WG1- Dan Pintea, dan.pintea@ct.upt.ro

33 THERMAL ANALYSIS OF A DOUBLE DECK BRIDGE

Summary

The goal of the present case study is to present the thermal study of different components of a double deck bridge, for establishing the temperature evolution in a fire situation. Unprotected as well as protected cases are analysed using a protection material described in detail in the paragraph entitled "The Materials". Three structural elements have been submitted to a natural fire curve obtained through a CFD analysis given in detail in the paragraph entitled "The Fire".

33.1 INTRODUCTION

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Three structural elements have been submitted to a natural fire curve obtained through a CFD analysis given in detail in the paragraph entitled "The Fire".

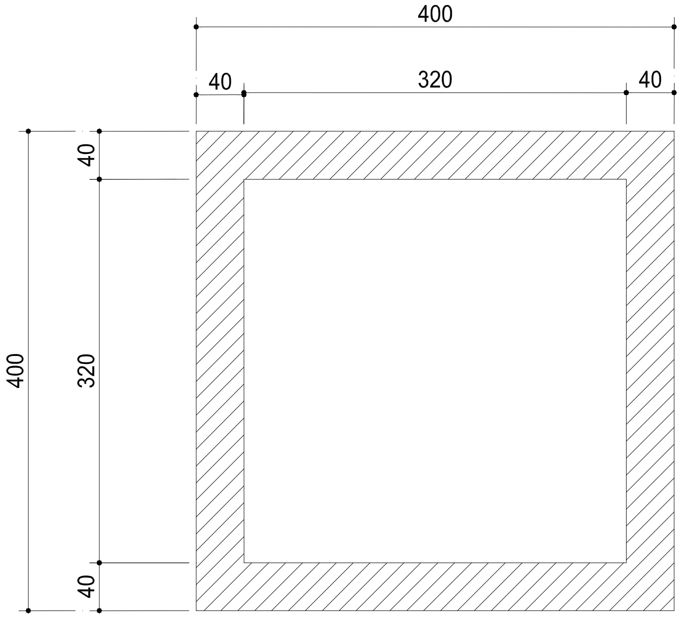

Fig. 33.1 The diagonal of the lattice girder

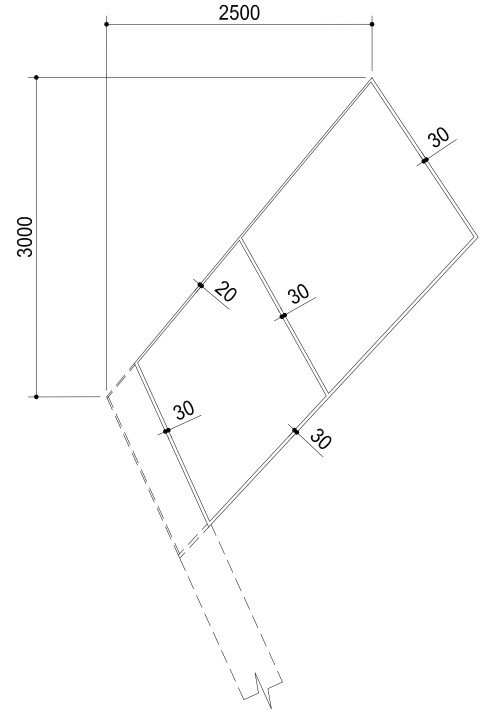

Fig. 33.2 The box girder

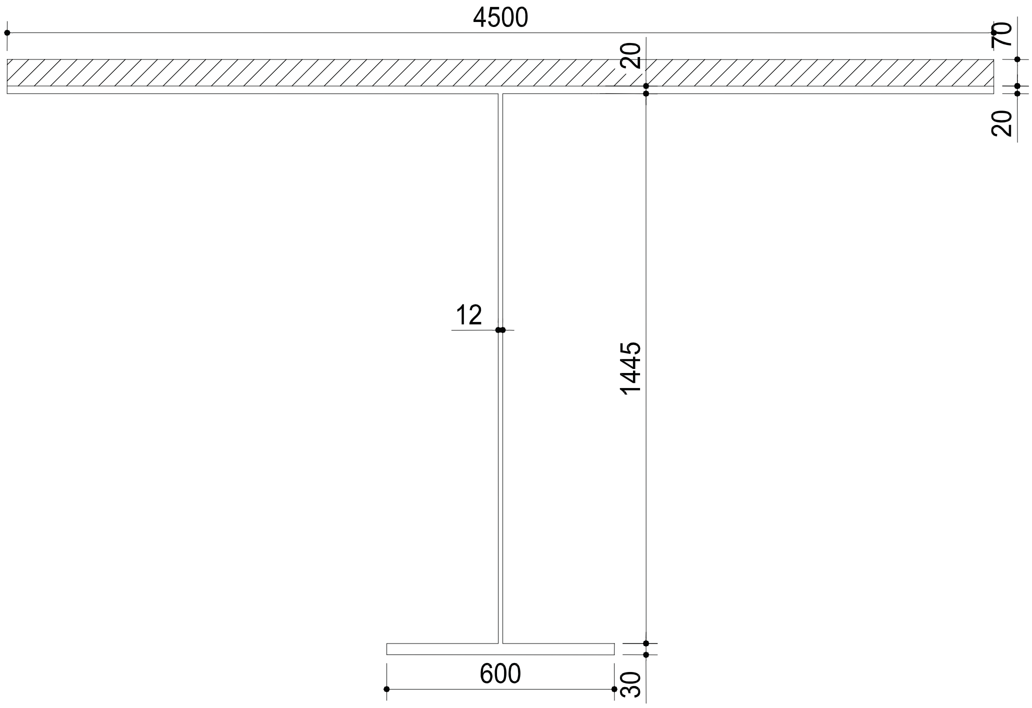

Fig. 33.3 The upper crossbeam

- The first structural element is a diagonal from the lattice girder (see Fig. 33.1).
- The second structural element is the box girder (see Fig. 33.2)
- The third element is the upper crossbeam (see Fig. 33.3)

Since the crossbeam has different widths of the upper flange and web on its span, a conservative beam is analysed having the minimum flange and web thicknesses (see Fig. 33.3).

33.2 THE MATERIALS

The material laws and physical principles of the thermal analysis are based on the Eurocode ENV 1993-1-2 and 1994-1-2.

Therefore the thermal properties of the steel for the diagonal of the lattice girder, the box girder and the upper crossbeam are those given in Eurocode ENV 1993-1-2.

Convection coefficients for the hot surfaces of 50 W/m^2K and for the cold surfaces of 9 W/m^2K are used. The relative emissivity is 0.5 for steel.

On the upper crossbeam the sheathing is assimilated to a siliceous concrete from Eurocode 1994-1-2, with a water content of 26 l/m^3, similar convection coefficients on the cold and hot surfaces as for the steel and a relative emissivity of 0.56.

The protection material that is used for the protected simulations, PROMATECT has the following thermal properties according to "Promat HTI": a constant specific heat of 1130 J/kg K, a constant density of 700 kg/m^3. No water is considered in this material, the convection coefficients for the hot and the cold surfaces are those from the steel and concrete elements. The relative emissivity is 0.56 as for the concrete material. The single property that has a linear distribution is the thermal conductivity. The manufacturer of the PROMATECT gives the thermal conductivities only up to 600°C. For this study we have extrapolated the thermal conductivity values up to 1200°C (see Tab. 33.1).

Tab. 33.1 The thermal properties of the protection material (PROMATECT)

Temperature [°C]	Thermal Conductivity [W/m K]	Specific Heat [J/kg K]	Density [kg/m^3]
0	0.10	1130	700
200	0.12	1130	700
400	0.14	1130	700
600	0.16	1130	700
800	0.18	1130	700
1000	0.20	1130	700
1200	0.22	1130	700

33.3 THE FIRE

Up to three fire curves have been applied on the cross sections of the structural elements. The base curve obtained through a CFD computation is the curve entitled F1100 (see Fig. 33.4) which reaches a maximum temperature of 1142°C. The other two curves are obtained from the base curve by interpolating the values as to reach a peak value of 800°C (the curve F800) and 400°C (the curve F400). After 40 minutes all three curves remain constant at 20°C.

