

WORKING PROJECT 3

COMPUTATIONAL MECHANICS

**Master of Science in
Construction Engineering
and
Industrial Engineering**



1- Problem:

Calculate temperature evolution on steel IPE100 profile, when submitted to fire conditions, using the ISO834 nominal fire curve. Student should consider two different solution methods for a fire duration of 60 minutes:

- 1- Numerical solution(Ansys approach);
- 2- Simplified Eurocode lamped model solution (Eurocode approach).

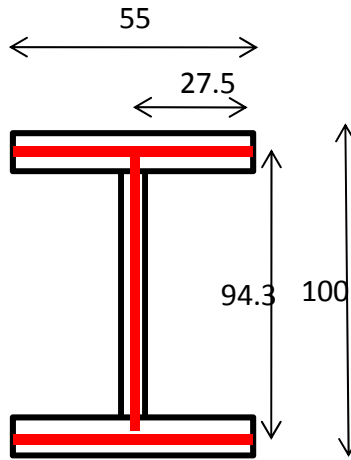


Figure 1 - Model dimension for IPE100.

The nominal fire curve is a conventional curve, adapted for classification or verification of fire resistance. For this working project, students should consider ISO834 standard fire curve, as represented in figure 2. With a nominal temperature-time curve, the temperature analysis of the structural members is made for a specified period of time, without any cooling phase.

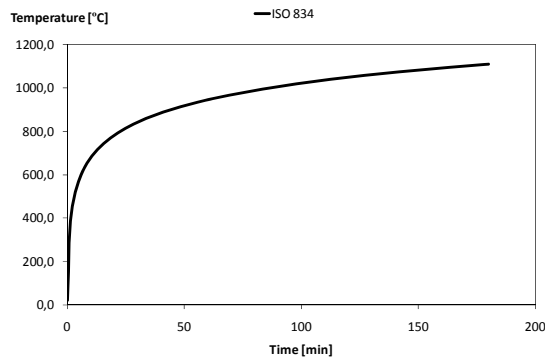


Figure 2 - Nominal fire curve (ISO834).

This curve presents the following formula, where "T_g" represents enclosure temperature [°C] and "t" represents time in [s], [1].

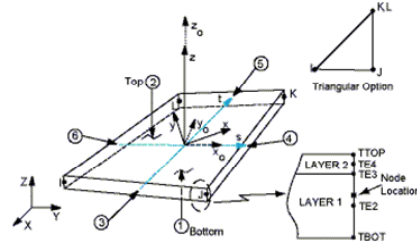
$$T_g = 20 + 345 \times \text{Log}\left(8 \times \frac{t}{60} + 1\right) \quad (1)$$

2- - Numerical solution (Ansys approach):

For the numerical simulation students should consider finite shell element SHELL131 to model this profile, adopting 4 elements for flanges and 4 elements for the web.

Shell131 is a 3-D layered shell element having in-plane and through-thickness thermal conduction capability. The element has four nodes, with up to 32 temperature degrees of freedom at each node. Usually one degree of freedom is associated with each node (temperature). The conducting shell element is applicable to a 3-D, transient thermal analysis. For this simulation, time should vary up to 3600 [s].

SHELL131 generates temperatures that can be passed to structural shell elements in order to apply thermo mechanical behaviour.



x_0 = element x-axis if ESYS is not supplied.

x = element x-axis if ESYS is supplied.

Figure 3 -Finite shell element Shell131 from ANSYS.

The KEY options for this element should consider to define option 2,3 4 and 6. For option 2 student may decide to evaluate film coefficient (if any) at fluid bulk temperature. This is not important because the convection coefficient is kept constant. For option 3 student should decide that there will not be temperature variation through layer, reason why the number of layers equal 1. For option 4 student may input a value to match SECDATA commands, or leave blank to default. For option 6 student must choose Thermal shell application, [3].

The properties of thermal conductivity and specific heat capacity of steel are dependent on steel temperature. This variation is in accordance to eurocode 3, [2].

The material properties that must be defined are: thermal conductivity, specific heat, emissivity and specific mass, for taking into account the solution of the following partial differential equation (PDE). All properties with the exception of the emissivity are explicitly defined in the next PDE. The material emissivity should be consider when defining the boundary conditions.

$$\left(\frac{\partial}{\partial x} \lambda_x \frac{\partial T}{\partial x} + \frac{\partial}{\partial y} \lambda_y \frac{\partial T}{\partial y} + \frac{\partial}{\partial z} \lambda_z \frac{\partial T}{\partial z} \right) = \rho C \frac{\partial T}{\partial t} \quad (2)$$

The variation of the thermal conductivity with temperature is represented in Figure 4.

