# HEAT BRIDGING SCOPING STUDY

Research progress and

COMPREHENSIVE jip opportunity

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22 October 2024

# Outline

- Introduction
- Technical approach to assess the consequenc bridging
- Heat transfer and structural response simulati preliminary results
- Large comprehensive study design

# Coatback Requirements

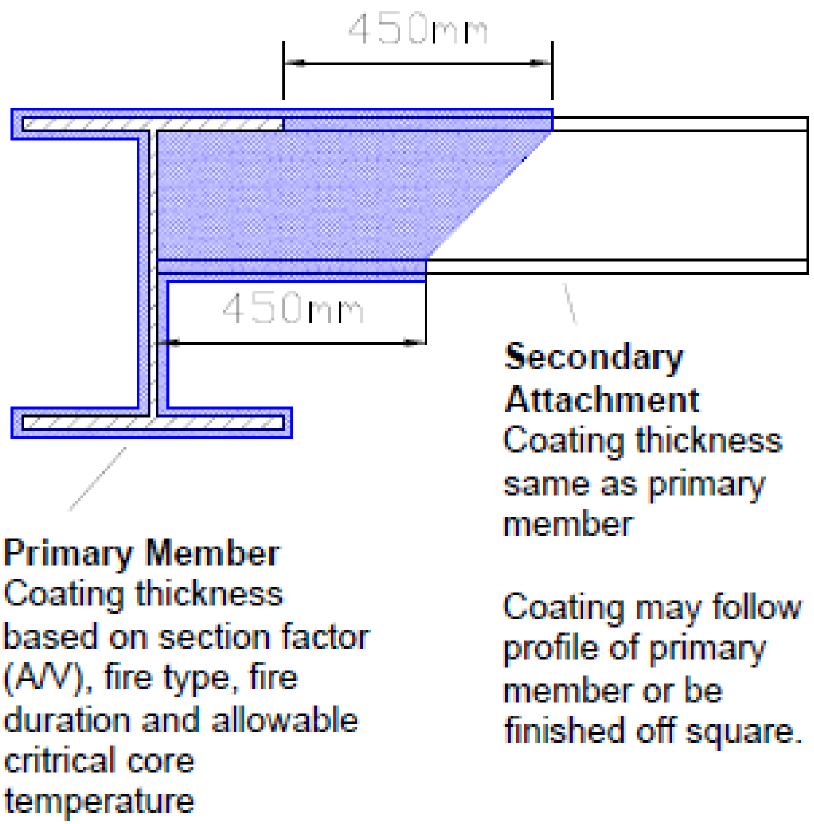
"Writing to get your opinion and request info regarding coatback requirements for non-fireproofed members for onshore facilities. Most industry recommended practices such as API-2218, DNV-OS-D301 recommend using 450 mm. However, this recommendation is made with a caveat that if 'heat conduction to primary beam is a concern then extend fireproofing' leaving the coming up with any requirement on the engineer. From construction point of view having different coatback lengths for different areas creates complexity with minimal gains.

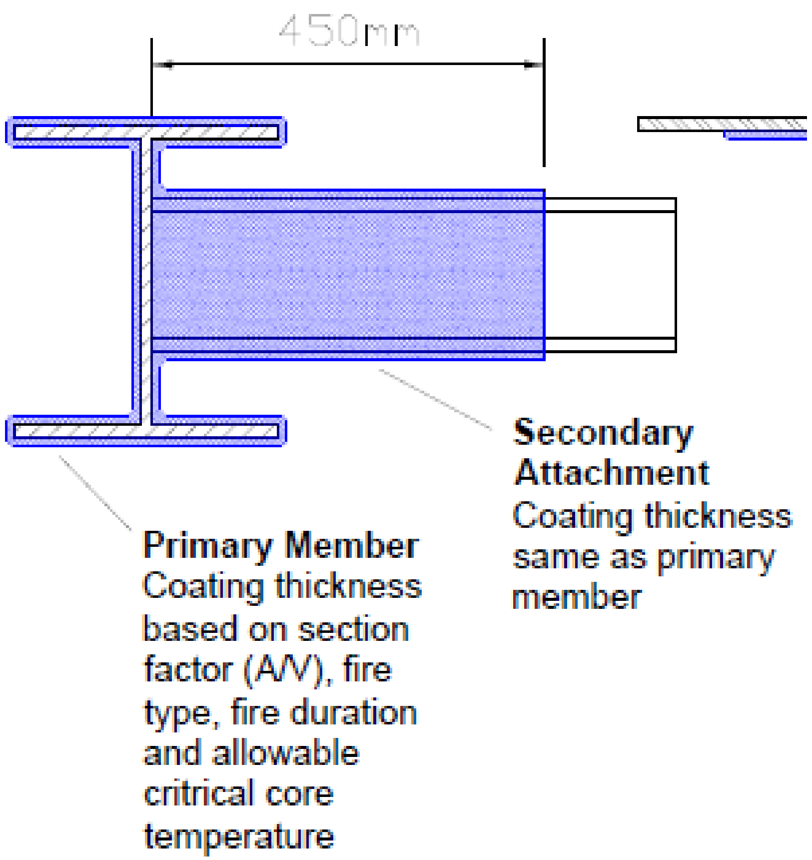
Can you share any info of published data on this matter especially for onshore facilities and your opinion on this matter. Thanks."

Chief Process Safety Engineer

Major EPC firm

- Secondary and tertiary members connected to PFP-applied primary steel members shall be coated with 450 mm PFP in order to minimize conduction heat transfer to protected members as per FABIG TN-13 if the cross-sectional area of the connected element is more than 3,000 $mm^2$



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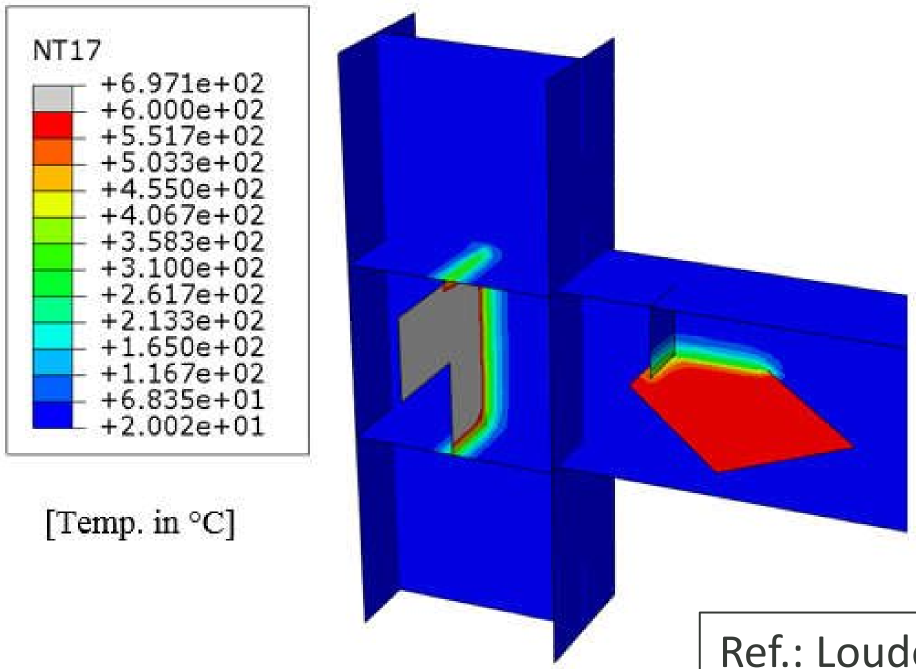
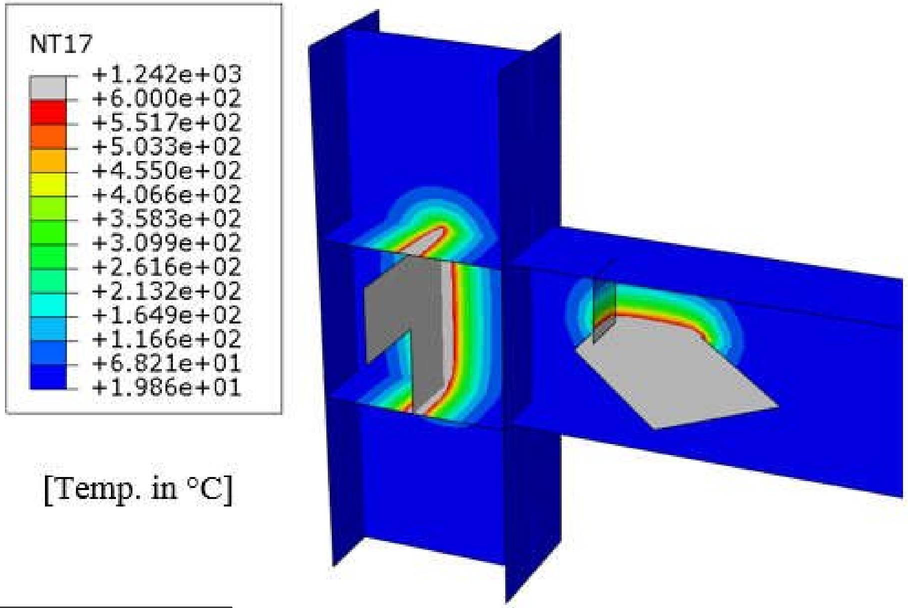
# Structural Steel

## Temperature at 1min




## Temperature at 5min




Ref.: Loudoun and Akinci, 2017

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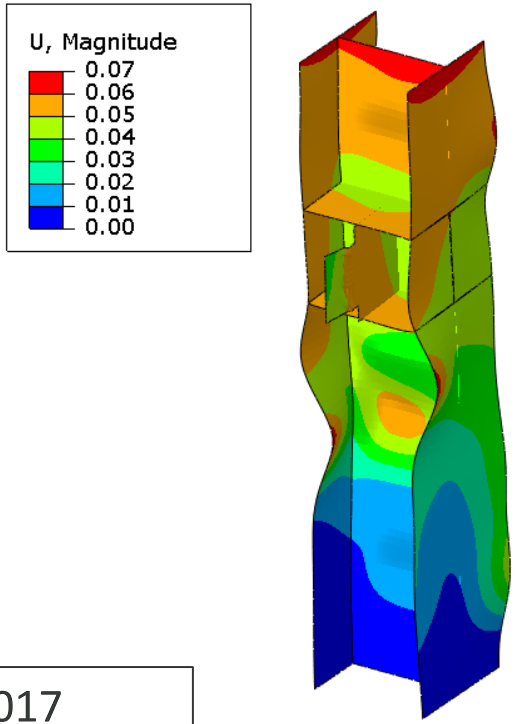
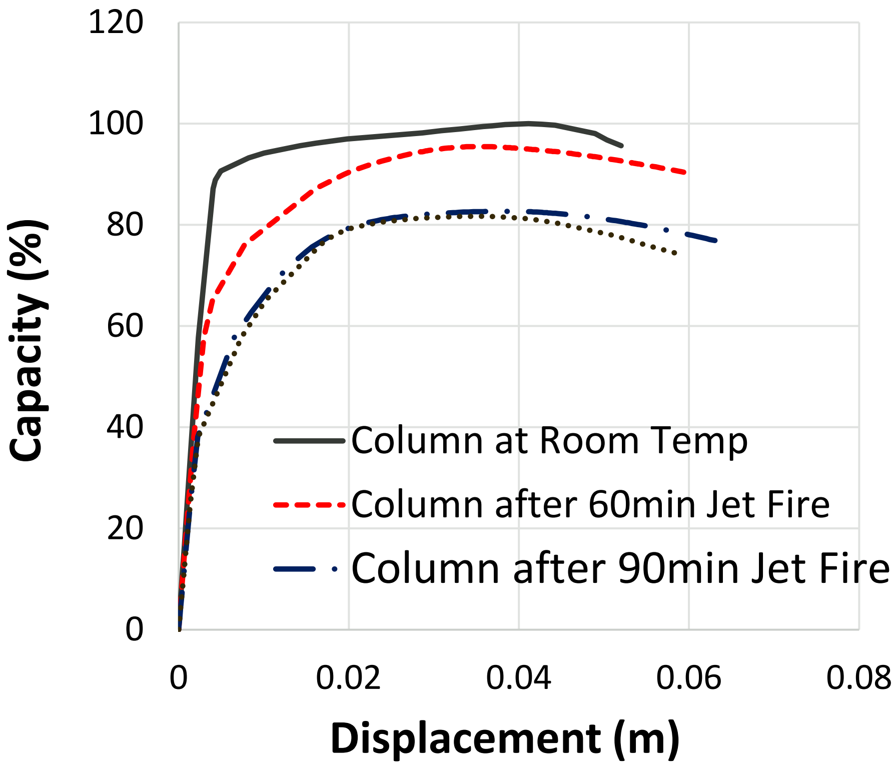
# Column Response

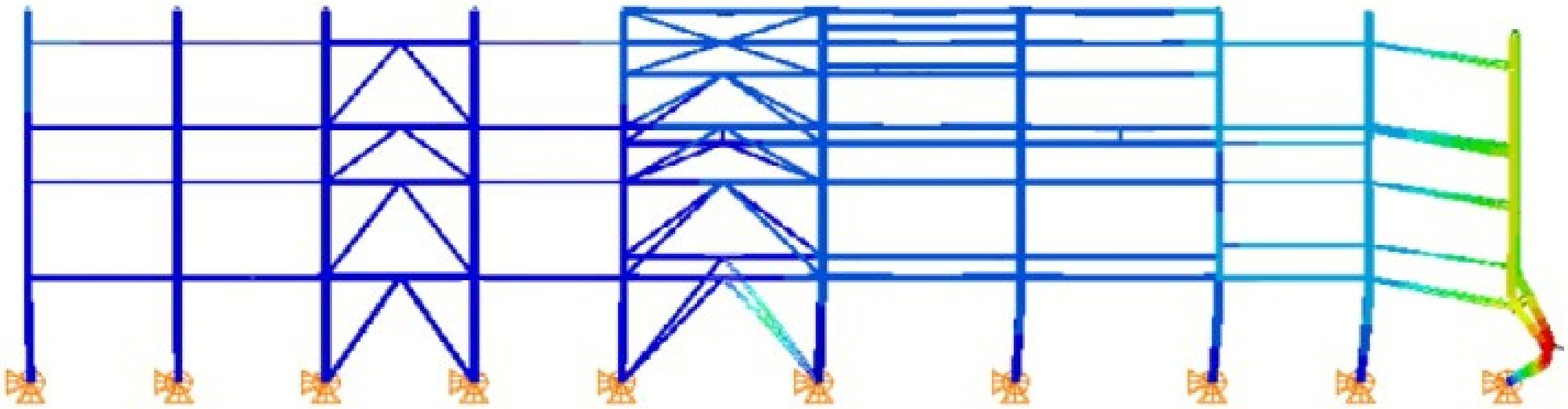
| Condition | Capacity |
|---|---|
| Room Temperature | 100% |
| After 60 min. Jet Fire | 95% |
| After 90 min. Jet Fire | 83% |
| After 2 hr. Pool Fire | 82% |
| Actual Utilization | 50% |




