WP6 – DEVELOPMENT OF USER-FRIENDLY SOFTWARE TO APPLY SIMPLE DESIGN RULES

TECHNICAL SPECIFICATION FOR THE COMPUTER PROGRAM "FIDESC4"

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This document describes the technical specifications for the software FIDESC4 which has been developed for the evaluation of the critical temperature and the verification of the fire resistance of cross-sections or structural elements, following to the simple calculation models of EN 1993-1-2. For the case of class 4 cross-sections the software has been developed in accordance with Annex E of EN 1993-1-2. Additionally, class 4 effective cross-section and Lateral Torsional Buckling calculations are based on the new approaches developed in the framework of the project FIDESC4. For the cases not covered by EN 1993-1-2, EN 1993-1-1 and EN 1993-1-5 have been used.

The software was developed using Visual Basic and is fully compatible with Windows standards.

1 Minimum requirements

FIDESC4 was optimized to run on the following Operating Systems:

- Windows XP (with the appropriate Microsoft .NET framework installed);
- Windows Vista;
- Windows 7.

Installation will require 25Mb of free disk space.

2 Brief description of the software

2.1 General

FIDESC4 calculates the critical temperature or checks the fire resistance of cross-sections and steel members loaded about the strong axis or about the weak axis for the case of doubly symmetric cross-sections.

The software has two modules: one dealing with the fire resistance of the cross-sections and the other with fire resistance of members (columns, beams and beam-columns), as shown in Figure 2.1.

Figure 2.1: Main menu

The software evaluates the critical temperature considering the resistance of cross-sections subjected to:

i) Axial force (tension or compression);

ii) Shear;

iii) Bending (Bi-axial bending);

iv) Bending and axial force (tension or compression);

Regarding the fire resistance of structural members, the software verifies the buckling resistance of the members submitted to:

i) Compression;

ii) Bending;

iii) Bending and compression.

The user can choose the section type of the profile. Typical cross-sectional shapes include: HD, HE, HL, HP, IPE, UB, UC, W, L, RHS, CHS from a database. User-defined dimensions can be included (hot rolled, welded (see Figure 2.2).

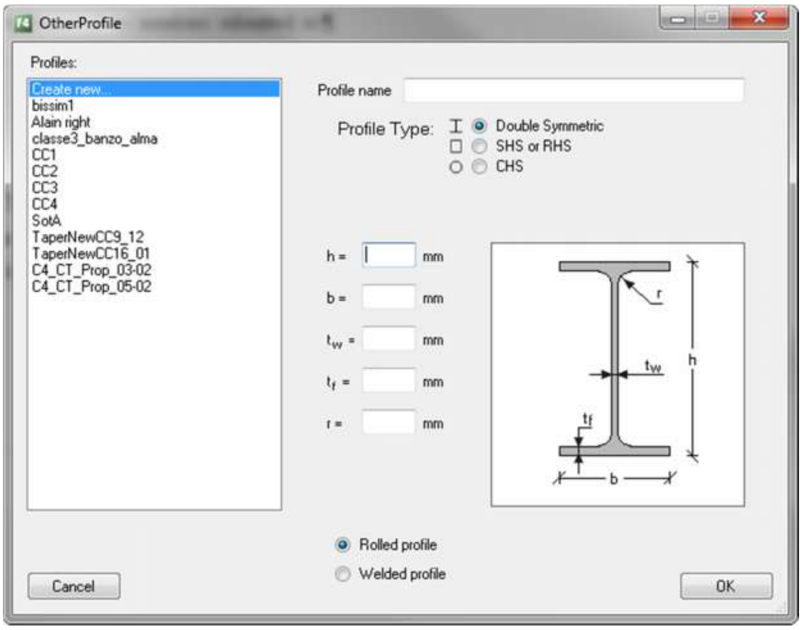
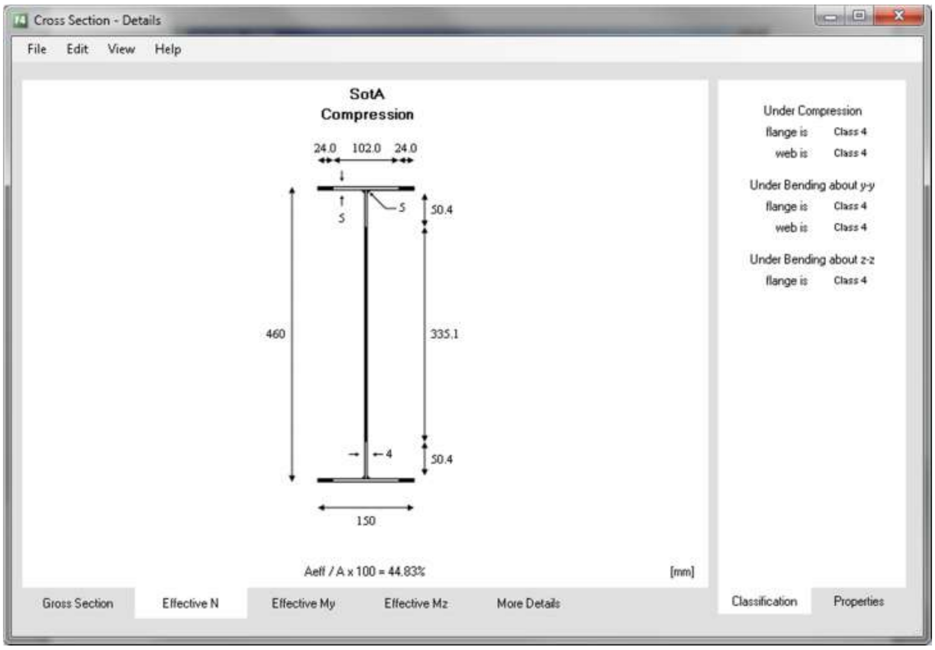
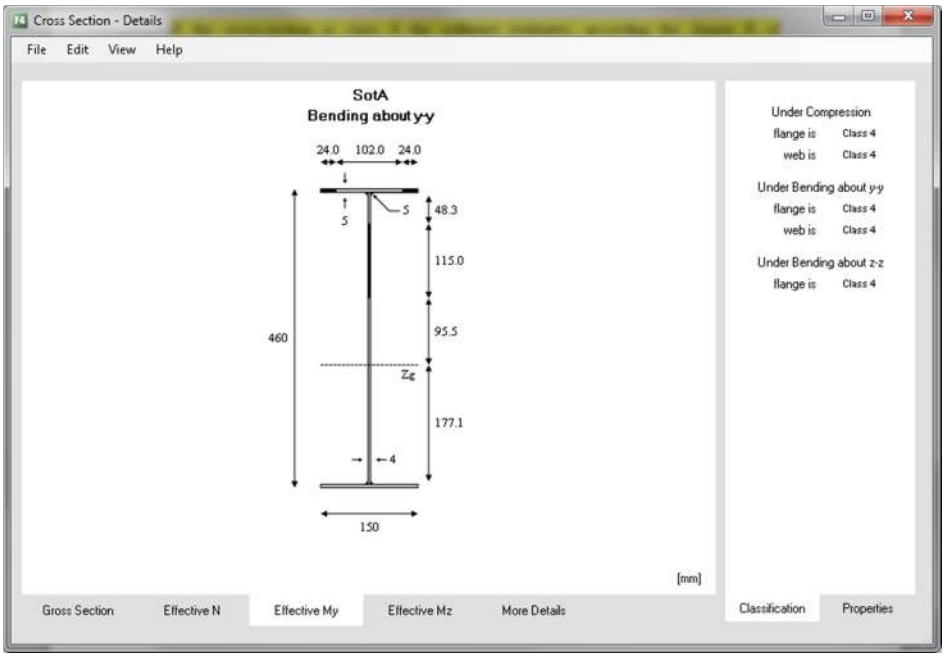


Figure 2.2: Dialog box for user-defined double symmetric sections

If the cross-section is class 4, the software evaluates its effective cross-section, as shown in Figure 2.3, according the new method developed in the framework of the project FIDESC4.



a)



b)

Figure 2.3: Effective cross-section: a) under axial compression, b) under bending about major axis

2.2 Adopted methodologies

For each load case the software evaluates the critical temperature (Option A) or, giving a specific temperature, the software verifies the fire resistance or gives the resistance depending on the type of loading (Option B). Figure 2.4 and Figure 2.5 show these two types of calculations.

2.2.1 Critical temperature

For the evaluation of the critical temperature, the software uses an incremental procedure starting with a temperature of 20 ºC and using a increment of $\Delta\theta = 0.1$ ºC until the design value of the fire resistance, $R_{fi,d,t}$ is equal to the design value of the effect of the actions in fire situation, $E_{fi,d}$ (see Figure 2.4):

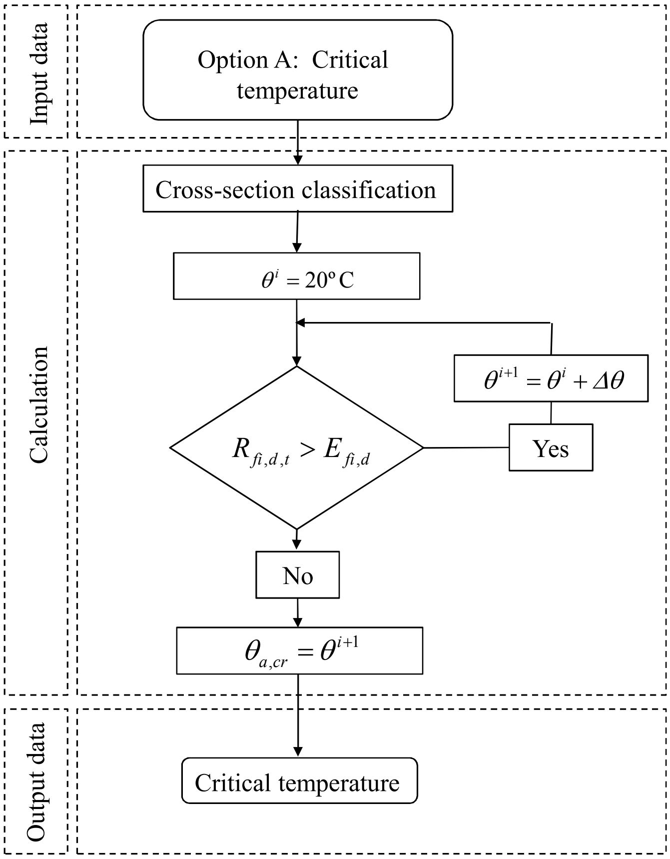


Figure 2.4: Option A: Calculation flowchart for evaluating the critical temperature

2.2.2 Fire resistance

For the evaluation of the design value of the fire resistance or for the verification of the fire resistance at a given temperature, the user introduces a temperature and the software checks the fire resistance of the cross-section or the structural element (see Figure 2.5).

