high temperatures, pieces of concrete on the surface of the element can jump off in a rather explosive way ('splashing' of concrete). This way, a reduced concrete section is created that is assumed to still work under the imposed fire curve and fire resistance. This reduced concrete section is also

used in the calculation of the reinforcement. For concrete that has not reached 500°C, it is assumed that it retains its original strength (at 20 ° C).

- The yielding strength of the reinforcement steel is adjusted in relation to the temperature of the reinforcement (EN 1992-1-2 §4.2.4.3).
- The tensile strength of concrete is neglected (EN 1992-1-2 §3.2.2.2. (1)).

3. Practical approach in Diamonds

3.1. Thermal protection

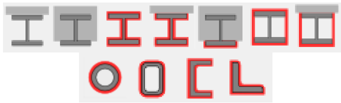
To define the (potential) **thermal protection**, proceed as follows:

- Define the structure (geometry + loads) like you would normally do.
- With the buttons and , you define the cross section that contributes to the moment of inertia.

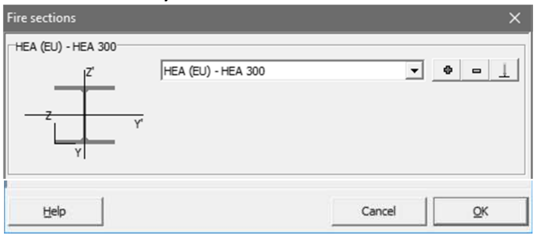
  With the button you define the fire protection. This fire protection does not contribute to the moment of inertia of the cross section. You can chose between:
  - an unprotected section (default setting)

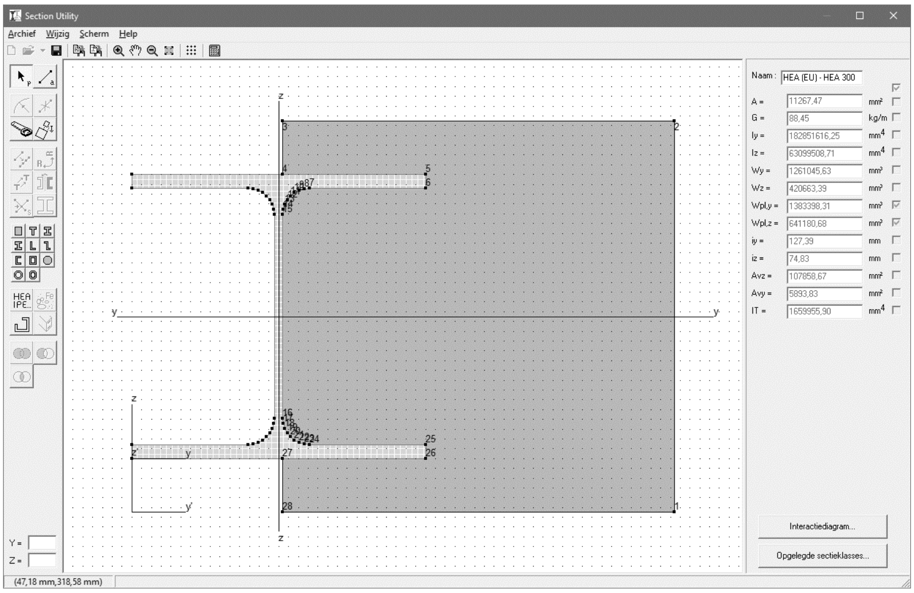
  - a protected section according to common standard cases. Select the desired case by clicking on it.

  - a protected section for which you define the protection manually
    - Select and click on .
      A dialog appears in which you can make different variations of the same cross section.

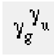
      

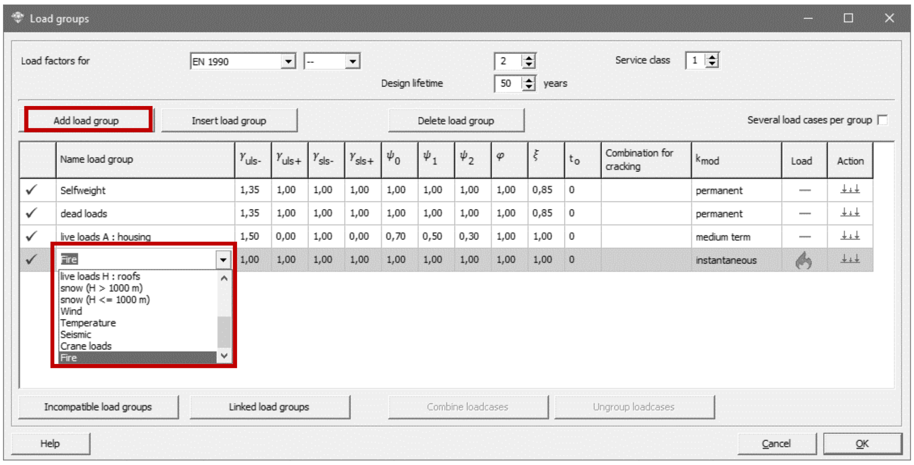
    - Add a variation with . Remove the visible variation with . The button open Section utility, allowing you to edit the variation.



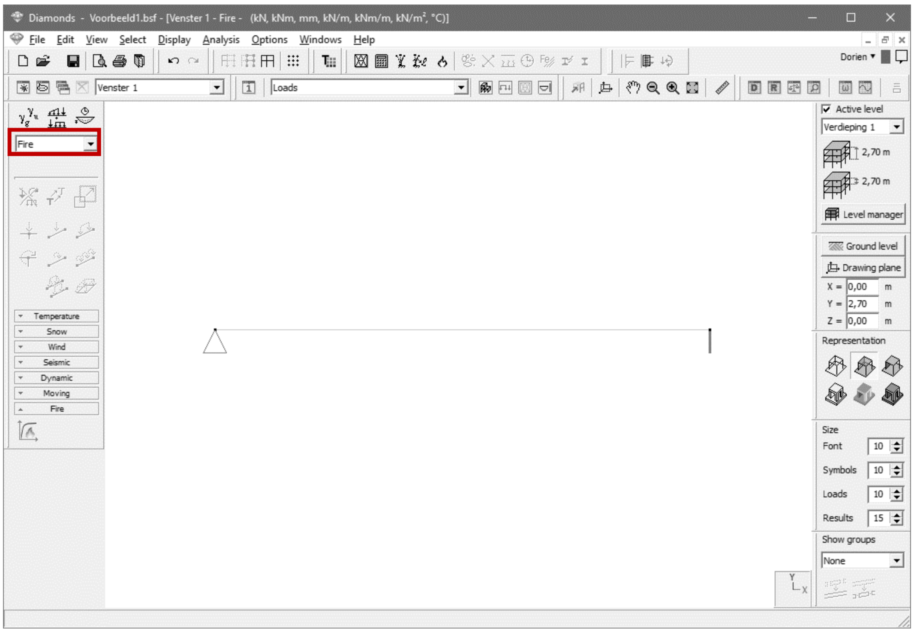
3.2. Thermal loading

To define the thermal load, proceed as follows:

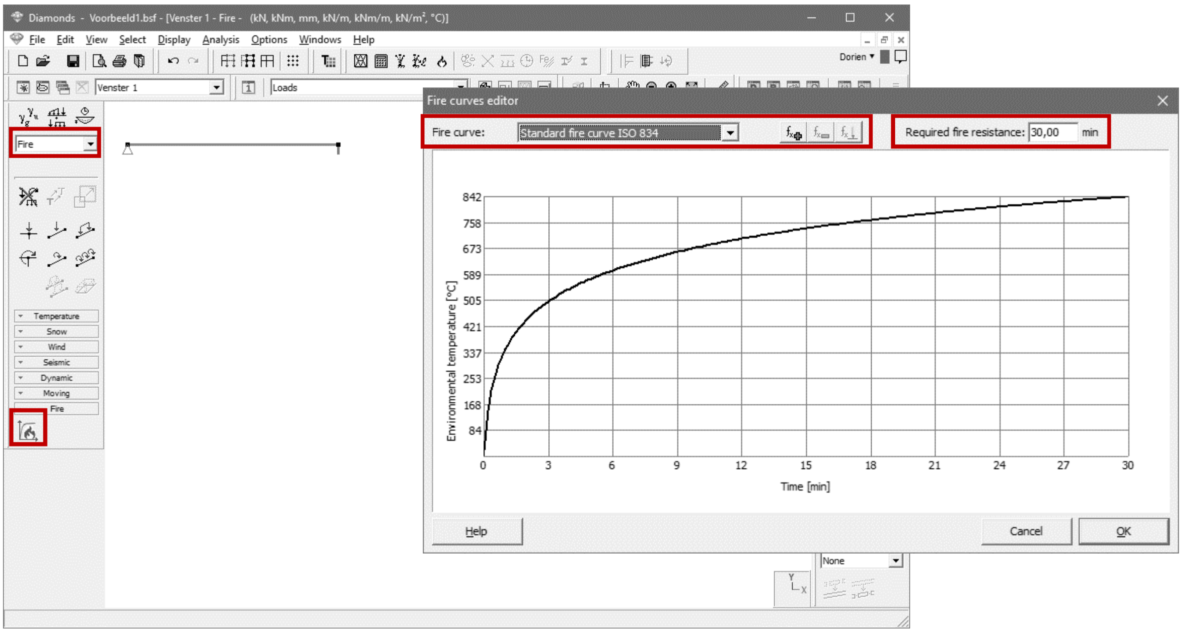
- Go to the loads configuration  and open the window for the load groups .
- Add a load group and select 'Fire' from the list.



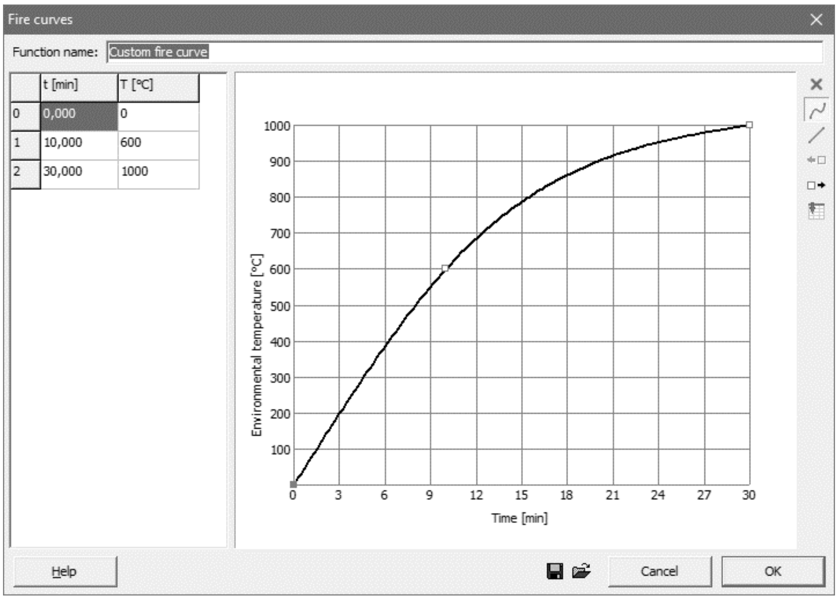
- Hit 'OK' to close this window.
- Activate the load group 'Fire' from the list.



- Select all bars on which you want to apply fire and click on .



- Enter the required fire resistance [min].
- Choose one the standard fire curves (see §2.1.2) from the pull down list on the left.
  It is also possible to enter a user-defined fire curve:
  - With the button you remove a user-defined fire curve.
  - With the button you edit a user-defined fire curve.
  - With the button you add a user-defined fire curve. The following dialog will appear:



  - Name the fire curve.
  - Define the function by dragging the red points.
    - deletes a point
    - ‘fluent’ interpolation between points. The points are being connected through a cubic spline.
    - linear interpolation between points. The points are being connected through straight.
    - adds a point, before the current and half way with the previous one.

- adds a point, after the current and half way with the next one.
- pastes an external table with value from the clipboard. In an external table (for example MS Excel), you need to have 2 columns: one with the time values and a second one with the temperatures. Select both columns with values and copy these to the clipboard (via CTRL+C) and paste the values in Diamonds with .

▪ With the buttons and you can import or export a fire curve.

Click on to remove the fire curve (and required fire resistance) from the selected bars.

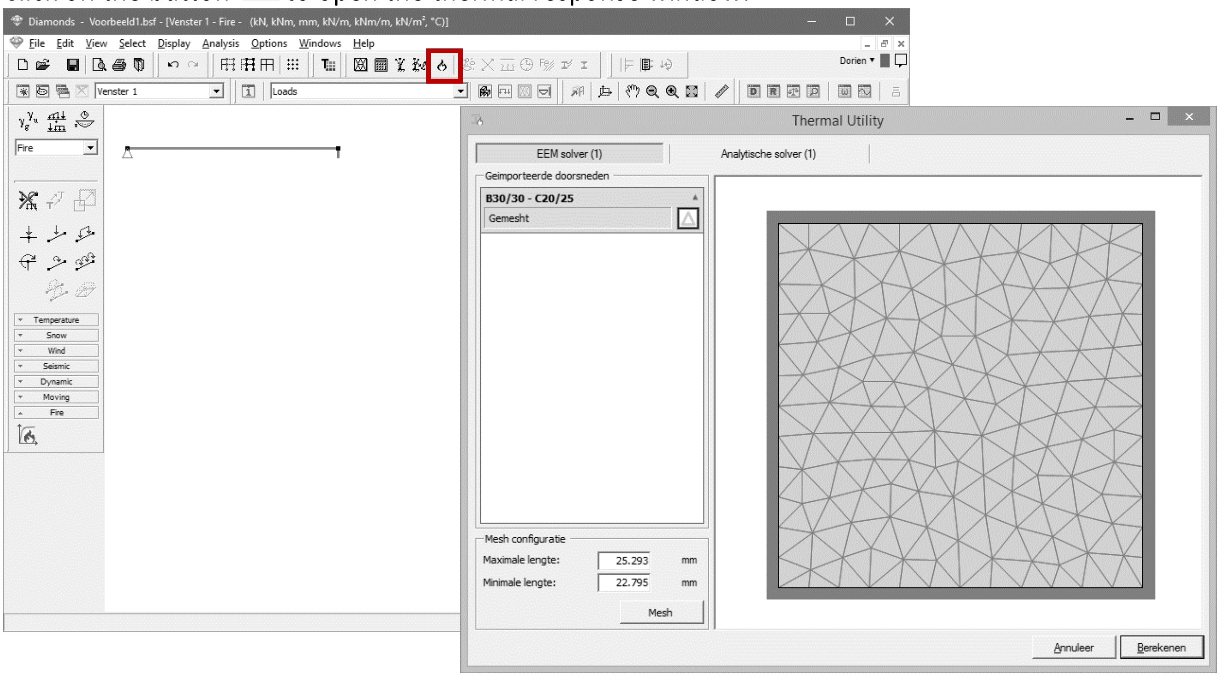
If a structure (or a part of it) with fire load is copied using , then the fire load will also be copied.

Notes:

- A fire curve on a bar without section or material has no meaning.
- A fire curve can only be applied on bars, not on plates.
- A fire curve and fire resistance [min] are linked to one or more bars, not to the project. So, one project can contain multiple bars that are subject to different fire curves and require different fire resistances.

3.3. Thermal response

Click on the button to open the thermal response window.



