Technical Conference on the Federal Building and Fire Safety Investigation of the World Trade Center Disaster

Comments on NIST'S recommendations

by

Roger Plank and Ian Burgess
University of Sheffield, UK

NIST, Gaithersburg, MD, USA 13-15 September 2005

NIST's Recommendations

Increase structural integrity

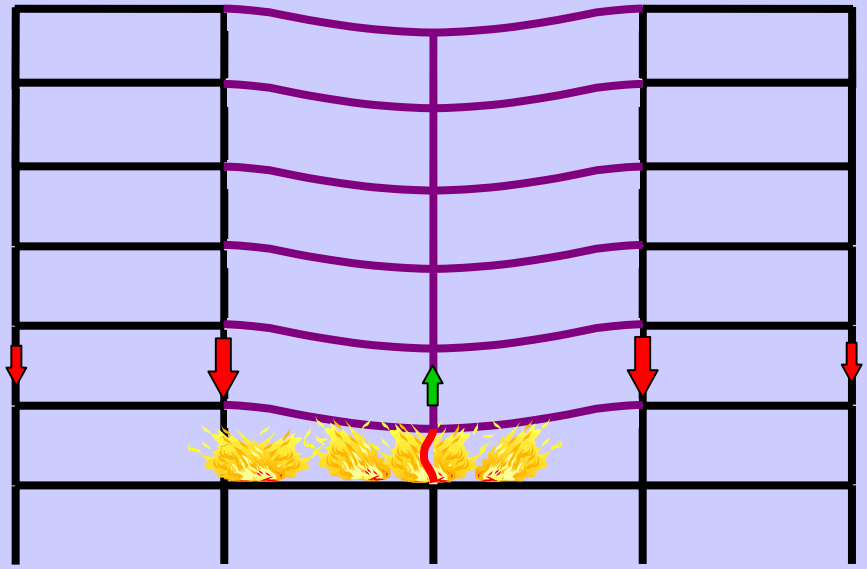
1. Develop design tools and modify codes to prevent progressive collapse.

2. Develop new standards for wind tunnel testing and performance standards for estimating wind loads on tall buildings.

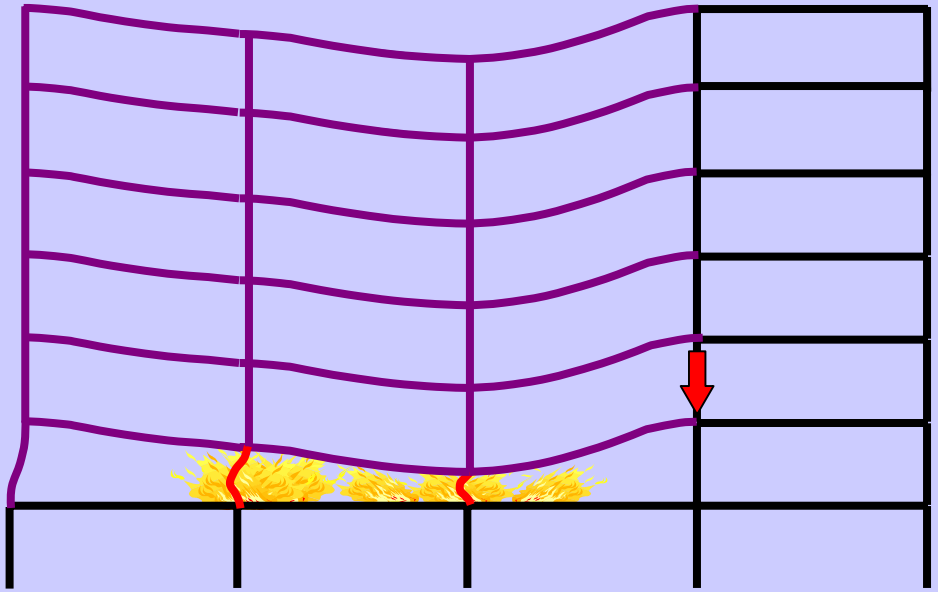
3. Develop limits for lateral sway for tall buildings.

Important to distinguish between different degrees of local failure

Column failure – progressive collapse



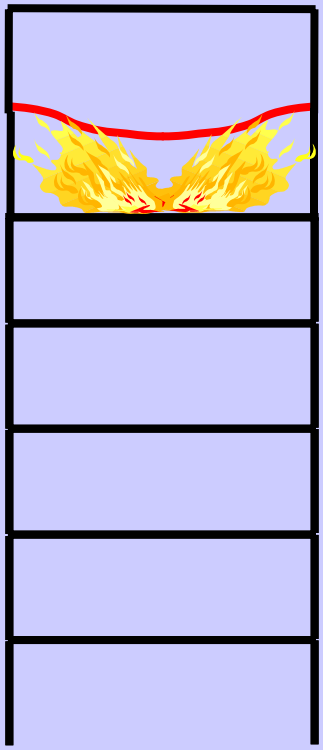
Single column failure may be sustained by alternative load paths



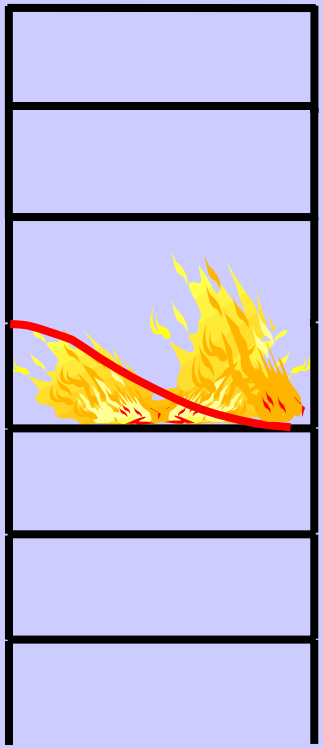
Multiple column failure catastrophic

Consequence of element failure

Beams:



Joints:



Consequences differ

- **Columns** are key elements – failure may be disastrous.
- **Joint** failure may initiate fire spread and progressive collapse.
- **Beam** deflection does not in itself cause structural failure, unless it allows fire spread or causes effects to columns or joints.

NIST's Recommendations

Enhance fire resistance

4. Review basis for construction classification and fire rating requirements.
5. National programme of research into improved fire testing of structural components and systems.
6. Improve testing methods for spray-applied fire protection that reflect in-service conditions.
7. Adopt "structural frame" approach - ensure whole structural frame has same fire resistance rating.

Similar approaches being used in UK

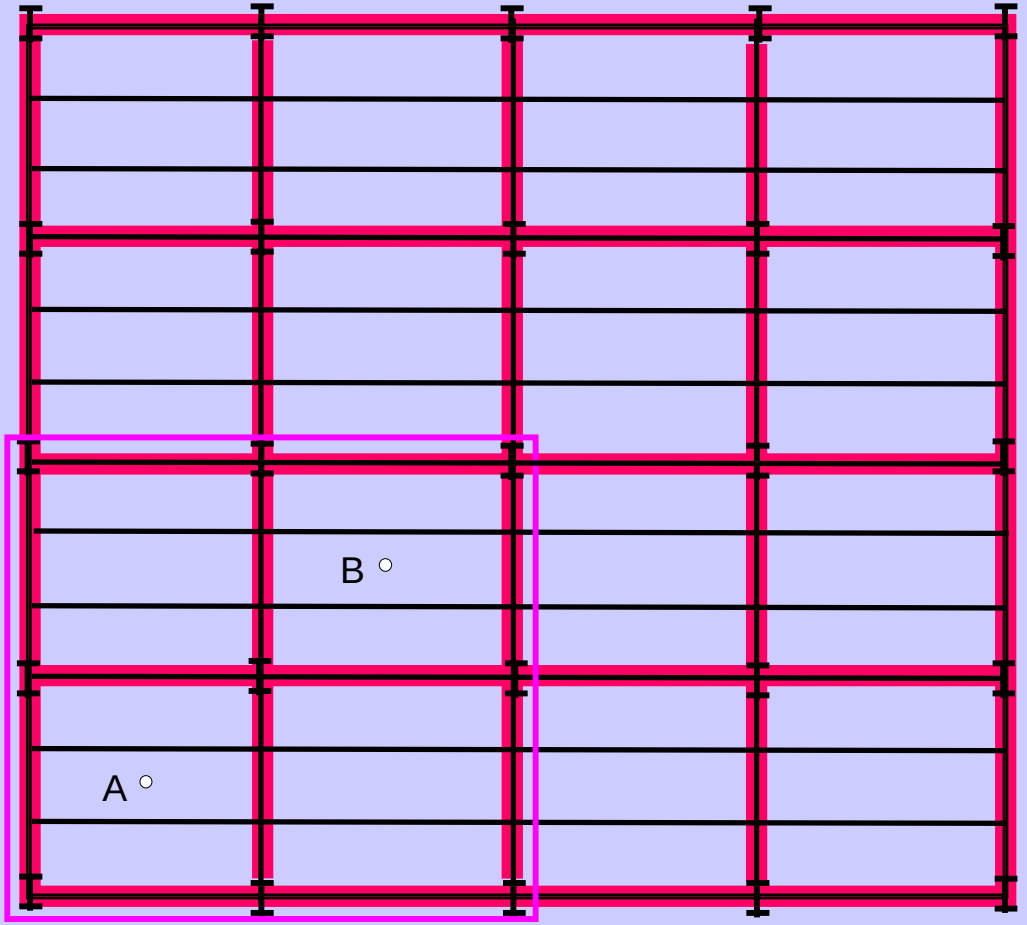
May be inconsistent depending on aspect ratio and type of slab

Structural fire resistance methods

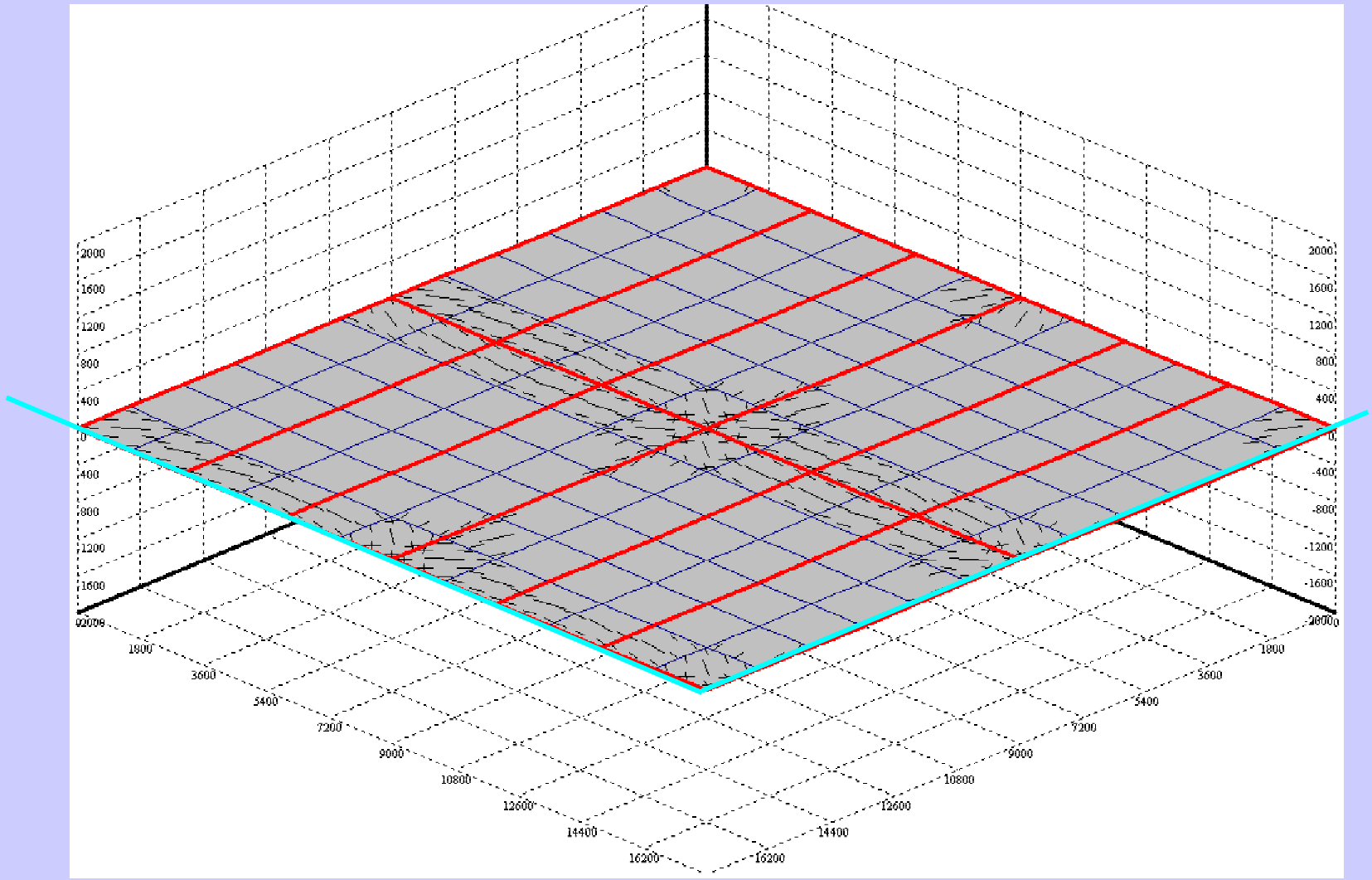
Protect members on column gridlines

Similar philosophy to "Structural Frame" approach.

Numerical modelling of representative areas of structure in design fire scenarios.

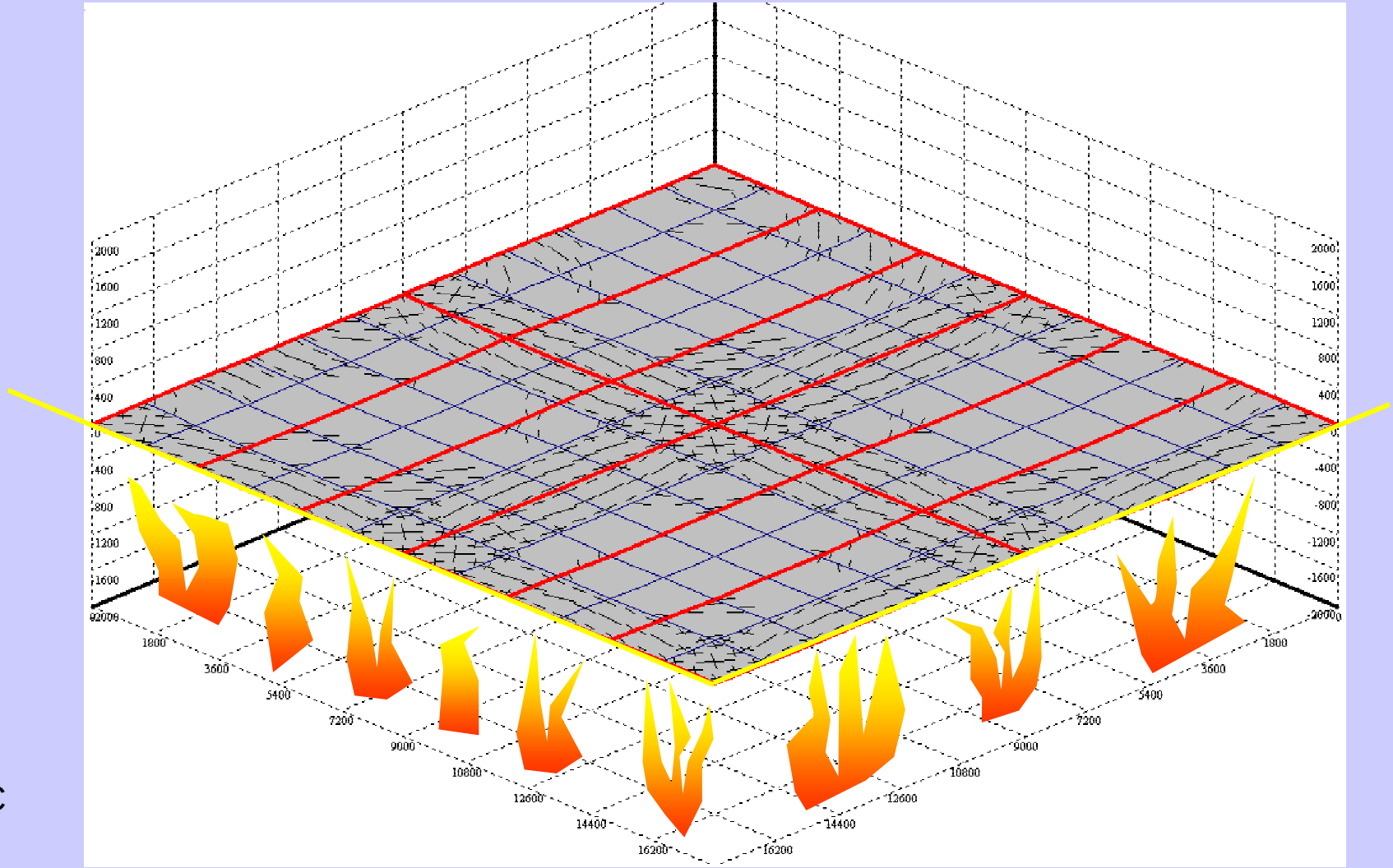


Example: Deflected shapes



20°C

Example: Deflected shapes



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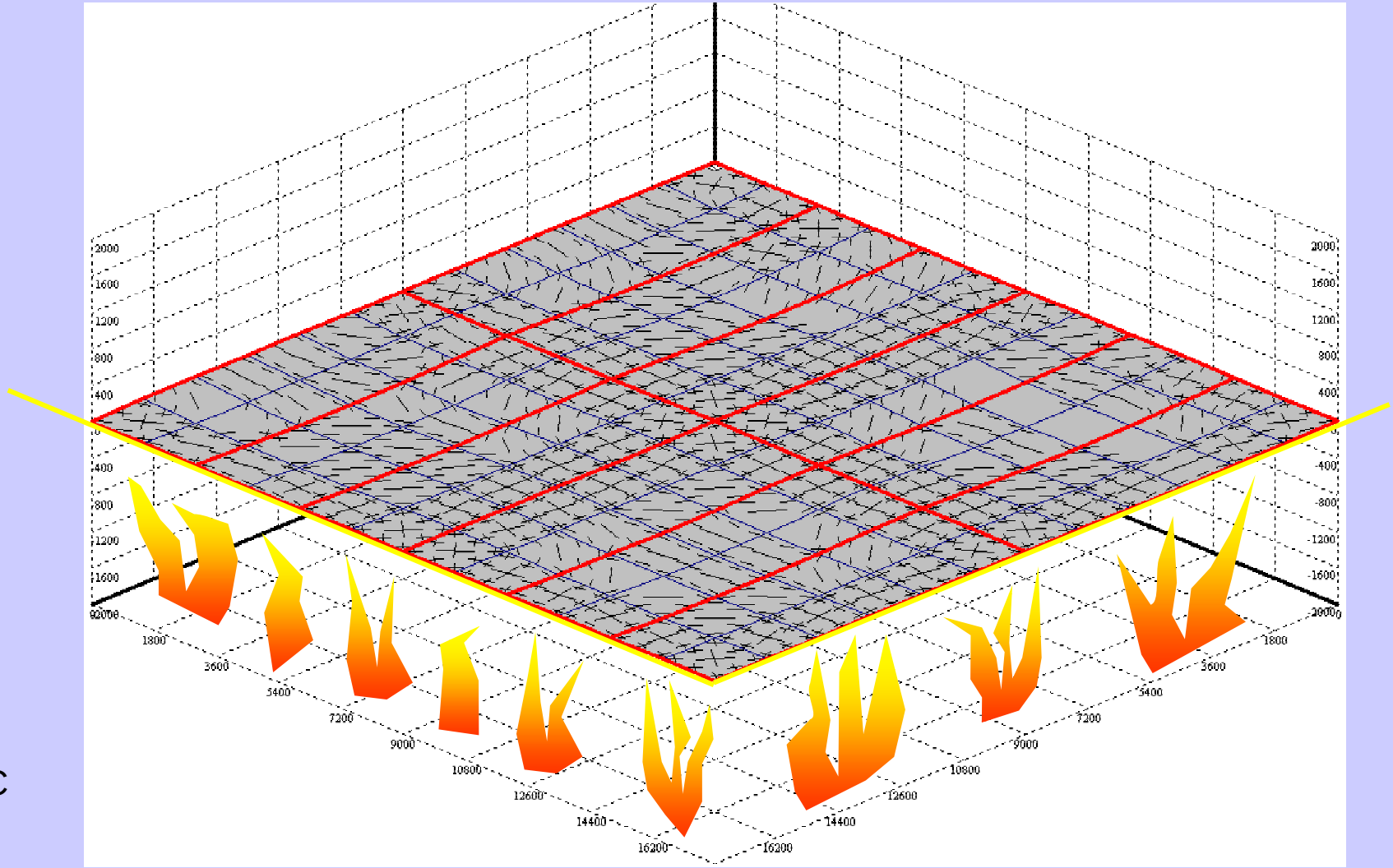

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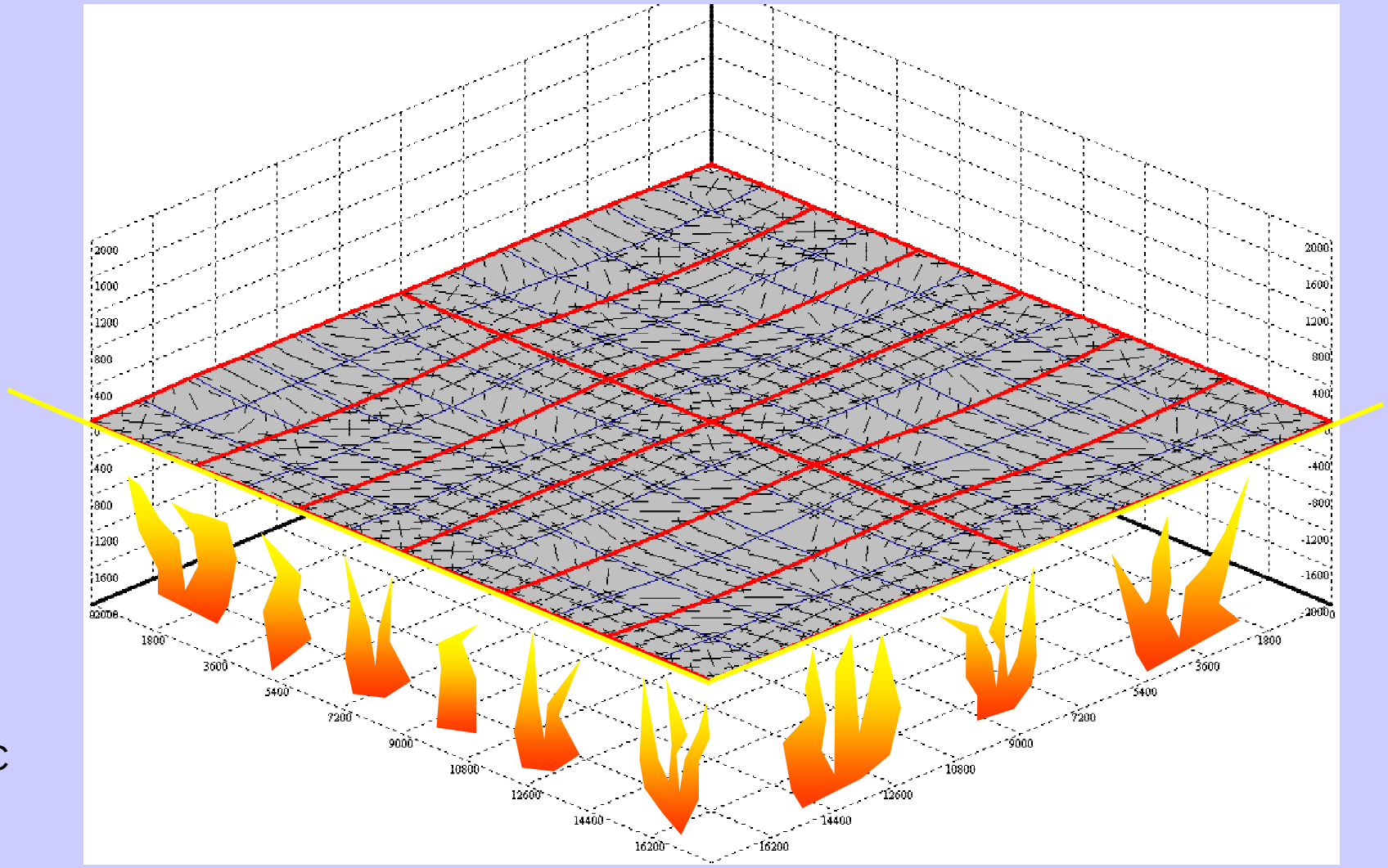