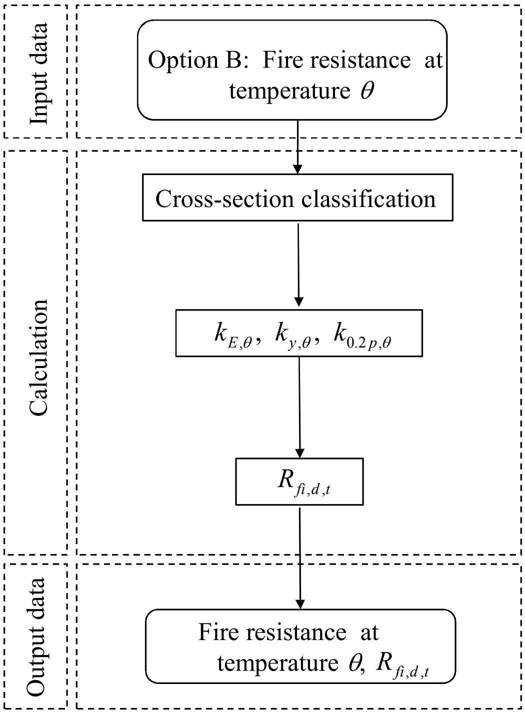


Figure 2.5: Option B: Calculation flowchart for checking the fire resistance

2.2.3 Effective class 4 cross-section

The calculation of class 4 effective cross-sections is based on the new approach developed in the framework of the project FIDESC4.

According to this methodology, new expressions for the plate reduction factor (ρ) were developed in order to replace the use of the design yield strength corresponding to the 0.2% proof strength ($f_{0.2p,\theta}$) with the stress for 2% total strain ($f_{y,\theta}$).

For internal compression elements, the following expression is used:

$$\rho = \frac{\left(\overline{\lambda}_p + 0.9 - \dfrac{0.26}{\varepsilon}\right)^{1.5} - 0.055(3+\psi)}{\left(\overline{\lambda}_p + 0.9 - \dfrac{0.26}{\varepsilon}\right)^{3}} \leq 1.0 \qquad (2.1)$$

And for outstand compression elements:

$$\rho = \frac{\left(\overline{\lambda}_p + 1.1 - \dfrac{0.52}{\varepsilon}\right)^{1.2} - 0.188}{\left(\overline{\lambda}_p + 1.1 - \dfrac{0.52}{\varepsilon}\right)^{2.4}} \leq 1.0 \qquad (2.2)$$

Where

$\varepsilon = \sqrt{235 / f_y}$

2.3 Detailed description of the software

In this section a detailed description of the capabilities of the software will be given showing the correspondent screens.

2.3.1 Resistance of the cross-section

In this section, the implemented calculations for the evaluation of the critical temperature of cross-section as well as its fire resistance will be shown.

2.3.1.1 Tension

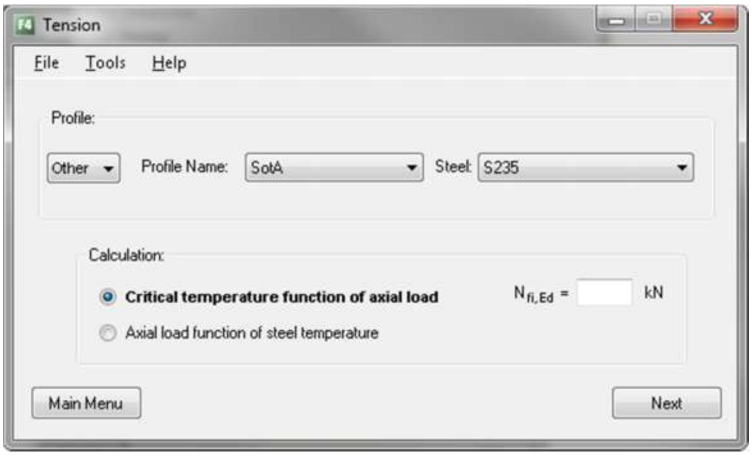
2.3.1.1.1 Formula used

The formulae used are the same as in EN 1993-1-2.

2.3.1.1.2 Software interface

The following screens deal with cross-sections and members subjected to tension. They are shown in Figure 2.6.

a)



b)

Figure 2.6: Screens used to deal with cross-sections subjected to tension. a) Main menu; b) Screen for choosing the type of calculation

2.3.1.2 Compression

2.3.1.2.1 Formulae used

The design resistance $N_{c,fi,t,Rd}$ at time *t* of class 4 cross-section subject to compression with a uniform temperature θ should be determined from:

$$N_{c,fi,t,Rd} = A_{eff} k_{y,\theta} f_y / \gamma_{M,fi} \tag{2.3}$$

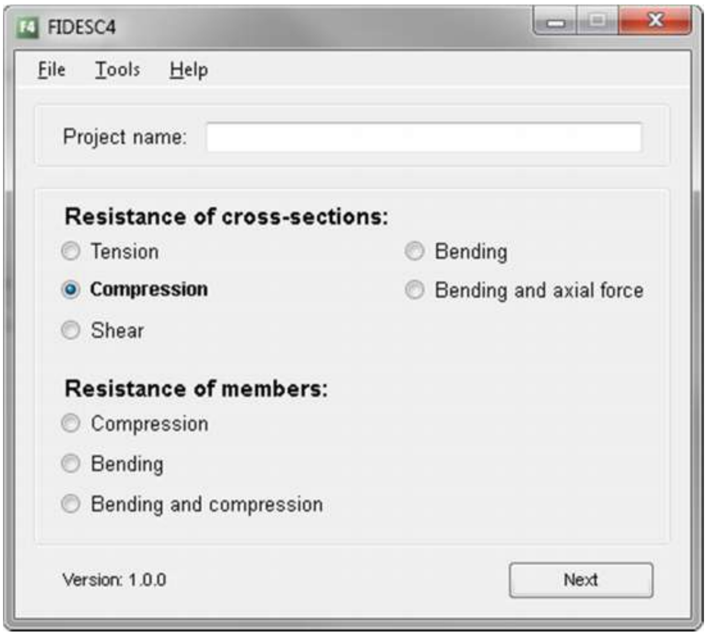
Where

A_{eff} is the effective area of the cross-section when subjected only to uniform compression;

$k_{y,\theta}$ is the reduction factor for the 2% proof strength of steel at uniform temperature θ, reached at time *t*.

2.3.1.2.2 Software interface

The screens used to deal with cross-sections subjected to compression are shown in Figure 2.7.



a)

b)

Figure 2.7: Screens used to deal with cross-sections subjected to compression: a) Main menu, b) Screen for choosing the type of calculation

2.3.1.3 Shear

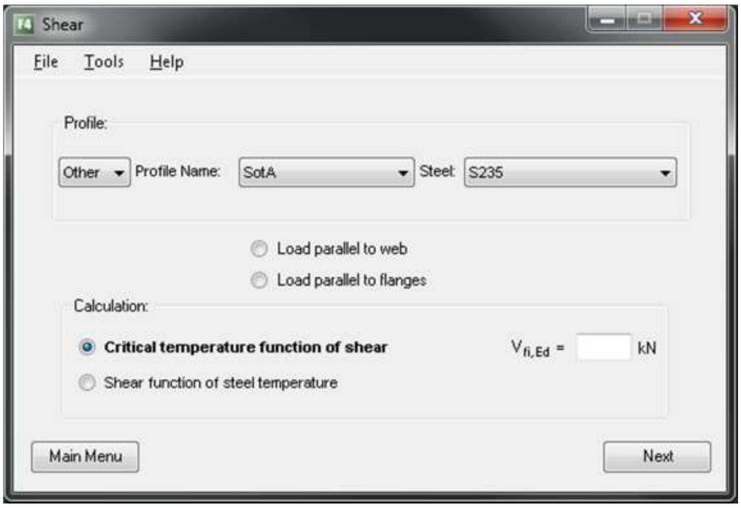
2.3.1.3.1 Formulae used

The formulae used are the same as in EN 1993-1-2.

2.3.1.3.2 Software interface

The screens shows the menu for cross-section subjected to shear, as shown in Figure 2.8.

a)



b)

Figure 2.8: Screens used to deal with cross-sections subjected to shear: a) Main menu, b) Screen for choosing the type of calculation

2.3.1.4 Bending

2.3.1.4.1 Formulae used

The design moment resistance $M_{fi,t,Rd}$ of a class 4 cross-section with a uniform temperature θ should be determined from:

$$M_{fi,t,Rd} = W_{eff,\min} k_{y,\theta} f_y / \gamma_{M,fi} \tag{2.4}$$

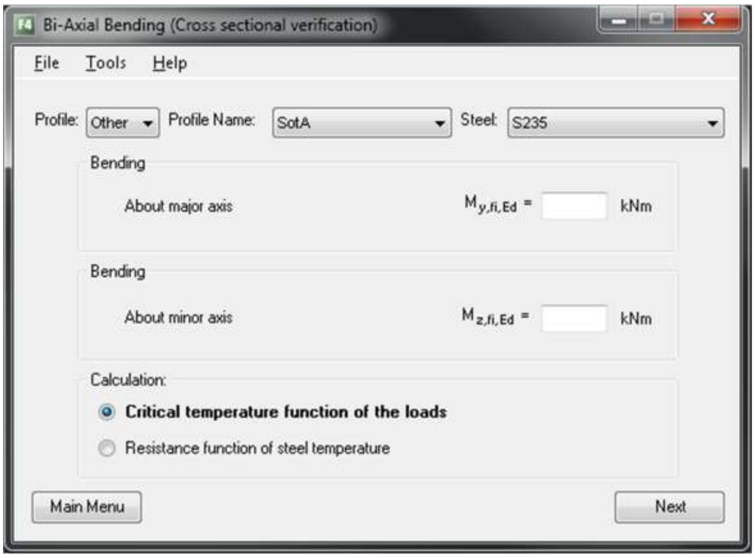
Where

$W_{eff,\min}$ is the effective section modulus (corresponding to the fibre with the maximum elastic stress) of the cross-section when subjected only to moment about the relevant axis.