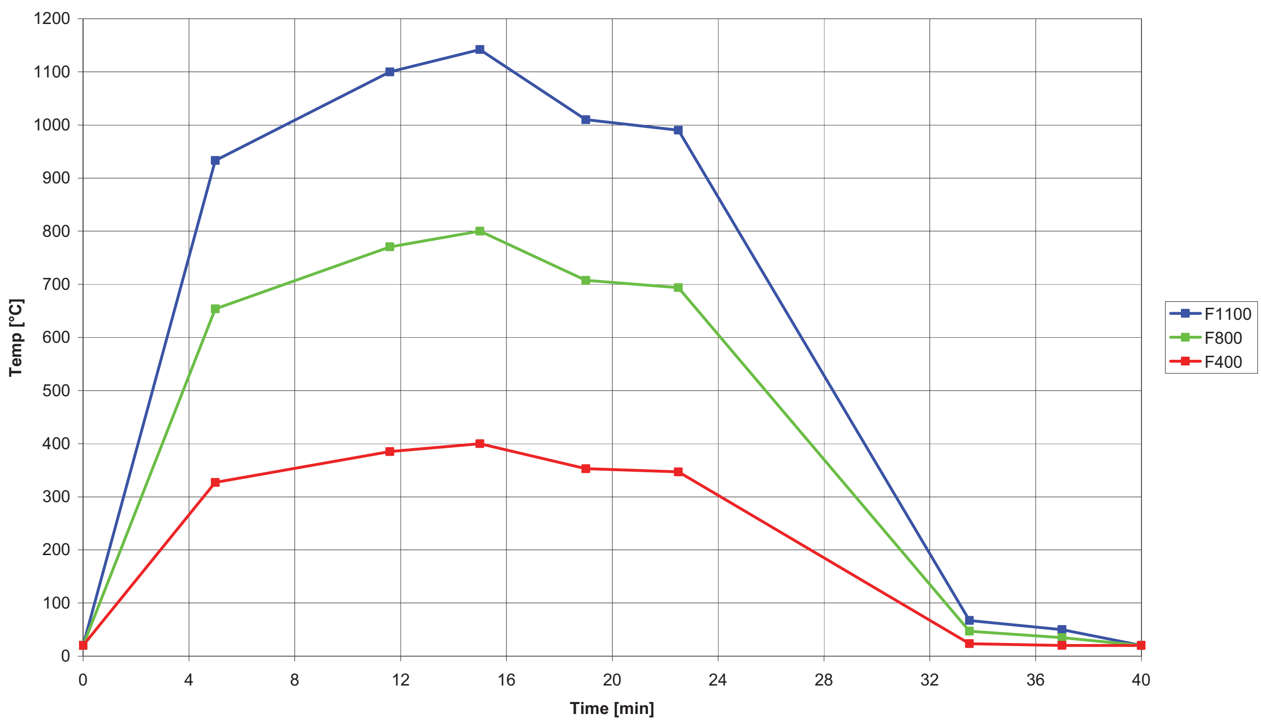

Fig. 33.4 The fire curves used in the analysis

The following three figures show the boundary conditions considered on each of the cross sections (thermal boundary conditions).

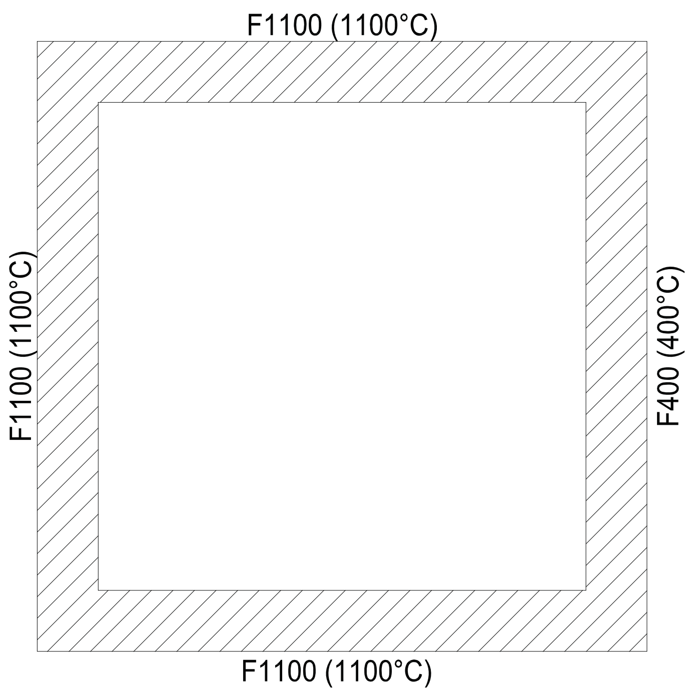

Fig. 33.5 Applied fire curves on the protected and unprotected diagonal

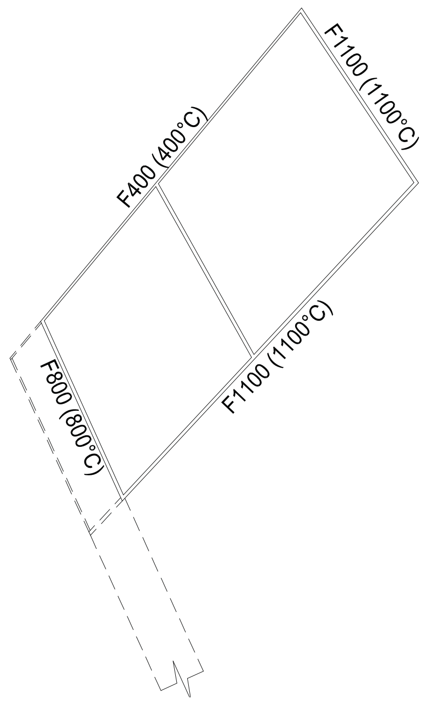

Fig. 33.6 Applied fire curves on the protected and unprotected box girder

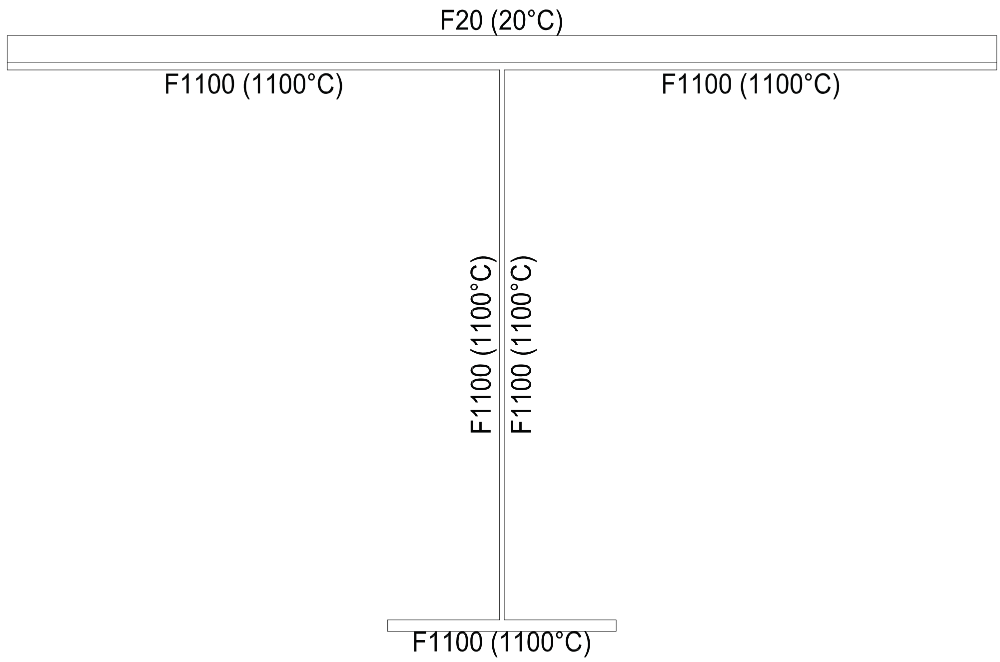

Fig.33.7 Applied fire curves on the unprotected crossbeam

33.4 MESHING AND PROTECTION

All the models are meshed using SAFIR 2D SOLID elements with four nodes. A rather regular, Cartesian mesh is sought for easier processing of the results of the analysis. A sufficiently fine mesh for each case is used for capturing with good accuracy the temperature distribution having a good ratio computation time/mesh.