Ref.: Loudoun and Akinci, 2017

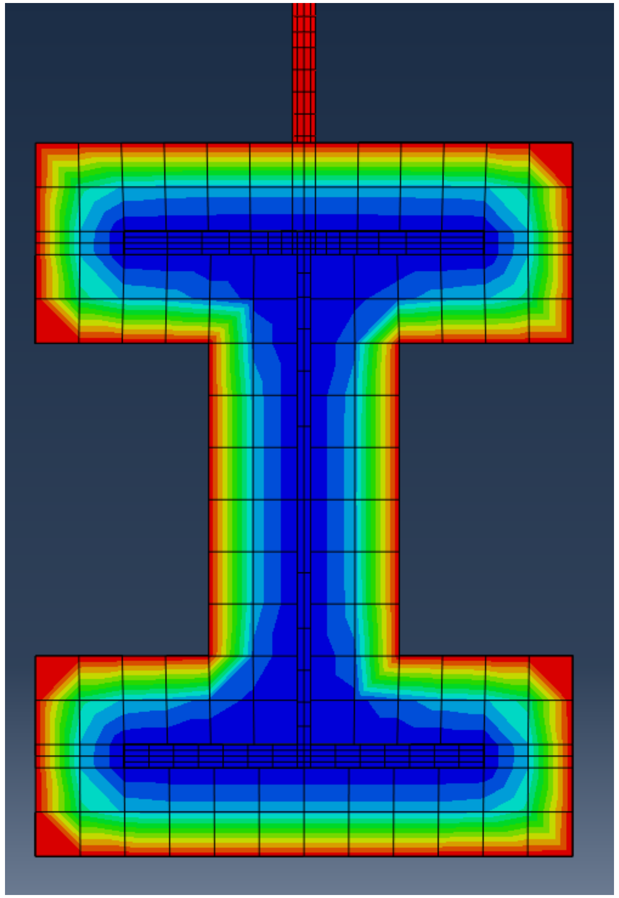
# Global Response



# Research Areas of Interest

- PFP Damage
  - Partial thickness loss in a localized area
  - Complete loss of PFP in a localized area

- Aging PFP
  - General degradation
  - Erosion
  - Partial conductivity loss due to aging

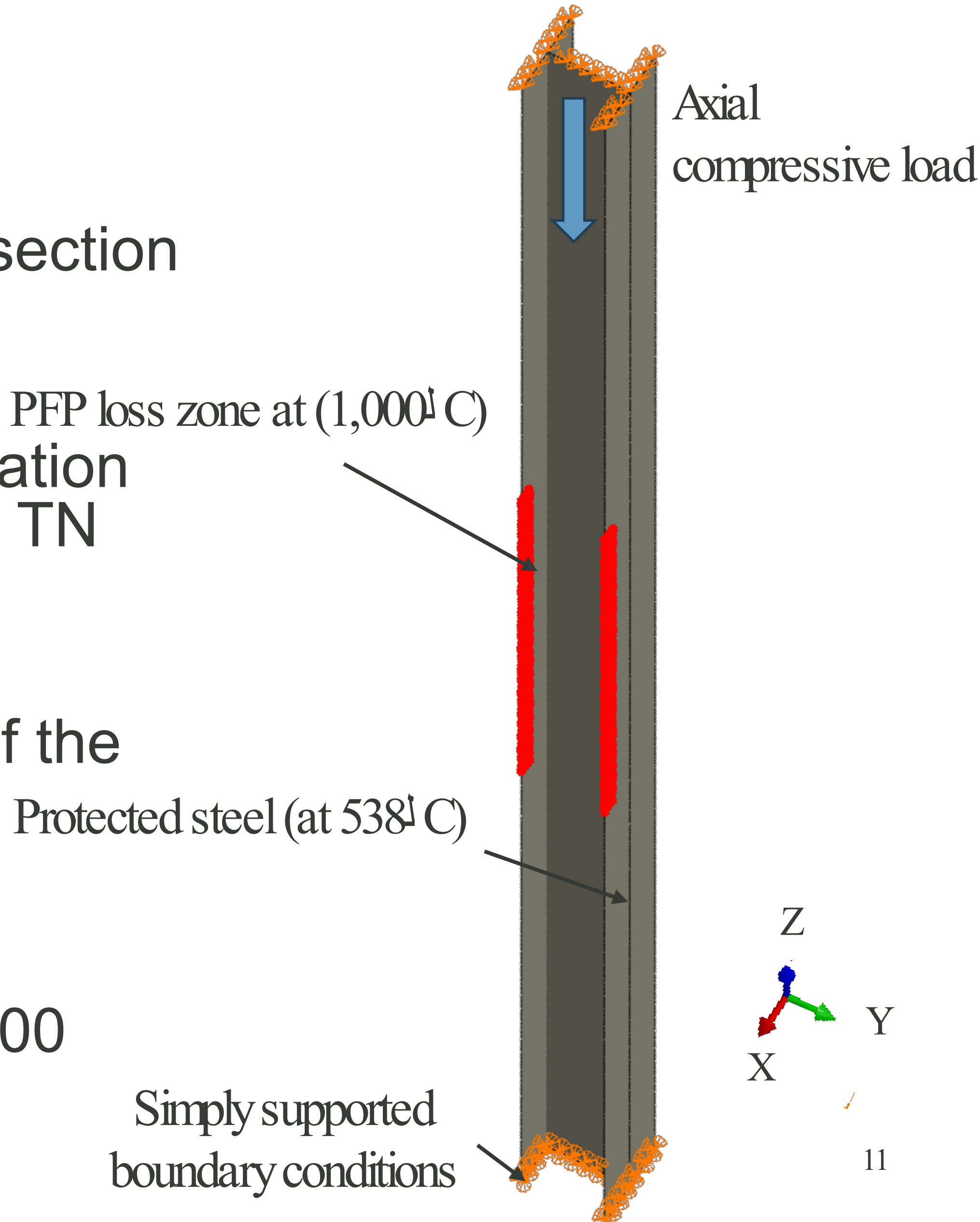


# Approach to Assess the Consequences of Heat Bridging

- PFP damage, aging PFP, and coatback
  - Conduct heat transfer analysis considering the key parameters identified in ou
  - Estimate temperature profiles in the protected elements based on the learning representative heat transfer analysis cases
  - Consider pool fire and jet fire scenarios
  - Develop structural models utilizing temperature dependent material properties various failure modes, including local and global buckling
  - Impose the temperature profile predicted from the heat transfer analysis on th
  - Increase loads incrementally until failure / collapse of the element
  - Assess the consequences of heat bridging

## Case 1 – W10x49 Column

- Nonlinear static analysis of a W10x49 column section using ABAQUS
- FE model includes
  - Strength and modulus of elasticity degradation as a function of steel temperature (FABIG TN 6)
  - Large displacement effects
- PFP damage at the tip of the flanges (0.5 m (10% of height) and 1.25 m (25% of height), and 15% of the flange width
- Pool fire scenario
- Column temperature rises to 538°C after which the exposed flange region temperature rises to 1,000°C
- Axial pushdown loads applied on the column



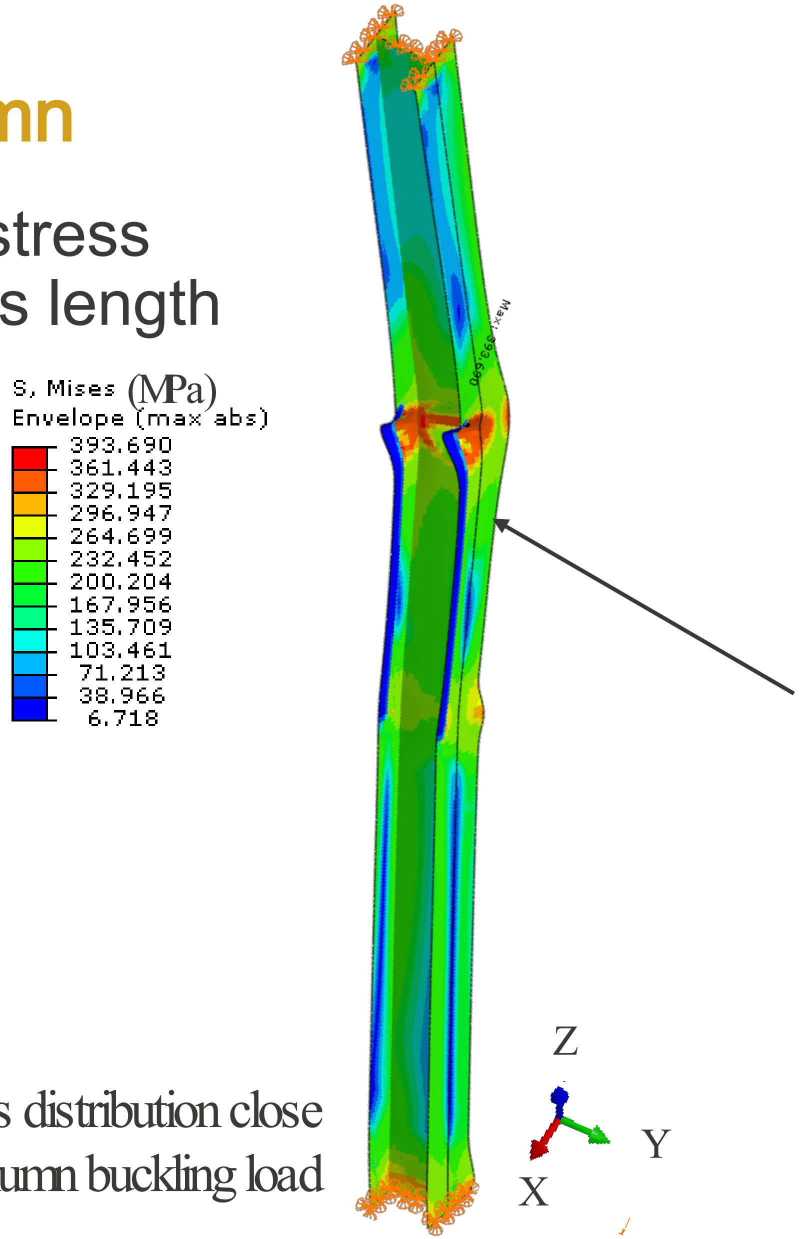
# Case 1 W10x49 Column

- We performed pushdown analysis to determine capacity of the column subjected to damaged PFP configuration
- 30% of the half flange (0.15xbf) width is exposed to fire with different PFP loss leng

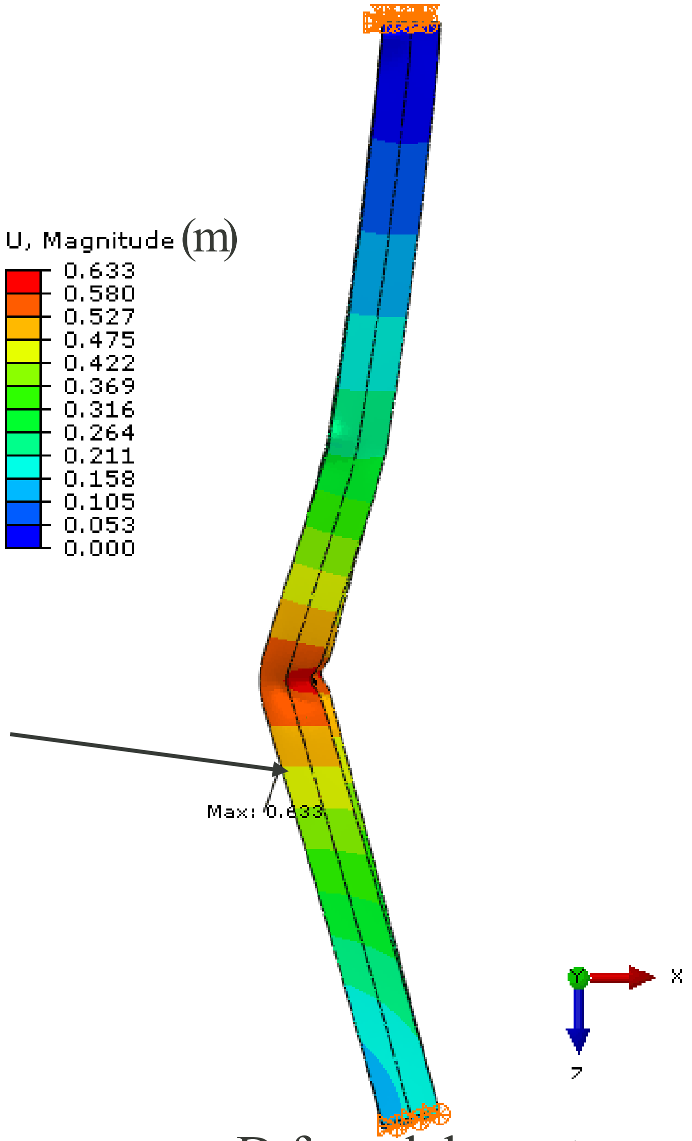
| Exposed Steel Temperature (°C) | PFP Loss Length | Capacity / Failure Load (kN) | Failure Mode |
|---|---|---|---|
| 26°C | – | 2,000 | Capacity governed by yielding |
| 1,000°C | 0.5 m | 1,098 (55%) | Flange local buckling and subsequent global buckling |
| 1,000°C | 1.25 m | 976 (49%) | Flange local buckling and subsequent global buckling |

