

NISTIR 6890

**Fire Resistance Determination and
Performance Prediction Research
Needs Workshop: Proceedings**

William Grosshandler
Editor

NIST

National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

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Building and Fire Research Laboratory

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U.S. Department of Commerce
Donald L. Evans, Secretary

Technology Administration
Phillip J. Bond, Under Secretary of Commerce for Technology

National Institute of Standards and Technology
Arden L. Bement, Jr., Director

N. Structural Fire Modeling: Where is the Frontier Nowadays?
 Jean-Marc Franssen, Institute de Mecanique et Genie Civil
 University of Liege, BELGIUM

Structural Fire Modelling.
Where is the frontier nowadays?

Jean-Marc FRANSSSEN
 jm.franssen@ulg.ac.be



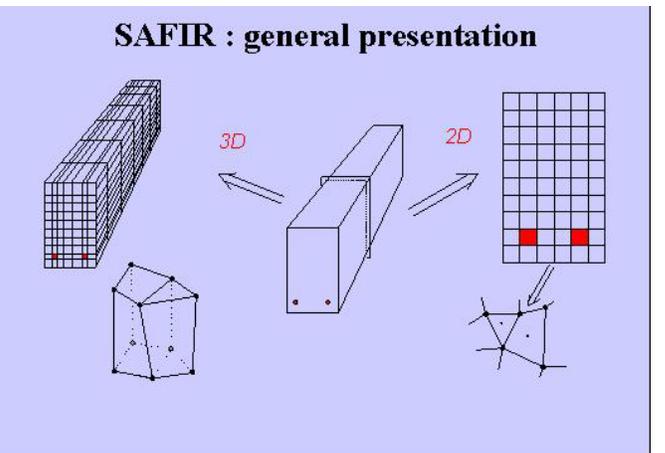

Numerical modelling
of building structures under fire

1 – Temperatures in the compartment => *OZone*
 2 – Temperatures in the structure }
 3 – Mechanical behaviour } => **SAFIR**

SAFIR : non linear finite element software

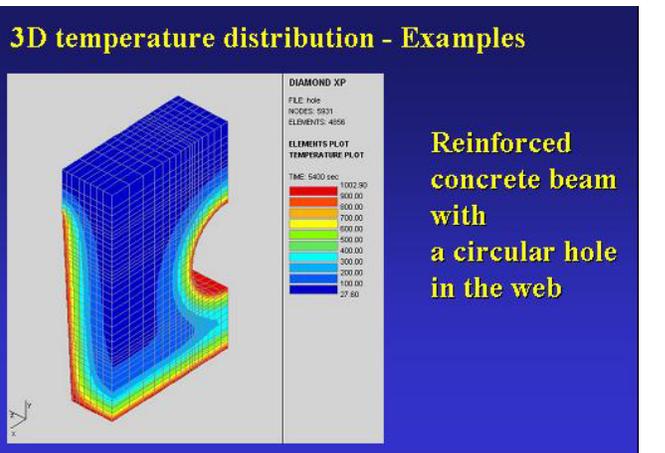
Determination

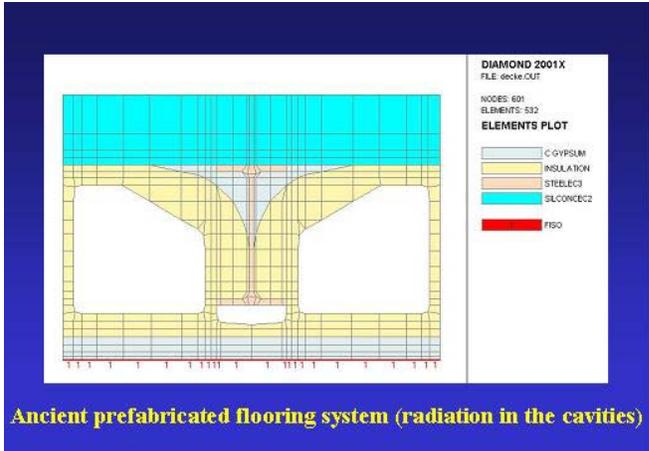
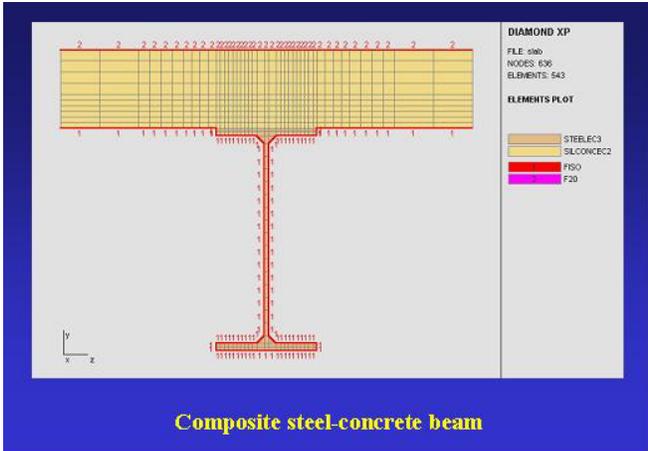
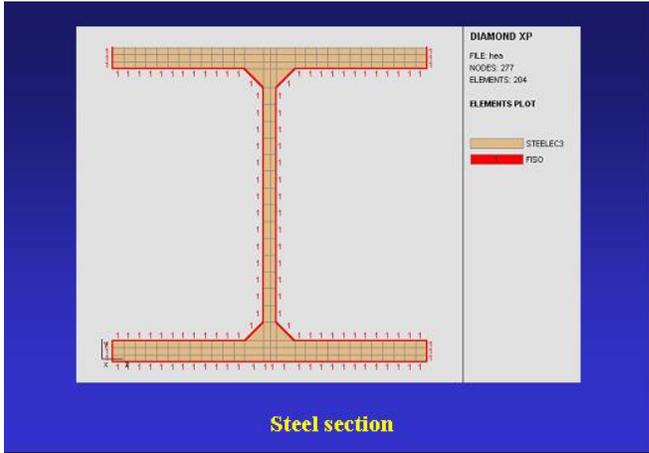
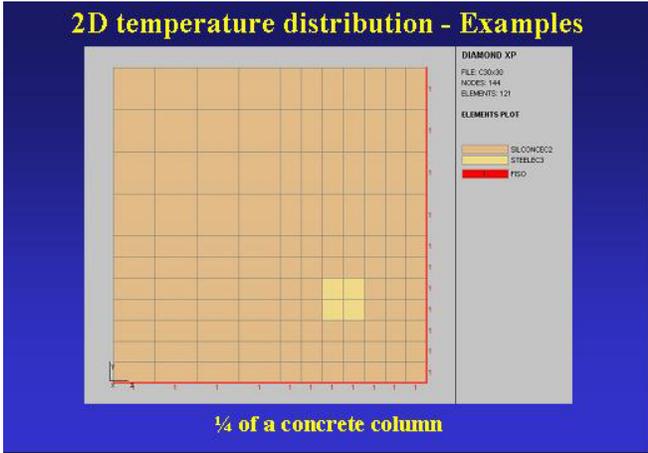
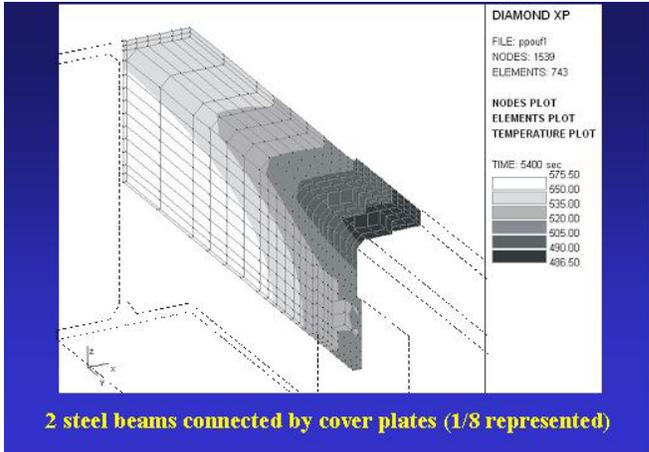
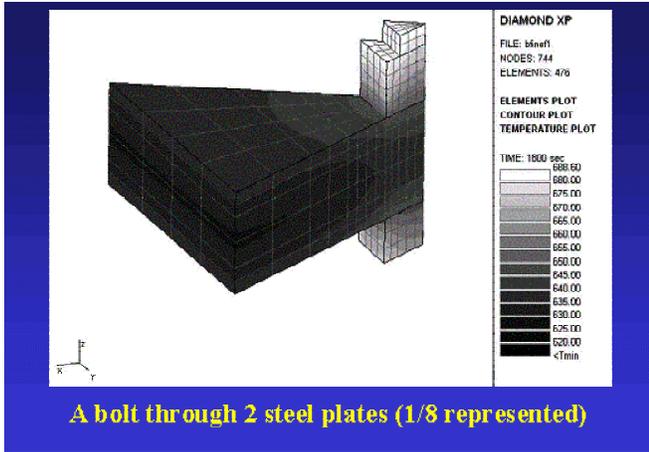
- of the temperature in the structure; $T_s = f(x, y, z, T_g)$
- of the mechanical response; $u = f(x, y, z, \text{loads}, T_s)$