All the figures that follow show the mesh of the cross section, the materials used, and the frontiers (applied fire conditions on the cross section).

The diagonal of the lattice girder is analysed in two cases, an unprotected case, with the fire applied on the bare steel of the hollow tube (see Fig. 33.8), and a protected case with a 15 mm box protection using the PROMATECT material presented above (see Fig. 33.9).

The box girder is analysed in two cases, an unprotected case with the fire applied on the bare steel, on the contour of the box girder and a box protected case using a 15 mm PROMATECT on the contour.

The crossbeam is analysed in four configurations: Case A – an unprotected steel beam with the fire (F1100) engulfing the lower part of the girder (see Fig. 33.10), Case B – a ceiling protection using a 15 mm PROMATECT protection, with the fire (F1100) applied on the lower edge of the protection (see Fig. 33.11), Case C – a box protection around the girder with 15 mm of PROMATECT (see Fig. 33.12), and Case D – a box protection around the girder extending on the lower edge of the upper flange (see Fig. 33.13).

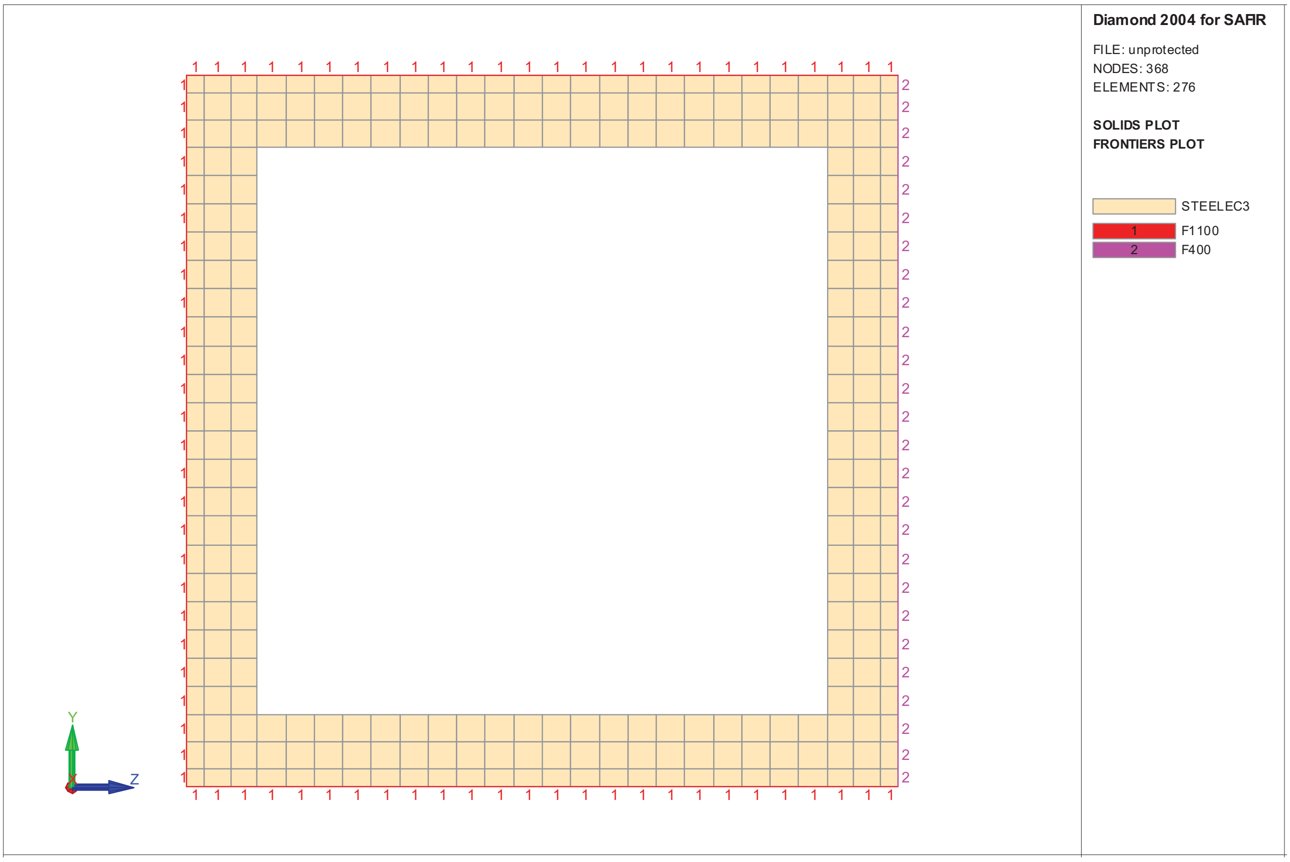

Fig. 33.8 Mesh, materials and frontiers on the unprotected diagonal of the lattice girder

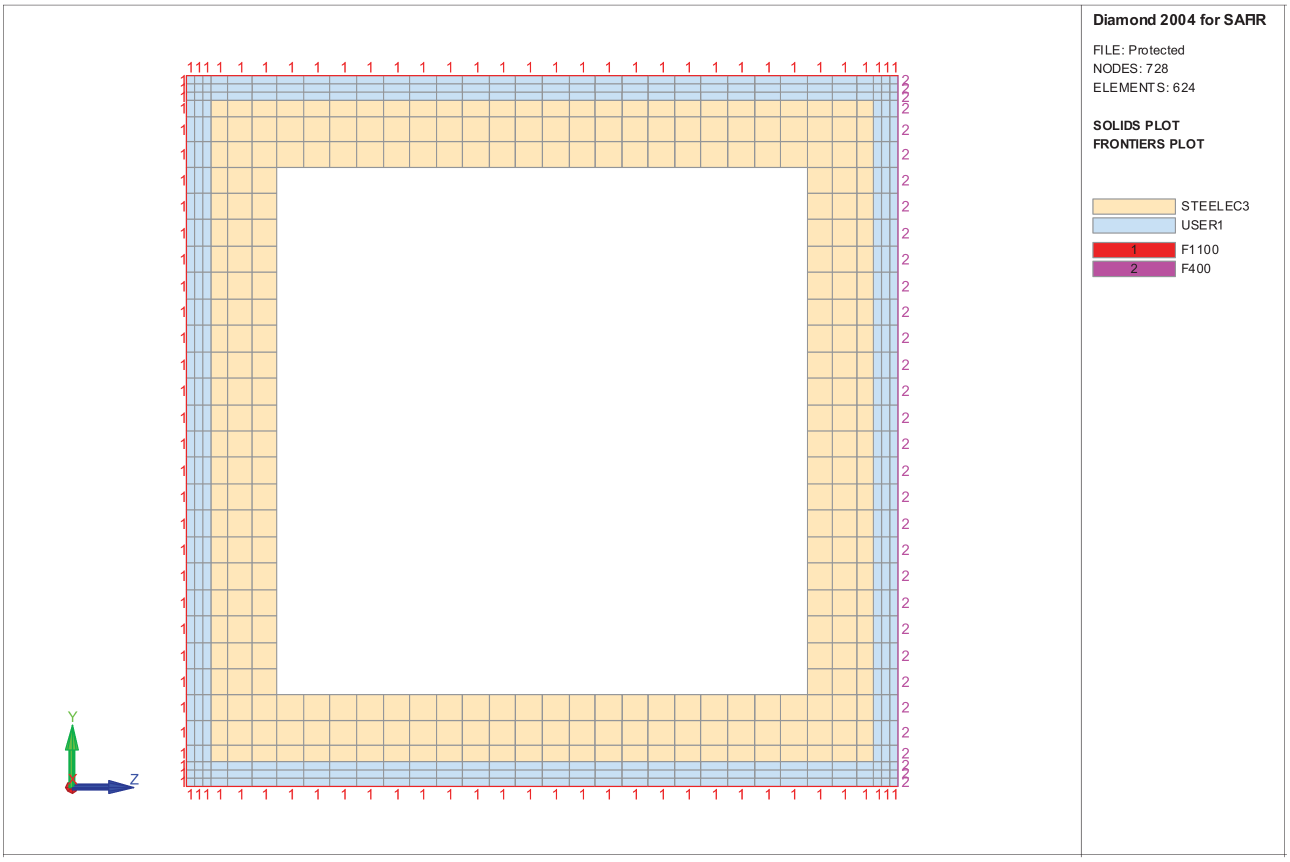

Fig. 33.9 Mesh, materials and frontiers on the protected diagonal of the lattice girder