# Case 4W10x49 Column

- Deformed shape and stress contours for 1.25m loss length and 0.04m width




Stress distribution close to column buckling load




Deformed shape at column buckling load

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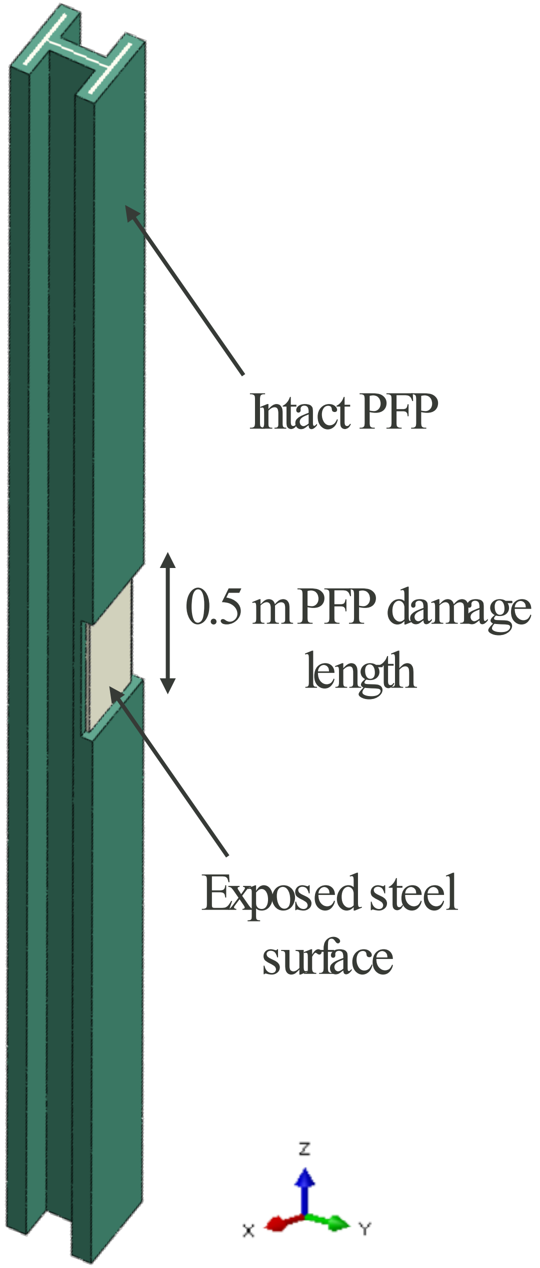
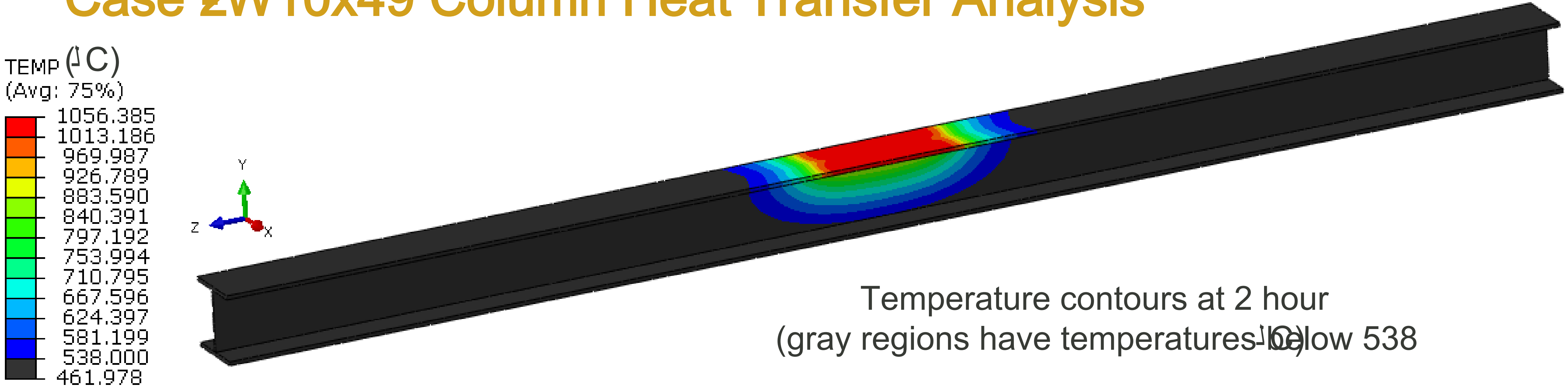
# Case 2 – W10x49 Column Heat Transfer Analysis

- Finite element (FE) transient heat transfer analysis performed for a W10x49 column section using ABAQUS
- Column height = 5 m
- PFP thickness = 1.125 in. (28.5 mm)
- Damage to top flange PFP for 0.5 m length
- Heat-up of the column per UL1709 fire scenario (up to 1,100°C)

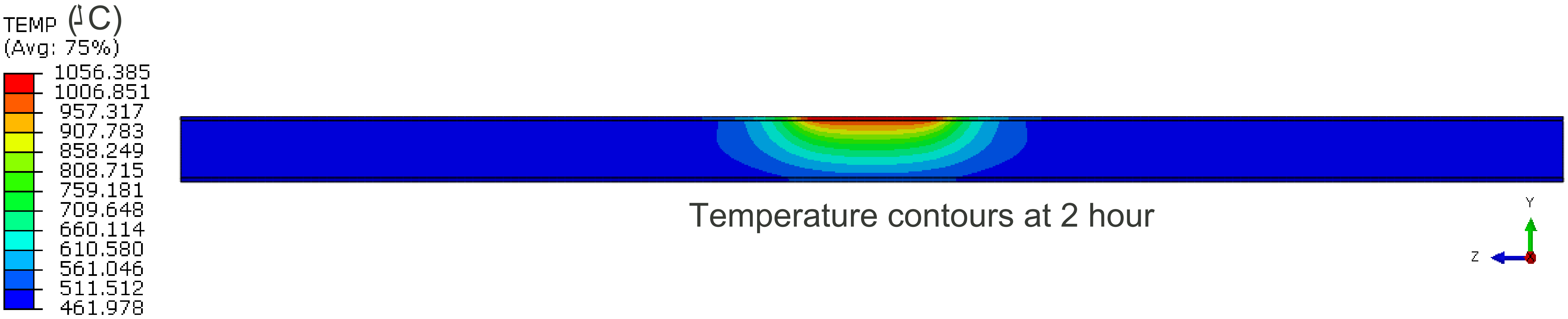



W10x49 with PFP loss zone 3-D view

# Case 2 – W10x49 Column Heat Transfer Analysis



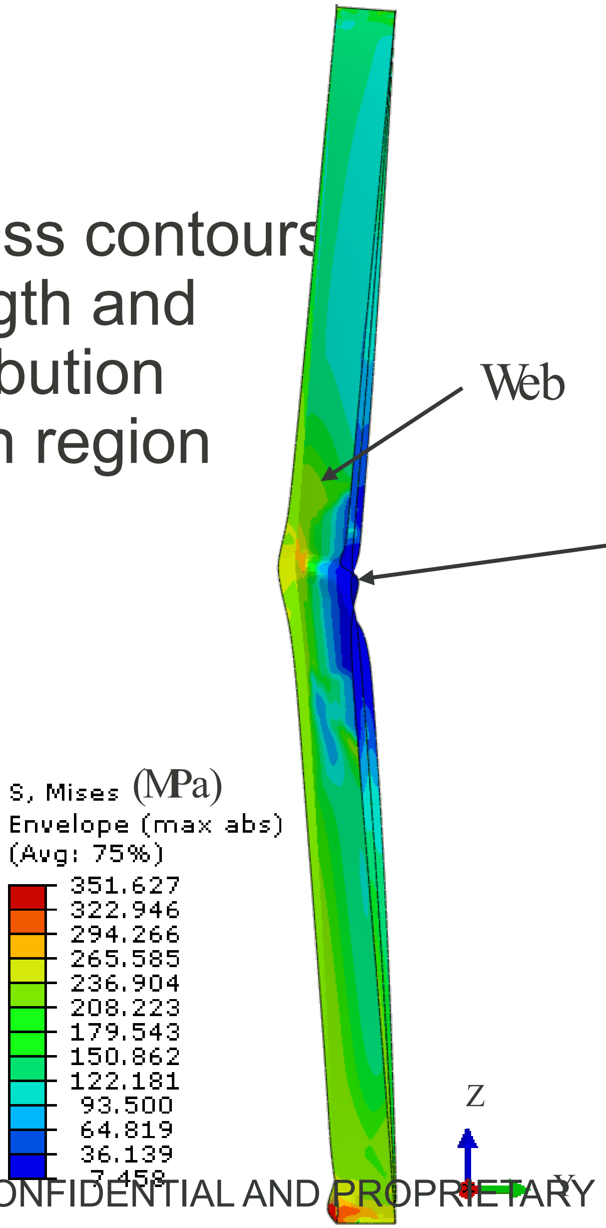

Temperature contours at 2 hour
(gray regions have temperatures below 538 °C)



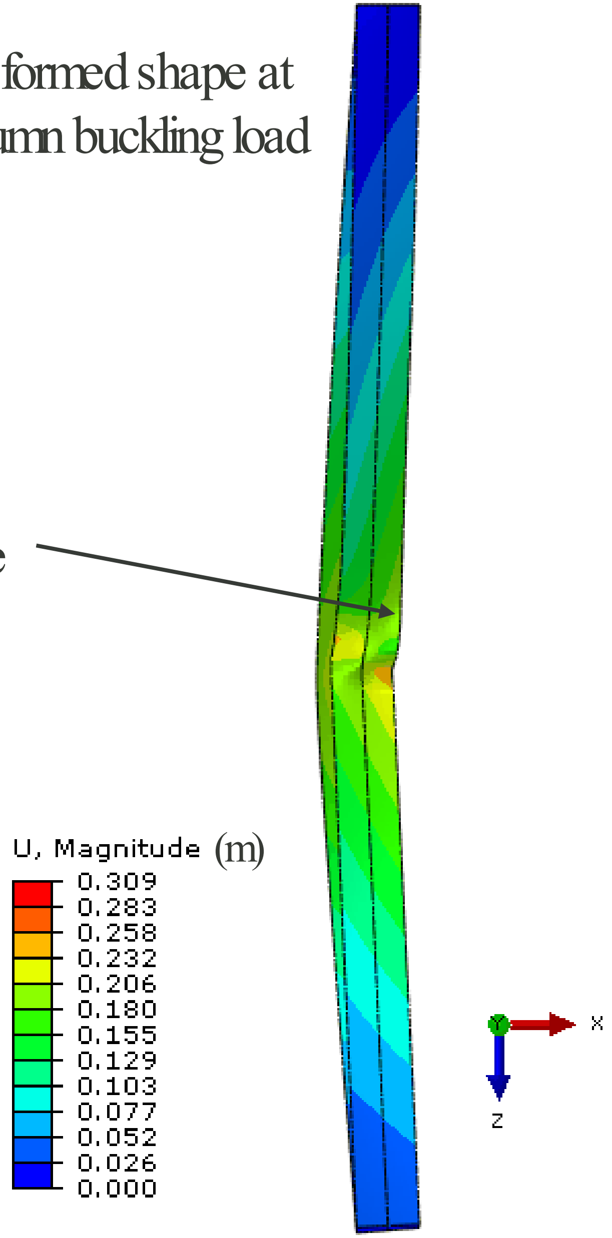

Temperature contours at 2 hour

## Case 2 W10x49 Column

- Deformed shape and stress contours with 1.25 m PFP loss length and refined temperature distribution applied near the transition region




Stress distribution close to column buckling load




Deformed shape at column buckling load

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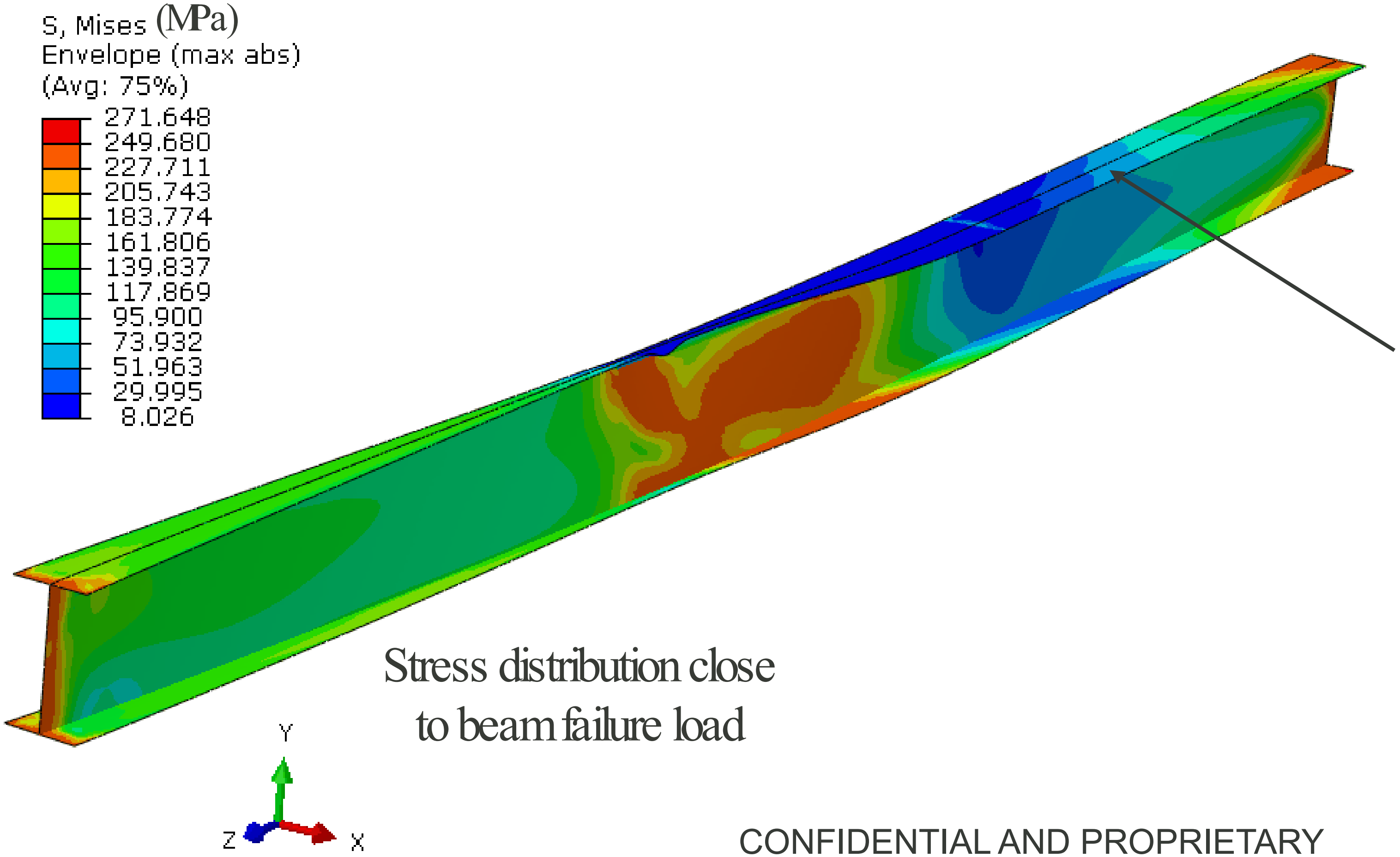
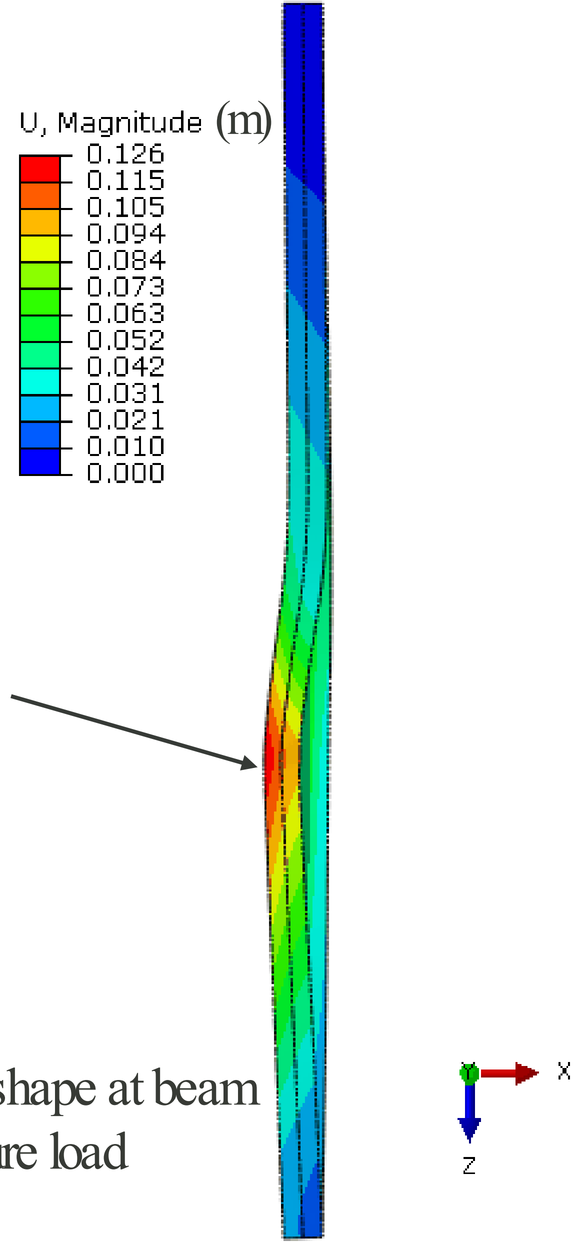
# Case 2W10x22 Beam

