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

Coupled Fire Dynamics and Thermal Response Analysis of WTC Towers and Bldg. 7

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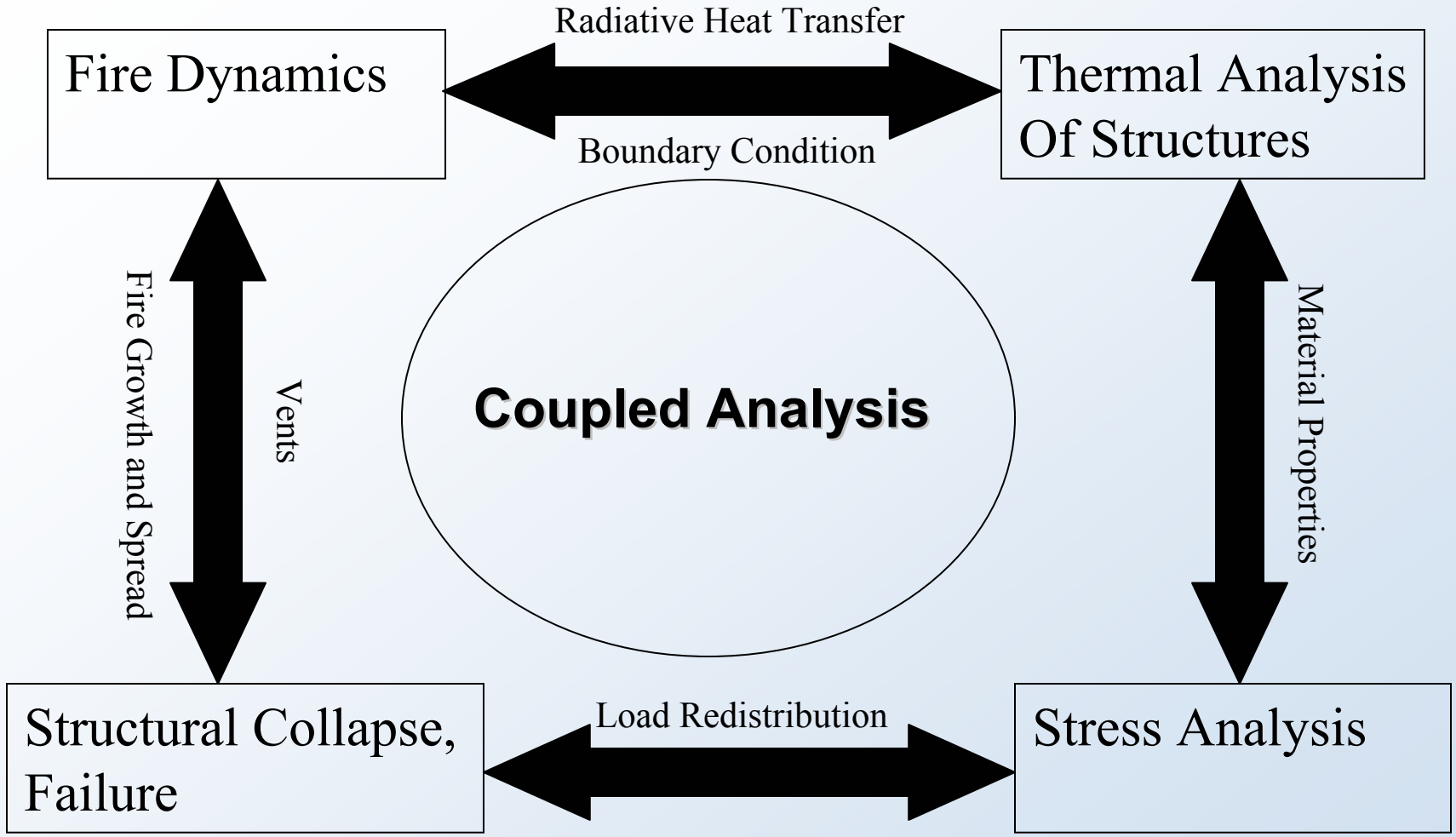
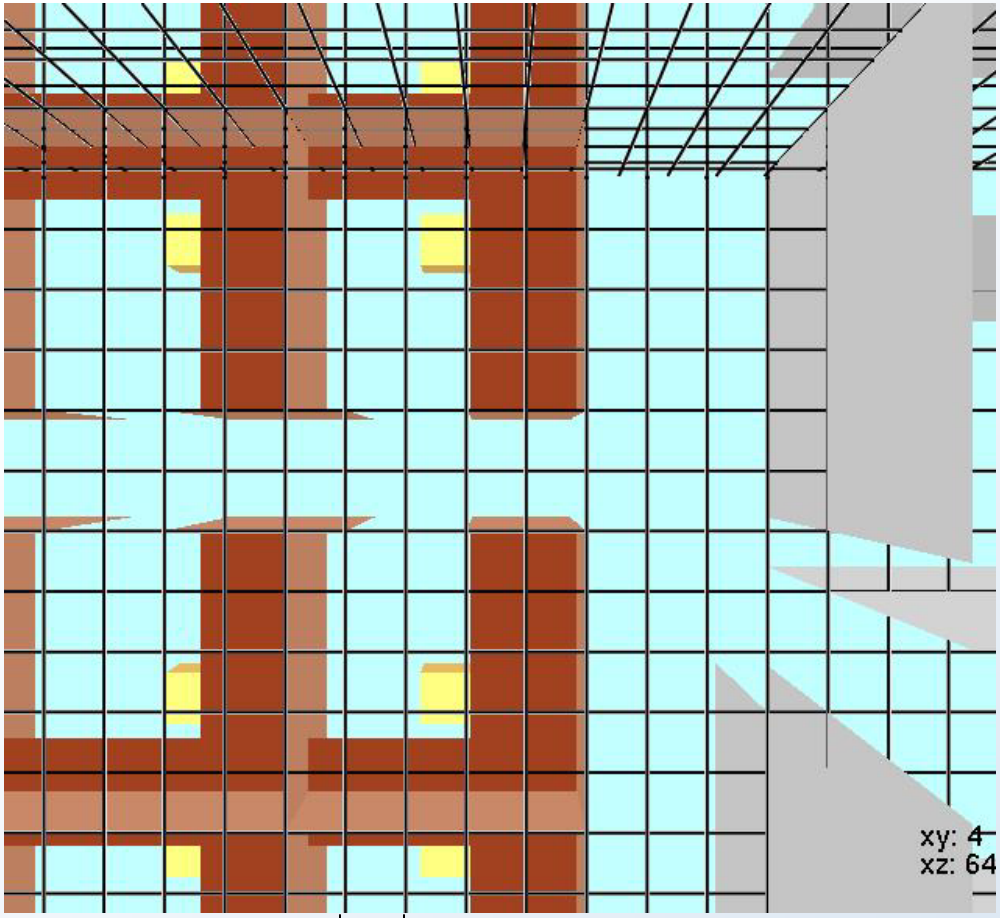
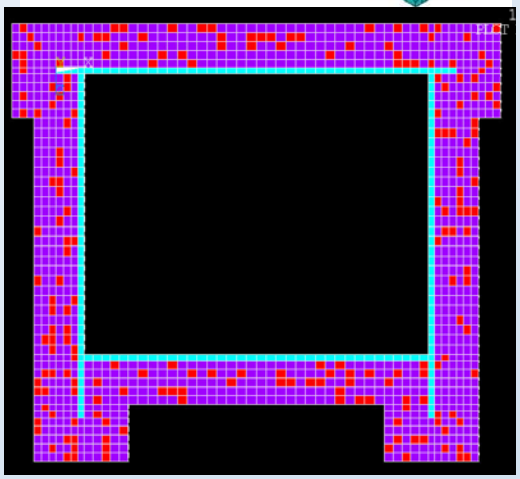
Objectives