- At the top, there are two tab pages: 'FEM solver' and 'Analytical solver'.
  - FEM solver
    - will be solved with FEM (Finite Element Method)
    - is adequate for massive cross-section (usually in concrete)
  - Analytical solver

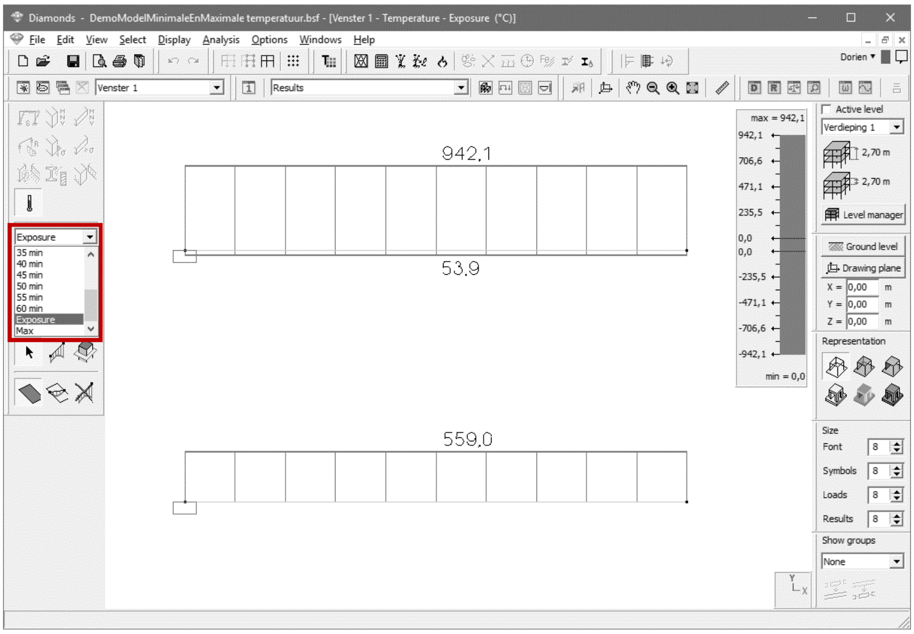
- will be solved with the formulas of EN 1993-1-2
- is adequate for slender sections (steel)

- Analytical solver

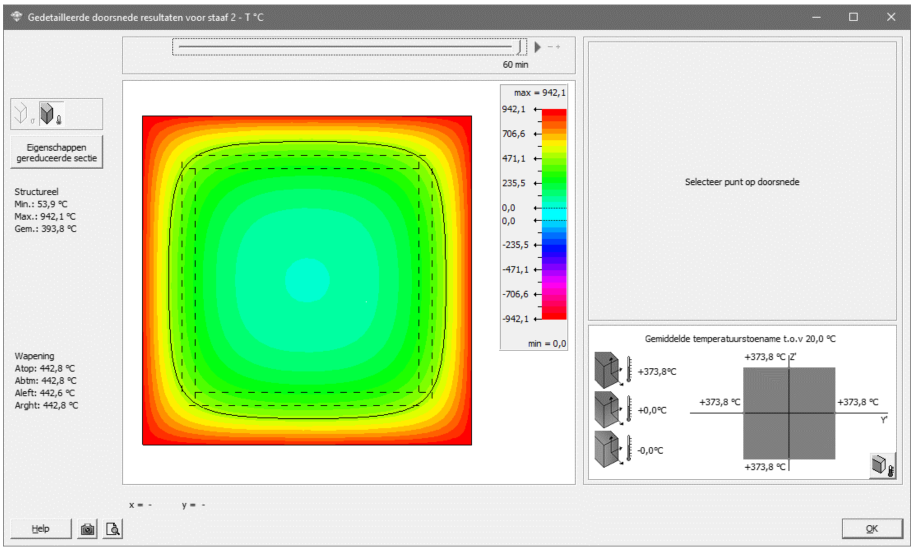
Diamonds will determine automatically whether a section should be calculated.

- An internal algorithm will calculate an appropriate mesh. The proposed values are fine for most cases, so no need to adjust it. Only for cross section with a lot of difference between the width of the parts, you could decide to adjust the mesh in order to obtain a proper distributed mesh.
- Click  to quite the calculations.

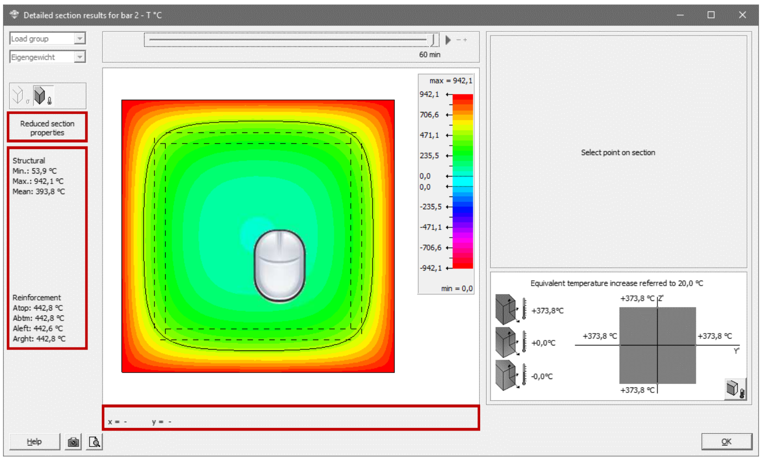
The results of the thermal calculation can be viewed in the results window with .



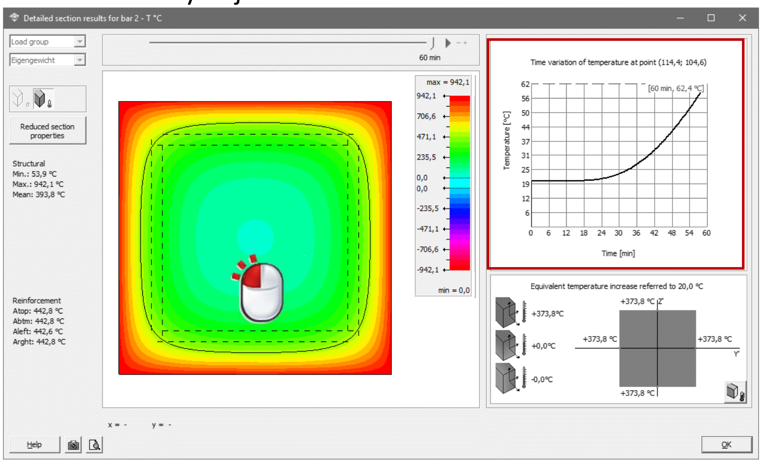
- The pull down list allows you to visualize the temperature in function of time for all elements. Diamonds will show the maximum temperature and minimum temperature (if relevant).
- Double-click on a bar to see the detail section thermal results:



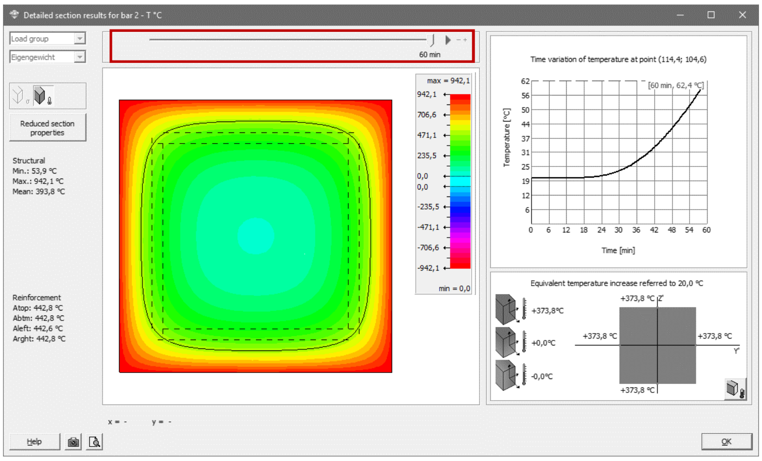
- Move the mouse over the cross section to view the temperature as the function of the time in each position.



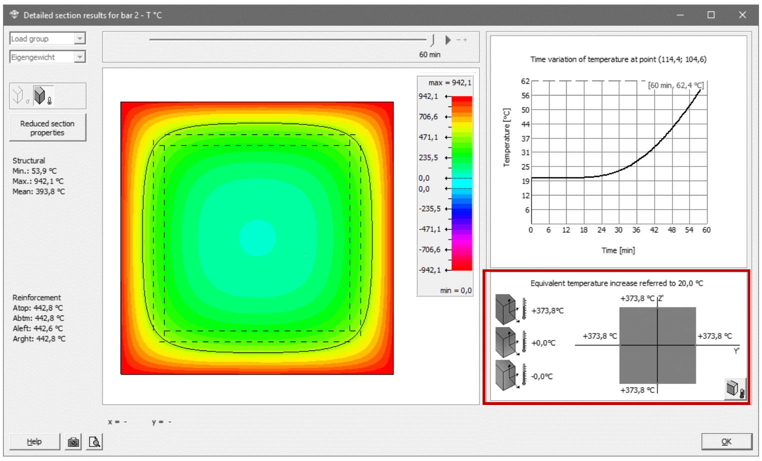
Click somewhere in the section to see a graph of the temperature increase as a function of the time on the location you just clicked.



- Move the slider to see the temperature after x minutes. Press ▶ to play an animation of the temperature over time. Use ■ to stop the animation. With the buttons − and + you can accelerate or decelerate the animation.



- On the right bottom side, you see the temperature gradient and the global temperature change resulting in the same thermal deformations as the calculated fire effect at a given time. This is particular interesting when you want to model the fire load as a thermal load (see §2.3.2).



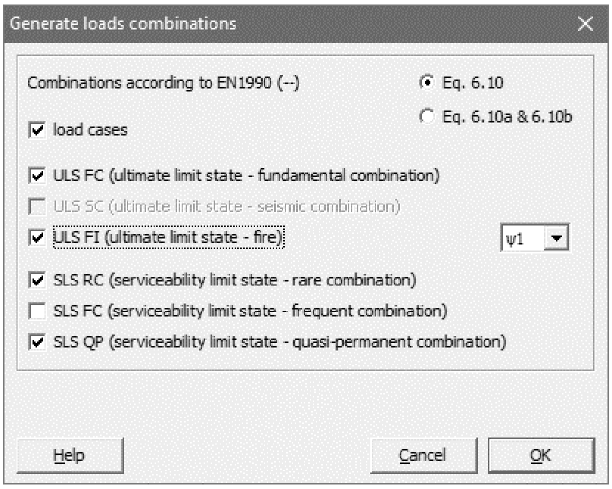
- With the button you make a print screen of the section with the temperature scale.
- With the button you make a print preview of the section with the temperature scale.

3.4. Mechanical response

3.4.1. Design load for fire

To generate the combinations

- Click on the button for the load combinations .
- Click on Generate all combinations automatically. Select the desired combinations AND the combinations ULS FI.



- Close this window.

Note: Diamonds will decide to use $\psi_{1,1} Q_{k,1}$ or $\psi_{2,1} Q_{k,1}$ based on the selected national annex. If no national annex was selected, you'll have to choose yourself.

3.4.2. Verification

Once the global analysis is performed, the design can be done based on the obtained internal forces.

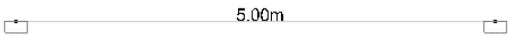
- For steel a strength and stability check will be done in correspondence to EN 1993-1-2 §4.2.

- For concrete the reinforcement will be calculated  based on the reduced concrete section and reduced steel strength. The other properties remain the same as concrete at 20°C.

For both materials the partial safety factor γ_m is equal to 1.

4. Examples

In the examples below, the thermal and mechanical response of some type of cross section is viewed. The bar always looks like this:



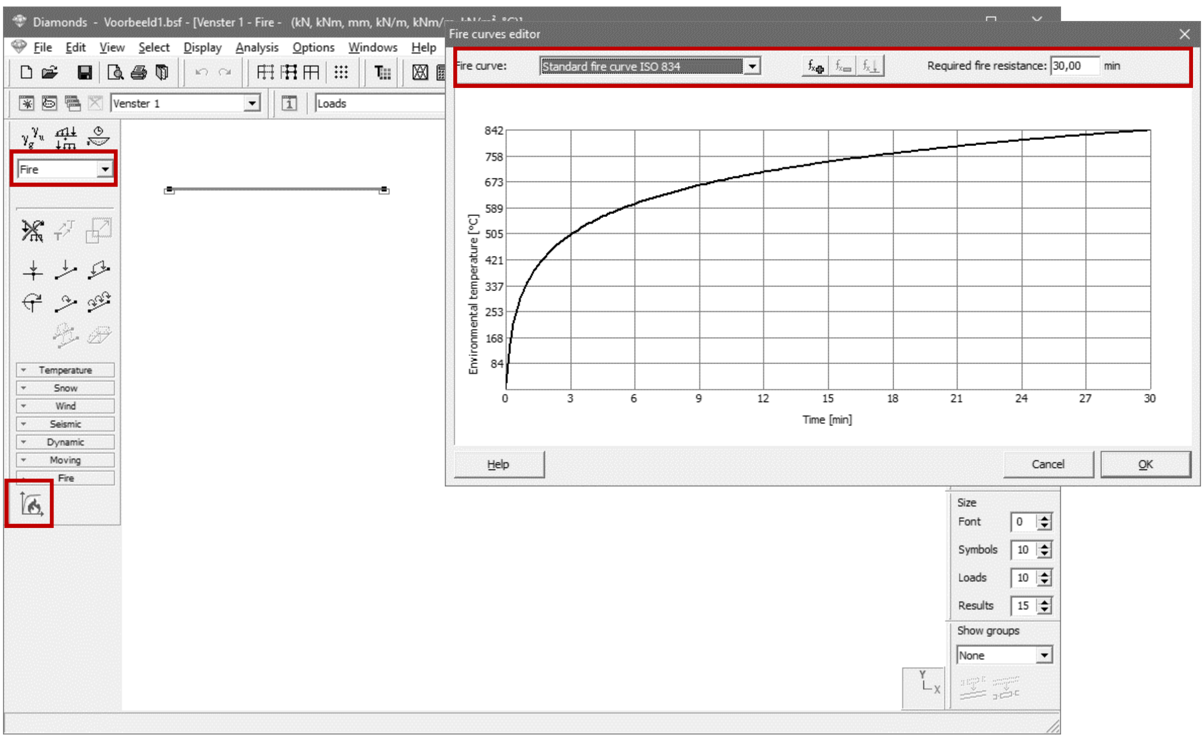
This bar is loaded with:

- Self-weight
- Dead loads 30kN/m
- Life load 50kN/m

A standard fire (ISO 834) is assumed and a required fire resistance of 30min.
We do not take any internal forces generated due to prevented deformation into account. **The calculations are done according to Eurocode without a national Annex**.
The geometry and the loads are defined as it would be done for a normal (cold) calculation.