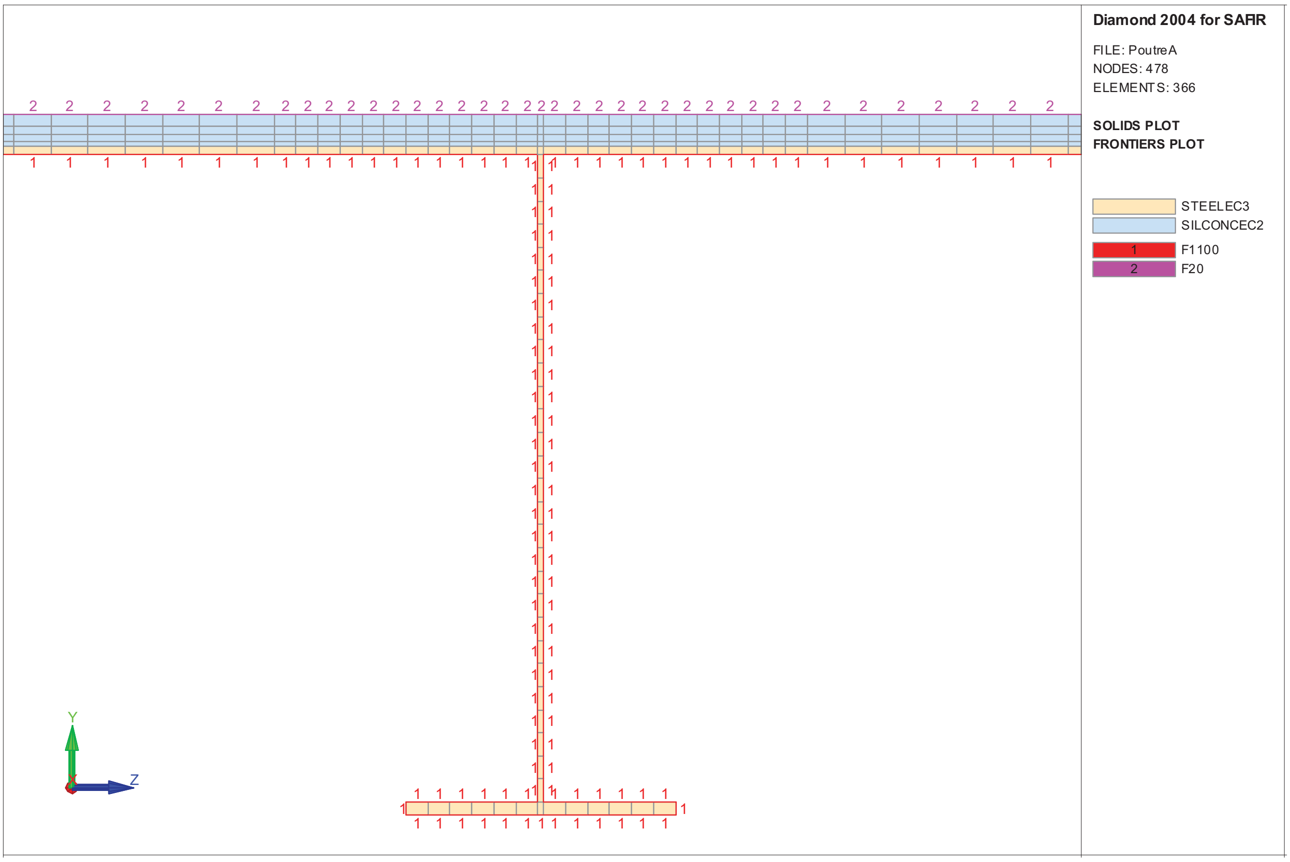

Fig. 33.10 Mesh, materials and frontiers on the unprotected crossbeam (case A)

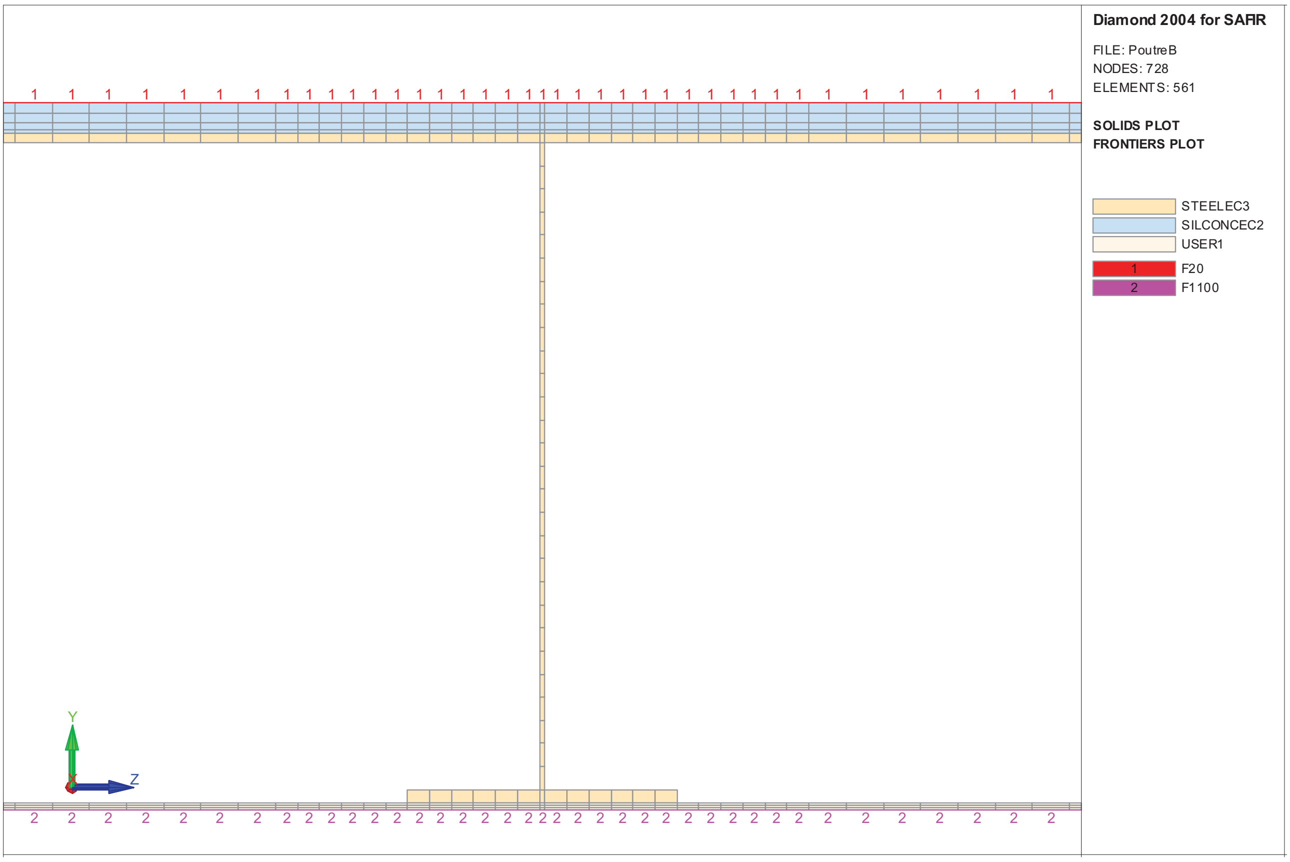

Fig. 33.11 Mesh, materials and frontiers on the ceiling protected crossbeam (case B)