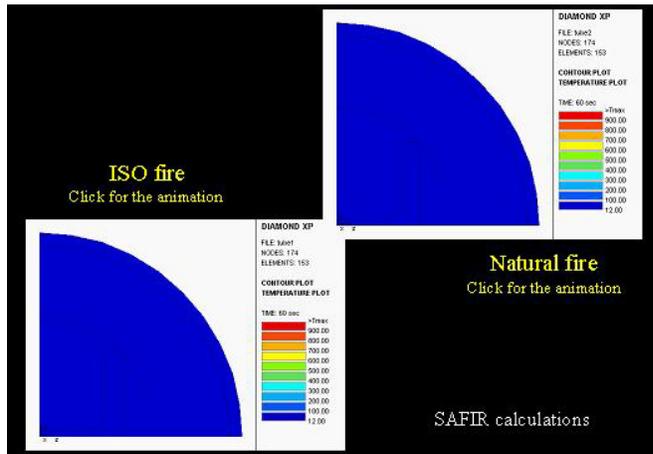
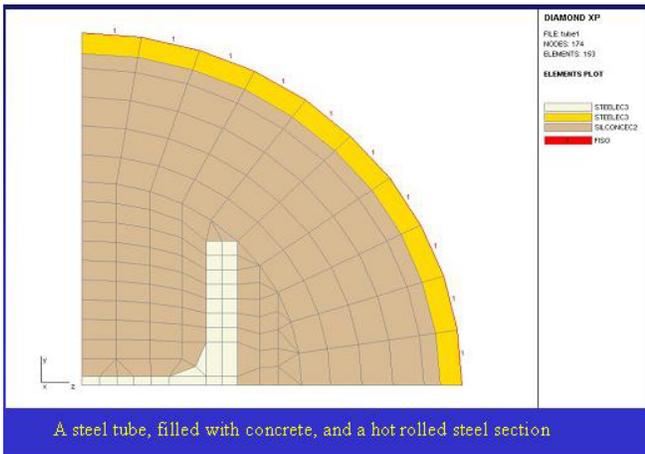
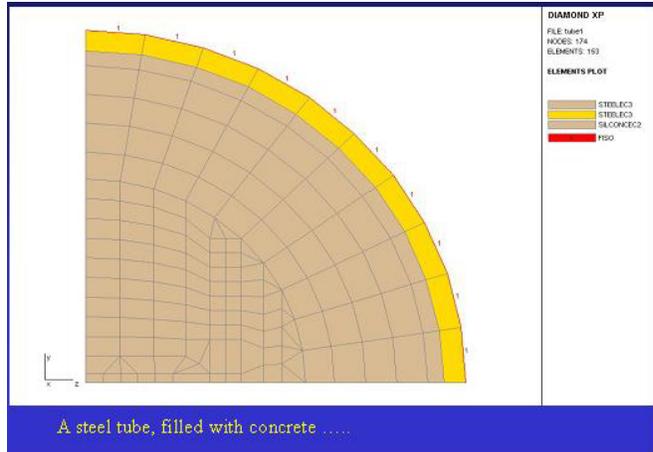
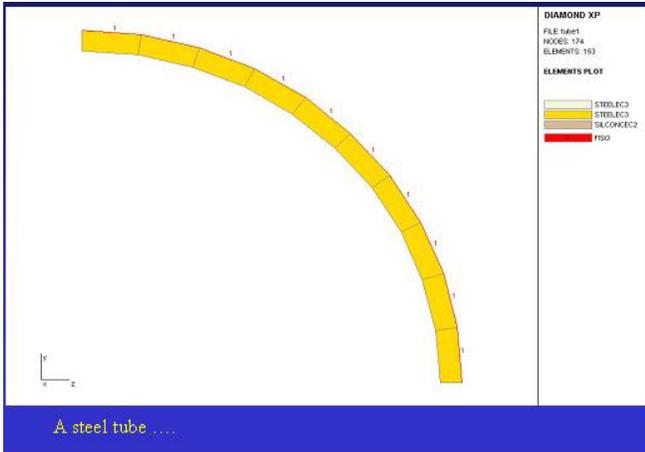


