3D simulation of Industrial Hall in case of fire
Benchmark between ABAQUS, ANSYS and SAFIR

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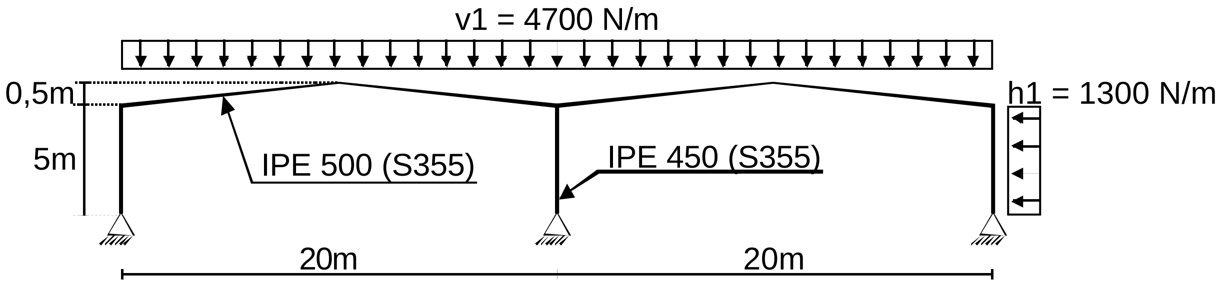
INTRODUCTION

For simple storey buildings, the structural behaviour in case of fire is relevant only for the safety of the firemen. The protection of occupants and goods is a matter of fire spread, smoke propagation, active fire fighting measures and evacuation facilities. Brittle failure, progressive collapse and partial failure of façades elements outwards may endanger the fire fighters and have to be avoided. In order to deal with such an objective, the simulation softwares has to cover the 3D structural behaviour including membrane and restrained effects as well as the failure mode so that post-local failure stage can be analysed. Such calculation models (ANSYS, ABAQUS and SAFIR [1]) have been compared true a benchmark. In this benchmark, two different users used ABAQUS.

BENCHMARK DEFINITION

This benchmark is based on the following structure :



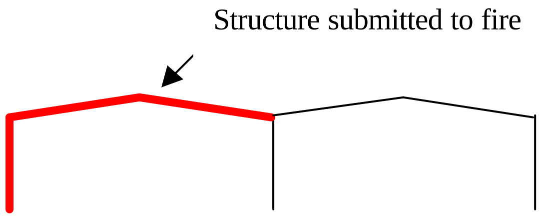
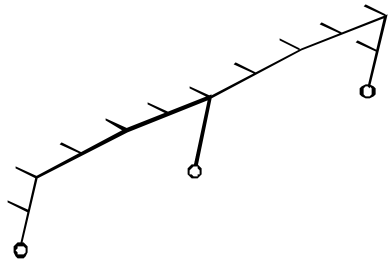
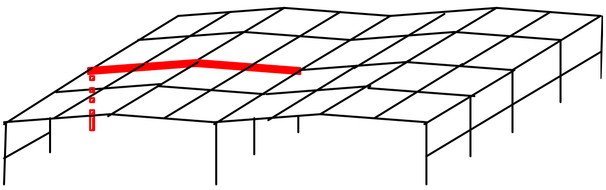
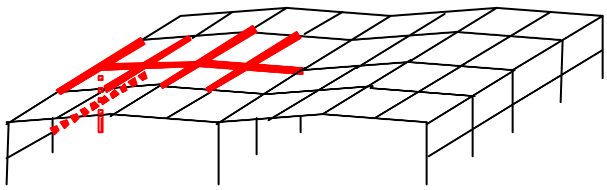
The material laws for thermal and mechanical properties come from the EC3 Fire parts [2]. For the mechanical properties, the strain hardening is not considered.
All the profiles will be assumed class 1 section during the fire.
For the calculation of the temperature in the steel, an ISO fire curve is considered [3].
For the thermal transfer, convection and radiation have been considered true the following parameters:

α = 25 W/m^{2}K
ε = 0.5

No shadow effect has been taken into account.

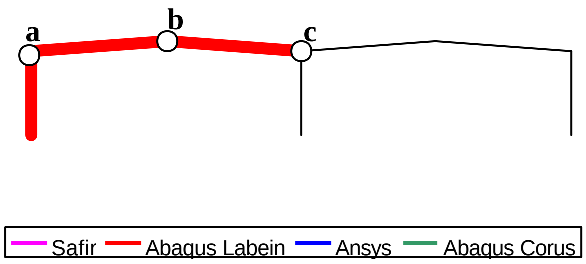
The simple calculation method of EC3 [2] will be used to evaluate the temperature curves of steel members (IPE 450, IPE 500). This lead to an uniform distributed temperature in the cross sections.