2.3.1.4.2 Software interface

The following figures illustrate the screens for cross-sections subjected to bending (Figure 2.9).

a)



b)

Figure 2.9: Screens used to deal with cross-sections subjected to bending: a) Main menu, b) Screen for choosing the type of calculation

2.3.1.5 Bending and axial force

2.3.1.5.1 Formulae used

The design resistance at time *t* for a class 4 cross-section subject to combined bending and axial compression should be verified by satisfying the following expression:

$$\frac{N_{fi,Ed}}{A_{eff}\, k_{y,\theta}\, \dfrac{f_y}{\gamma_{M,fi}}} + \frac{M_{y,fi,Ed}}{W_{eff,y,\min}\, k_{y,\theta}\, \dfrac{f_y}{\gamma_{M,fi}}} + \frac{M_{z,fi,Ed}}{W_{eff,z,\min}\, k_{y,\theta}\, \dfrac{f_y}{\gamma_{M,fi}}} \leq 1 \qquad (2.5)$$

Where

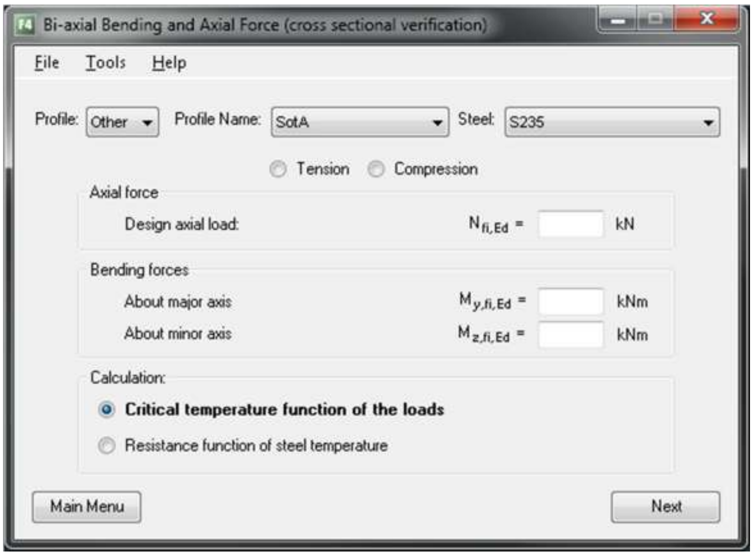
A_{eff} is the effective area of the cross-section when subjected to uniform compression;

$W_{eff,y,\min}$ is the effective section modulus (corresponding to the fibre with the maximum elastic stress) of the cross-section when subjected only to moment about the relevant axis.

2.3.1.5.2 Software interface

Figure 2.10 shows the screens used to deal with cross-sections subjected to bending axial force.

a)



b)

Figure 2.10: Screens used to deal with cross-sections subjected to bending and axial force: a) Main menu, b) Screen for choosing the type of calculation

2.3.2 Resistance of members

This section provides detailed specifications regarding the fire design of columns submitted to flexural buckling, beams submitted to lateral-torsional buckling (LTB) and buckling of beam-columns submitted or not to LTB.

2.3.2.1 Compression

2.3.2.1.1 Formulae used

The design buckling resistance $N_{b,fi,t,Rd}$ at time *t* of a compression member with a class 4 cross-section with a uniform temperature θ_a should be determined from:

$$N_{b,fi,t,Rd} = \chi_{fi} A_{eff} k_{y,\theta} f_y / \gamma_{M,fi} \tag{2.6}$$

Where

χ_{fi} is the reduction factor for flexural buckling in the fire design situation, given by Eq. (2.7).

The value of χ_{fi} should be taken as the lower of the values of $\chi_{y,fi}$ and $\chi_{z,fi}$ determined according to:

$$\chi_{fi} = \frac{1}{\phi_\theta + \sqrt{\phi_\theta^{\ 2} - \bar{\lambda}_\theta^{\ 2}}} \tag{2.7}$$

Where

$$\phi_\theta = \frac{1}{2}\left[1 + \alpha\bar{\lambda}_\theta + \bar{\lambda}_\theta^{\ 2}\right] \tag{2.8}$$

And the imperfection factor α is given by

$$\alpha = 0.65\sqrt{235 / f_y} \tag{2.9}$$

The non-dimensional slenderness $\bar{\lambda}_\theta$ for the temperature θ, is given by:

$$\bar{\lambda}_\theta = \bar{\lambda}\sqrt{k_{y,\theta} / k_{E,\theta}} \tag{2.10}$$

Where

$\bar{\lambda}$ is the non-dimensional slenderness at room temperature given by Eq. (2.11) using the buckling length in fire situation l_{fi}.

$k_{E,\theta}$ is the reduction factor for the slope of the linear elastic range at the steel temperature θ ,reached at time *t*.

The non-dimensional slenderness at room temperature $\bar{\lambda}$ is given by:

$$\bar{\lambda} = \sqrt{\frac{A_{eff} f_y}{N_{cr}}} \tag{2.11}$$

Where

N_{cr} is the elastic critical force for the flexural buckling based on the gross cross sectional properties, the buckling length in fire situation, l_{fi}, and the steel properties at 20 ºC.

$$N_{cr} = \frac{\pi^2 EI}{l_{fi}^{\ 2}} \tag{2.12}$$

Where

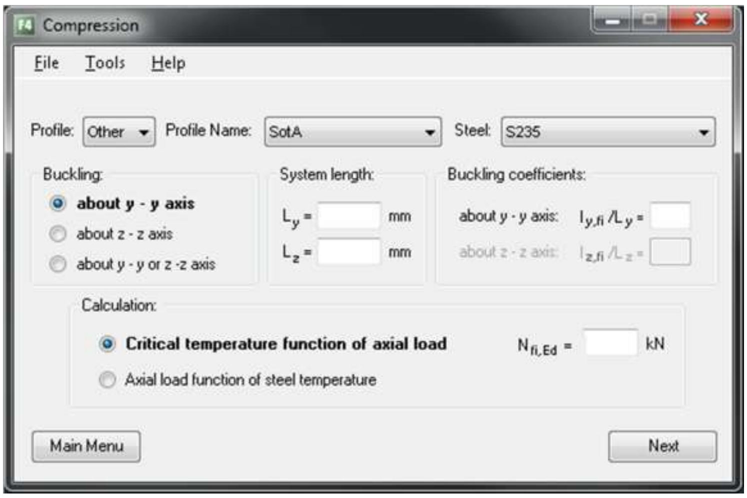
E is the Young's modulus at room temperature;

I is second moment of area about y-y or x-x axis based on the gross cross sectional properties.

2.3.2.1.2 Software interface

Figure 2.11 shows the screens used to deal with columns subjected to flexural buckling.

a)



b)

Figure 2.11: Screens used to deal with columns: a) Main menu, b) Screen for introducing the buckling lengths and choosing the type of calculation

2.3.2.2 Bending

2.3.2.2.1 Formulae used

The design lateral-torsional buckling resistance moment $M_{b,fi,t,Rd}$ at time t for a laterally unrestrained beam with a class 4 cross-section is determined from:

$$M_{b,fi,t,Rd} = \chi_{LT,fi} W_{eff,y,\min} k_{y,\theta} f_y / \gamma_{M,fi} \tag{2.13}$$

Where

$\chi_{LT,fi}$ is the reduction factor for lateral-torsional buckling in the fire design situation;

The value of $\chi_{LT,fi}$ should be determined according the new approach developed in the framework of the project FIDESC4, as shown below:

$$\chi_{LT,fi} = \frac{1}{\phi_{LT,\theta} + \sqrt{[\phi_{LT,\theta}]^2 - [\lambda_{LT,\theta}]^2}} \tag{2.14}$$

With

$$\phi_{LT,\theta} = \frac{1}{2}\left[1 + \alpha_{LT}(\bar{\lambda}_{LT,\theta} - 0.2) + \bar{\lambda}_{LT,\theta}^{\ 2}\right] \tag{2.15}$$

And the imperfection factor α_{LT} is calculated according to Table 2.1:

Curve	Limits	α_{LT}
L1	$\frac{W_{eff,y}}{W_{el,y}} > 0.9$	1.25ε
L2	$0.8 < \frac{W_{eff,y}}{W_{el,y}} \le 0.9$	1.00ε
L3	$\frac{W_{eff,y}}{W_{el,y}} \le 0.8$	0.75ε

Table 2.1: Imperfection factor.

And

$$\bar{\lambda}_{LT,\theta} = \bar{\lambda}_{LT}\sqrt{k_{y,\theta} / k_{E,\theta}} \tag{2.16}$$

Where the non-dimensional slenderness at normal temperature is given by:

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_{eff,y,\min} f_y}{M_{cr}}} \tag{2.17}$$

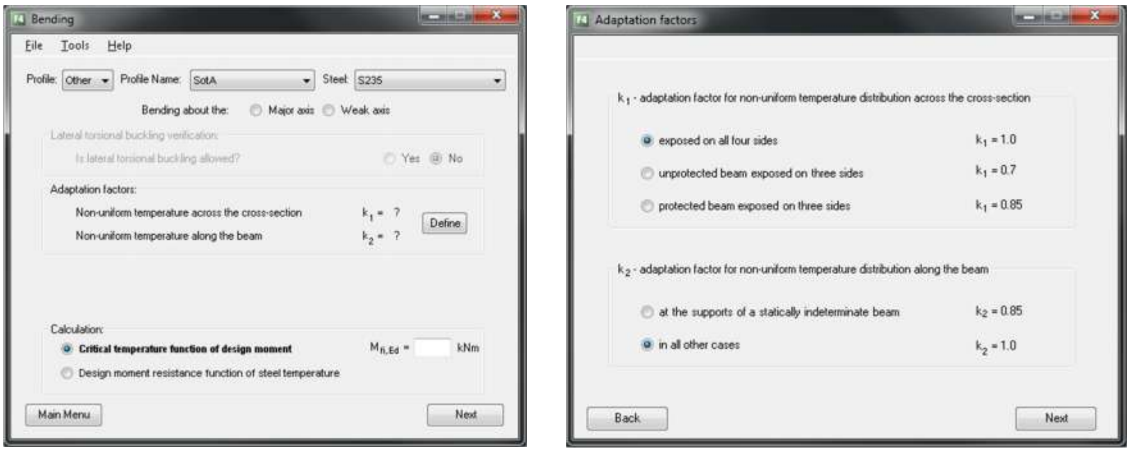
And

M_{cr} is the elastic critical moment for lateral-torsional buckling based on the gross cross sectional properties, and the steel properties at 20 ºC.