- Develop an interface between the Fire Dynamics Simulator (FDS) and the thermal response of structural elements for predicting the structural performance of buildings.
- Reconstruct the time-evolving and spatially evolving temperature fields in the steel and concrete in World Trade Center buildings 1, 2, and 7.
- Evaluate the role of variability in fireproofing thickness and damage caused by aircraft on steel temperature.
- Estimate the sensitivity of model parameters.



Non-linear, Coupled Fire – Thermal –Structural Analysis





50 cm

Subgrid scale model for radiative heat transfer to structural elements

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Plane Layer Analysis: Two Layer Model

Grey Gas Assumption: Properties independent of frequency.

Radiative transport equation:

$$\boldsymbol{\Omega}\cdot\nabla \mathrm{I} = \kappa\left(\frac{\sigma \mathrm{T}^4}{\pi} - \mathrm{I}\right) \quad , \quad \text{integrated intensity is} \quad \mathrm{I}(\mathbf{r},\boldsymbol{\Omega}) = \int_0^\infty \mathrm{I}_\upsilon d\upsilon$$

Soot particulate is dominant absorber and emitter of radiation.
Spectral dependence of absorption coefficient is small.

Enclosures have Large Aspect Ratio.

Induces a vertically stratified distribution.

Hot layer that forms has spatial variations in temperature that vary much more rapidly in the vertical than in the horizontal direction.

Prasad & Baum, "*Coupled Fire Dynamics and Thermal Response of Complex Building Structures*," accepted for publication, 30th International Symposium on Combustion**, 2004.**

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Pre Impact Damage to Fireproofing

- Insulation was not applied evenly over the trusses.

- What happens to insulation over 30 + years of renovations?
- Effect of vibrations on insulation over an extended period?