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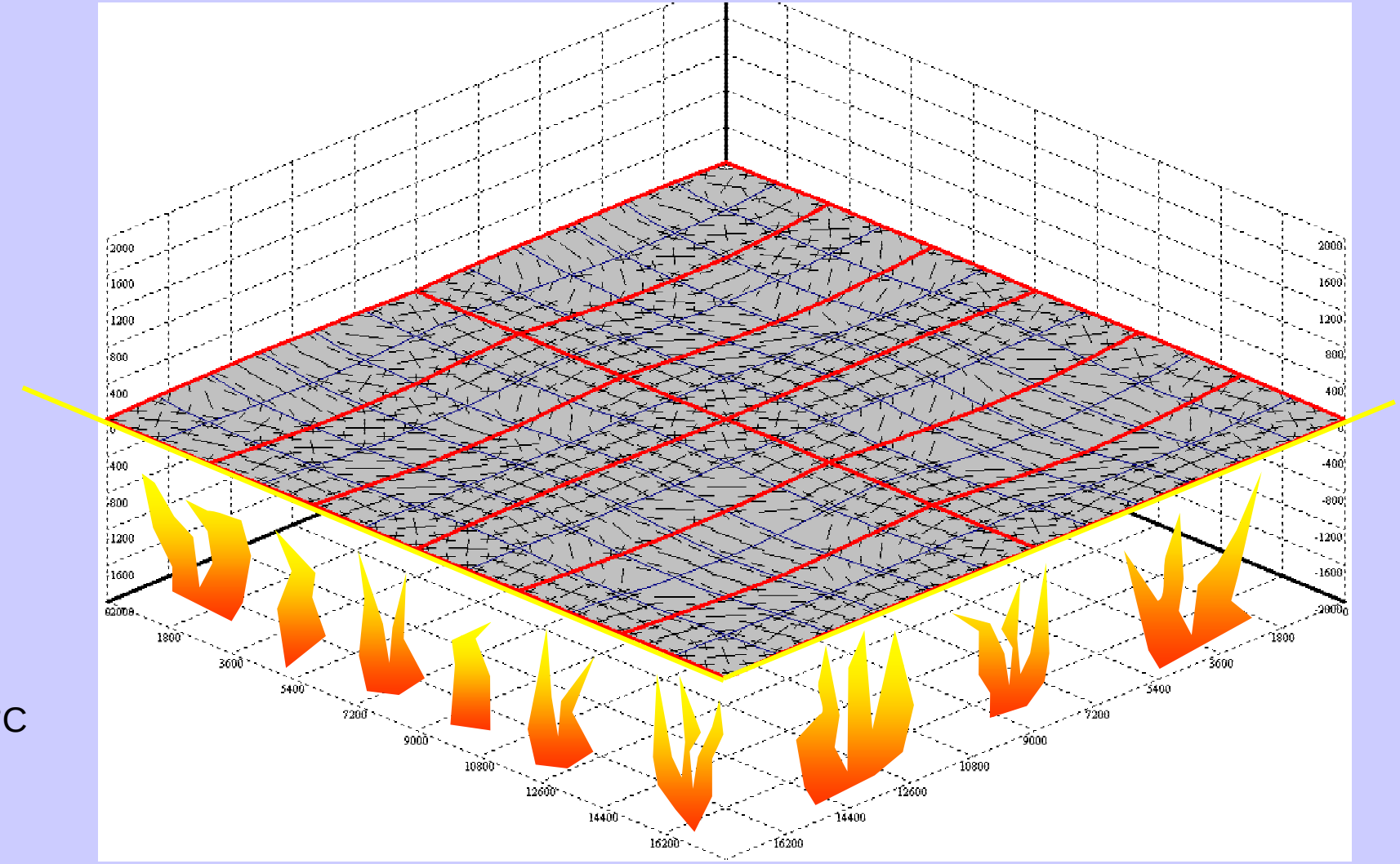
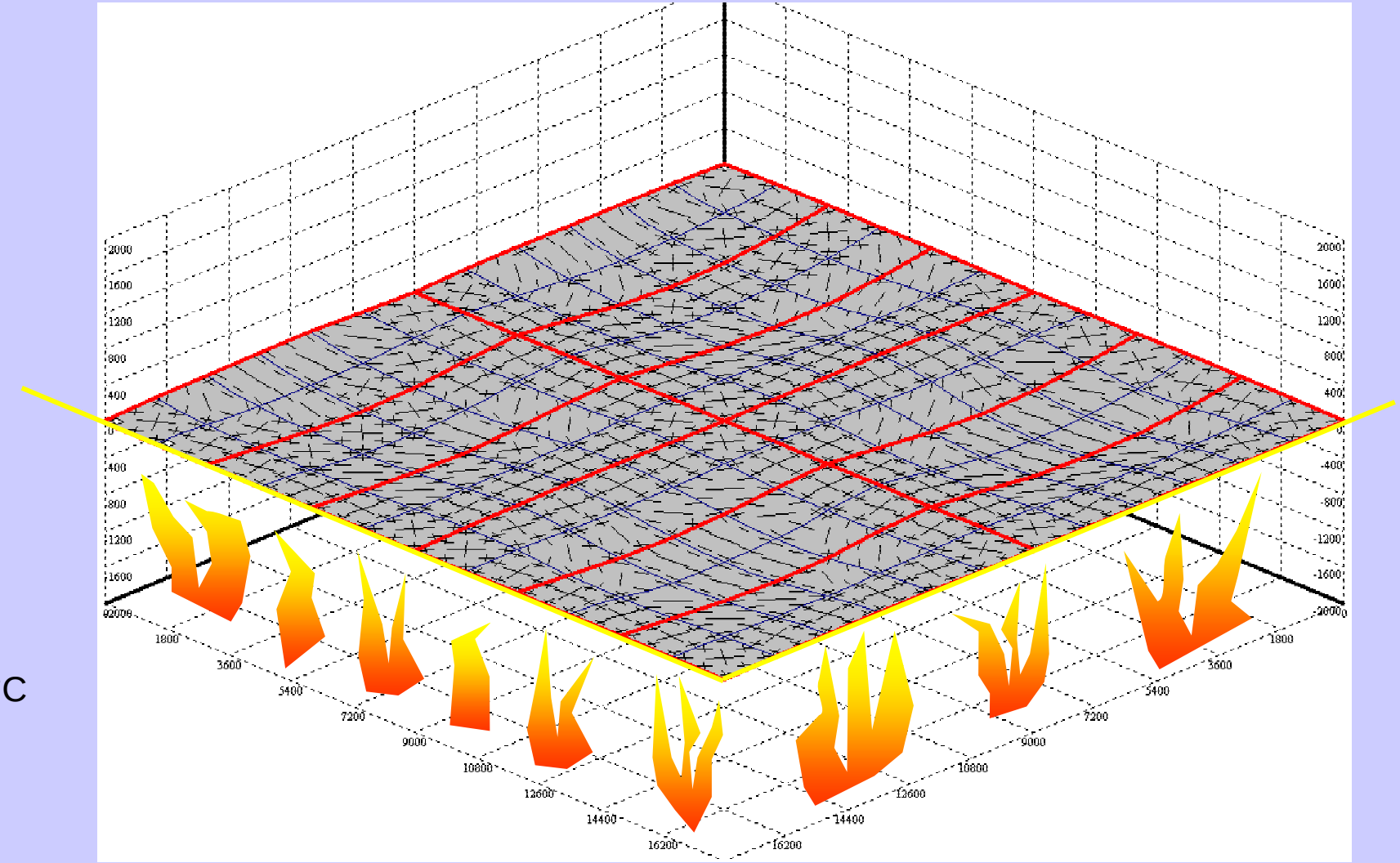


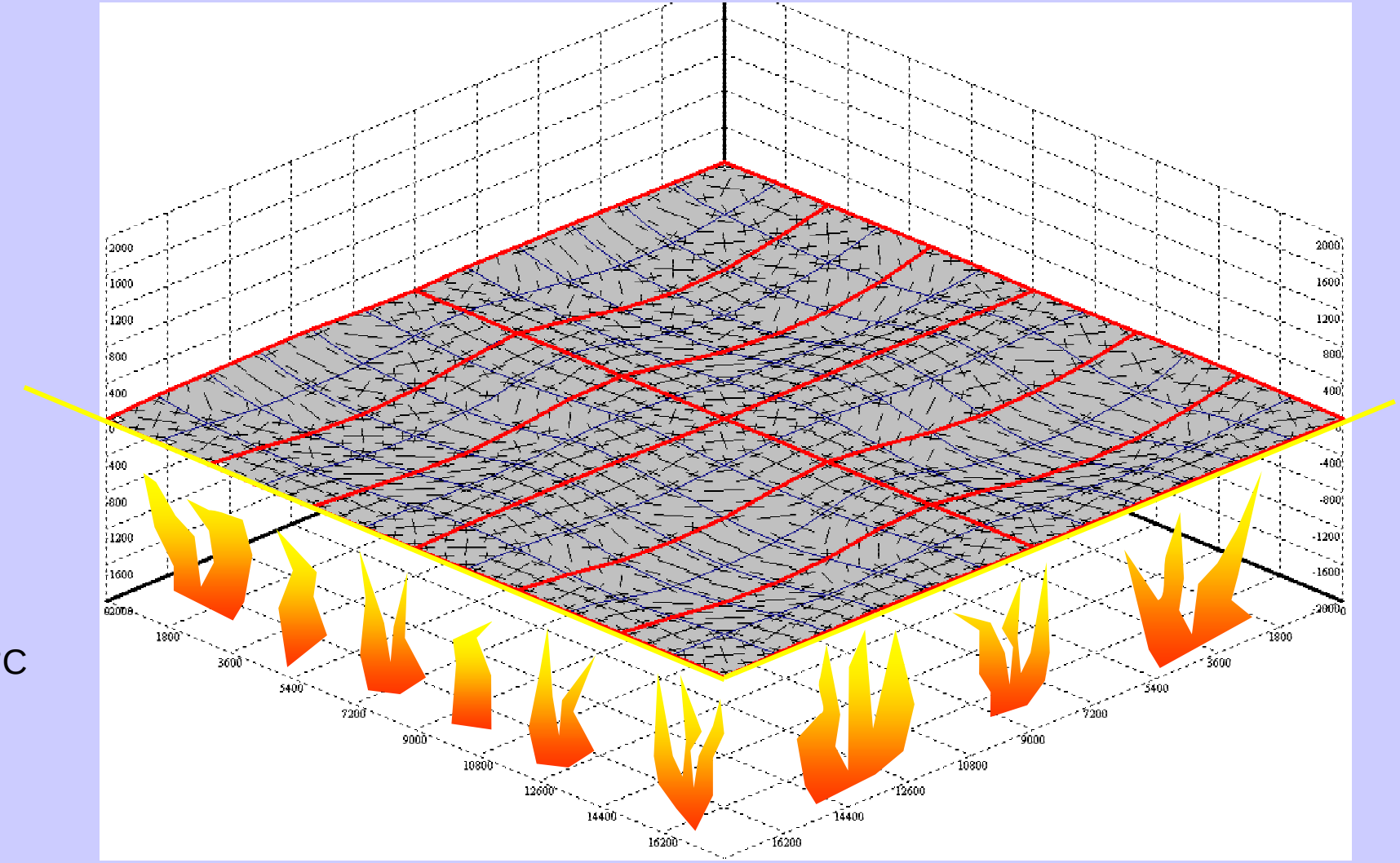
400°C

Example: Deflected shapes



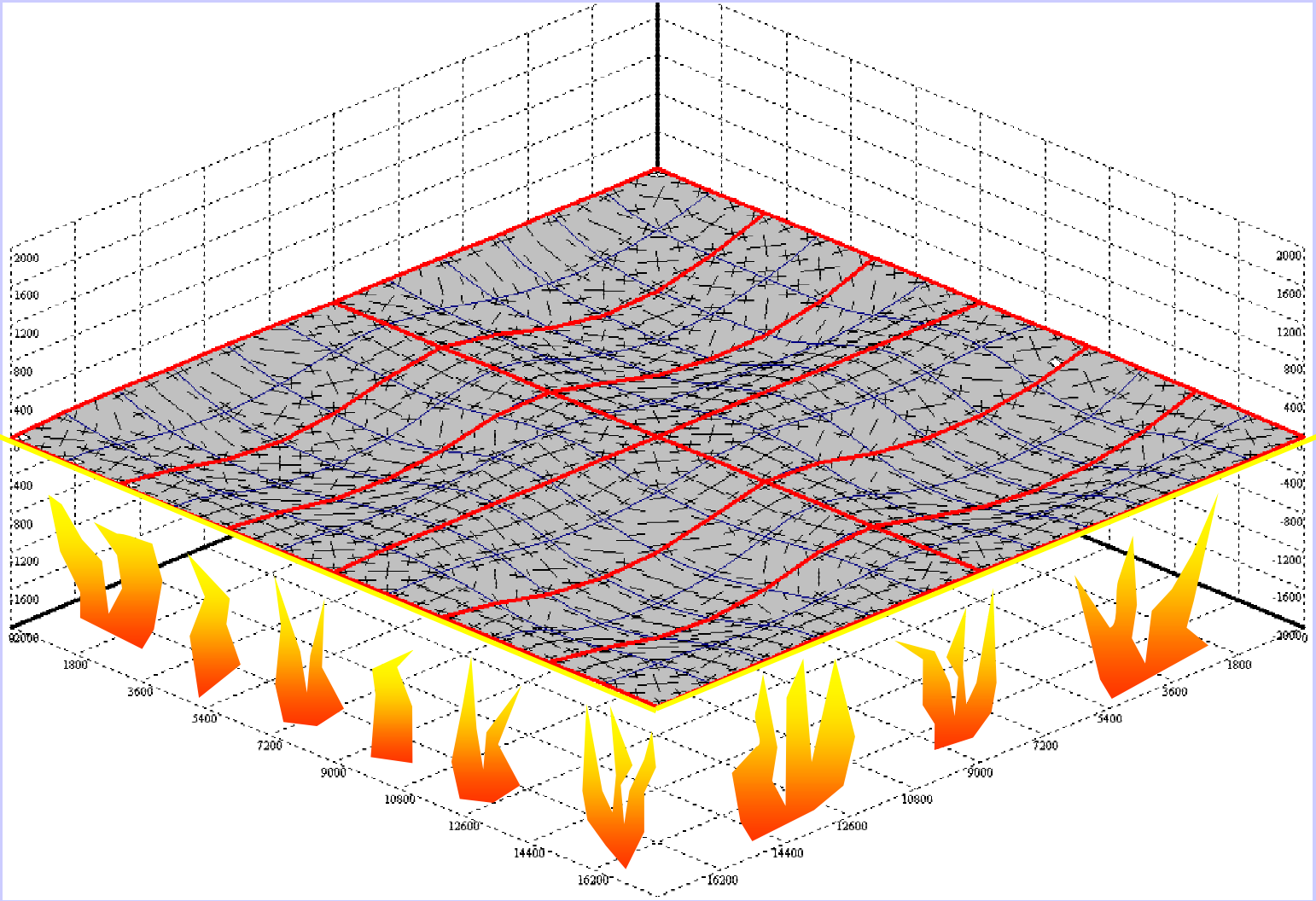
500°C

Example: Deflected shapes



600°C

Example: Deflected shapes



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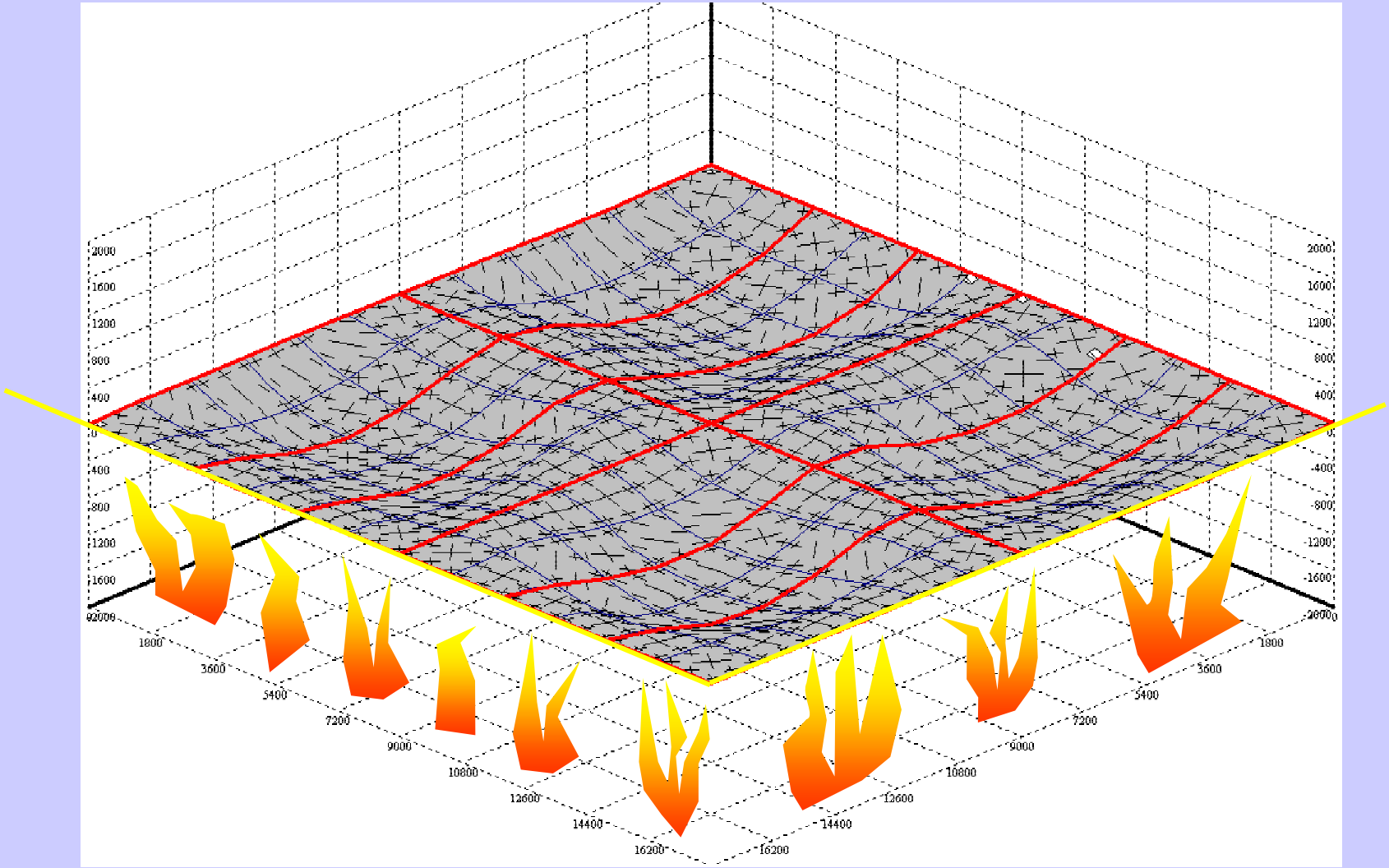
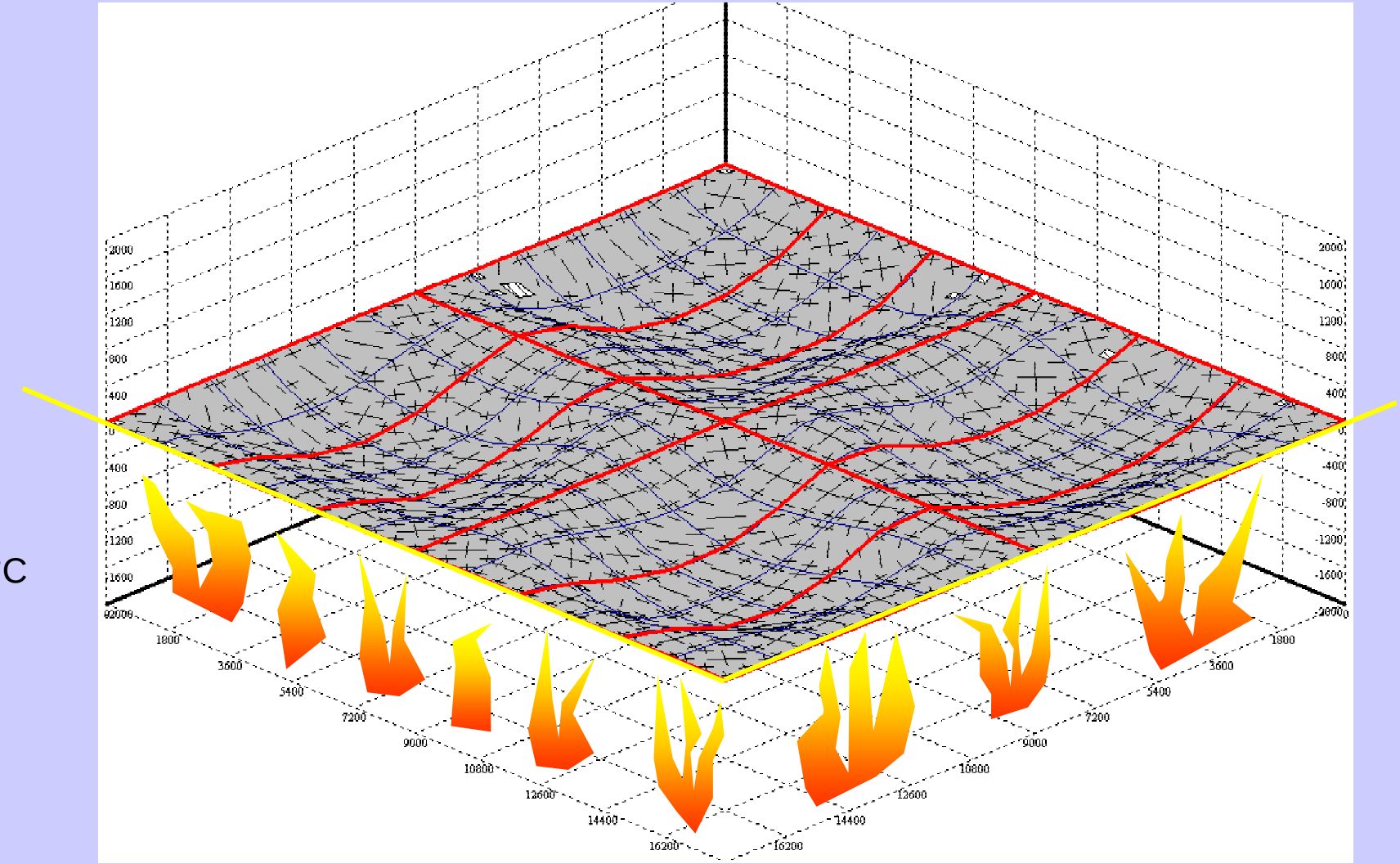