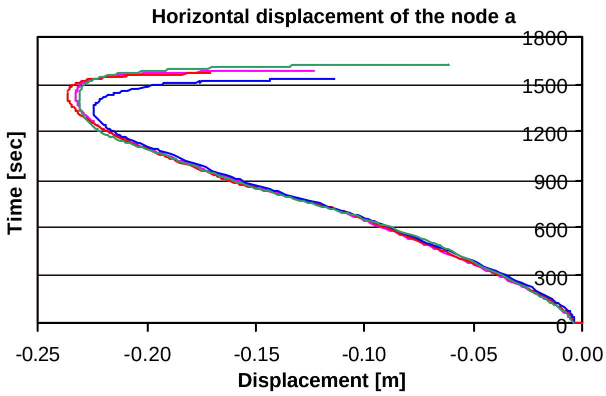
The study is composed of 4 parts :

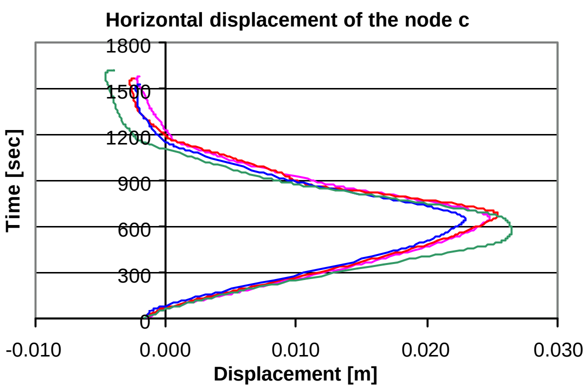
a double frame in 2 dimension 	***a double frame in 3 dimensions partially maintained in the third dimension*** 
a full study in 3 dimensions with more than one double frame 	***a full study in 3 dimensions with more than one double frame and hot purlins*** 

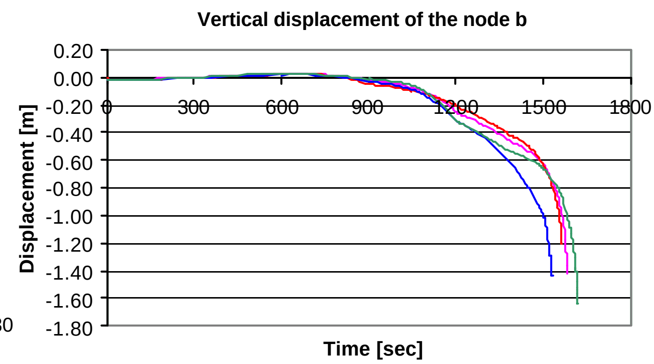
RESULTS IN 2 DIMENSIONS

- Evolution of the horizontal and the vertical displacements at different places (Nodes a to c) with respect to time :



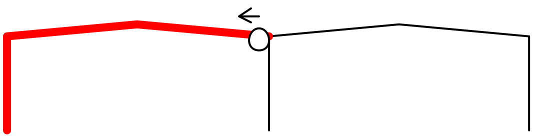


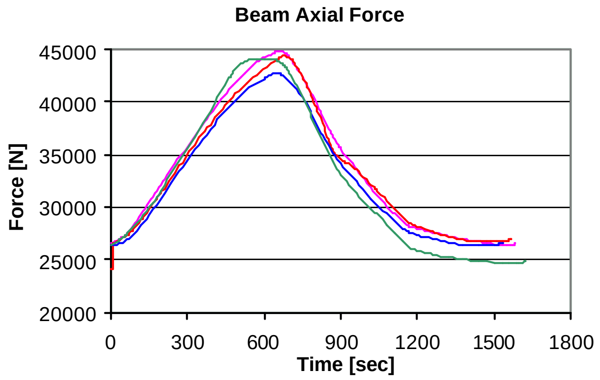




After analyse of these different figures it is expected that the left frame collapses towards the inside of the building. Unfortunately, the statical finite element calculation stops before the node a (top of the heated column) had come back to the inside part of the building.
In order to avoid this annoyance, the possibility to perform a dynamic analysis of the structure has been studied with the different softwares [4]. Dynamic approach has been applied to the full 3D calculation.

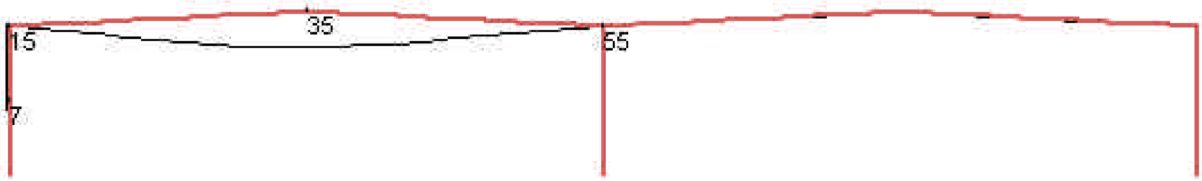
- Evolution of the normal force with respect to the time at the connection between the central column and the beam under fire :





This figure shows that until the end of the simulation, the hot part of the structure pushes on the cold part (which remains stable) and the value of this force is not bigger than the effect of the wind in service condition.

- Drawing of the deformed structure without amplification of the deformations :



This figure shows that the failure mechanism is a beam mechanism. The right frame, which is not under fire, remains at its initial position and does not suffer from the left frame collapse.

