



The Real Behaviour of Buiding Structures in Fire – Implications for Design and Research



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PROPEC, Ouro Preto

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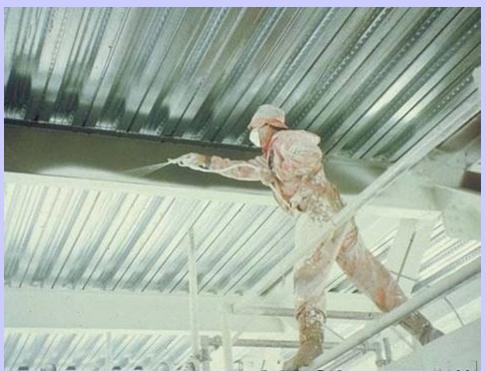












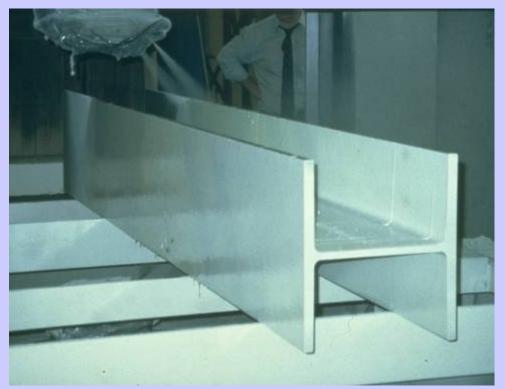
- Recent developments:
 - Reduced costs
 - Improved performance
 - Development of off-site application
- Market share increased from 7% to 40%







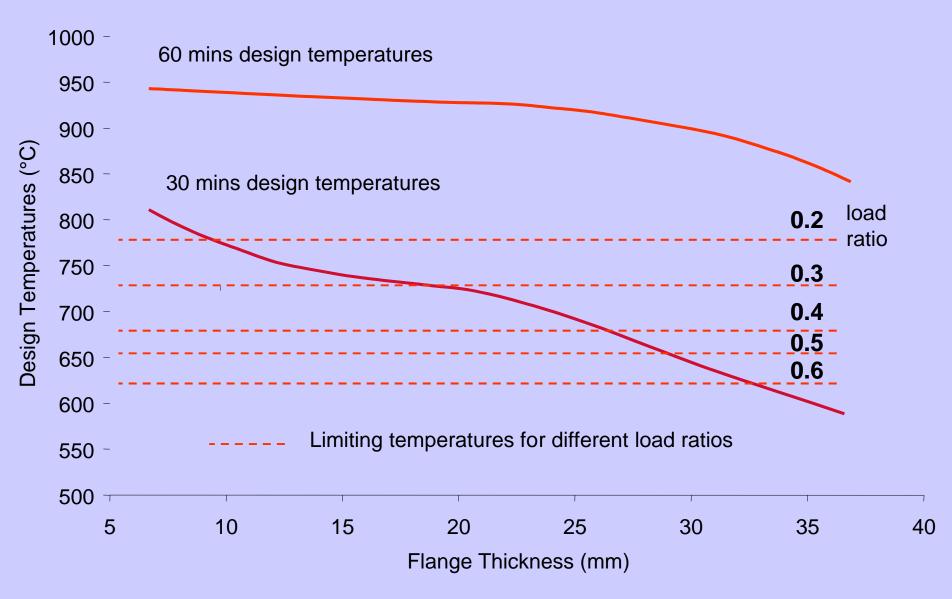
Saves time on site Reduces overall cost

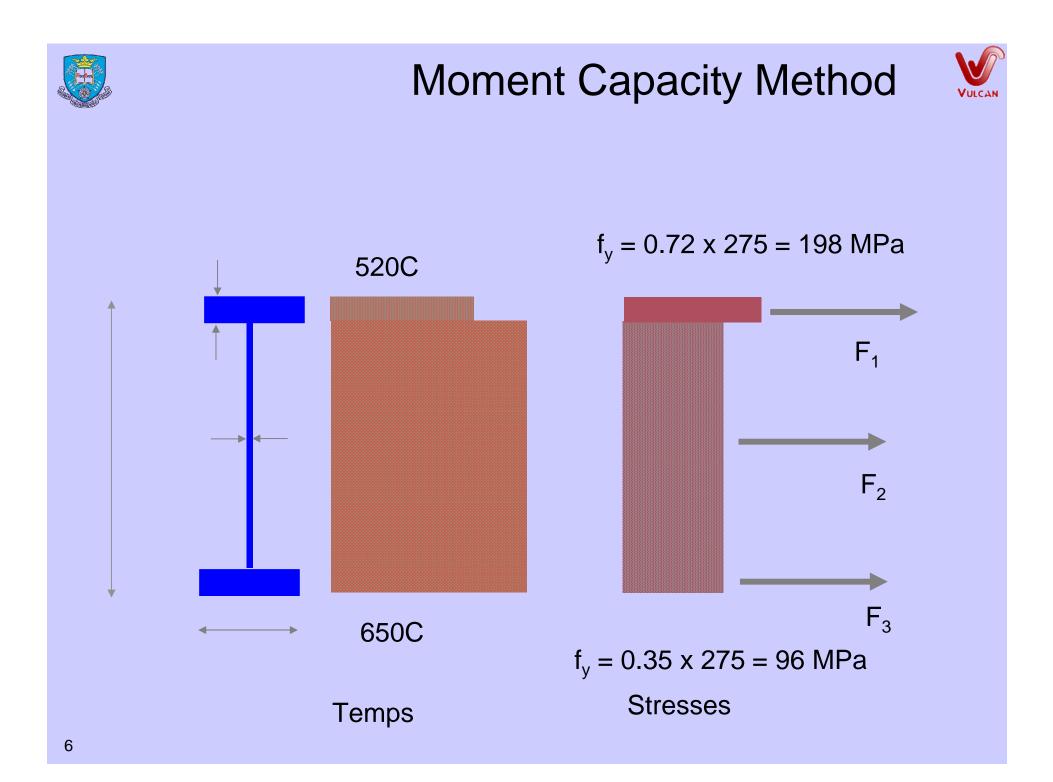






Limiting Temperature Method









Stock Orchard St Steel framed P/C joist + block floor No composite action No membrane action But...

Some shielding Low load ratios



Beams and columns treated as simple isolated elements Outcome:

> Most elements unprotected Significant cost savings







- Haunched precast floor slabs
- External steelwork exposed
- 60 minute fire period









'Slimfloor' construction





Asymmetric Slimflor Beam (ASB) Manufactured as standard

- Becoming popular
- Provides implicit protection





Broadgate Phase 8, London



- 4½ hours' duration
- Unprotected steel
- Total cost of fire £20m
- Structural repair cost £1.5m

Real structures more fireresistant than simple rules suggest? Cardington research programme

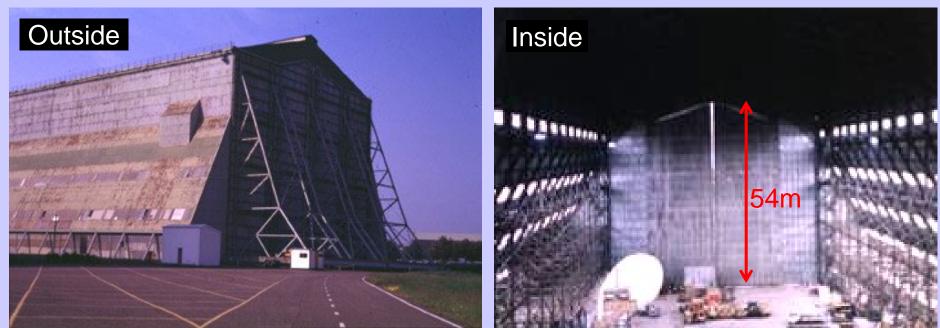


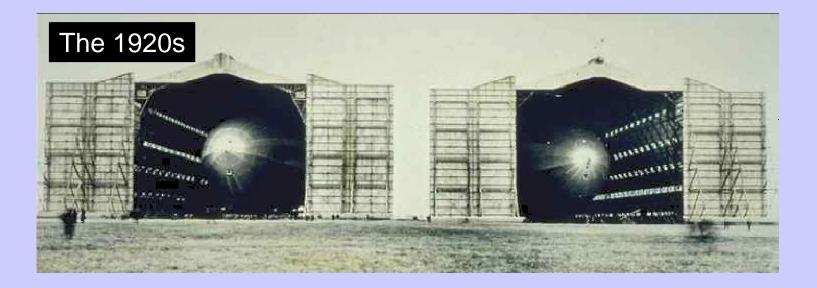




The BRE Cardington laboratory



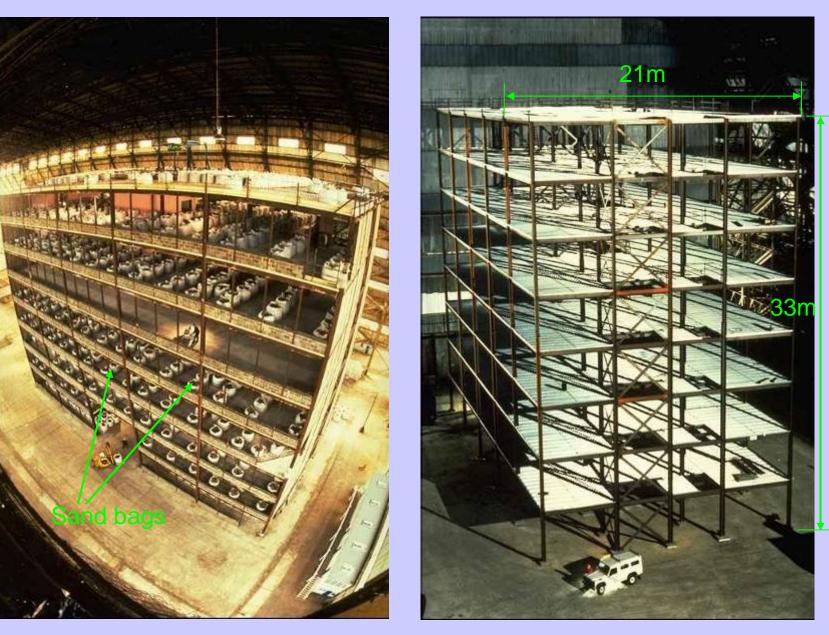






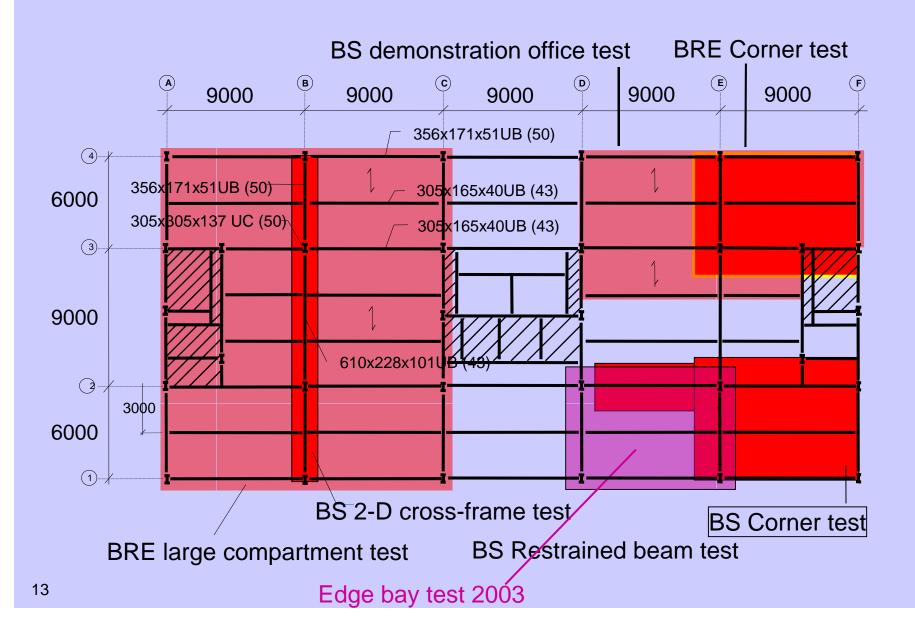
The Cardington composite building







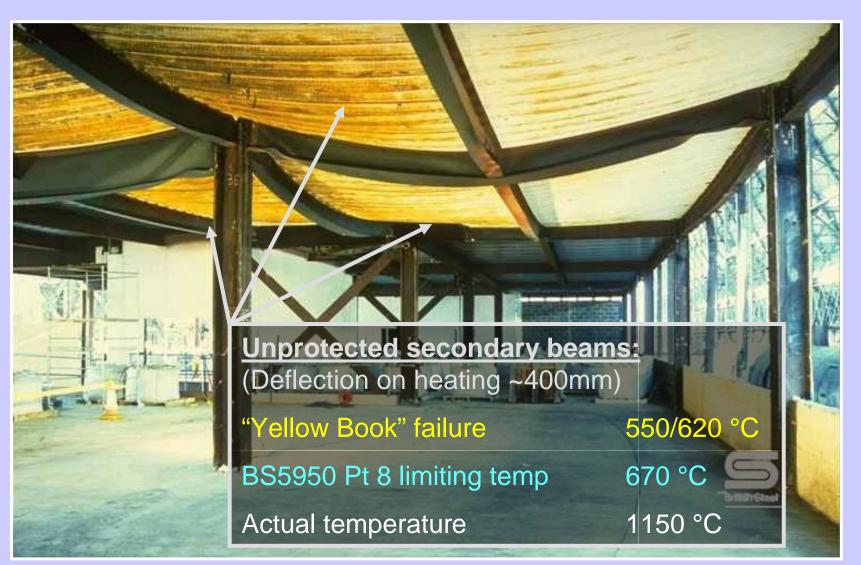






BS demonstration fire test





Why did unprotected beams survive to double the conventional critical temperatures ?



