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20 A PRACTICAL APPROACH TO STUDY OF FIRE RESISTANCE OF A STEEL STRUCTURE WITH OPEN BUILT-UP MEMBERS AND COLUMNS

Summary

The case study exposes a practical evaluation of fire resistance of an old structure of Spanish industrial building composed of steel built-up members; the truss members are angles connected through packing plates and the columns are battened chords.

A simple calculation model was used element by element. First, heat is transferred to individual steel elements by convection and radiation in thermal study. The contributions of these two modes of heat transfer were treated by a practical approach. In mechanical study, the second order analysis was used with global imperfections. Finally, the fire resistance was evaluated R15 after some proposals.

20.1 PRECEDENTS OF THE CASE

The analyzed industrial building is a steel workshop that was erected more than 25 years ago. In the past, there were no specific mandatory rules in Spain to regulate this kind of industrial structures against fire, consequently the fire resistance was not taken into account in the structural design process.

In 2006, in order to renovate the activities permissions, the authorities requested the company to be in accordance with the current Spanish standard for industrial buildings (RSIEI, 2005). Following this standard, the requirement was to resist 15 minutes in an ISO 834 standard, R15. The Spanish standard (RSIEI, 2005) allows the use of Eurocode 3 (EN 1993-1-2, 2005) for checking structural fire resistance.

The company contacted the university in order to know if the current structure could be able to resist R15 without any specific fire protection.

20.2 BUILDING DESCRIPTION

The structure of this industrial building is made by several frames separated 5m between them. Each frame has 17,2m of span and the total length and total surface of the building are 76,2m and 1341,5m^2 respectively. The frame is symmetric about its centre. Fig. 20.1 below, shows a detail of geometry (Tekla, 2011).

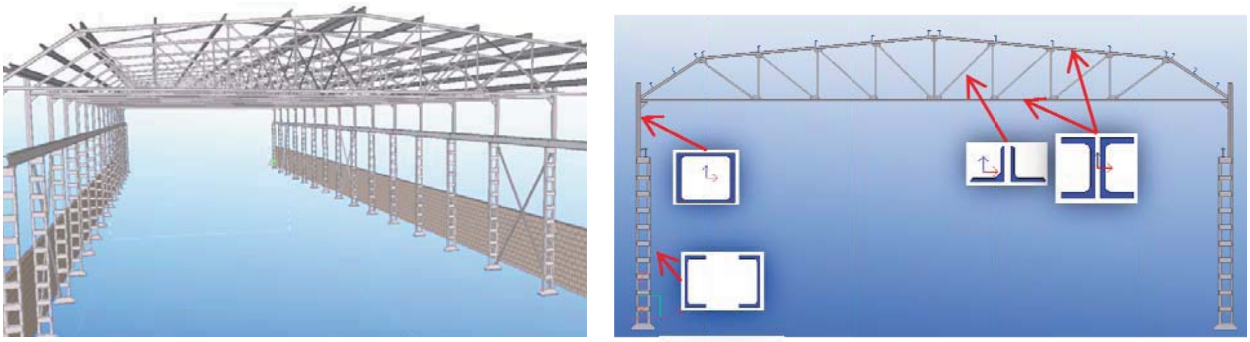


Fig. 20.1 Built-up members of the frame

Columns consist of battened built-up members of 7m height using two UPN 160 profiles, being separated at the part bellow the crane runway beam, and being a closed box above it. The column is fixed to the foundations and pinned to the truss. The upper and bottom chords of the truss are made by closely spaced built-up members using two UPN 80 profiles. They are connected through packing plates. The web members of the truss are spaced built-up members made up of battened equal angles L 40.4 or L 50.5.

Along the longitudinal direction, a resistant wall of 2,4m height offers a protection from the wind forces up to this height. As shown in Fig. 20.2, the longitudinal bracing systems in the walls and the roof provide fixed points to the frame; columns and truss. This construction results in a very light structure of 0,23 kN/m^2.