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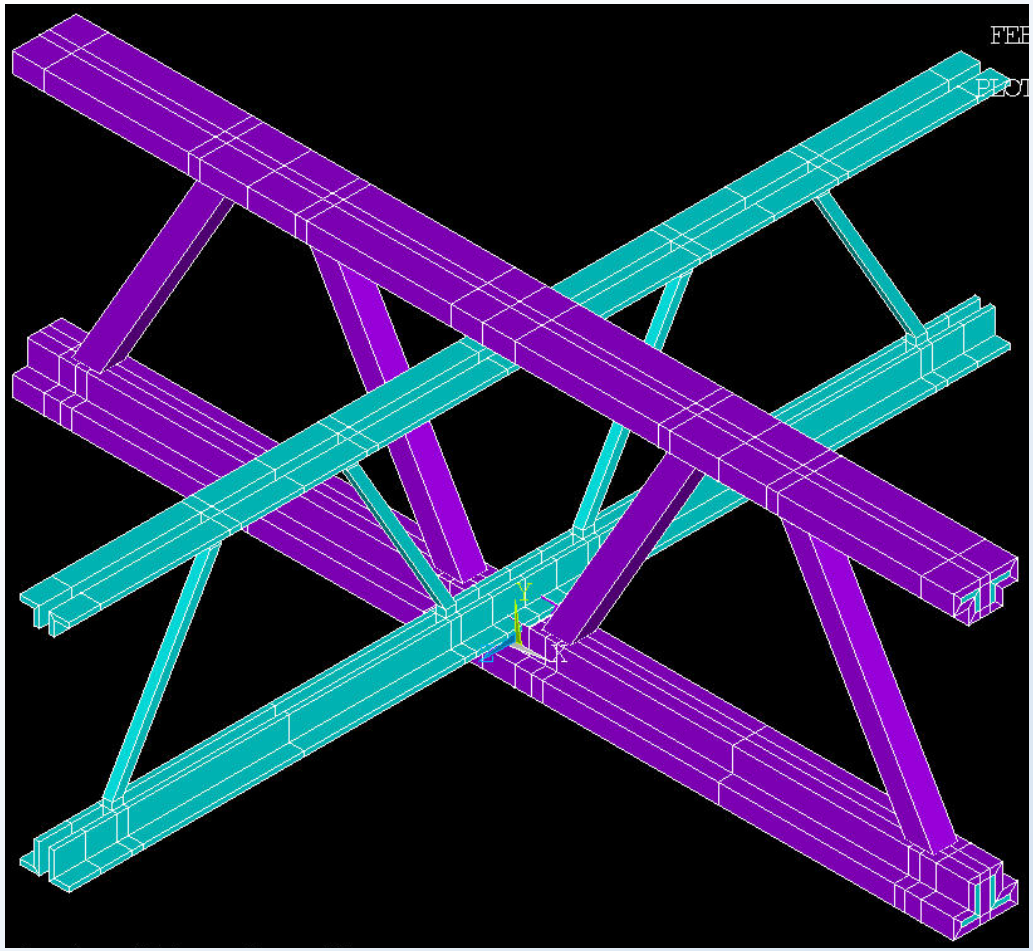