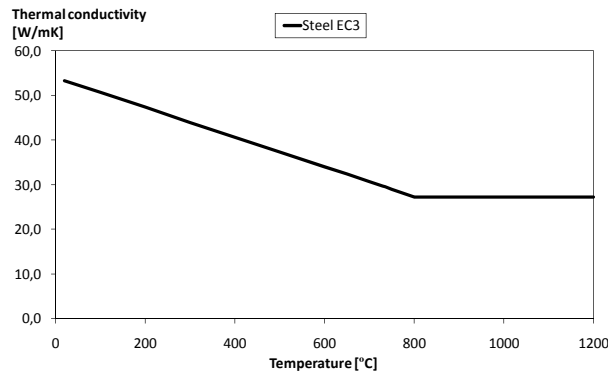


Figure 4 -Conductivity of steel.

Equation 2 represents the mathematical expression for this property, [2].

$$\lambda_a = 54 - 3.33 \left(\frac{\theta_a}{100} \right); \quad 20 < \theta_a \leq 800 [^{\circ}\text{C}] \quad (3)$$

$$\lambda_a = 27.3; \quad 800 < \theta_a \leq 1200 [^{\circ}\text{C}]$$

The variation of the specific heat with temperature is represented in figure 5. The pick value is a consequence of allotropic phase transformation, regarding the austenitic phase. Steel will require more heal flux to increase temperature, when it is between 700 and 800 [°C]. This is the reason why temperature evolution in steel is slowdown at this stage.

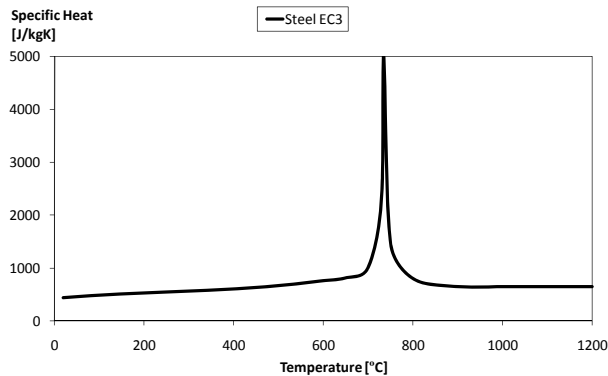


Figure 5 -Specific Heat of steel.

Equation 3, [2], represents the mathematical expression for this property.

$$C_a = 425 + 7.73 \times 10^{-1}(\theta_a) - 1.69 \times 10^{-3}(\theta_a)^2 + 2.22 \times 10^{-6}(\theta_a)^3; \quad 20 < \theta_a \leq 600[^\circ\text{C}]$$

$$C_a = 666 - \left[\frac{13000}{\theta_a - 738} \right]; \quad 600 < \theta_a \leq 735[^\circ\text{C}]$$

$$C_a = 545 + \left[\frac{17820}{\theta_a - 731} \right]; \quad 735 < \theta_a \leq 900[^\circ\text{C}]$$

$$C_a = 650; \quad 900 < \theta_a \leq 1200[^\circ\text{C}]$$
(4)

Students should introduce material properties with temperature dependence as table data points, as represented in next table data.

Table 1 - Conductivity and Specific heat dependence on temperature.

T	20	100	200	300	400	500	600	650	700	730	735	750	800	900	1000	1100	1200
Kx	53.3	50.7	47.3	44.0	40.7	37.4	34.0	32.4	30.7	29.7	29.5	29.0	27.3	27.3	27.3	27.3	27.3
Cp	439.8018	487.62	529.76	564.74	605.88	666.5	760.2174	813.75	1008.158	2291.25	5000	1482.895	803.2609	650	650	650	650

The specific mass (mass to volume ratio) should be consider constant and equal to 7850 [kg/m³] and the emissivity for this material should be equal to 0.7.

According to the eurocode, [1], two methods of heat transfer should be consider to simulate fire. The convection and radiation methods. For the first mode of heat transfer the convection coefficient, α_c , may be consider equal to 25 [W/m²K], when this nominal curve is considered.

For hydrocarbon nominal curve a different convection coefficient should be consider.

For the second mode of heat transfer, the view factor, ϕ , may be consider equal to unit or may be calculated. The emissivity represents the ratio between the radiative heat absorbed by steel and that of a black body surface. The value of 0.7 should be appropriate for ϵ_m , [2]. A different value should be considered for stainless steel. The Stefan Boltzmann constant, σ , should be considered equal to 5.67E-8 [W/m²K⁴]. The emissivity of the fire, ϵ_f , is taken in general equal to 1 (enclosure), [2].