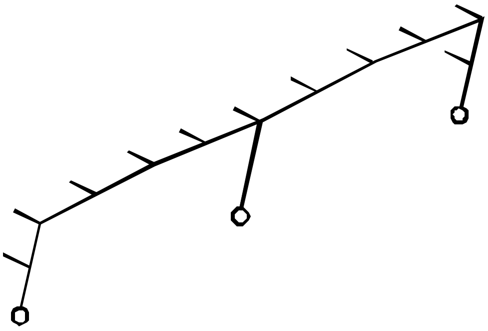
RESULTS IN 3 DIMENSIONS

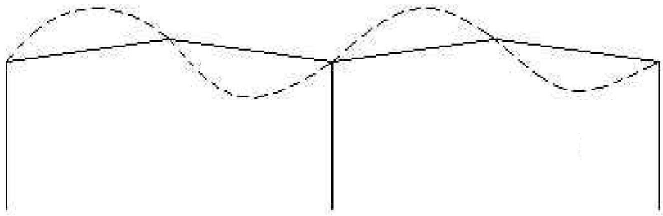
One frame in 3 dimensions

This case represents the same structure as the one in 2 dimension, but the out-of-plane displacements are here allowed. For recall, the supports of the structure are made of hinges, it means that some fixations in the third dimension must be added (the 11 fixations in the third direction are shown on the next figure). These restrains are provided, in the reality, by the purlins.

The only initial deformation is in the plan XY according to the Y axis. The maximum value is L/1000 = 0.01 m. There is no initial deformation for the column because moment at the top should be sufficient to initiate displacement perpendicular to the plan XZ.

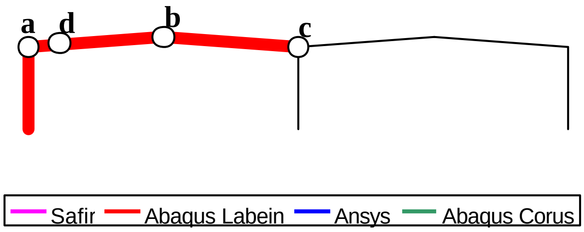
So the two next figures show the fixed points in the third dimension Y and a scheme of the initial deformations:

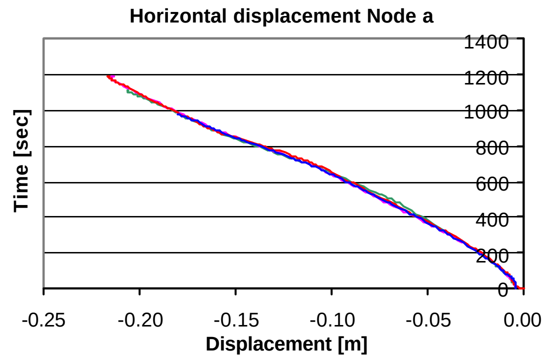


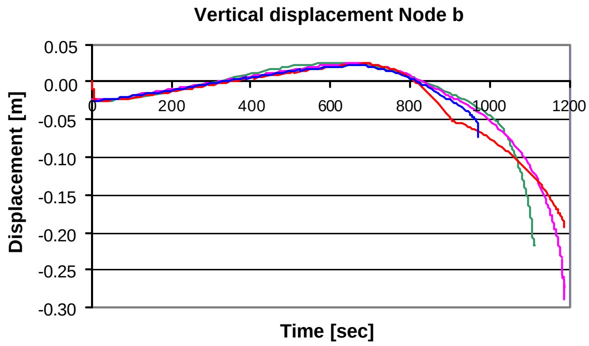


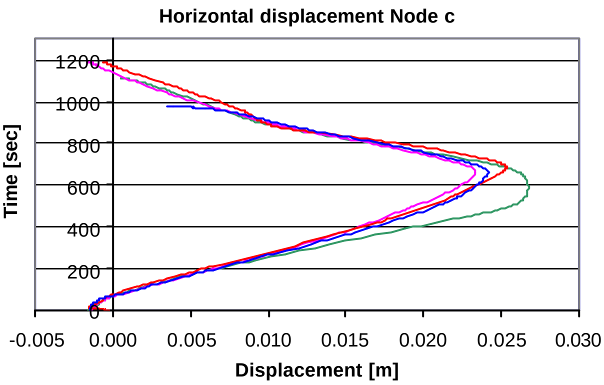
- Evolution of the horizontal and the vertical displacements at different places (Nodes a to d) with respect to time :

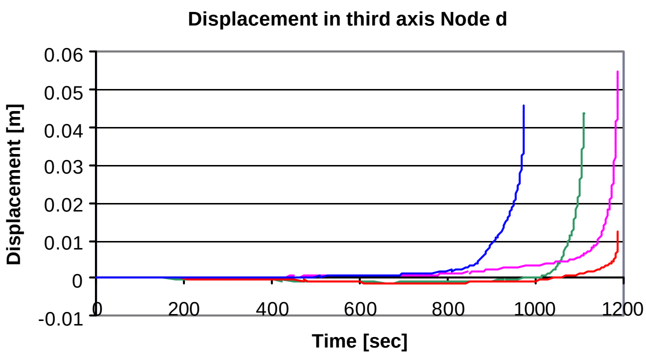
As you can see in the following figure, the node d is located at 1/4 of the length of the first beam:





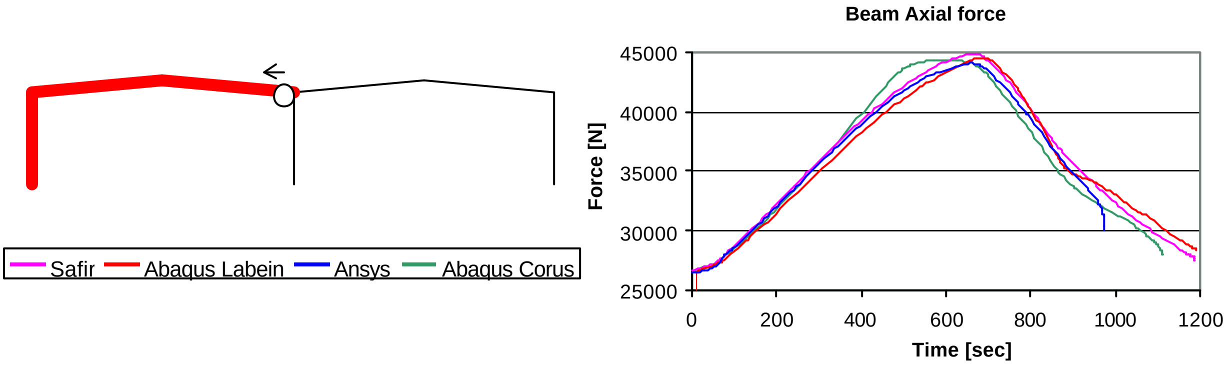






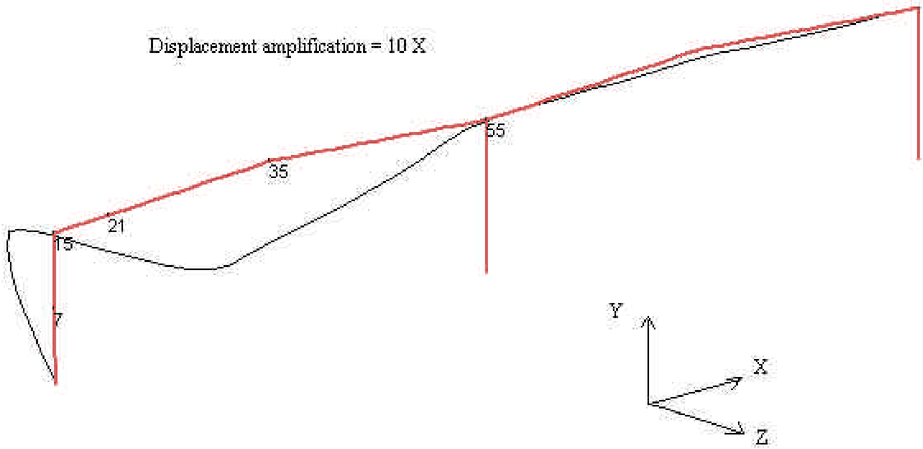
The collapse of the structure occurs some minutes before the 2D analysis due to the lateral buckling of the beam under fire.

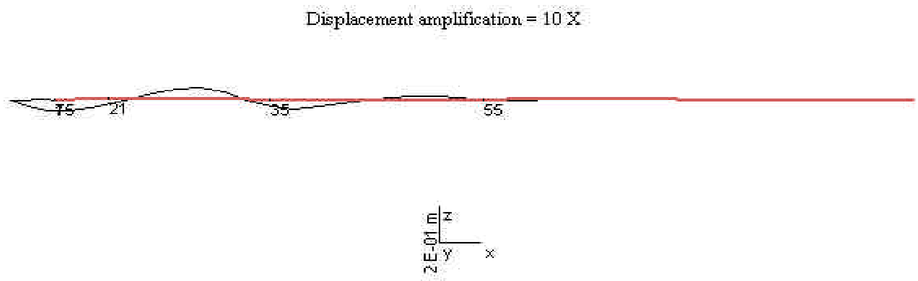
- Evolution of the normal force with respect to the time at the connection between the central column and the beam under fire and at the connection of the central column and the beam without fire :



The axial forces applied on the cold part of the structure are on the same order of magnitude than the 2D analysis.

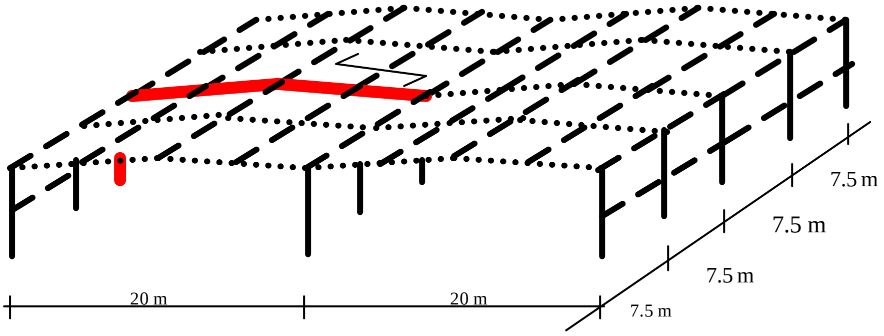
- Drawing of the deformed structure with amplification of the deformations :