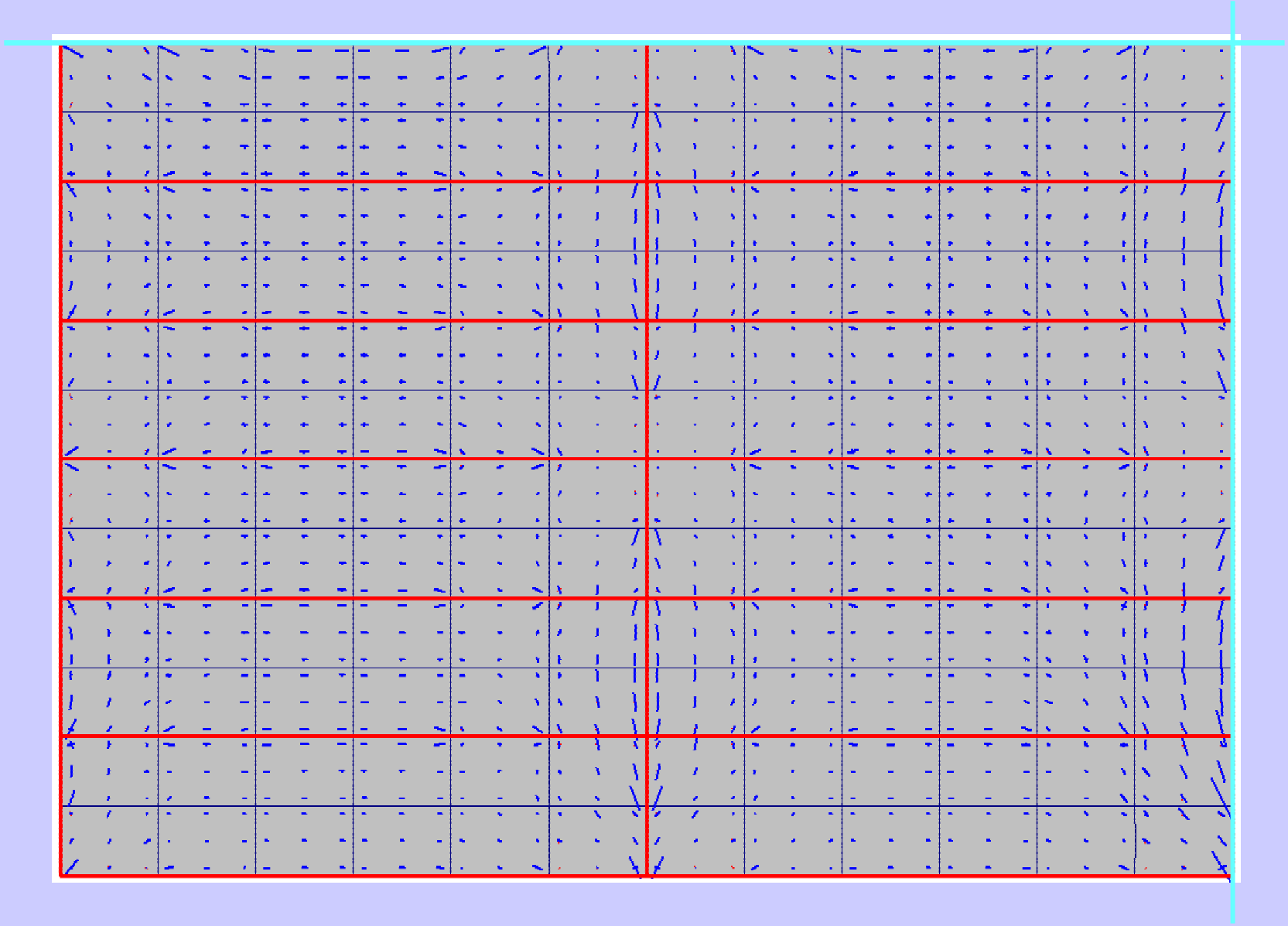
800°C

Example: Deflected shapes



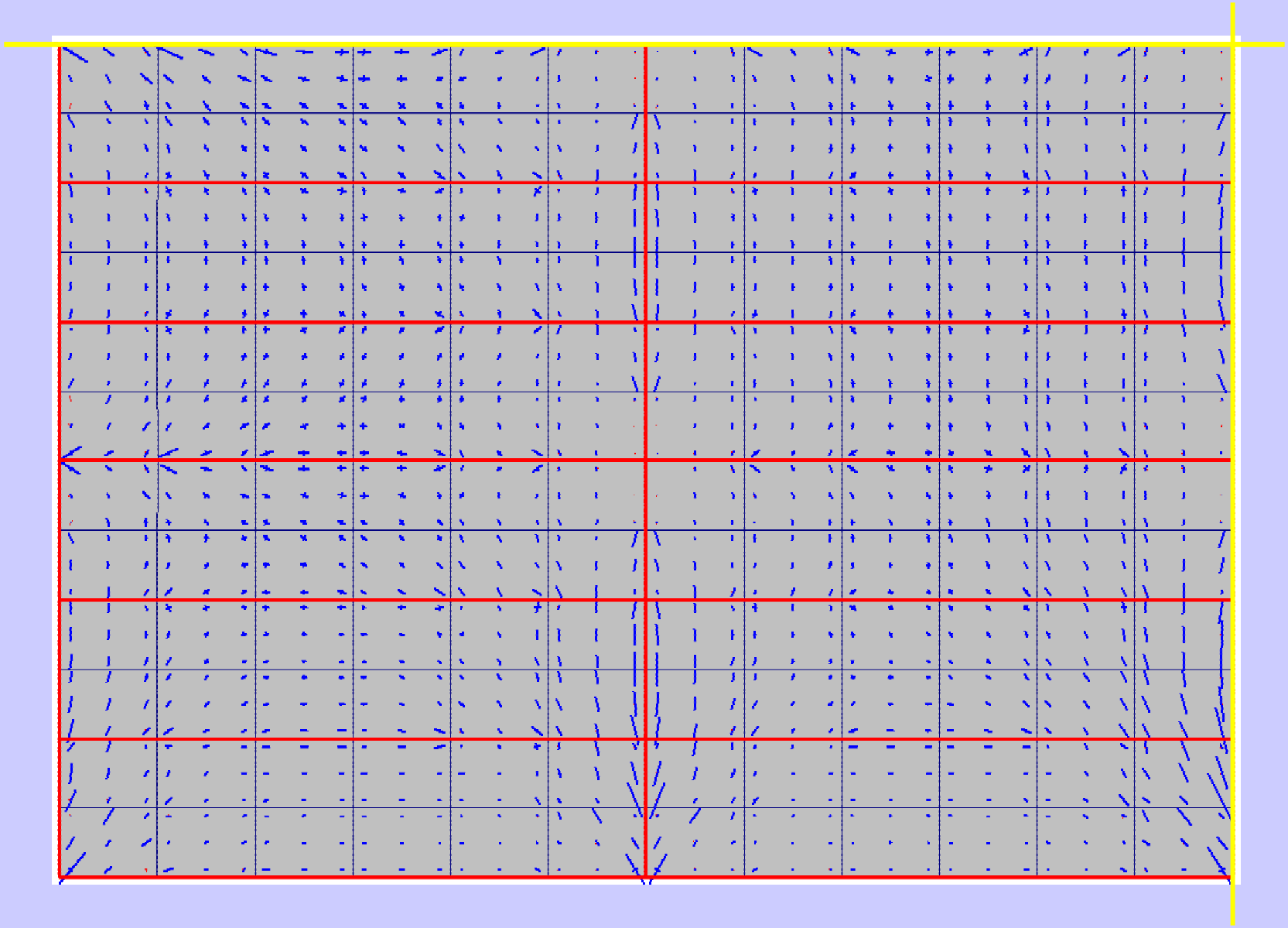
900°C

Example: Principal membrane tractions



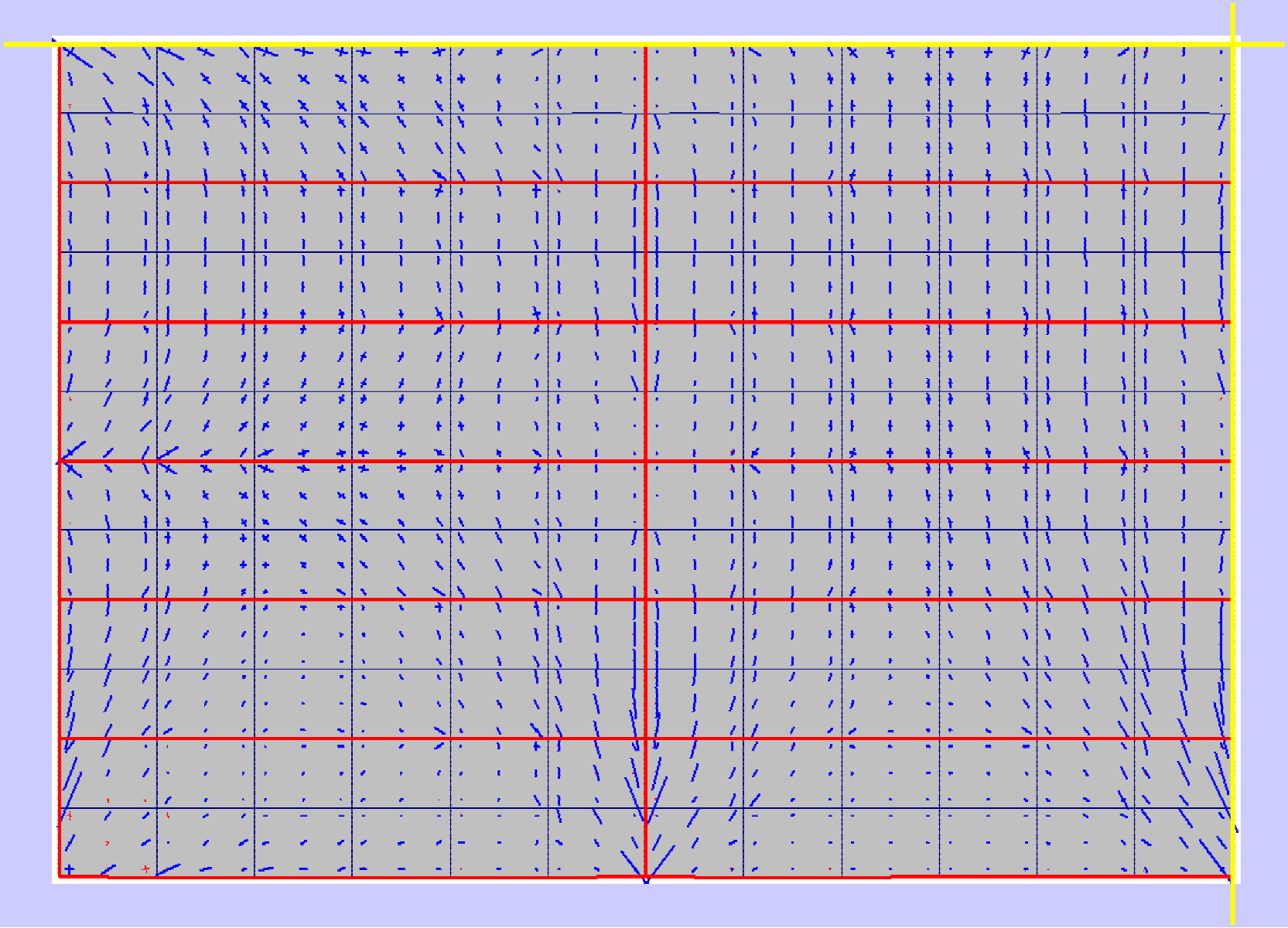
20°C

Example: Principal membrane tractions



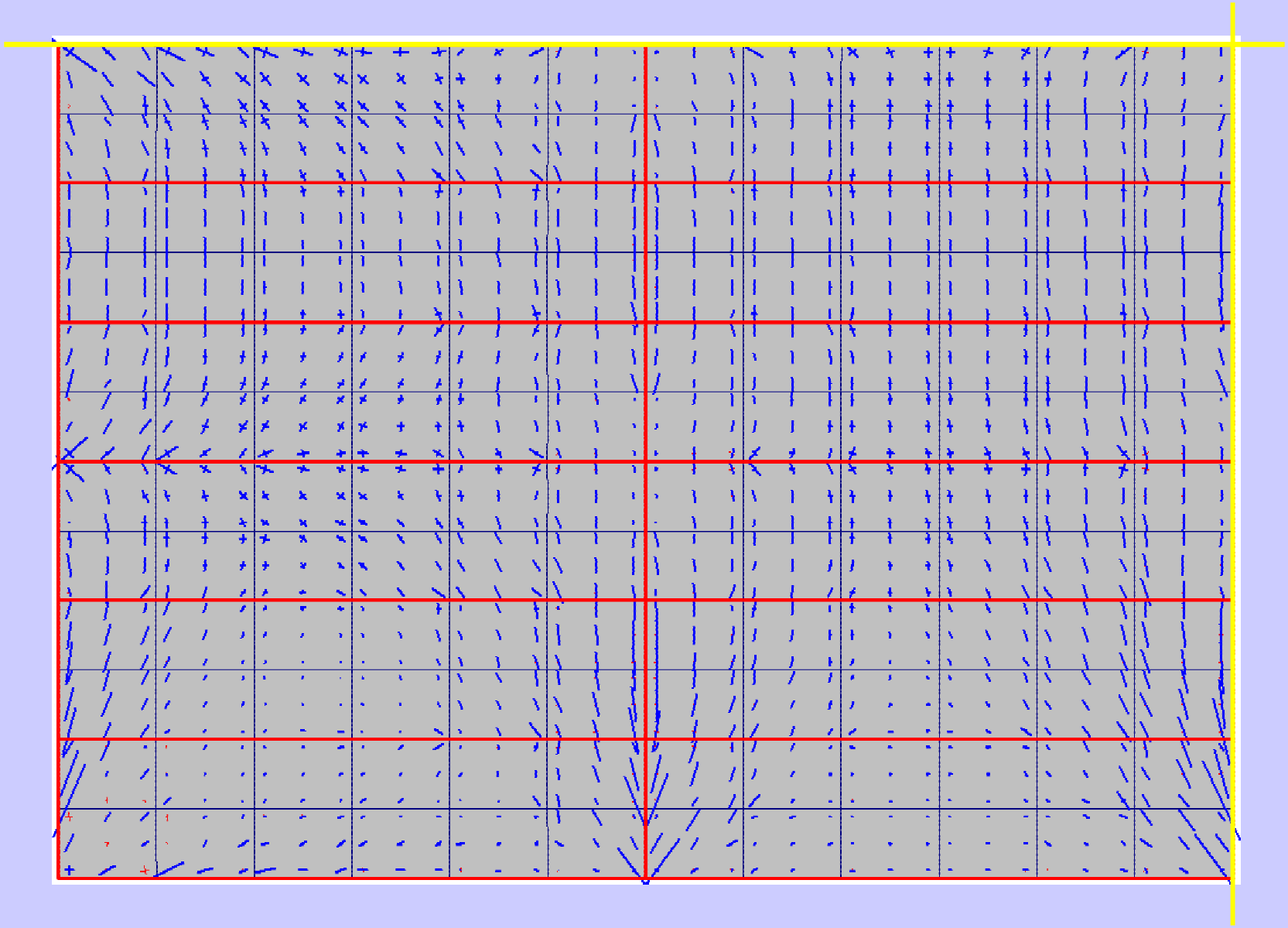
100°C

Example: Principal membrane tractions



200°C

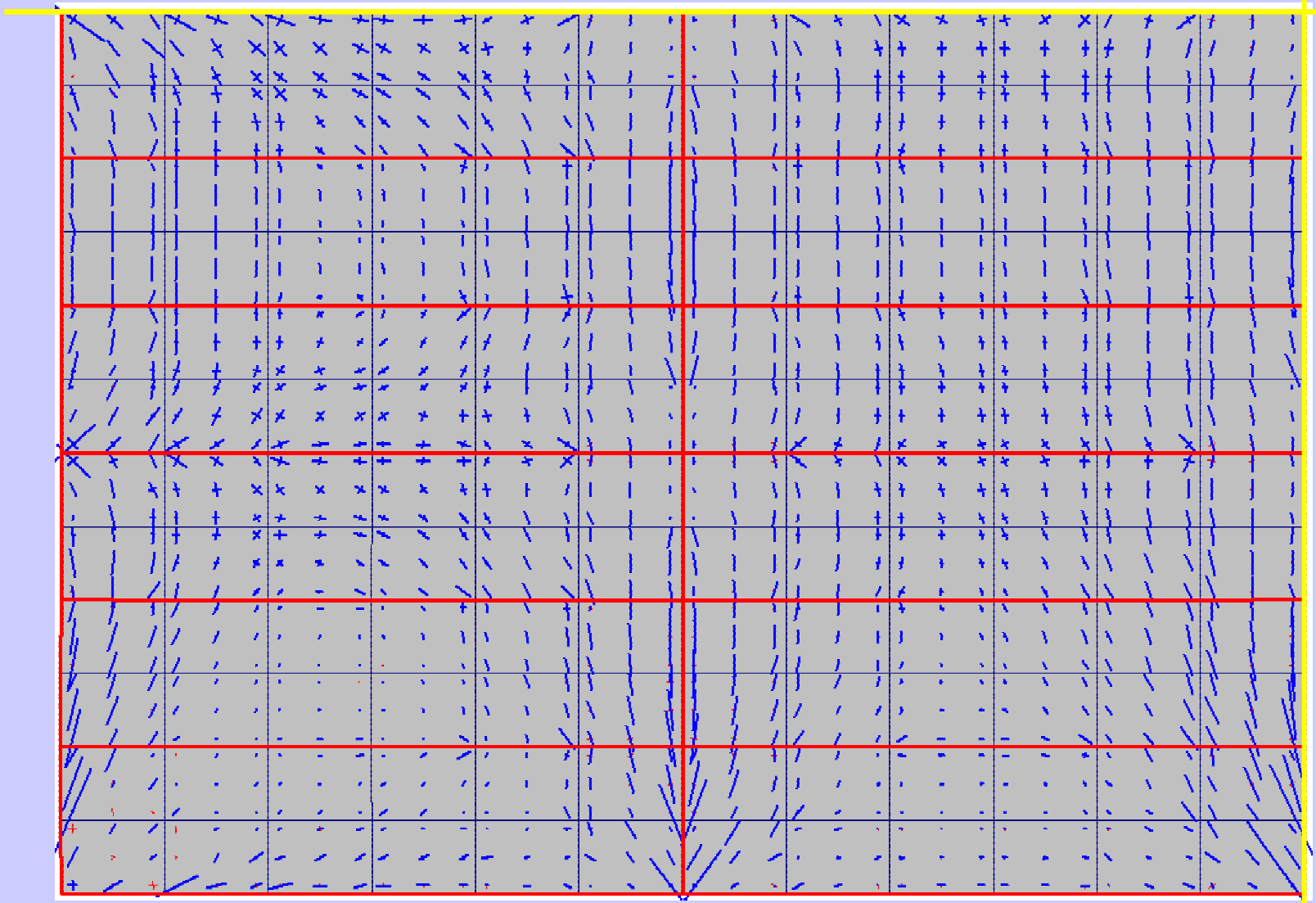
Example: Principal membrane tractions



300°C

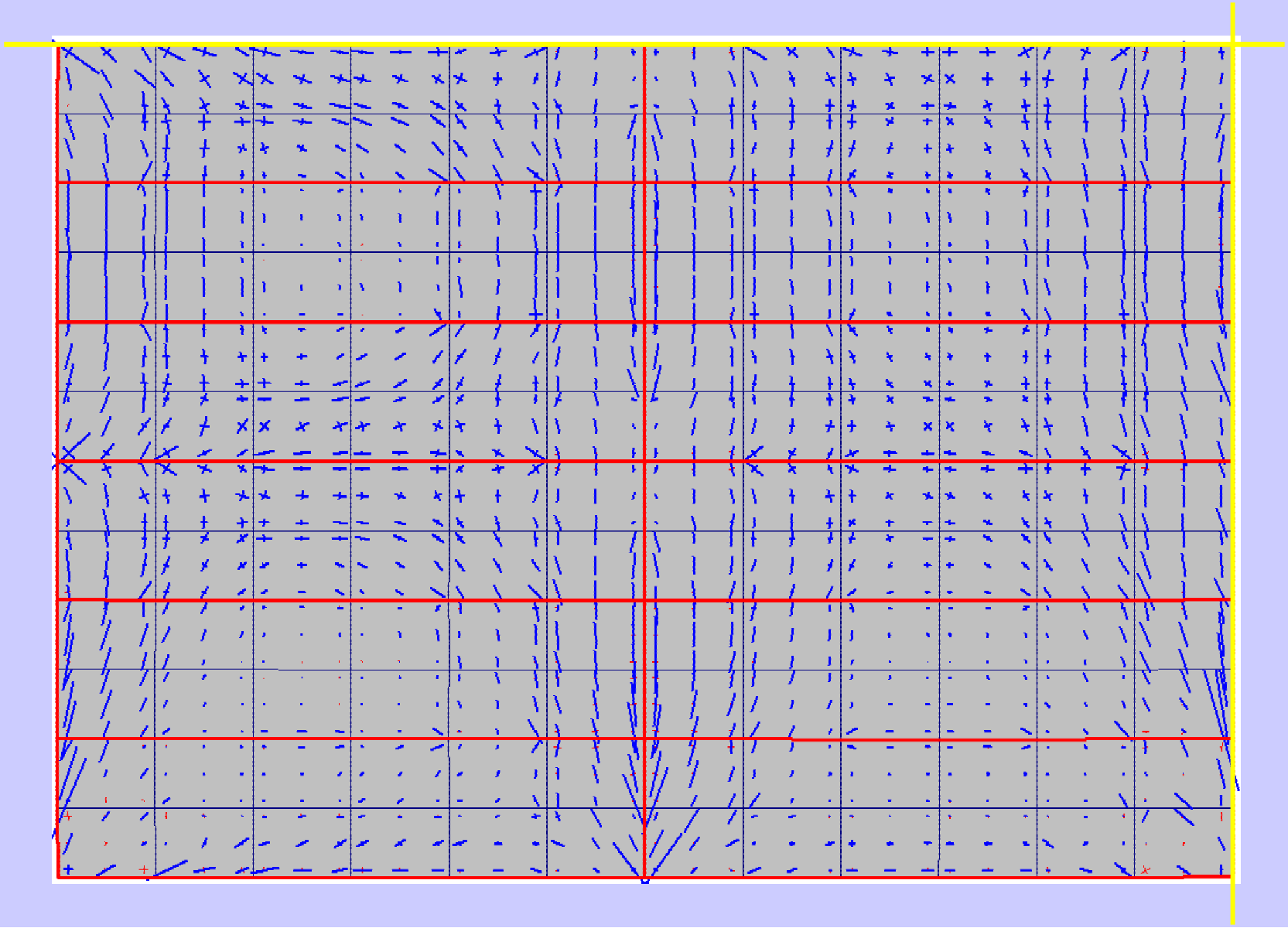
20

Example: Principal membrane tractions



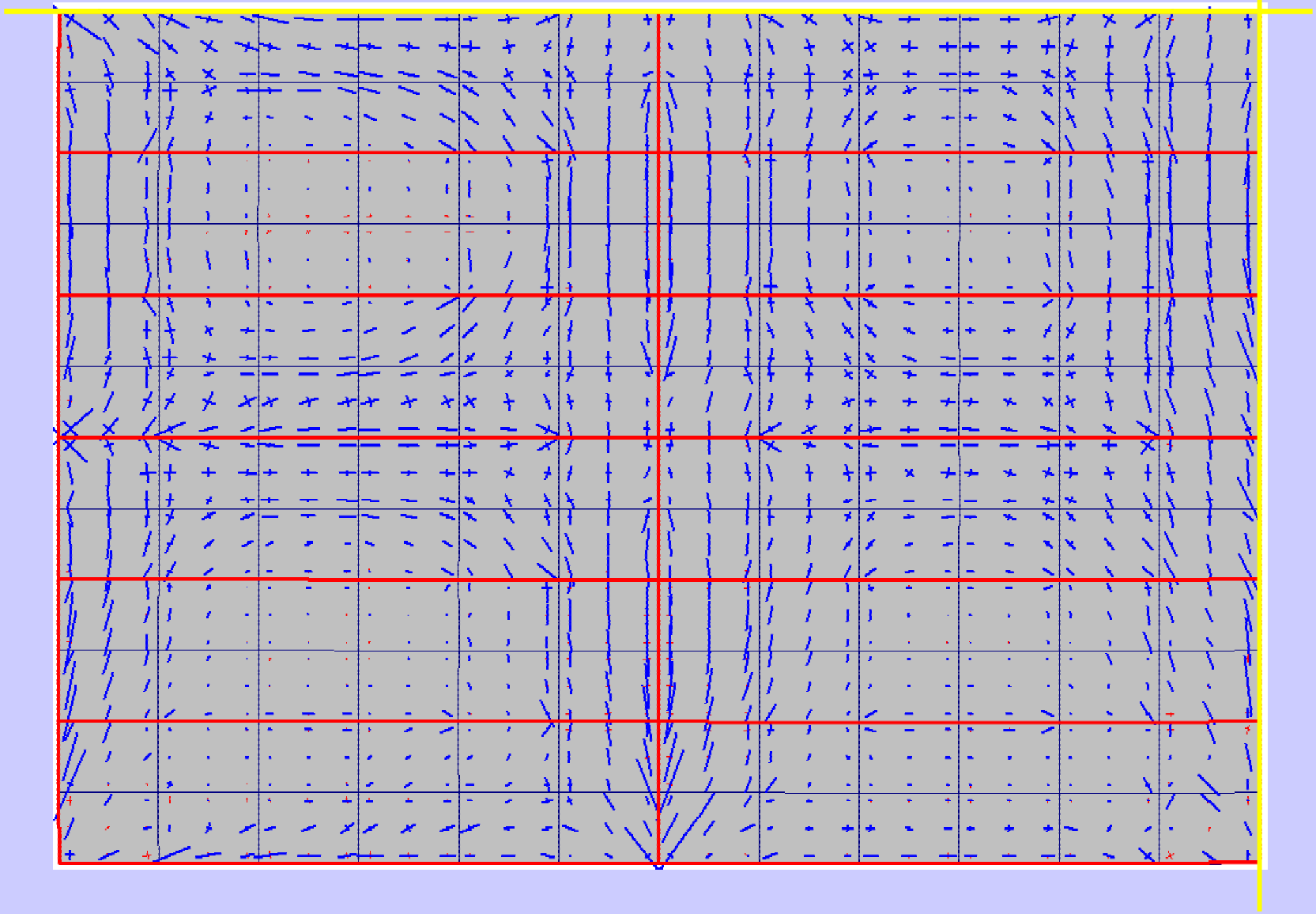
400°C