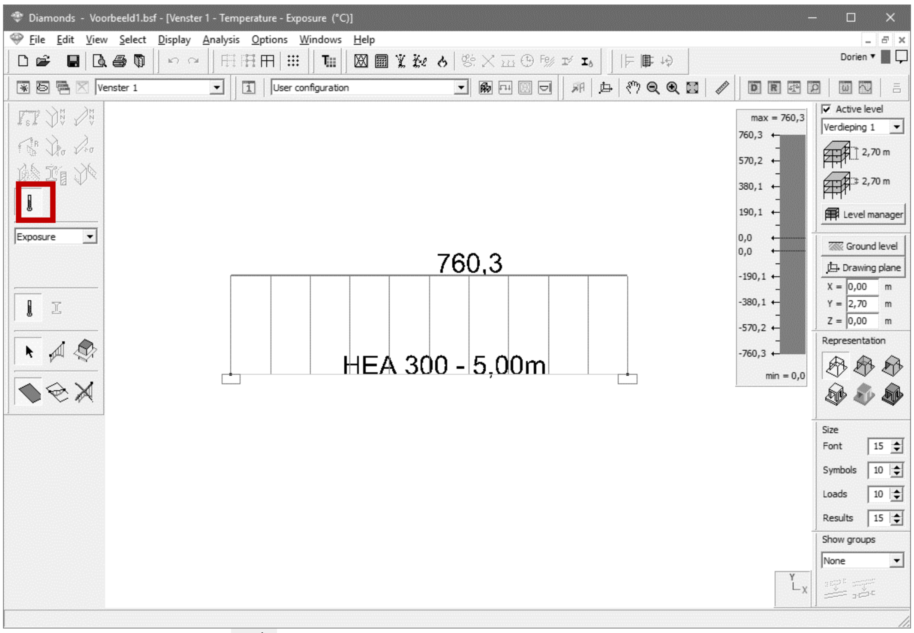
4.1. Unprotected HEA-profile (4 sides)

- Draw the geometry. Assign a HEA 300 to the line .
- Make three load groups: dead loads, live load A and fire.
- Define the loads in dead load and live load (= like you would do for a cold calculation).
- Select the load group 'Fire' from the list. Select the beam and click on  .
- Select the ISO-fire curve and set the fire resistance to 30 min.



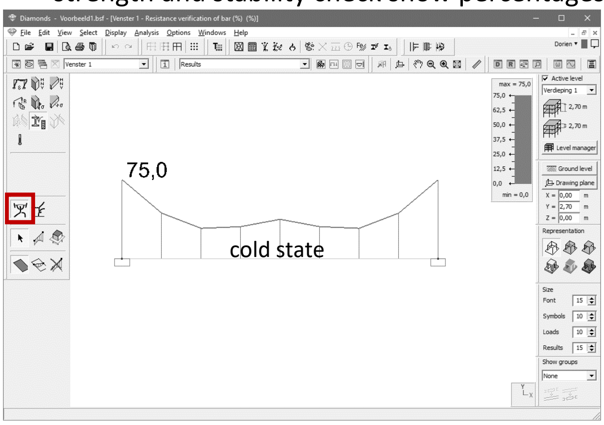
- Then calculate the thermal response  .

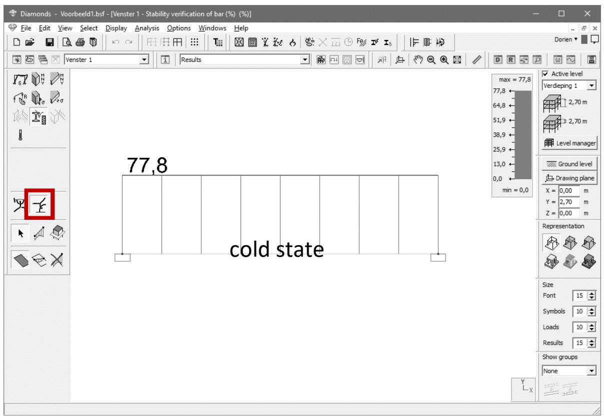
Because of the good thermal conductivity of steel, we expect that the beam will collapse quickly in the event of fire. Due to the imposed fire load, the profile has a uniform temperature increase of 760.3 °C after 30 minutes.



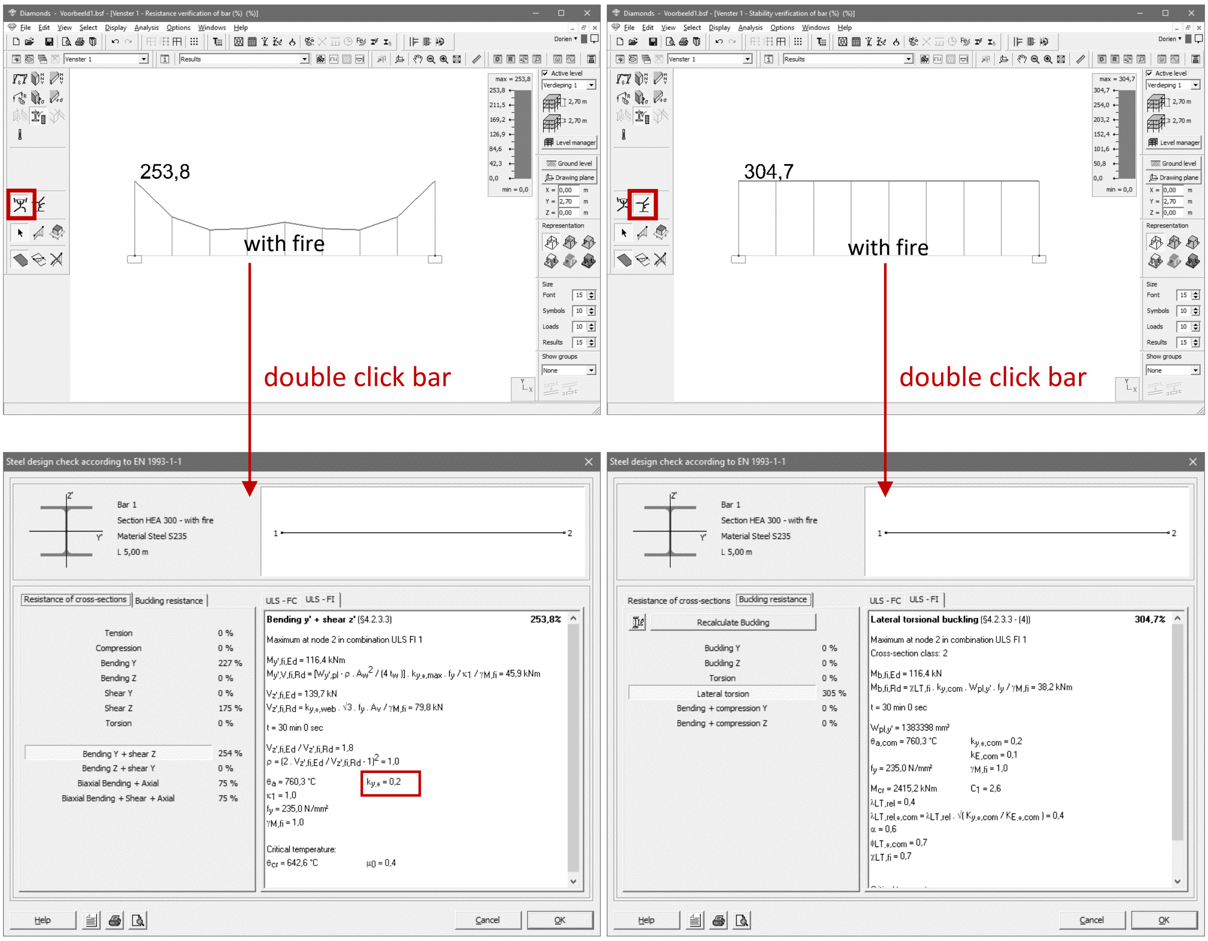
- Generate the combination ULS FC and ULS FI (Ψ_1).
- Calculate the mechanical response .
- Run the steel check .

From a cold calculation (results only in ULS FC) it follows that the beam can bear the load. The strength and stability check show percentages smaller than 100%.





However, at a temperature of 760.3°C, the yield strength of steel has decreased to almost 37N/mm² ($= k_{y,\theta} \cdot f_{yd} = 0.158 \cdot 235N/mm^2$) (results for ULS FC and ULS FI). The resistance and stability check is shown below:



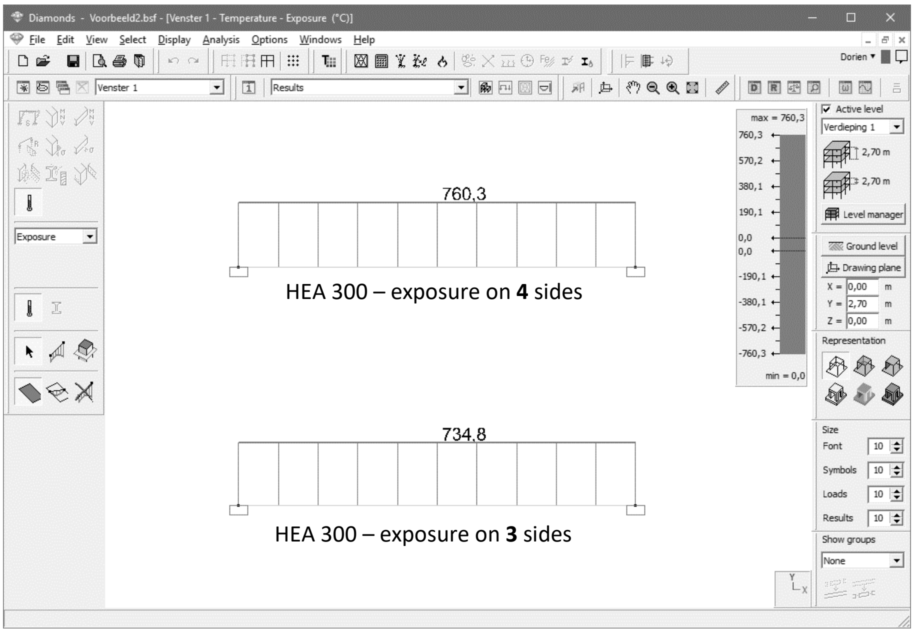
Notwithstanding the fact that a HEA 300 is heavy enough to bear the load, this profile cannot provide the required fire resistance. Given the high temperature increase and the corresponding reduced yield strength of the steel, this is not surprising.

4.2. Unprotected HEA-profile (3 sides)

Suppose the HEA profile is now exposed to fire on 3 sides.

- Go to the geometry configuration .
- Select the beam and click on . Choose the correct protection type:

- Calculate the thermal response .
  The presence of the fire buffer on the top surface will not affect the results much. The steel temperature is still 734,8°C after 30 minutes.



4.3. Protected HEA-profile

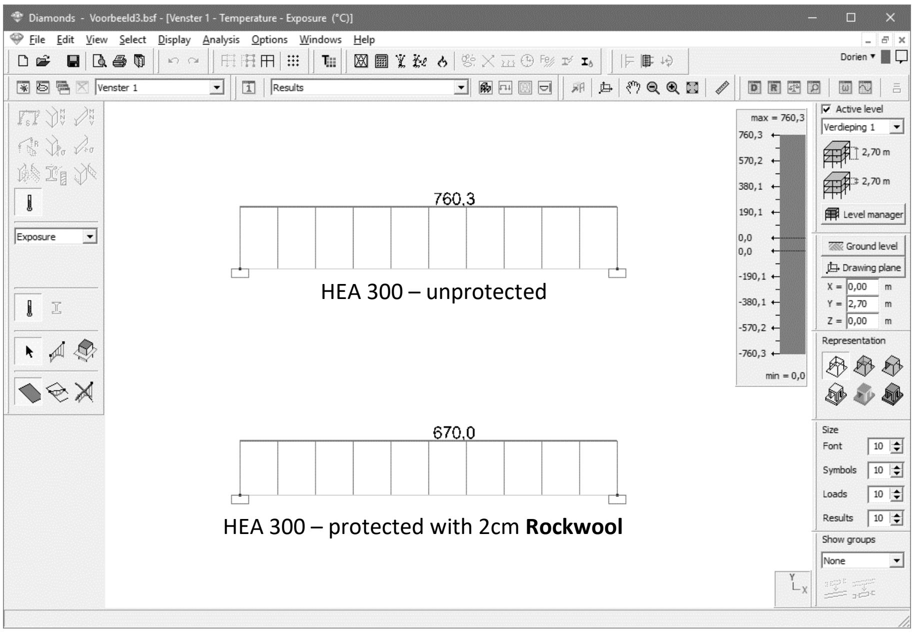
We still consider the HEA 300 profile, but now protected with an insulation material (Rockwool Conflit P 756 - 2 cm thick).

- Go to the geometry configuration .
- Select the beam and click on .
- Define a 2cm insulation layer of 'Rockwool' around the profile.

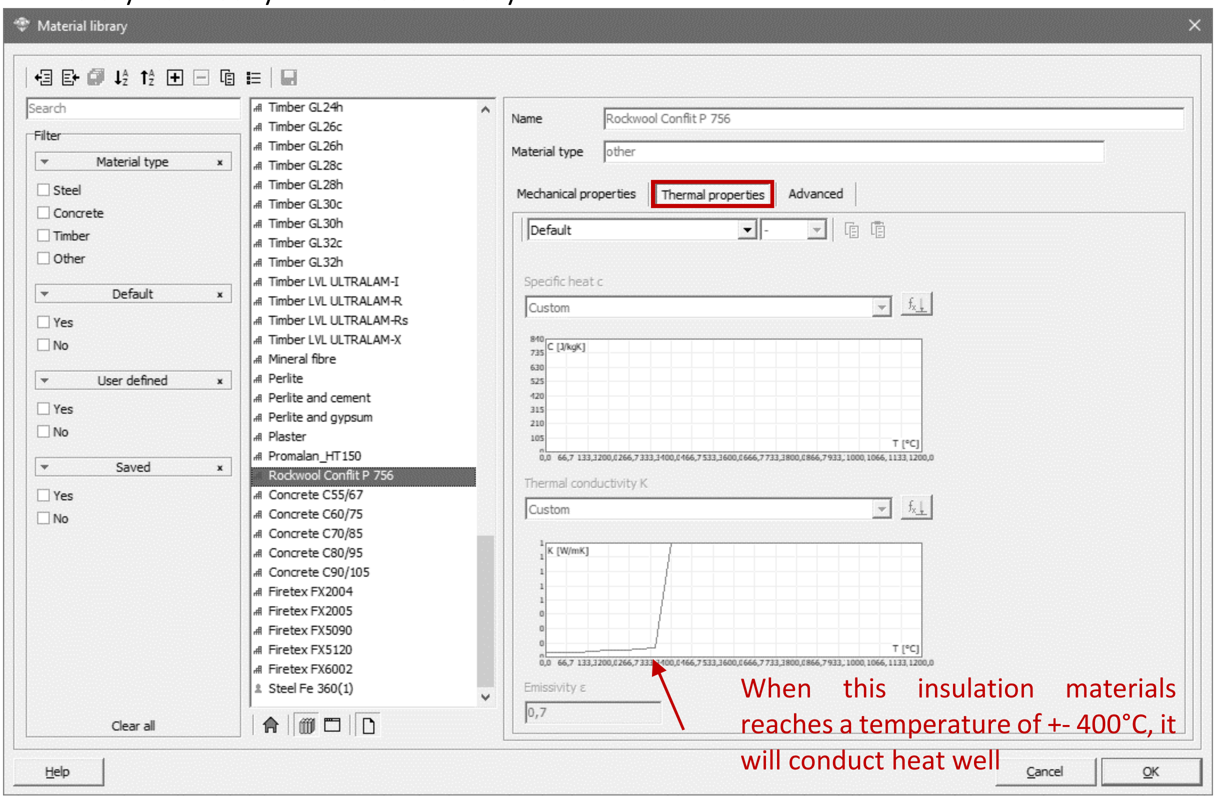
In addition to Rockwool, the following protection materials are also available:
  - The protection materials mentioned in §5.
  - Euroquimica paints
  - Hempel paints
  - Sherwin-William paints

- Calculate the thermal response .