In 3 dimensions with more than one frame

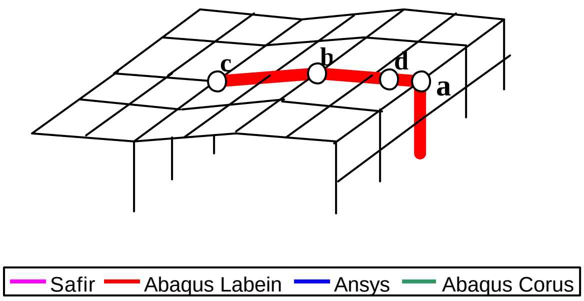
The frame is now included in a full 3D structure with other parallel frames connected to the first one by purlins. As in the precedent cases, the only central left frame is heated.

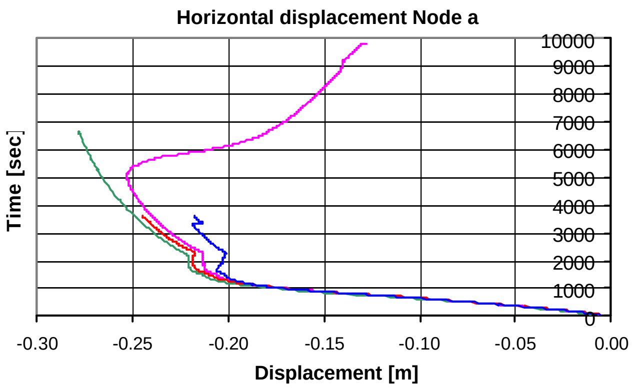


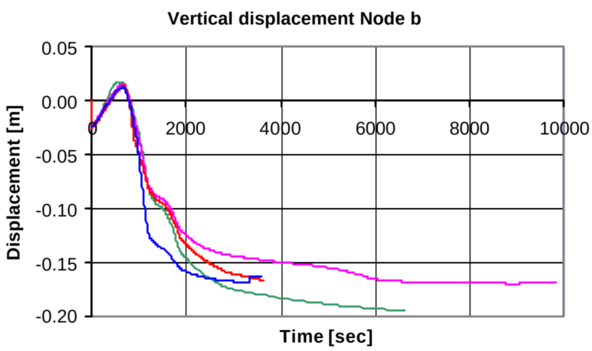
The initial deformations are the same ones as at the preceding point and are applied only to the central double frame.
The 3 displacements (X, Y, Z) are the same for the purlins and for the beam.
For the rotation, **the rotation around the Z axis are the same** for the beam and for the purlins because the purlins are fixed by 2 bolts on the beam. But the **rotation around the X axis, Y axis and the warping are free** between the purlins and the beam.
The structure is maintained in several points to simulate the presence of wind bracing.
For the loads, every purlins are loaded to have a simulation closed to the reality.

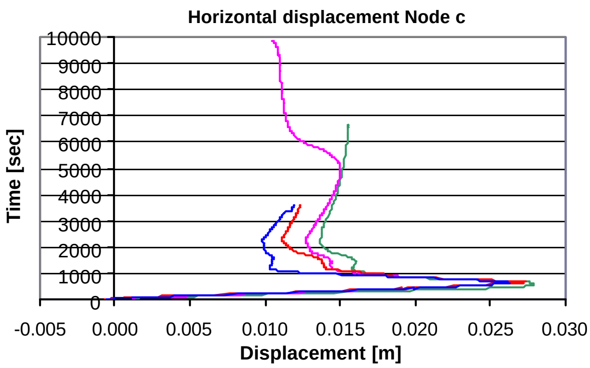
- Evolution of the horizontal and the vertical displacements at different places (Nodes a to d) with respect to time :

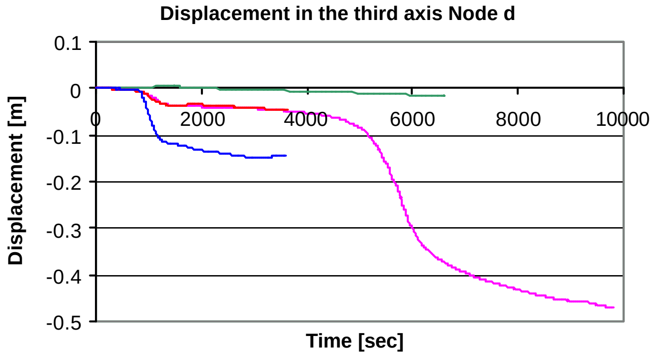
As you can see in the following figure, the node d is located at 1/4 of the length of the first beam :