Fig. 20.2 Conventional bracing systems in the walls and rafter

20.3 ASSUMPTIONS FOR THE ANALYSIS AND REGULATORY REQUIREMENTS

The simple calculation model member by member was used to proceed in the resistance domain (EN 1993-1-2, 2005). This method is based on some appropriate hypotheses for their application to single structural members, for instance:

- No interaction between thermal and mechanical actions. Thermal and mechanical problems are solved independently.
- Effects of axial or in-plane thermal expansions may be neglected.

First, in thermal study, the uniform fire standard ISO834 was assumed for external temperature of the truss and columns in order verify R15 requirements (Fig. 20.3)

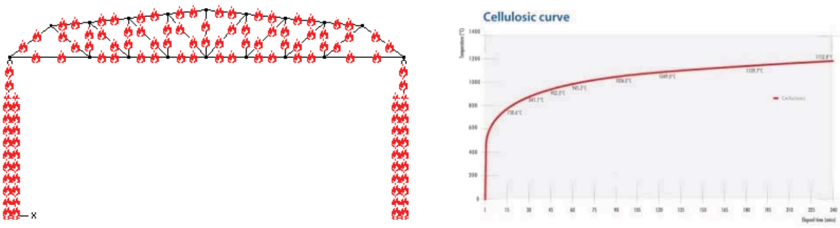


Fig. 20.3 Uniform fire standard ISO834 in the structure

Then, a global second order elastic analysis was carried out with constant elastic modulus for steel at normal temperature design, 20ºC. The boundary conditions at supports were assumed to remain unchanged throughout the fire exposure. Finally, the resistance and buckling were checked according to Eurocode 3 Part 1-2 (EN 1993-1-2, 2005). The Fig. 20.4 shows the procedure scheme.

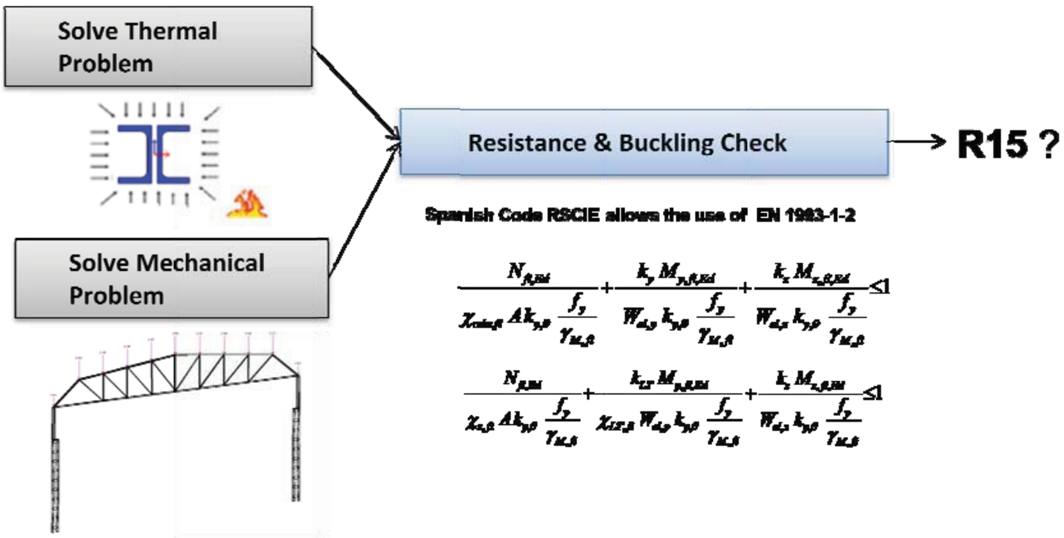


Fig. 20.4 Scheme of simple calculation model in resistance domain

20.4 RESOLUTION OF THE THERMAL PROBLEM

To solve the thermal problem and to know how the temperature increases in the specific built-up sections, we have used commercial finite element software. It allows the simulation of transient heat transfer in 2D free-form objects (Brista-Physibel, 2011) where the view factor is based on non-linear radiation, and the empirical convection in enclosures and boundaries. In practice, the results were very similar as use the conventional concept of the correction factor for the shadow effect for sections under nominal fire actions (EN 1993-1-2, 2005). Other models based in partial heat radiation, limited inside of built-up sections, were not considered since lower temperatures were obtained. Finally, Fig. 20.5 shows the temperature results for each cross section type after ISO 834 fire curve.