Example: Principal membrane tractions



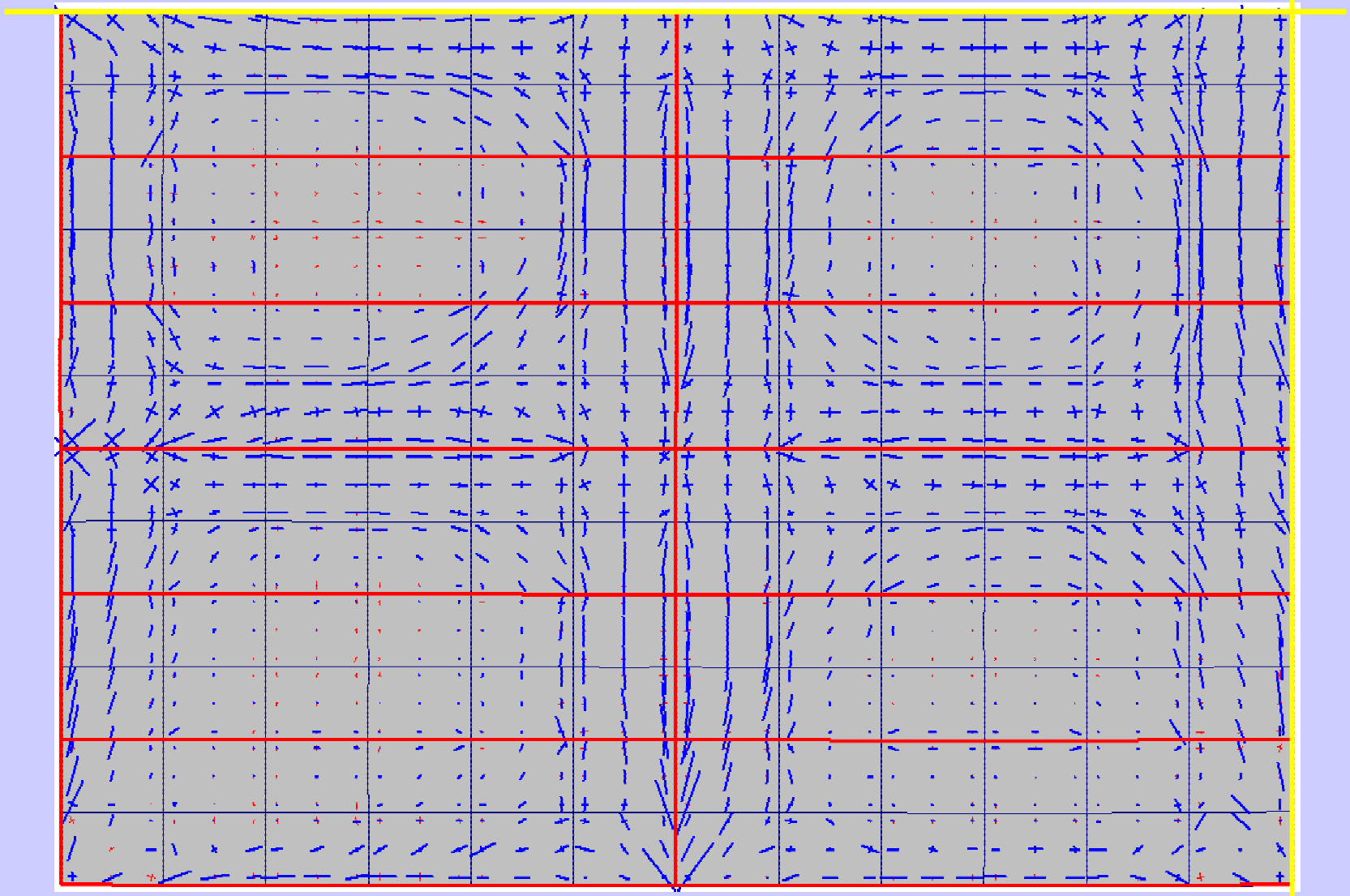
500°C

Example: Principal membrane tractions



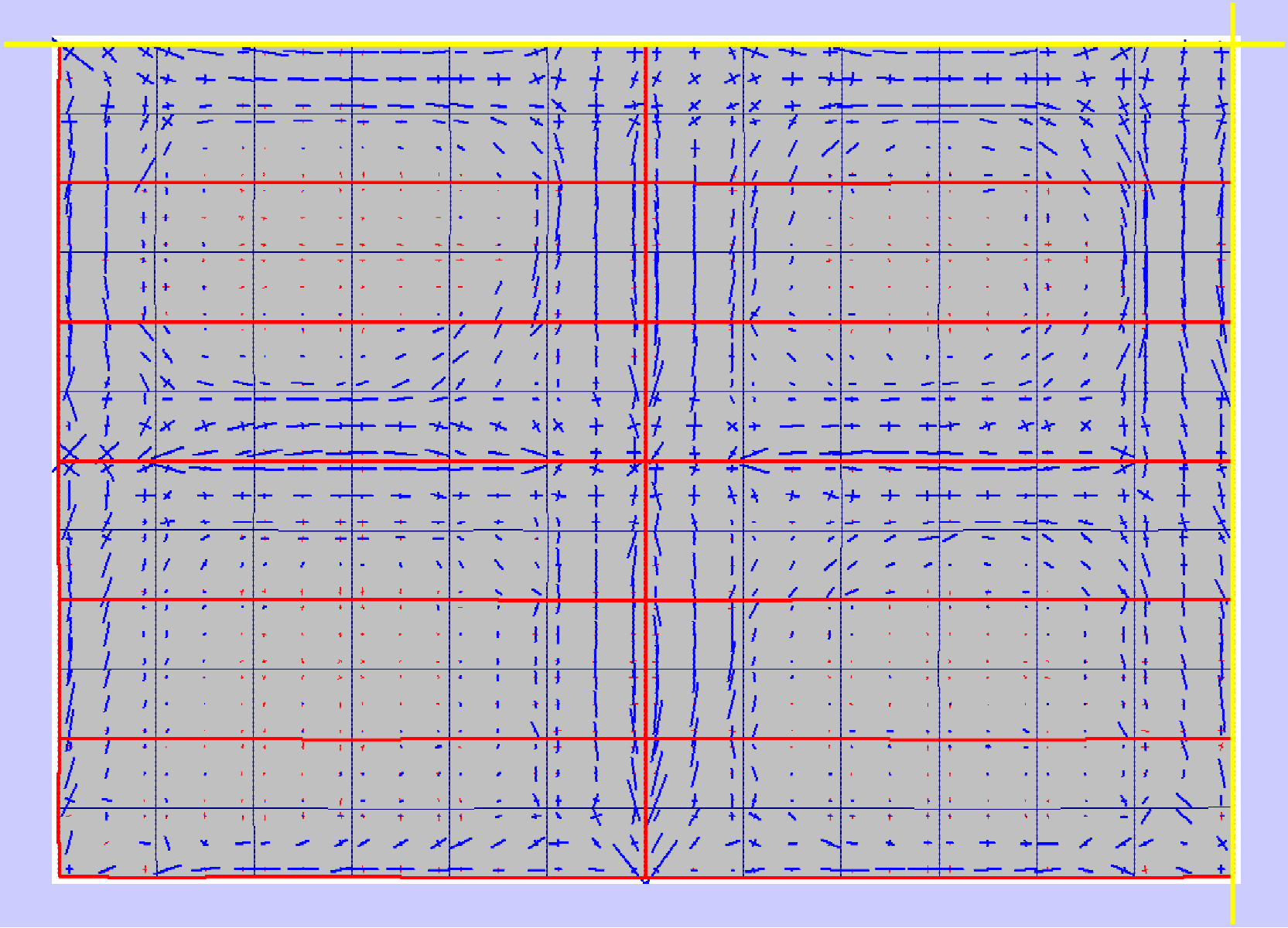
600°C

Example: Principal membrane tractions



700°C

Example: Principal membrane tractions



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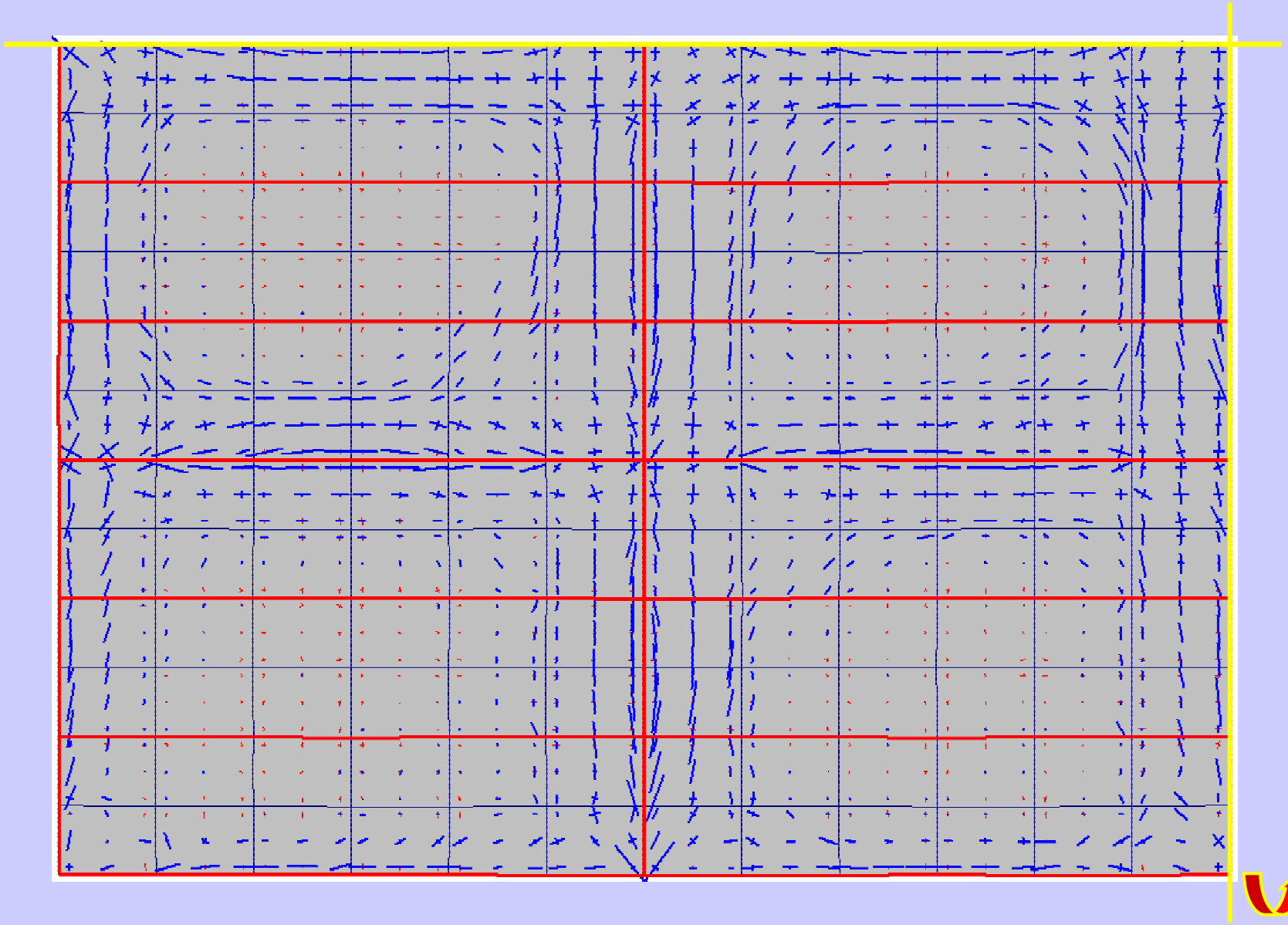
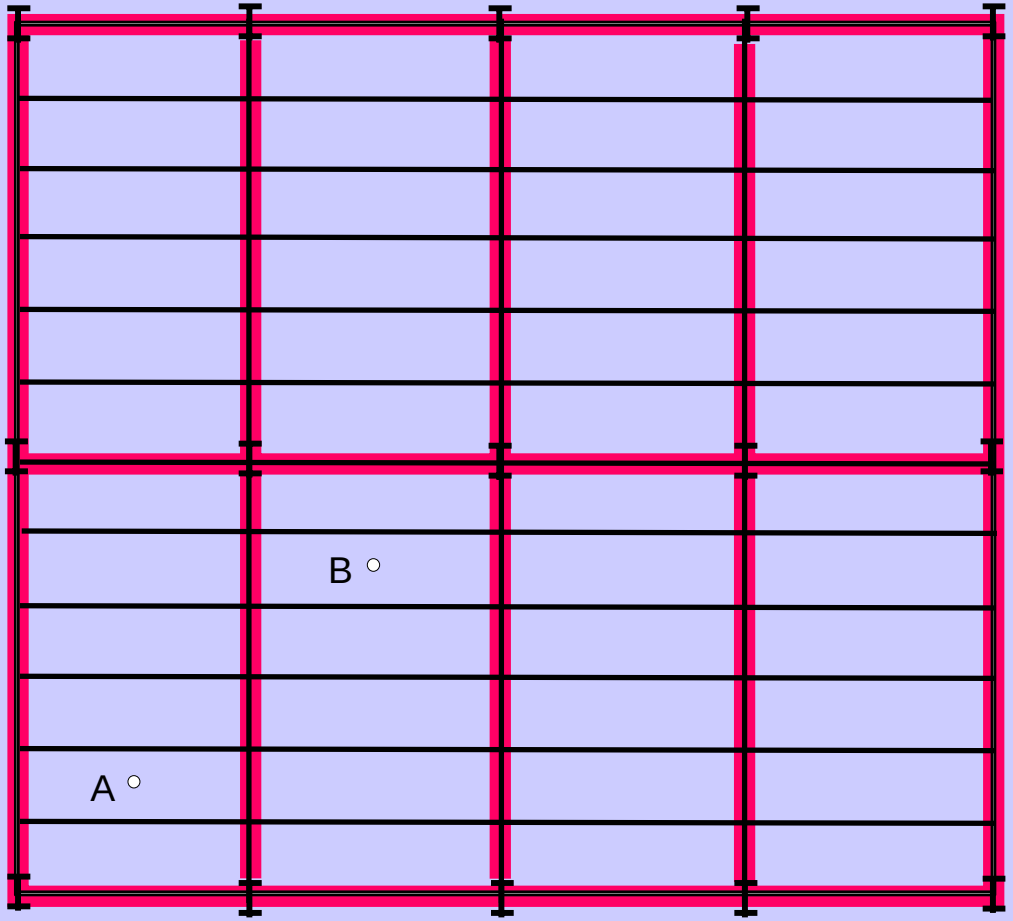


900°C

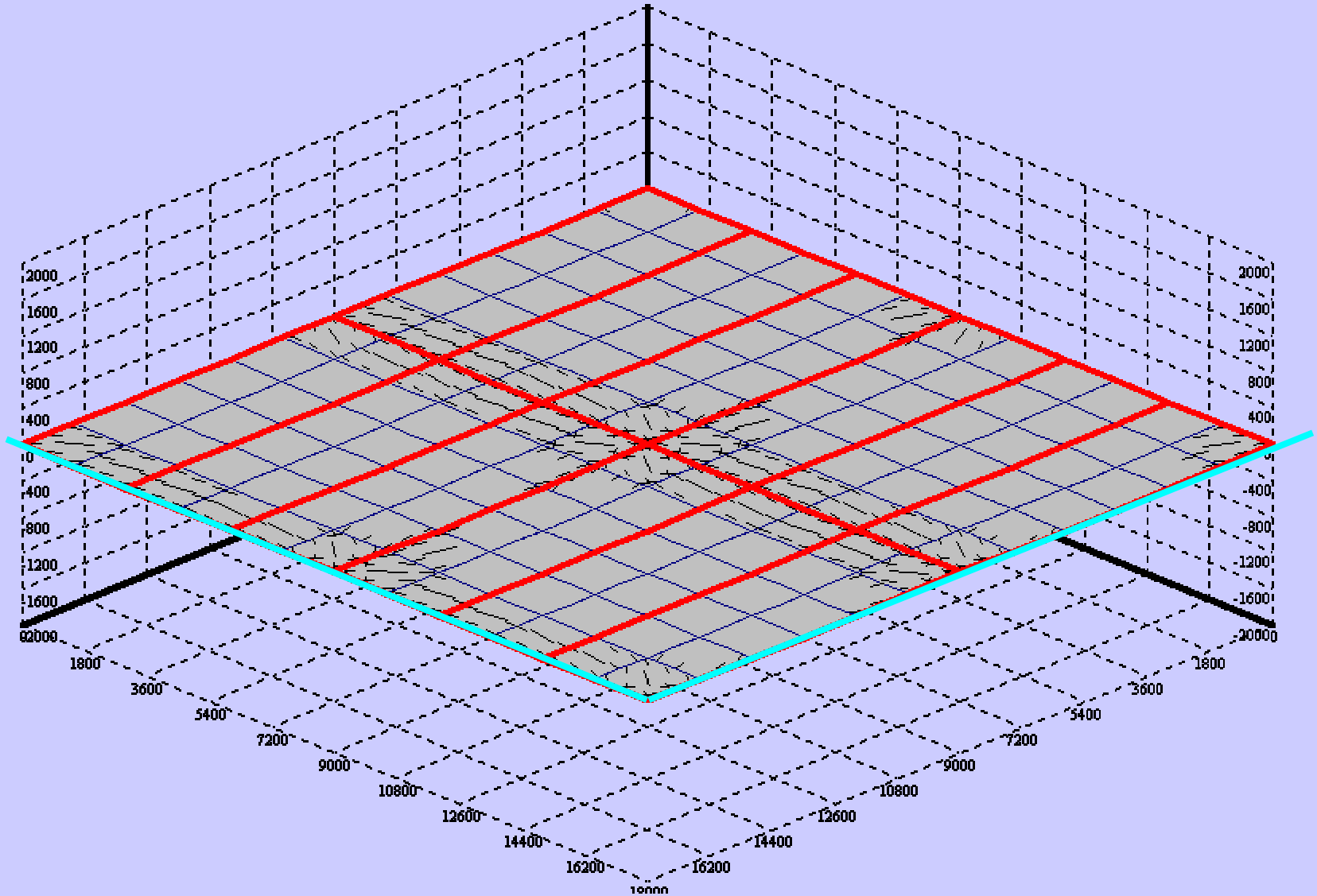
Structural fire resistance methods

Non-square structural frames:

Much lower enhancement of capacity due to tensile membrane action.