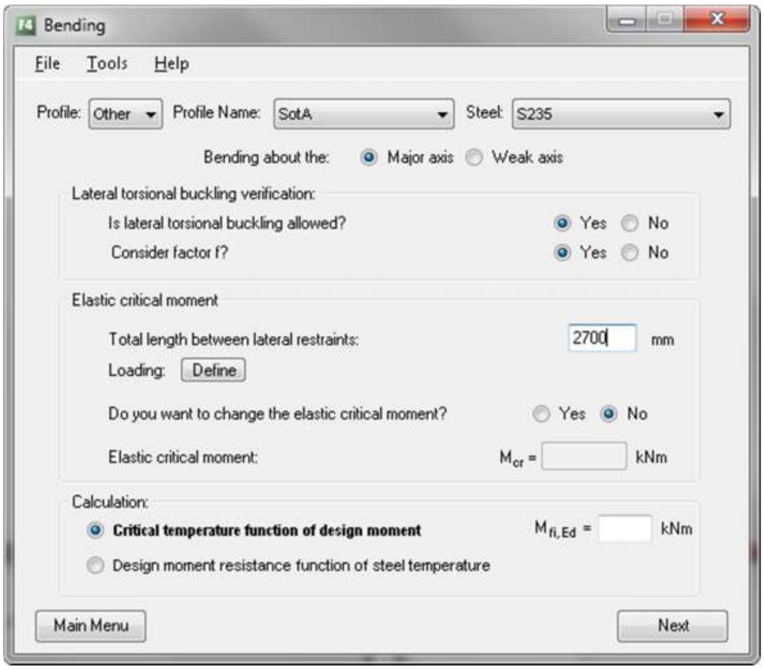
2.3.2.2.2 Software interface

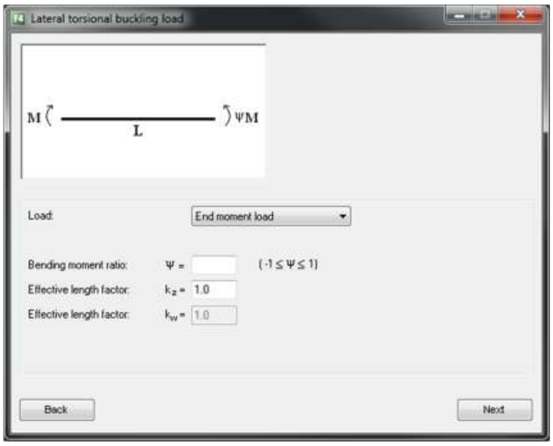
Figure 2.12 shows the screens used to deal with beams subjected or not to Lateral-Torsional Buckling.

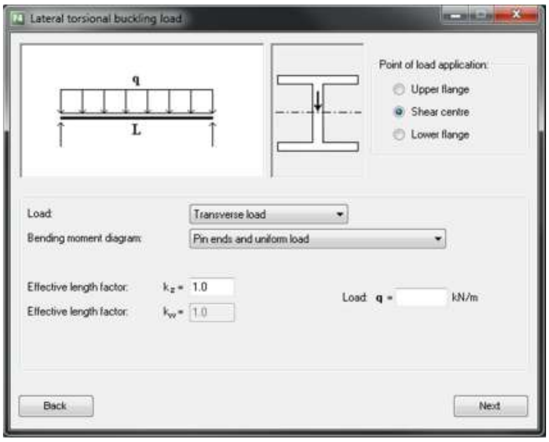
a)

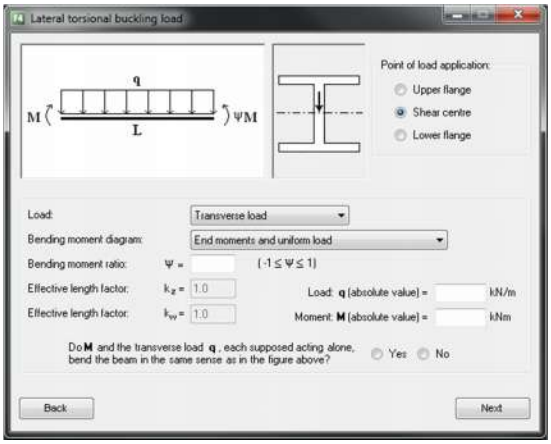


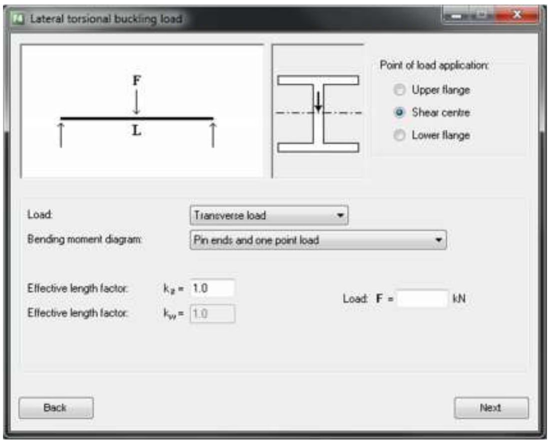
b)

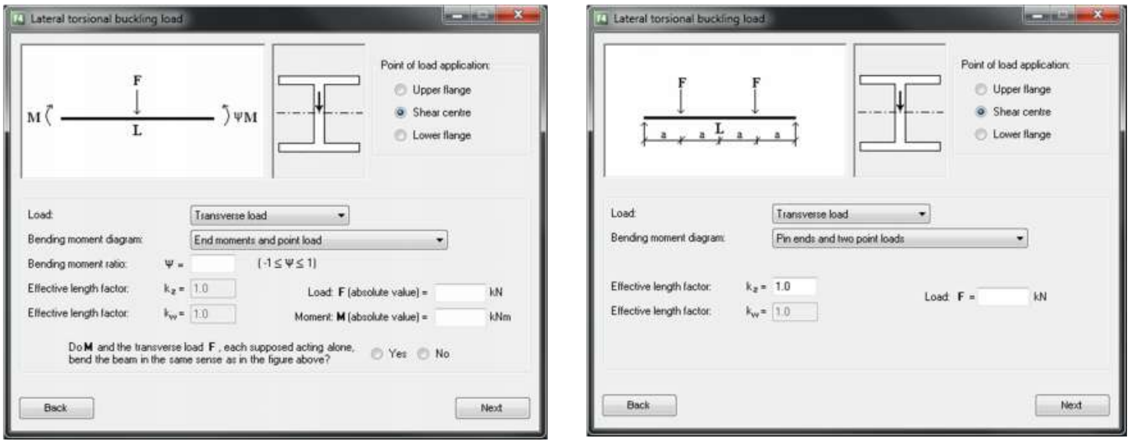

Bending
File Tools Help
Profile: Other Profile Name: SotA Steel: S235
Bending about the: Major axis Weak axis
Lateral torsional buckling verification:
Is lateral torsional buckling allowed? Yes No
Consider factor f? Yes No
Elastic critical moment
Total length between lateral restraints: 2700 mm
Loading: Define
Do you want to change the elastic critical moment? Yes No
Elastic critical moment: M_cr = kNm
Calculation:
Critical temperature function of design moment M_fi,Ed = kNm
Design moment resistance function of steel temperature
Main Menu
Next


Lateral torsional buckling load
M
L
ΨM
Load: End moment load
Bending moment ratio: Ψ = (-1 ≤ Ψ ≤ 1)
Effective length factor: k_z = 1.0
Effective length factor: k_w = 1.0
Back
Next


Lateral torsional buckling load
q
L
Point of load application:
Upper flange
Shear centre
Lower flange
Load: Transverse load
Bending moment diagram: Pin ends and uniform load
Effective length factor: k_z = 1.0
Effective length factor: k_w = 1.0
Load: q = kN/m
Back
Next


Lateral torsional buckling load
q
M
L
ΨM
Point of load application:
Upper flange
Shear centre
Lower flange
Load: Transverse load
Bending moment diagram: End moments and uniform load
Bending moment ratio: Ψ = (-1 ≤ Ψ ≤ 1)
Effective length factor: k_z = 1.0
Effective length factor: k_w = 1.0
Load: q (absolute value) = kN/m
Moment: M (absolute value) = kNm
Do M and the transverse load q, each supposed acting alone, bend the beam in the same sense as in the figure above? Yes No
Back
Next


Lateral torsional buckling load
F
L
Point of load application:
Upper flange
Shear centre
Lower flange
Load: Transverse load
Bending moment diagram: Pin ends and one point load
Effective length factor: k_z = 1.0
Effective length factor: k_w = 1.0
Load: F = kN
Back
Next



c)

Figure 2.12: Screens used to deal with beams: a) Main menu, b) Screen for the case where LTB does not occur and non-uniform temperature is considered, c) Load types for the evaluation of the elastic critical moments

2.3.2.3 Bending and compression

2.3.2.3.1 Formulae used

The design buckling resistance at time *t* for a member with a class 4 cross-section subject to combined bending and axial compression should be verified by satisfying expressions (2.18) and (2.19).

$$\frac{N_{fi,Ed}}{\chi_{\min,fi}\ A_{eff}\ k_{y,\theta}\ \dfrac{f_y}{\gamma_{M,fi}}}+\frac{k_y\ M_{y,fi,Ed}}{W_{eff,y,\min}\ k_{y,\theta}\ \dfrac{f_y}{\gamma_{M,fi}}}+\frac{k_z\ M_{z,fi,Ed}}{W_{eff,z,\min}\ k_{y,\theta}\ \dfrac{f_y}{\gamma_{M,fi}}}\leq 1 \qquad (2.18)$$

$$\frac{N_{fi,Ed}}{\chi_{z,fi}\ A_{eff}\ k_{y,\theta}\ \dfrac{f_y}{\gamma_{M,fi}}}+\frac{k_{LT}\ M_{y,fi,Ed}}{\chi_{LT,fi}\ W_{eff,y,\min}\ k_{y,\theta}\ \dfrac{f_y}{\gamma_{M,fi}}}+\frac{k_z\ M_{z,fi,Ed}}{W_{eff,z,\min}\ k_{y,\theta}\ \dfrac{f_y}{\gamma_{M,fi}}}\leq 1 \qquad (2.19)$$