SAFIR : general presentation

Temperature field	Mechanical model
3D F.E.	=> Simple calculation model
2D F.E.	=> Beam F.E. (2D or 3D)
1D F.E.	=> Shell F.E. (3D)
Simple calculation model	=> Truss F.E. (2D or 3D)







Beam finite element
Link between the thermal and the mechanical analysis

Integration on the section

$$EA^* = \sum_{i=1}^n E_i(T_i) A_i \quad (= E b h)$$

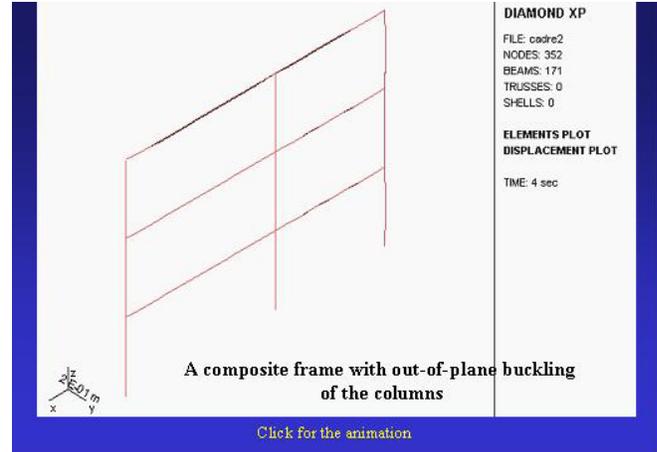
$$ES_y^* = \sum_{i=1}^n E_i(T_i) y_i A_i \quad (\neq 0)$$

$$EI_y^* = \sum_{i=1}^n E_i(T_i) y_i^2 A_i \quad \left(\neq E \frac{b h^3}{12} \right)$$

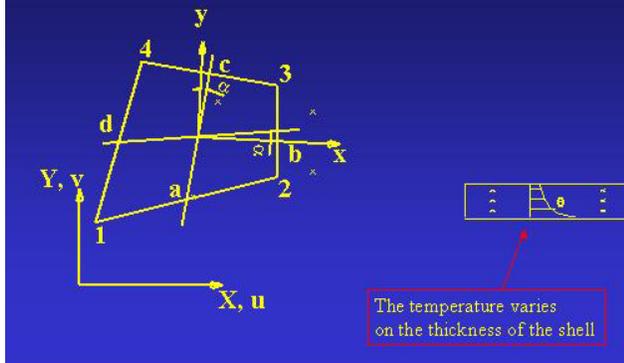
$$N^* = \sum_{i=1}^n \sigma_i(T_i) A_i$$

$$M_y^* = \sum_{i=1}^n \sigma_i(T_i) y_i^2 A_i$$

Beam finite element Example

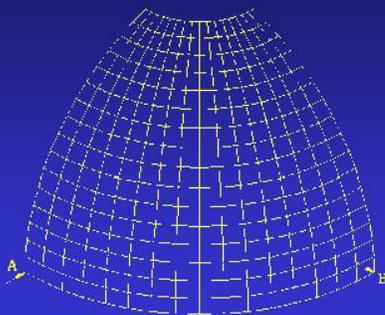


The shell finite element



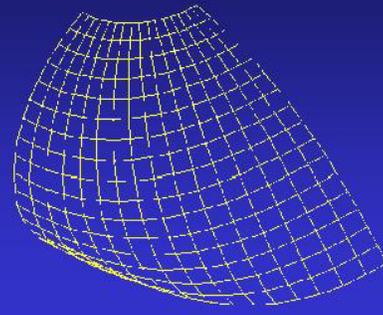
Shell finite element Examples

Benchmark test : hemispheric dome (1/4 modelled)

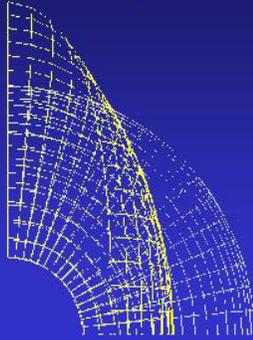


The same after deformation

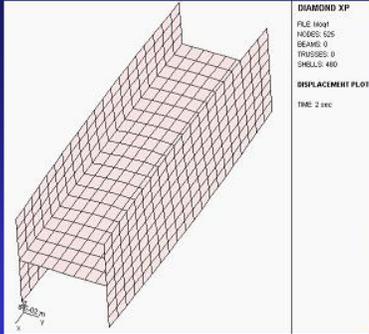
(elastic calculation at 20°C)



Comparison between deformed et initial shape
 (No amplification of the displacements in the drawing)

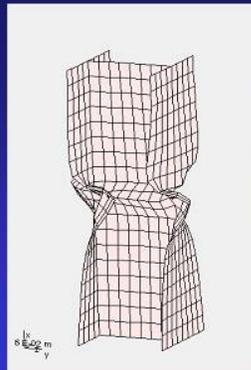


U section in bending
 elastic at 20°C
 Displacements x 1



DIAMOND XP
 FILE: 10/01
 NODES: 525
 BEAMS: 0
 TRUSSES: 0
 SHELLS: 400
 DISPLACEMENT PLOT
 TIME: 2 sec

Imposed shortening and heating : 1°C/sec
 No amplification of the displacements in the drawing
 Click for the animation



Structural Fire Modelling
 What are the limits we are facing today?

Structural Fire Modelling
 What are the limits we are facing today?