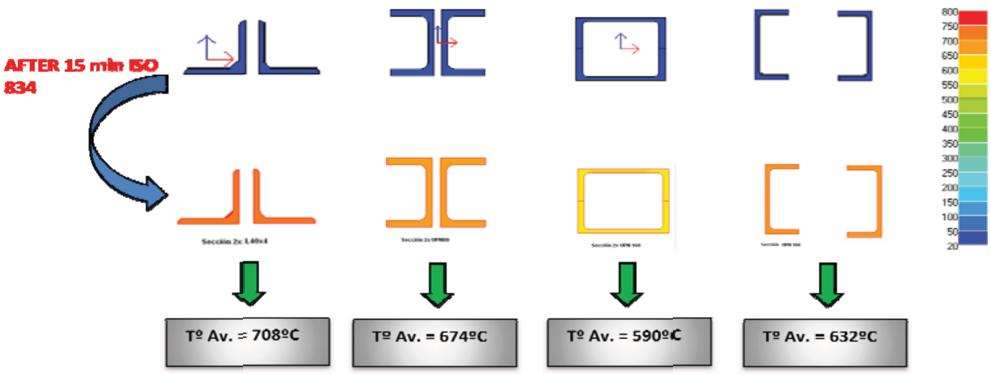


Fig. 20.5 Temperature distribution in built-up members after 15 minutes fire standard ISO 834

20.5 RESOLUTION OF THE MECHANICAL PROBLEM

A 2D model was used to solve global analysis and to know the internal mechanical efforts in a fire scenario, using the second order analysis by conventional structural software (PowerFrame, 2011). The frame is fixed in the longitudinal direction by the bracing systems. The next sub steps have been done:

20.5.1 Model

The truss beam members have modeled as their center of gravity axis lines with their respectives built-up sections in the software. In order to obtain more realistic efforts, the columns have been modeled as two different lines for each UPN chord connected by the battens in their real positions (see Fig. 20.6)

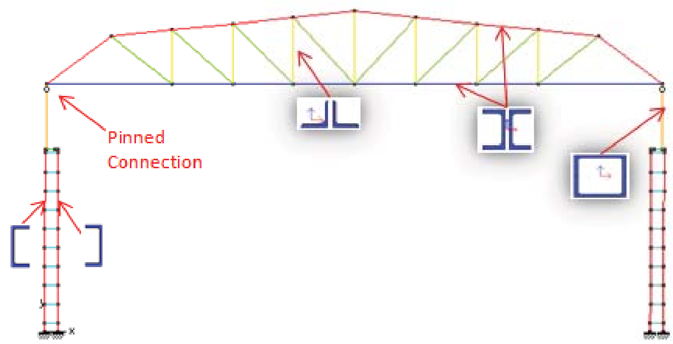


Fig. 20.6 The built-up columns were simulated by individual beams in a conventional global 2D model

Rigid links has been introduced in the model, as showed in Fig. 20.7, in order to take into account the eccentricities due to the change of section in battened columns and the exact position of the load from crane.

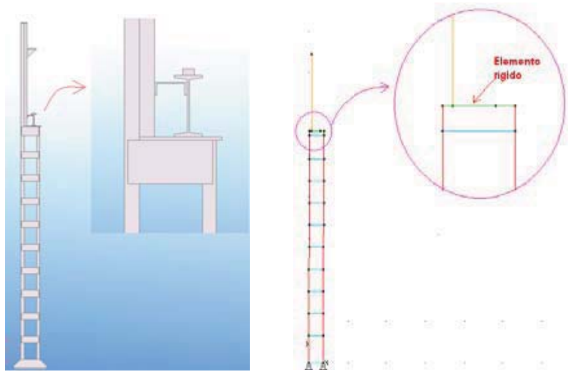


Fig. 20.7 Eccentricities of crane beam loads

20.5.2 Applied loads and relevant combinations

All loads taken into account are shown below. It must be said that loads for all kind of buildings have to be in accordance to the Spanish Technical Code (CTE, 2006), which describes climatic loads, majority factors and load combinations in fire scenario (see Fig. 20.8 and 20.9). Special considerations were done for the crane in fire scenario, only self weight of the crane and its accessories were used in two relevant positions (Fig. 20.10)

