7th International Conference on Structures in Fire
M. Fontana, A. Frangi, M. Knobloch (Eds.)
Zurich, Switzerland, June 6-8, 2012

FIRE ANALYSIS OF A NEW STEEL BRIDGE

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Keywords: Fire, Structures, Bridge, CFD, F.E. analysis.

Abstract. *The new steel bridge "Hans-Wilsdorf" in Geneva is an exceptional steel structure that will drive general traffic through a main transportation axis. As the investment cost of the project is important, a structural fire analysis has been performed to study the sensitivity of the structure to a high temperature exposure, such as a truck in fire on the deck. This analysis will allow deciding whether a severe fire could be an unacceptable economical risk for the bridge.*

1 INTRODUCTION

Fire protection or fire analyses are rarely applied to bridges. When a new steel bridge is designed, fire is normally not an issue, especially if it crosses a river without navigation. But when a special project, donated to the City of Geneva by the Hans-Wilsdorf Foundation, is shaped like a "tunnel" of steel, the question may be asked: "And what about a fire on the bridge?"

This project is not a usual bridge. Its architecture is modern and spectacular. Carefully designed by *Brodbeck-Roulet* architects in Geneva and *Amsler&Bombelli* engineers in Lausanne, the main structure is made of several arches intersecting each other and the deck is made of a prestressed composite steel-concrete section. The 85m single span bridge weights 3000 tons.

Figure 1. Virtual image of the bridge (image © Brodbeck-Roulet SA)

The structural design and optimization of such a bridge is very complicated, even in normal “cold” ULS situation. So, when the fire resistance of the structure have been asked and investigated, many questions must find answers, and the use of advanced analysis methods and tools is necessary.

This fire design has been done by Eric Tonicello, *MP Ingénieurs Conseils* in Crissier, and checked by Sylvain Desanghere (FDS models and simulations), Olivier Vassart and Jean-Marc Franssen (SAFIR model).

2 STRUCTURE OF THE BRIDGE

The 85m single span bridge structure has been designed for the cold ULS situation, and led to the following structure:

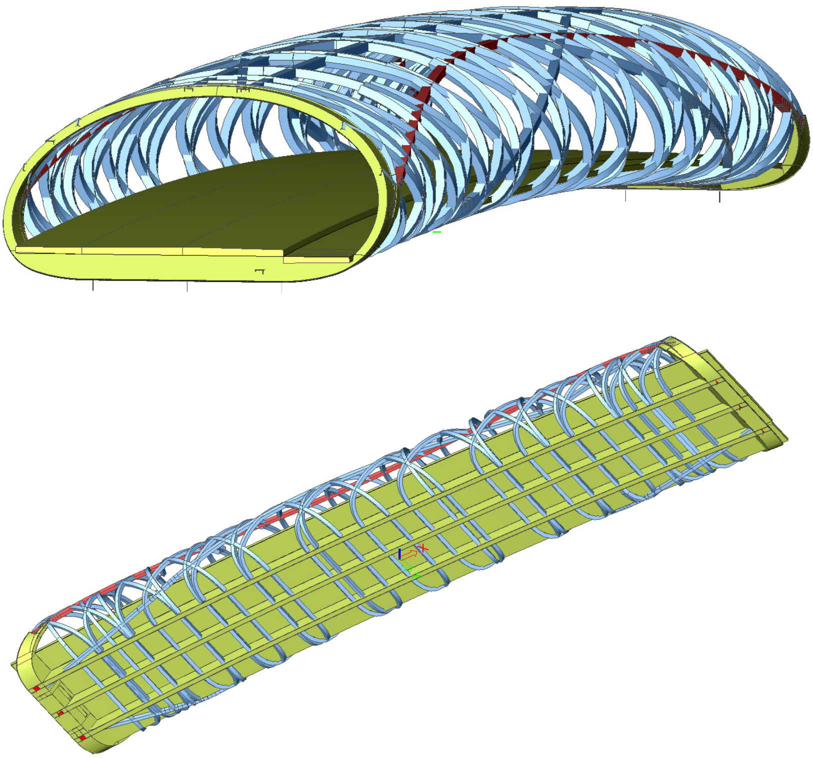

Figure 2. Different views of the SCIA Engineer design model

The deck is a prestressed RC composite slab, which is surrounded by a very complex 3D steel grid, made of welded steel sections.

The whole steel structure has been optimised and designed for optimum performance. Each truss member is a parallelepiped section (boxes size is about 400x400 mm), with continuously skewed sides and thicknesses varying from 25 till 100 mm, made of steel grade S355 or S460. The lower members, working a composite section with the concrete slab, are 1 000 mm height and 400 mm width.