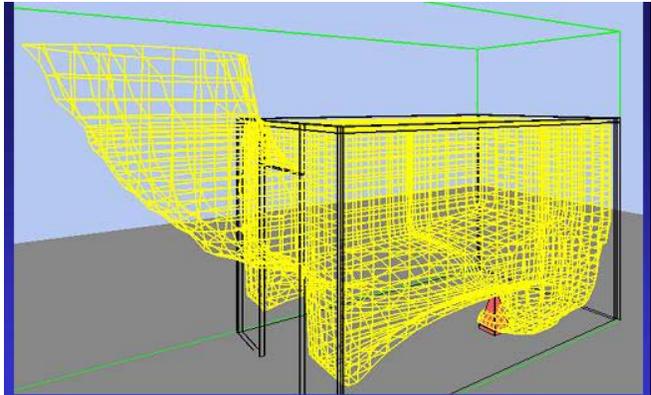
1. Thermal properties of materials
 1. Thermal conductivity of concrete
 2. Shadow effect around H steel sections

N.B. This is a *European* problem

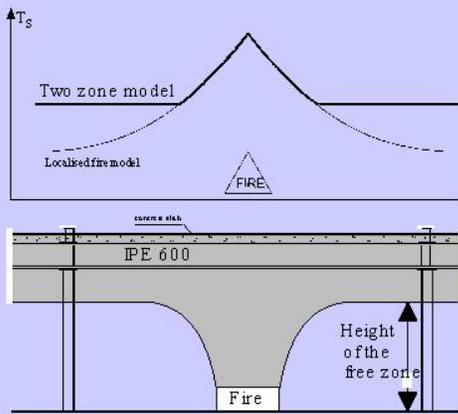
Structural Fire Modelling

What are the limits we are facing today?

1. Thermal properties of materials
2. Interaction between the gas and the structure in case of localised fires
 1. In case of C.F.D. modelling
 2. Also for zone models



Example of result from a field model (SOFIE)
How to transfer the results to the structure?



Structural Fire Modelling

What are the limits we are facing today?

1. Thermal properties of materials
2. Interaction between the gas and the structure in case of localised fires
3. Spalling in concrete

More a producers's problem than a modeller's problem.
Research can help in explaining the phenomena and identifying the parameters, but not give a deterministic answer (even if it could, at what price in terms of required data?).

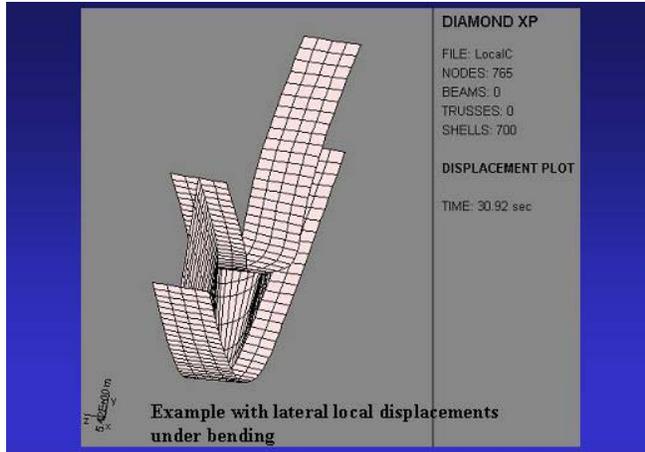
Structural Fire Modelling

What are the limits we are facing today?

1. Thermal properties of materials
2. Interaction between the gas and the structure in case of localised fires
3. Spalling in concrete
4. Consequences of Bernoulli hypotheses in the beam F.E.
 1. Rotation capacity
 2. Local buckling
 3. Shear failure
 4. Debonding

All sections are seen by a Bernoulli beam F.E. as Class 1 sections

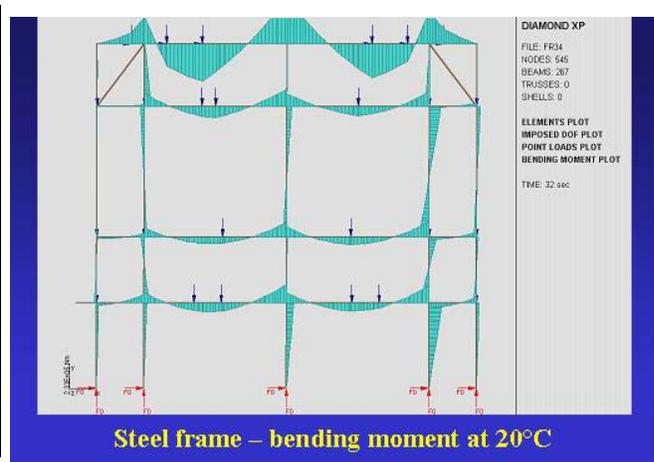
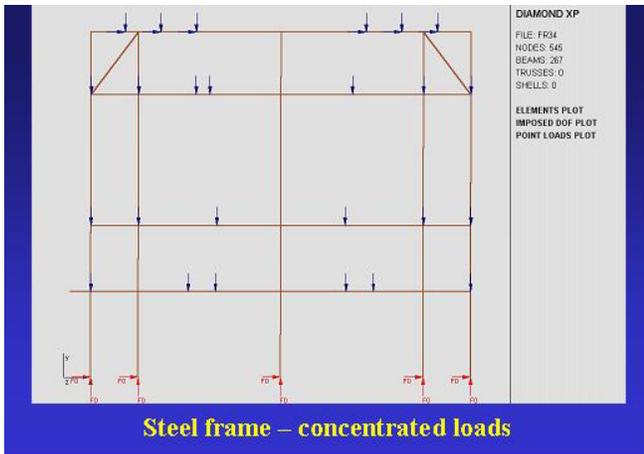
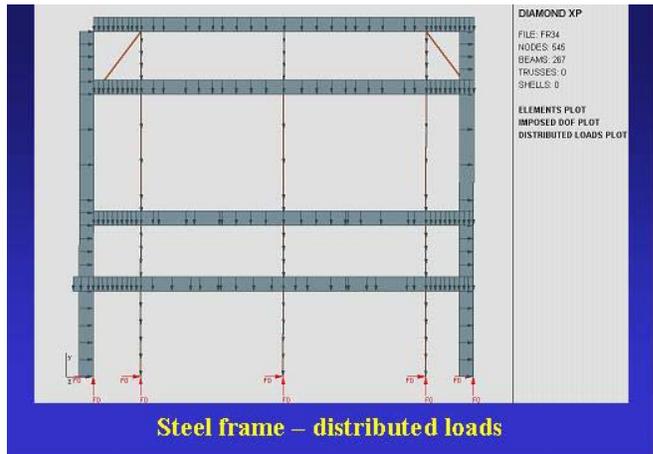
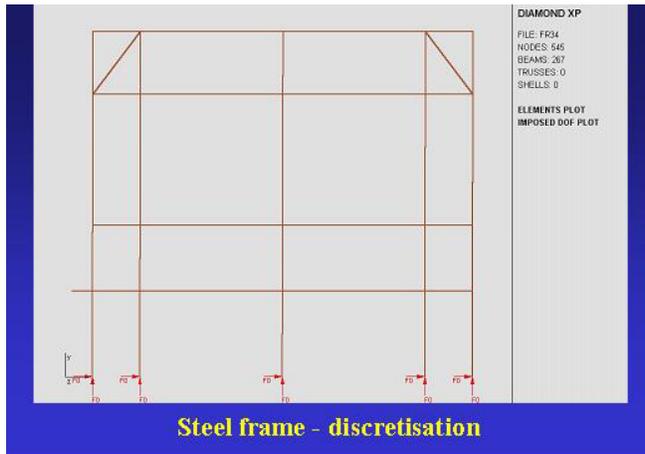
- Class 1 => no problem
- Class 2 => normally, no hyperstatic structure
- Class 3 => use modified properties
- Class 4 => ?????