- Deformed shape and stress contours




Stress distribution close to beam failure load

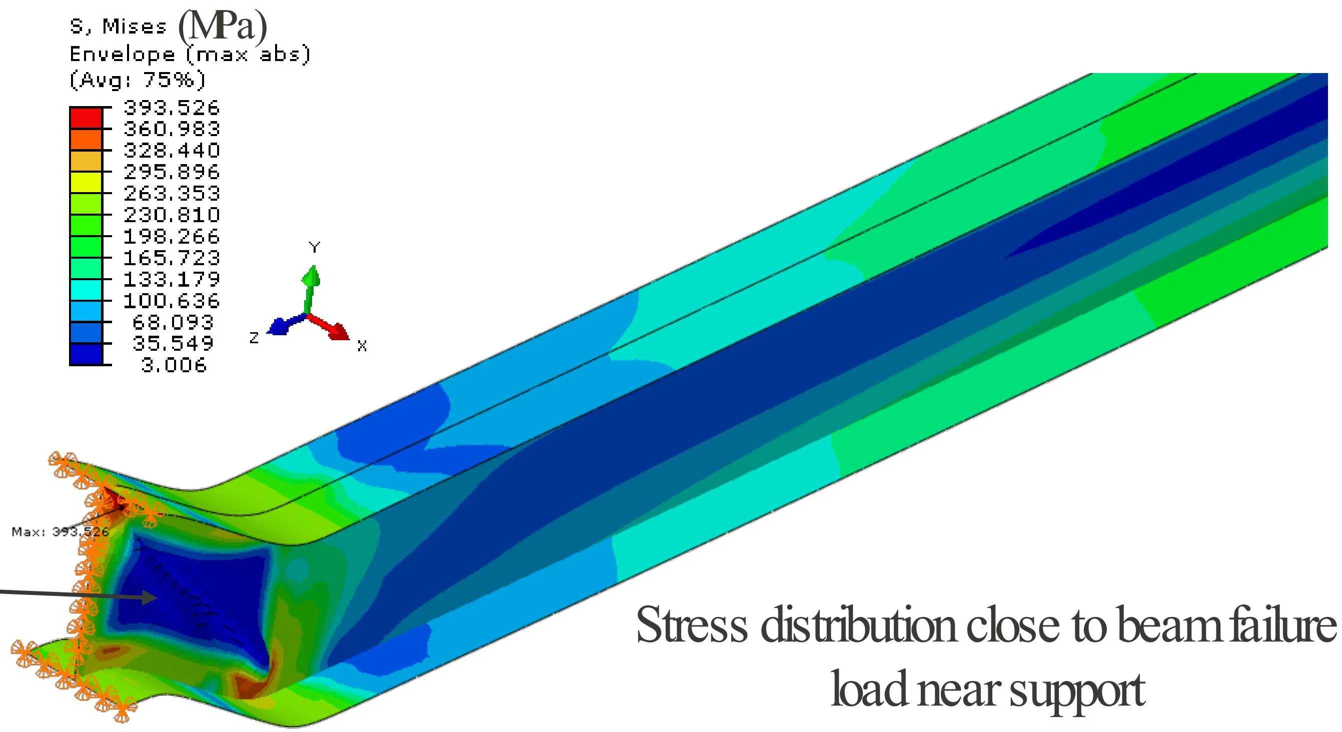
Top flange



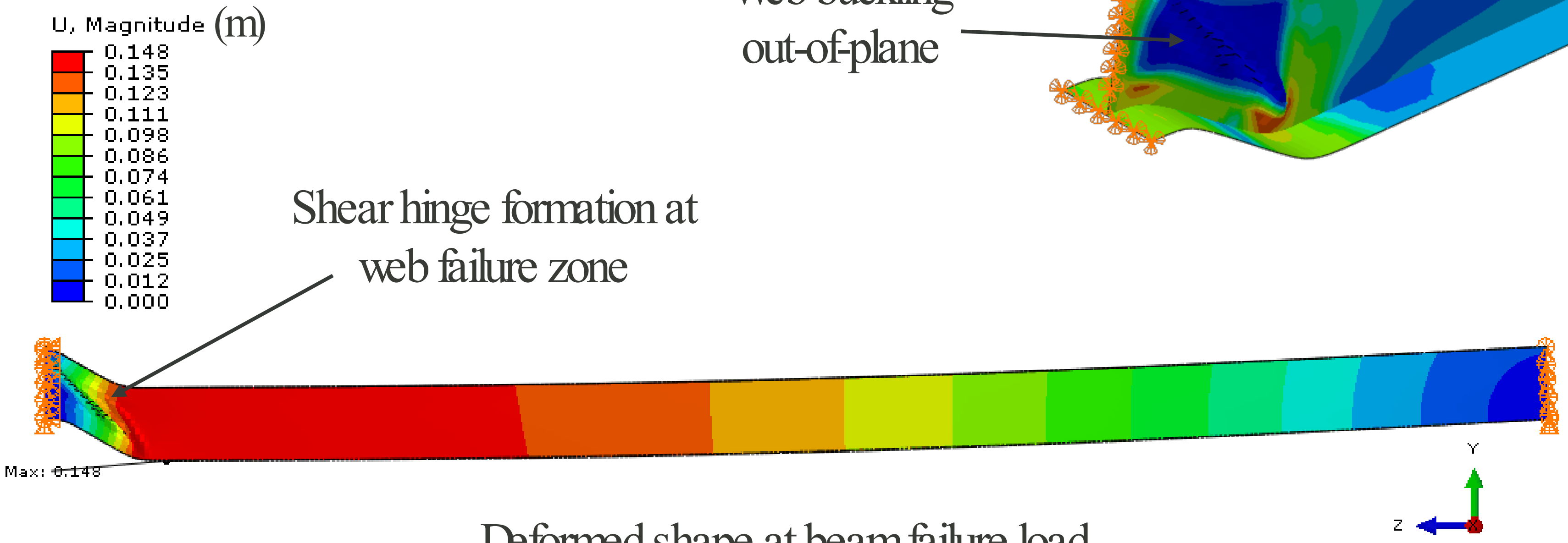

Deformed shape at beam failure load

# Case 3W10x22 Beam

- Deformed shape and stress cont



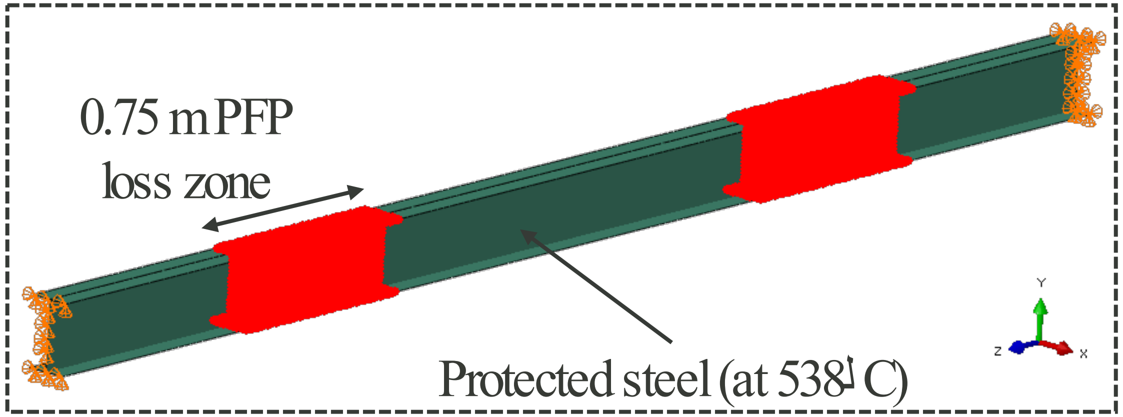

Stress distribution close to beam failure load near support

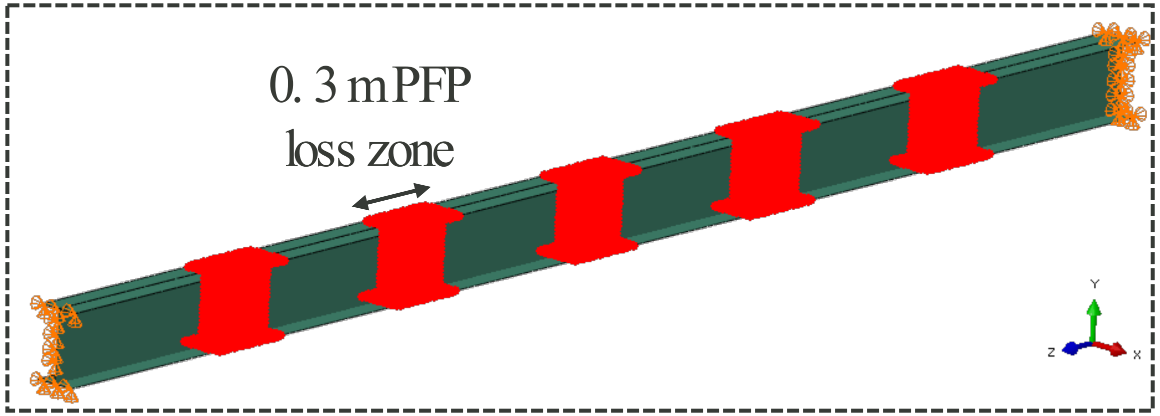



Deformed shape at beam failure load

# Case 4W10x22 Beam

- We observed member failure under fire loads (without operational loads) with the g damage configurations




| Exposed Steel Temperature (C) | Number of Segme without PFP | Failure Temperature (C) | Failure Mode |
|---|---|---|---|
| 1,000 C | 2 | 897 | Instability caused by large out-of-plane displacements |
| 1,000 C | 5 | 893 | Instability caused by large out-of-plane displacements |