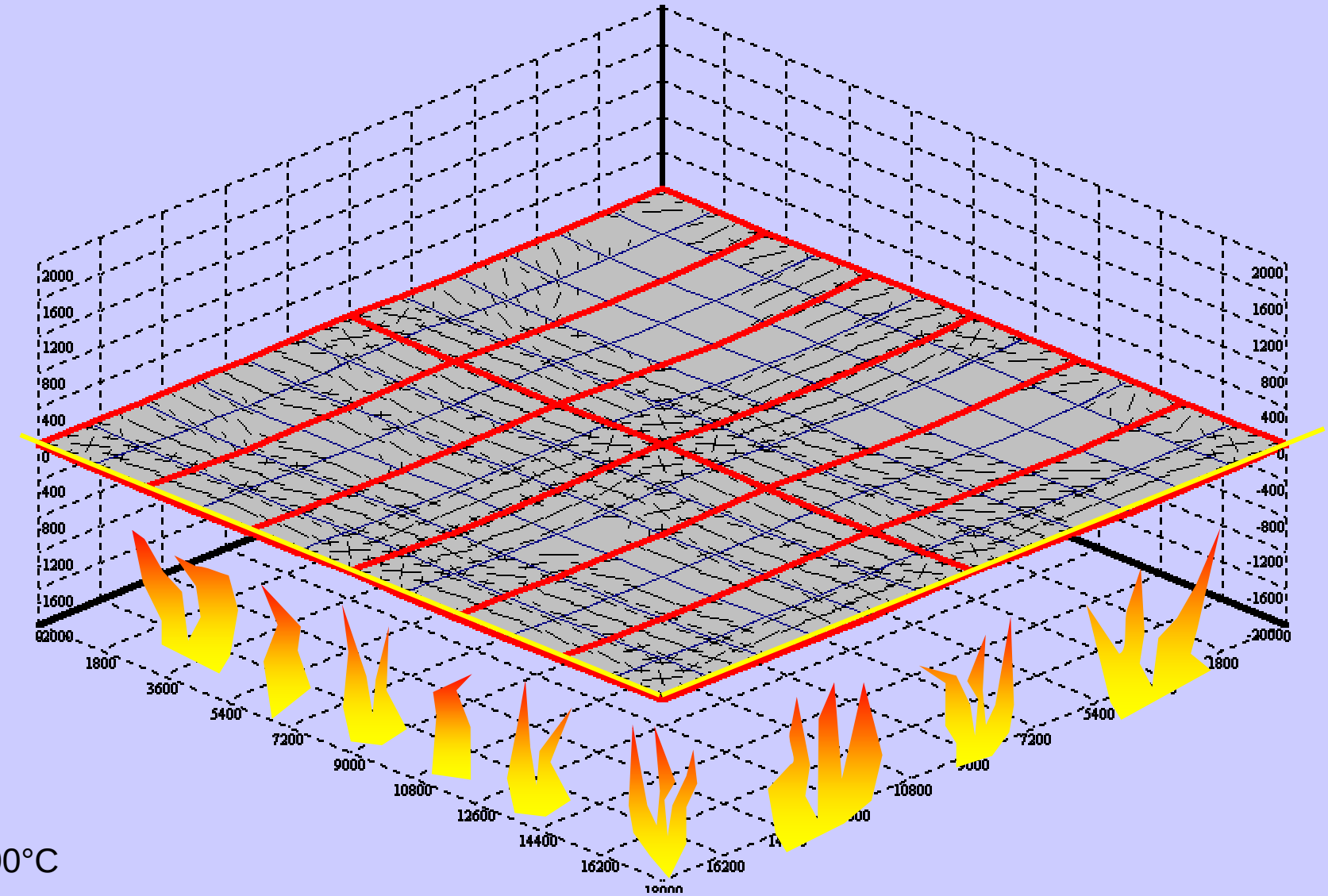


Protection Regime 2: Deflection profile



20°C

Protection Regime 2: Deflection profile



200°C

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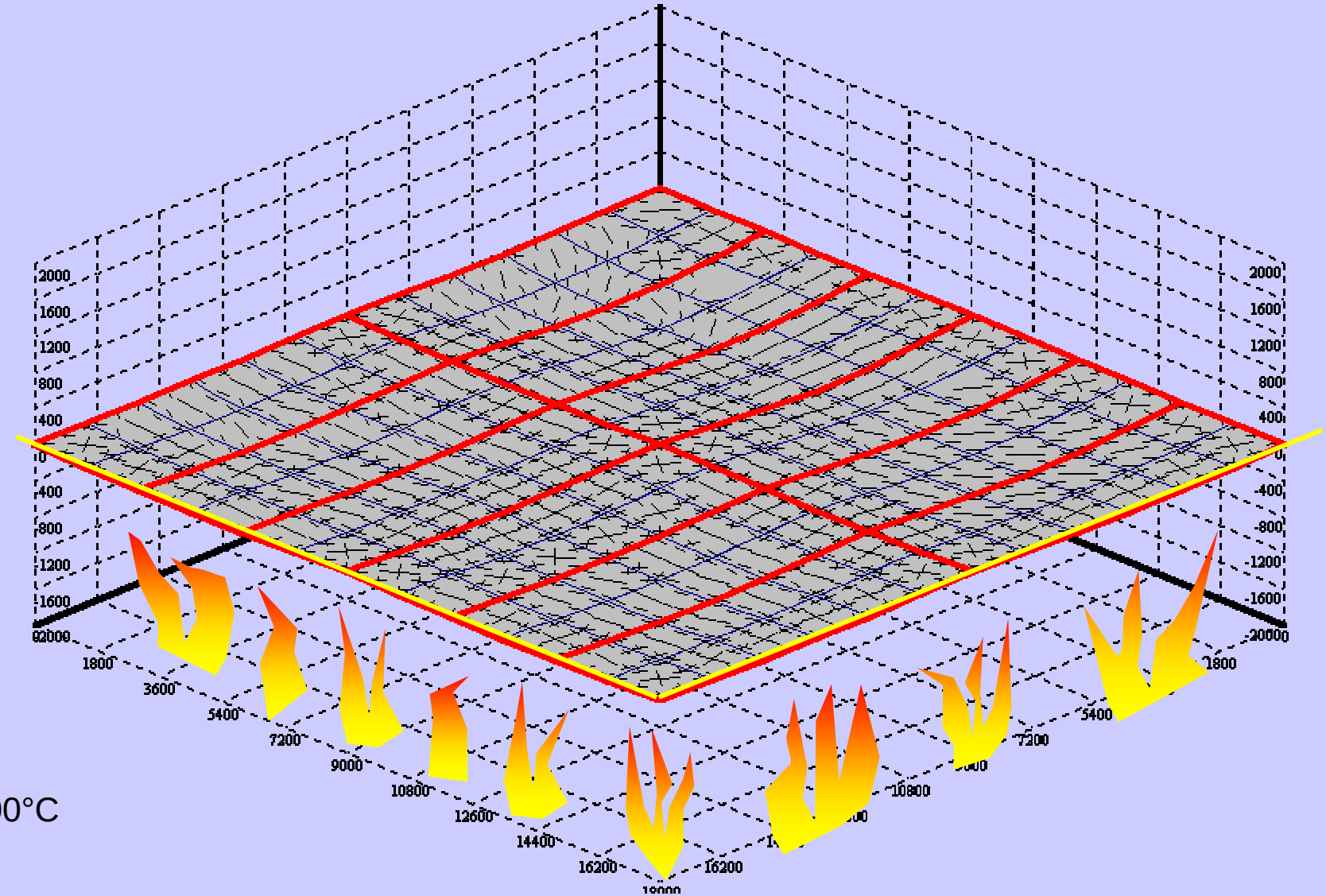

400°C

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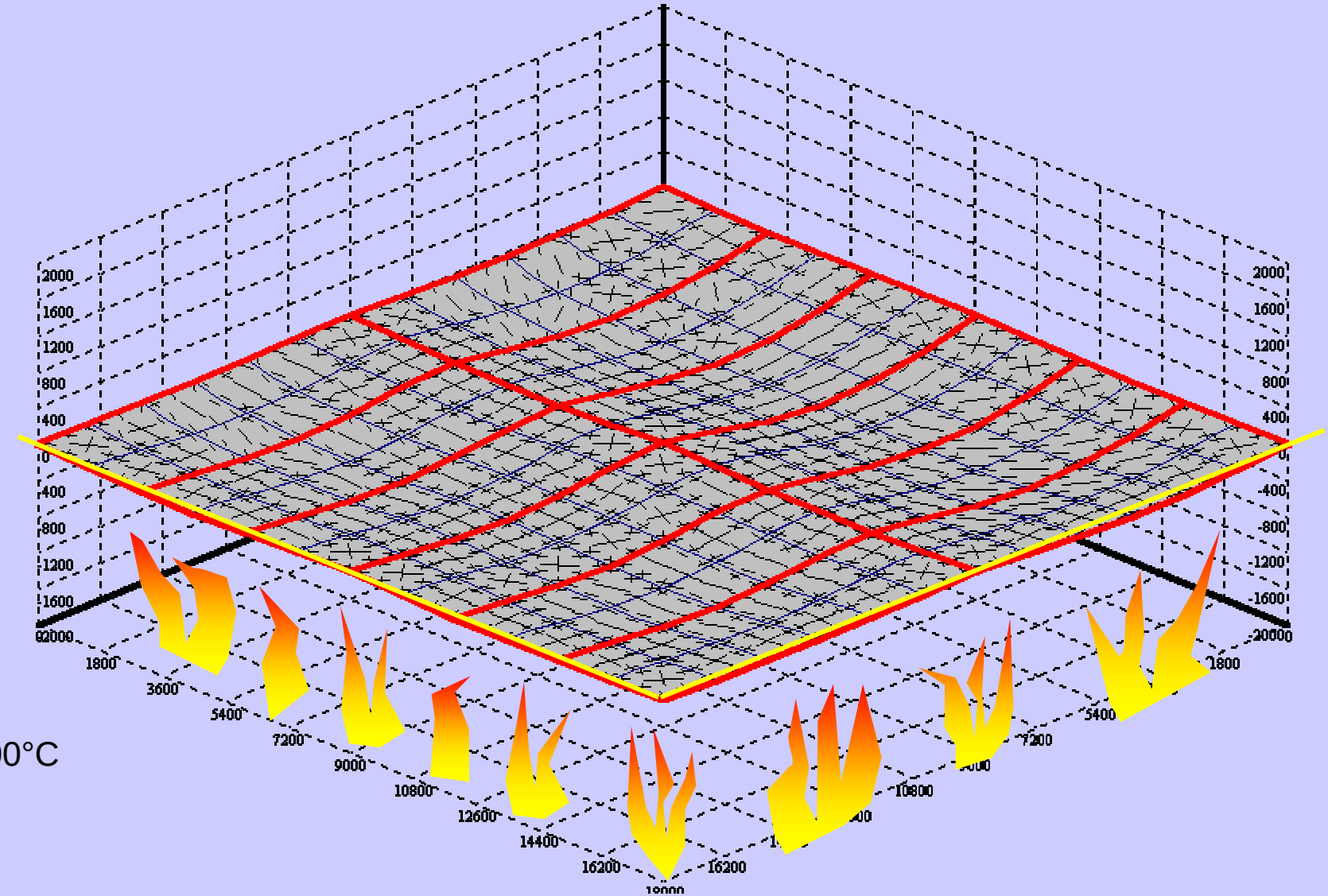

600°C

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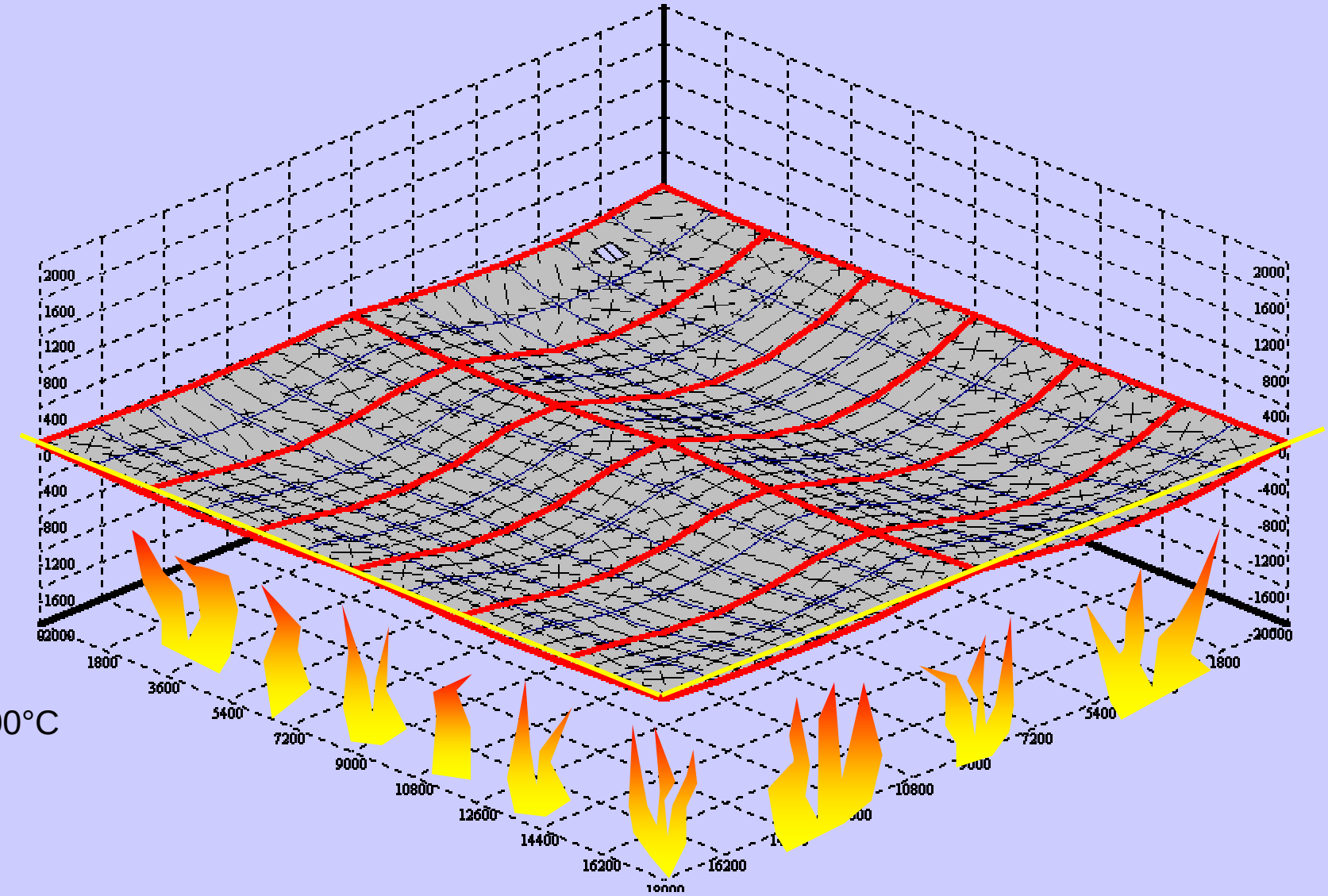

700°C

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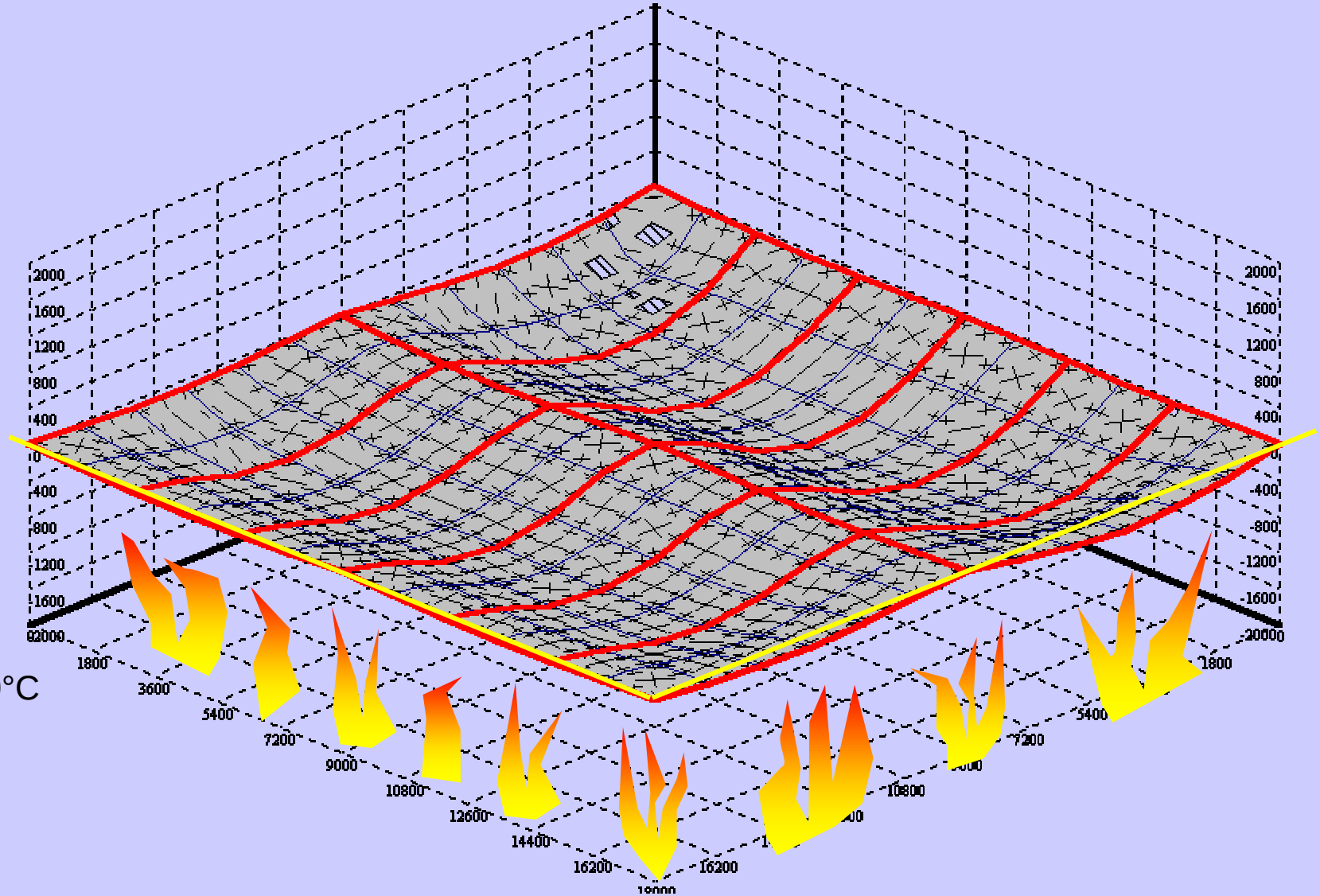
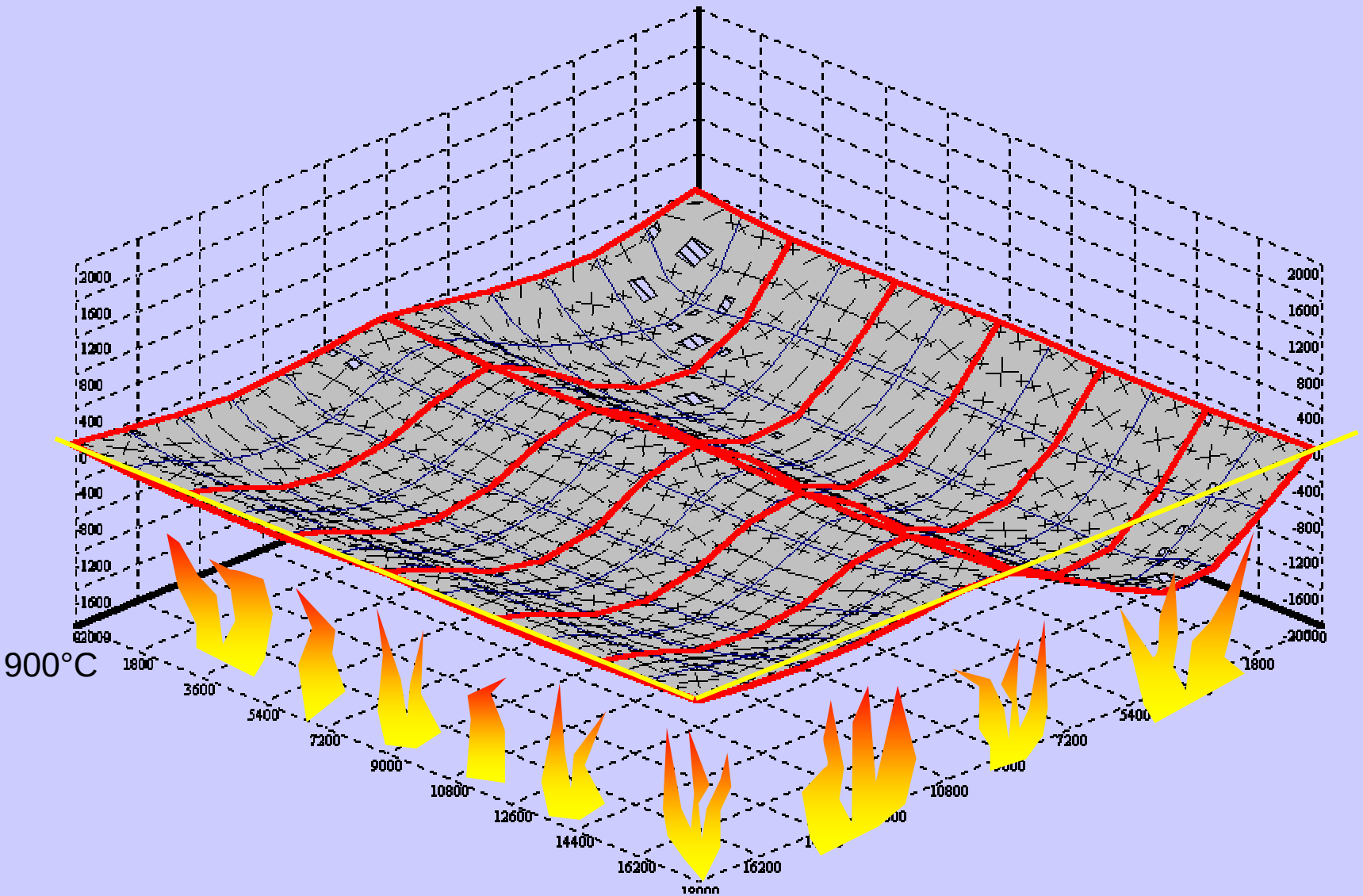
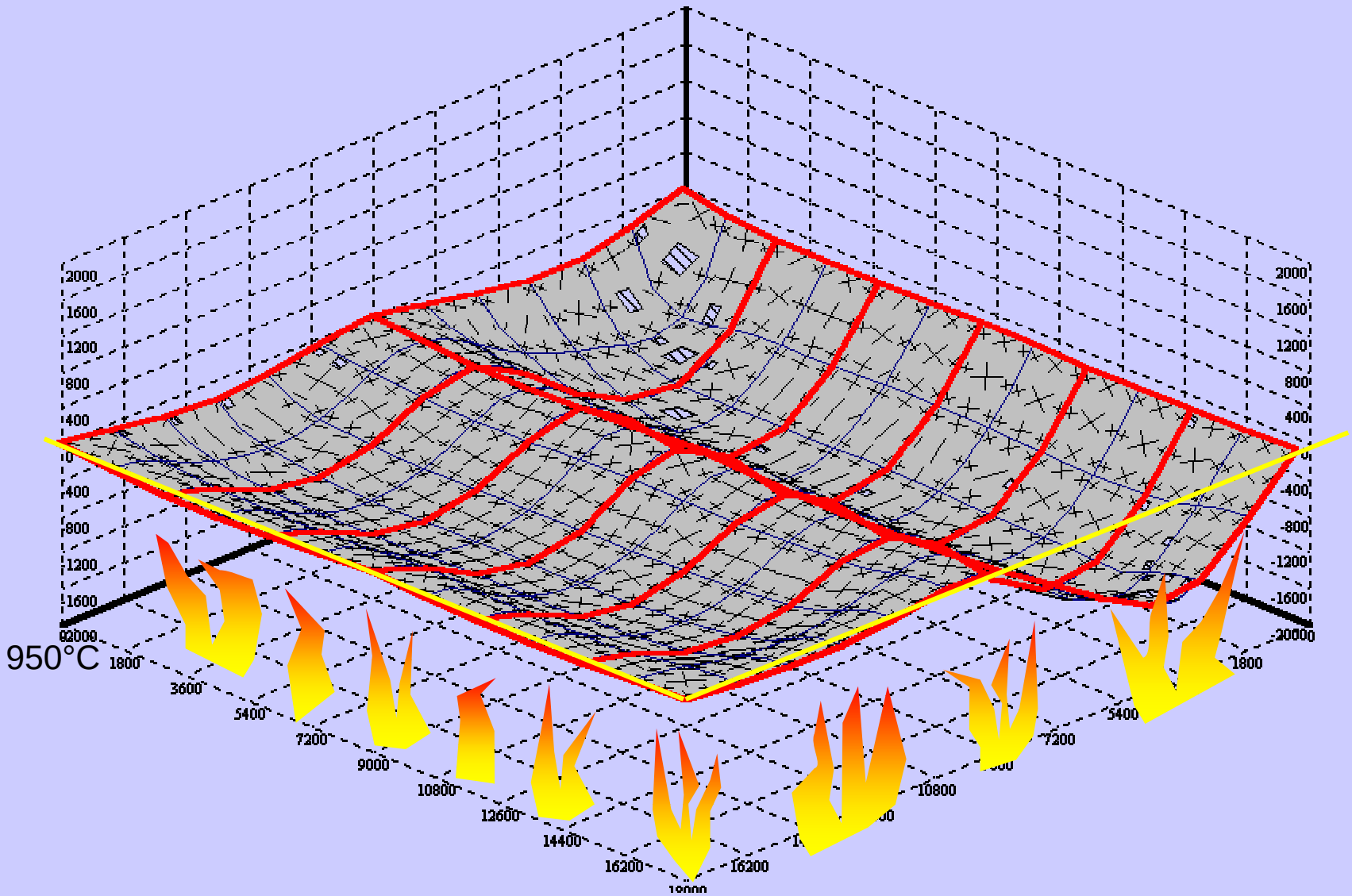


800°C

Protection Regime 2: Deflection profile



Protection Regime 2: Deflection profile



NIST's Recommendations

New methods for fire-resistant design

8. Set the objective that uncontrolled building fires should burn out without local or global collapse.

9. Develop performance based codes and supporting test methods and design tools to allow the fire performance of the entire structure in real building fires to be evaluated.