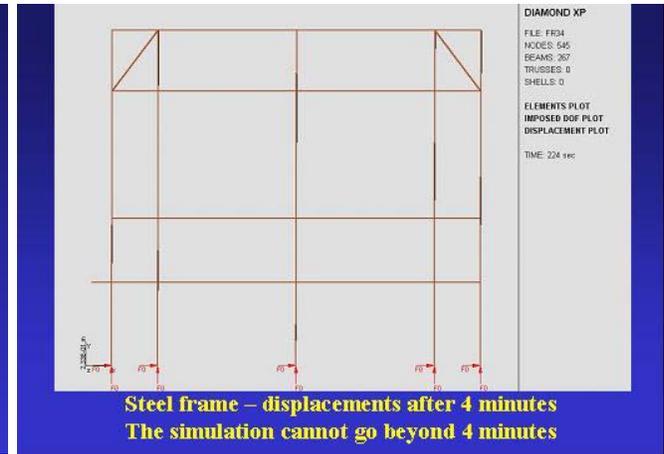
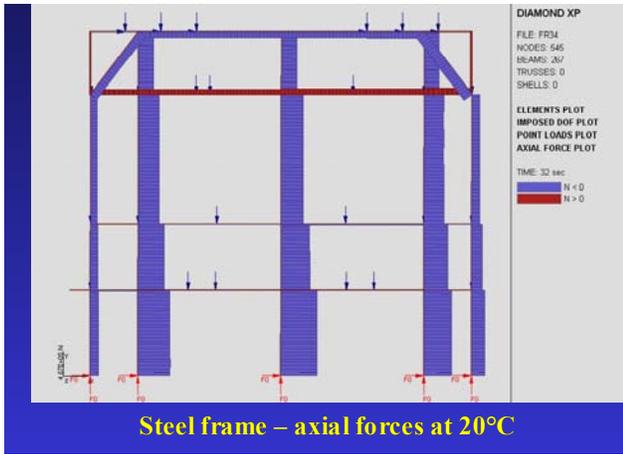


Structural Fire Modelling

What are the limits we are facing today?

1. Thermal properties of materials
2. Interaction between the gas and the structure in case of localised fires
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4. Consequences of Bernoulli hypotheses in the beam F.E.
5. Local and/or temporary negative stiffness



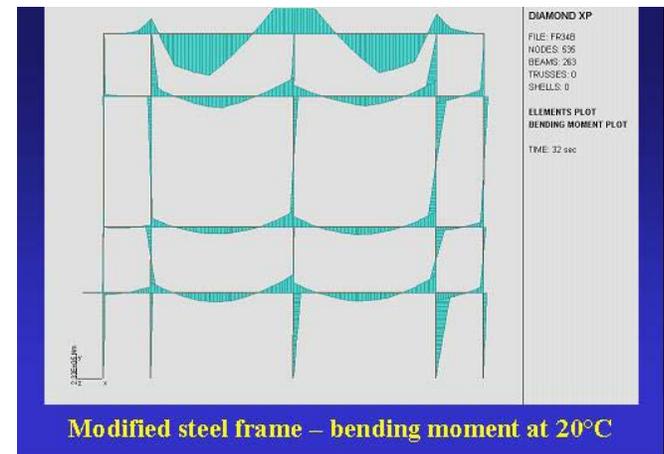
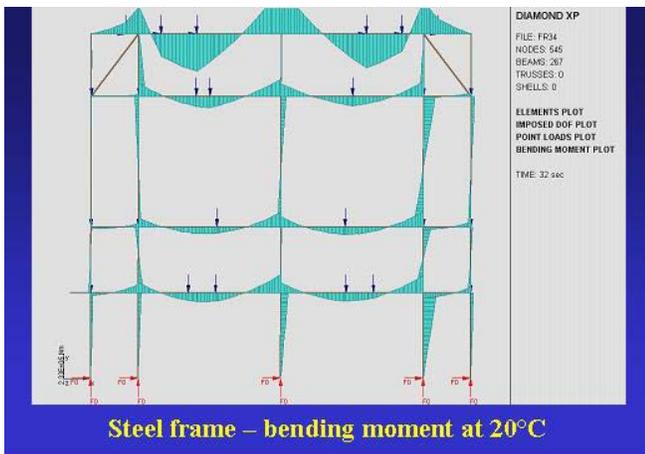
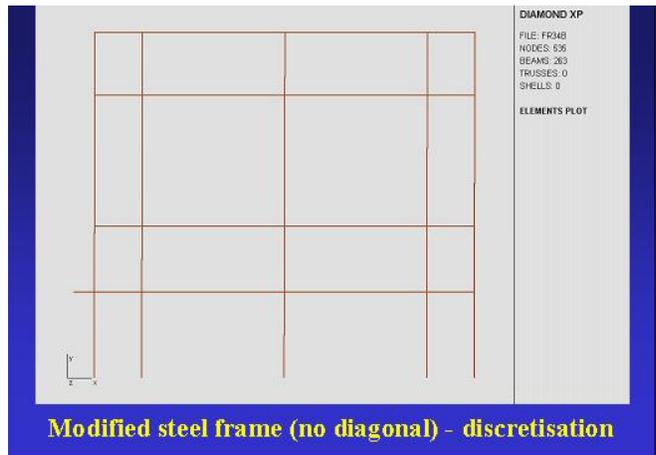