Geometrically non-linear actions in slabs

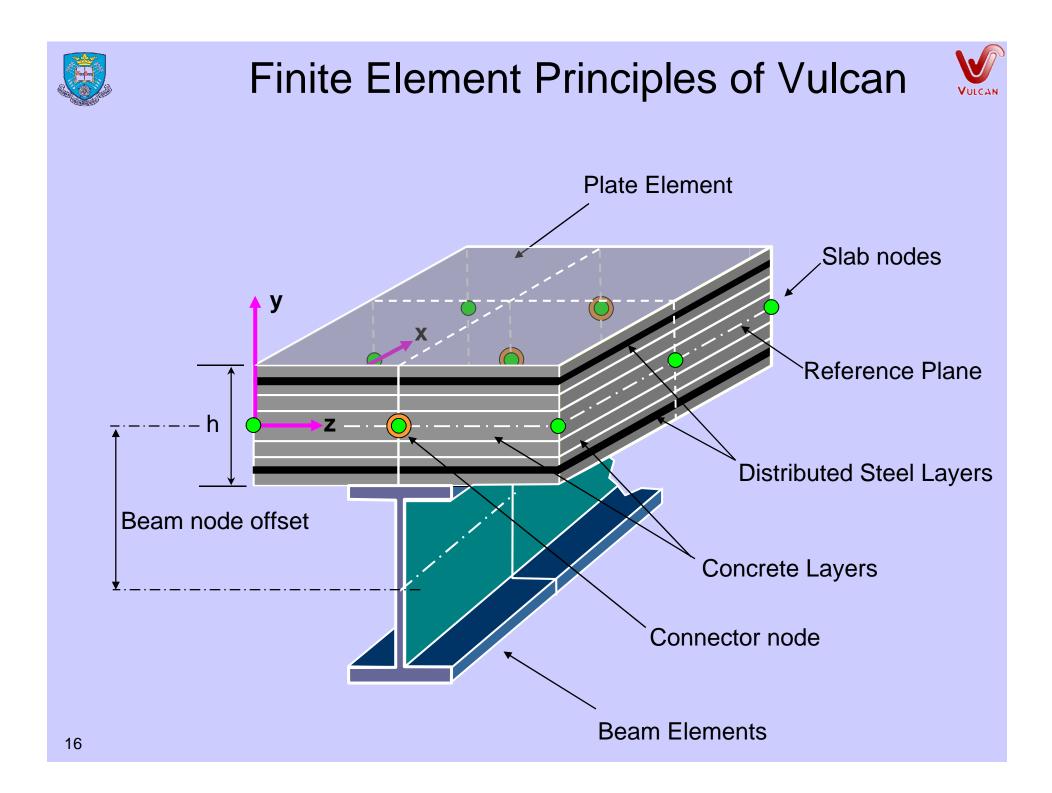


At low deflections:

- Compressive arching against adjacent structure
- Thermal buckling

At high deflections:

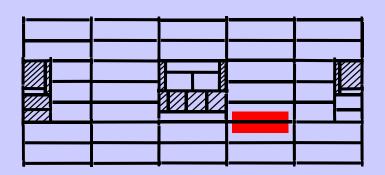
- Biaxial tension in mesh at centre of slab; compressive ring in concrete around edge
- Catenary tension support, reacting against adjacent structure







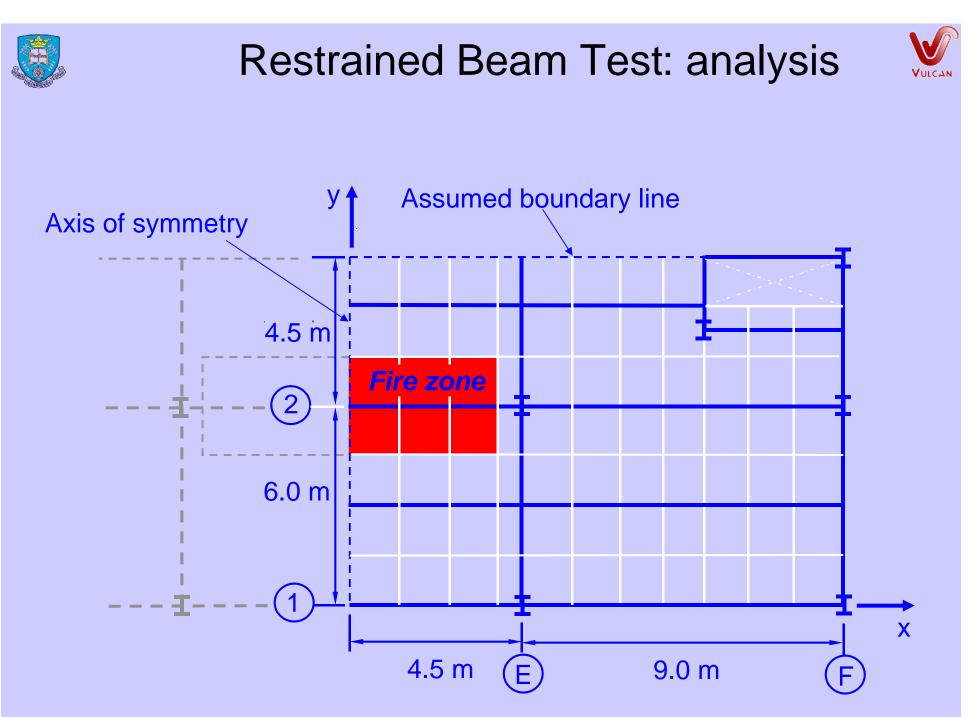




BS Restrained beam test 8m heated

- Steel temperature 834°C
- Slab temperature 481°C
- Deflection \approx span/40
- Test terminated due to very slow heating rate

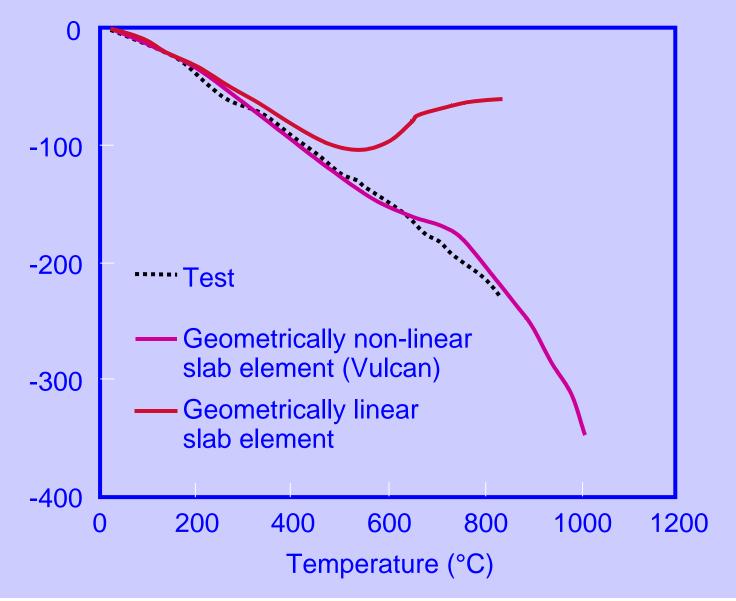








Mid-span deflection (mm)





BS demonstration test: fire load



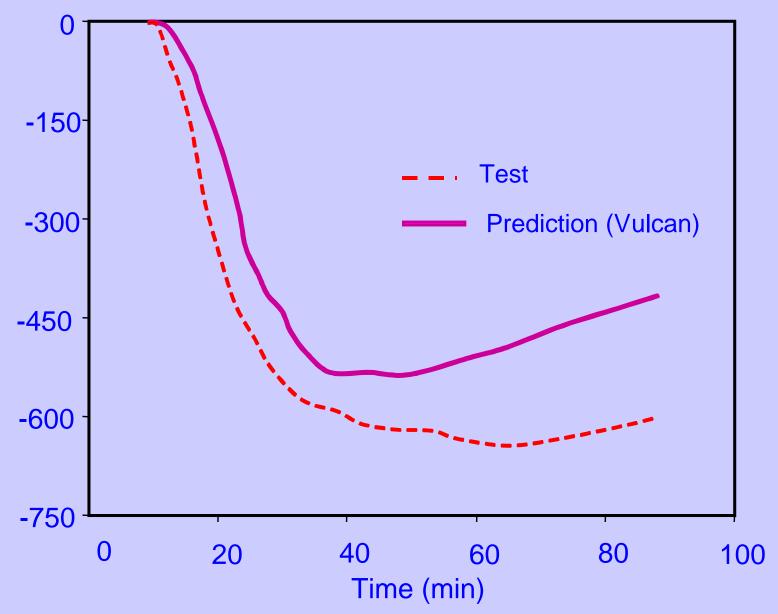






British Steel demonstration test

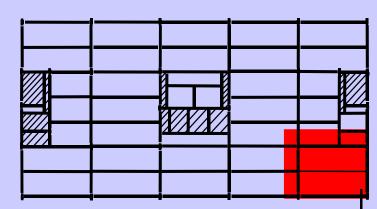






The British Steel Corner Bay Test



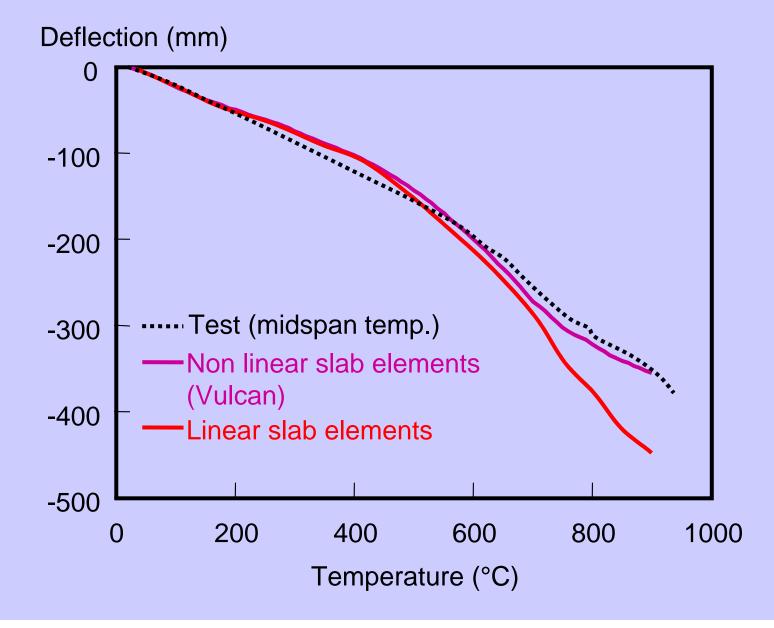


BS Corner test

- Fire: 45kg/m² of timber
- Max. fire temperature 1028°C at 80 minutes
- Max. steel temp >900°C
- Max. slab temperatures 360°C (bottom) and 70°C (top)



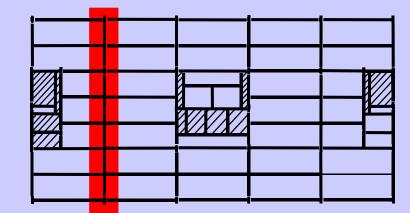


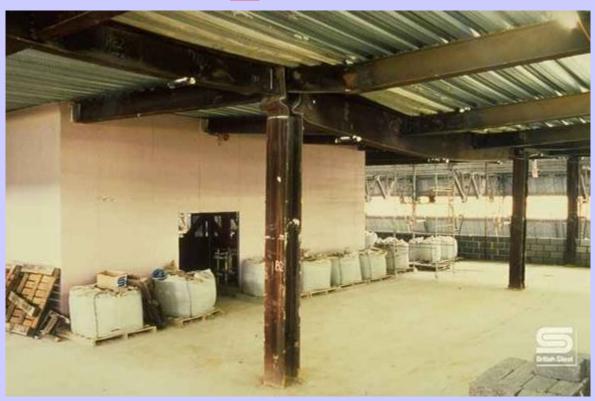






- Gas furnace across primary frame
- Max. steel temperature (lower flange) 1150°C
- Top 500mm of internal columns unprotected – with very visible results