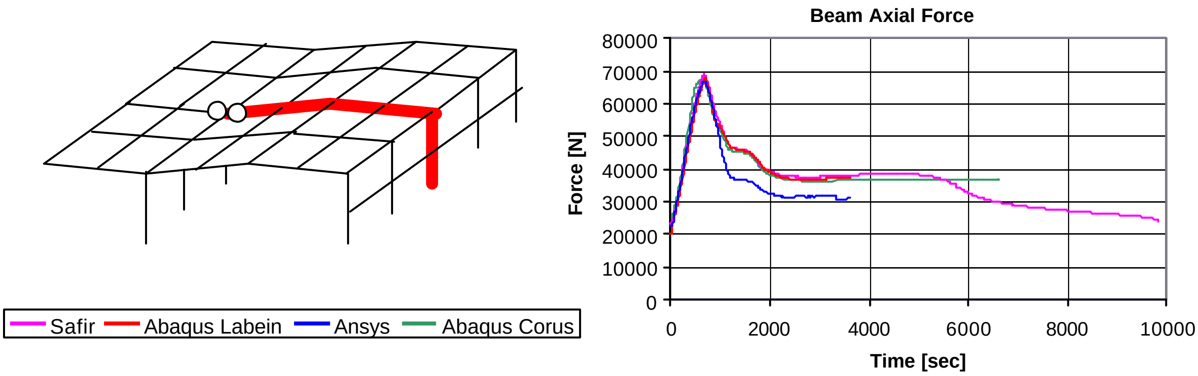




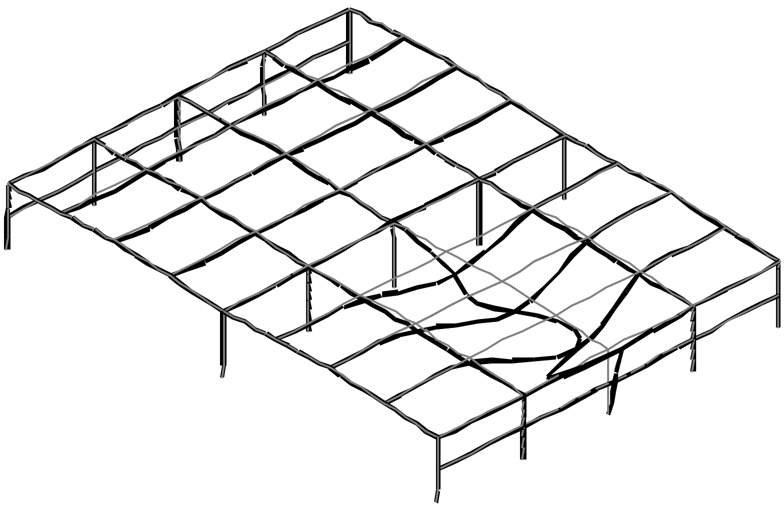


The collapse of the structure is not really visible. Progressively, the loads applied to the central frame are transferred to the neighbouring frames, and finally the two neighbouring frames through the purlins withstand the central frame. That explains why the reached time is greater in this case than in the 3D case with only one frame. This phenomenon is due to the fact that in this case, the purlins remain cold.

- Evolution of the normal force with respect to the time at the connection between the central column and the beam under fire and at the connection of the central column and the beam without fire :



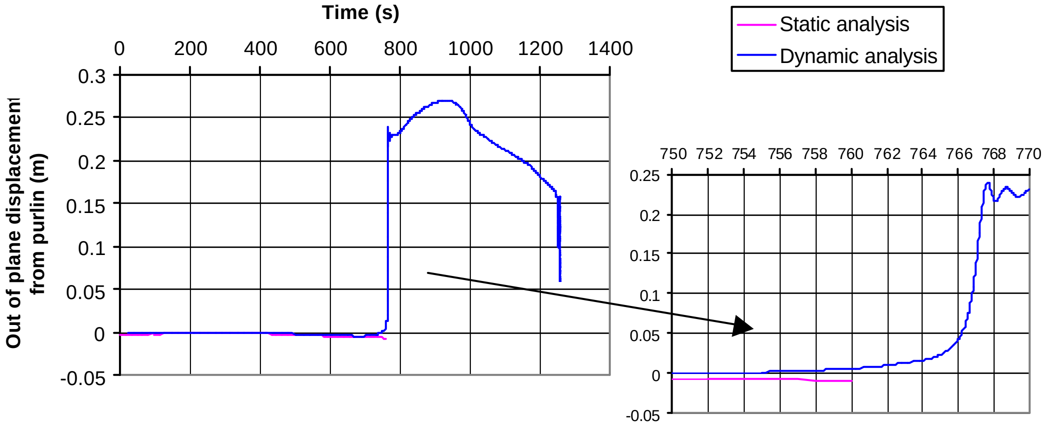
- Drawing of the deformed structure with amplification of the deformations = 10X :



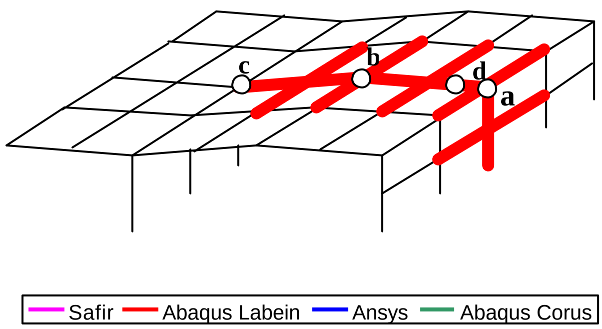
In 3 dimensions with more than one frame and with hot purlins