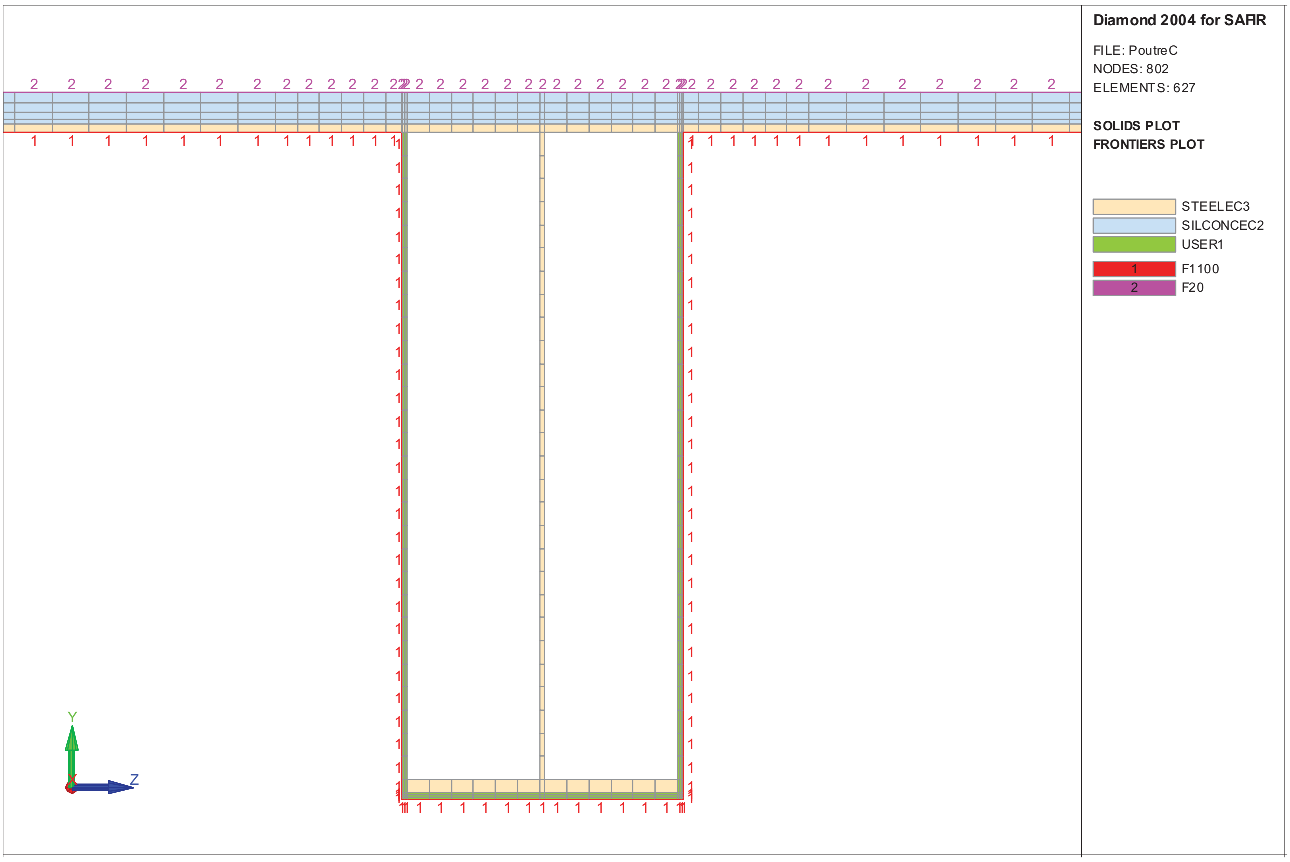

Fig. 33.12 Mesh, materials and frontiers on the box protected crossbeam (case C)

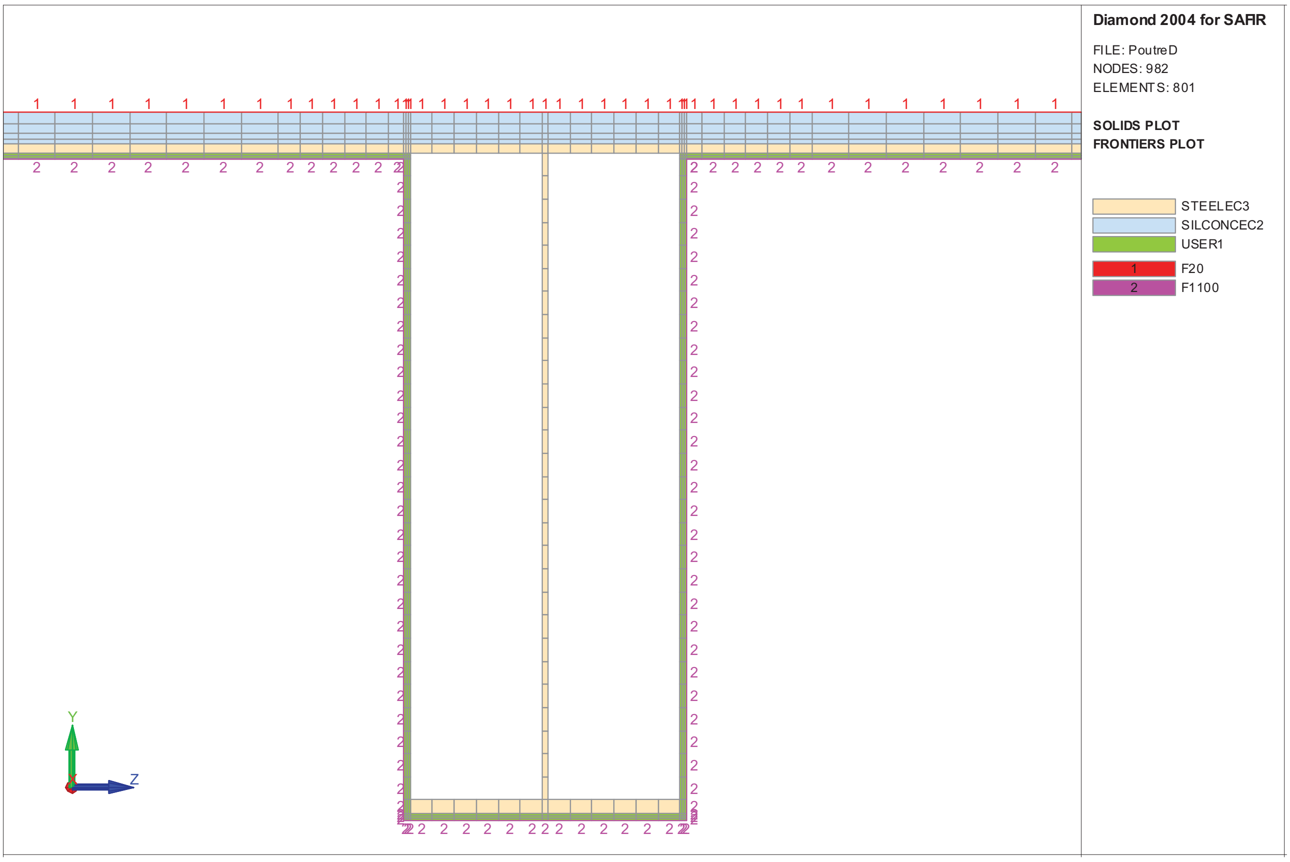

Fig. 33.13 Mesh, materials and frontiers on the box protected crossbeam (case D)

33.5 RESULTS

Since the fire curves applied on the cross sections have all a descending branch, the cross sections reach a maximum temperature at a certain time. The temperatures decrease afterwards more steeply for the unprotected sections and slowly for the protected ones.

The unprotected diagonal of the lattice girder reaches its maximum temperature of 780°C at 22.5 minutes (1350 sec). The temperature evolutions in four representative points on the cross section (see Fig. 33.14) are shown in the Fig. 33.15.

On the protected cross section the maximum temperature of 125.4°C is reached after 32.5 minutes (2000 sec), (there is a delay in the heating of the cross section due to the protection). While the exposed side to the lower temperatures (F400) tends asymptotically towards 90°C after 1 hour of fire exposure, the rest of the cross section is already in the cooling phase (see Fig. 33.16).

The unprotected box girder reaches its maximum temperature of 798°C at 22.5 minutes (1350 sec), a steep descending phase following this peak. For the protected box girder, with a 15 mm PROMATECT protection, the temperatures do not exceed 145°C, and after a heating phase of 33.5 minutes (2000 sec) when the maximum temperature of 143.8°C is reached, the cross section starts to cool slowly. No figures are shown.