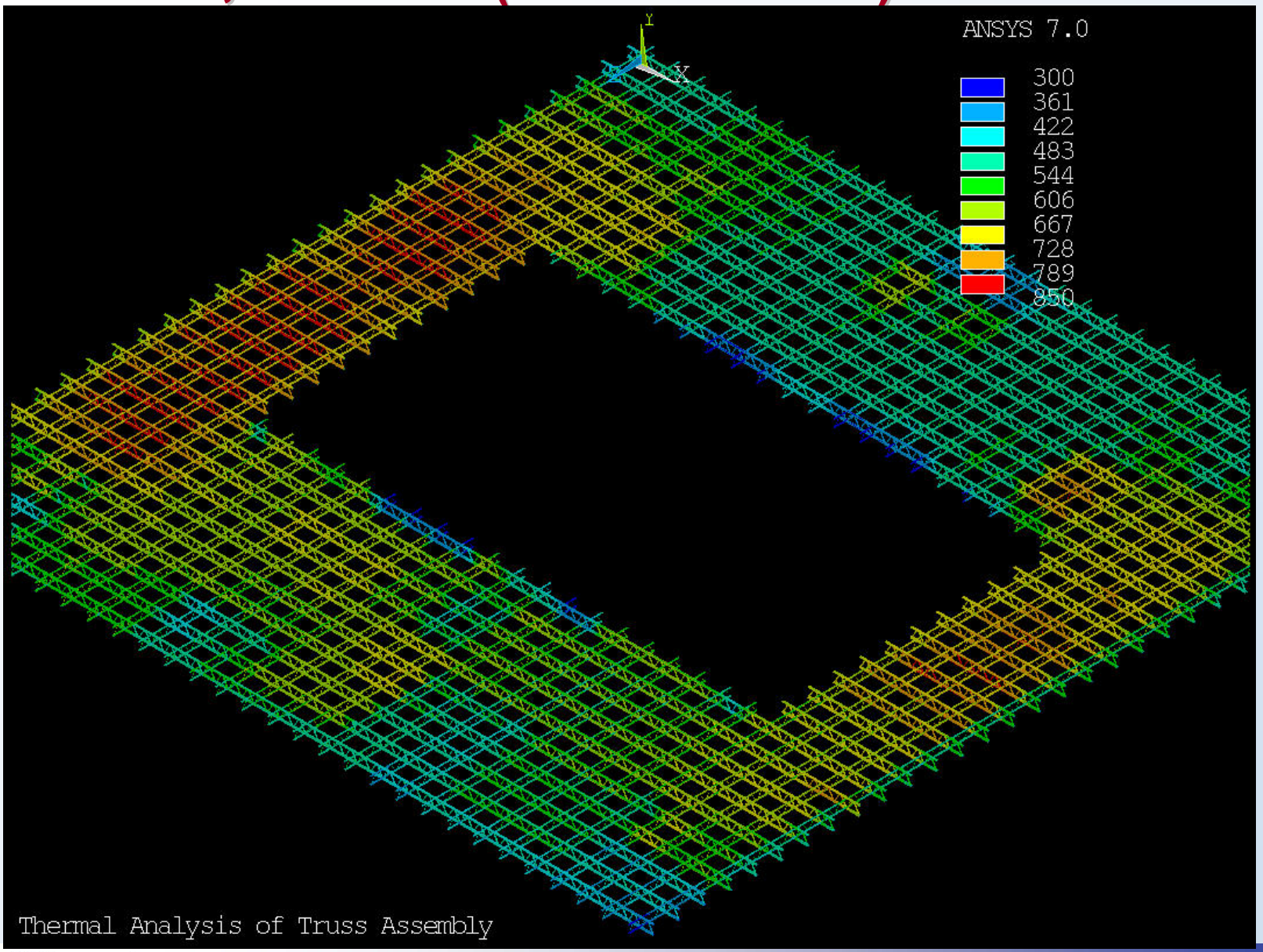
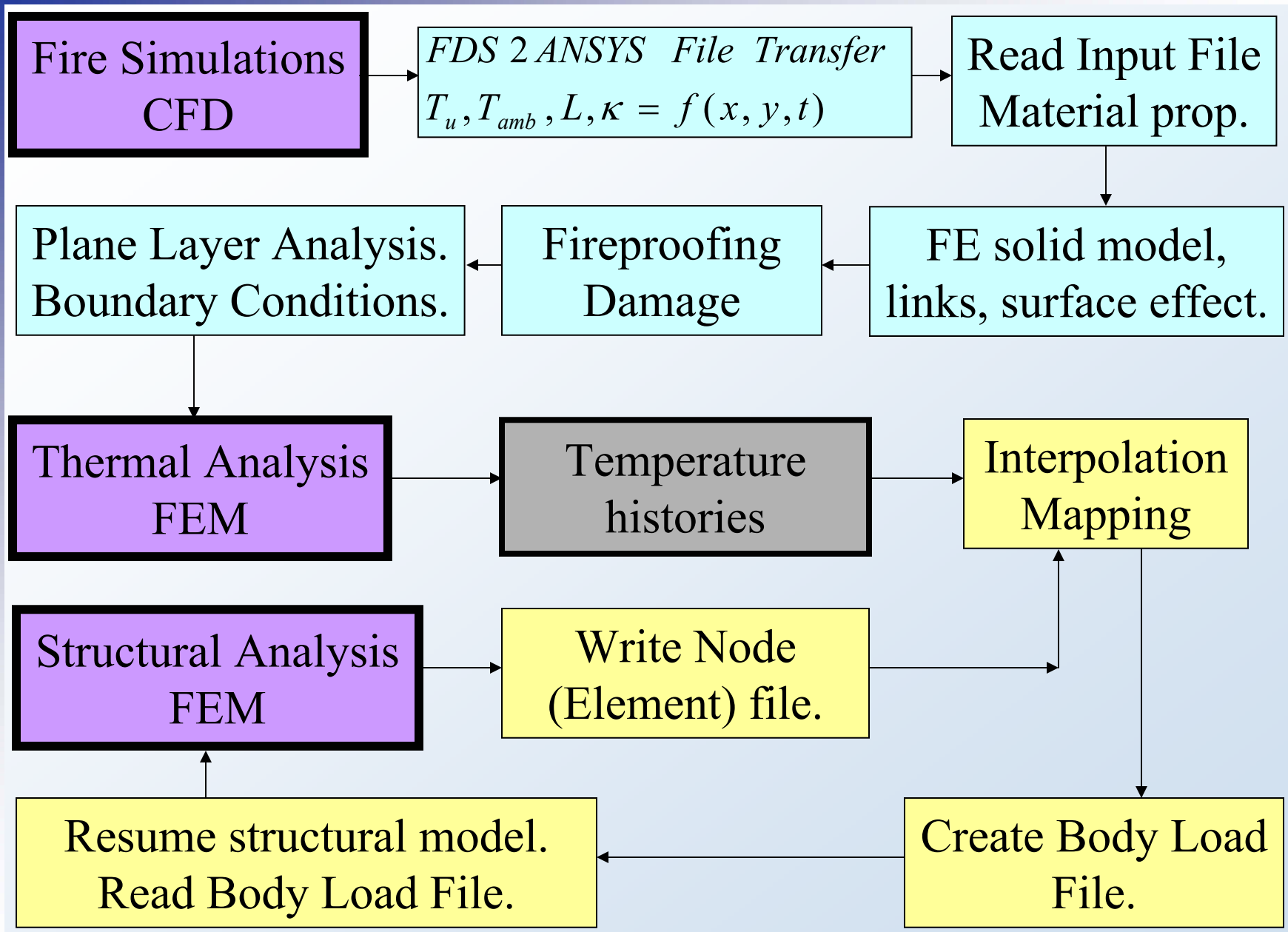
Finite Element Model of Steel Truss