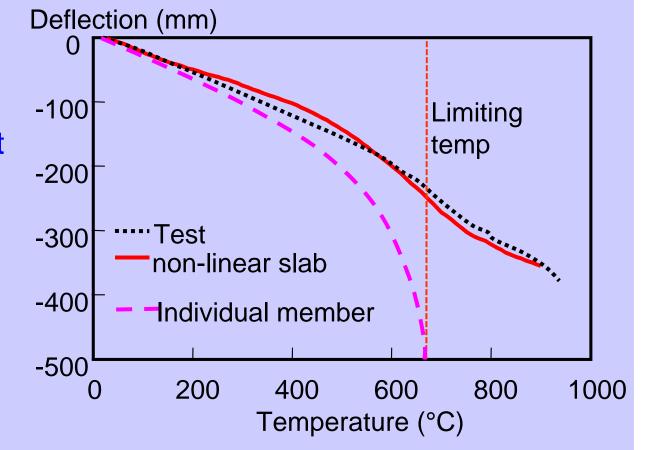




Summary of Cardington results

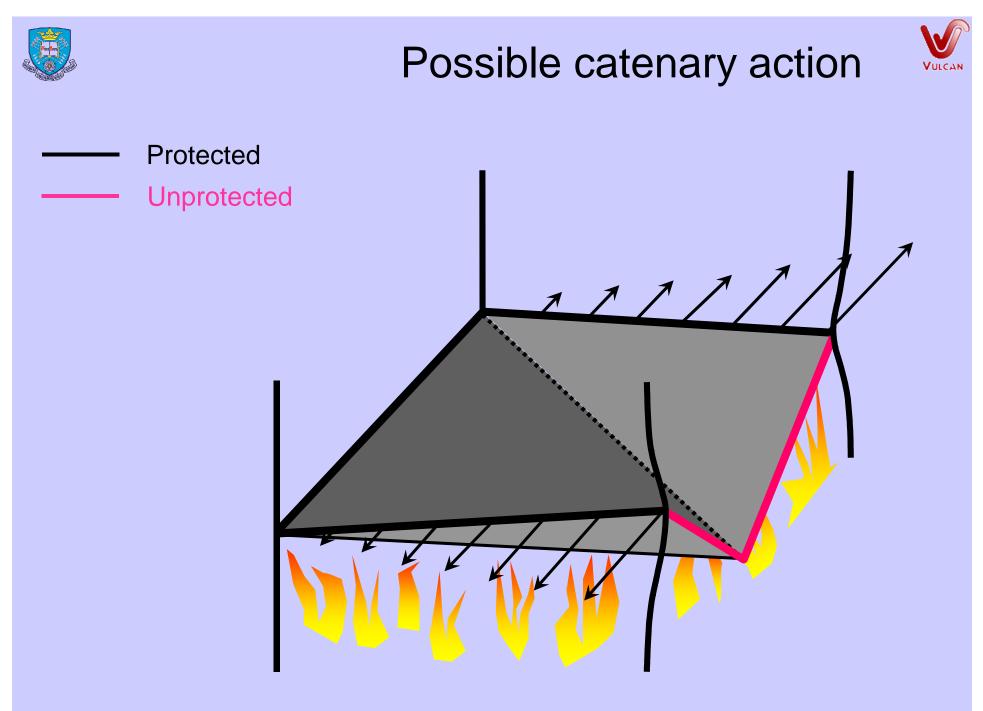


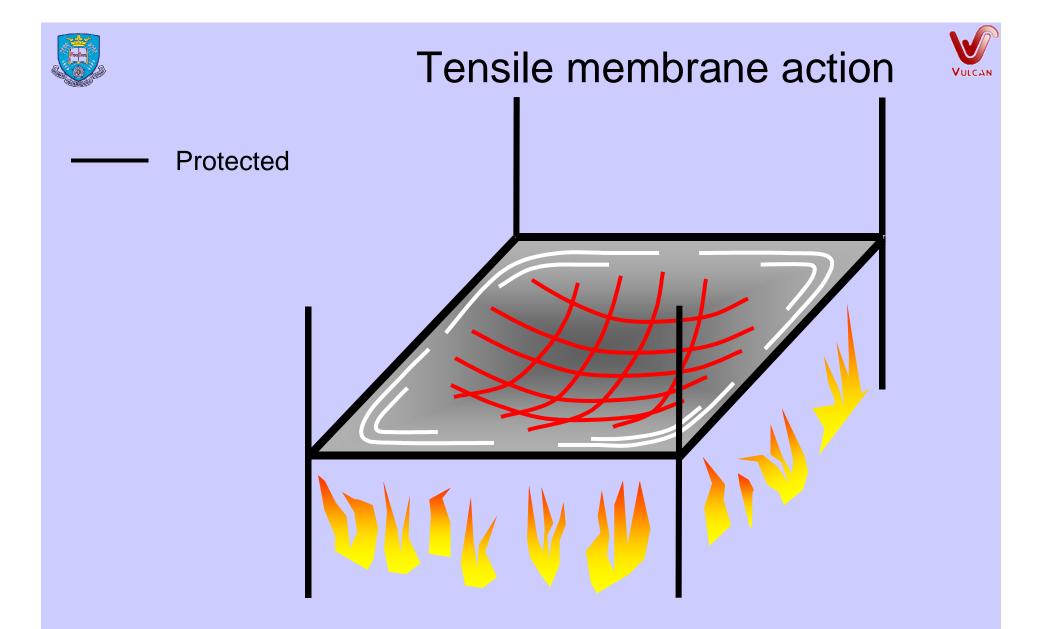
- Contribution of slab very important
- Non-linear analytical model validated
- Translation into practice



What conditions required for membrane action

- Physical requirements
- Simplified design approaches for non-specialists

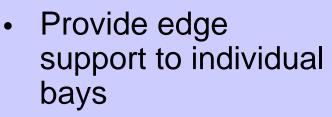




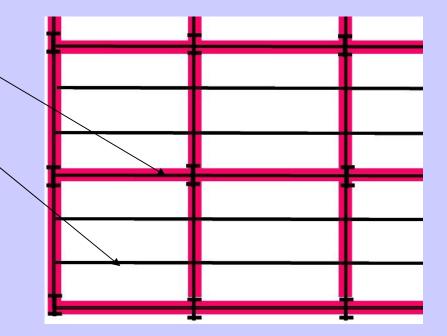
Vertical support required on all 4 edges to enable tensile membrane action to develop