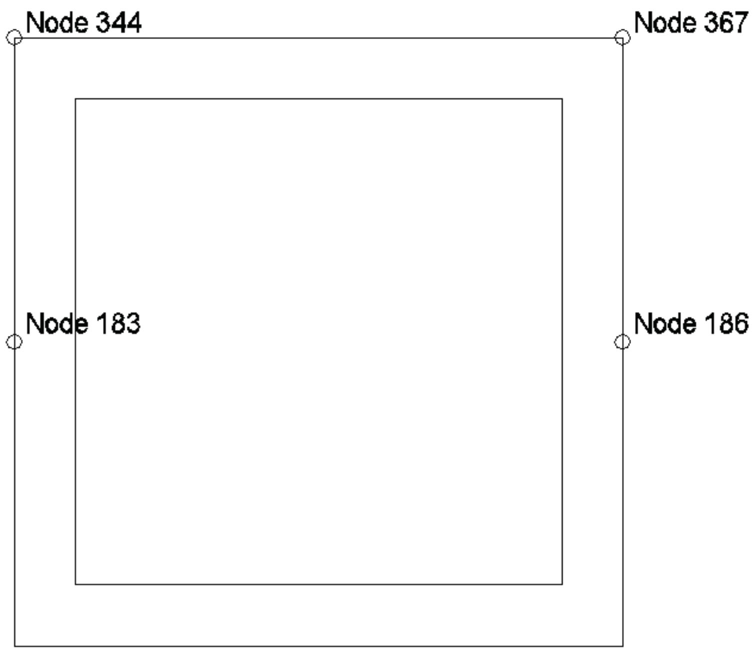

Fig. 33.14 The representative points on the cross section where temperature evolution in sought

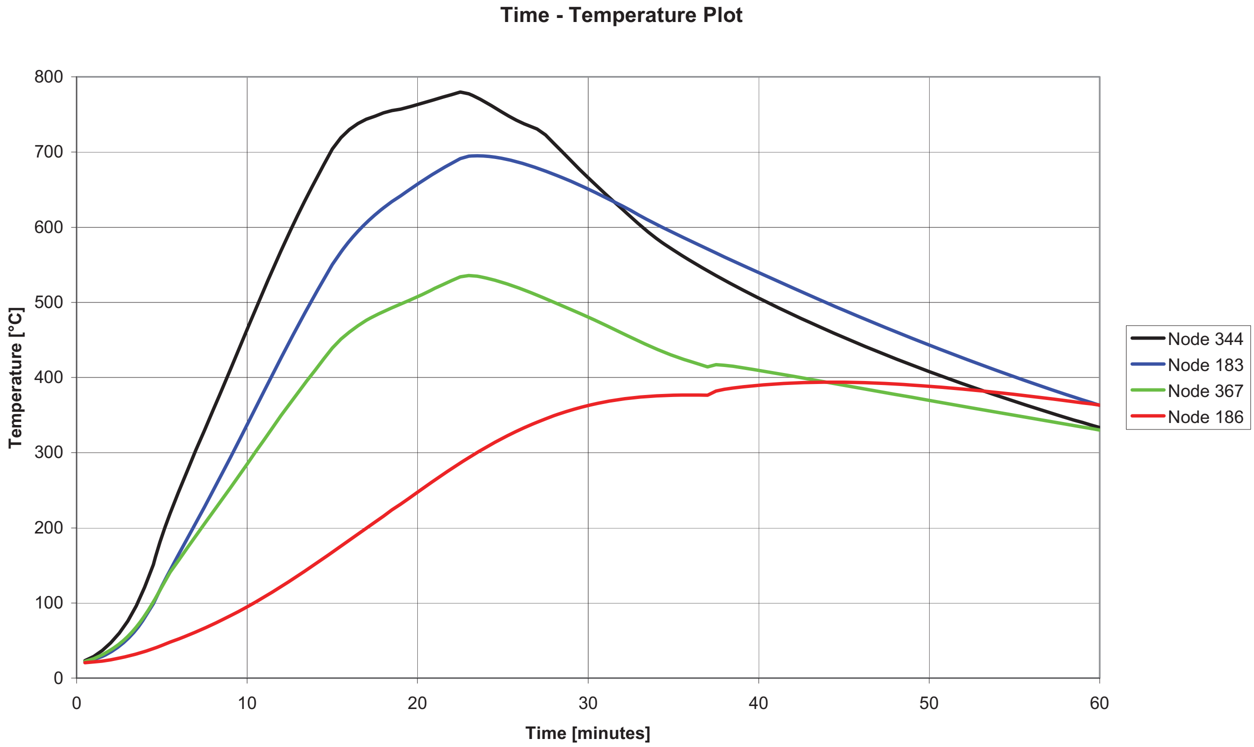

Fig. 33.15 Temperature evolution on the unprotected diagonal of the lattice girder