  Given a standard protection type is chosen , the differential equations for coated steel profiles will be applied during the thermal response analysis. We find that the application of the insulation material does not provide spectacular improvements. The steel temperature (670.0°C) has decreased by about 90°C, relative to an unprotected steel profile (760.3°C).

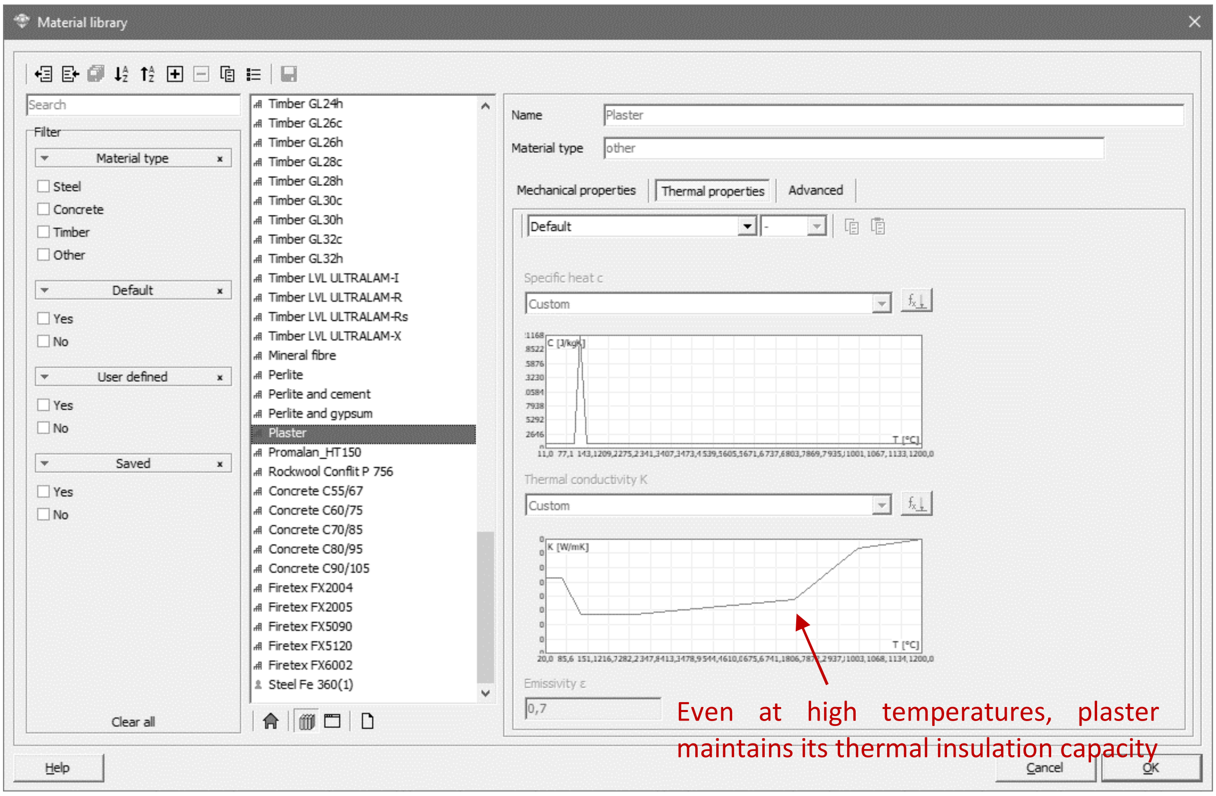


This is understandable considering that the insulation material loses its insulation capacity from a temperature of 400°C. The heat conductivity K increases to the maximum at 400°C (as shown in the material library). The properties of the insulation material can be requested in the material library via 'Modify' → 'Material Library'.

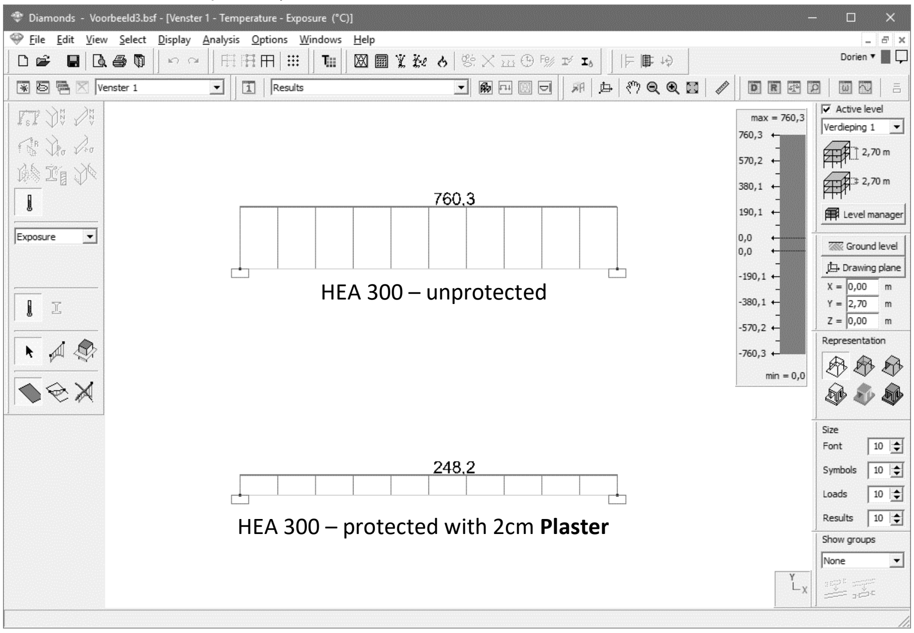


This insulation material is therefore not suitable as a fire protection when strict fire demands are required.

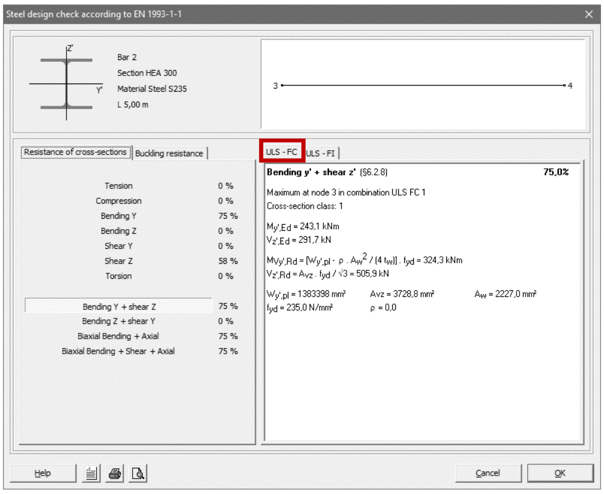
Choose for example ‘Plaster’ from the list.

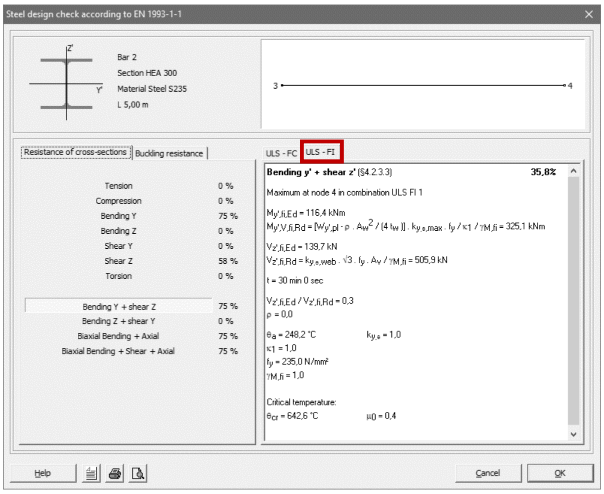


- Replace the 'Rockwool' insulation with 'Plaster' .
- Calculate the thermal response .
  The steel temperature is only 248.2°C after 30 minutes. Since the yield strength at this temperature is still 235 N/mm², the results will not differ from that of a cold steel calculation.



- Calculate the mechanical response .
- Run the steel check .
  Indeed, the following dialogs show that the basic combination ULS FC1 is more critical than the ULS FI fire combinations (the maximum percentages are in the ULS FC tab, not in the ULS FI tab).





Notes:

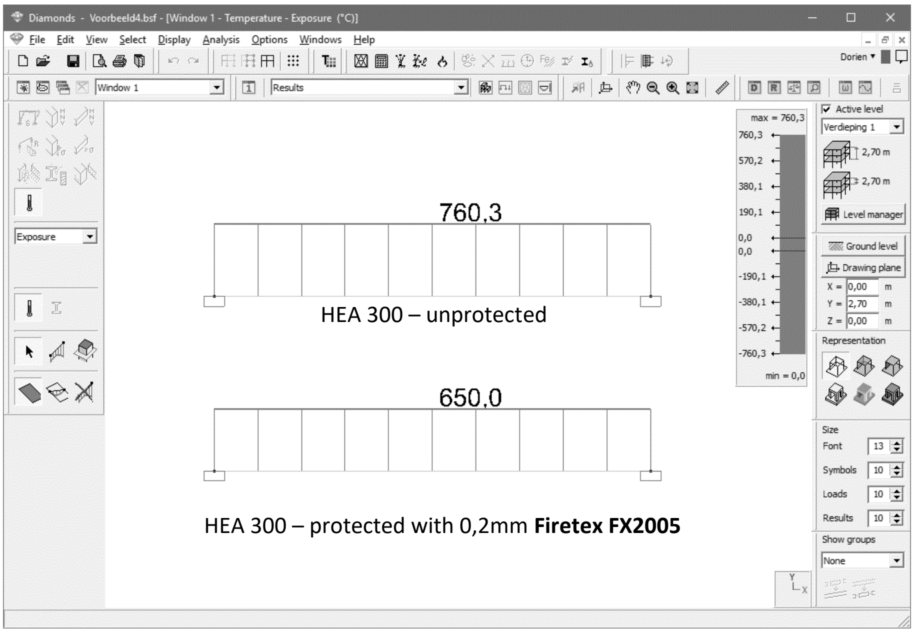
- **The insulation material does not contribute to the stiffness/ self-weight of the cross section**. Optionally, the end user may define the self-weight of the insulation material in the 'dead loads' load group.
- An insulation material with variable thickness can be entered via Section Utility. This section will no longer be calculated with the analytical formulas but with the EEM method.

4.4. Painted HEA – profile

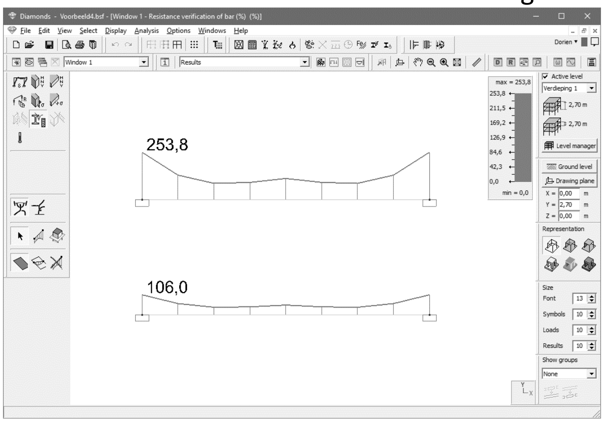
- Go to the geometry configuration .
- Select the beam and click on .
- Define a paint coat in 'Firetex FX2005' of 0,20mm around the section.

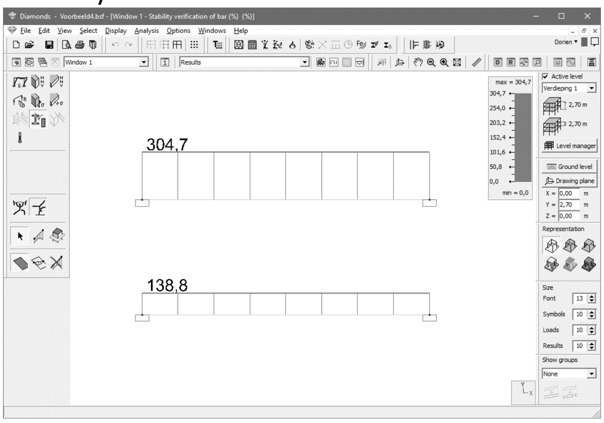
For this paint type, a distinction is made between beams and columns . Choose to let Diamonds decide whether an element is a beam (= elements that are horizontal or inclined) or a column (= vertical elements).

- Calculate the thermal response .
  The steeltemperature is now 650°C. The unprotected beam had a temperature of 760,3°C.

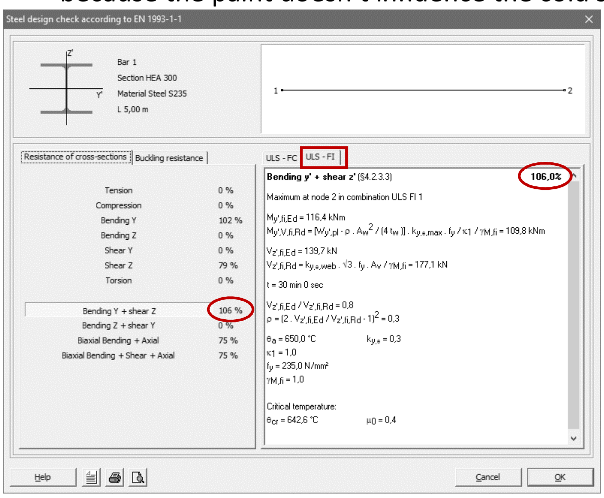


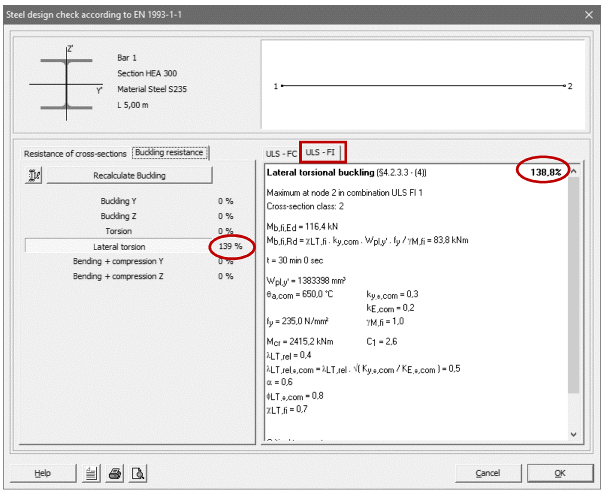
- Calculate the mechanical response .
- Run the steel check . For both strength and stability the section is not sufficient.