10.

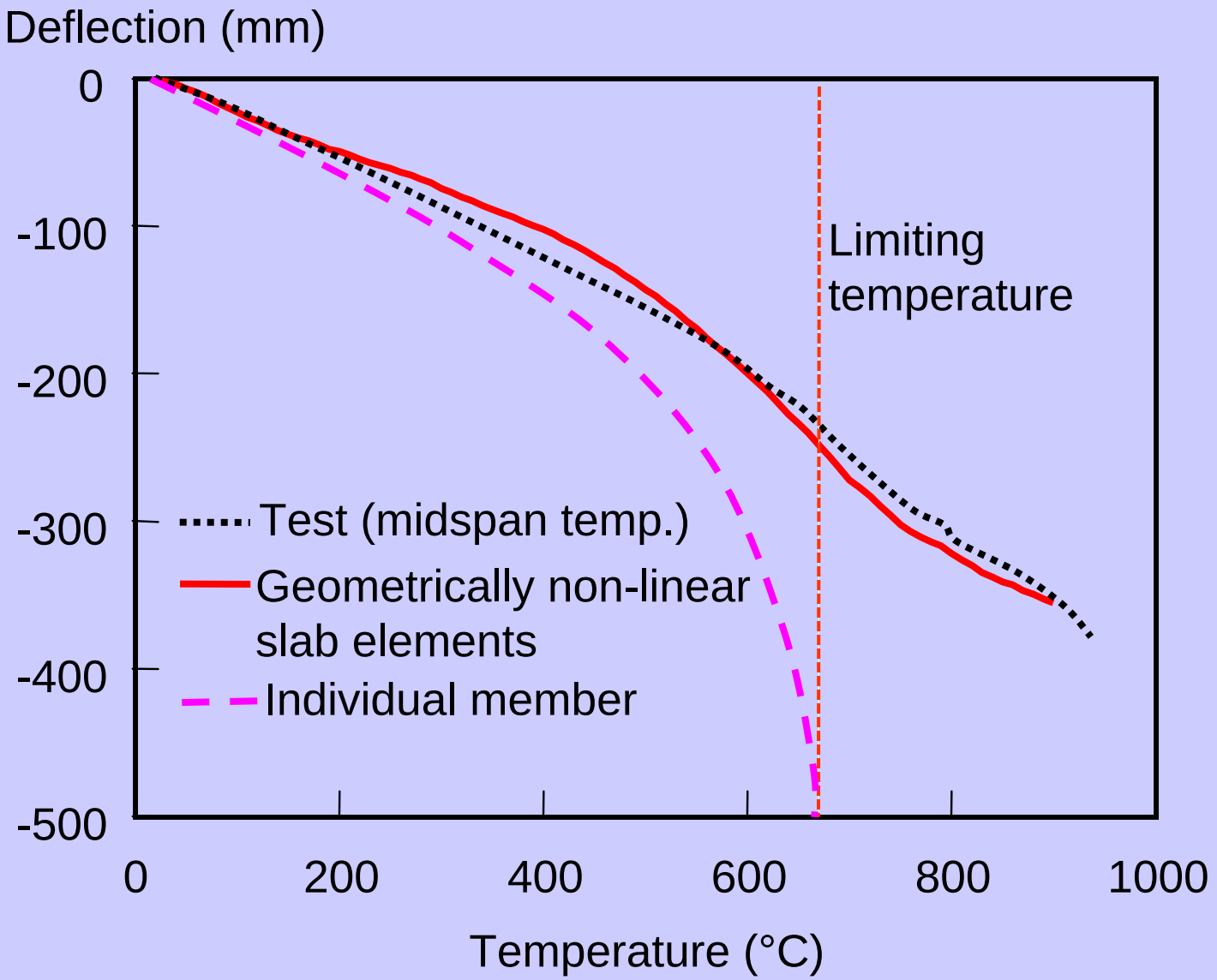
11.

Realistic fire model + burnout more logical than standard fire + time

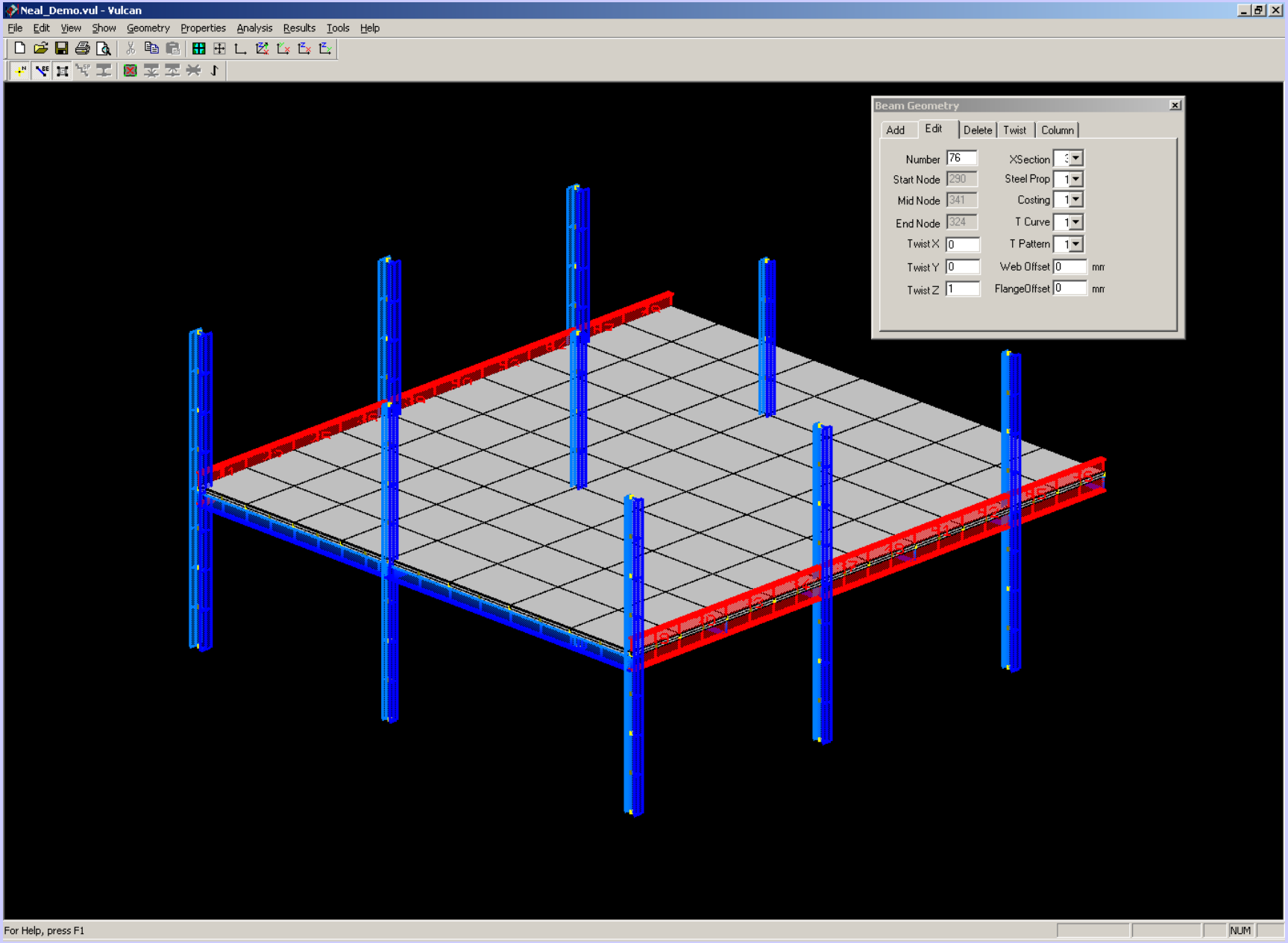
Global behaviour very different from individual elements in isolation

Also provides details of connection forces

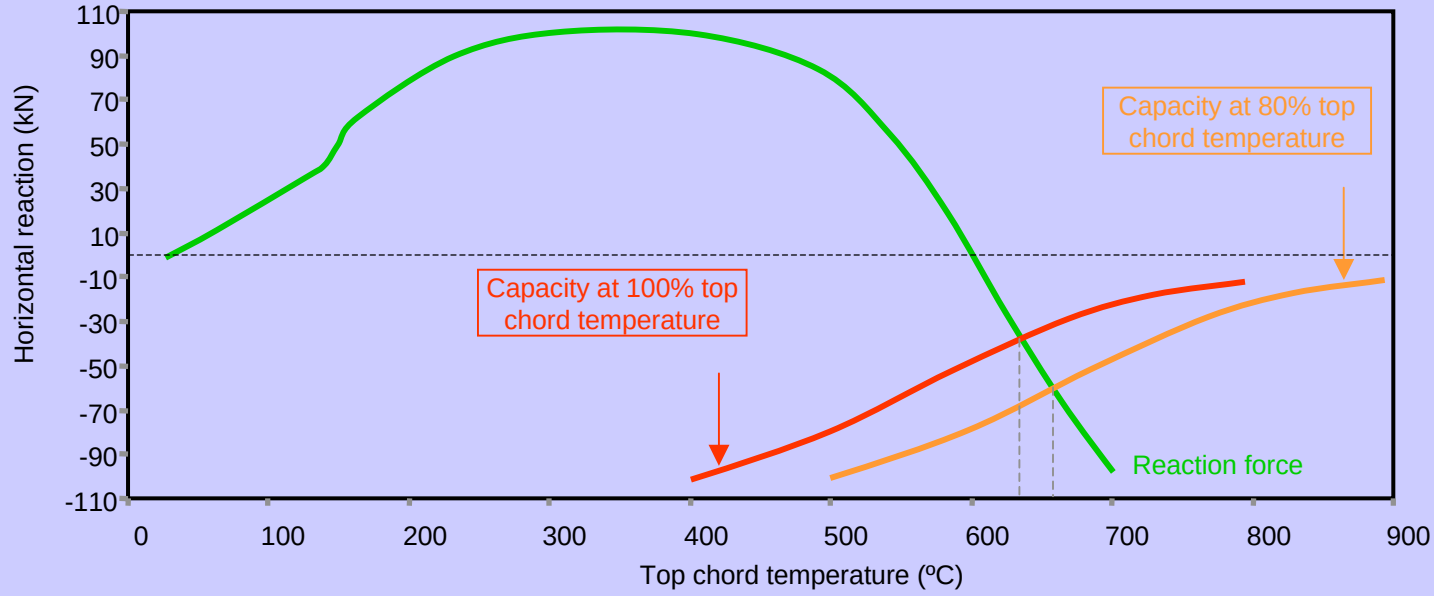
Whole structure/member analysis

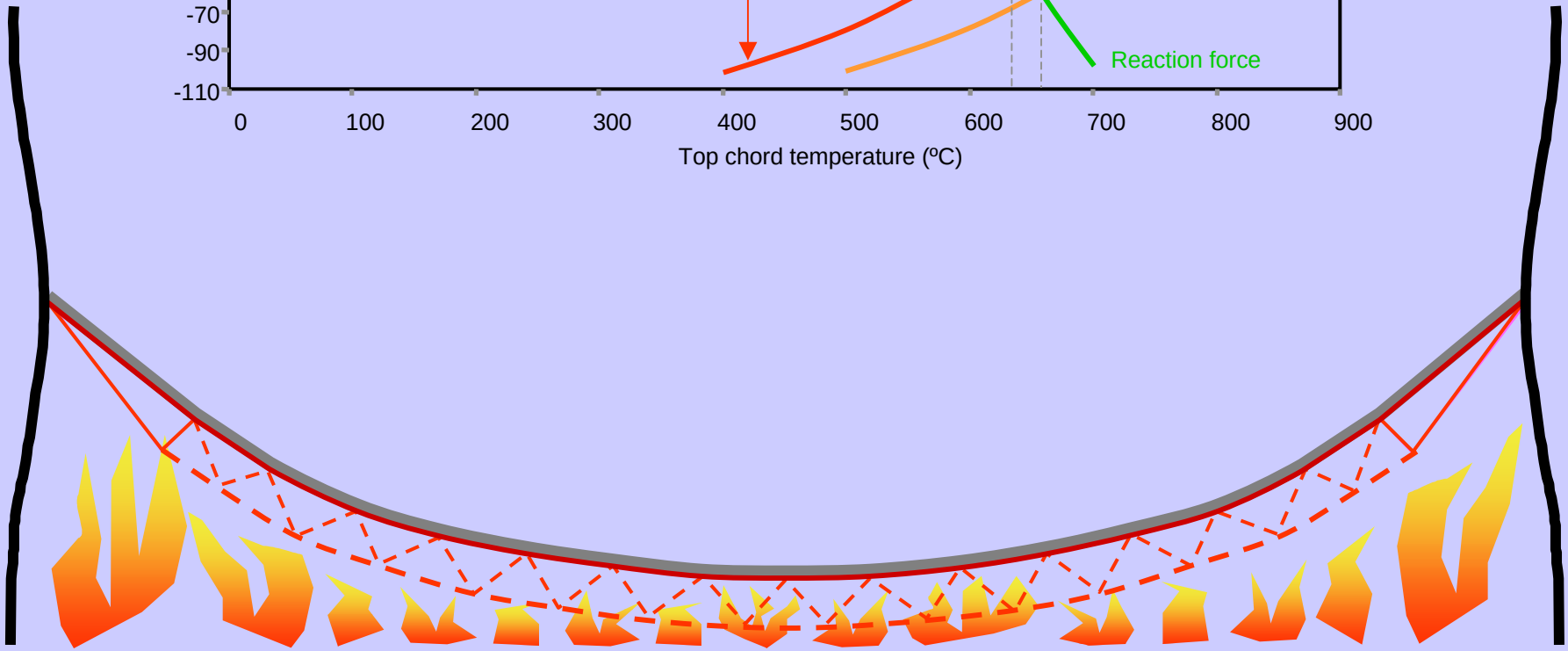


Design tools for structural fire engineering



Axial forces in heated floor truss





NIST's Recommendations

New methods for fire-resistant design

8. Set the objective that uncontrolled building fires should burn out without local or global collapse.

9. Develop performance based codes and supporting test methods and design tools to allow the fire performance

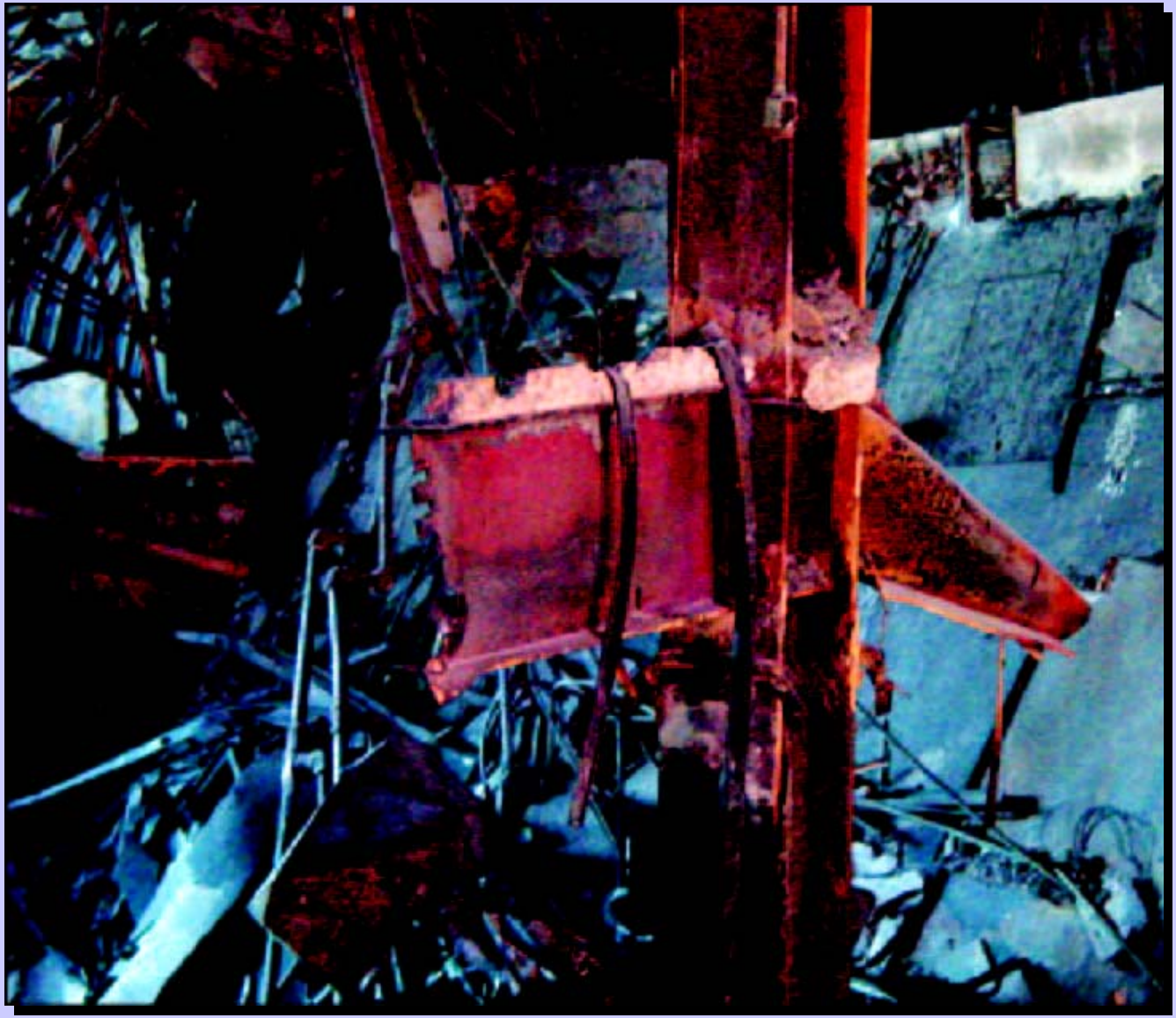
Connection forces can be very large

Need to know connection robustness as well as stiffness

Benefit of component based approach for connections

performance material systems.