The assembly of the bridge was made onsite, fully welded, for better quality and aesthetics. The bridge weights 3 000 tons, from which half is reinforced concrete and half is construction steel.

3 FIRE ANALYSIS

3.1 Normative thermal actions

To analyse the thermal actions, several fire curves where considered in preliminary investigations (figure 3): ISO and hydrocarbon ones, besides a special artificial fire curve considering that the firemen could not be on site the immediately. This assumption is done modifying an ISO curve where the temperature starts decreasing after 30 minutes, until reaching 20°C at 60 minutes.

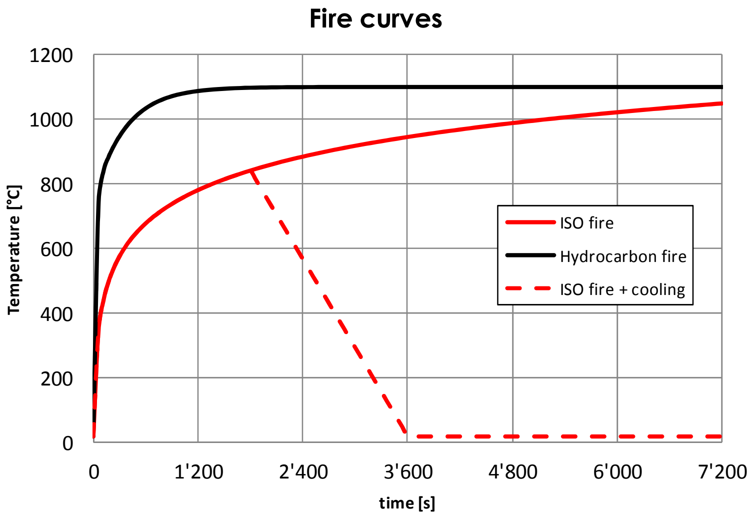

Figure 3. Fire curves used for the preliminary calculations

These first three scenarios should provide enough information about the thermal elevation sensitivity of the steel members. The first element to be heated with SAFIR software [1] is the arch section, made of a 400 mm side box with a plain round steel section, diameter 300 mm, inside.

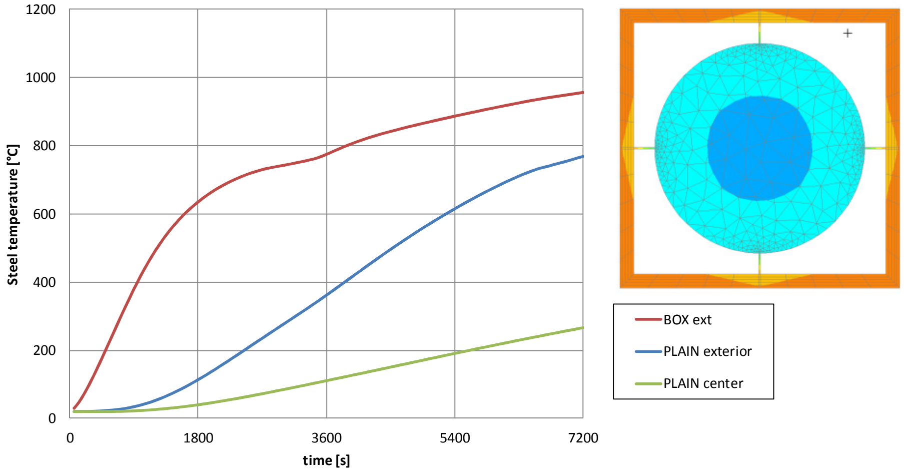

Figure 4. Arc section’s steel temperature with ISO fire

We can observe that, if the inner plain section remains quite cold (< 400 °C) after 1 hour of ISO fire exposure, the outer box heat rapidly, losing its bearing capacity. The engineers intuition is then confirmed: they added this plain section inside the arch box to reinforce the bridge, as well as offering a “little” fire resistance. This calculation shows that full resistance could be reached by this structural element; to be confirmed by the structural design later.

The hydrocarbon fire led to worse results, as expected, and the “ISO + cooling” scenario gave better results. The effect on the full bridge will be analysed later with the structural model.

3.2 CFD fires

After the standard fires calculations first results, and having in mind the architecture and the shape of the structure, the only realistic way is to run several CFD simulations, carried out with FDS [2] software and using several fire scenarios. These scenarios are mainly based on the recommendations issued by CETU in France [3], and others were discussed with the main engineering office.