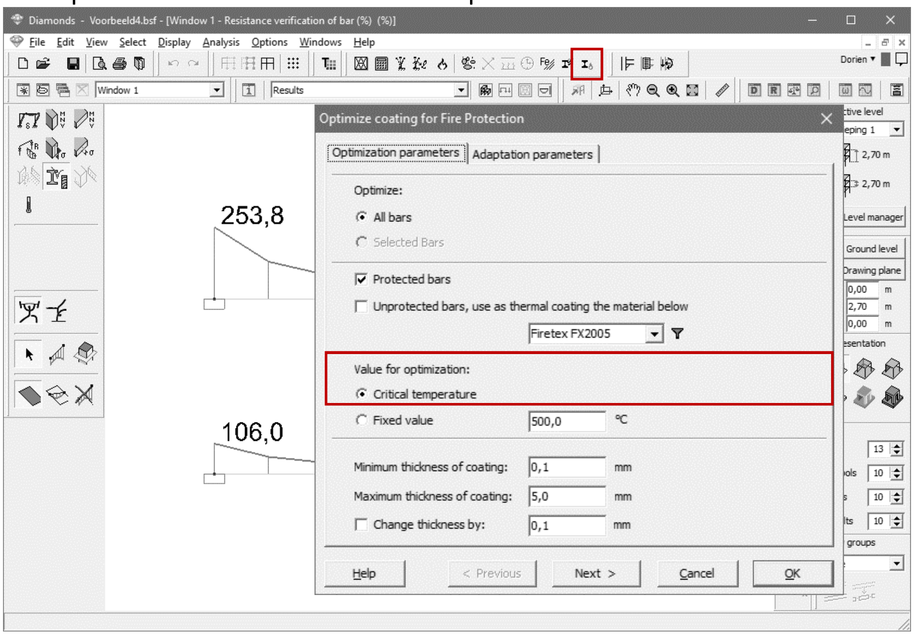
When double clicking the protected beam, you can see that the ULS FI combinations are the determine combinations. In that case we can try to optimise the paint thickness.
When ULS FC is the most determine combinations, it has no use to change the paint thickness because the paint doesn't influence the cold state results.



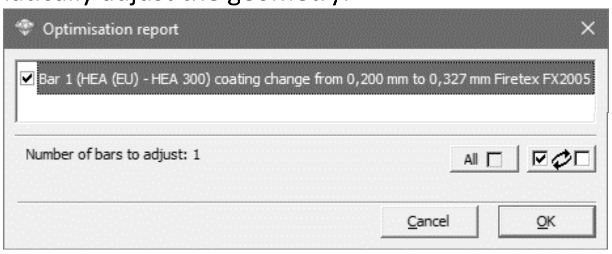


- Using the button you can optimize the paint thickness so that:
  - Either the temperature of the profile remains under **the critical temperature**.
    The critical temperature is the temperature at which a check from the steel verification reaches 100%. In other words, if you use this method, the paint thickness will be determined so that the steelverifciation reaches 100%.
  - Either the temperature of the profile remains under **an imposed temperature**.
    Note: this does not necessarily mean that the steel check then remains below 100%!

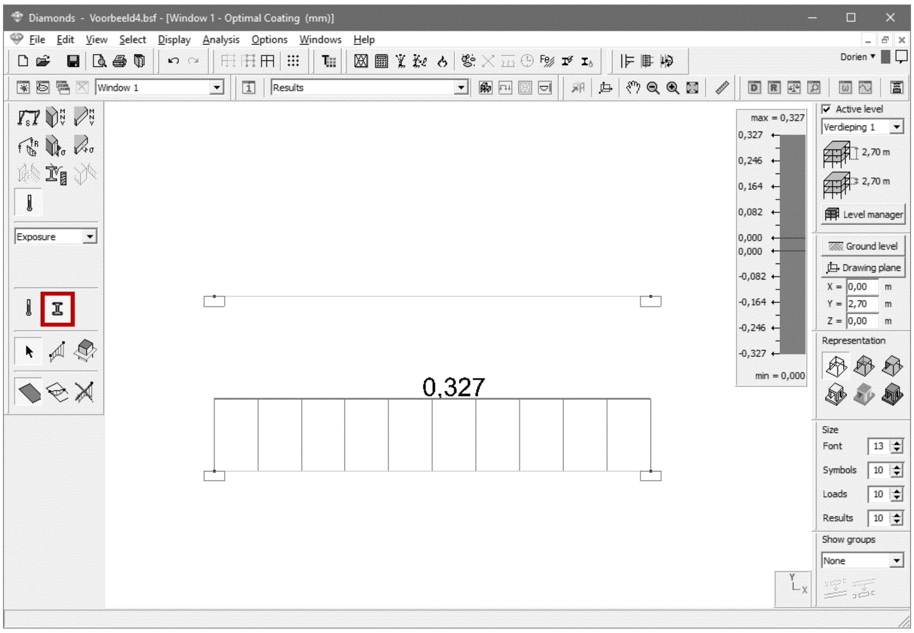
Optimize the paint thickness to the critical temperature :



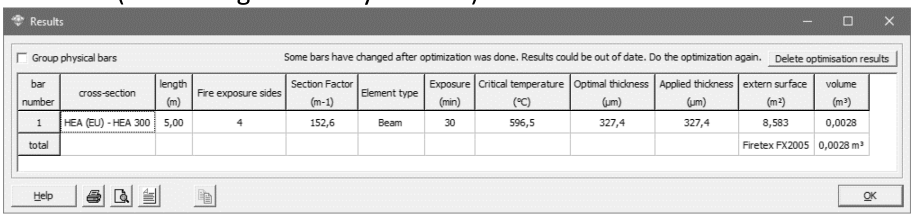
Diamonds suggests to increase the paint thickness to 0,327mm. Click ‘OK’ to accept the changes. Diamonds will automatically adjust the geometry.



- The optimal paint thickness can be consulted with the icon in the results configuration.



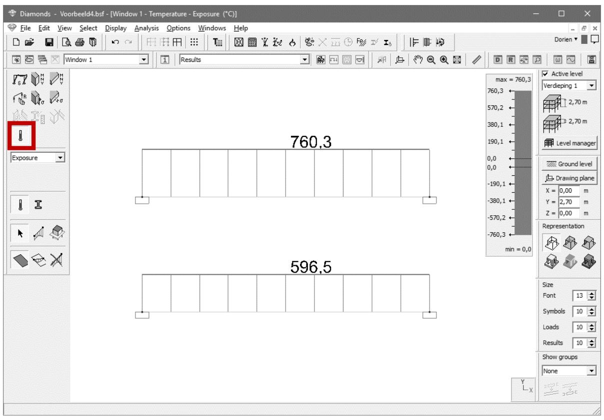
Teh results of the optimisation can also be requested in the results table .
In this table you can consult for example the section fractor, the critical temperature, the optimal and applied paint thickness and the volume of the paint.
The volume of dry and wet paint is usually not the same (a conversion factor is required). Therefore the paint volume is sometimes expressed in liter (= referring to the wet volume), sometimes in m³ (= referring to the dry volume).

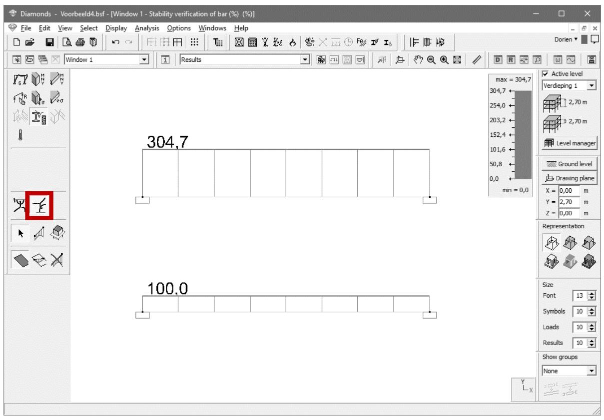


Group physical bars — Some bars have changed after optimization was done. Results could be out of date. Do the optimization again. Delete optimisation results

bar number	cross-section	length (m)	Fire exposure sides	Section Factor (m-1)	Element type	Exposure (min)	Critical temperature (°C)	Optimal thickness (µm)	Applied thickness (µm)	extern surface (m²)	volume (m³)
1	HEA (EU) - HEA 300	5,00	4	152,6	Beam	30	596,5	327,4	327,4	8,583	0,0028
total										Firetex FX2005	0,0028 m³

- Calculate the thermal response , calculate the mechanical response and run the steel verification once more . Now the section is sufficient.

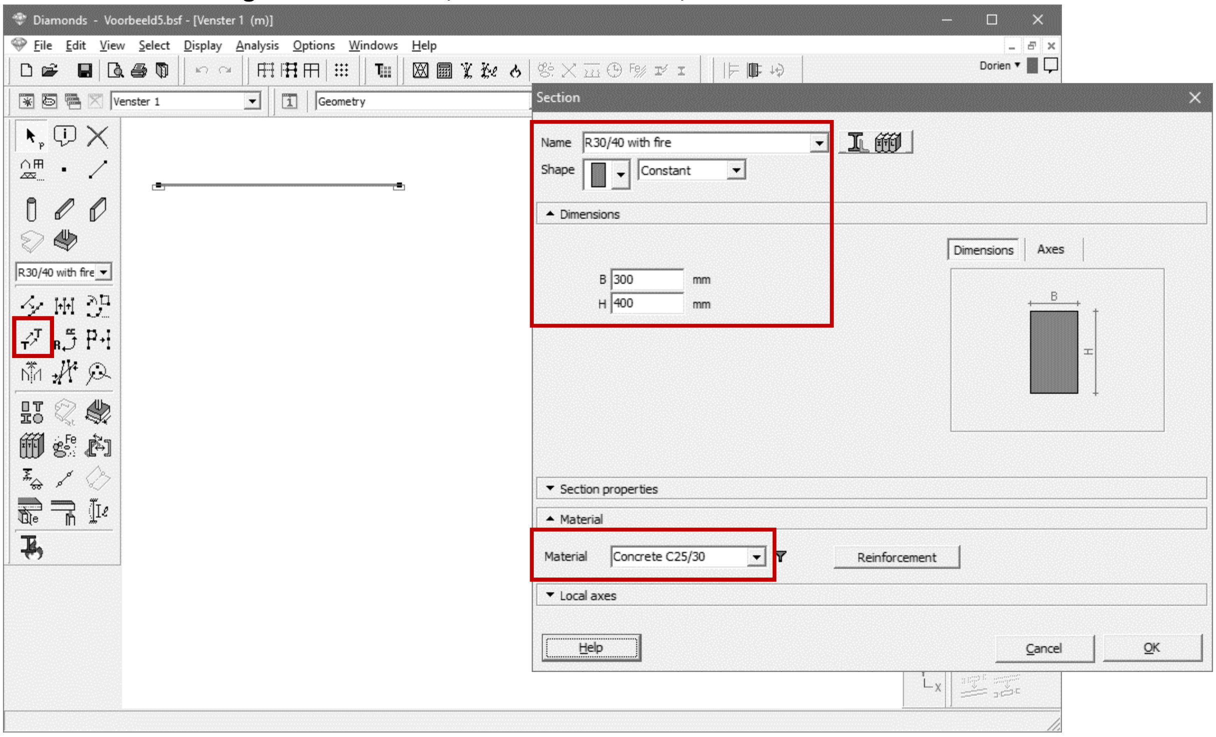




4.5. R-Section in reinforced concrete

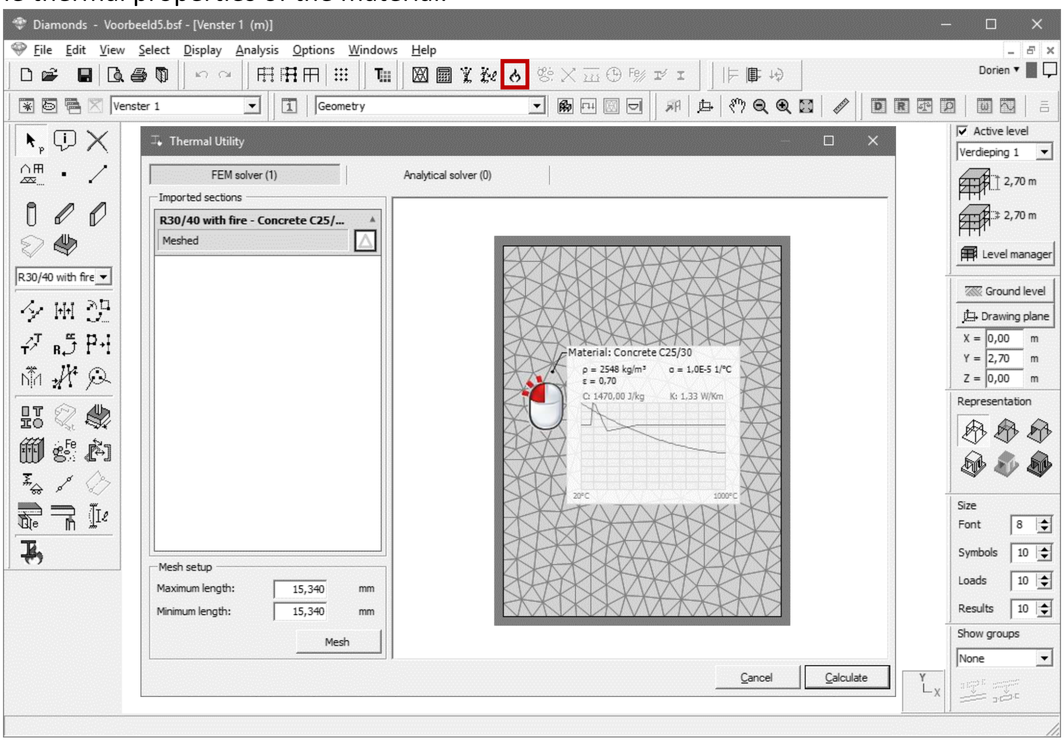
- Go to the geometry configuration .

- Select the beam and click on .
- Define a rectangular section R30/40 in concrete C25/30.

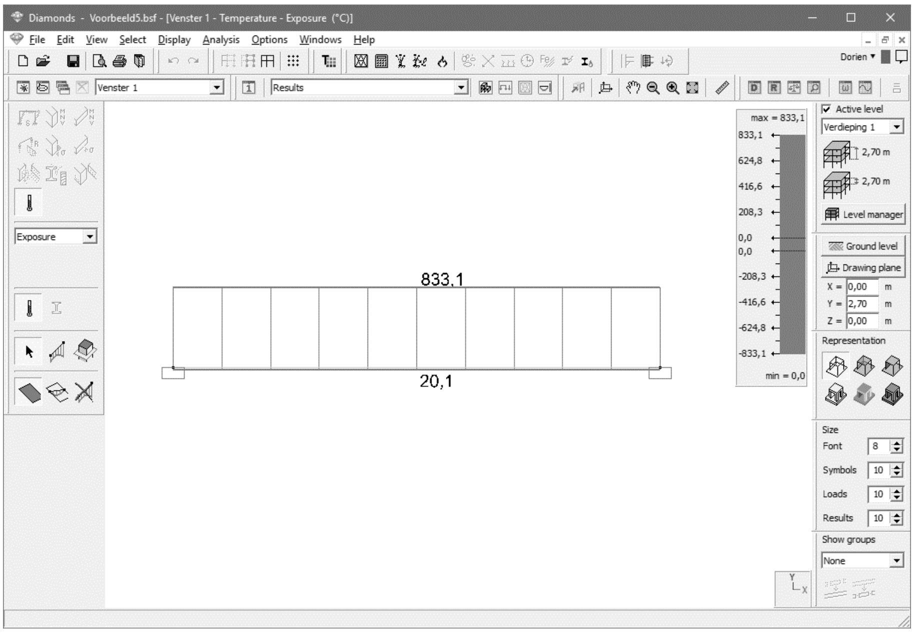


- Calculate the thermal response . Leave all parameters to default.