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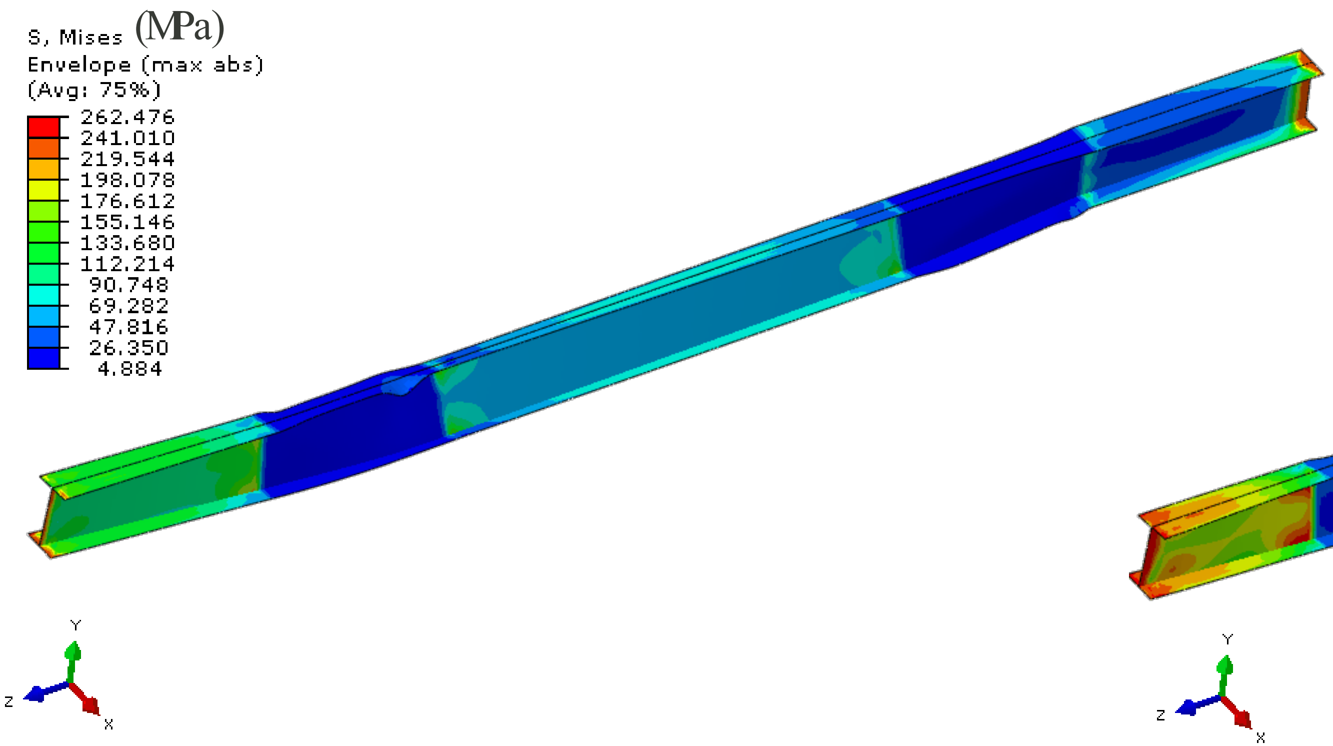
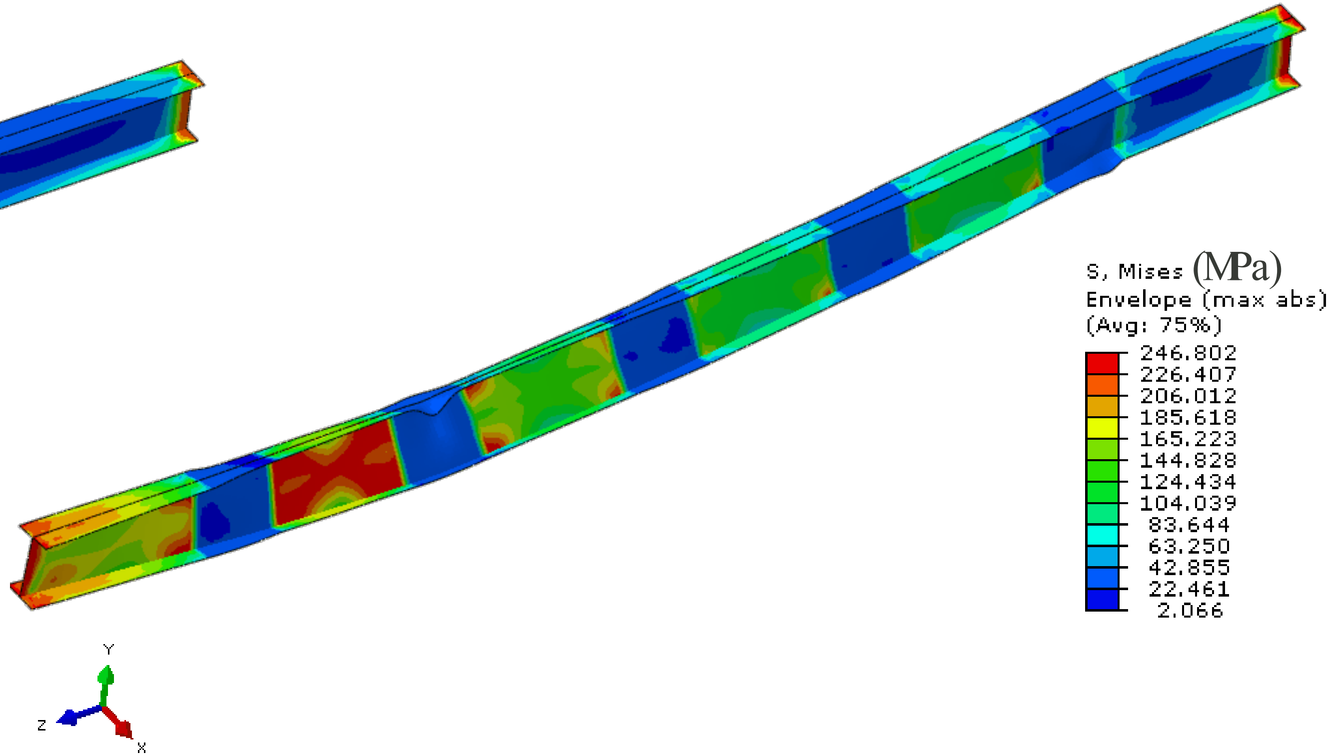
# Case 4W10x22 Beam

- Deformed shape and stress contours




Stress distribution close to beam failure temperature with two 0.75 m PFP loss zones




Stress distribution close to beam failure temperature with five 0.3 m PFP loss zones

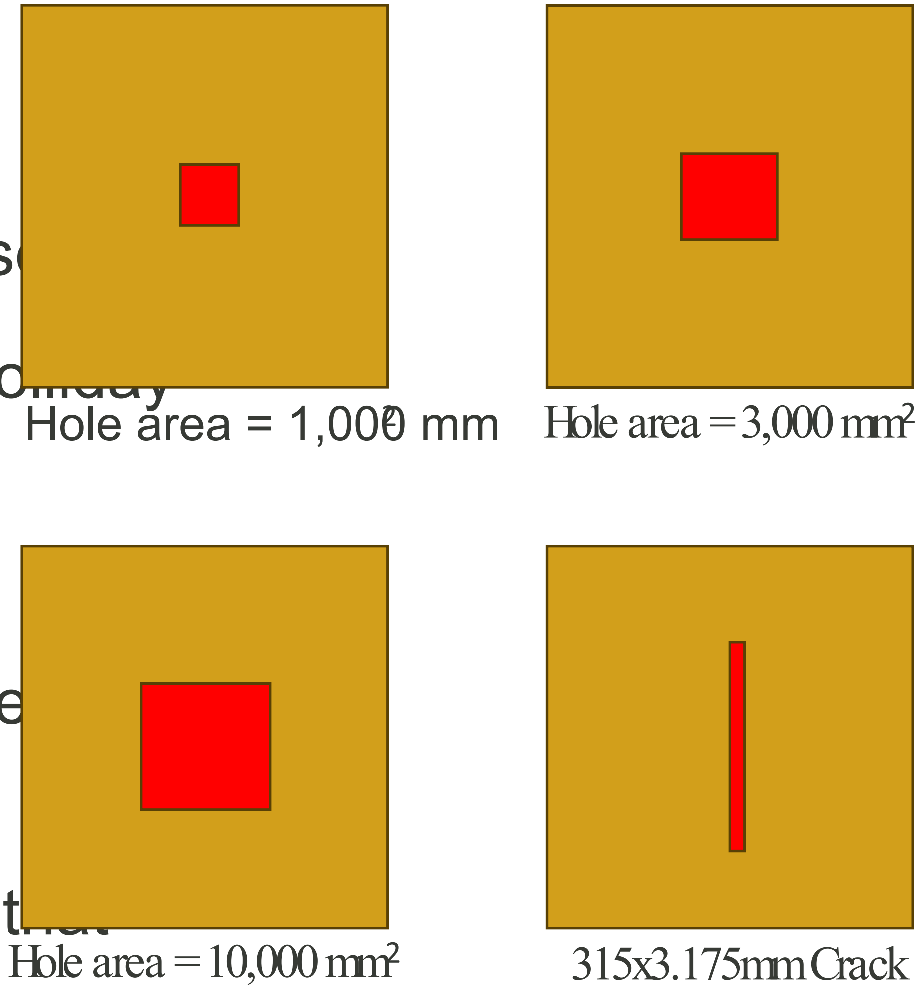
# Richard Holliday (PPG)

# Case 5

## PFP Damage

5) Steel Plate Heat Transfer Analyses

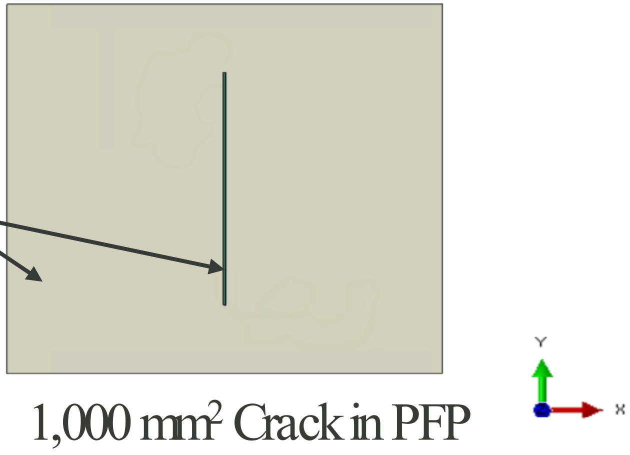
- Representing the experimental testing from a se[parate] research project – plates with varying holes in PFP subjected to fire tests conducted by Richard Holliday
- Plate dimensions:
  - 500x500x8mm
  - PFP thickness = 25mm
- PFP Damage: Assume 2 different damage types
  - Square hole of area = 1,000, 3,000 $mm^2$, and 10,000 $mm^2$
  - Crack with 1/8 in. thickness with a length that results in a total area of 1,000 $mm^2$



# Case 5: Square Plate Heat Transfer Analysis

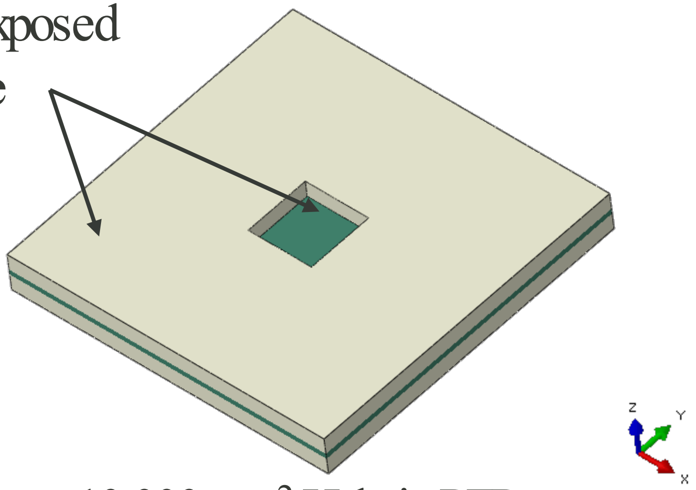
- Finite element (FE) transient heat transfer analysis performed for an insulated square steel plate using ABAQUS
- Heat-up of the exposed surface per UL1709 fire scenario (up to 1,100 C)
- Heat flux due to fire applied on the top exposed surfaces
- To capture the experimental boundary conditions, all other unexposed surfaces have adiabatic boundary

Surfaces exposed to fire




1,000 mm$^2$ Crack in PFP

Surfaces exposed to fire




10,000 mm$^2$ Hole in PFP

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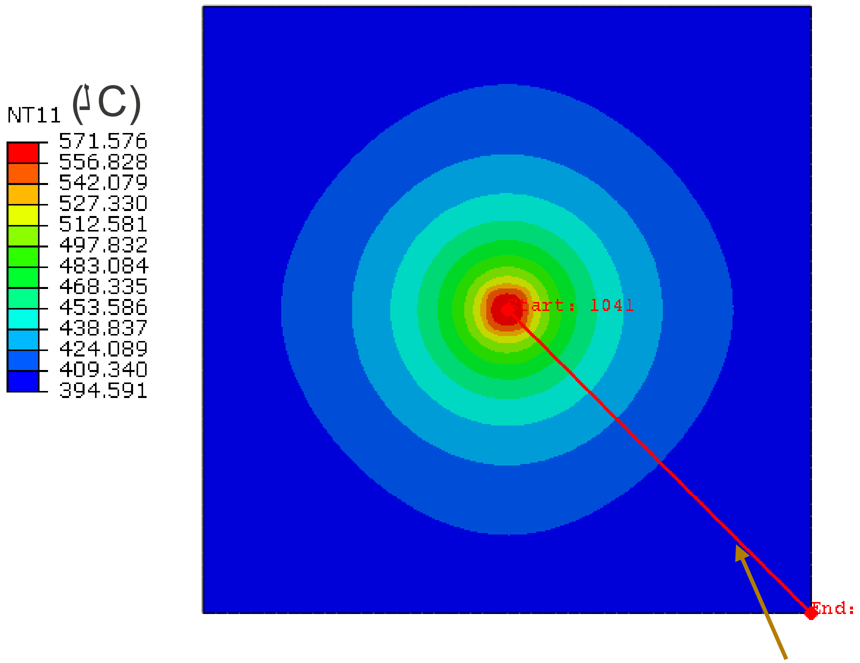
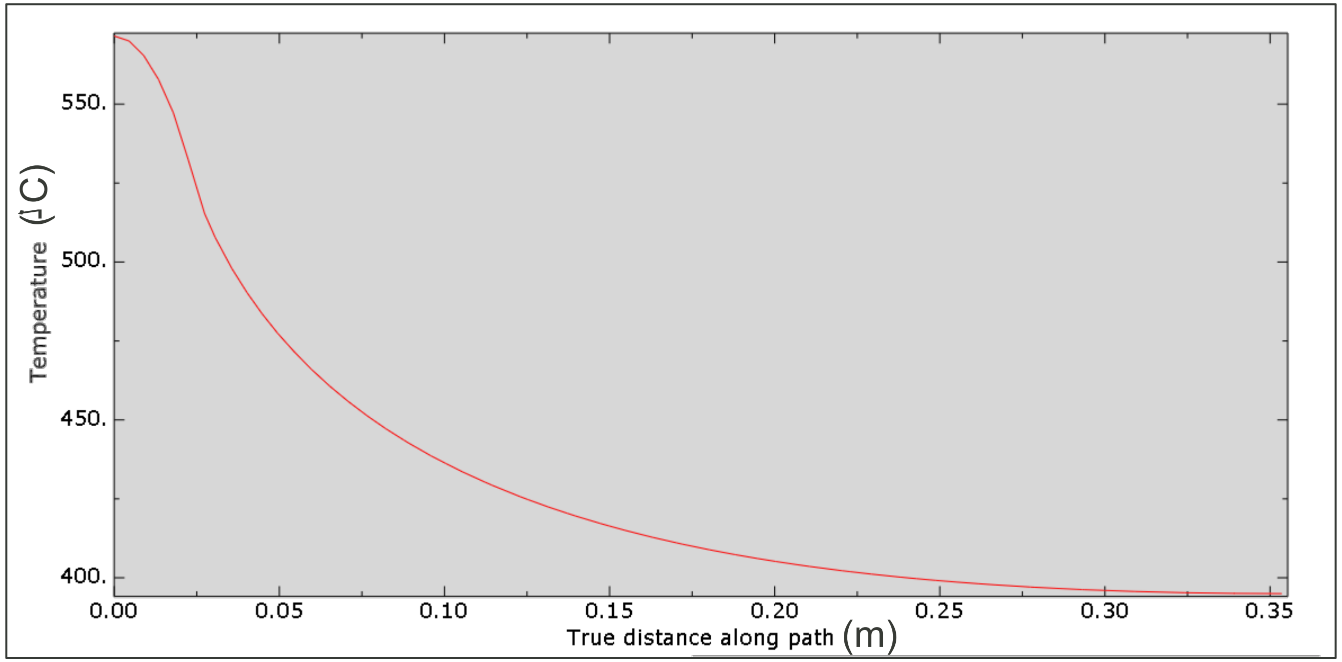
# Case 5: Square Plate