Where

$\chi_{\min,fi}$ should be taken as the lower of the values of $\chi_{y,fi}$ and $\chi_{z,fi}$ determined according to Eq. (2.7);

$\chi_{LT,fi}$ is as defined in Eq. (2.14), according to the approach developed in the framework of the project FIDESC4;

And

$$k_y = 1-\frac{\mu_y N_{fi,Ed}}{\chi_{y,fi}\ A\ k_{y,\theta}\ \dfrac{f_y}{\gamma_{M,fi}}}\leq 3 \qquad (2.20)$$

With

$$\mu_y = \left(2\beta_{M,y} - 5\right)\bar{\lambda}_{y,\theta} + 0.44\beta_{M,y} + 0.29 \leq 0.2 \text{ with } \bar{\lambda}_{y,20°C} \leq 1.1 \tag{2.21}$$

And

$$k_z = 1 - \frac{\mu_z N_{fi,Ed}}{\chi_{z,fi}\, A\, k_{y,\theta}\, \dfrac{f_y}{\gamma_{M,fi}}} \leq 3 \tag{2.22}$$

With

$$\mu_z = \left(1.2\beta_{M,z} - 3\right)\bar{\lambda}_{z,\theta} + 0.71\beta_{M,z} - 0.29 \leq 0.8 \tag{2.23}$$

And

$$k_{LT} = 1 - \frac{\mu_{LT}\, N_{fi,Ed}}{\chi_{z,fi}\, A\, k_{y,\theta}\, \dfrac{f_y}{\gamma_{M,fi}}} \leq 1 \tag{2.24}$$

With

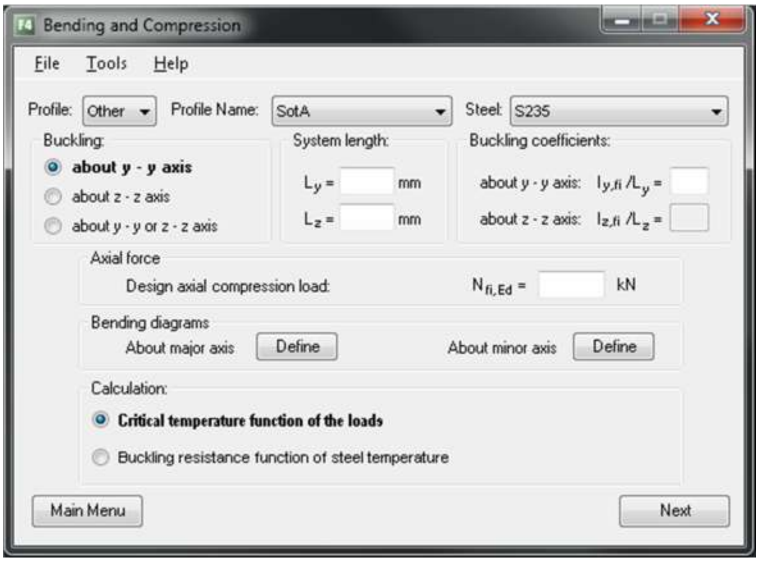
$$\mu_{LT} = 0.15\bar{\lambda}_{z,\theta}\ \beta_{M.LT} - 0.15 \leq 0.9 \tag{2.25}$$

For the equivalent uniform moment factors $\beta_{M,y}$, $\beta_{M,z}$ and $\beta_{M,LT}$ (this last one evaluated using the bending diagram of $M_{y,fi,Ed}$), see Figure 4.2 from EN 1993-1-2.

2.3.2.3.2 Software interface

The following screen illustrates the fir resistance of beam-columns and possible corresponding load cases, see Figure 2.13:

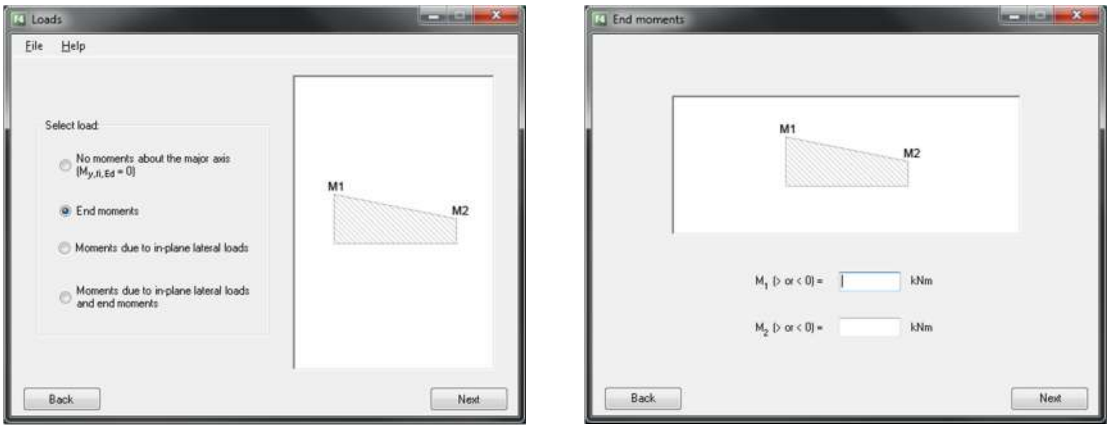
a)


Bending and Compression
File Tools Help
Profile: Other
Profile Name: SotA
Steel: S235
Buckling:
about y - y axis
about z - z axis
about y - y or z - z axis
System length:
Ly = mm
Lz = mm
Buckling coefficients:
about y - y axis: ly,fi /Ly =
about z - z axis: lz,fi /Lz =
Axial force
Design axial compression load:
Nfi,Ed = kN
Bending diagrams
About major axis Define
About minor axis Define
Calculation:
Critical temperature function of the loads
Buckling resistance function of steel temperature
Main Menu
Next

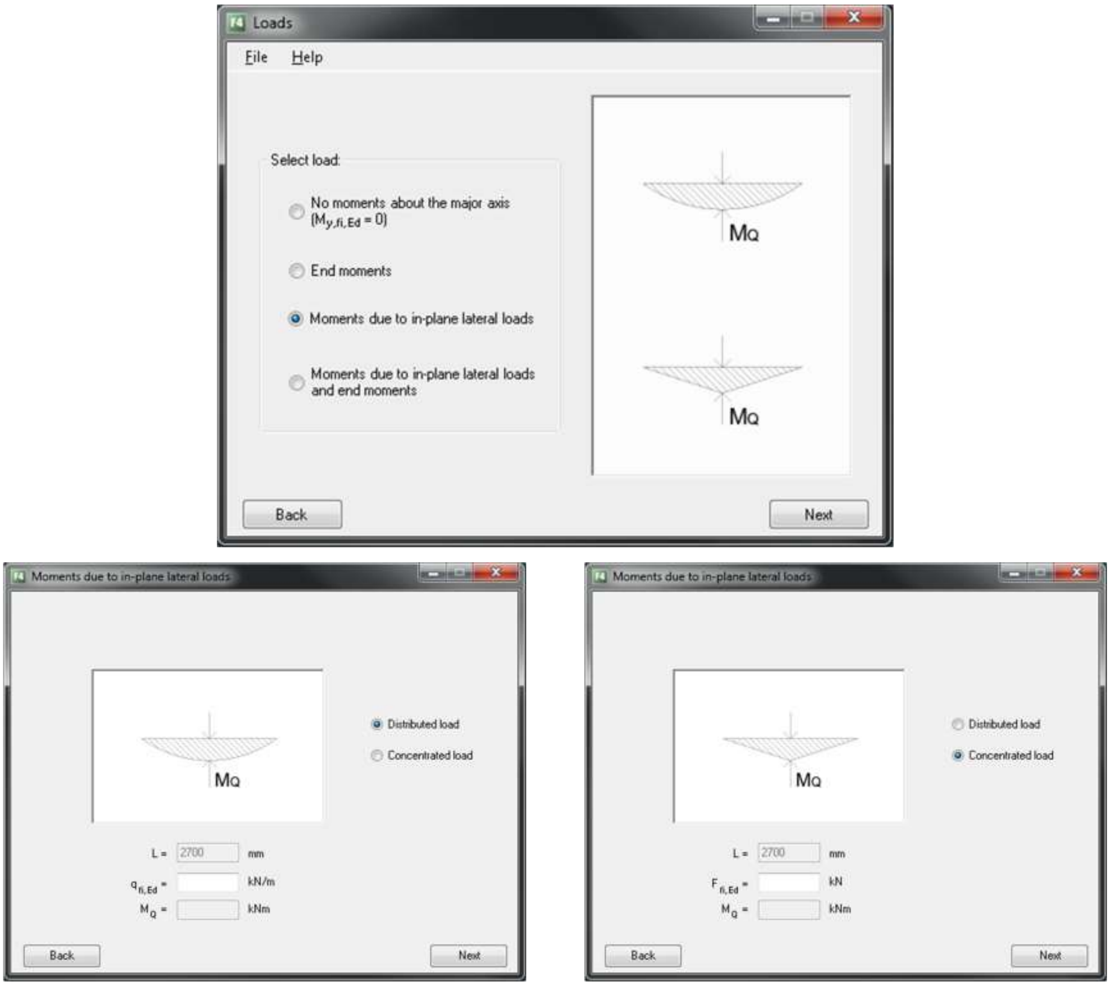
b)


Loads
File Help
Select load:
No moments about the major axis (My,fi,Ed = 0)
End moments
Moments due to in-plane lateral loads
Moments due to in-plane lateral loads and end moments
Back
Next