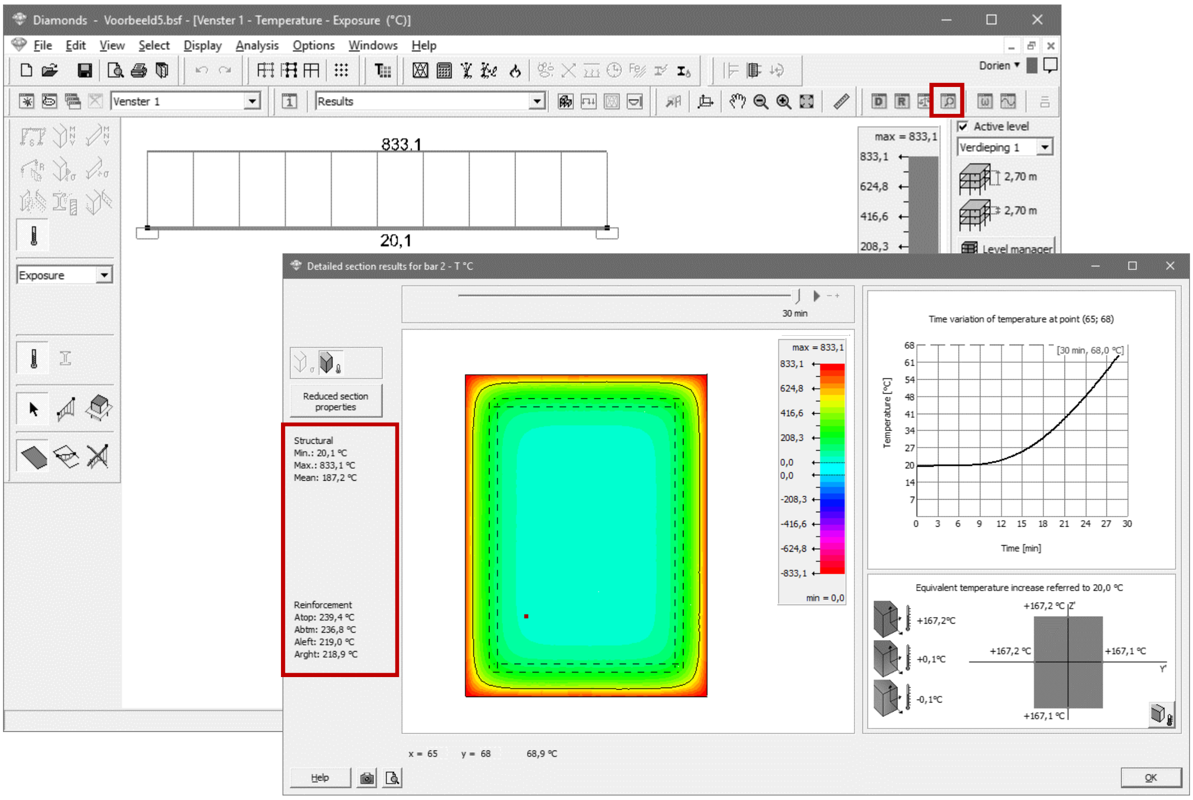
  The EEM method will be used to determine the temperature gradient across this (solid) section. The yellow zone indicates where the fire is engaged. Click in the concrete cross section to request the thermal properties of the material.



After 30min of fire the maximum temperature is 834.6°C and the minimum temperature is 21°C.



Double click the bar or select the bar and click on  to see the increase in temperature in more detail.

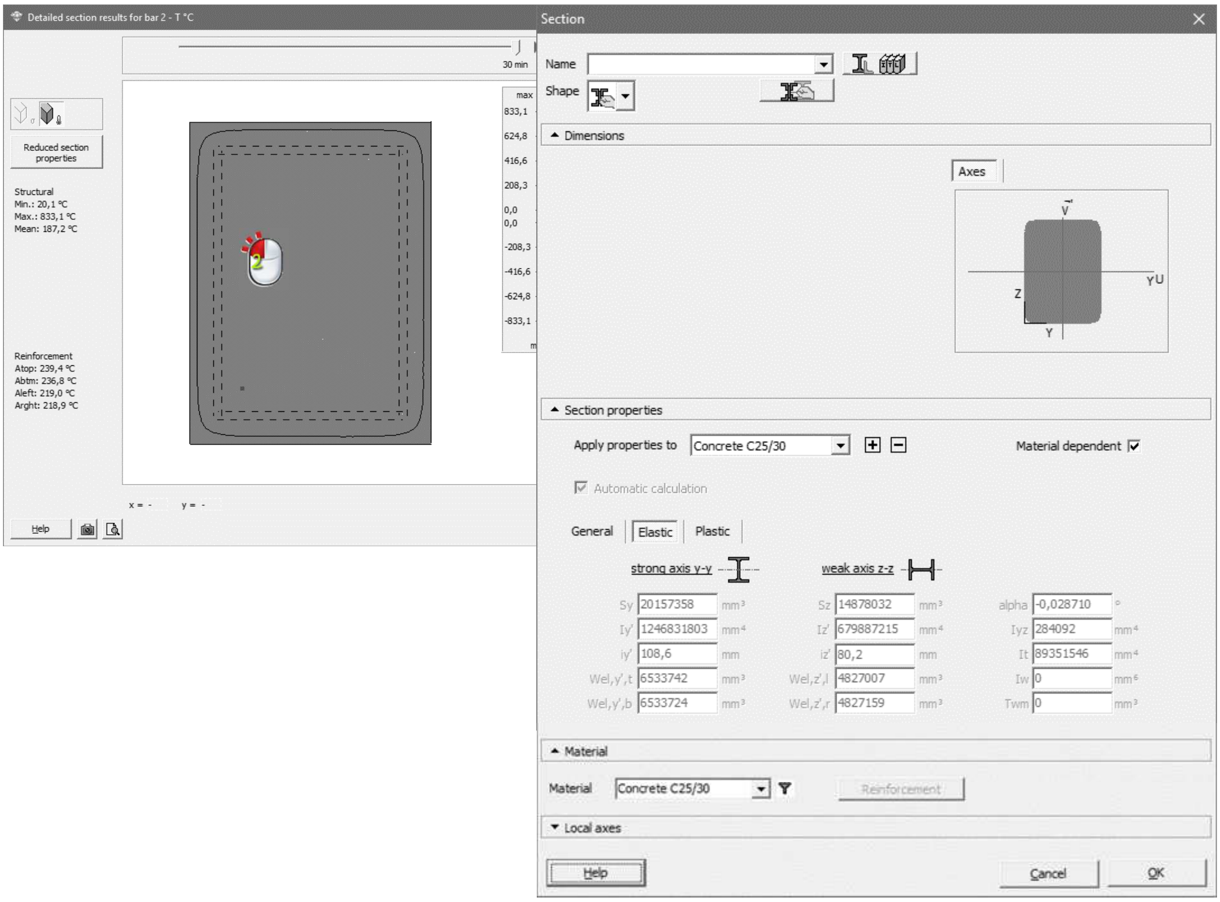


On the left, you see the minimum, maximum and average temperature of the profile. This profile has **a mean temperature** of 187,2°C after 30 minutes of fire.
The temperature of the upper, lower and flank reinforcement is given under 'Reinforcement'.

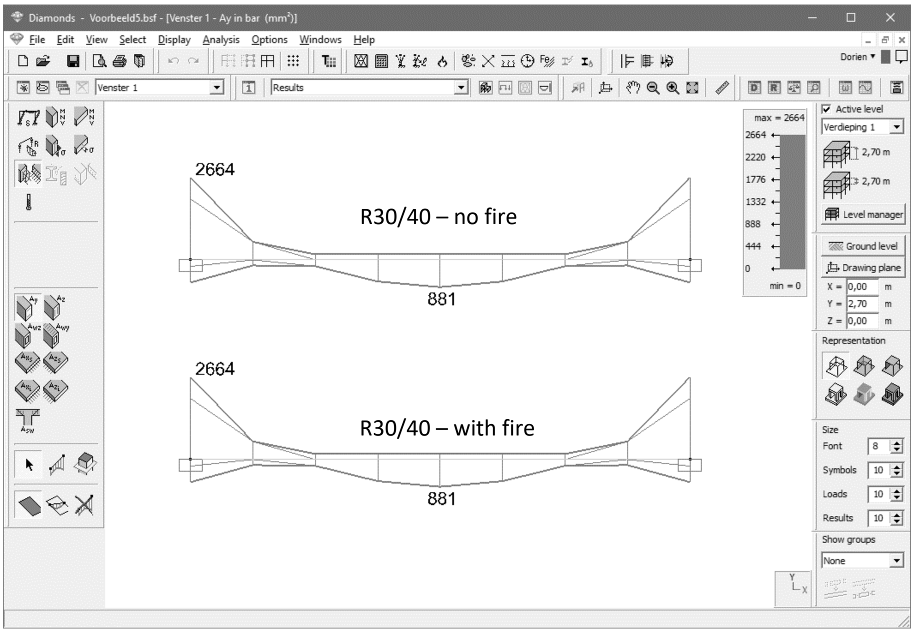
At the bottom right, you see the temperature gradient and global temperature indicator that gives a similar temperature gradient at the given time. This is especially interesting if you want to take into account the thermal load due to fire. Although this is not required according to Eurocode, this is illustrated in §4.6.

Given the double symmetry of this rectangular cross section and the fact that all sides of the concrete cross section are exposed to fire, the temperature gradients are negligible.

Double click on the section to view the properties of the reduced concrete section (or click on the button Reduced section properties). Concrete with a temperature above 500°C will be neglected in the reinforcement calculations.



- Generate the combinations ULS FC, ULS FI (Ψ_1), SLS RC, SLS QP .
- Calculate the mechanical response .
- Calculate the reinforcement .



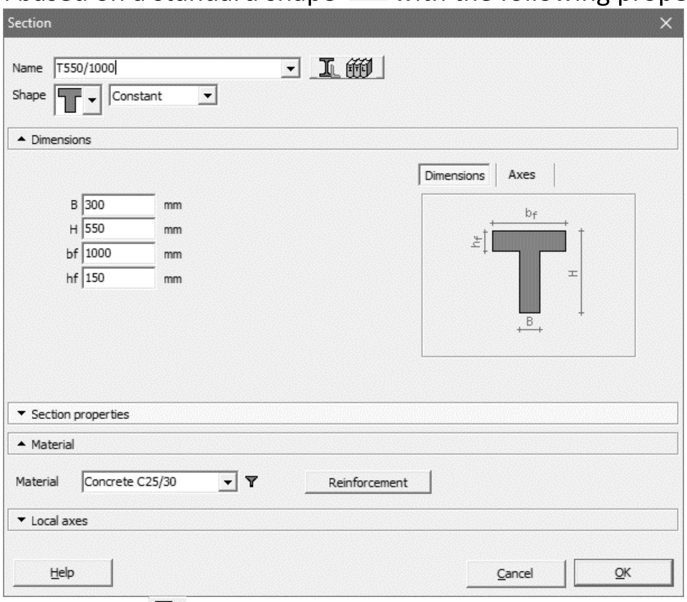
The reinforcement in the beam with fire is the same as the reinforcement in the beam without a fire. This is because:

- The fire combinations ULS FI result in less internal forces than the basic combinations ULS FC.
- The partial safety coefficients of concrete and concrete steel are equal to 1 in the ULS FI.
- The heating of the cross section is so small that the yield strength of the reinforcement steel should not be reduced.

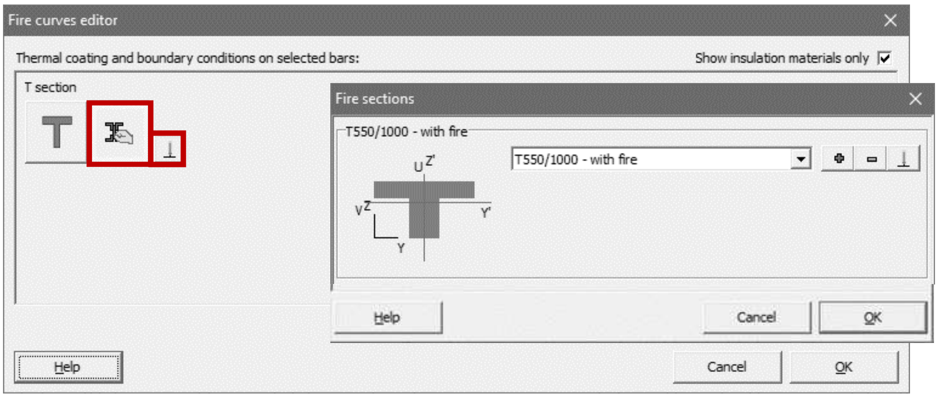
4.6. T- Section in reinforced concrete

Now imagine that the R30/40 beam is poured together with a plate (150mm and a co-operating width of 1000mm). We also define that only the space under the plate is exposed to fire.

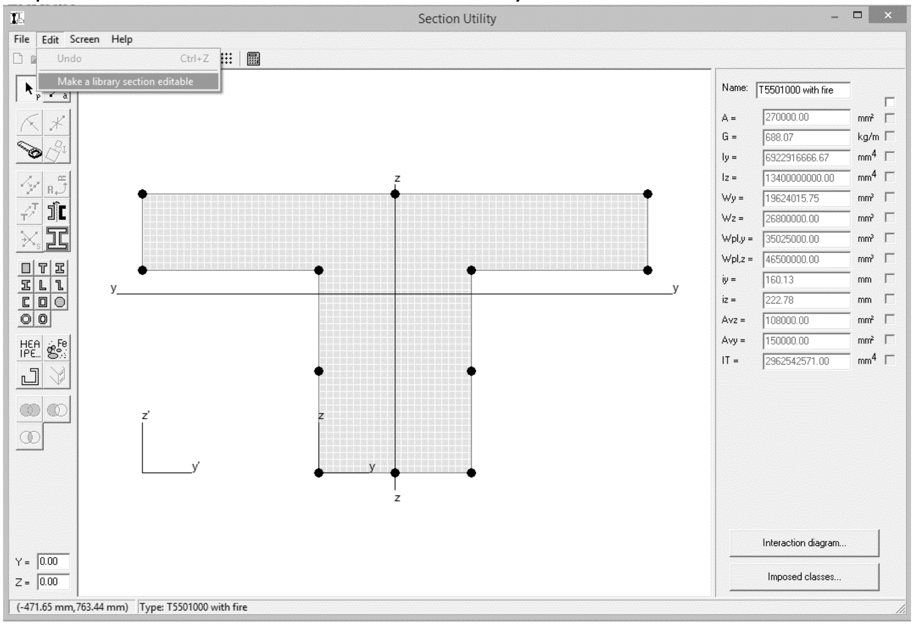
- Define a T-section based on a standard shape with the following properties:



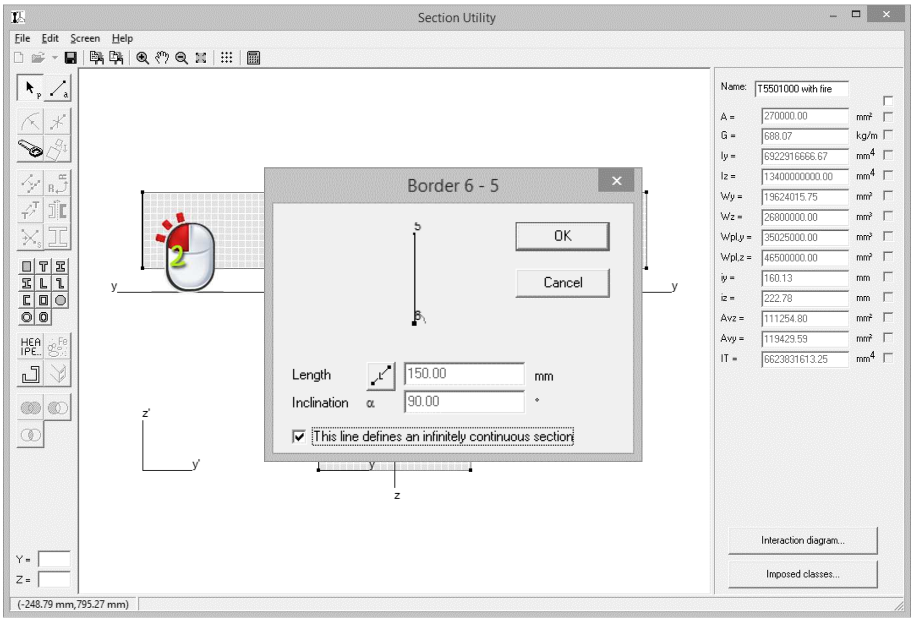
- Select the beam and click on .
- Then click on and on .
- Then click on and . The profile will be send to Section Utility.