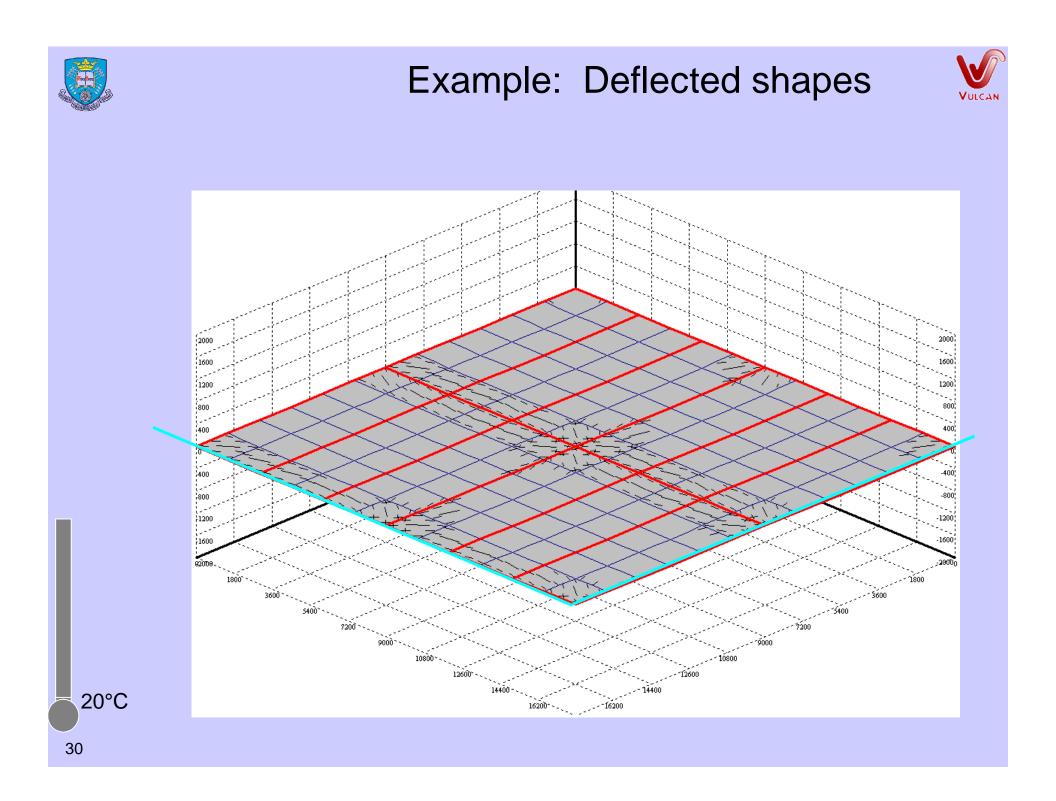


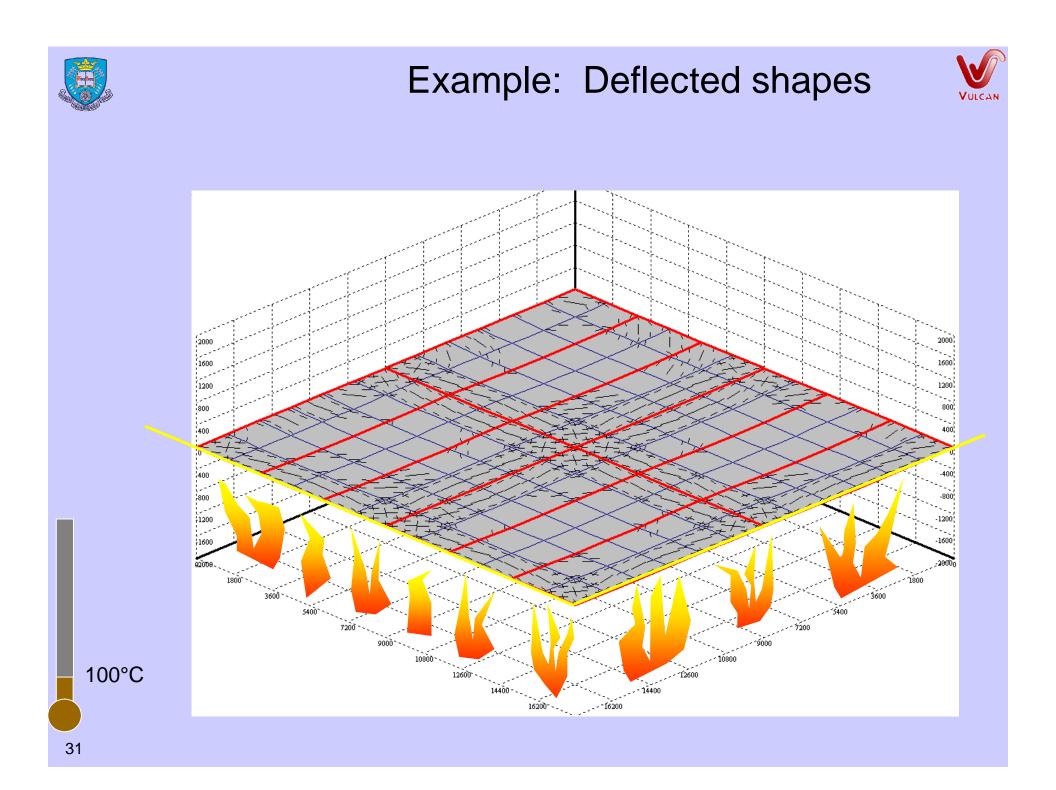


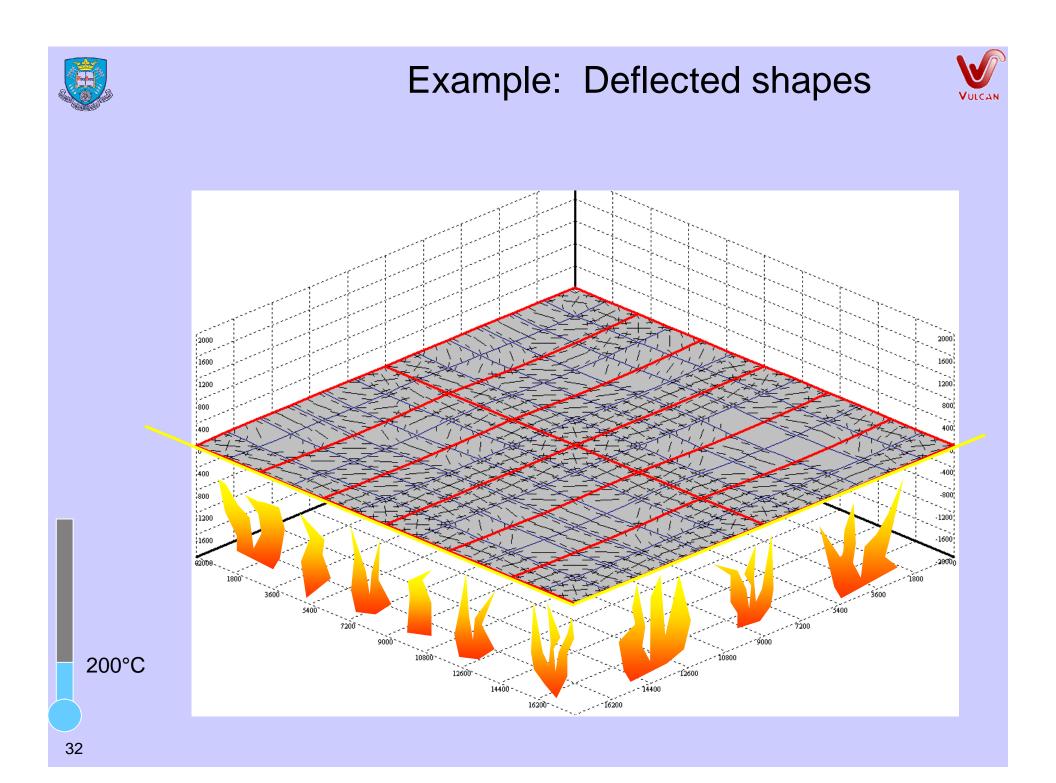


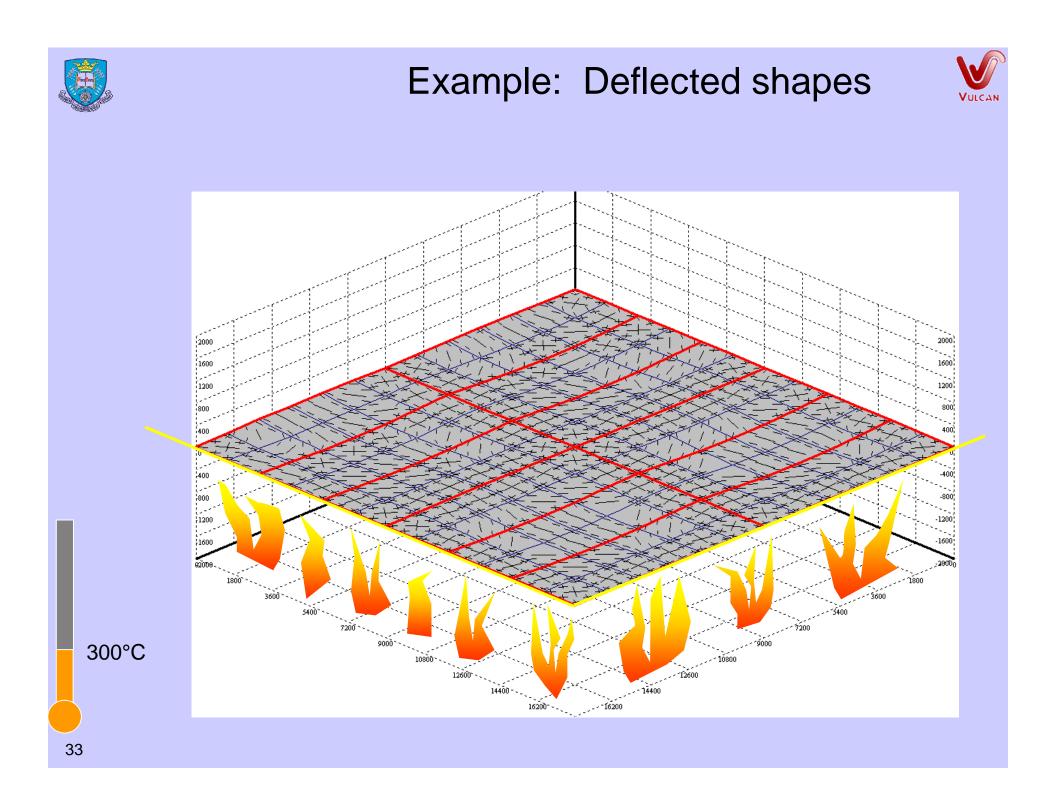
- Protect columns on column gridlines
- Leave intermediate
 beams unprotected
- Consider tensile membrane action between protected members
- FE analysis (*Vulcan*) or simplified design approaches