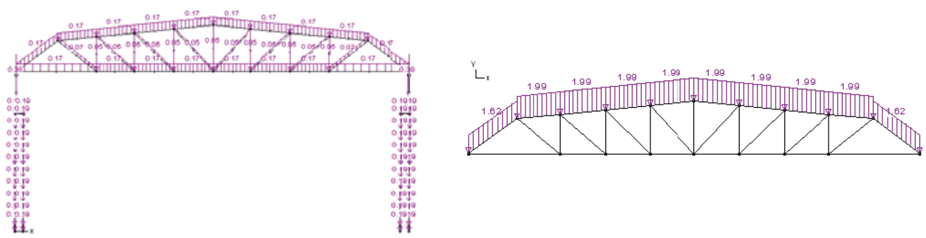


Fig. 20.8 Self weight, permanent loads and snow loads

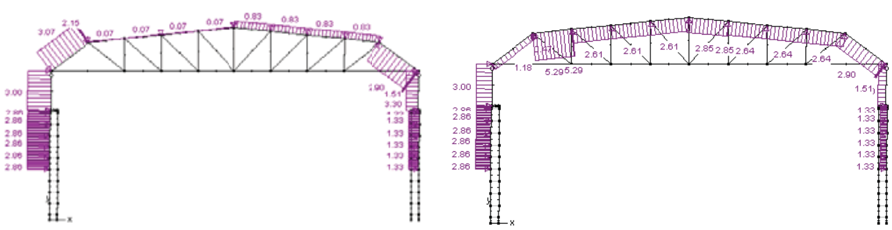


Fig. 20.9 Wind loads; two load cases from Spanish Technical Code (CTE, 2006)

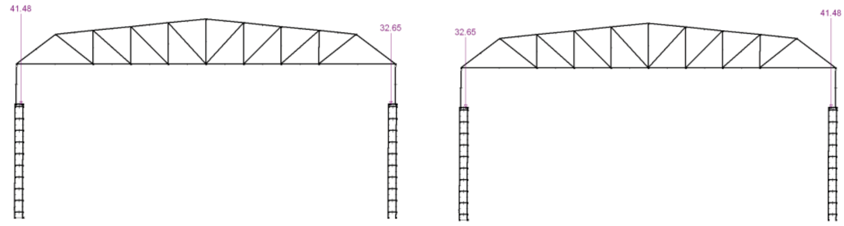


Fig. 10 Loads from the crane in fire scenario for two relevant positions

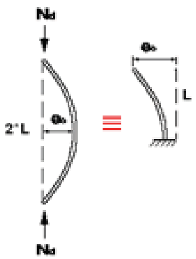
The effect of actions was determined using combinations factors $\psi_{1,1}$ and $\psi_{2,i}$ according the Spanish Technical Code (CTE, 2006):

$$\Sigma G_{k,j} + \psi_{1,1} Q_{k,1} + \Sigma \psi_{2,i} Q_{k,I} \qquad (1)$$

These values have significant differences front the recommended national values of Eurocode. For instance, in case of wind action the factor $\psi_{1,1}$= 0,5 versus recommended national value $\psi_{1,1}$= 0,2 from Eurocode.

20.5.3 Analysis Type

A global second order elastic analysis, including global imperfections at the top of the columns, has been carried out. No information was found about special indications to apply global imperfection in battened columns under fire conditions; so, the common value L/500 for standard conditions was used.



$$e_0 = 2 \cdot L / 500$$

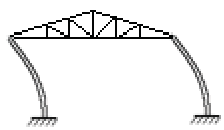


Fig. 20.11 Imperfection e_0 used in battened built-up columns

20.5.4 Flexural buckling critical length in members

The existence of two possible buckling planes shall be taken into account, requiring different checks. As long as the simplified method is used to solve the fire problem, the common buckling critical lengths used in non fire cases were implemented.