- We performed heat transfer analysis replicating the -experimental set

| Defect Geometry | Temperature (°C) after 2 hour at | |
|---|---|---|
| | Plate Center | Plate Corner |
| Hole: 1,000 mm$^2$ | 572 | 395 |
| Hole: 3,000 mm$^2$ | 749 | 438 |
| Hole: 10,000 mm$^2$ | 946 | 535 |
| Crack: 1,000 mm$^2$ | 560 | 425 |

# Case 5: Square Plate Heat Transfer Analysis




Temperature plotted along this line

Temperature contours at 2 hr. (1,000 $m^2$ square hole)

Temperature variation from the center to the plate (1,000 $m^2$ square hole)

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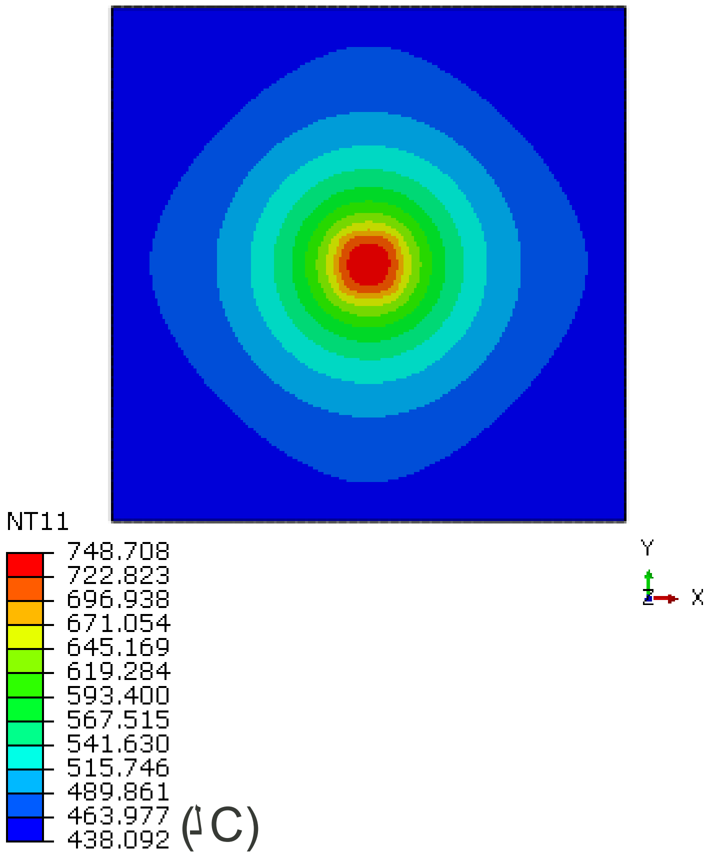
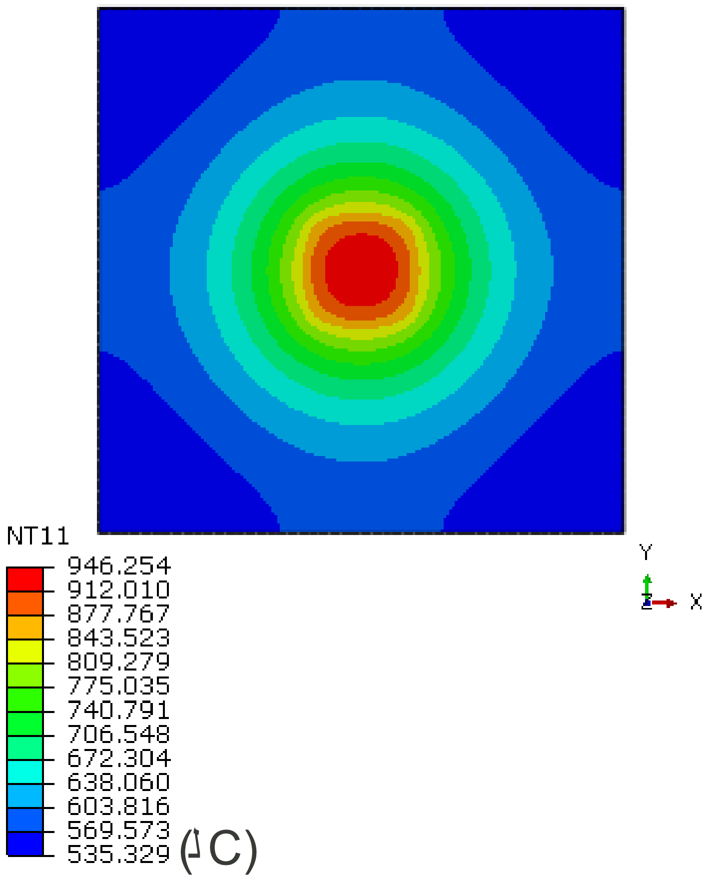
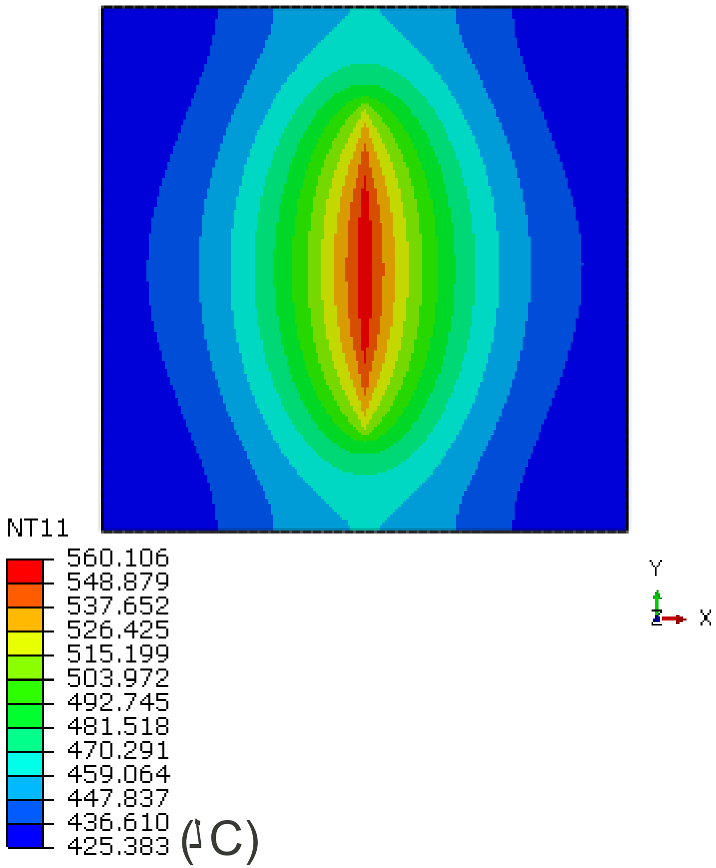
# Case 5 Square Plate Heat Transfer Analysis




Temperature contours at 2 hr.
(3,000 mm$^2$ square hole)




Temperature contours at 2 hr.
(10,000 mm$^2$ square hole)




Temperature contours at 2 hr.
(1,000 mm$^2$ crack)

# Case 6 and Case 7

## Aging PFP

6) W10x49 column

7) Plate Girder (48 in. deep)

- Effects of aging PFP on fire protection performance

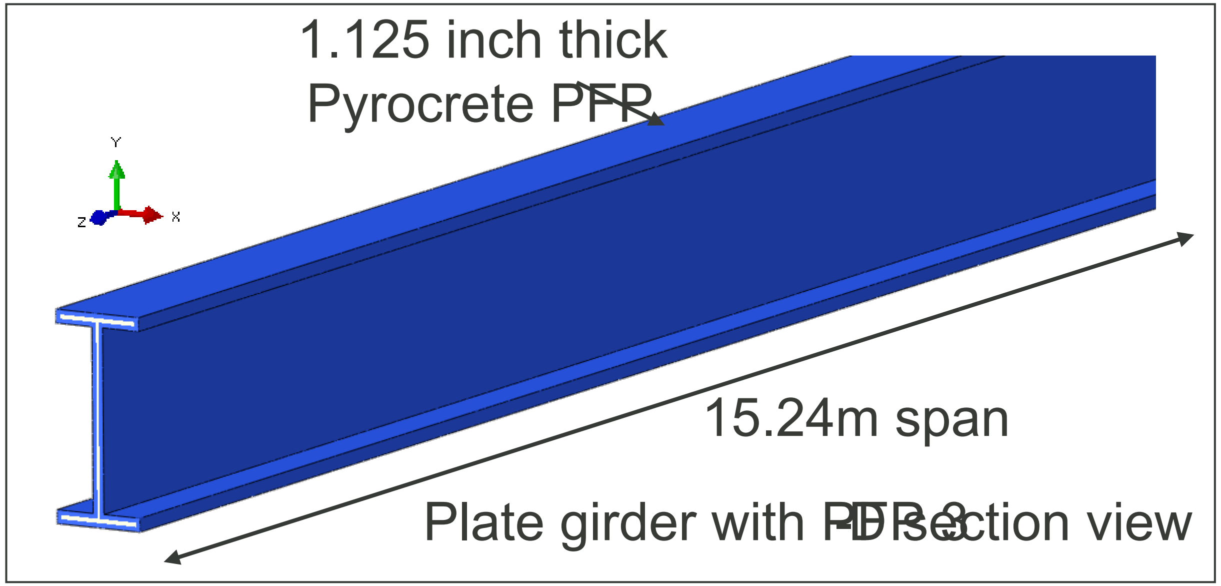
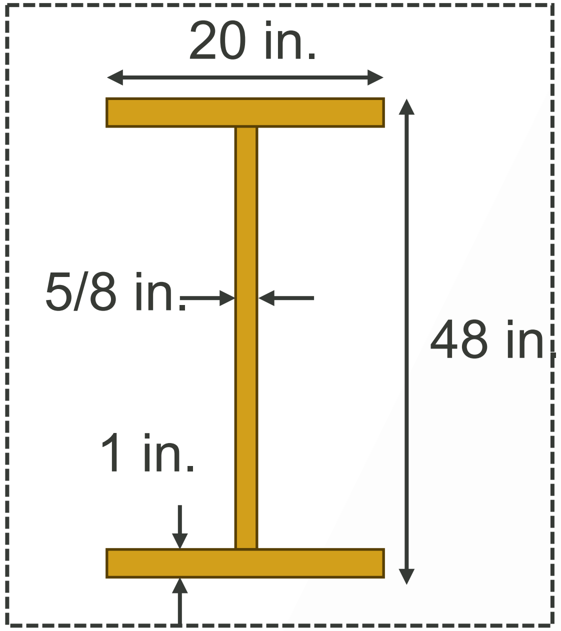
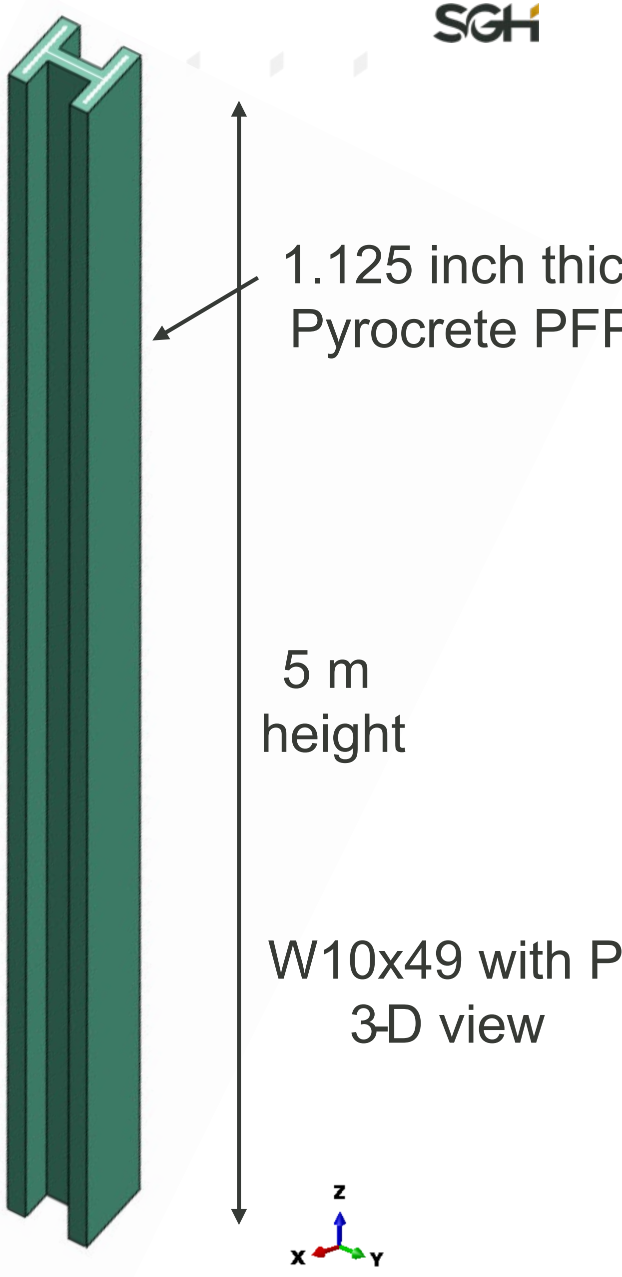