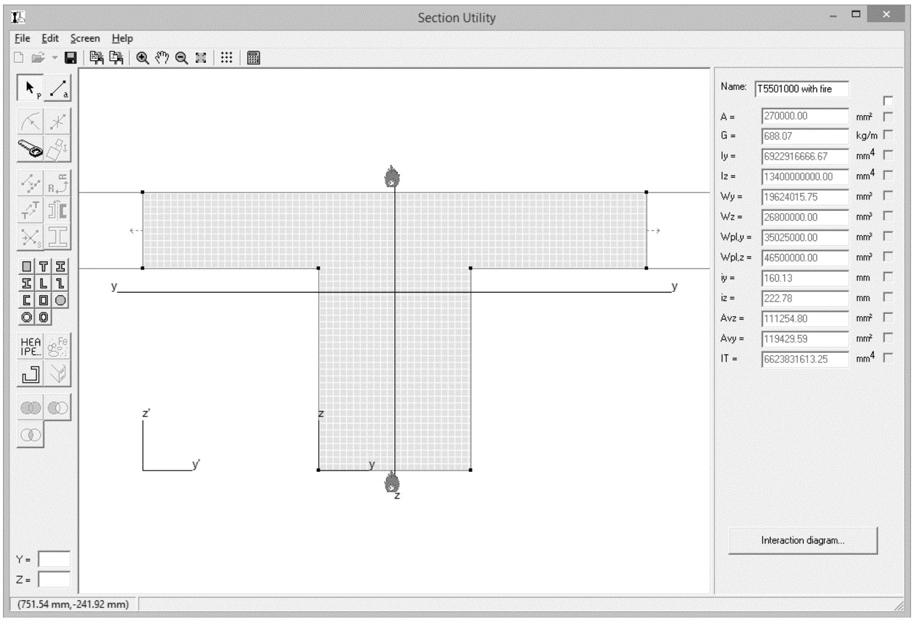
- Select the profile and select ‘Edit’ → ‘Make a library section editable’.



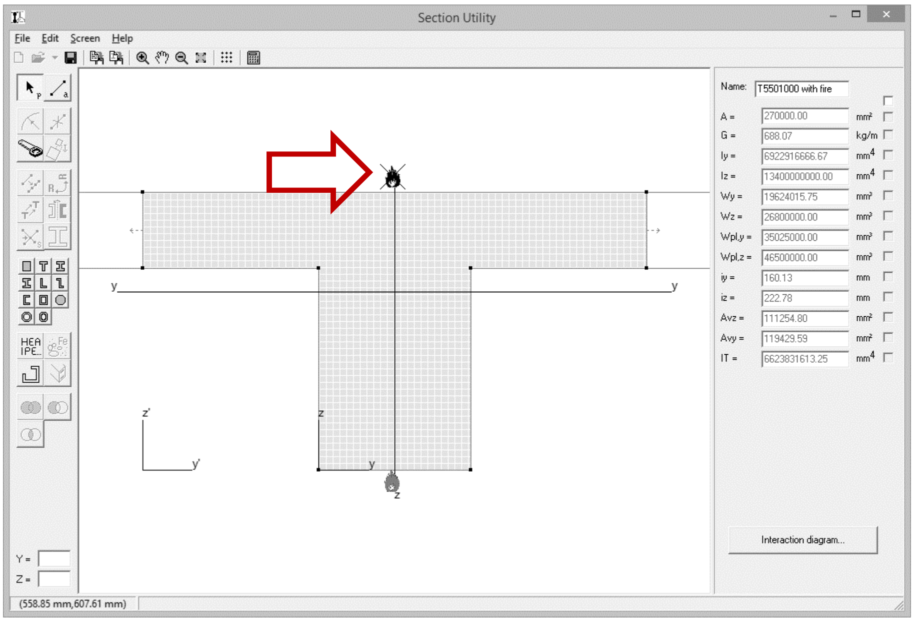
- Double click the borders on the left and right and select ‘This line defines an infinitely continuous section’.



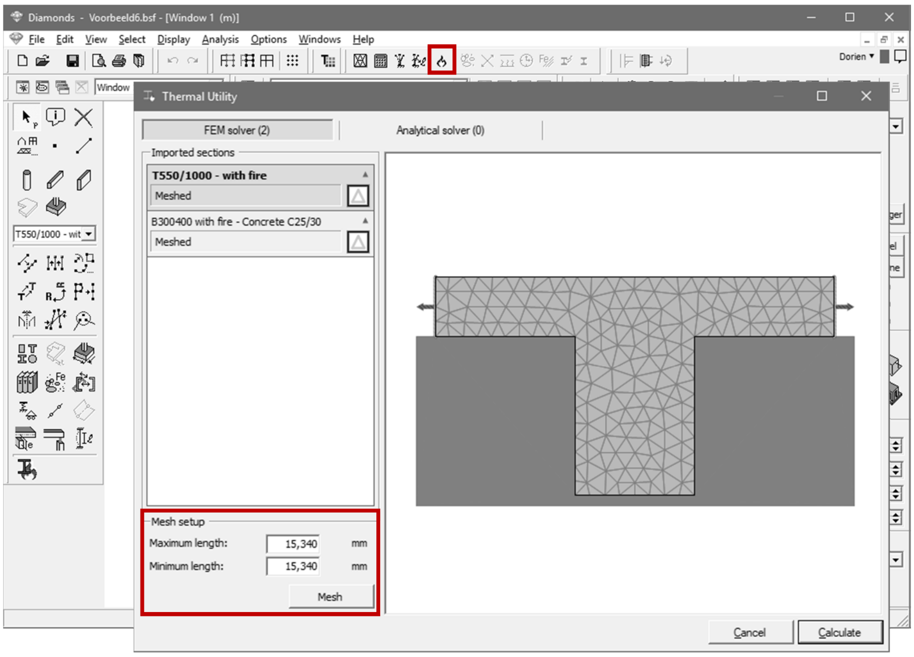
- Section Utility immediately distinguishes two fire positions. They are each referred to with a flame.



- Quench the top flame by clicking it once. This specifies that there is no heat supply from the upper floor.

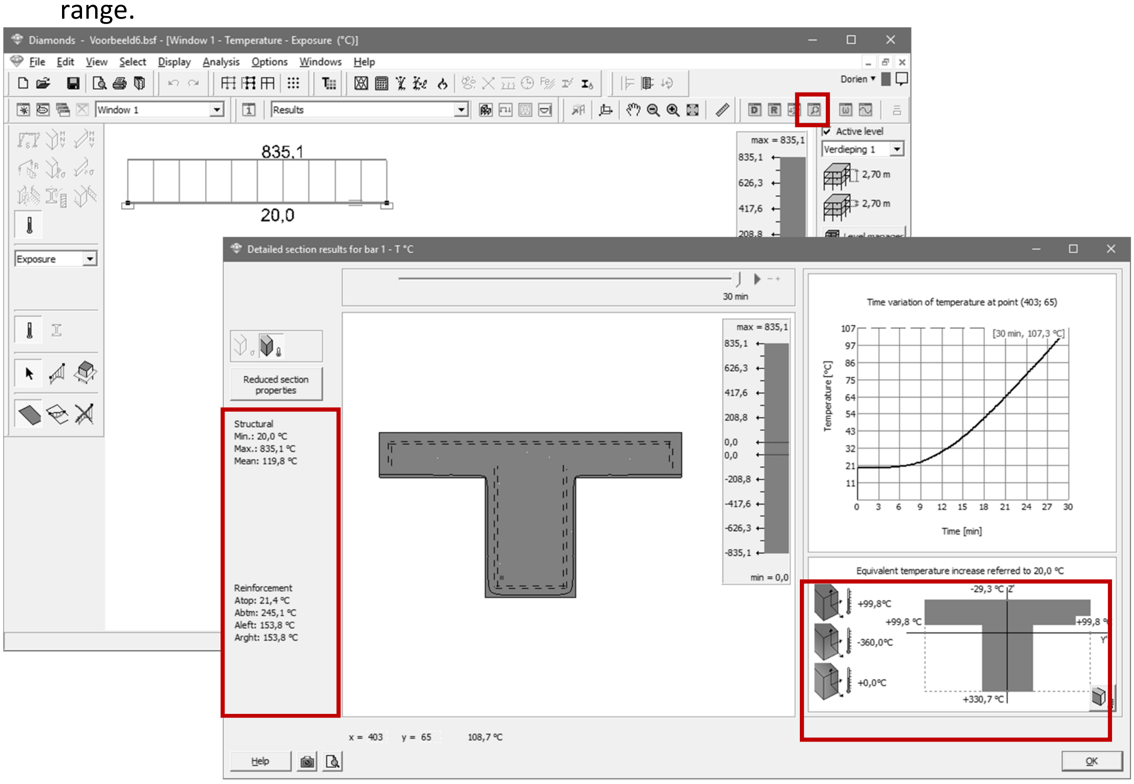


- Close Section Utility and take the section to Diamonds.
- Calculate the thermal response . We want to calculate this T-section with the same accuracy as the rectangular section from §4.5. Therefore, adjust the minimum mesh size to 15,34mm and then the maximum to 15mm. Then click the 'Mesh' button and then 'Calculate'.



After 30 minutes of fire, the maximum temperature is 835°C, and the minimum temperature is 20°C.

Double click the bar or select the bar and click [icon] to see a detailed overview of the temperature range.

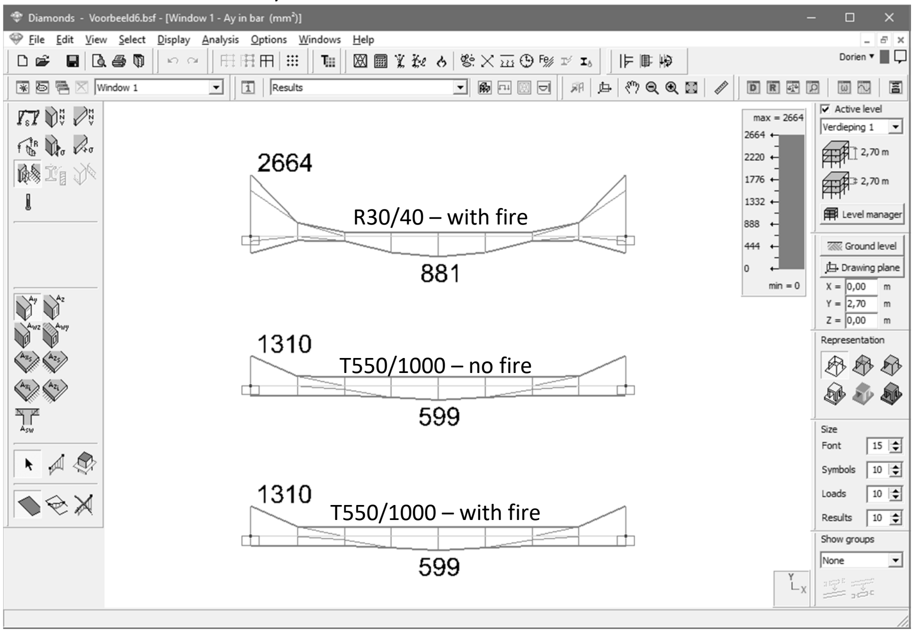


On the left under ‘Structural’ you read the minimum, maximum and average temperature of the profile. This profile has a **mean** temperature of 119,8°C after 30 minutes of fire.

Due to the asymmetry of the cross section and the uneven warming, temperature gradients occur according to the local y'-axis. However, given the thermal load in the global analysis is not included, these gradients do not cause internal stresses in the construction.

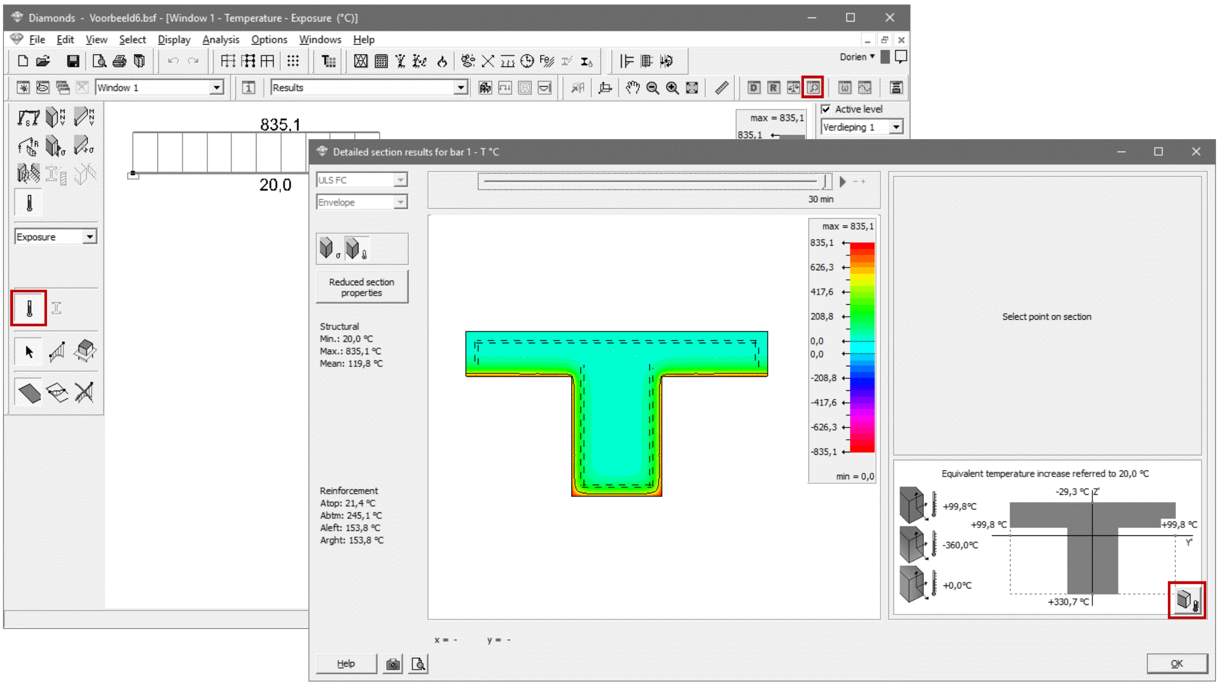
- Generate the combinations ULS FC, ULS FI (Ψ_1), SLS RC, SLS QP [icon] .

- Calculate the mechanical response .
- Calculate the reinforcement .
  Again, the combinations ULS FC are stricter than the ULS FI combinations. Because the floor plate now works with the beam, the longitudinal reinforcement can be reduced (compared to the beam B300 / 400 without floorboard).