- Buckling lengths in upper chord of truss. The length of each split member for the buckling in the plane (β_y=1) was taken as buckling length. For the out of plane buckling, the original bracing system was modified to fix every node out plane (β_z=1). No considerations of diaphragm effect are considered.
- Buckling lengths in bottom chord of truss. There is no compression.

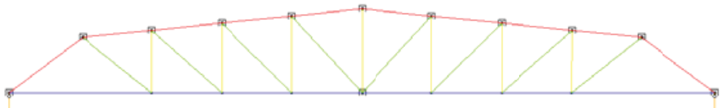


Fig. 20.12 Fixed points for out of plane flexural buckling of truss members

- Buckling lengths in battened columns. Plane buckling length of chords of columns is equal to the distance between two battens (β=1) because a second order analysis was carried out with global imperfection (see 20.5.3). In order to know the out of plane buckling length of the columns, a eigen buckling analysis was carried out using the commercial software (Consteel, 2011) (see Fig. 20.13). The second eigenvalue was used to calculate the out of plane buckling length. It was necessary a modification of original bracing system. No diaphragm effect was considered.

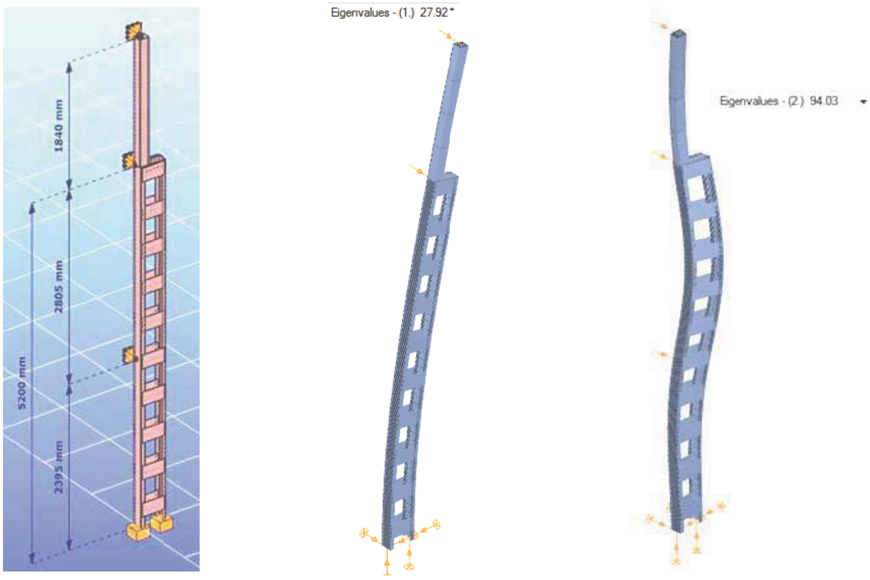


Fig. 20.13 Model with boundary restrictions and the first (in-plane) and second (out-plane) buckling modes

20.6 CHECKING ALL MEMBERS OF THE FRAME

For verifying standard fire resistance requirement, for instance R15, a member analysis is enough. Each member of the frame is checked at calculated temperature and compared with the efforts in fire scenario (EN 1993-1-2, 2005):

$$E_{fi,d} \leq R_{fi,d,t} \qquad (2)$$

20.7 CONCLUSIONS

Spanish standard for industrial buildings lets the engineer to apply modern concepts of fire engineering and allows the use of structural Eurocodes. A prescriptive requirement for structural resistance of old industrial Spanish building was verified. This building had a problematic light structure composed of steel built-up members. The thermal and mechanical study of these open members was treated by a practical approach using several commercial software. The simple calculation model in resistance domain was enough to verify the requirement of R15. Only the bracing system must be reconsidered.

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