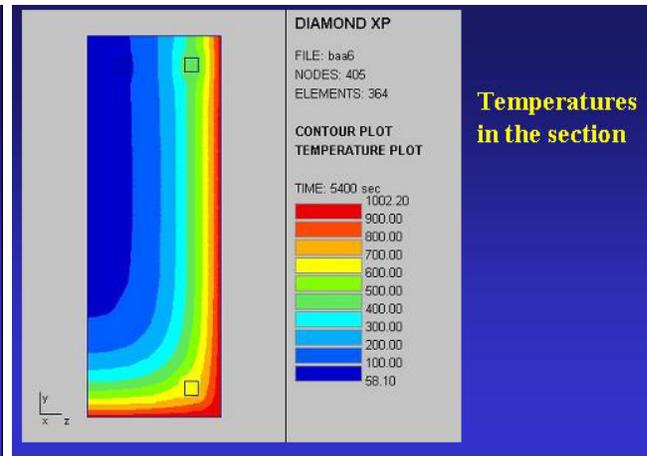
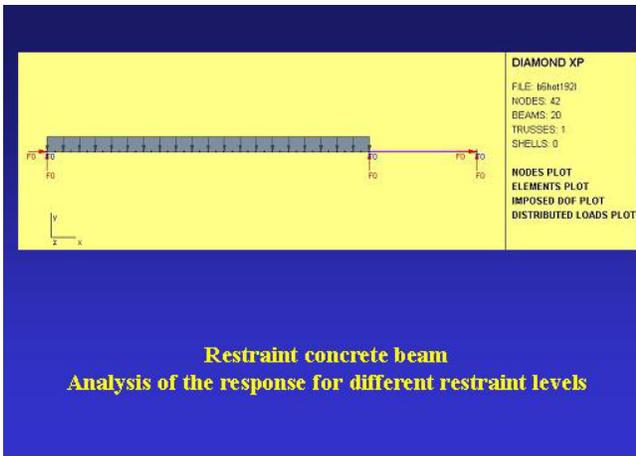
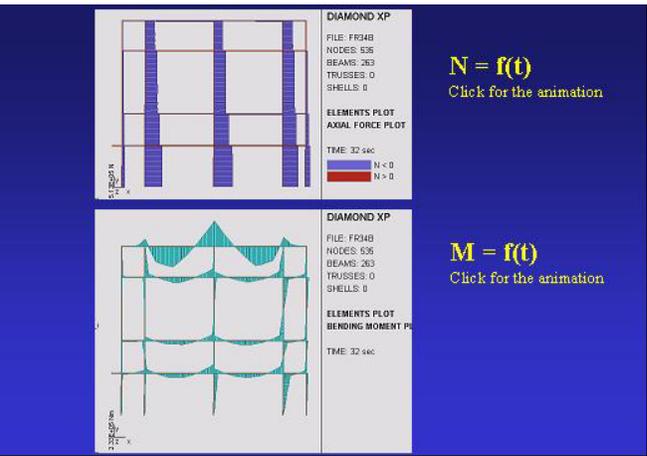
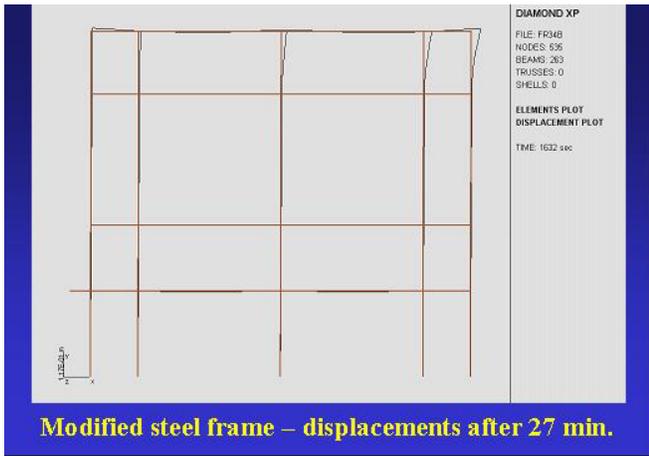
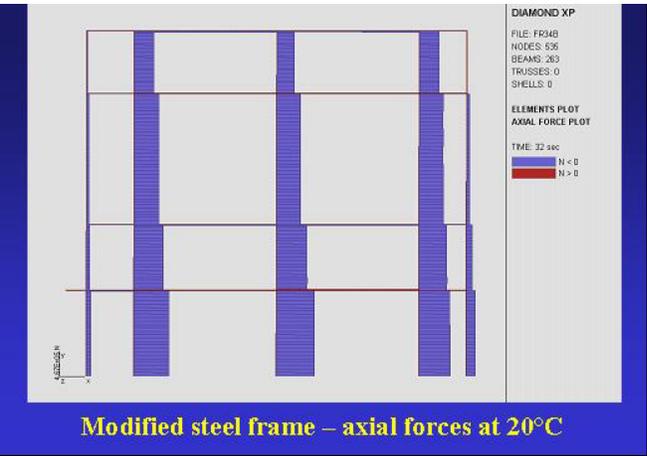
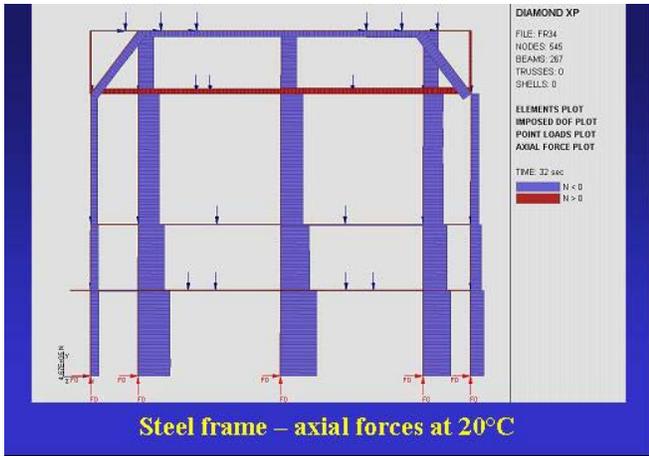
DIAMOND XP
 FILE: FR34
 NODES: 545
 BEAMS: 267
 TRUSSES: 0
 SHELLS: 0
 ELEMENTS PLOT
 AXIAL FORCE PLOT
 TIME: 32 sec
 N < 0
 N > 0