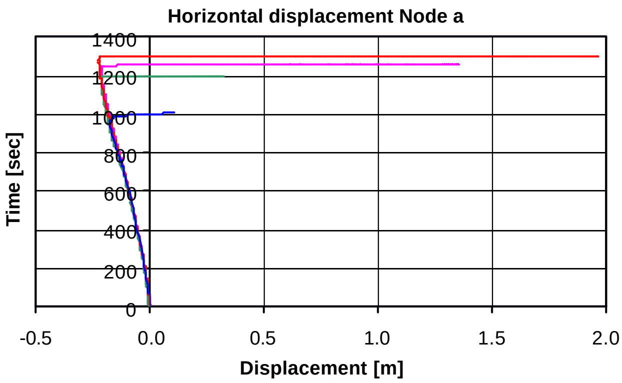
The structure and the hypotheses are exactly the same than in the precedent point but the number of hot profiles is different, the purlins connected to the heated frame are also affected by the fire.

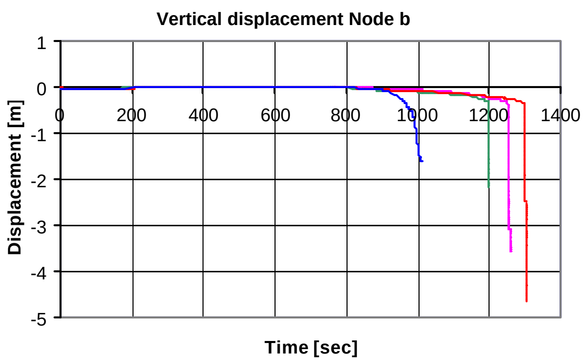
In a first step, statical analyses were made using the different softwares. But a lateral buckling of a purlin occurs after approximately 790 seconds (see following figures). This event explains why the static analysis stops at this time. The dynamic analysis allows following this buckling and so that post-local failure stage can be analysed.

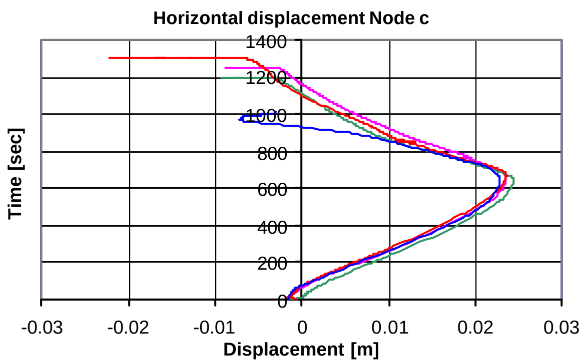


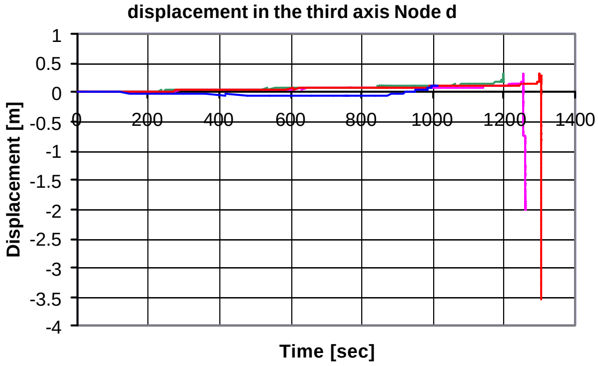
As you can see in the following figure, the node d is located at 1/4 of the length of the first beam :



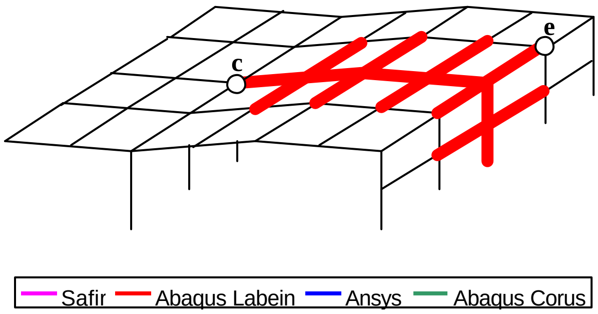


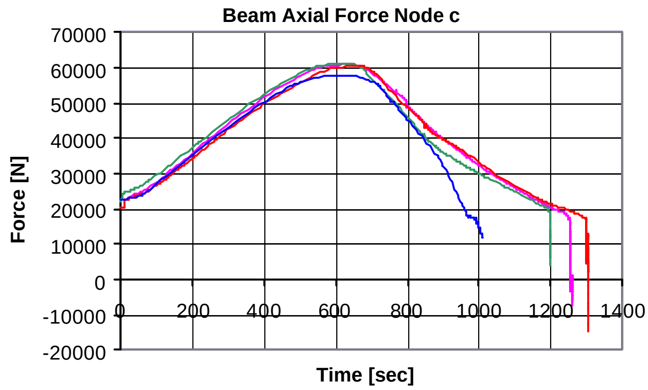


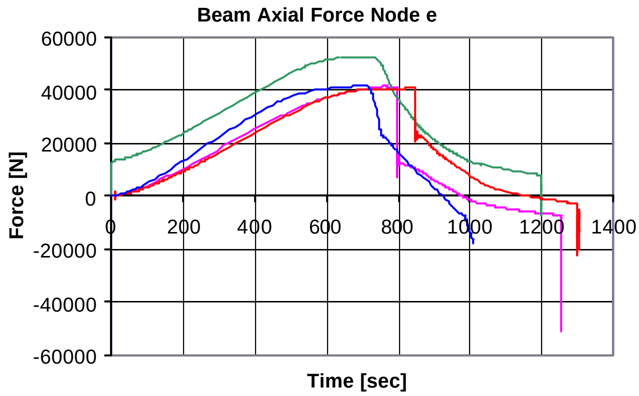




- Evolution of the normal force with respect to the time at the connection between the central column and the beam under fire and at the connection of the cold frame and the purlins under fire :