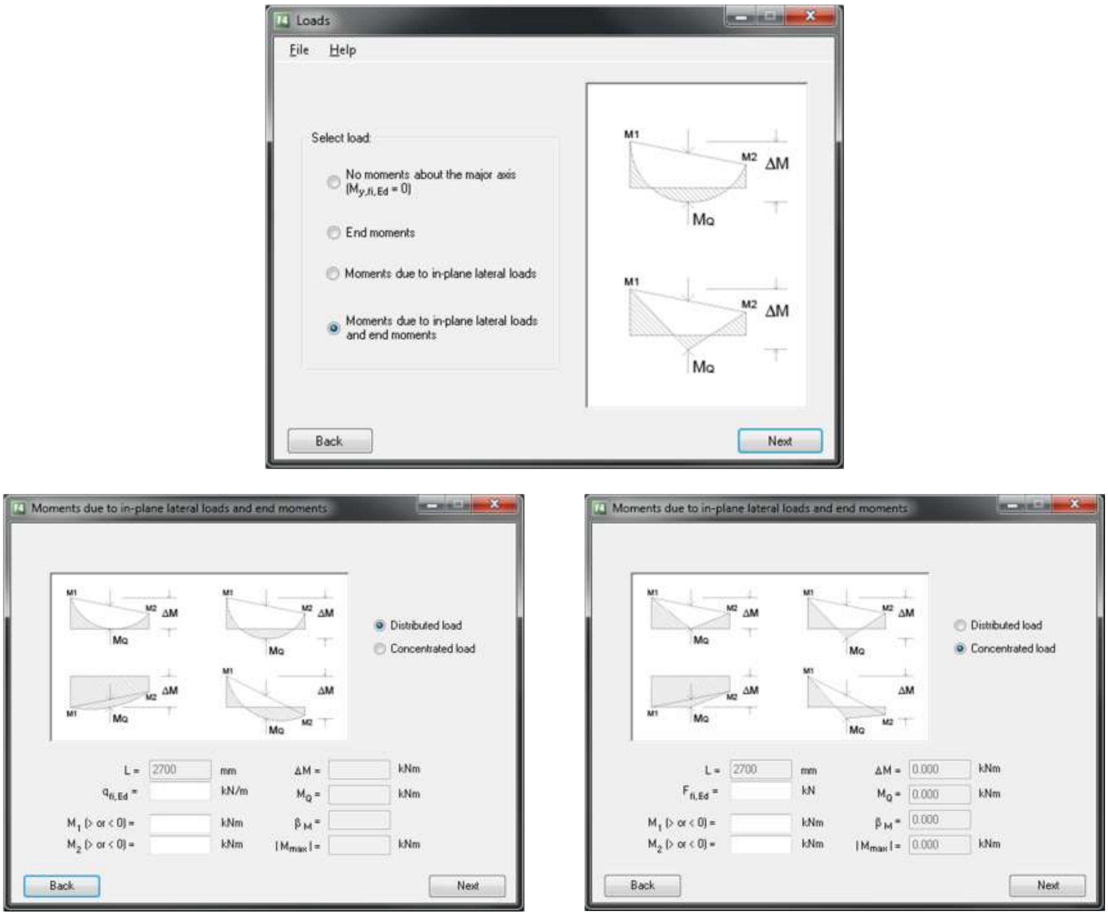
c)


Loads
File Help
Select load:
No moments about the major axis (My,fi,Ed = 0)
End moments
Moments due to in-plane lateral loads
Moments due to in-plane lateral loads and end moments
M1
M2
Back
Next
End moments
M1
M2
M1 (> or < 0) = kNm
M2 (> or < 0) = kNm
Back
Next

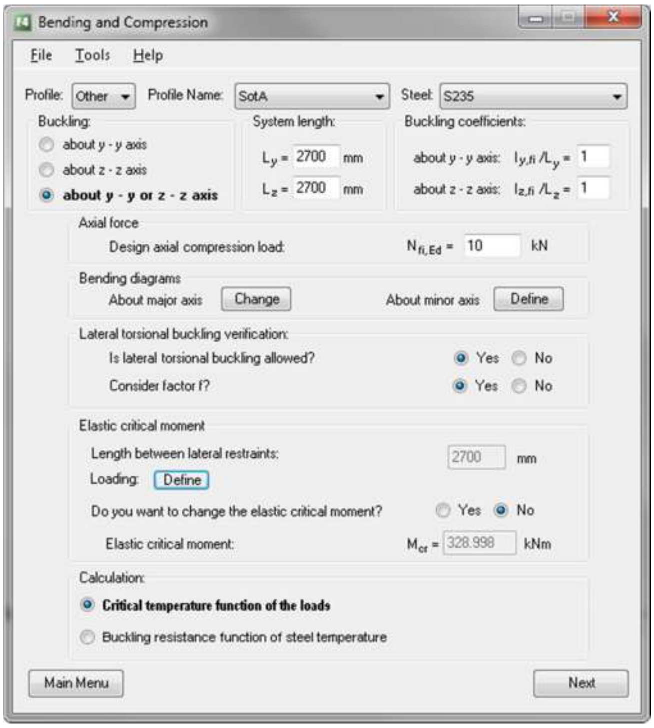
d)


Loads
File
Help
Select load:
No moments about the major axis
(My,fi,Ed = 0)
End moments
Moments due to in-plane lateral loads
Moments due to in-plane lateral loads
and end moments
MQ
MQ
Back
Next
Moments due to in-plane lateral loads
MQ
Distributed load
Concentrated load
L = 2700 mm
qfi,Ed = kN/m
MQ = kNm
Back
Next
Moments due to in-plane lateral loads
MQ
Distributed load
Concentrated load
L = 2700 mm
Ffi,Ed = kN
MQ = kNm
Back
Next

e)



f)



g)

Figure 2.13: Screens used to deal with beam-columns: a) Main menu, b) Buckling lengths definition, c) Loading types, d) End moments, e) In-plane lateral loading, f) In-plane lateral buckling and end moments, g) Possibility of changing the elastic critical moment to be used in the calculations

3 Worked example: a class 4 beam-column

3.1 General description

Consider a 2.7 m high built up beam-column in steel grade S355, as shown in Figure 3.1.

h = 460 mm (total depth of the section)

b = 150 mm

t_w = 4 mm

t_f = 5 mm

a = 5 mm (effective throat thickness of the fillet weld)

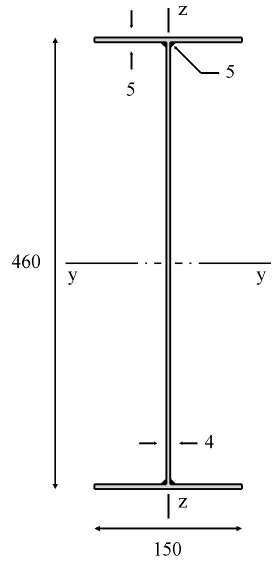


Figure 3.1: Dimensions of the built up cross-section

Assuming that the beam-column is subjected to a uniform bending moment diagram which design value in fire situation is $M_{y,fi,Ed} = 20$ kNm about major axis and to an axial compression force in fire situation of $N_{fi,Ed} = 20$ kN. The lateral torsional buckling of the beam-column is prevented. Evaluate:

a) the critical temperature of the beam-column considering both the cross-sectional resistance (Eq. (6.44) from EN 1993-1-1 adapted to fire) and the beam-column resistance using Eq. (4.21c) from EN 1993-1-2;
b) the fire resistance of the beam-column at a temperature of 500ºC.

The following data is relevant for solving the problem:

- Young's modulus: $E = 210000 N/mm^2$;
- Cross-section gross area: $A = 3300 mm^2$.

3.2 Analytical solution

The analytical solution of this problem is detailed in deliverable n°3: Experimental and numerical investigation of class 4 columns, simple design rules and application examples.

3.3 Solution using "FIDESC4" software

3.3.1 Critical temperature

The following screens show the procedure to obtain the critical temperature of the beam-column.

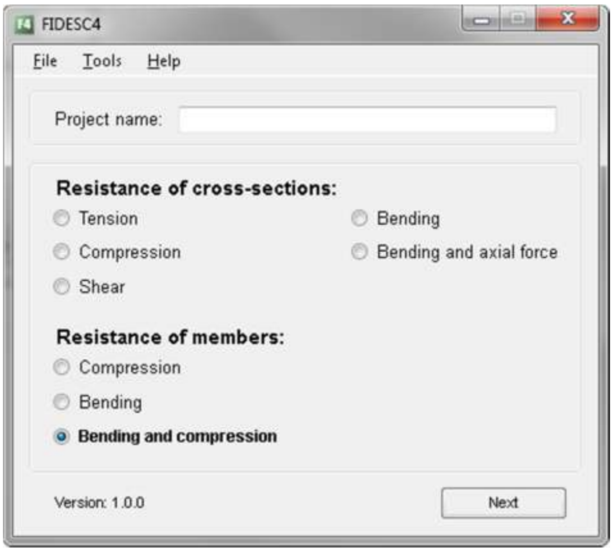


Figure 3.2: Worked example - Main menu

Selecting the "Bending and compression" radio button opens the following dialog box.

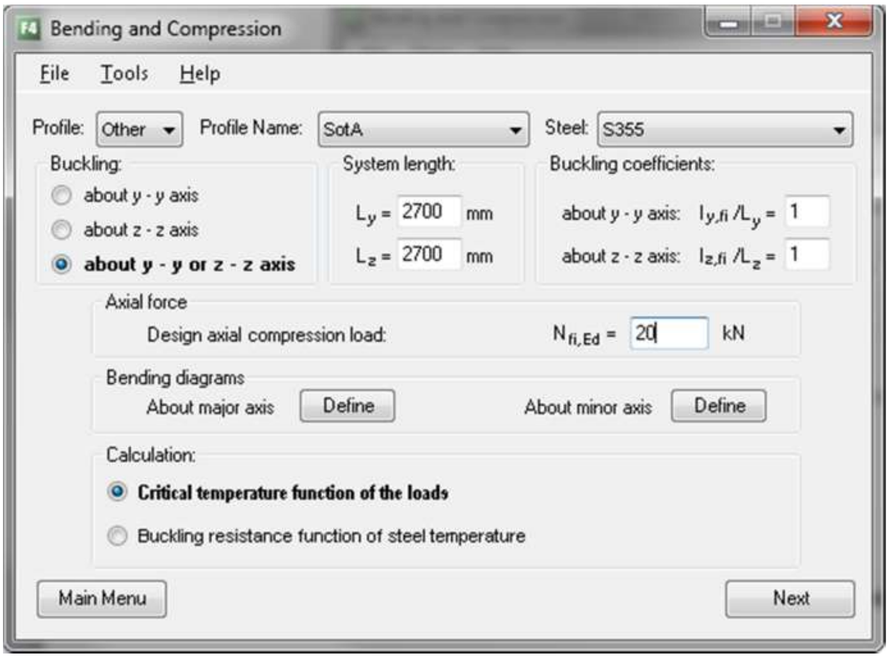


Figure 3.3: Worked example - Bending and Compression

Clicking on the button “Define” on the “Bending Diagrams” group box, opens the following dialog box.