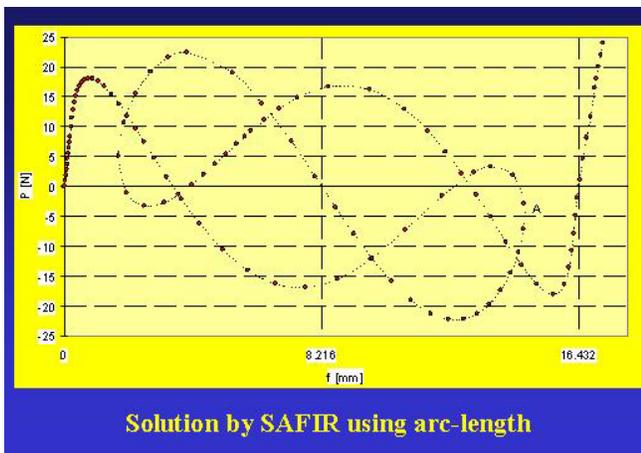
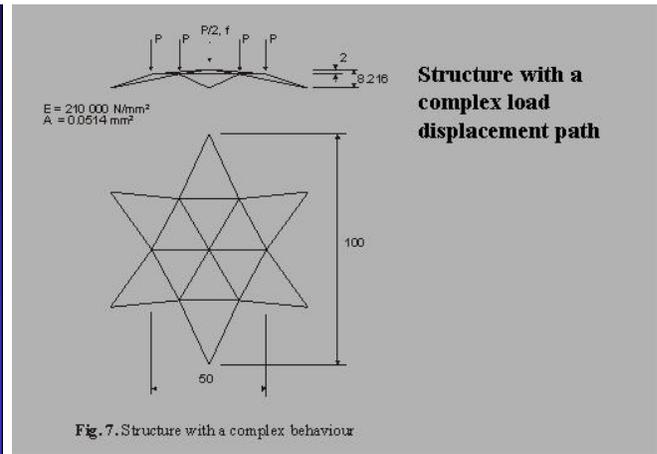
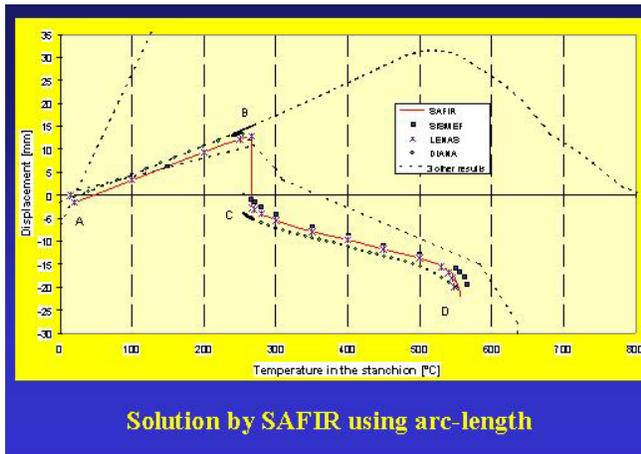
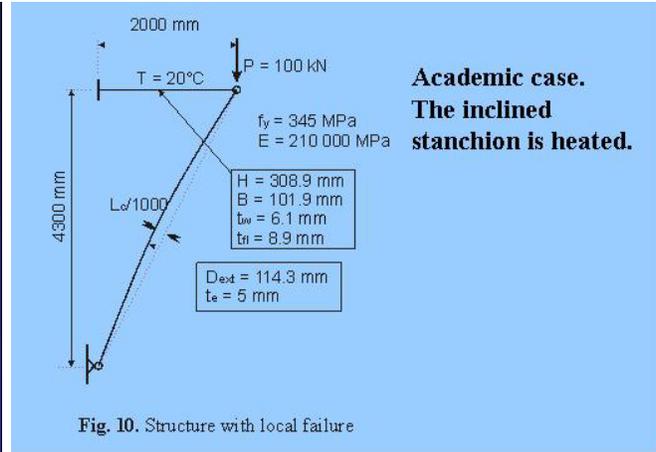
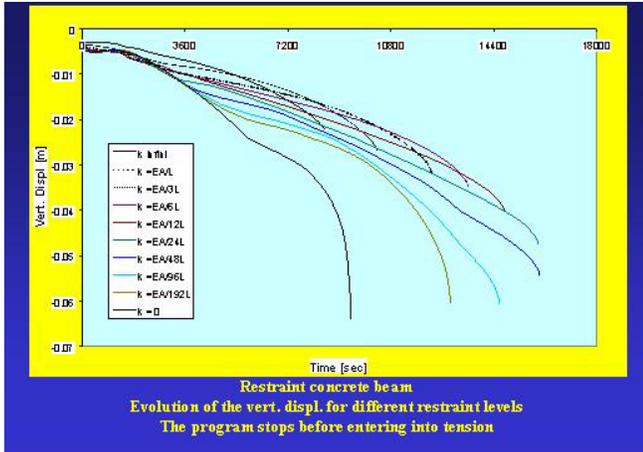
$N = f(t)$
 Click for the animation

DIAMOND XP
 FILE: FR34
 NODES: 545
 BEAMS: 267
 TRUSSES: 0
 SHELLS: 0
 ELEMENTS PLOT
 BENDING MOMENT PLOT
 TIME: 32 sec

$M = f(t)$
 Click for the animation







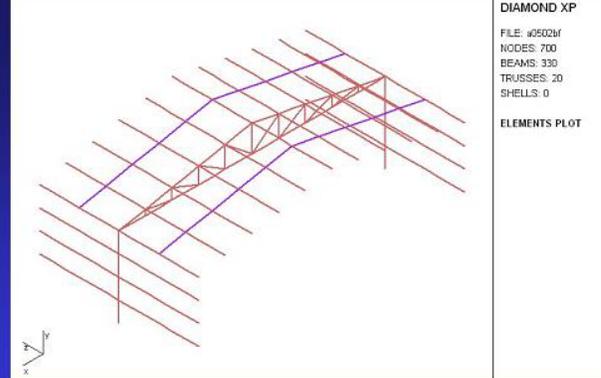
Unfortunately, arc length

- does not work in all cases
- involves an unloading that is not physical correct

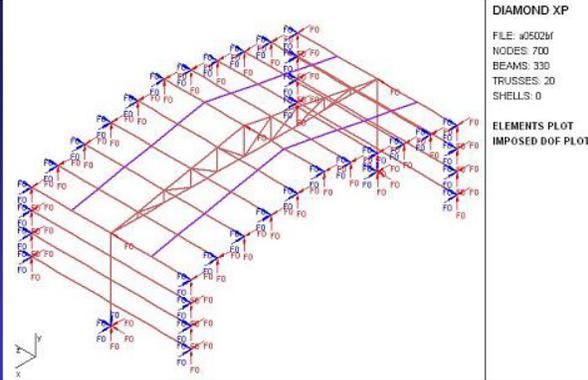
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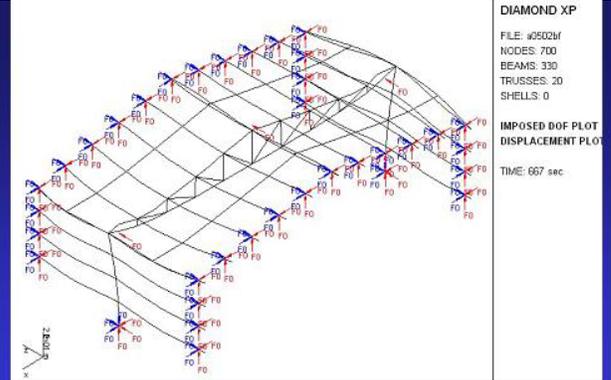
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6. Boundary conditions in substructures