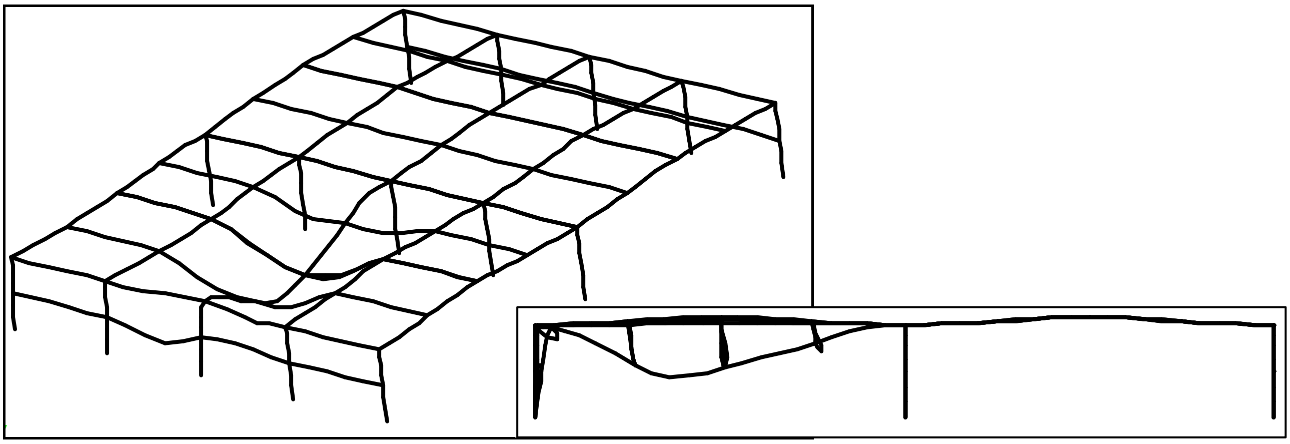






The evolution of the normal forces in the purlin at point e shows the instantaneous buckling at approximately 800 seconds. When the purlin buckles the normal force falls. That physical phenomenon made the convergence not possible for simulation without activate the dynamic approach. At the final time, the hot part of the building pulls on all the cold parts but the value of this force remains acceptable to not endanger this part.

- Drawing of the deformed structure without amplification of the deformation :



This figure shows that we can now simulate the behaviour of the global structure until the complete failure and very large displacements.

CONCLUSION

This paper has presented a comparison between different FEM softwares (ABAQUS, ANSYS and SAFIR) analysing 3D structures. Some benchmarks were realised in the past to compare different softwares [5] but always simulations in two dimensions. Some new regulation imposed to predict the failure mode and to verify the non-progressive collapse. So that 3D model are required. This benchmark shows that the three softwares give close results for the three dimensional analysis. In the last simulation, the dynamic analysis has enable to analyse the structural behaviour after the buckling of the purlins so that post-local failure stage could be analysed.

By means of theses three softwares, it's now possible to simulate the complete failure mechanism, to predict the influence of a local failure on the global behaviour of the structure and to follow eventually the progressive collapse. Therefore the resistance time is now really determined where in the past many numerical failure corresponding to local failure were interpreted as resistance time of the whole structure.

REFERENCES

[1] SAFIR , *A Computer Program for Analysis of Structures Submitted to the Fire*, University of Liège, Department Structures du génie Civil, Service Ponts et Charpentes (2000)

[2] EC-3 prEN 1993-1-2, European Prestandard Draft, *Eurocode 3 : "Design of steel structures", Part 1.2 : Structural fire design*, European Committee for Standardisation – CEN, Brussels (2001)

[3] ISO 894-1, *Fire-resistance tets – Elements of buildings construction, Part 1: General requirements*, ISO (International Organisation for Standardisation), Geneva

[4] "*Fire Safety of Industrial Halls and Low-rise Buildings : Realistic Fire Design, Active Safety Measures, Post-local failure simulation and Performance Based Requirements*", ECSC Research 7210-PA/PB/PC/PD/378

[5] J.B. Schleich, L-G. Cajot, J. Kruppa, D. Talamona, W. Azpiazu, J. Unanue, L. Twilt, J. Fellinger, R-J. Van Foeken, J-M. Franssen, *"Bucking curves of hot rolled H steel sections submitted to fire"*, ECSC Research 7210-SA/316/515/618/931, Final report EUR 18380 EN, Luxembourg, (1995)