Suppose we want to deviate from the simplification imposed by the norm and to account for the influence of the fire on internal forces. Then proceed as follows:

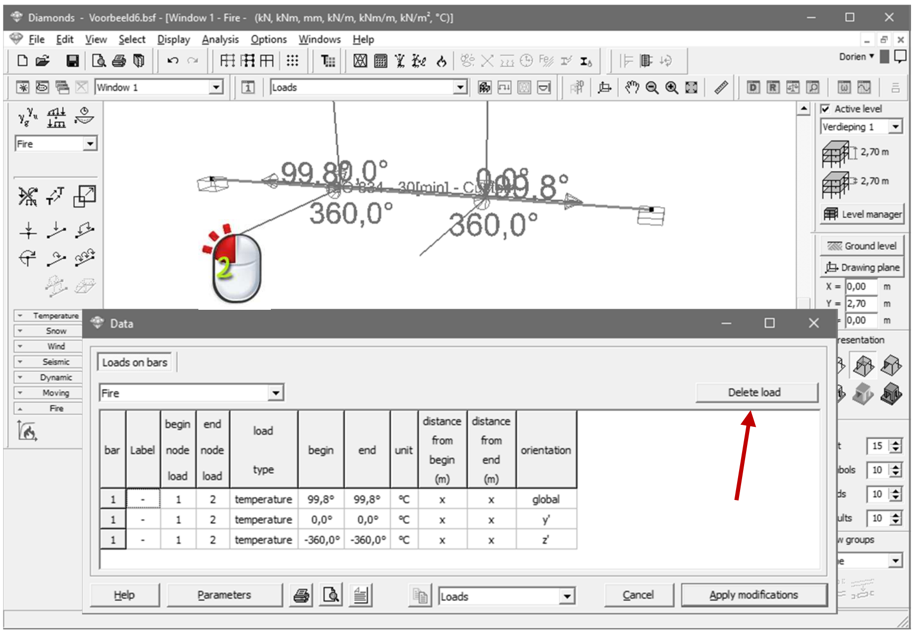
- Click on .
- Select the beam and click on . Then click on . This will copy the temperatures to the load groups 'Fire'.



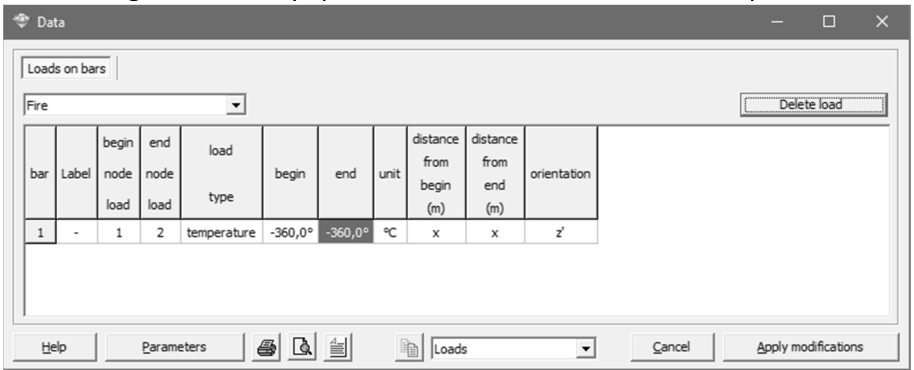
- In the load group 'Fire' we now retrieve the temperature loads.

The arrows always points to the hottest side.

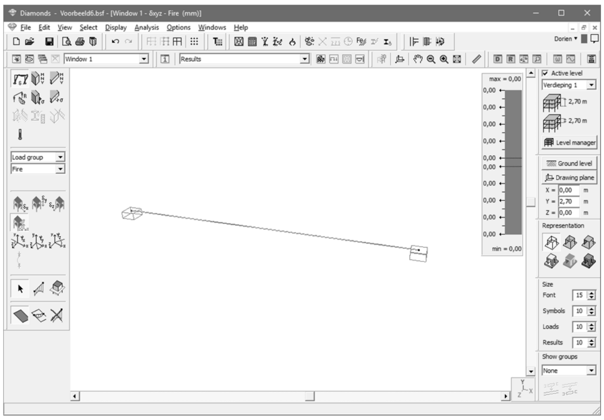
With the button you remove all temperatures loads as well as the fire curve.
If you want to remove one compound of the temperature loads, you can do so by double clicking the beam (or select the beam and click).

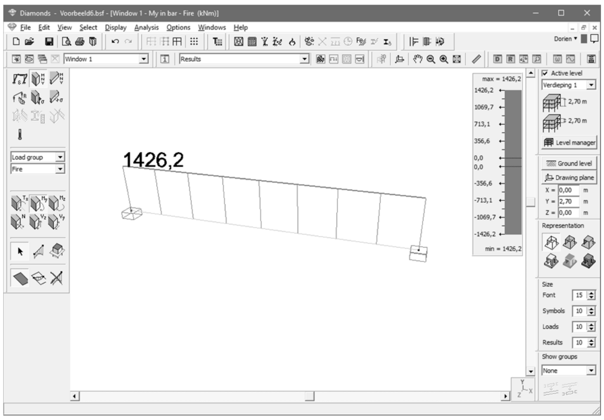


We can for example neglect the global temperature change in accordance with EN 1992-1-2 §2.4.2 (4) and remove the gradient in the y'-direction since it is 0°C.
The arrows of the gradient always point towards the warm side of the profile.

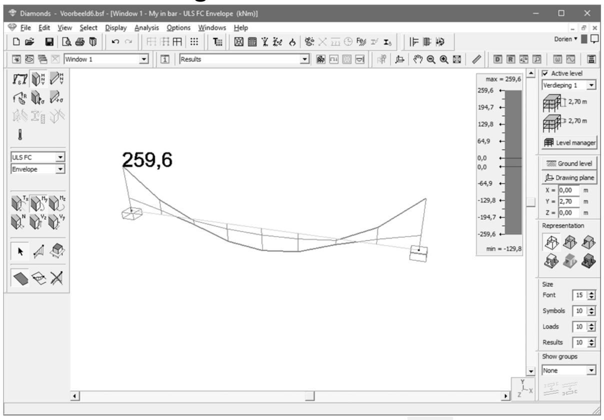


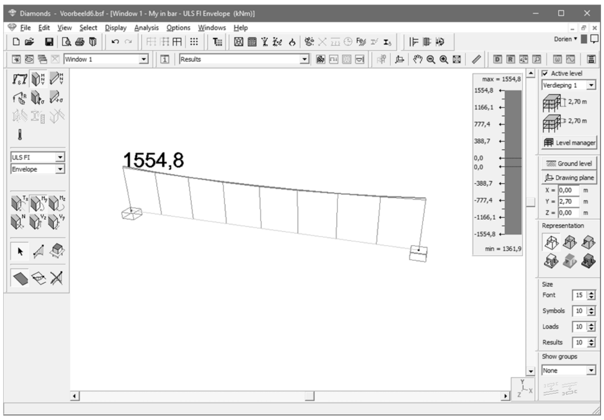
- Calculate the mechanical response .
  If the beam is simply supported, it would deflect downwards (the deflection is always in the direction of the warmest temperature). However, because the beam is built-in at both ends, internal forces will be arise to counteract this deflection. **Counteracting a downward deflection, implies a bending moment that gives tension on the upper side and compression on the lower side.**



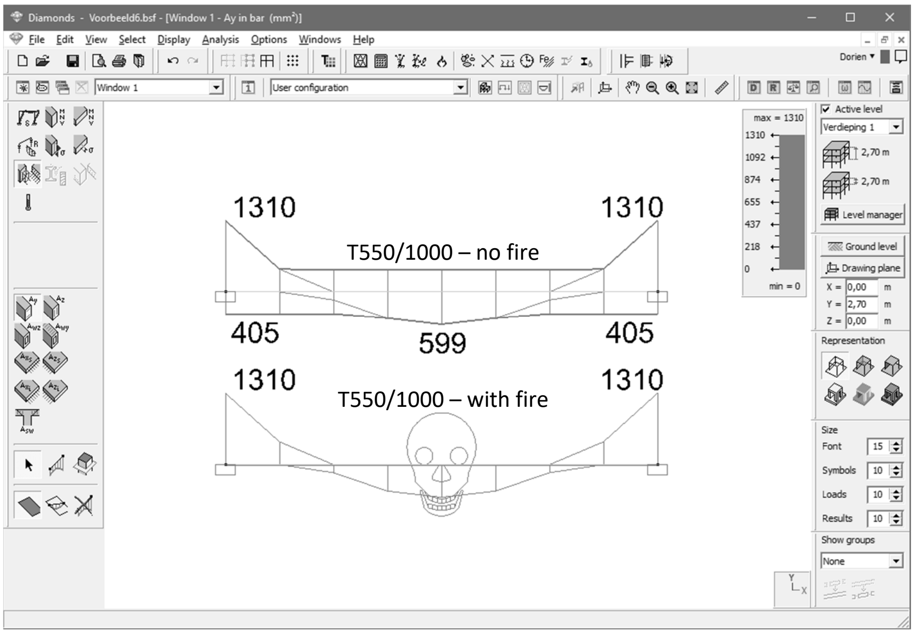


The bending moment in ULS FC and ULS FI look like this now:





- Calculate the reinforcement .
  We see that the section is no longer sufficient as a result of the gradient.



5. Thermal properties of insulation materials

Material	Thermal conductivity $\lambda_p \left[\frac{W}{m \cdot K}\right]$	Specific heat $c_p \left[\frac{J}{kg \cdot K}\right]$	Density $\rho_p \left[\frac{J}{kg \cdot K}\right]$
Sprays			
• Mineral fibre	0.12	1200	300
• Vermiculite cement	0.12	1200	350
• Perlite	0.12	1200	350
High density sprays			
• Vermiculite (or perlite) and cement	0.12	1100	550
• Vermiculite (or perlite) and plaster	0.12	1100	650
Boards			
• Vermiculite (or perlite) and cement	0.20	1200	800
• Fibre-silicate or fibre-calcium-silicate	0.15	1200	600
• Fibre-cement	0.15	1200	800
• Gypsum boards	0.20	1700	800
Compressed fibre boards in fibre silicate, mineral wool or stone wool	0.20	1200	150
Concrete	1.60	1000	2300
Concrete (light weight)	0.80	840	1600
Concrete bricks	1.00	1200	2200
Brick with holes	0.40	1200	1000
Solid bricks	1.20	1200	2000

Source: J.M. Franssen and P. Vila Real, Fire Design of Steel Structures, Eurocode 1 Part 1-2, ECCS Eurocode Design Manuals, Table A.6

6. References

- NBN EN 1990: 2002
- NBN EN 1991-1-2:2003
  - NBN EN 1991-1-2 ANB: 2008 (national annex for Belgium)
  - NEN EN 1991-1-2 +C1:2011 (national annex for the Nederland's)
- NBN EN 1992-2: 2005
  - NBN EN 1992-2 ANB:2010 (national annex for Belgium)
  - NEN EN 1992-2+C1: 2011 (national annex for the Nederland's)
- NBN EN 1993-2: 2007
  - NBN EN 1993-2 ANB:2011 (national annex for Belgium)
  - NEN EN 1993-2+C1:2011 (national annex for the Nederland's)
- J.M. Franssen and P. Vila Real, Fire Design of Steel Structures, Eurocode 1 Part 1-2, ECCS Eurocode Design Manuals, 2010
- C.R. Braam, Ontwerpen in gewapend beton - Cement en beton 4, 2012

lateral buckling restraint – attaches – steel check – creep – charges climatiques – dynamic analysis – lateral buckling – brandweerstandsanalyse – timber – 1st order – verstijvers – buisverbinding – diseño de planos de armaduras – pandeo lateral – verbindingen – shear connection – verificación – armatures longitudinales – pórtico – unión base columna – voorontwerp – unión tubular – haunch – connexion moment – cimbras – vérification acier – unity check – Eurocode 2 – mesh – retaining wall – raidisseur – Eurocode 3 – longitudes de pandeo – connections – ACI 138 – acero – 2nd ordre – portal frame – Eurocode 8 – andamios – kip – dwarskrachtverbinding – BS 8110 – dalle de fondation – seismische analyse – armaduras longitudinales – BIM – gelaste verbinding – 2de orde – buckling – funderingszool – poutre sur plusieurs appuis – maillage – malla – uniones – 2D raamwerken – fire resistance analysis – voiles – cracked deformation – gescheurde doorbuiging – longueurs de flambement – pandeo – reinforcement – unity check – cantonera – dynamische analyse – hout – ossatures 3D – koudgevormde profielen – placa de extreme – 1er orden – continuous beam – connexion soudée – momentverbinding – praktische wapening – renforts au déversement – fluencia – estribos – déformation fissurée – EHE – beugels – Eurocódigo 3 – platine de bout – análisis dinámico – column base plate – kruip – rigid link – welded connection – charpente métallique – moment connections – estructuras 2D – kniestuk – assemblage métallique – 3D raamwerken – second ordre – beam grid – cargas climáticas – Eurocode 2 – Eurocode 5 – wall – deformación fisurada – lien rigide – enlace rígido – 2D frames – estructuras 3D – éléments finis – vloerplaat – steel connection – scheurvorming – integrated connection design – armatures pratiques – analyse sismique – nieve y viento – practical reinforcement – charges mobiles – dalle – wapening – perfiles conformados en frío – Eurocode 3 – connexion tubulaire – unión a momento – 3D frames – treillis de poutres – roof truss – practical reinforcement design – portique – kipsteunen – análisis sísmico – Eurocode 8 – seismic analysis – B.A.E.L 91 – uniones atornilladas – bolts – ossatures 2D – eindige elementen – losa de cimentación – restricciones para el pandeo lateral – optimisation – wand – kniklengtes – end plate – dakspanten – kolomvoetverbinding – stirrups – acier – staalcontrole – cálculo de uniones integrado – paroi – dessin du plan de ferraillage – stiffeners – mobiele lasten – Eurocódigo 8 – Eurocódigo 5 – longitudinal reinorcement – doorlopende liggers – rigidizador – beton armé – fluage – CTE – connexion pied de poteau – langswapening – connexions – hormigón – neige et vent – elementos finitos –

BuildSoft

Hundelgemsesteenweg 244-1
9820 Merelbeke (België)
T +32 (0)9 252 66 28
www.buildsoft.eu
support@buildsoft.eu

armaduras – cold formed steel – jarret – uittekenen wapening – puente grúa – analyse dynamique – flambement – keerwanden – optimisation – steel – cercha – 2º orden – slab on grade foundation – entramado de vigas – Eurocode 5 – prédimensionnement – multi span beam – bouten – armatures – floor slab – poutre continue – pared – staal – 1er ordre – NEN 6770-6771 – connexion cisaillement – losa – déversement – viga continua – predimensionering – 1ste orde – unión metálica – CM 66 – madera – análisis resistencia al fuego – verbindingen – 2nd order – bois – Eurocode 2 – profilés formés à froid – verificación acero – predesign – unión soldada – fisuración – beton – muro de contención – optimalisatie – foundation pads – fissuration – concrete – AISC-LRFD – HCSS – assemblage métallique – Eurocode 3 – viga con varios apoyos – armaduras prácticas – balkenroosters – unión a cortante – buckling length – boulons – cracking – Eurocode 8 – knik – Eurocode 2 – radier – eindplaat – Eurocódigo 2 – FEM – tornillos – NEN 6720 – moving loads – balk op meerdere steunpunten – cargas móviles – funderingsplaat – étriers – analye resistance au feu – cercha – unión a momento – 3D frames – treillis de poutres – brandweerstandsanalyse – eindige elementen – losa de cimentación – restricciones para el pandeo lateral – viento – practical reinforcement