To represent in a real way the modelled fire in a CFD model, we need to quantify the potentially energy that will we liberated during the fire. In our case, a normal car and a truck were available in the references we used [3]:

- Car $Q_{f,k}$ = 8 [MW]
- Lorry $Q_{f,k}$ = 30 [MW]
- Truck $Q_{f,k}$ = 100 [MW]

The HRR diagrams are given in the CETU guide:

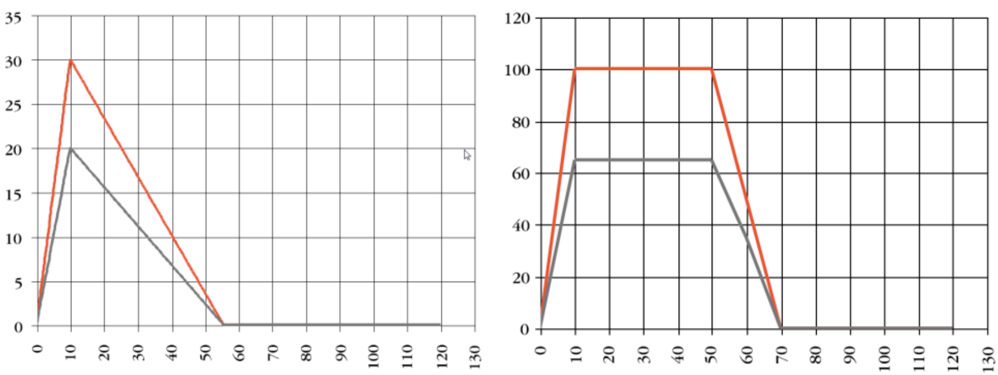

Figure 5. HRR diagram for a little truck (30 MW) and big (100 MW) truck in [MW and min] [3]

With these hypotheses, several scenarios were calculated using FDS software. Here we can see the truck scenario heating a simplified representation of the real structure, as in FDS version 5 mesh grid is only orthogonal. To get the adiabatic gas temperatures seen by the structure, a number of captors were set in the model.

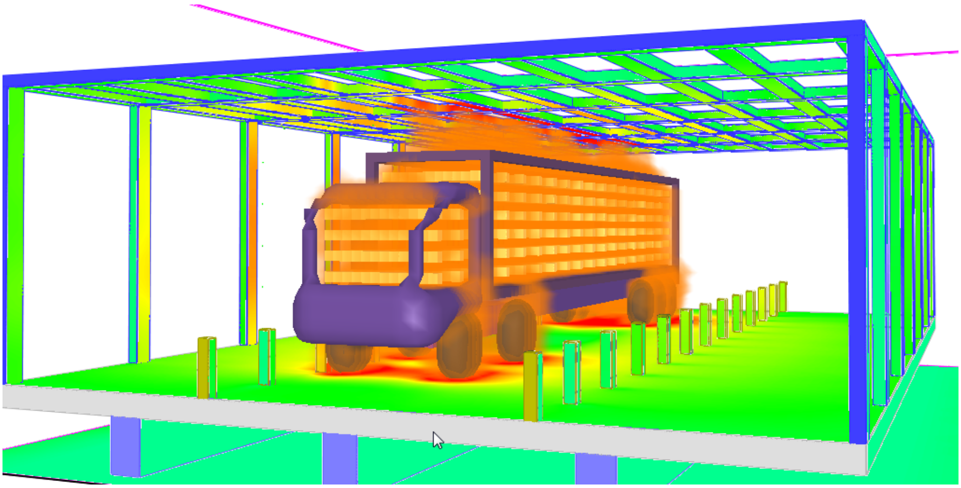

Figure 6. FDS simulation of a burning truck on a simplified geometry of the bridge's structure

The resulting adiabatic temperatures provided by FDS as input data in the structural model to analyse the section's heating and then the structural response of the bridge.