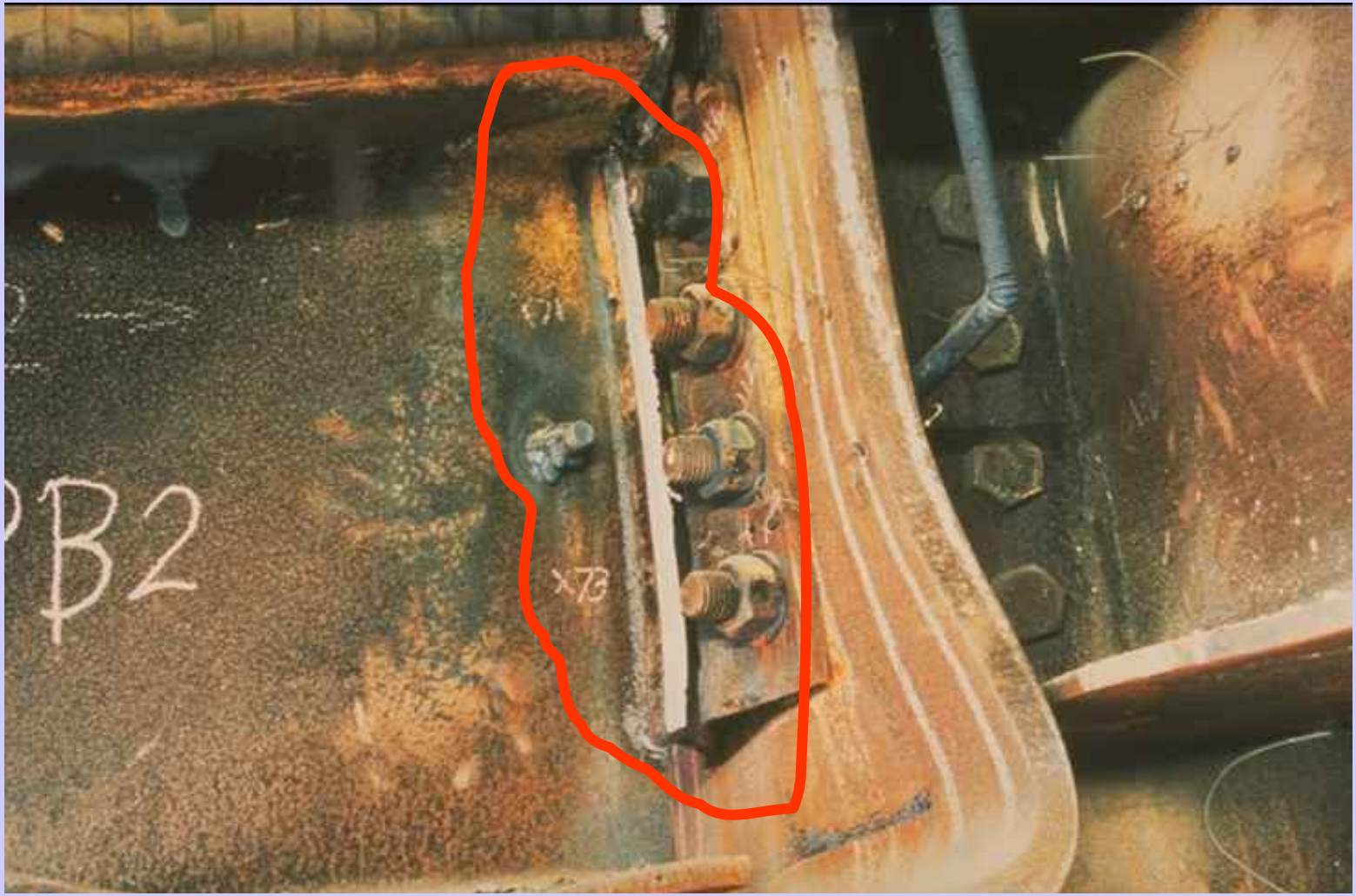
Failure at tab plates in WTC 5 column trees



Cardington Beam-Column Joint Fire Test 7

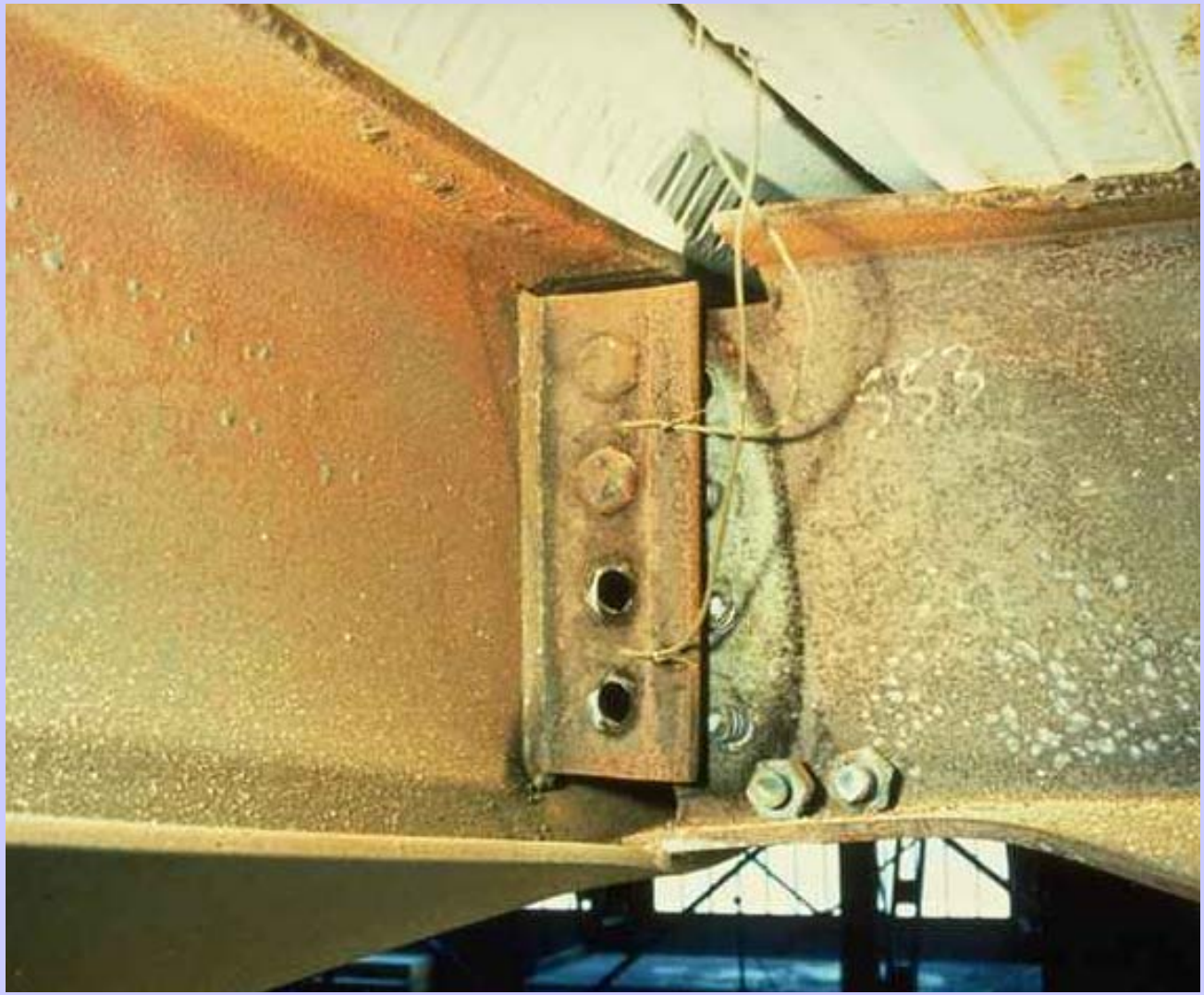
Beam shear buckling Beam flange buckling

Cardington Beam-Column Joint Fire Test 2



End plate split on one side of attachment to web

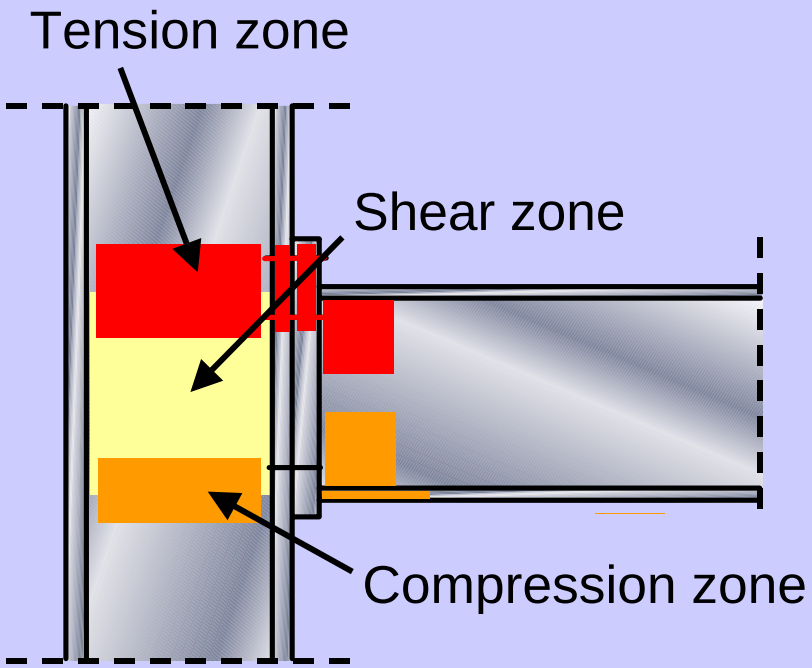
Cardington Beam-Beam Joint Fire Test 2

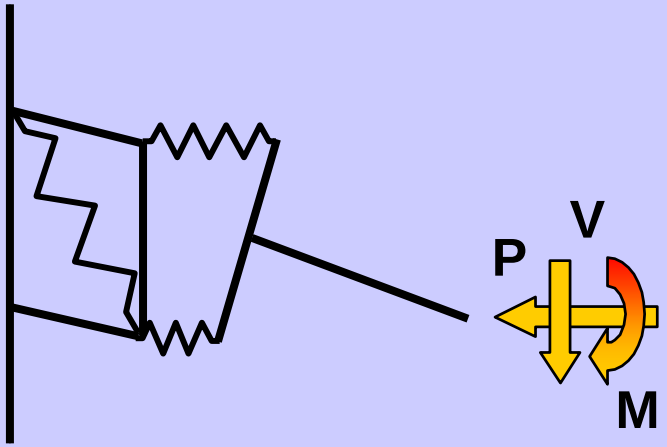


Shear failure of bolts in fin plate connection

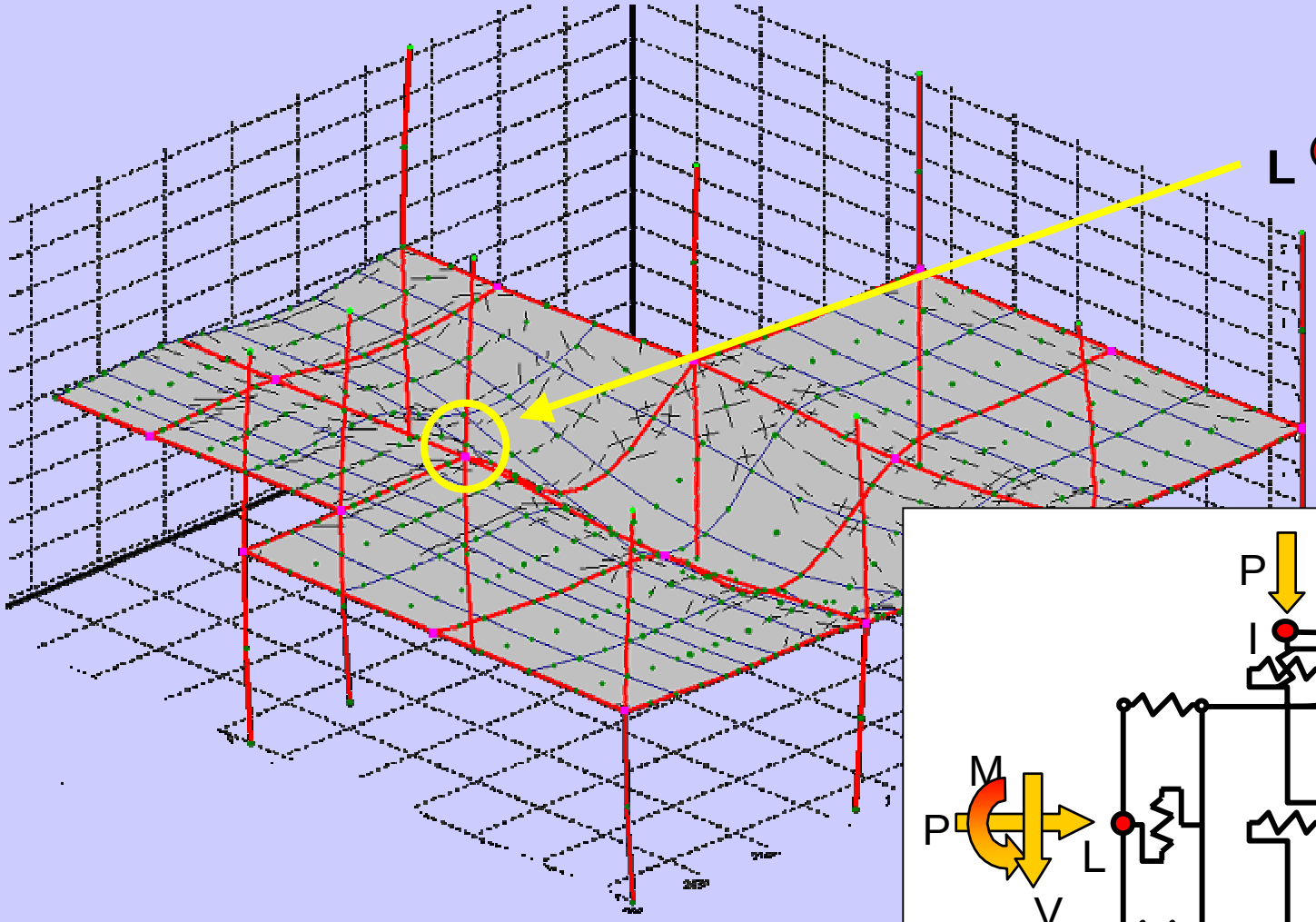
The Component Method

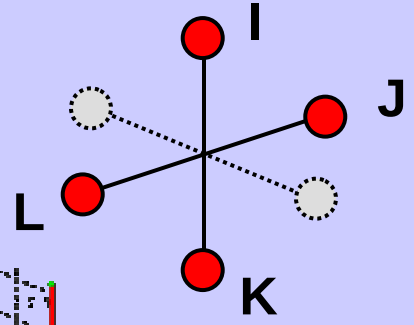
- A flexible approach based on modelling the zones of fundamental behaviour (“components”) within a joint.
- Reassembling a model of the joint with springs.

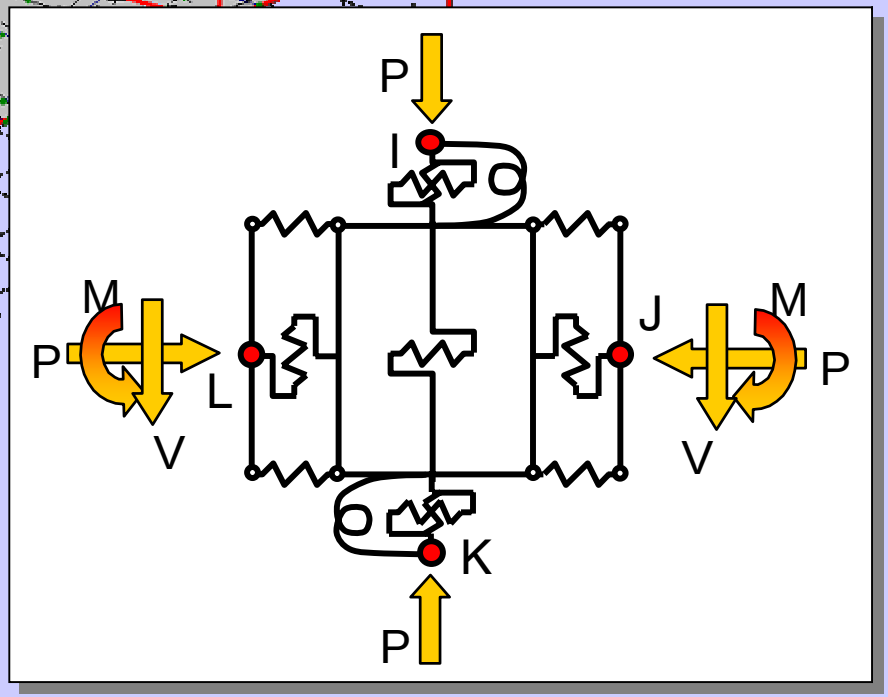




Implementation of the element in *Vulcan*



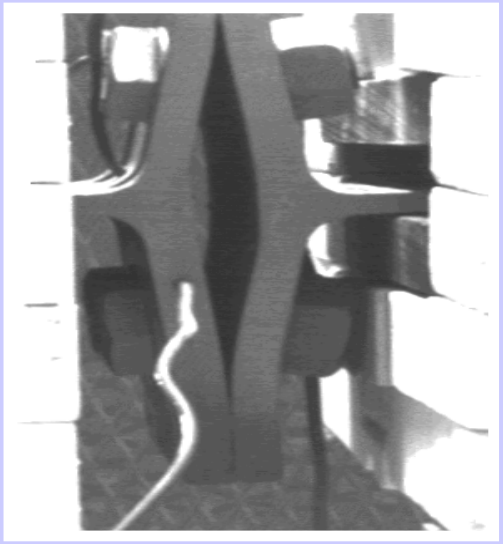


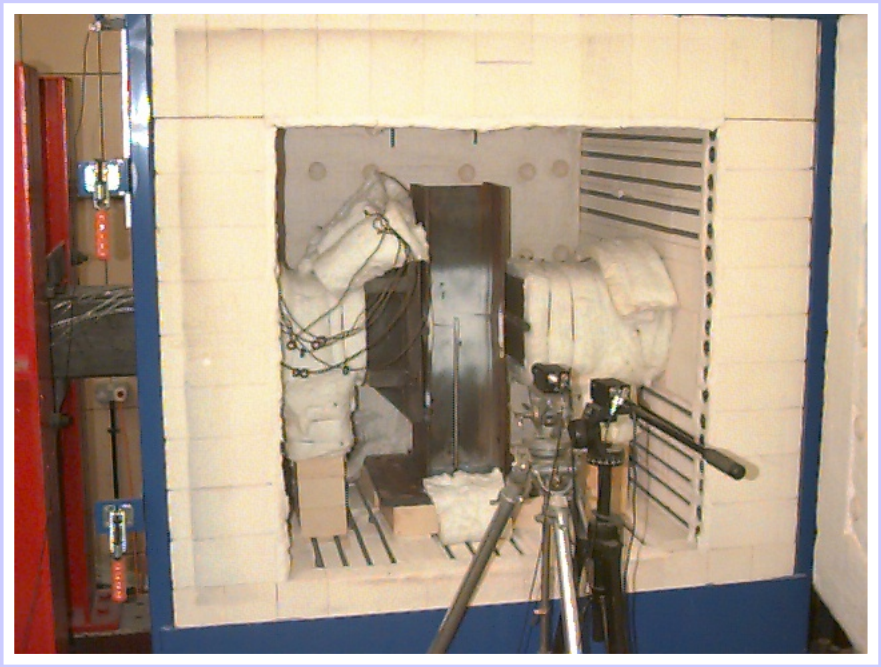


High-temperature component testing

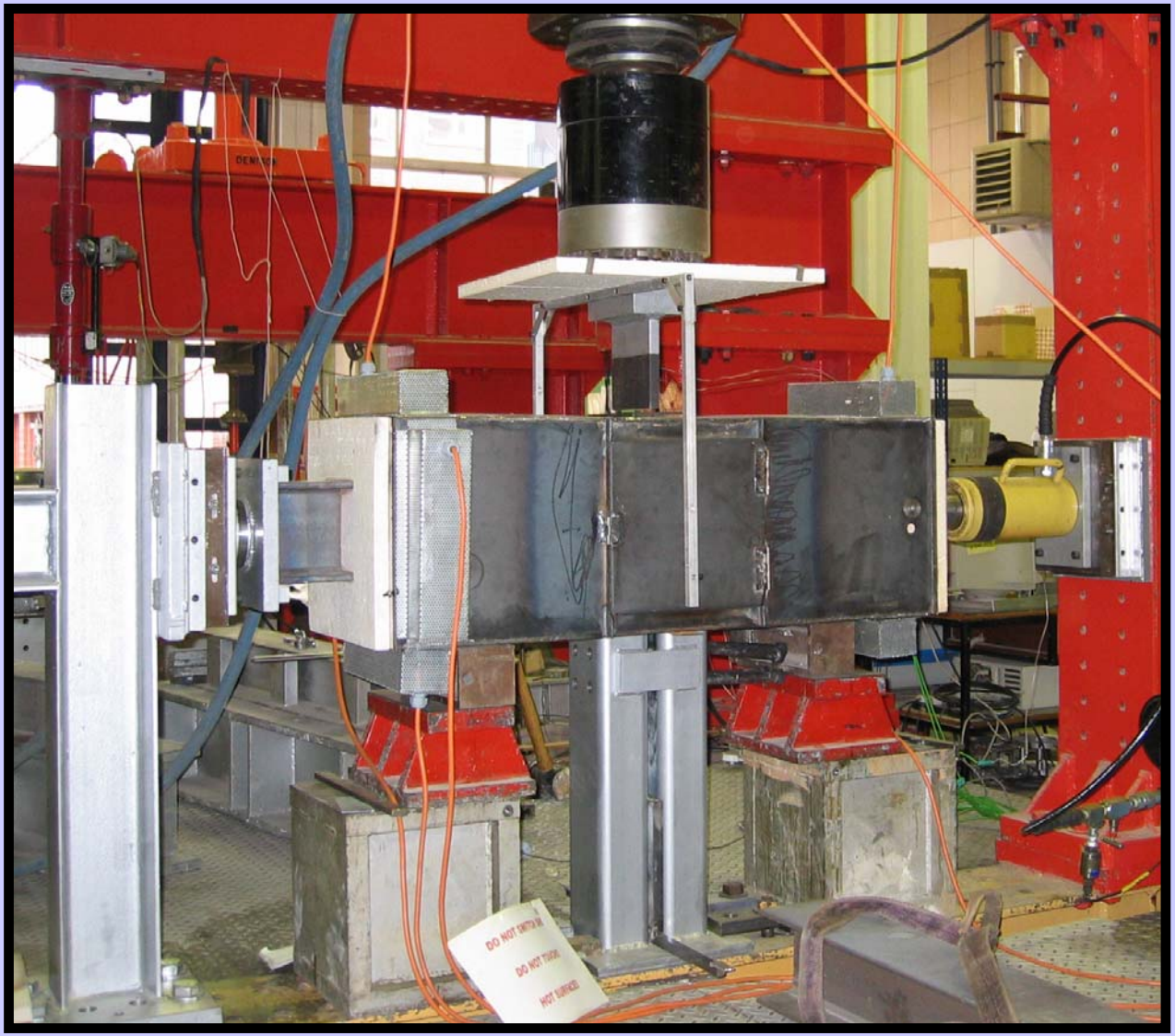
Experimental test program and analytical / semi-empirical models by S. Spyrou (1998 – 2001) at the University of Sheffield:

- Tension zone of endplate joints as T-Stub
- Compression zone in the column web





Compression zone testing



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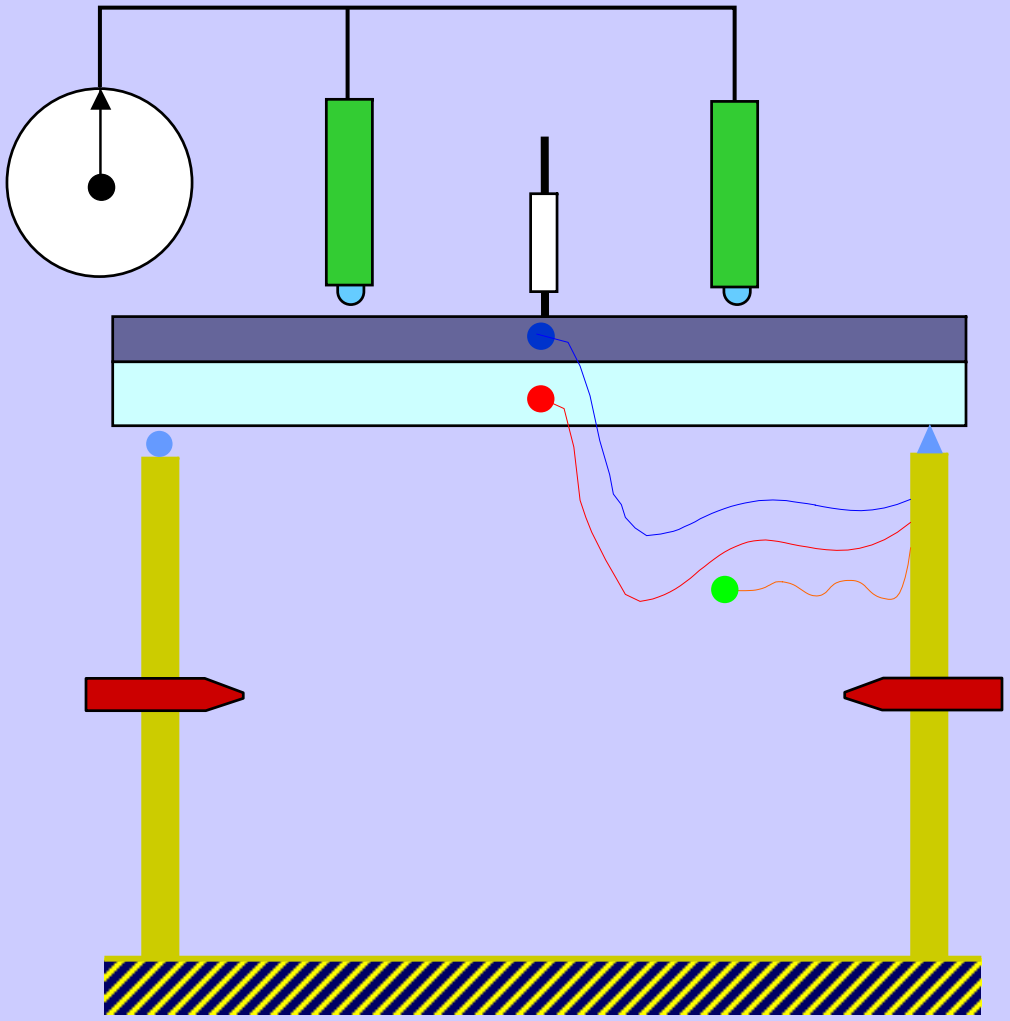
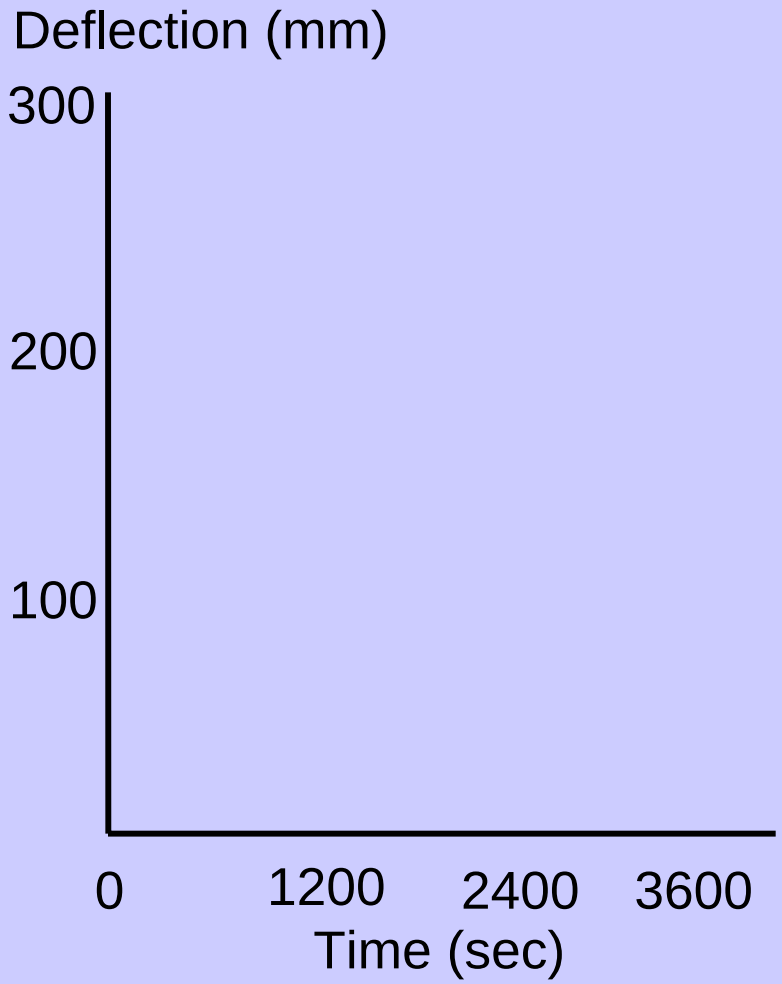
Enhance fire resistance

4. Review basis for construction classification and fire rating requirements.
5. National programme of research into improved fire testing of structural components and systems.
6. Improve testing methods for spray-applied fire protection that reflect in-service conditions.
7. Adopt "structural frame" approach - ensure whole structural frame has same fire resistance rating.