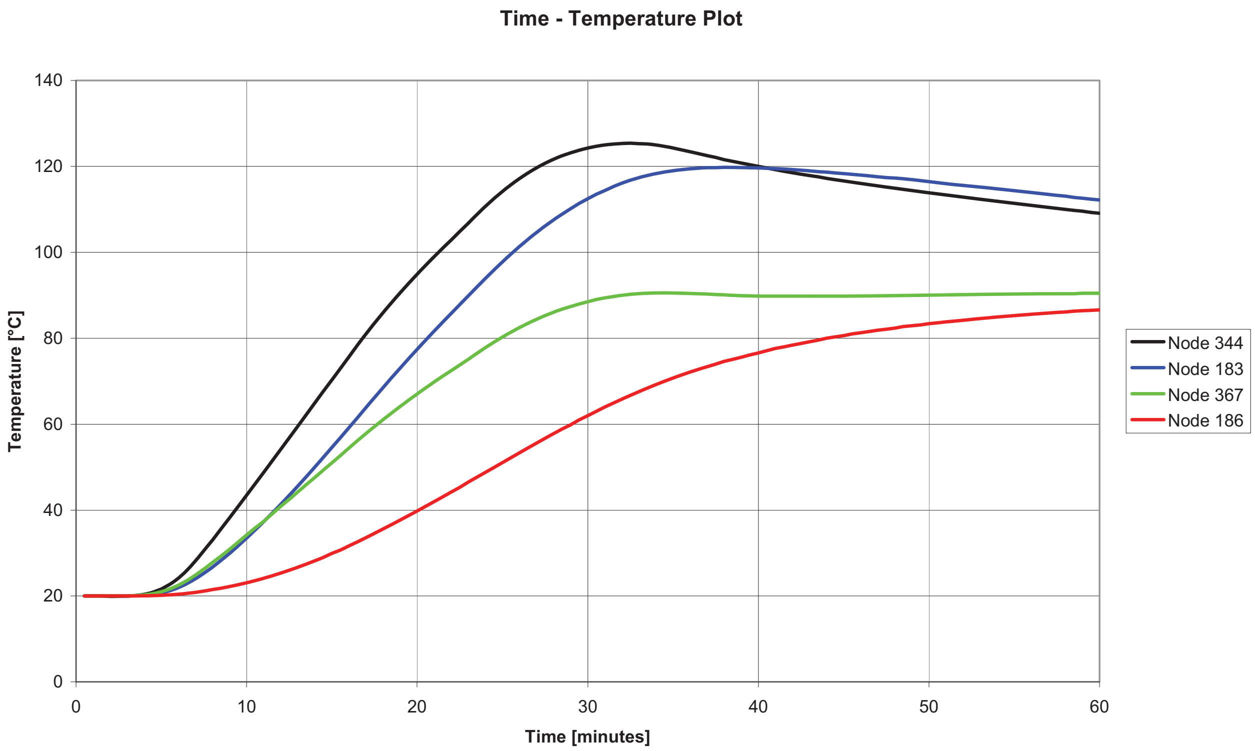

Fig. 33.16 Temperature evolution on the protected diagonal of the lattice girder

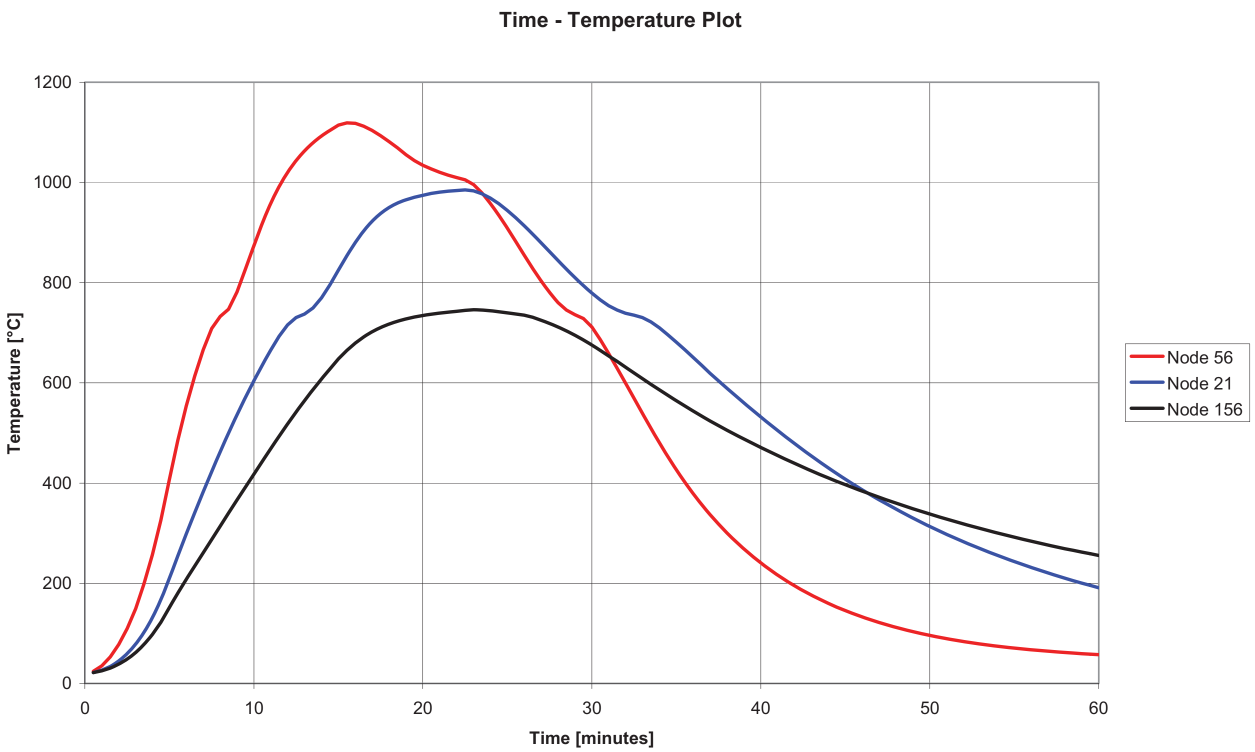

Fig. 33.17 Temperature evolution on the unprotected crossbeam (case A)

The temperature evolution on the unprotected crossbeam (Case A) is shown in Fig. 33.17. The three representative points in which the temperature evolution is checked are selected in the lower flange (Node 21), mid-height of the web (Node 56) and upper flange (Node 156).

In this case, because of the low section factor of the steel girder, the maximum temperature reaches 1119°C after 15.5 minutes (900 sec) in the hottest spot of the cross section (Node 56, which is the mid height of the web), followed by a steep decrease after 22 minutes (1300 seconds).

The temperatures in the upper web are lower than the ones in the rest of the steel, due to the concrete slab which acts as a heat sink. The maximum temperatures in the upper flange do not exceed 750°C.

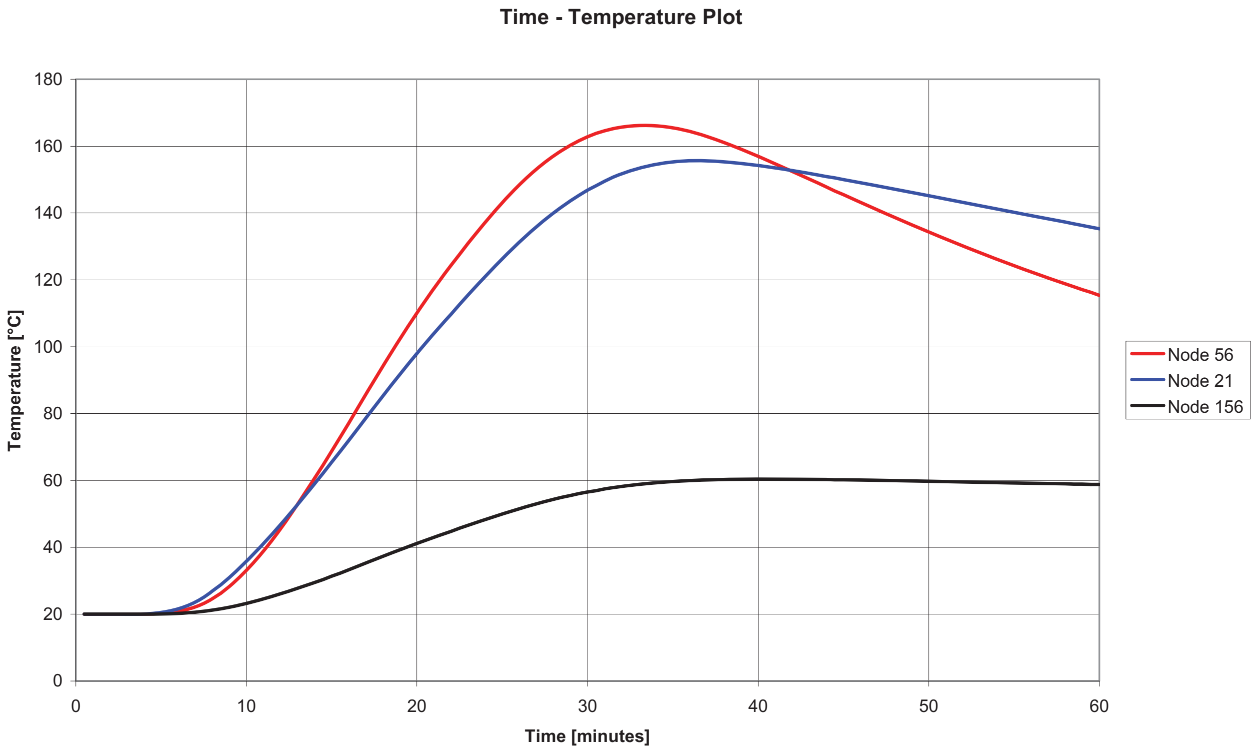

Fig. 33.18 Temperature evolution on the ceiling protected crossbeam (case B)

For the first protection scenario (Case B), using a 15 mm PROMATECT ceiling under the lower flange, the temperature evolution is presented in Fig. 33. 18. The temperature evolution is presented in the same nodes as in the previous case.

The maximum temperature on the cross section of 166.2°C is attained in the node 56 (the mid height of the web) at 33.5 minutes.

In the box protected case (Case C), two extra nodes where the temperature is inspected are added to the set of nodes (see Fig. 33.19).

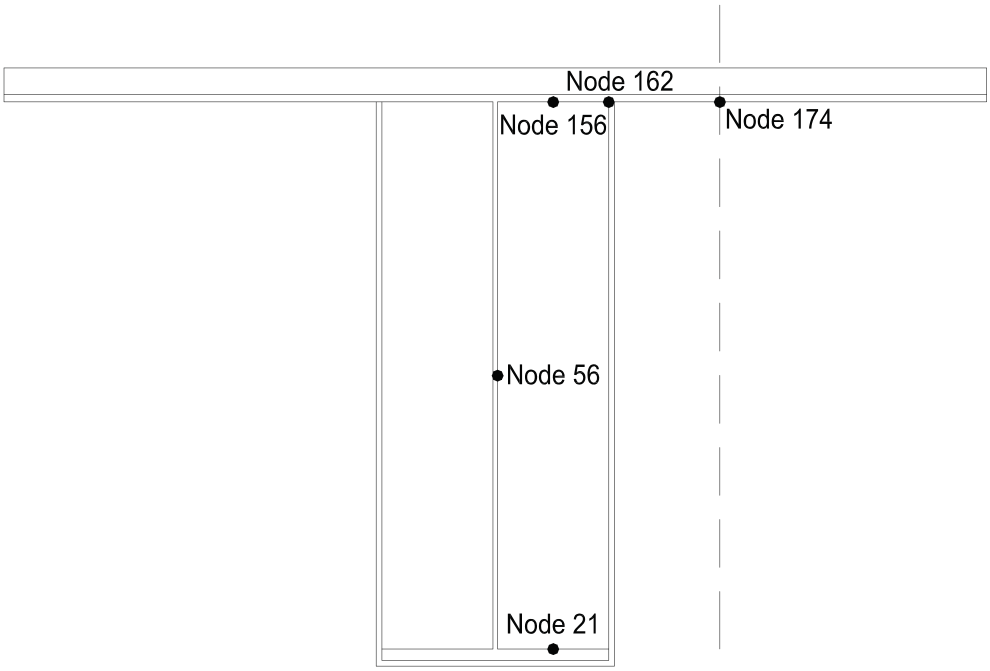

Fig. 33.19 Representative nodes on the box protected cross section of the crossbeam (case C)