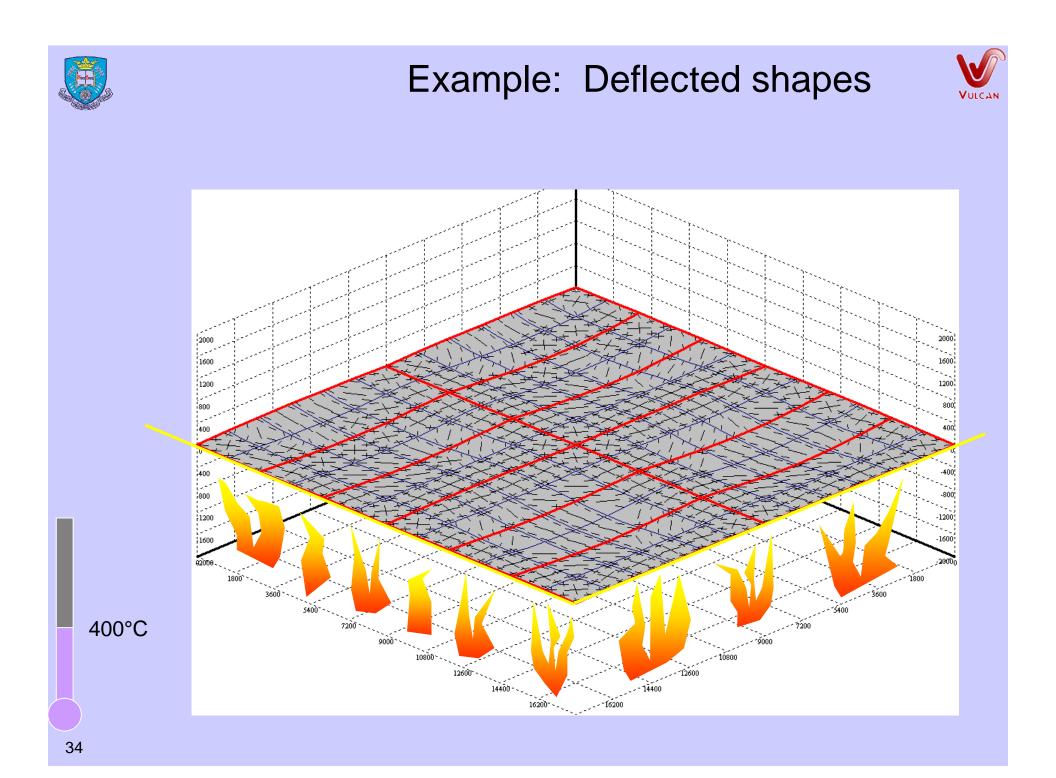


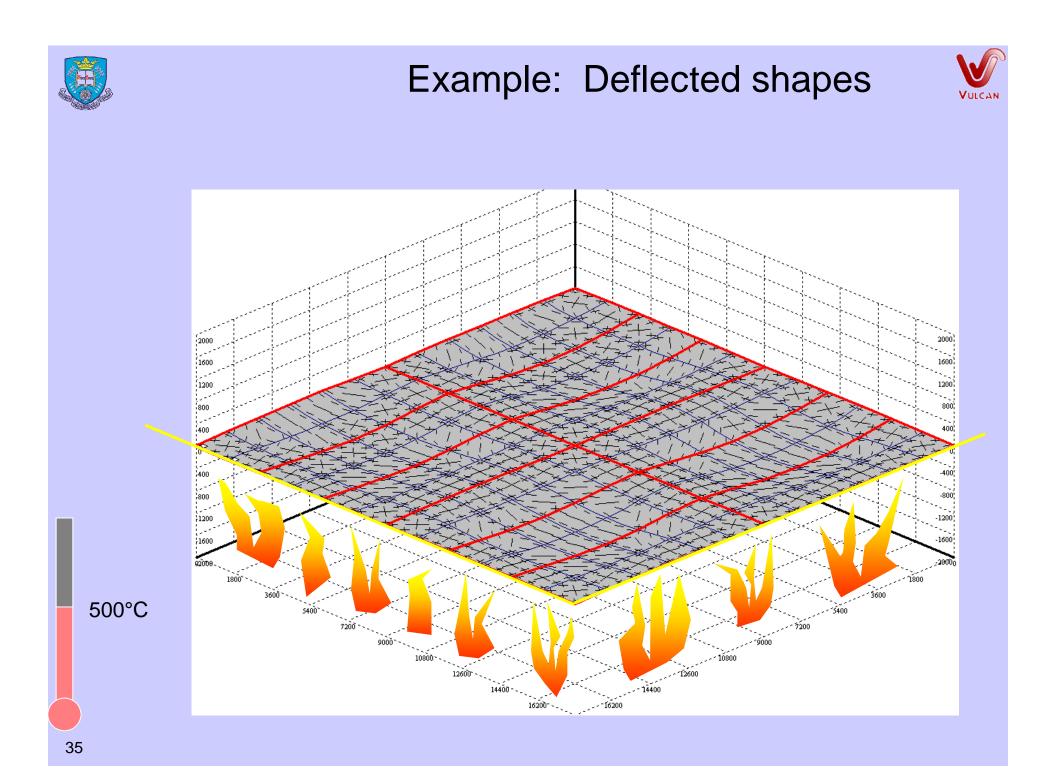


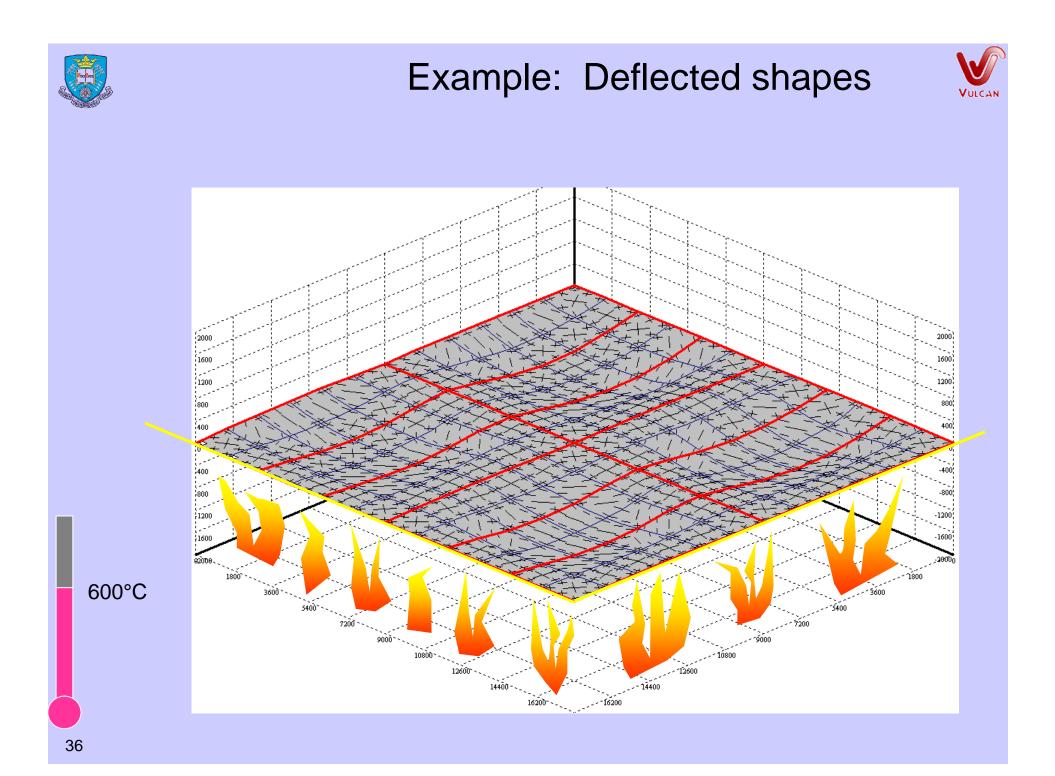


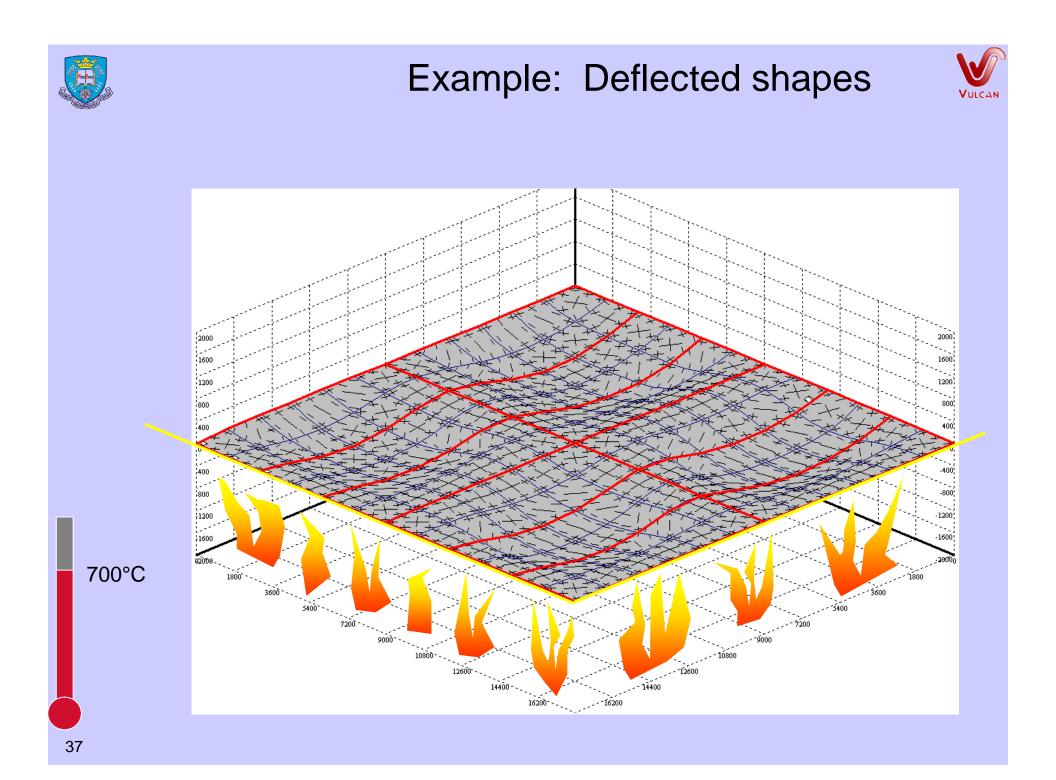


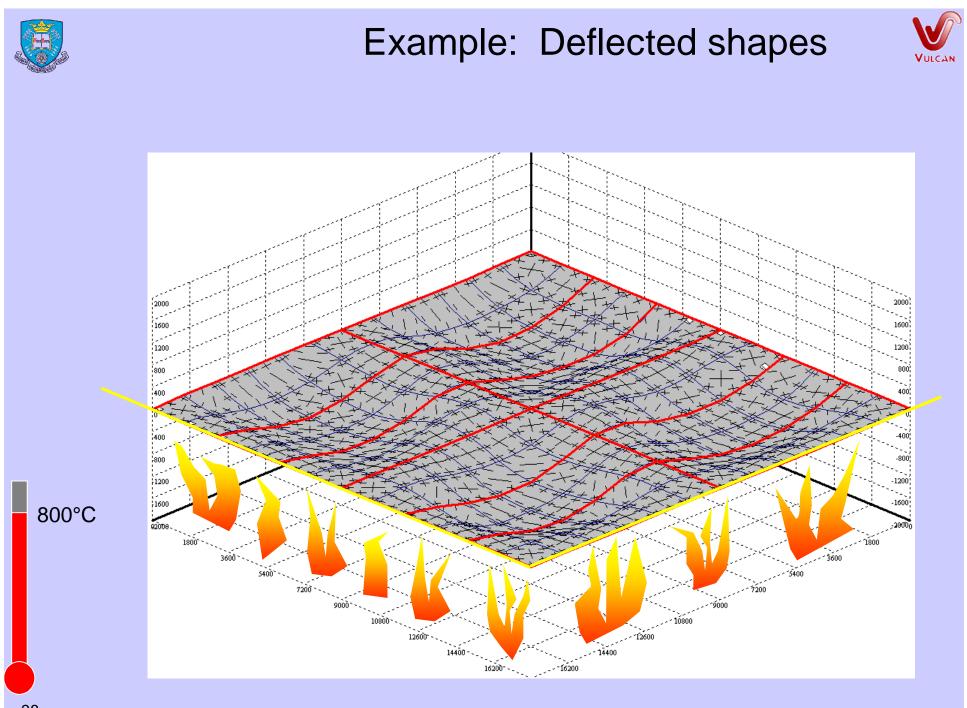


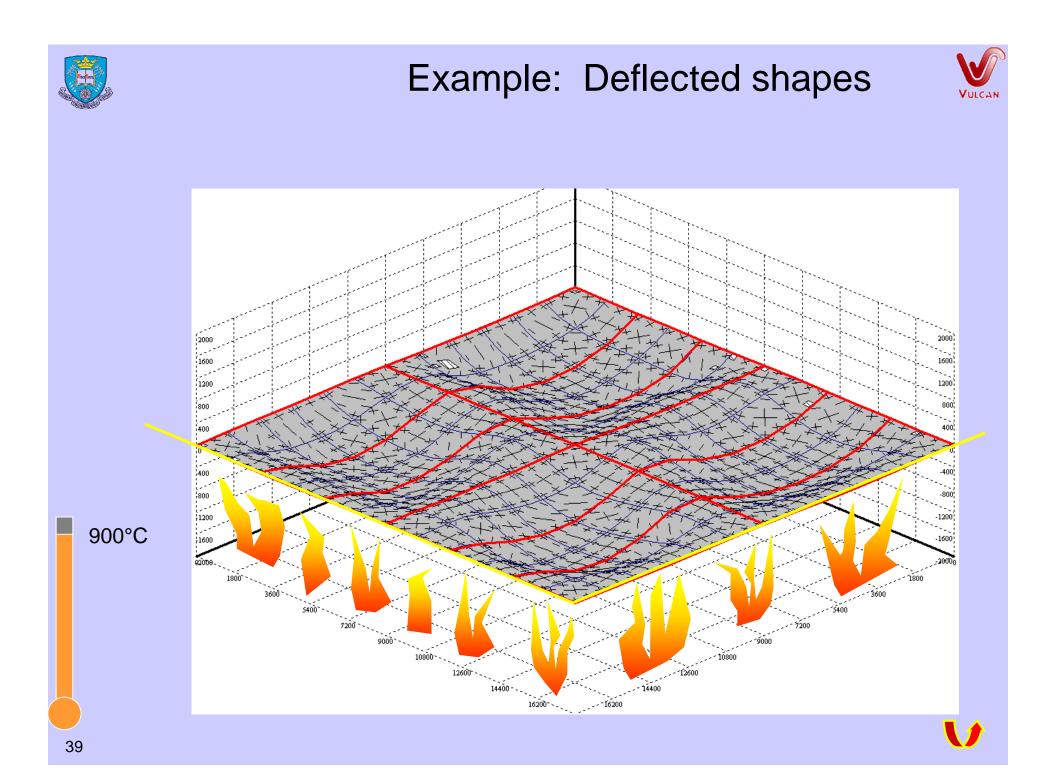
















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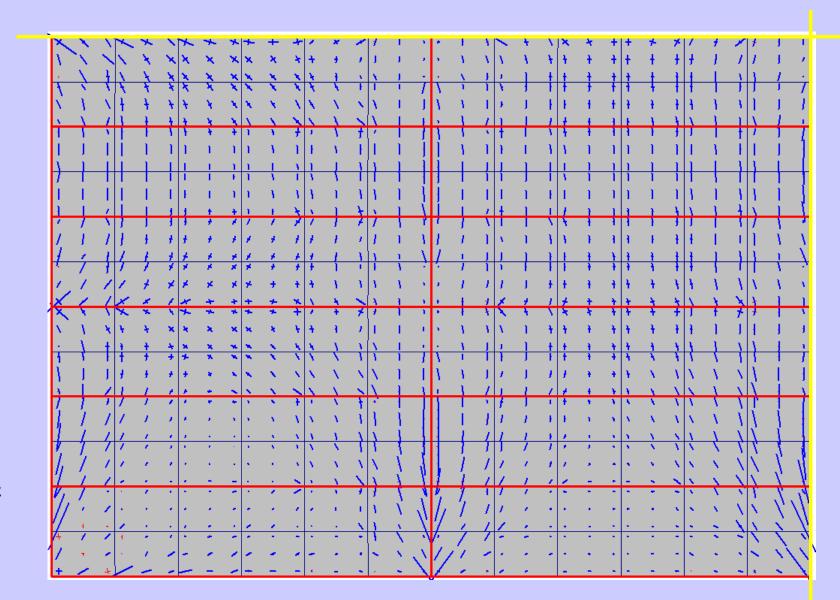