More emphasis on scientific rather than proof testing – to improve understanding.

Standard beam fire resistance furnace test





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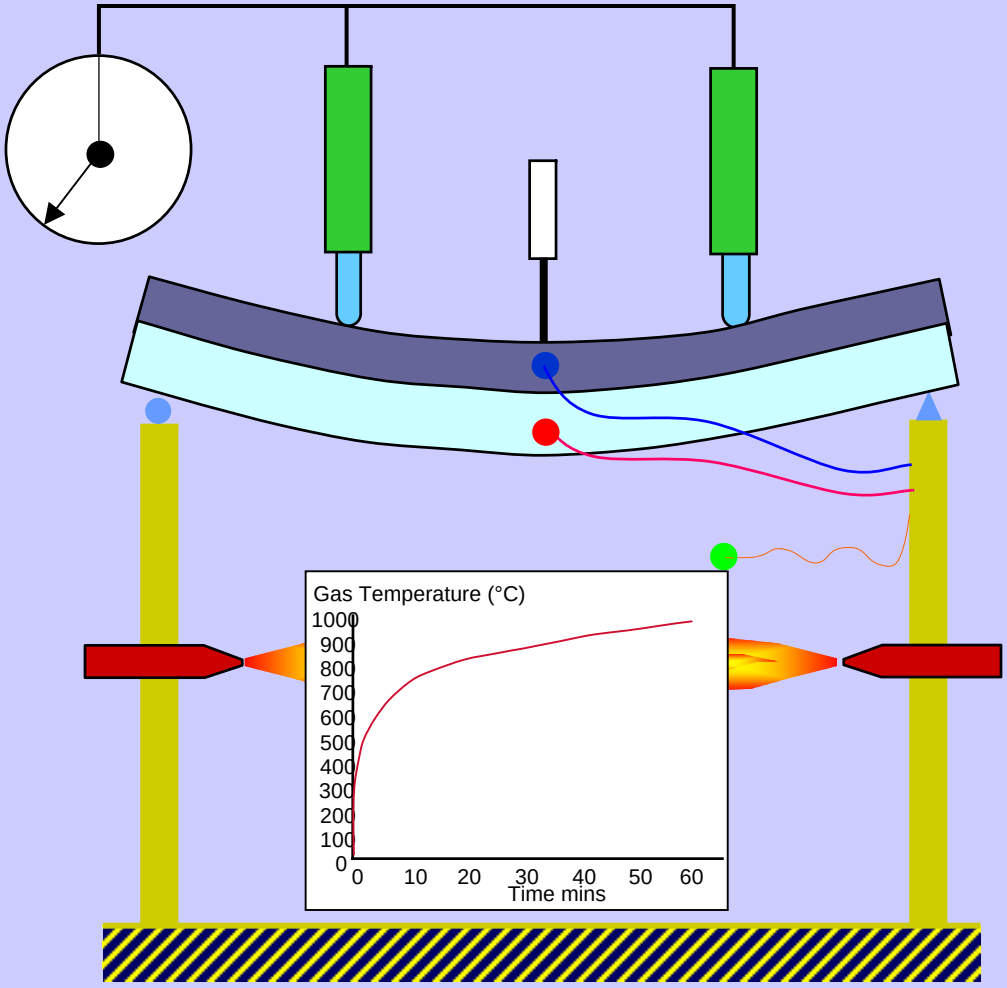
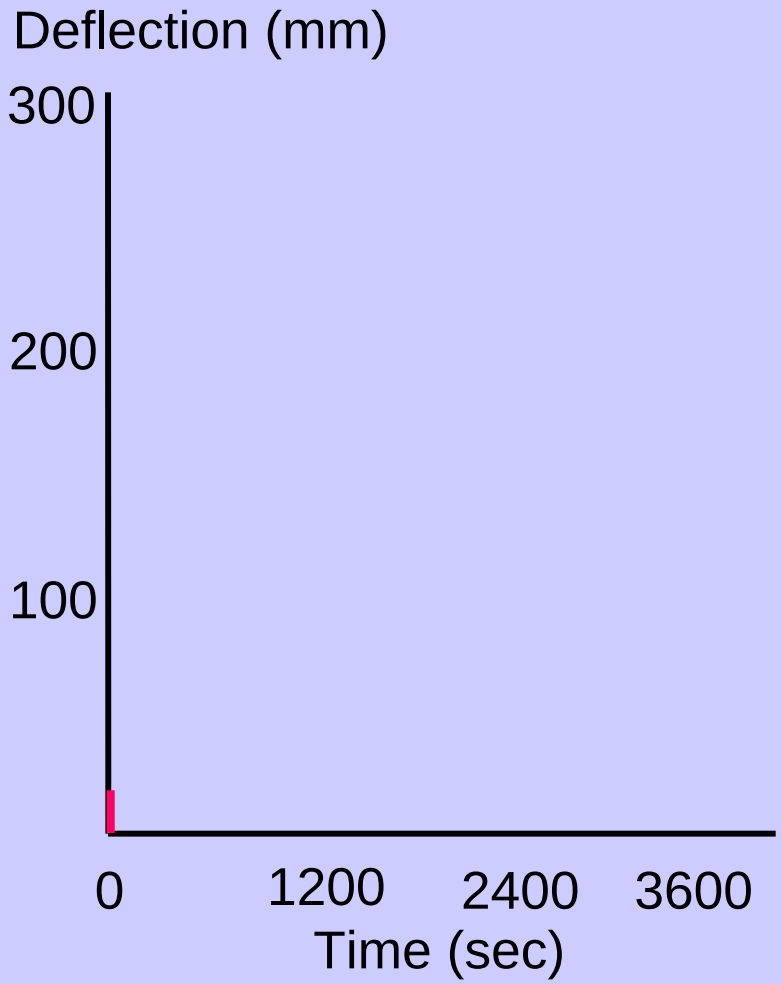
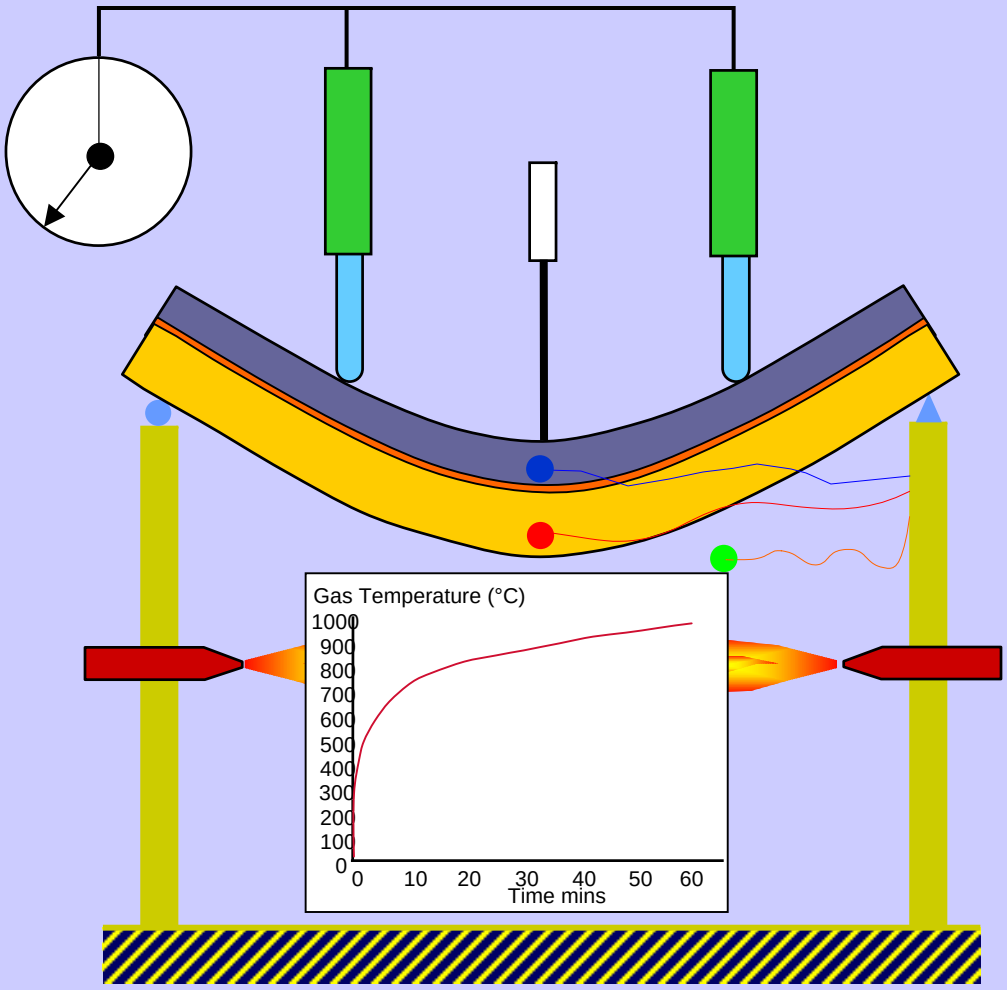
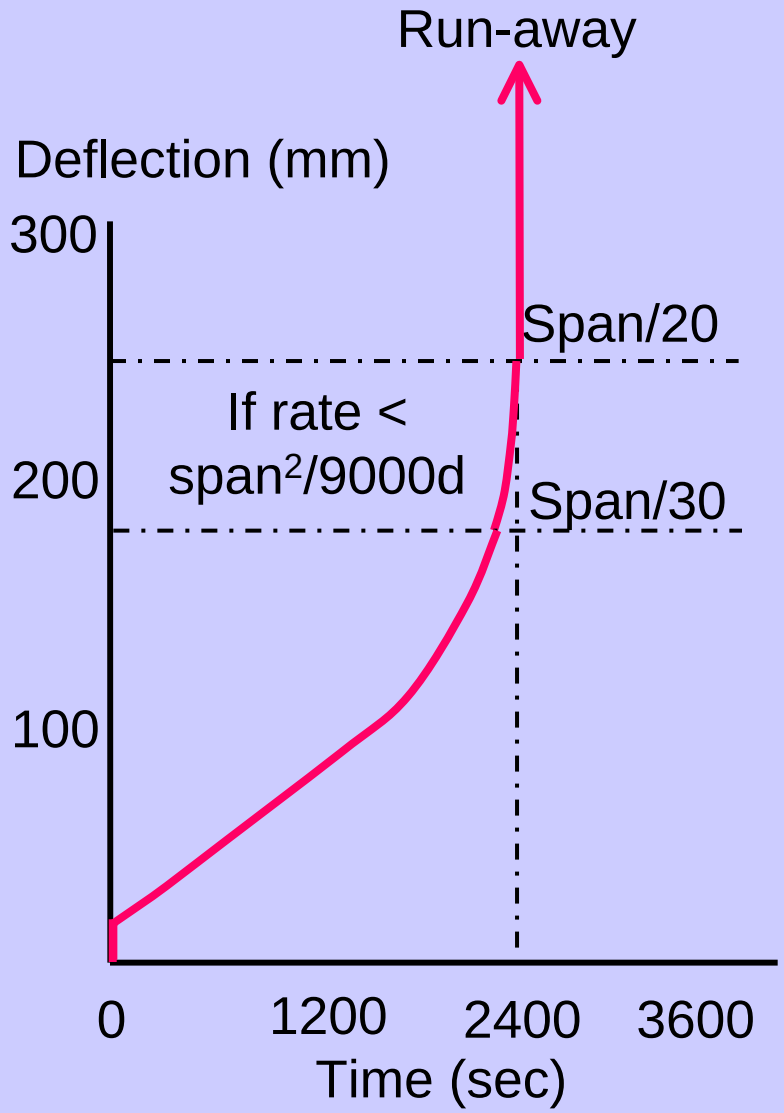




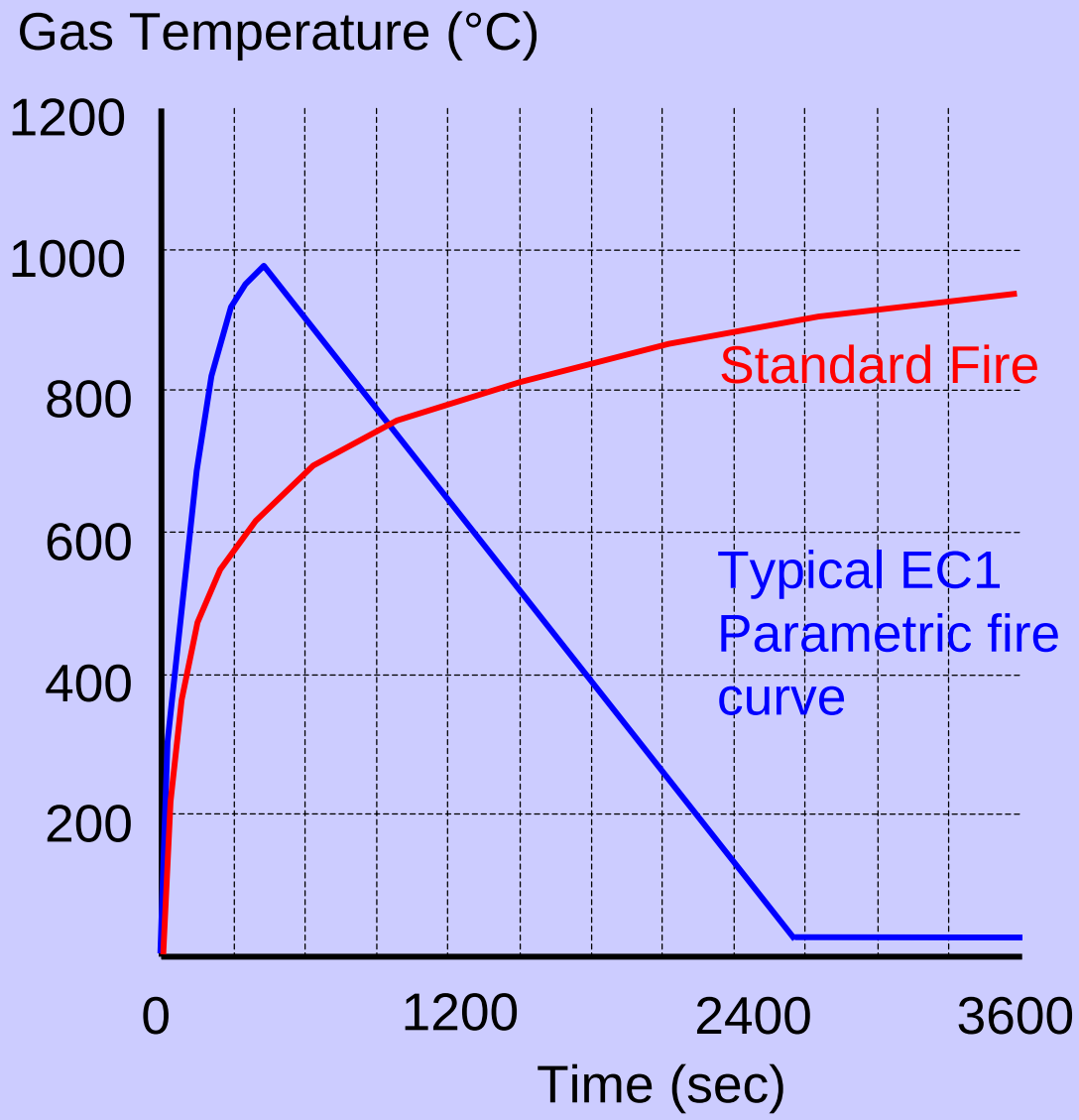
Standard beam fire resistance furnace test



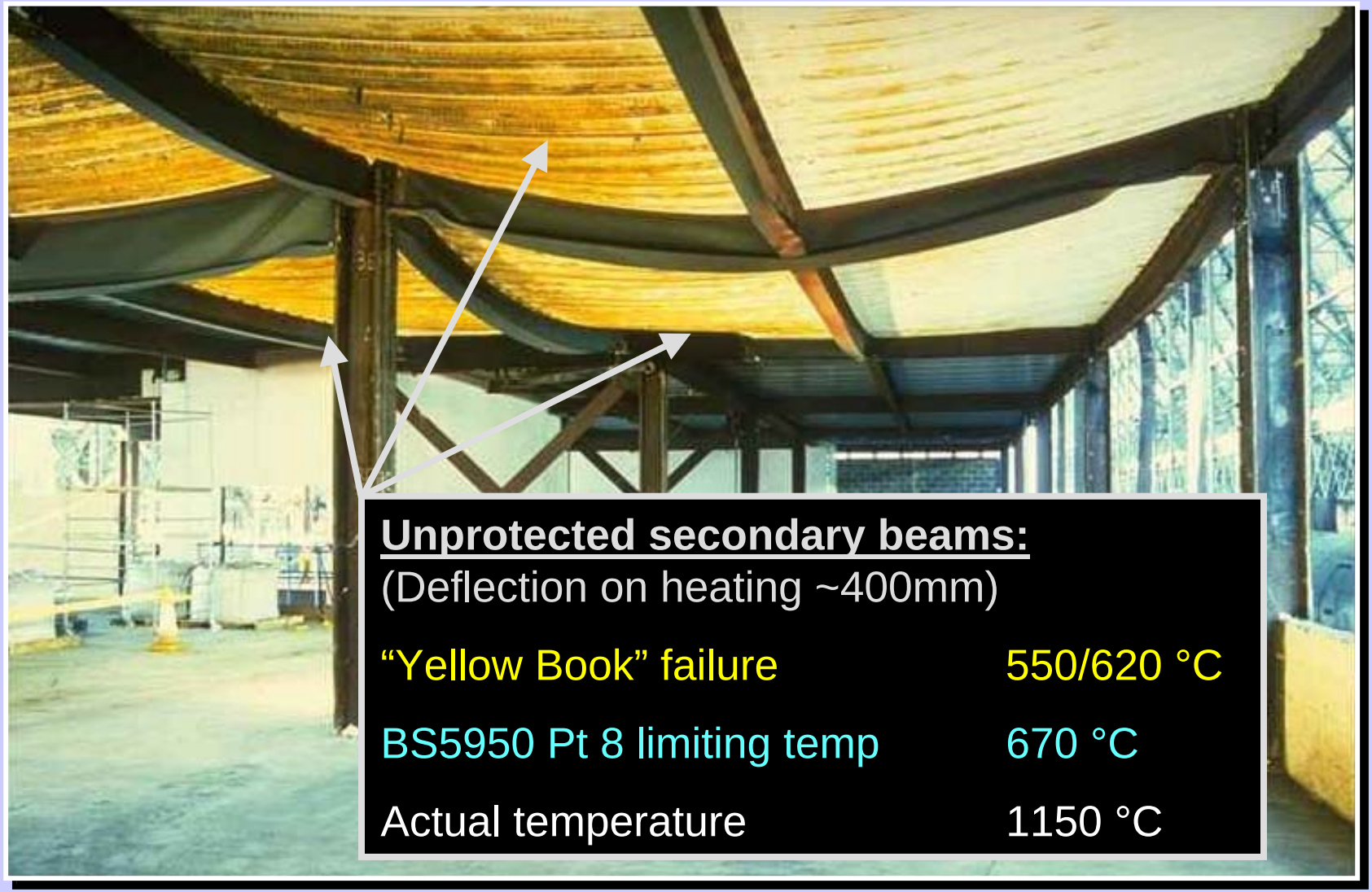


Different EC1 fire time-temperature curves

- Fire resistance times based on standard furnace tests - NOT on survival in real fires.
- EC1 Parametric Fire temperature-time curves. Based on fire load and compartment properties.



BS demonstration fire test: the aftermath



Unprotected secondary beams:
(Deflection on heating ~400mm)

"Yellow Book" failure	550/620 °C
BS5950 Pt 8 limiting temp	670 °C
Actual temperature	1150 °C

NIST's Recommendations

Improved procedures and practice

25. Independent third party certification of as-designed and as-built safety.

26. Aggressively enforce current building regulations on sprinklers and egress on existing buildings.

27. Require building owners to retain records of design, test data, construction, maintenance and modifications for the whole life of a building and store them securely off-site.

28. Ensure structural and fire safety engineers work together with architects to ensure fire safety where innovative or unusual structural or fire safety systems are involved.

NIST's Recommendations

Education and training

29. Train architects and fire safety engineers in structural engineering; train structural engineers, architects and fire protection engineers in modern fire engineering principles.

30. Develop training material in the use of computational fire dynamics and thermo-structural analysis tools.

Better to give structural engineers training in effects of fire on structure (rather than train fire engineers/scientists in structural engineering)

Press coverage

… “Engineers fear their efforts to produce innovative tall building designs will be stifled following publication of a comprehensive report into the World Trade Center tower collapses in 2001.”

- NCE

Thank you