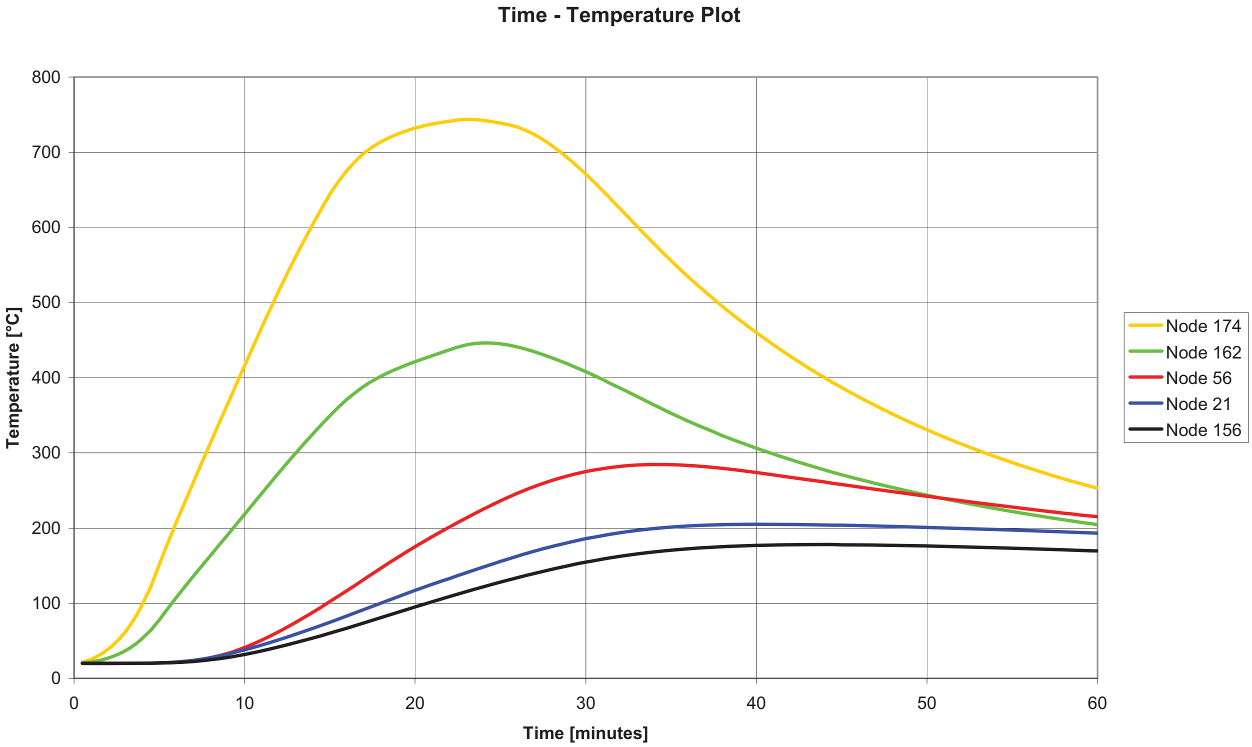

Fig. 33.20 Temperature evolution in the box protected crossbeam (case C)

The node 174 is on the lower edge of the upper flange, at a distance from the node 162 equal to half of the lower flange (≈150 mm). This node is added to inspect the temperatures in the unprotected steel.

While the steel inside the box protection has a temperature of up to 300°C, the bare upper flange, exposed to the fire with a peak of 1100°C reaches at 23 minutes (1400 sec) a temperature of 744°C. The temperature evolution in the five representative nodes of the cross section is presented in Fig. 33.20.

The last protection case (Case D), with a 15 mm PROMATECT box protection around the girder, and continued under the upper flange gives the temperature evolution presented in Fig. 33.21. The same nodes as in the previous model are inspected. With this protection, the maximum temperature in the steel girder at 34 minutes is 274.3°C.

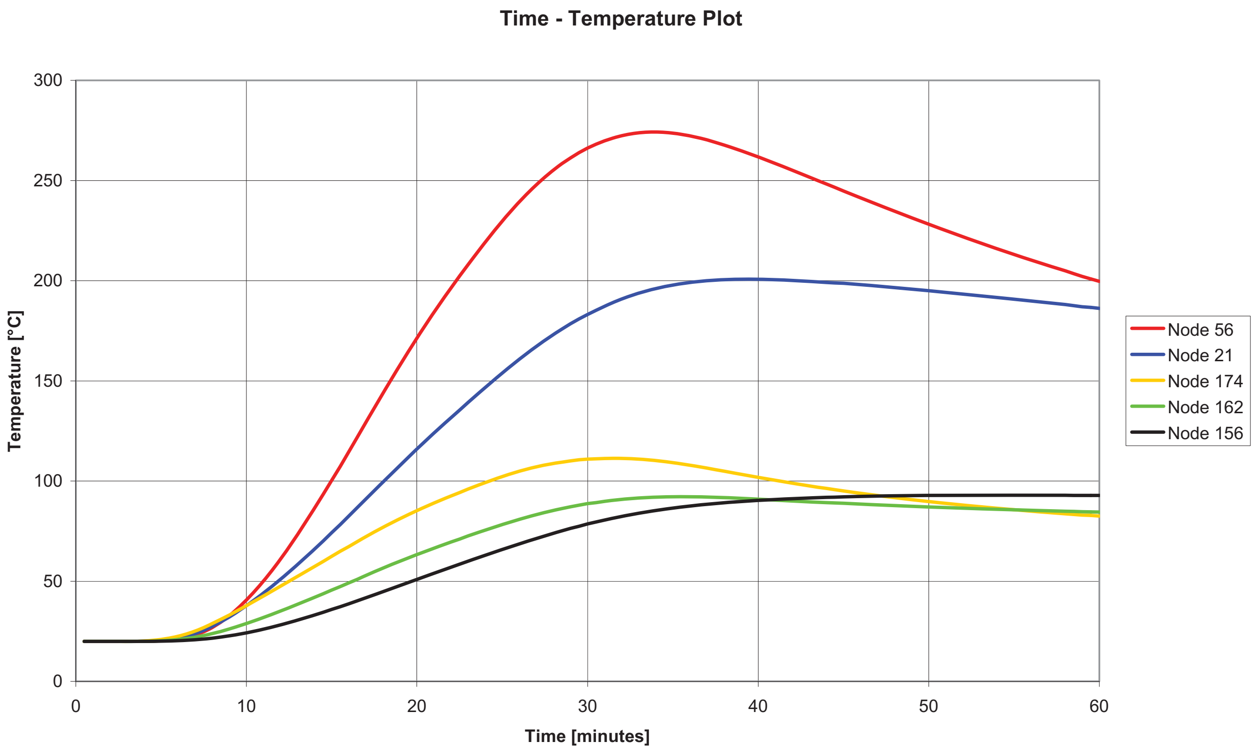

Fig. 33.21 Temperature evolution on the extended box protected crossbeam (case D)

33.6 SUMMARY AND CONCLUSIONS

This case study presents the thermal analysis of the main components of a double deck bridge, without any protection and with thermal protection, selecting several protection scenarios to ensure a maximum protection under minimum cost.

Analysing and presenting several cases to the beneficiary gives him the choice of selecting the best cost effective solution to be used.

Acknowledgement

The author would like to thanks Prof. dr. ing. Jean Marc Franssen from the University of Liege for his invaluable support and guidance.

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