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300°C



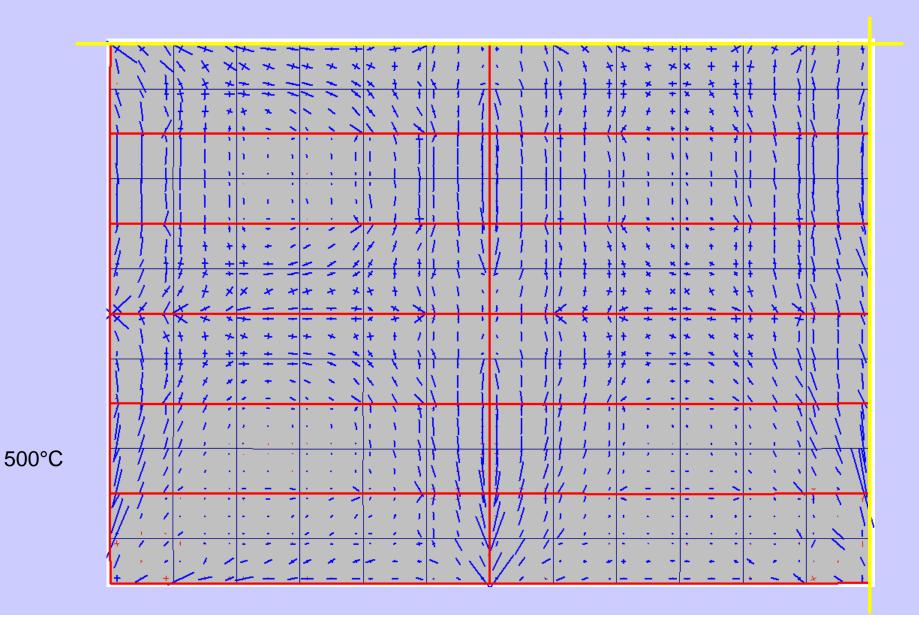


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400°C

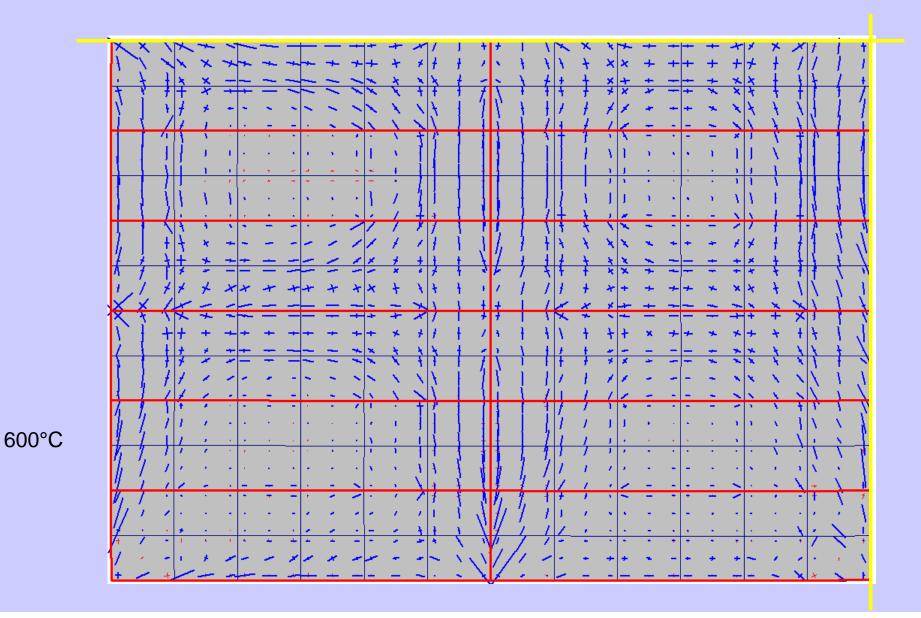






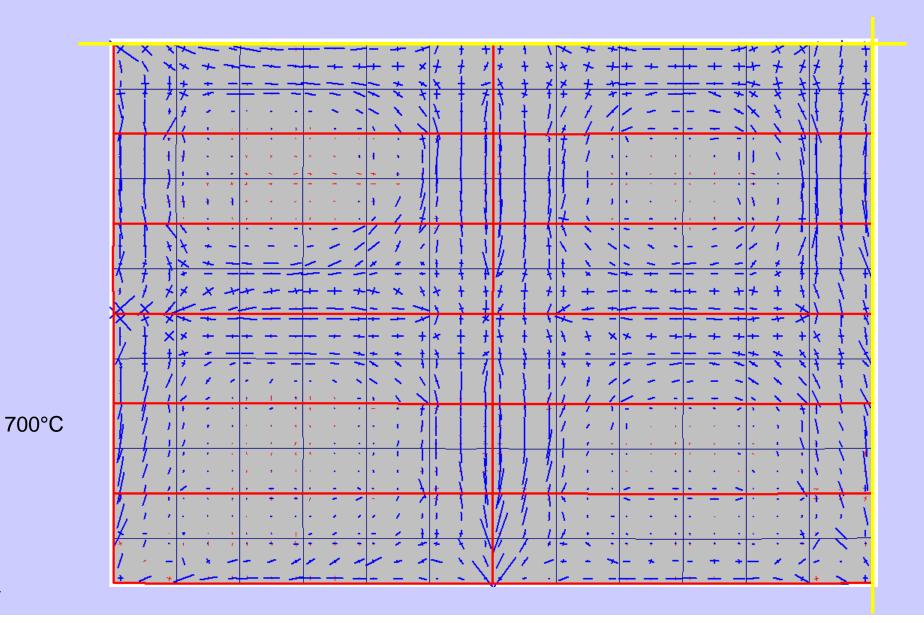






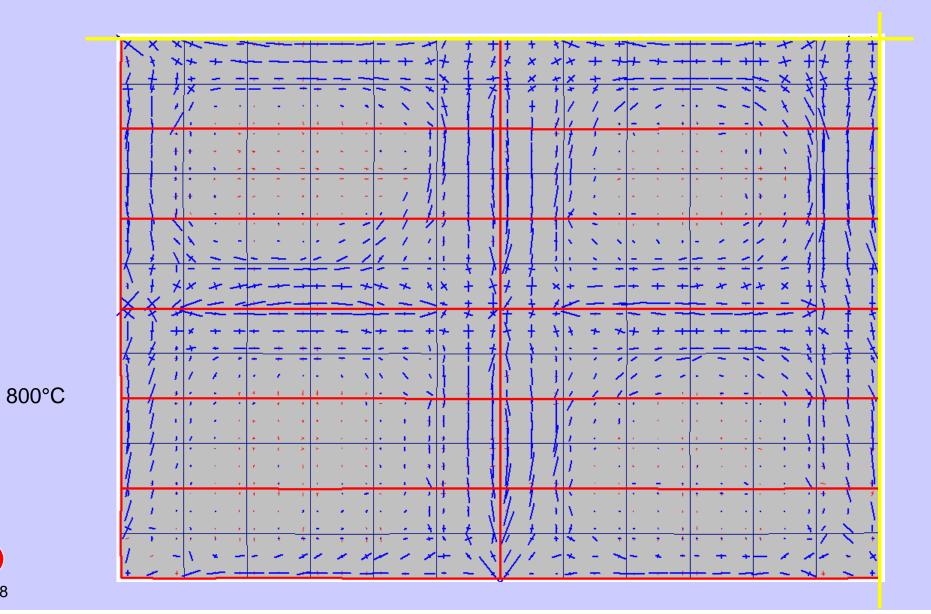






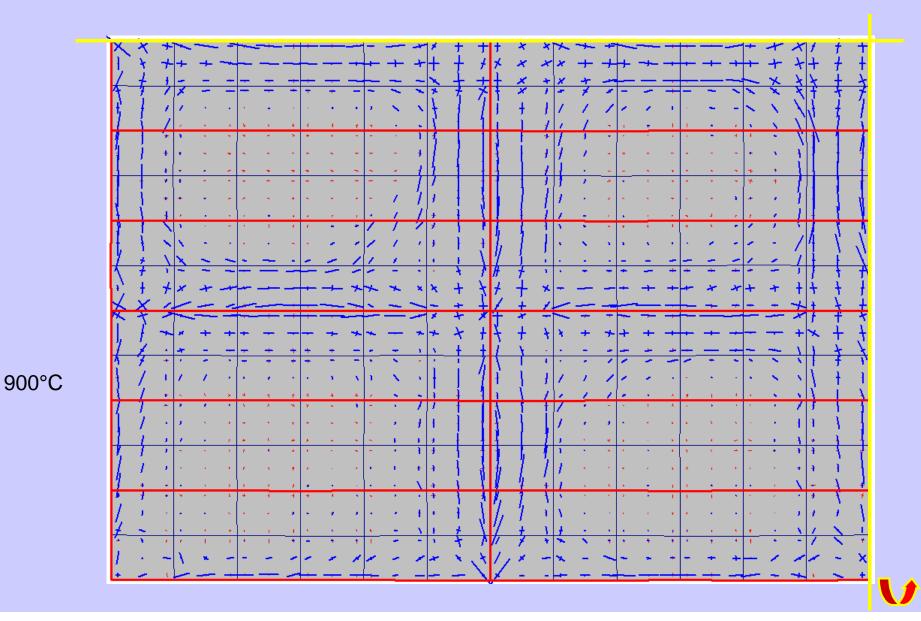












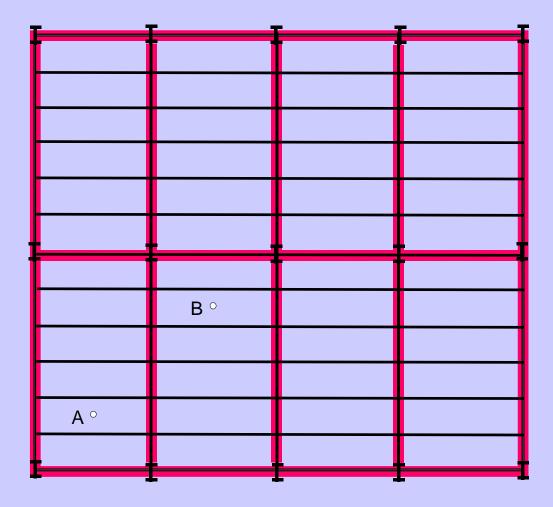


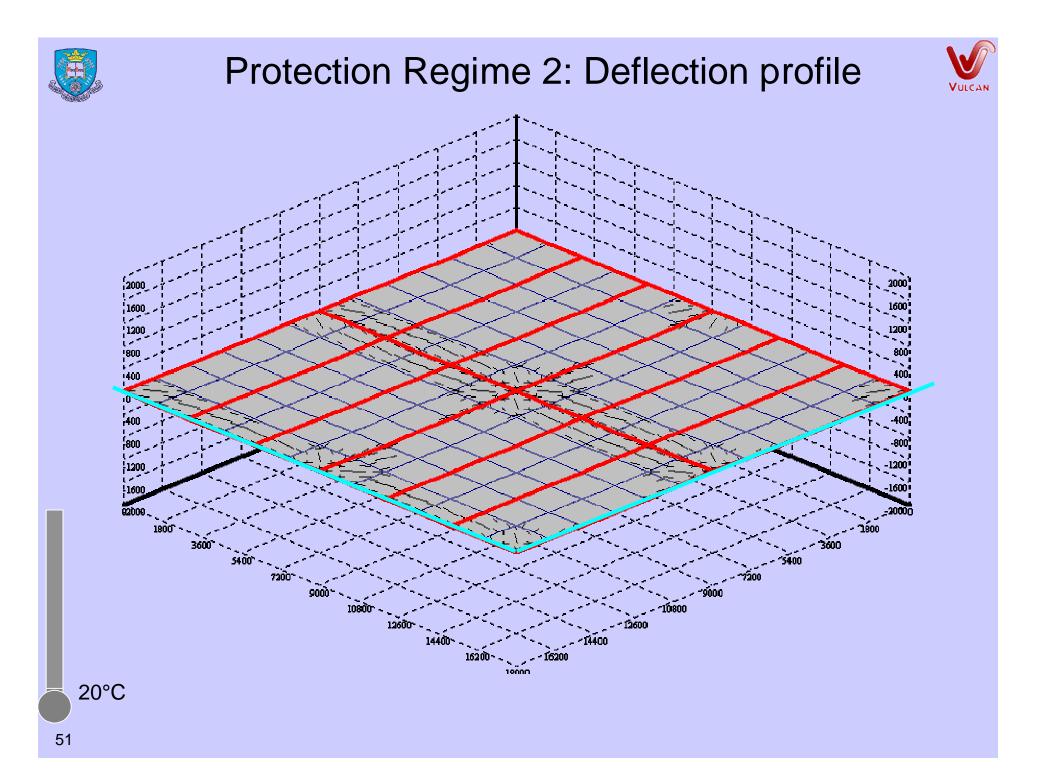
Structural fire resistance methods

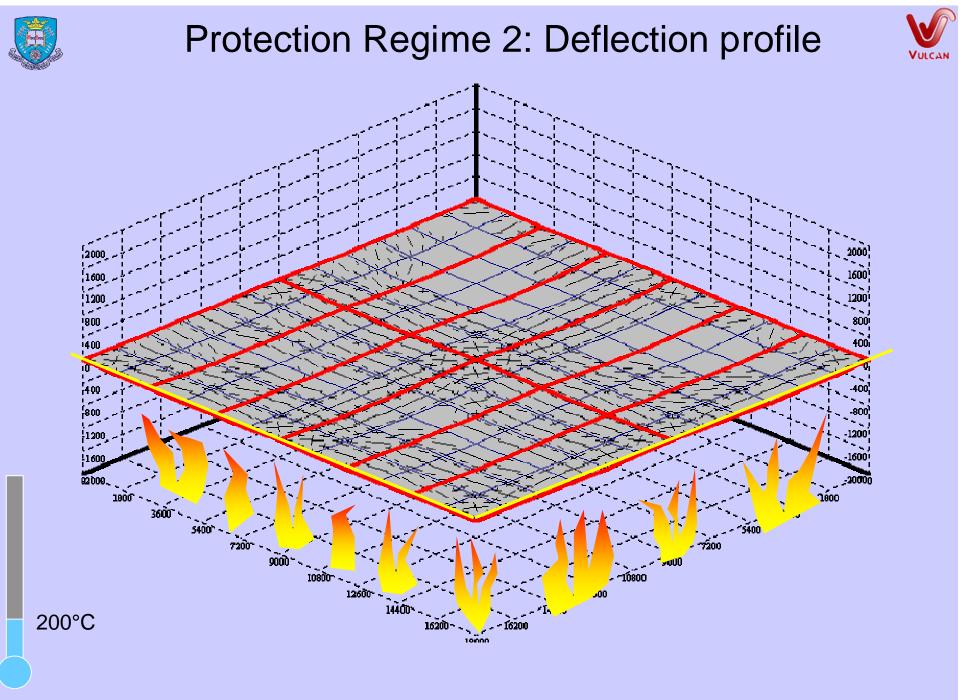


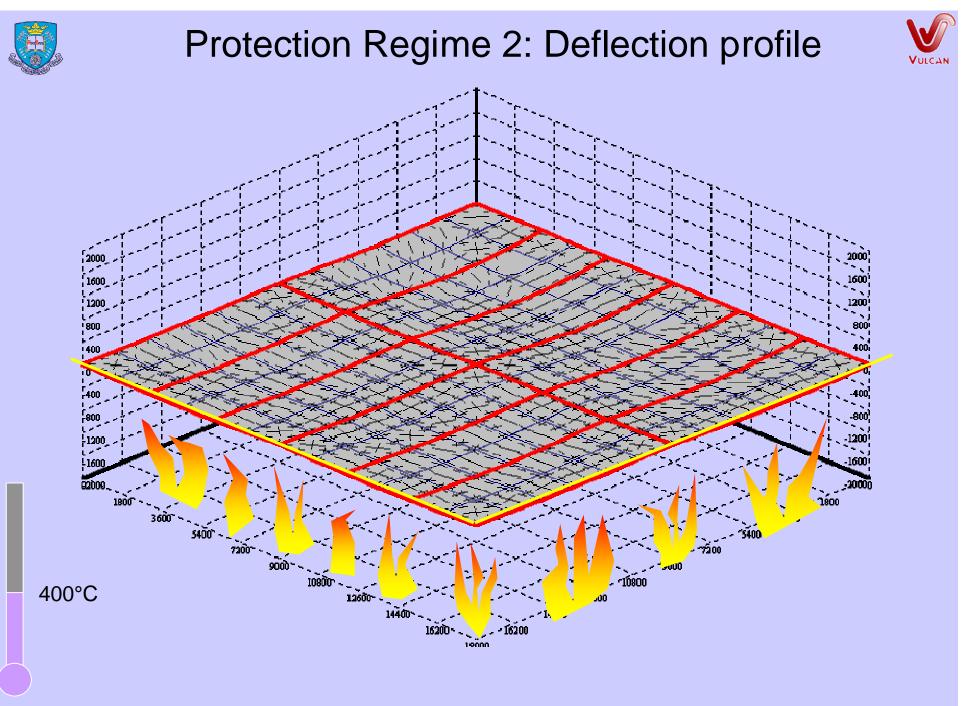
Non-square structural frames:

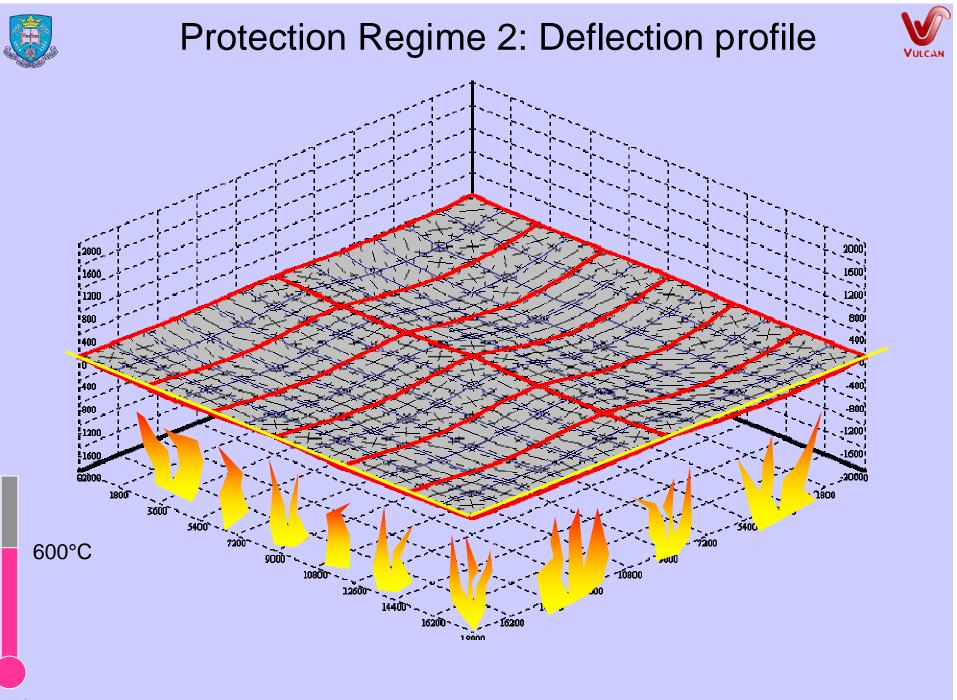
Much lower enhancement of capacity due to tensile membrane action.