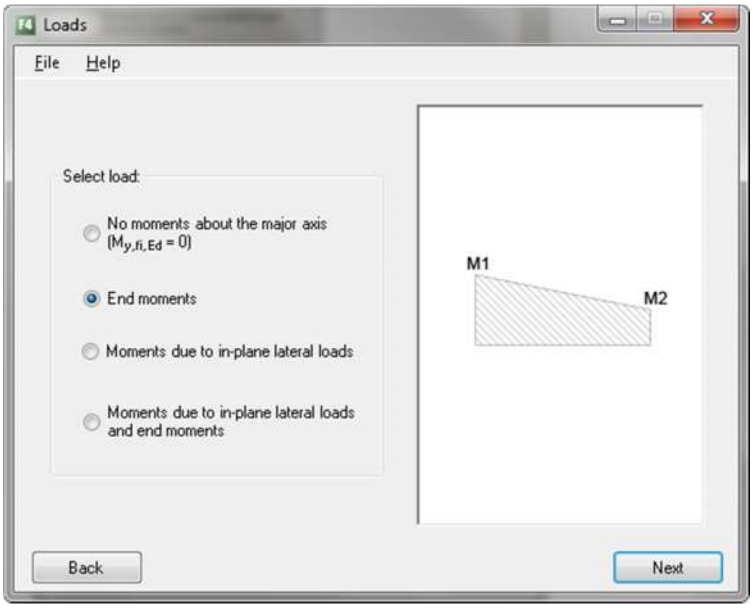


Figure 3.4: Worked example - Loads

Selecting the “End moments” radio button opens the following dialog box.

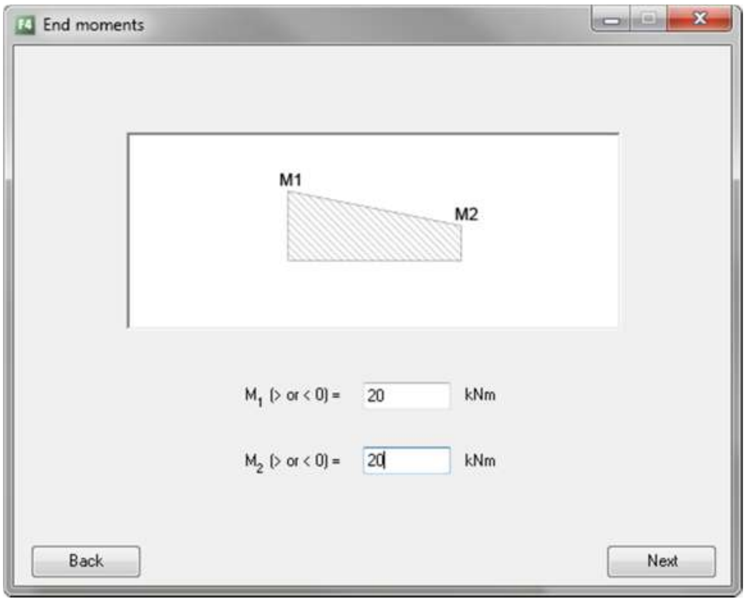


Figure 3.5: Worked example - End moments

Clicking on the button "Next", the following screen is shown.

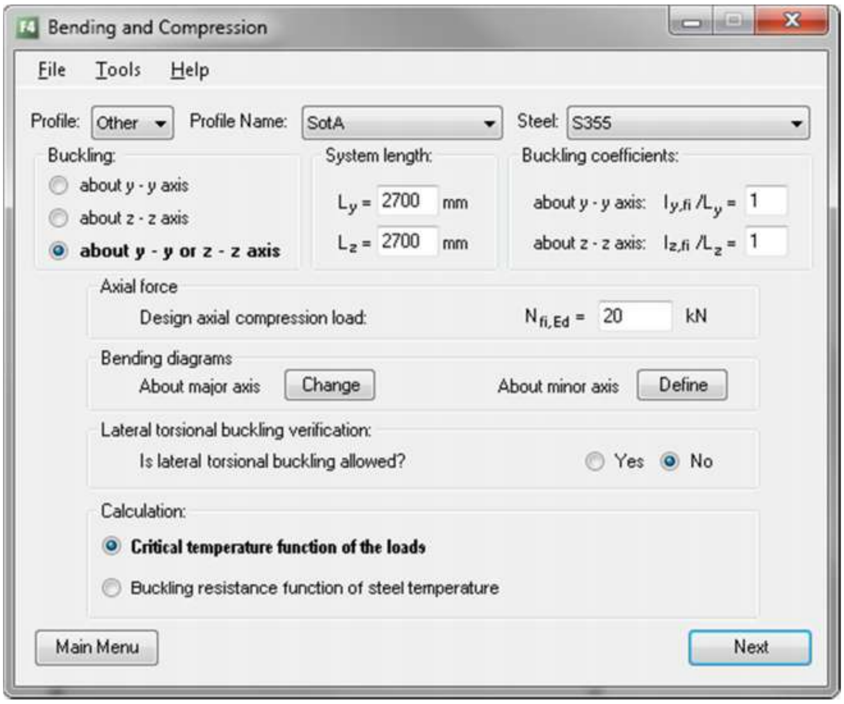


Figure 3.6: Worked example - Bending and Compression

Finally, clicking "Next" again will lead to the critical temperature results.

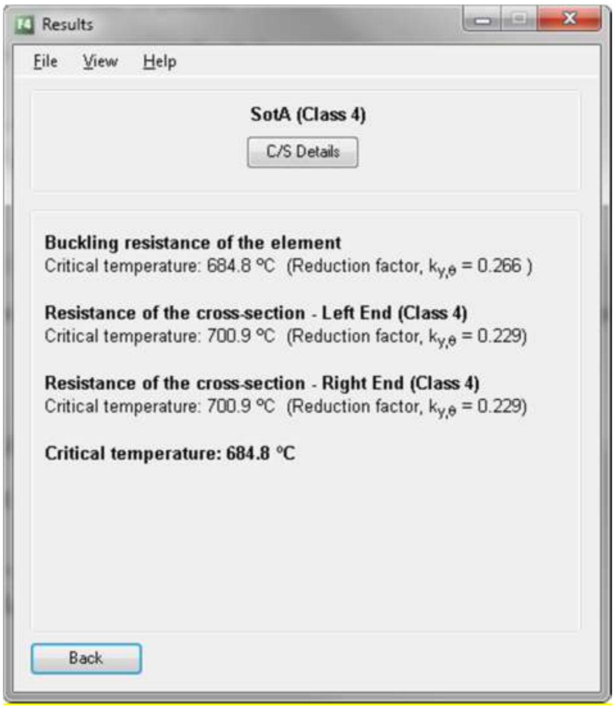


Figure 3.7: Worked example - Critical temperature

Additionally, clicking the button "C/S Details" will show the effective cross-section when subject to compression (Figure 3.8) and bending about y-y (Figure 3.9) as well as details about the calculations (**Erreur ! Source du renvoi introuvable.**16).

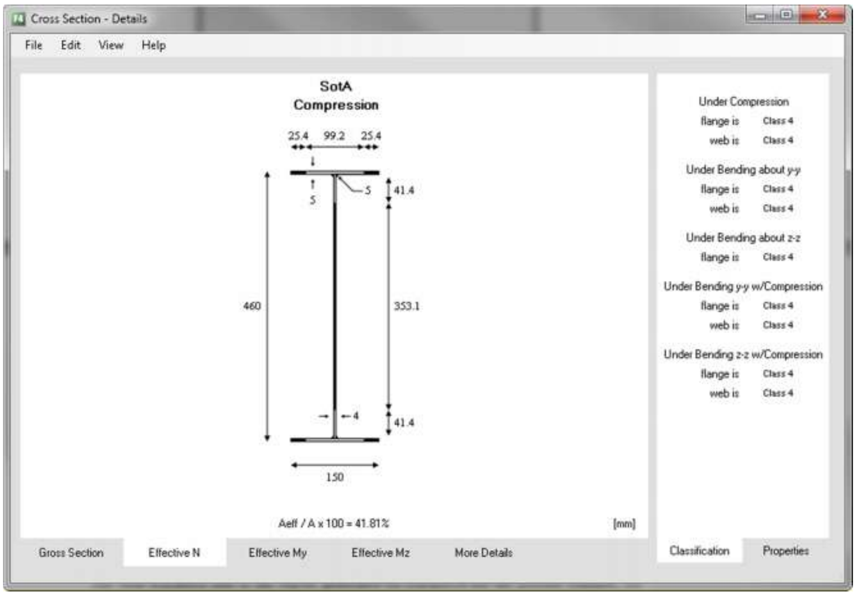


Figure 3.8: Worked example - Effective cross-section when subject to compression

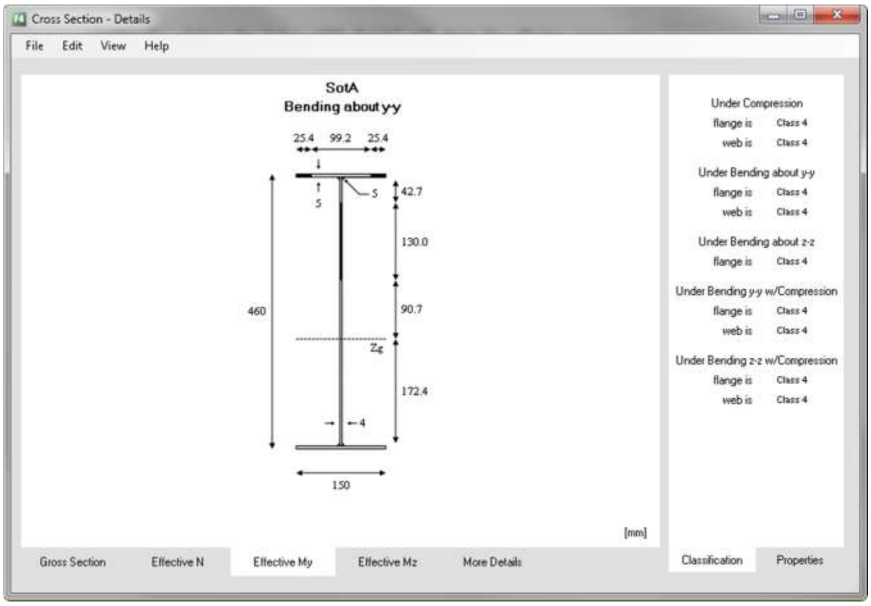


Figure 3.9: Worked example - Effective cross-section when subject to bending about y.y