Plate girder dimensions

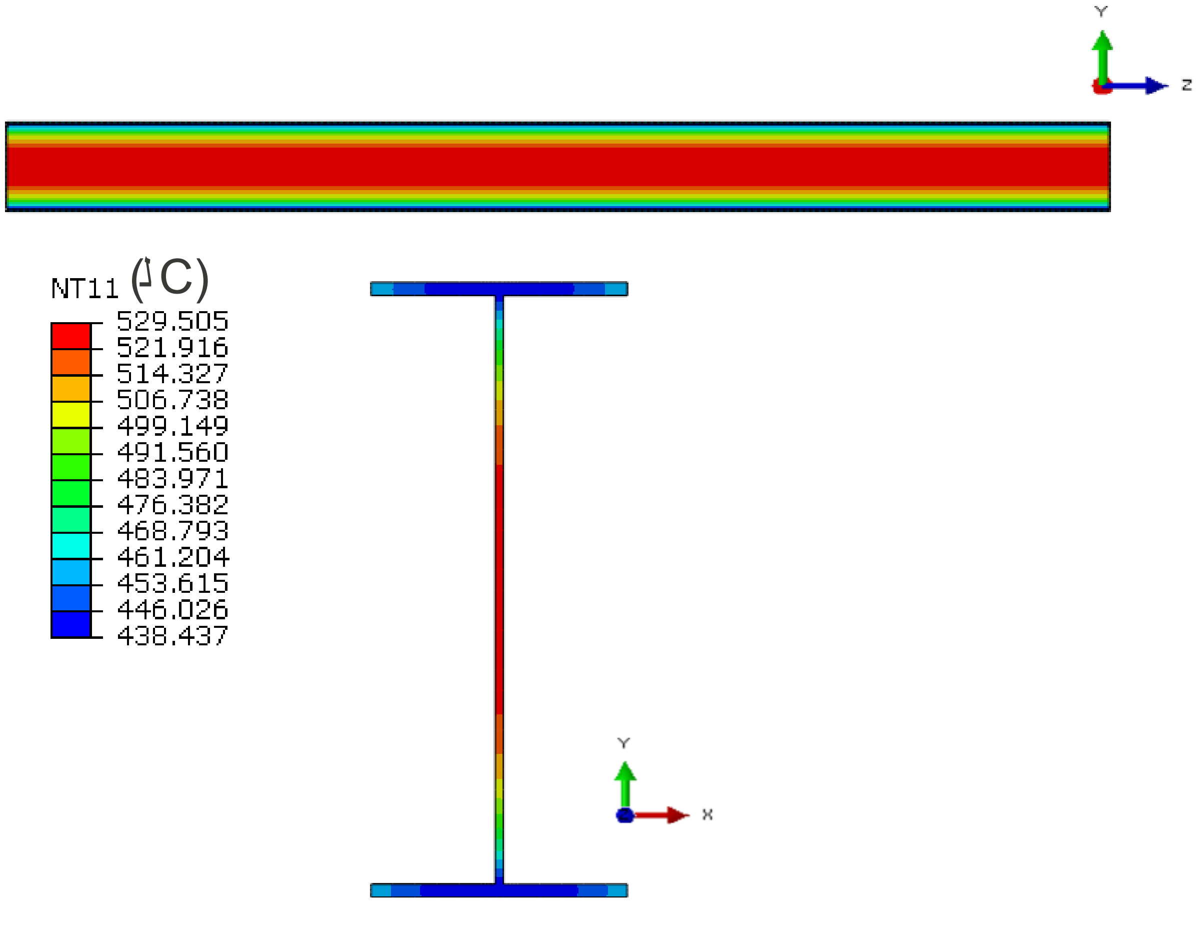


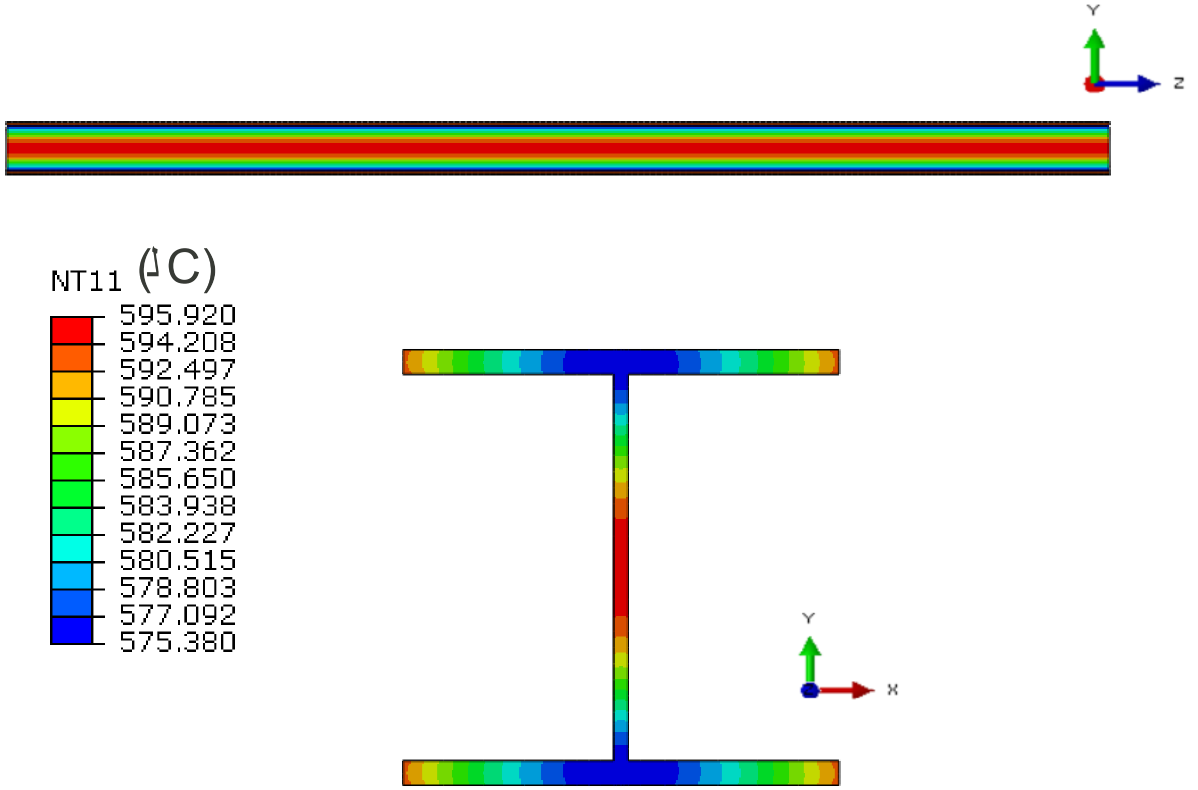
## Case 6 and Case 7 - Aging PFP

- Finite element (FE) transient heat transfer ana performed for a protected W10x49 column and girder using ABAQUS
- PFP thickness of 1.125 in.
- Heat-up of the exposed surface per UL1709 fire (up to 1,100°C)
- 25% increase in the conductivity and 25% dec specific heat to capture aging of the PFP

# Case 7 and Case 8
# Aging PFP Heat Transfer Analysis




Temperature contours at 2 hr. in the plate girder




Temperature contours at 2 hr. in a W10x49

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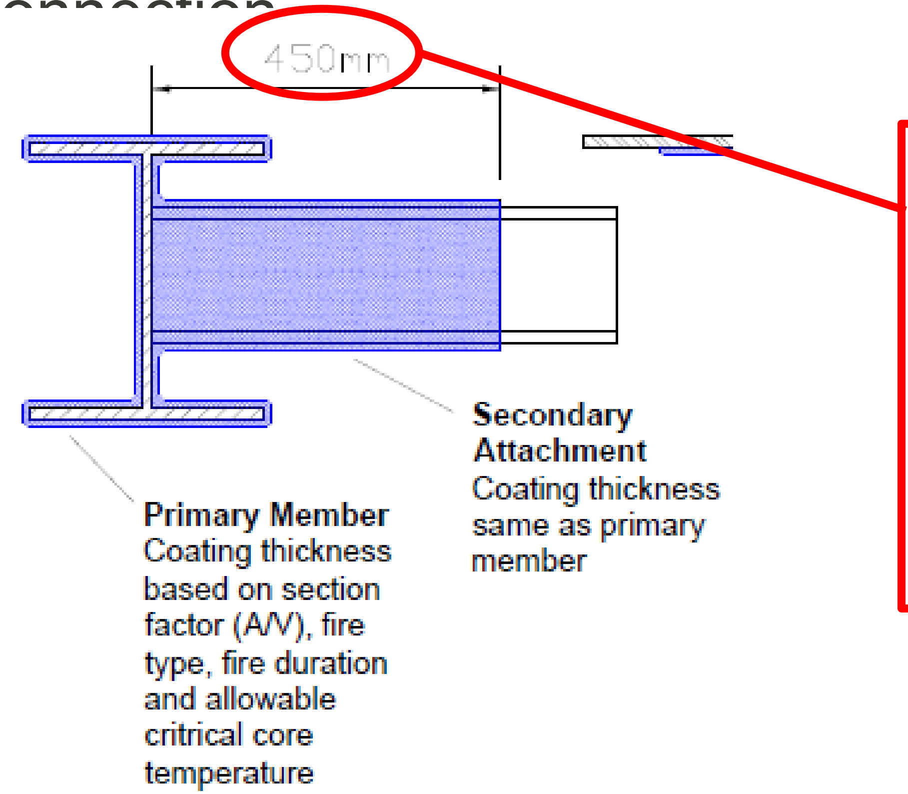
## Case 8

Coatback PFP

8) Beam to column shear connection

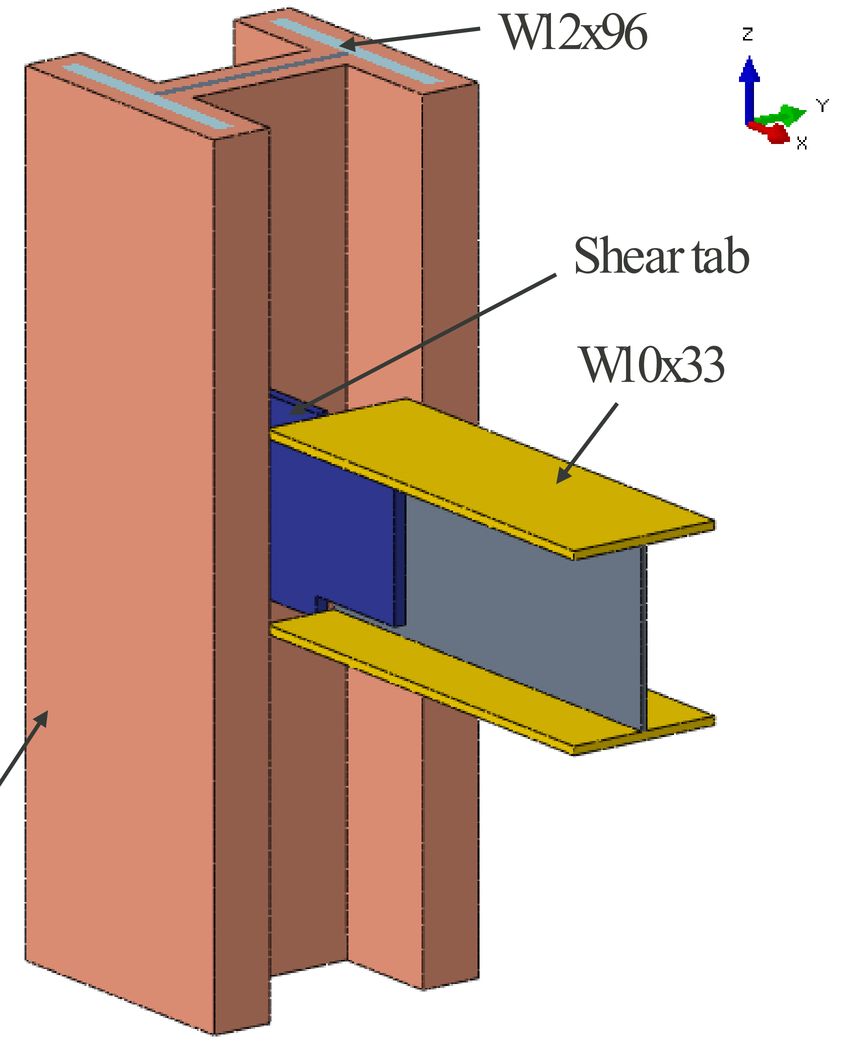
- Shear tab is 16 mm thick and the connection area is just over 3,000 mm$^2$
- No coatback PFP applied




Coatback length from surface of the protected member if the cross-sectional area of the connected element is more than 3,000 mm$^2$ (FABIG TN-13)

# Case 8 – Connection

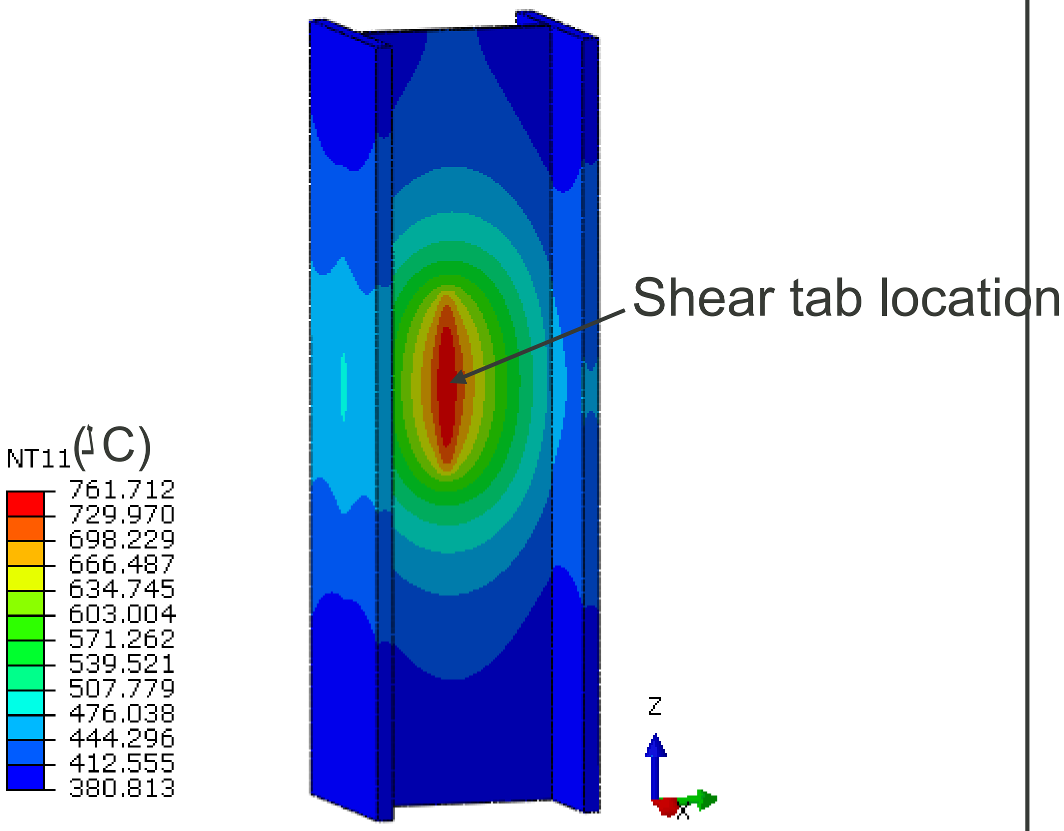
- Transient heat transfer analysis performed for a beam-column connection using ABAQUS
- PFP thickness of 1.125 in.
- Heat transfer analysis for two cases:
  - Beam and shear tab are unprotected
  - Connection is partially protected, and the beam is unprotected. Cutback PFP on the shear tab as per FAB-13 TN
- Heat-up of the exposed surface per UL1709 fire scenario (up to 1,100