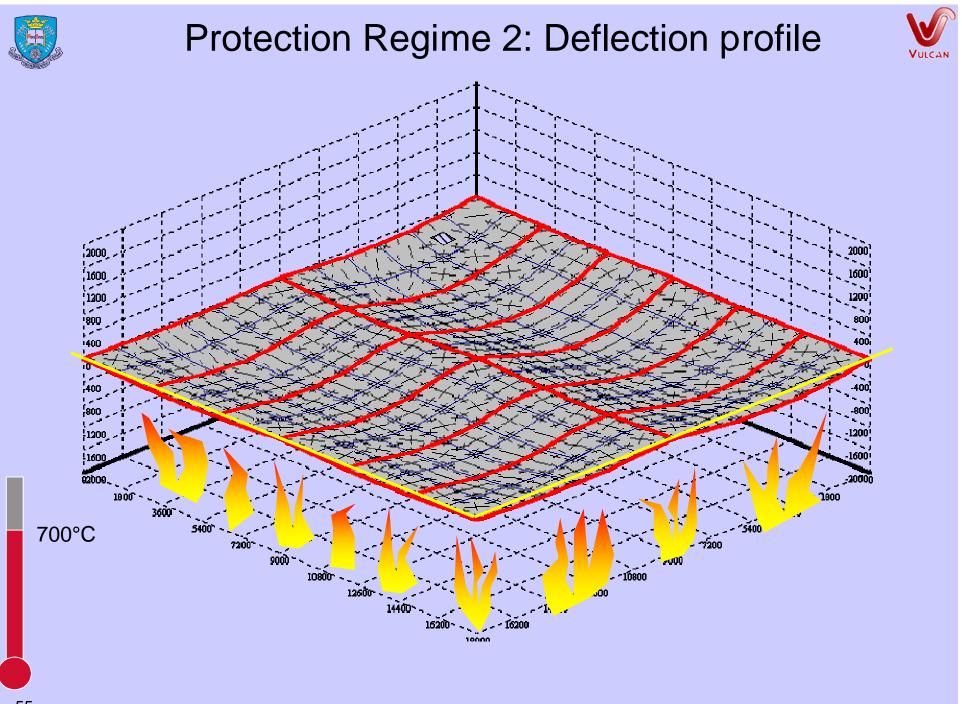


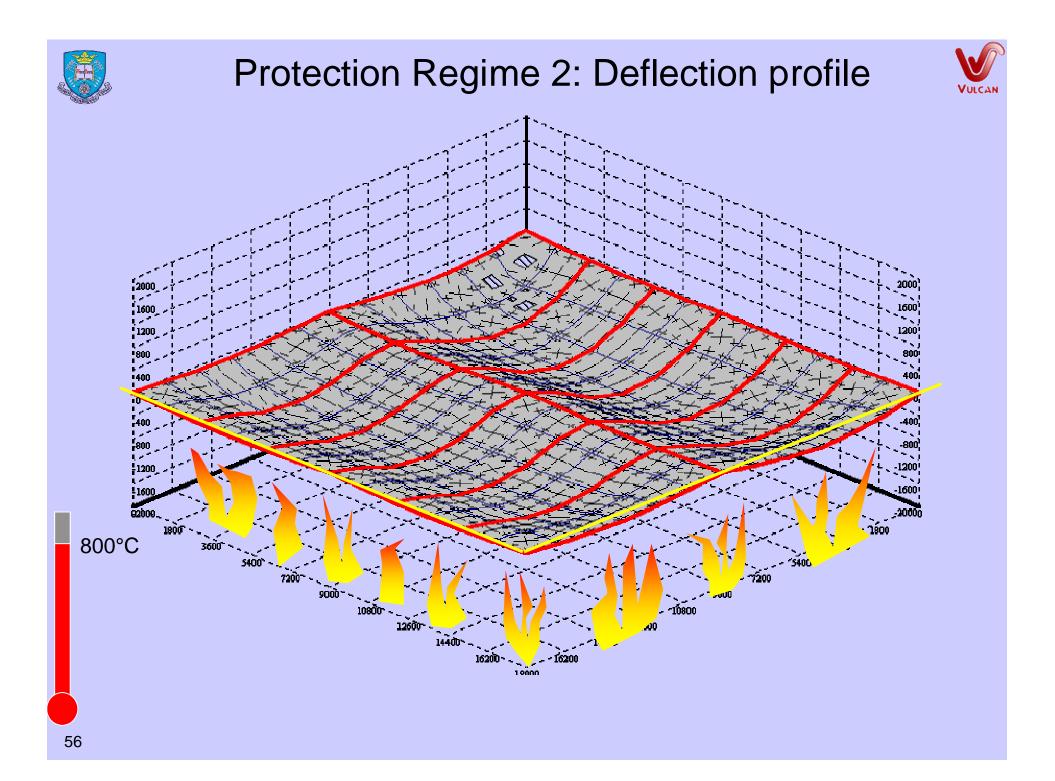


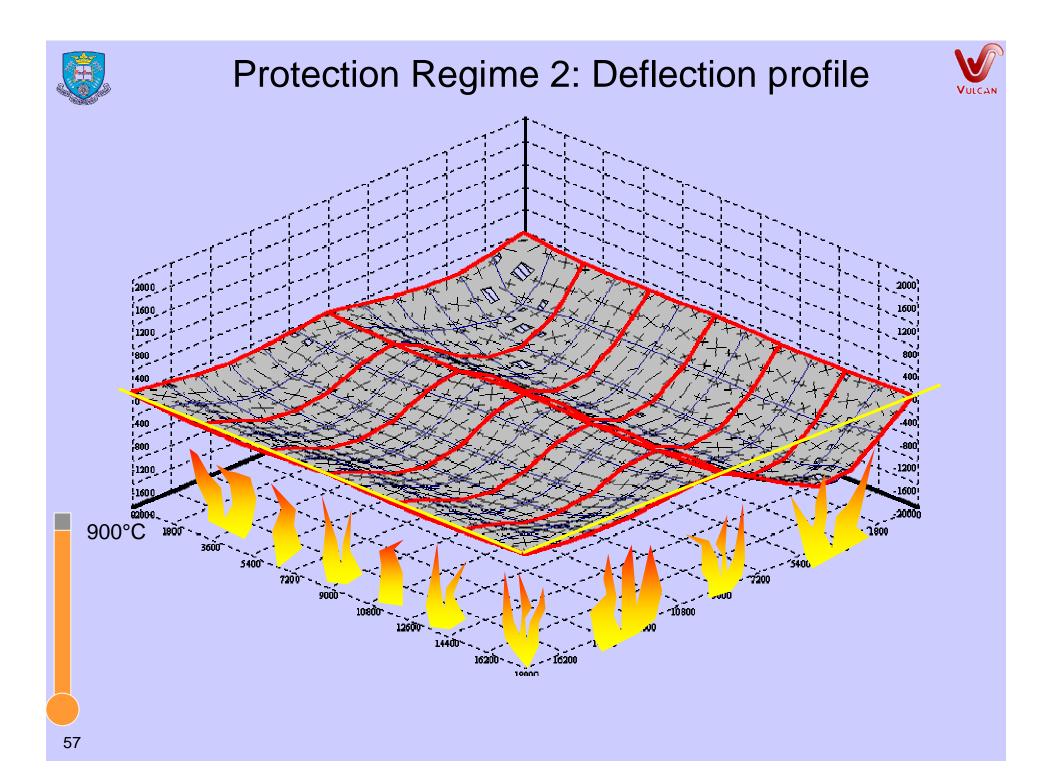


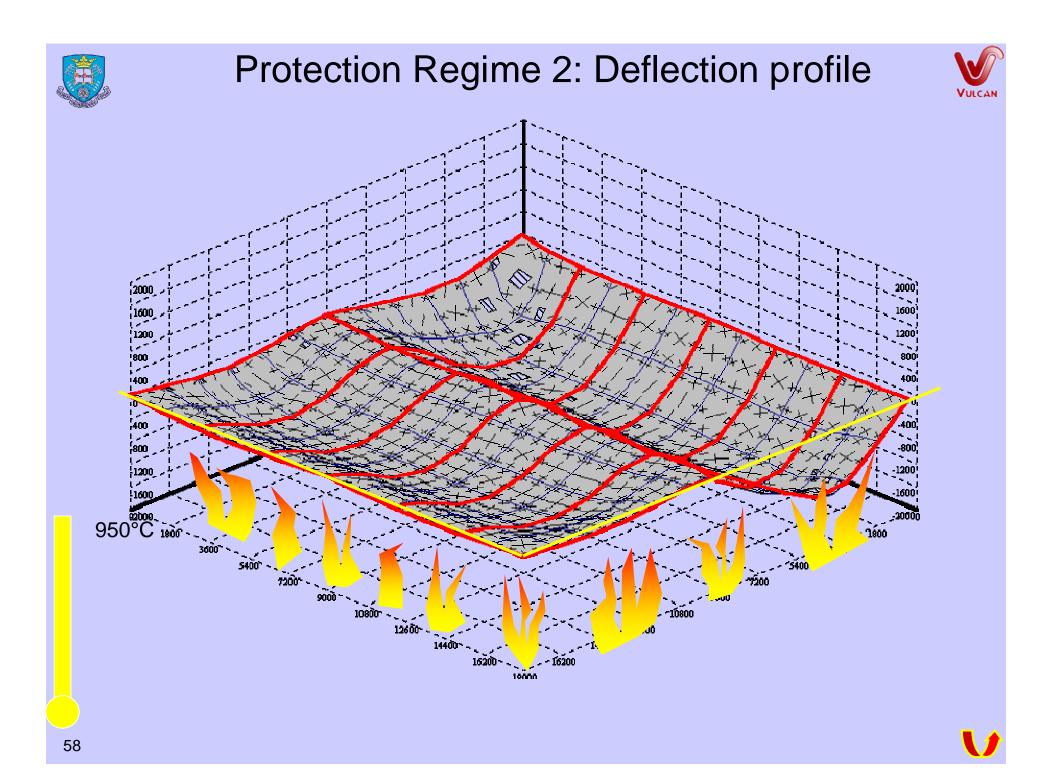








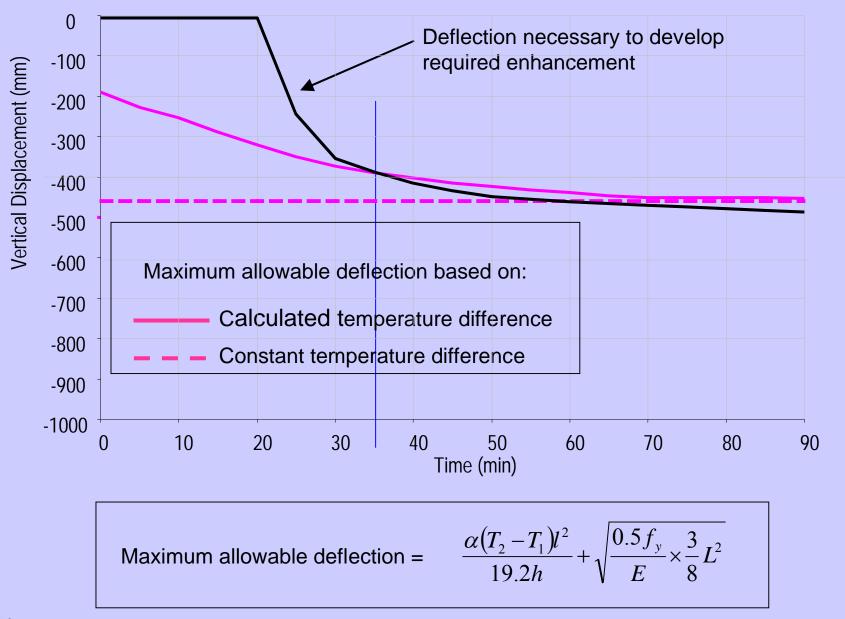


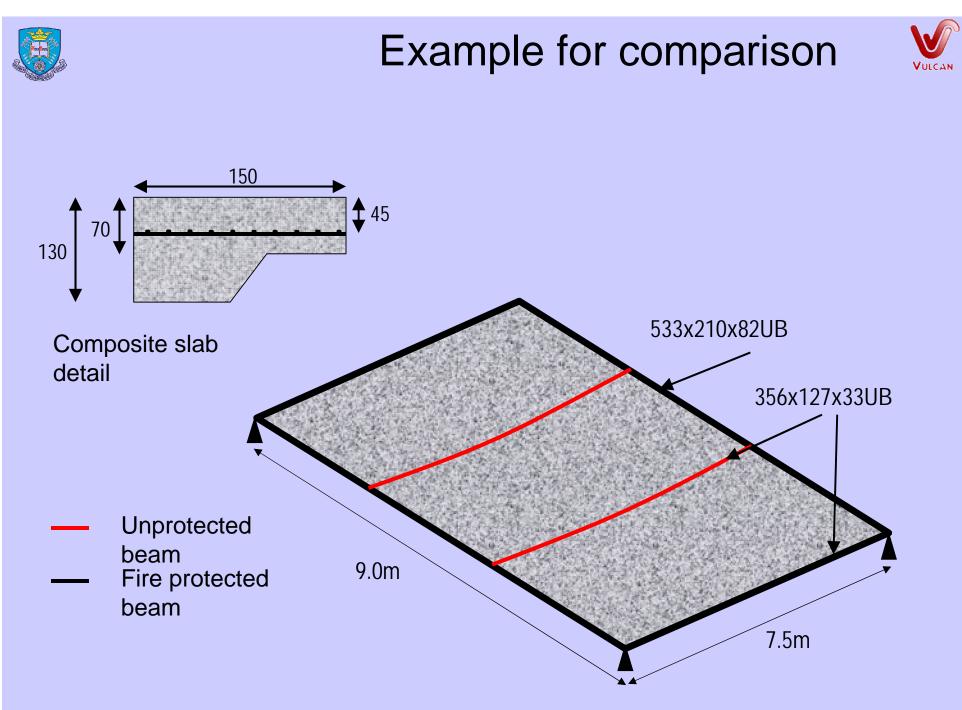




Simplified BRE Design Method



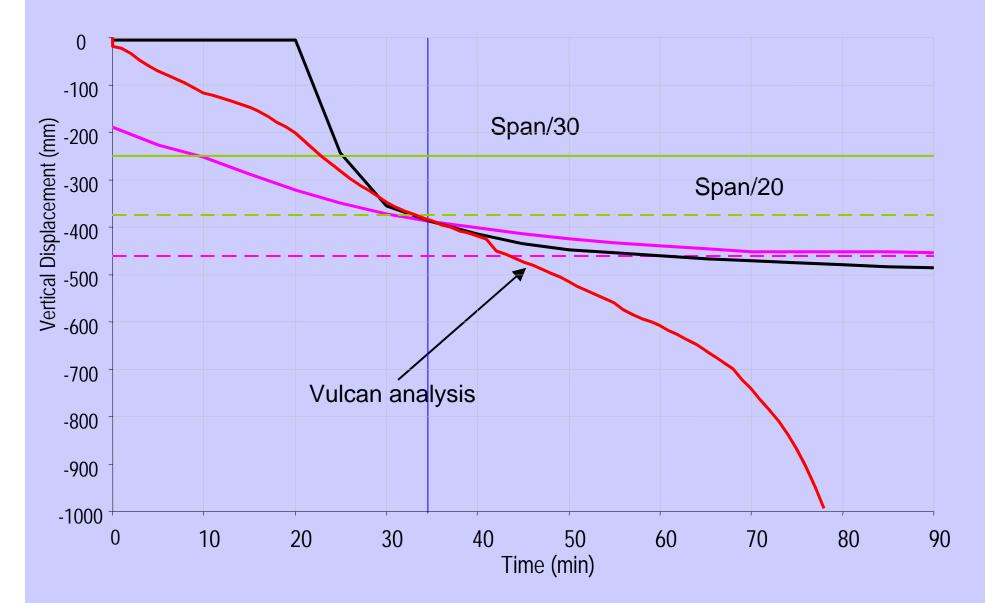








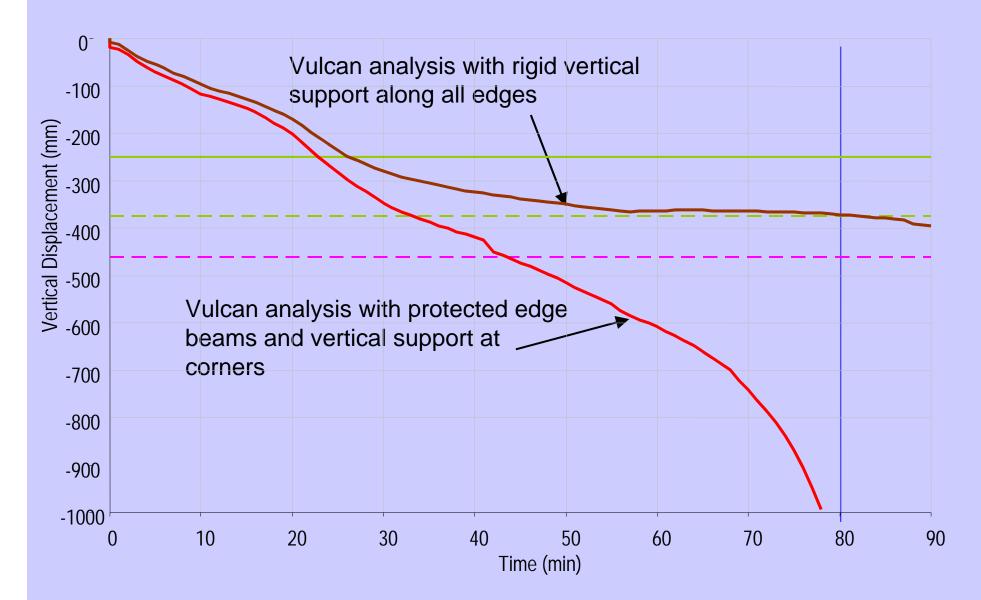






Effect of Vertical Edge Support

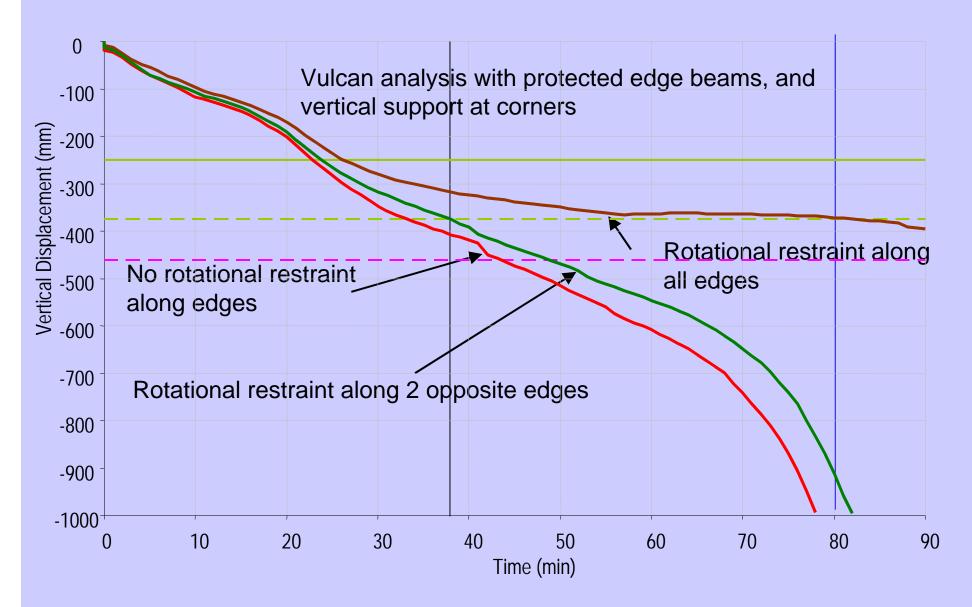






Effect of Rotational Edge Continuity

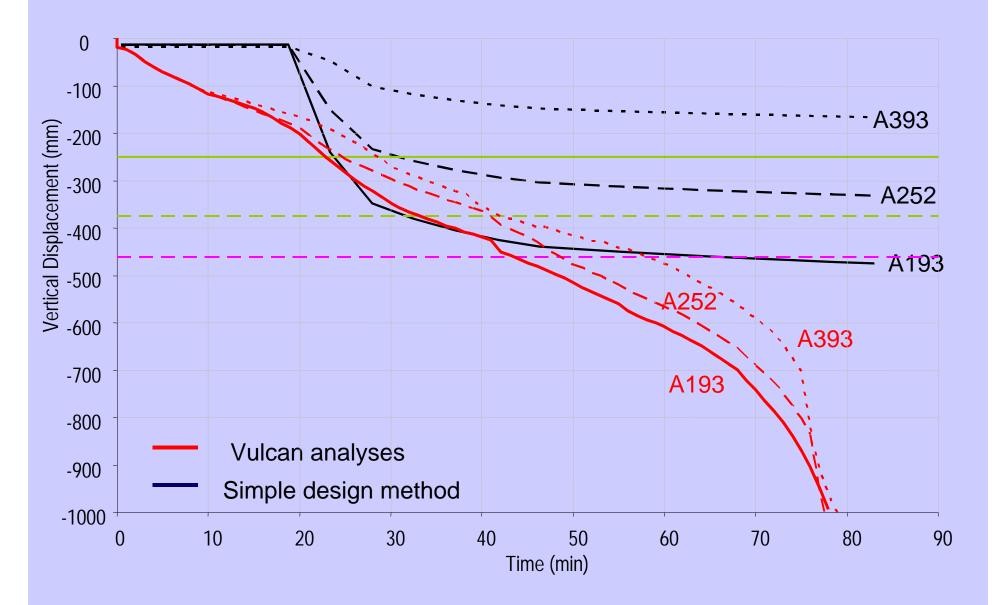






Effect of increasing reinforcement

VULCAI









- Connection forces can be very large
- Need to know connection robustness as well as stiffness
- Benefit of component based approach for connections









Connection behaviour in fire



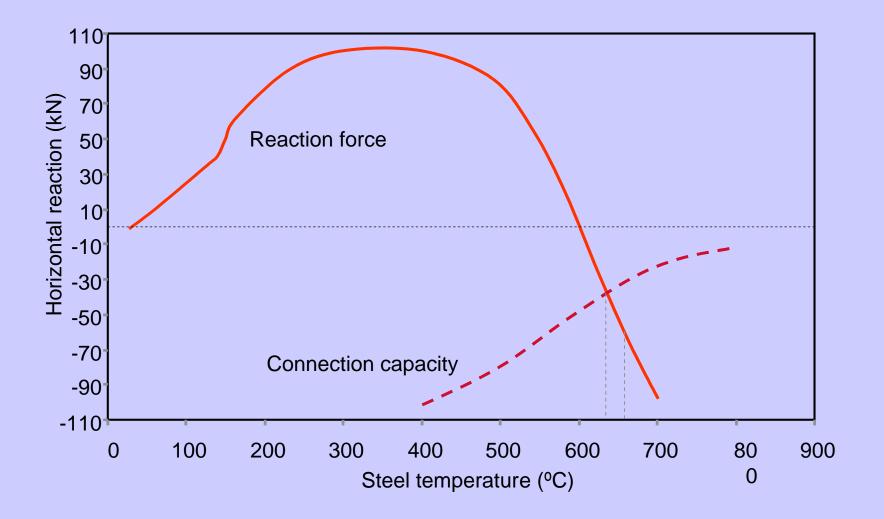
- Traditional moment-rotation characteristics inappropriate
 - Impractical
 - Axial forces important







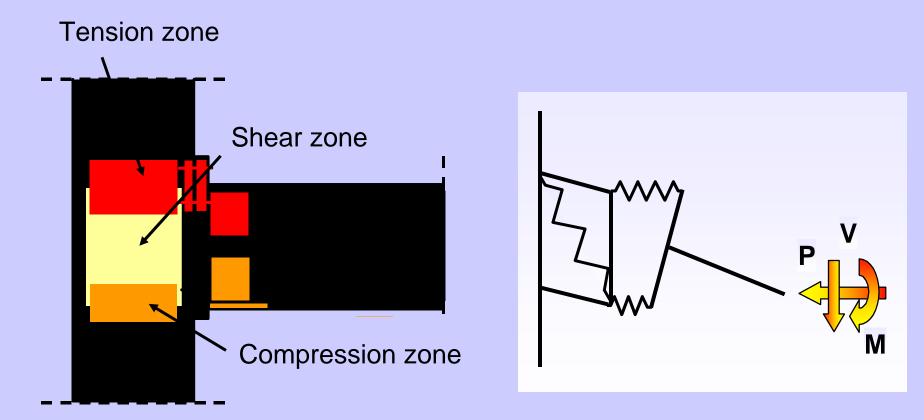
Reaction Forces at Beam Supports