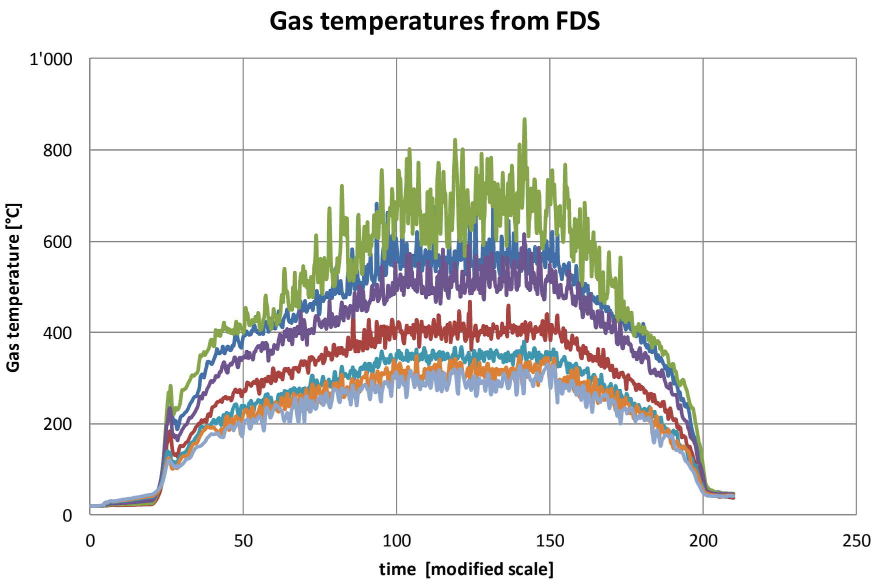

Figure 7. Adiabatic temperatures extracted from the FDS model

Figure 7 shows that the time scale has been modified. This has been done to reduce computational times. Indeed, FDS is used here only to compute thermal actions corresponding to a given heat release rate. Members' heating is not considered and we don't have to simulate the real fire curve in this first step.

In a second step, from these data, simplified fire curves were made, to be used as input in SAFIR 2D section heating calculation (as made with the ISO fire):

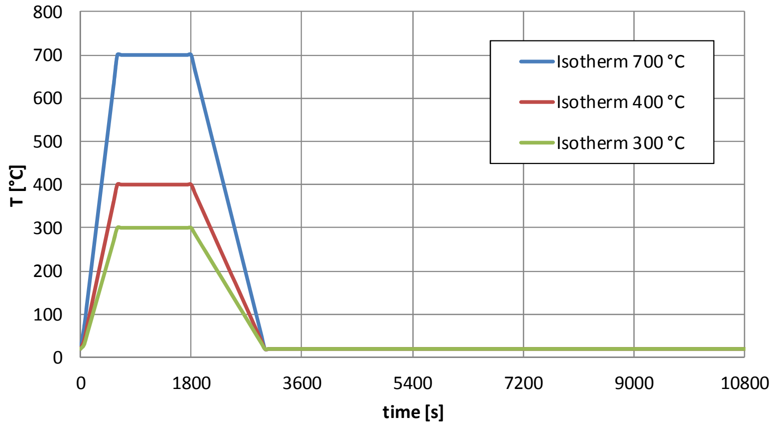

Figure 8. Simplified fire curve of a scenario used to heat steel elements

4 STRUCTURAL ANALYSES

The whole bridge components were introduced into a SAFIR 3D structural model [2], with BEAM elements for the arches and SHELL elements for the deck and the rigid connecting ring at both ends. As it can be seen in figure 9, the resulting model is very complex.

Is this model, the thermal actions were introduced in localized zones, as shown below for a fire at mid span (heated BEAM Finite Elements in colours, cold ones in blue and violet):

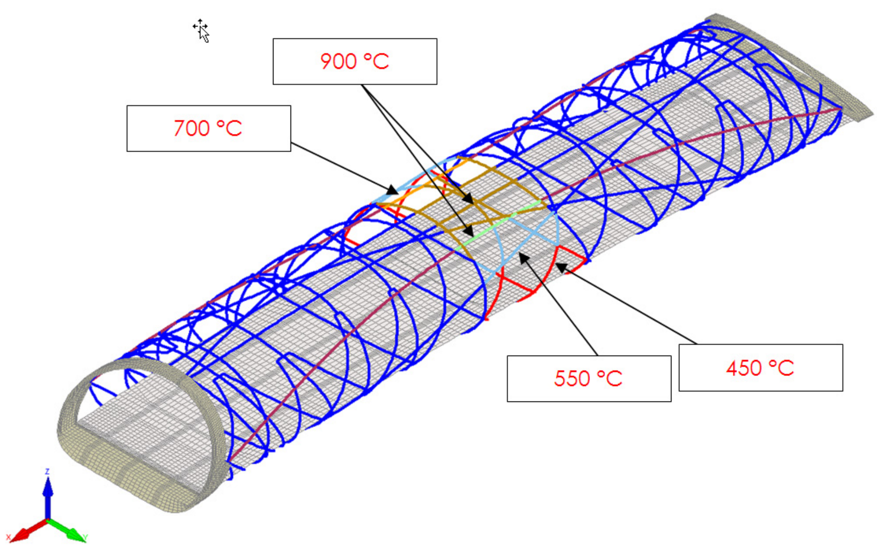

Figure 9. SAFIR 3D structural model with fire action at mid span

With the incremental (time dependent) non-linear structural calculation process of SAFIR software, the behaviour of the bridge can be predicted and analysed up to the eventual collapse, helping the engineer to understand and check the models and results.