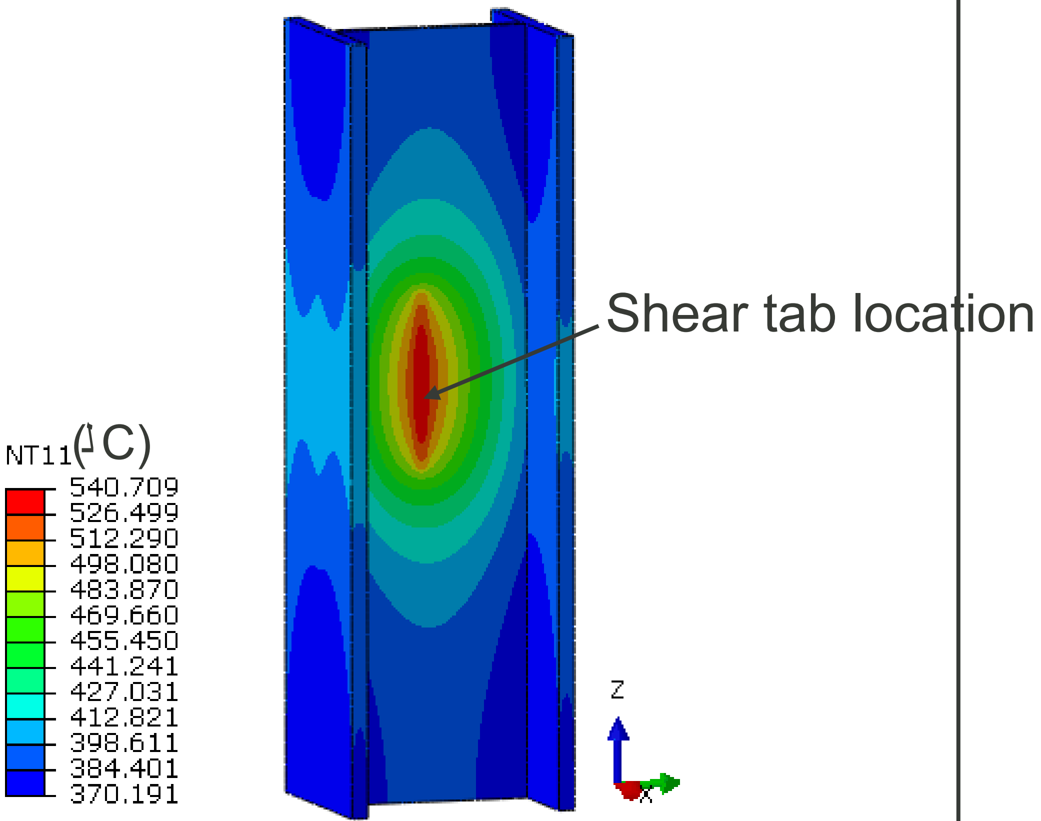

Beam-column connection with column PFP 3-D view

# Case 8 Connection Heat Transfer Analysis

Without coatback




With 6.3 in. coatback



## Conclusions

- Even a relatively smaller width of damage in the PFP at the tip of the column flange
width) can lead to significant reduction in the load capacities during fire.

- 0.3 m of PFP damage across the entire cross section can have severe implications
of the beam/column during fire.

# Conclusions

- The heat transfer in an element with a localized unprotected area is highly depende unprotected area (square hole vs. crack)

- Increasing the conductivity and decreasing the specific heat of the PFP material by aging of the PFP
  - Column section (W10x49) does not meet the UL1709 temp. criteria
  - Plate girder section meets the UL1709 temp. criteria

- The 3,000 $mm^2$ connection area doesn’t work for smaller members

## Large Comprehensive Study Design

- The large comprehensive study (a potential JIP) will focus on the development of th amount/degree of additional heat input into the protected elements/structures while resistance performance of the protected element/structure, either quantitatively or q
- Following slides present
  - Potential key parameters and case studies design
  - Recommended methodology
  - Expected outputs
  - Applications of the large study

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# Large Comprehensive Study Design

# Potential Key Parameters

| Heat Bridge Area | |
|---|---|
| Location and extent in the cross-section | Flange of the section (5% of the flange width at the tip to entire flange width), web of the section (>30% height of the web), entire cross-section |
| Location along the length of the element | At the center of the span, at the end of the span, at the location of concentrated loads |
| Size of the heat bridge area | 1,000 $mm^2$, 3,000 $mm^2$, 5,000 $mm^2$, 10,000 $mm^2$ |
| Geometry of the heat bridge area | Square shape, rectangular shape (2x1, 3x1), crack-like shape |

| Type of PFP Material | Thickness of PFP | PFP Application | Damage to PFP | Aging PFP |
|---|---|---|---|---|
| Pyrocrete | 1 1/8 in thick (2 hour rated),<br><br>11/16 in. (1 rated) | Three-sided and four-sided | Thickness reduction ranging from 30% to 100% including mesh damage | Thermal property degradation ranging from 30% to 75% including mesh damage |
| Intumescent coating | 161 mils (1 hour rated),<br><br>308 mils (2 hour rated) | Three-sided and four-sided | Thickness reduction ranging from 10% to 100% | Thickness reduction ranging from 10% to 100% |

# Large Comprehensive Study Design – Potential Key Parameters

| Structural Elements and Structure Configurations | Element Types | Type of Reactions | Typical Utilization Ratios under Operating Load Conditions |
|---|---|---|---|
| Oil and gas (onshore and offshore) | Beams, columns, bracing, moment connections, shear connections, smaller attachments such as pipes, cable trays, etc. to the structural elements | Flexure and shear;<br><br>Axial and shear;<br><br>Axial, shear and flexure;<br><br>Axial only | Ranging from 0.4 to 0.9 |

| Steel Sections | |
|---|---|
| Shape of the sections for both the protected and unprotected members | Wide flange and narrow flange sections, hollow sections, angle and channel sections |
| Depth of the section | Shallow (6 in.) to deep (60 in.) |
| Length of the section | L/D ranging from 6 to 24 |

# Large Comprehensive Study Design – Potential Key Parameters

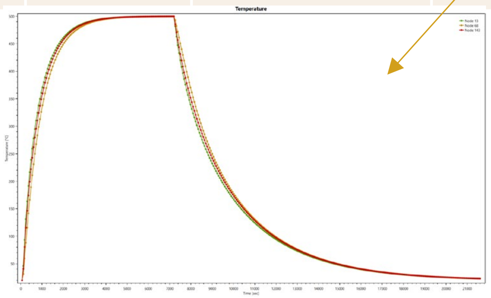
| Coatback PFP | |
|---|---|
| Length of coatback PFP | 450 mm (FABIG TN-13),<br>12 mm to 400 mm, 500 mm to X |
| Cross section area of the connected unprotected element | 1,000 $mm^2$, 3,000 $mm^2$,<br>5,000 $mm^2$, 10,000$mm^2$ |
| Spacing and distribution of the connected unprotected element | Closely spaced and sparsely spaced,<br>Clustered within 0.75 m/1 m/1.5 m length |

| Fire Scenarios | |
|---|---|
| Hydrocarbon fire | Risk based pool and jet fire scenarios, including variable heat-up, cool-down and fire durations |

# Large Comprehensive Study Design – Case Studies

- Use grouping strategy to develop a sensitivity analysis matrix using individual para
  previous slides.
- For example,

| Case | Structural Elements | | | | Passive Fire Protection | | | | Steel Sections | | | Fire Scenario | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Application | Element | Loads | Utiliza-tion | PFP Material | Thickness of PFP | PFP Applica-tion | Damage to PFP | Shape | Depth | Length | Hydrocarbon fire | Fire Loading |
| 1 | Onshore structure | Beam (W10x22) | Shear and flexure | 0.7 | Pyrocrete | 1 1/8 in thick | Three-sided | 25% of thickness | Wide flange | 10 in | 17 ft | Pool fire | |



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## Large Comprehensive Study Design – Methodology

- We recommend using performance-based approach in the analysis
- The method of the analysis shall account for:
    - Time dependent heat spreading
    - Temperature gradient between various parts of the elements
    - Temperature dependent material properties of PFP and steel substrate
    - Potential failure modes in the structural elements/structures
- The analysis can be a transient thermal analysis followed by a structural analysis o structural analysis

## Large Comprehensive Study Design – Methodology

- Select few case studies derived from grouping the key parameters shall be fire test the hydrocarbon fire scenarios
  - The testing procedure can be developed as part of the study
  - Testing with/without structural loading
  - Record temperatures, any damage to PFP, strain and deflections at various p testing with loading)
- The first set of analysis of the case studies shall be calibrated with the test results b rest of the case studies

## Large Comprehensive Study Design – Outputs

- The results shall be categorized in terms of reduction in failure time and/or reductio capacities. The categories can be as follows:
  - low damage (insignificant reduction in failure time or load capacities),
  - medium damage (considerable reduction in failure time or load capacities), an
  - high damage (significant reduction in failure time or load capacities).
- These options can be presented in a matrix format or graphs suitable for potential e PFP applicators.

## Large Comprehensive Study Design – Applications

- The results of the large study can be used to develop preliminary design criteria an related to the allowable heat-bridging limits in terms of key parameters.
- The results can specifically be applied to develop
  - Acceptable damage criteria to use in the assessment of damage to PFP at exi
  - Generalized criteria to use in assessing the PFP at existing facilities
  - Modifications to current coatback application practices

## What's next?

This project is necessary for both the steel industry and the fireproofing industry.

If critical attachments are not protected resulting in excessive heat transfer into the primary or secondary steel, life safety could be at risk due to structural collapse during a fire event.

Or if attachments which not critical are protected, it leads to unnecessary or excessive costs, thereby making steel construction uncompetitive to concrete and wood construction.

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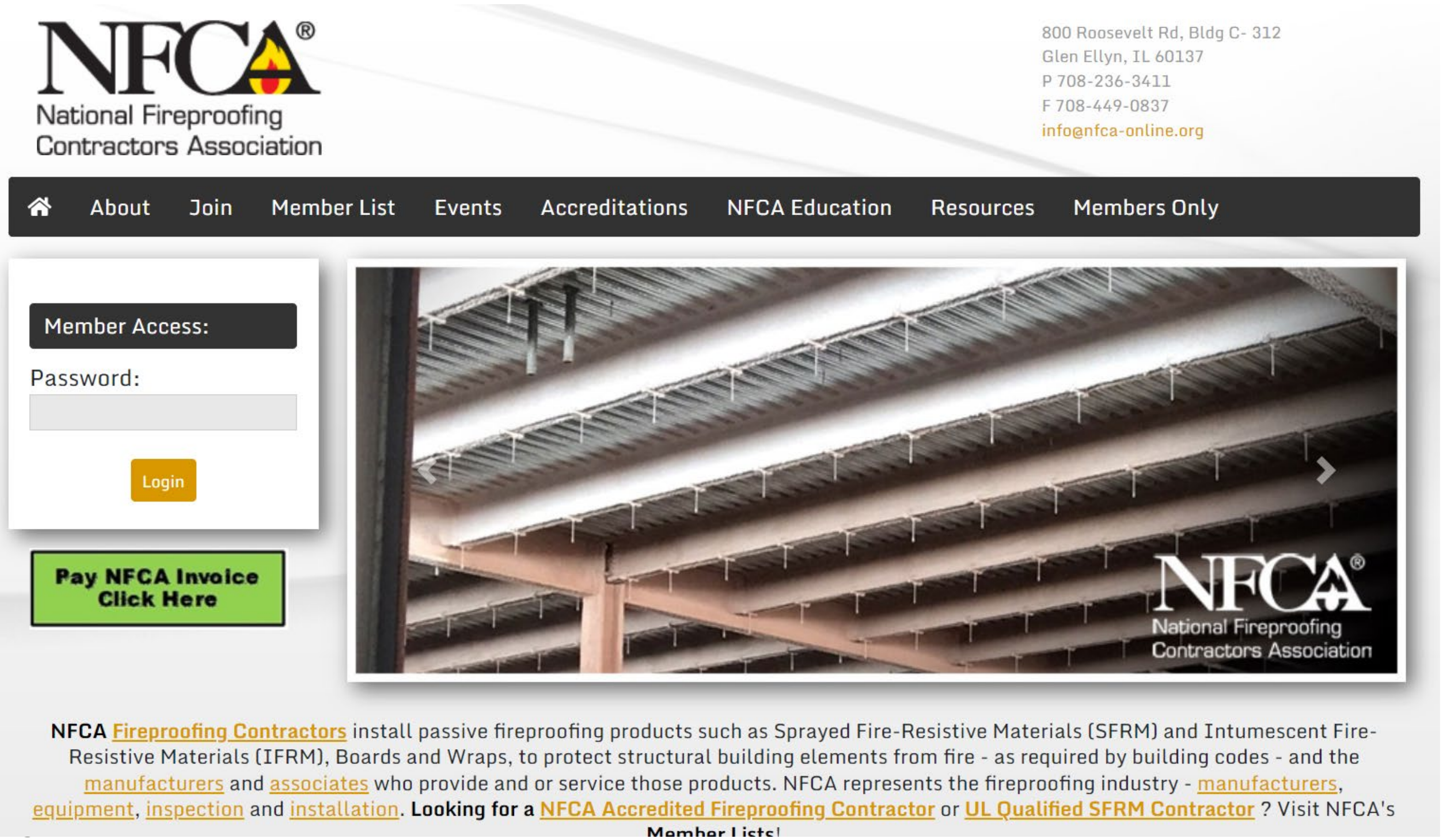

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# What's next?

NFCA®
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