The Component Method

- Treats separate zones of a joint
- Behaviour of each zone represented as a spring

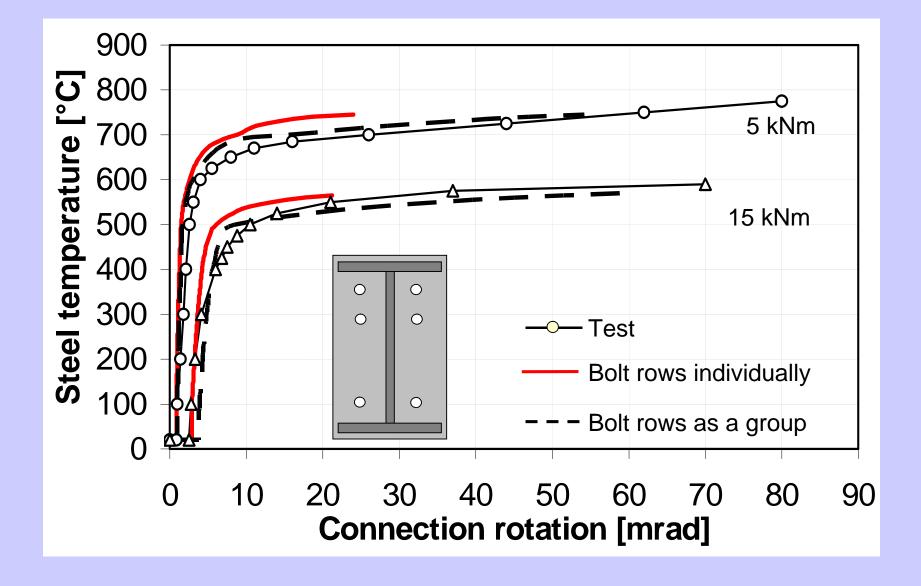


- Established for ambient temperature behaviour
- Currently being extended for high temperatures



Comparison with joint tests

VULCAN





Connection behaviour

















At 550°C





At 20°C



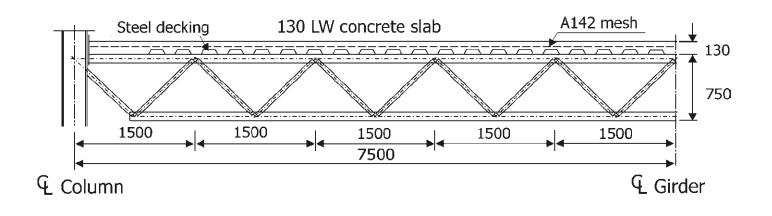




Standard test over 4.5m span unrepresentative Large scale testing needed



Long span systems





Reinforced concrete structures







Principal concern is spalling as seen in tests and real fires



Effect of top reinforcement





Flat slab 7.5m span; 250 mm thick; 25mm cover





Conclusions

- Advanced modelling offers a performance based
 approach to structural fire engineering
- Potential benefits include
 - Reduced protection
 - Consistent safety
 - Improved treatment of robustness
- Some outstanding issues
 - Failure criteria
 - Connection behaviour
 - Long span systems
 - Concrete spalling





Thank you