After a cold calculation was performed to check the FEM model, the fire simulations were done with each scenario. We can see that, given the high mass of the steel bridge, the deformations are only localised over the fire, rarely determining for the whole bridge stability and security:

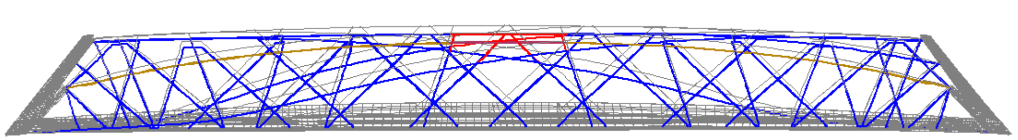

Figure 10. Deformation after 55 minutes of ISO fire: little influence (scale 1:1)

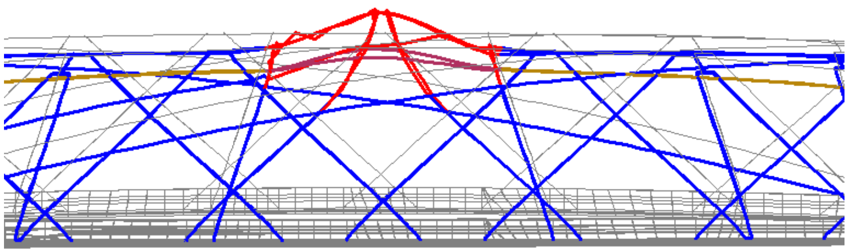

Figure 11. Localised deformation with hydrocarbon fire (scale 1:5)

With natural fire (FDS) scenarios, we have in the first stage of the fire (with maximal temperatures) an elevation of the bridge due to the thermal expansion of the members, then an increasing deformation due to the readjustments of the heated then cooled structure:

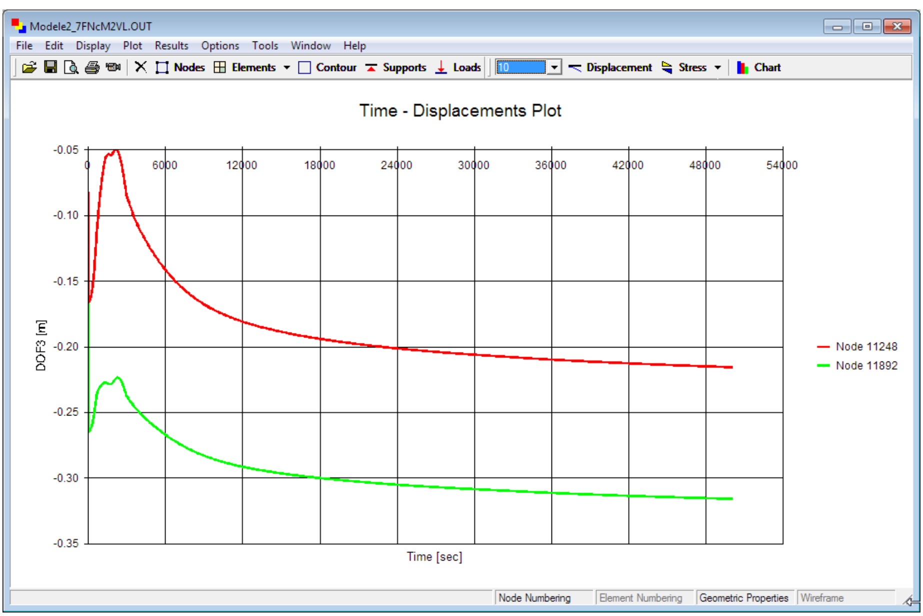

Figure 12. Mid-span deformation of the bridge under natural fire scenarios

5 RESULTS

The analysis realized showed that the «Hans-Wilsdorf Bridge» is to be considered safe for the studied fire situations, and numerical simulations showed a really satisfactory behaviour.

This result is obtained partly because the different fire scenarios develop in open air (as opposed to tunnel fires for instance) and also because the massive steel arches are made of closed sections with thick walls, some having been reinforced to stand the fire situation.

The CFD analysis was very helpful and confirmed the assumed maximal temperature expected using simplified analytical models. Finite Elements structural analysis showed that the structural stability can be guaranteed, as well as the relatively low maximum deflection under fire situation.

The possibility to get adiabatic temperature values from the FDS model to be introduced into the SAFIR model was very helpful. A tool is currently being developed to simplify this step and allow to apply it on more sophisticated models, avoiding the simplifications we used in this case.

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