Industrial building: one frame + purlins represented



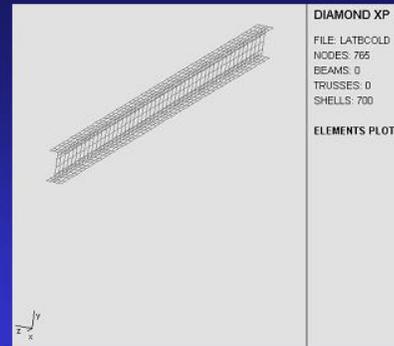
Elongation of the purlins: free or fixed?



Structural Fire Modelling

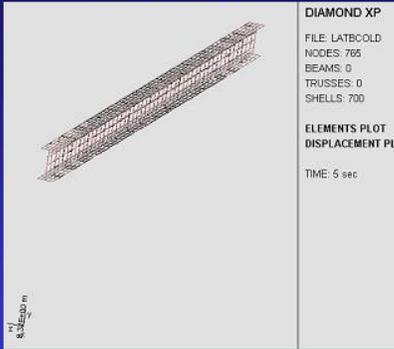
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7. Definition of failure in case of very large displacements



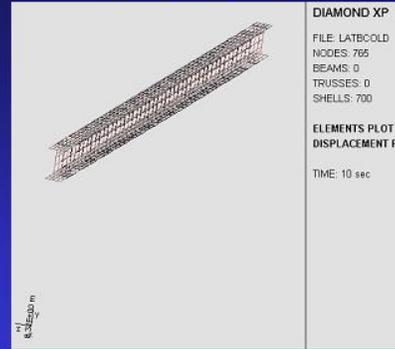
Simply supported beam (displacements x 1)

Is this failure or not?



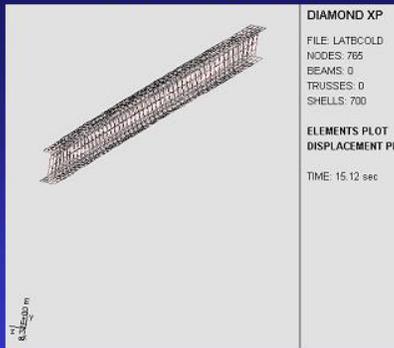
Simply supported beam (displacements x 1)

Is this failure or not?



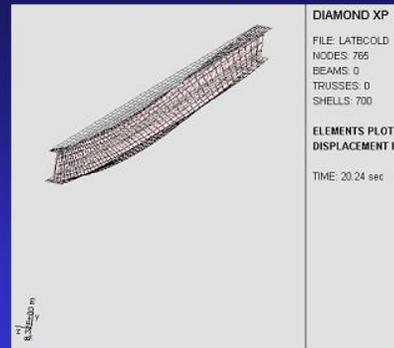
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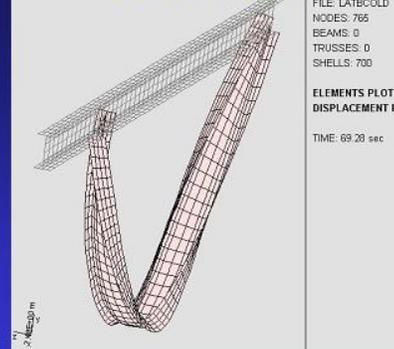
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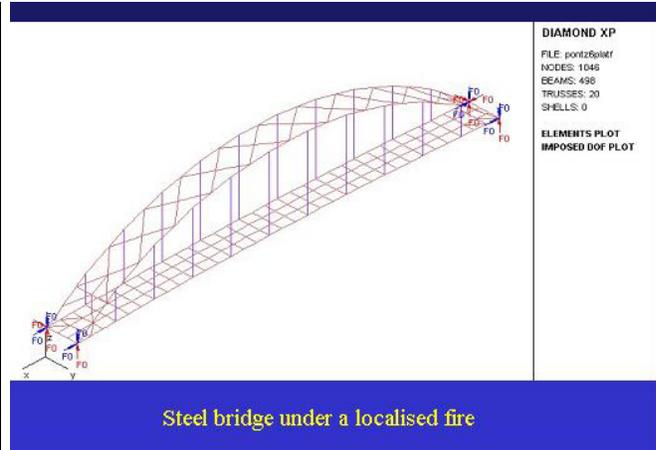


Simply supported beam (displacements x 1)

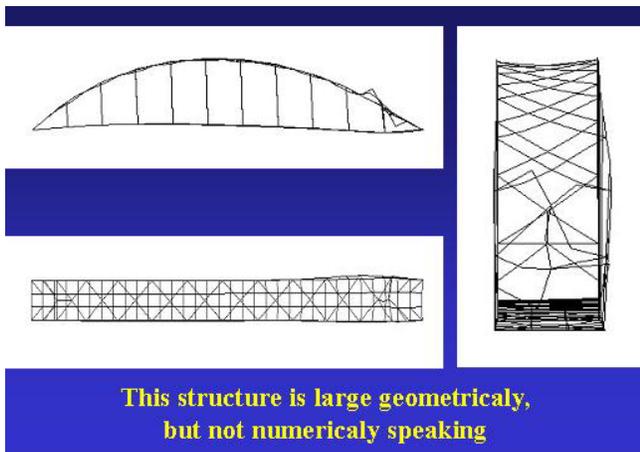
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7. Definition of failure in case of very large displacements
8. **Problems for solving very large structures**



Steel bridge under a localised fire



Conclusions

For understanding and designing structures submitted to fire, numerical modelling offers capabilities that are unique.

Conclusions

The frontiers are:

- Spalling in concrete
- Concrete properties
- Local or temporary failures
- Very large structures
- Very large displacements
- Boundary conditions
- Interface with environment in localised fires
- Ressources (money, time, people, ...)