The net convective heat flux component and the net radiative heat flux component per unit of surface area may be calculated according to next equation, [1].

$$\dot{h}_{net,c} = \alpha_c (\theta_g - \theta_m) \quad [W / m^2]$$

$$\dot{h}_{net,r} = \phi \times \epsilon_m \times \epsilon_f \times \sigma [(\theta_r + 273)^4 - (\theta_m + 273)^4] \quad [W / m^2]$$
(5)

The ISO834 temperature curve may be defined using the GUI (Graphical user interface) with the "parameter" menu or introducing the corresponding command lines, represented in the next table. With this last method, students may "copy" and "past" all the information lines at once, using a text editor.

Table 2 - Temperature function defined as a table input parameter.

ISO834
*DIM,ISO834,TABLE,181,1,1,,,
*SET,ISO834(1,0,1),0,1,1,,,
*SET,ISO834(1,1,1),20,1,1,,,
...
*SET,ISO834(181,0,1),10800,1,1,,,
*SET,ISO834(181,1,1),1109.7,1,1,,,

The boundary conditions should be introduced in ANSYS according to:

- Define nodal temperature for enclosure, eg node "777", using ISO823 nominal curve.
- Define radiation options: Stefan Boltzmann constant, Temperature OFFSET, Space NODE and temperature value, Enclosure identification number "1".
- Define initial boundary condition. All nodal temperatures from element should be equal to 20[°C] for time equal to zero.
- Define convective boundary conditions, based on a constant convection coefficient (25) and a variable bulk temperature following table ISO834. Student must select the adequate face of each element that is subjected to convection. Face 1 and 2 applies for all finite elements, while the other faces regarding the tips of flanges must be carefully select based on element coordinate system, see figure 3.
- Define radiative boundary conditions. Face 1 and Face 2 (only faces that can support radiation) from all finite elements must apply for this kind of boundary condition. Student must introduce this loading on element face by command line, using table 3. The first command line defines for element surface 1 emissivity of fire (equal to 1) and the second command line defines radiation enclosure number identification (equal to 1).

Table 3 - Ansys Command to apply radiation on surface elements.

Radiation for face 1 and face 2
SFE,ALL,1,RDSF,1,1
SFE,ALL,1,RDSF,2,1
SFE,ALL,2,RDSF,1,1
SFE,ALL,2,RDSF,2,1

Finally and to initiate the solution phase, student must define the analysis type (transient), solution method (full), and the solution control. Student should verify the adequate time increment for this non linear solution. The proposed solution control is define on table 4.

Table 4 - Solution controls.

Time Control	Value [s]
Time at the end of loadstep	3600
Time step size	60
Minimum step size	60
Maximum step size	60

3- Simplified Eurocode solution method (Analytical approach)

For an equivalent uniform temperature distribution in the cross-section, the increase of temperature, $\Delta\theta_{a,t}$, in an unprotected steel member may be determined using the following equation.

$$\Delta\theta_{a,t} = K_{sh} \frac{A_m/V}{c_a \rho_a} \dot{h}_{net,d} \Delta t \quad (6)$$

Δt represents time increment and should not be taken as more than 5 seconds, [2]. The section factor A_m/V represents the ration between the expose surface area to element volume (represented also by the ratio perimeter /cross section area) and depends on the section massivity, which in this case equals 387 [m-1].

The design value of the net heat flux per unit area, $\dot{h}_{net,d}$, should be calculated based on convection and radiation net fluxes.

$$\dot{h}_{net,d} = \Phi \sigma \varepsilon_m \varepsilon_f (T_g^4 - T_L^4) + \alpha (T_g - T_L) \quad (7)$$

The correction factor for the shadow effect, K_{sh} , may be used for I- section types according to next equation, otherwise ignoring would lead to conservative solutions. For cross sections with a convex shape (e.g. rectangular or circular hollow sections) fully embedded in fire, the shadow effect does not play role and consequently the correction factor, K_{sh} , equals unity.

$$k_{sh} = 0.9 \times \frac{[Am/V]_{box}}{[Am/V]} \quad (8)$$

$[Am/V]_{box}$ represents the box value of the section factor.

4- Final statement:

Students are invited to present their work on standard report format (Word), until 2 weeks after receiving this working project. Students are invited to present the main conclusions in next class, after delivering the report, using power point slides. The time schedule for each presentation is 15 minutes.

References:

- [1] - CEN; EN 1993-1-2; Eurocode 1, Actions on structures - Part 1-2: General actions -Actions on structures exposed to fire, November 2002.
- [2] - CEN; EN 1993-1-2; Eurocode 3, Design of steel structures - Part 1-2: General rules - Structural fire design, April 2005
- [3] - ANSYS® Academic Research, Release 12, Help System, Element reference, ANSYS, Inc.