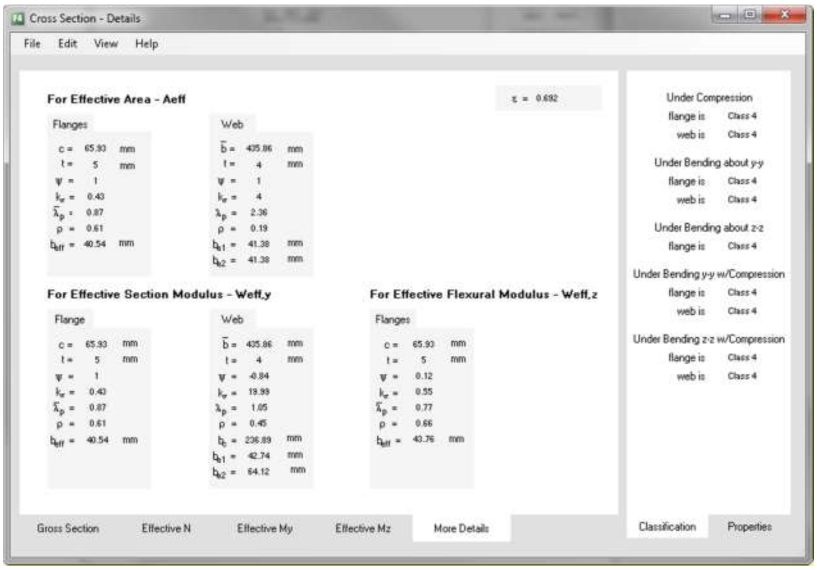


Figure 3.16 Worked example - Effective cross-section calculation details

The next bordered text is the report generated by FIDESC4 for the present example by clicking “View”->”Report” in the toolbar.

FIDESC4 REPORT

Project name:
Date: 26-03-2015
γ_{M0} = 1.0
$\gamma_{M,fi}$ = 1.0

Temperature evaluated using interpolation on the table 3.1 from EN 1993-1-2.

STEEL

Carbon steel, S355

Young modulus: 210 GPa

PROFILE

Classification
ε = 0.692
Under Bending about y-y with Compression:
flange is Class 4
web is Class 4
α = 0.516
ψ = -0.966

SotA (Class 4)

Geometry
h = 460 mm
b = 150 mm
t_w = 4 mm
t_f = 5 mm
a = 5 mm

Properties
A = 3300 mm²
P = 1.512 m²/m
η = 1.20
A_{vz} = 2160 mm²
A_{vy} = 1500 mm²
i_y = 180.9 mm
i_z = 29.2 mm
$W_{el,y}$ = 469620 mm³
$W_{pl,y}$ = 543750 mm³
I_y = 108012500 mm⁴
$W_{el,z}$ = 37532 mm³
$W_{pl,z}$ = 58050 mm³
I_z = 2814900 mm⁴
I_t = 22100 mm⁴
I_w = 145564453125 mm⁶

Effective Properties
A_{eff} = 1380 mm²
$I_{eff,y}$ = 82582234 mm⁴
$W_{eff,y}$ = 299694 mm³
$I_{eff,z}$ = 1835099 mm⁴
$W_{eff,z}$ = 23053 mm³

For Effective Area - A_{eff}
Flanges:
c = 65.9 mm
t = 5 mm
ψ = 1

$k_\sigma = 0.43$
$\lambda_p = 0.87$
$\rho = 0.61$
$b_{eff} = 40.5$ mm
$b_{eff,total} = 99.2$ mm
Web:
b = 435.9 mm
t = 4 mm
$\psi = 1$
$k_\sigma = 4$
$\lambda_p = 2.36$
$\rho = 0.19$
$b_{e1} = 41.4$ mm
$b_{e2} = 41.4$ mm
$b_{e1,total} = 48.4$ mm
$b_{e2,total} = 48.4$ mm

For Effective Section Modulus - $W_{eff,y}$
Upper Flange:
c = 65.9 mm
t = 5 mm
$\psi = 1$
$k_\sigma = 0.43$
$\lambda_p = 0.87$
$\rho = 0.61$
$b_{eff} = 40.5$ mm
$b_{eff,total} = 99.2$ mm
Web:
b = 435.9 mm
t = 4 mm
$\psi = -0.84$
$k_\sigma = 19.99$
$\lambda_p = 1.05$
$\rho = 0.45$
$b_c = 236.9$ mm
$b_{e1} = 42.7$ mm
$b_{e2} = 64.1$ mm
$b_{e1,total} = 49.8$ mm
$b_{e2,total} = 270.2$ mm

For Effective Flexural Modulus - $W_{eff,z}$
Flanges:
c = 65.9 mm
t = 5 mm
$\psi = 0.12$
$k_\sigma = 0.55$
$\lambda_p = 0.77$
$\rho = 0.66$
$b_{eff} = 43.8$ mm
$b_{eff,total} = 127.8$ mm

ELEMENT SUBMITTED TO BENDING AND COMPRESSION

Critical temperature function of the loads

System length: $L_y = 2700$ mm; $L_z = 2700$ mm
Buckling coefficients: $l_{y,fi}/L_y = 1$; $l_{z,fi}/L_z = 1$
Design axial compression load: $N_{b,fi,Ed} = 20$ kN

About major axis - End moments
$M_1 = 20$ kNm
$M_2 = 20$ kNm

Lateral torsional buckling not allowed.

$N_{cr,y}$ = 30708.990 kN
$N_{cr,z}$ = 800.303 kN
$\lambda_{y,20°C}$ = 0.126
$\lambda_{z,20°C}$ = 0.782
$\lambda_{y,\theta}$ = 0.164
$\lambda_{z,\theta}$ = 1.018
$\Phi_{y,\theta}$ = 0.557
$\Phi_{z,\theta}$ = 1.287
$\chi_{y,\theta}$ = 0.918
$\chi_{z,\theta}$ = 0.482
$\chi_{min,\theta}$ = 0.482
μ_y = 0.200
μ_z = -3.344
k_y = 0.967
k_z = 2.064
$\beta_{M,y}$ = 1.100
$\beta_{M,z}$ = 0.000

RESULTS

Buckling resistance of the element
Critical temperature: 684.8 ºC (Reduction factor, $k_{y,\theta}$ = 0.266)

Resistance of the cross-section - Left End (Class 4)
Critical temperature: 700.9 ºC (Reduction factor, $k_{y,\theta}$ = 0.229)

Resistance of the cross-section - Right End (Class 4)
Critical temperature: 700.9 ºC (Reduction factor, $k_{y,\theta}$ = 0.229)

Critical temperature: 684.8 ºC

3.3.2 Fire resistance

In the dialog box shown in Figure 3.6, selecting the "Buckling resistance function of steel temperature" and clicking "Next", the following screen is shown, with the buckling resistance and cross-sectional resistance.

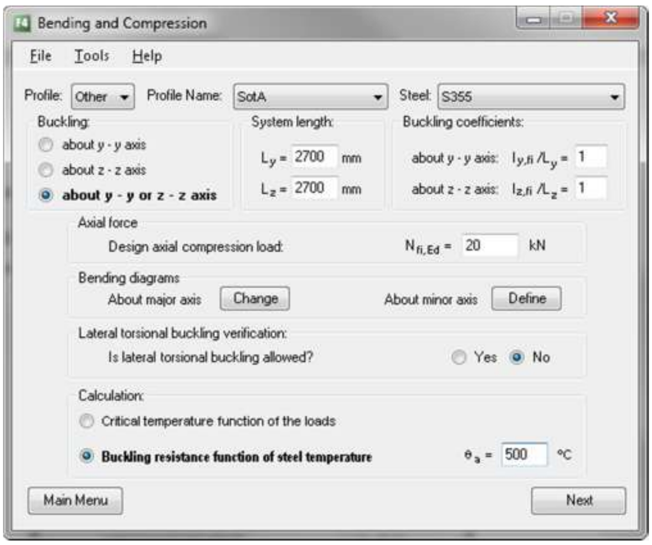


Figure 3.17: Worked example - Bending and Compression.

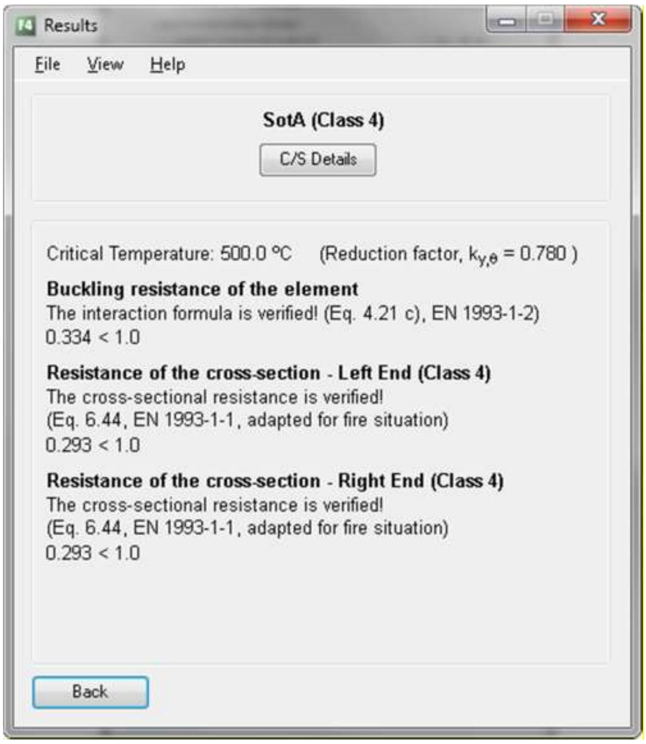


Figure 3.18: Worked example - Fire resistance.

The fire resistance of the beam-column is verified at 500ºC.