- ANSYS 8.0, APDL
- SOLID70,
- SURF 152
- LINK133
- Re-radiation
- Convection
- Perfect Contact
- SLATEC Numerical Analysis Libraries
- Material Models
- Fireproofing

Thermal Analysis (K) of truss assembly Floor 96, Tower 1 (Time=2000 s)

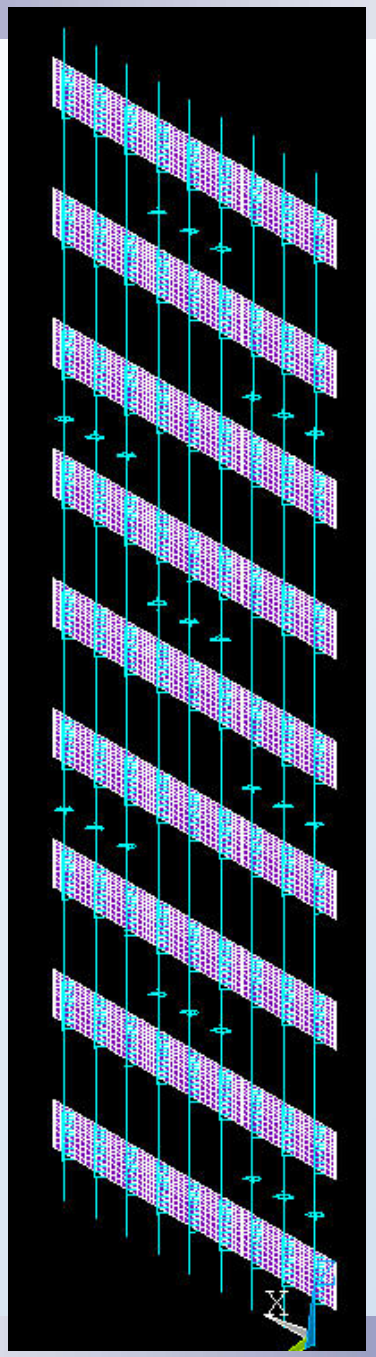


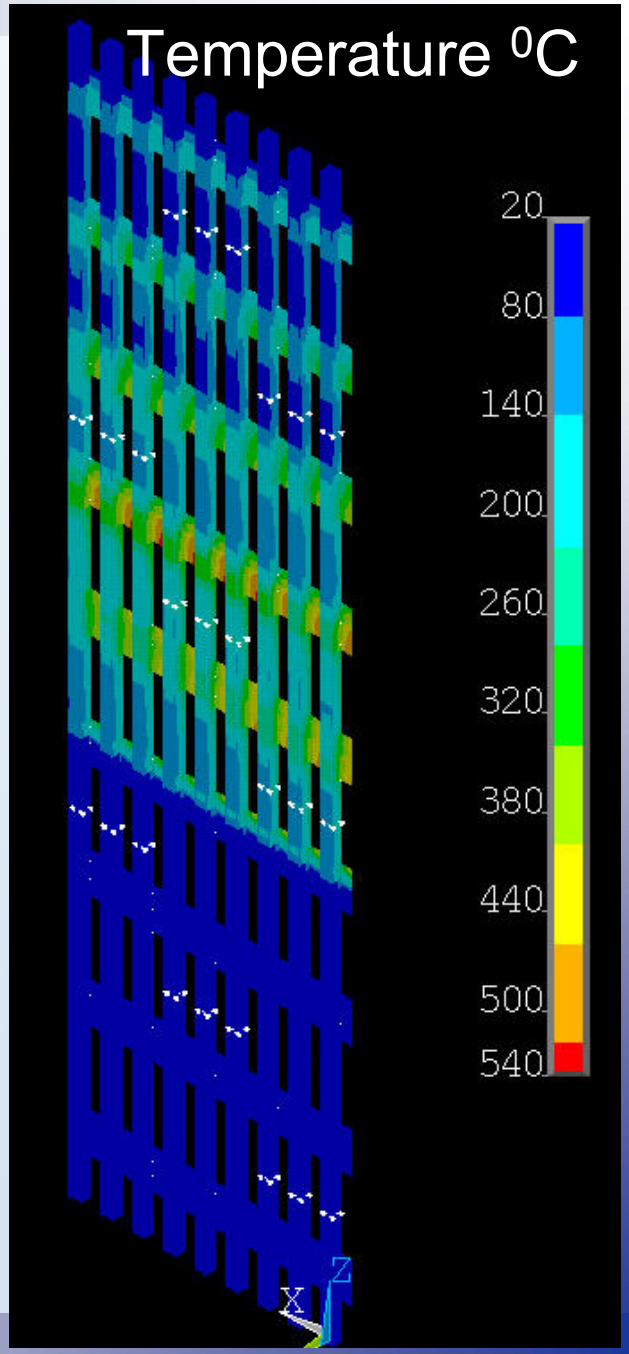


Fire – Thermal – Structural Interface

9 x 9 Wall Model

- Structural Model from Simpson, Gumpertz, & Heger, a NIST contractor: left
- Thermal Analysis & Mapping: right
- Floors 91-99.
- Columns 150-158
- Temperature in shell element.
- Temperature gradient in beam element.





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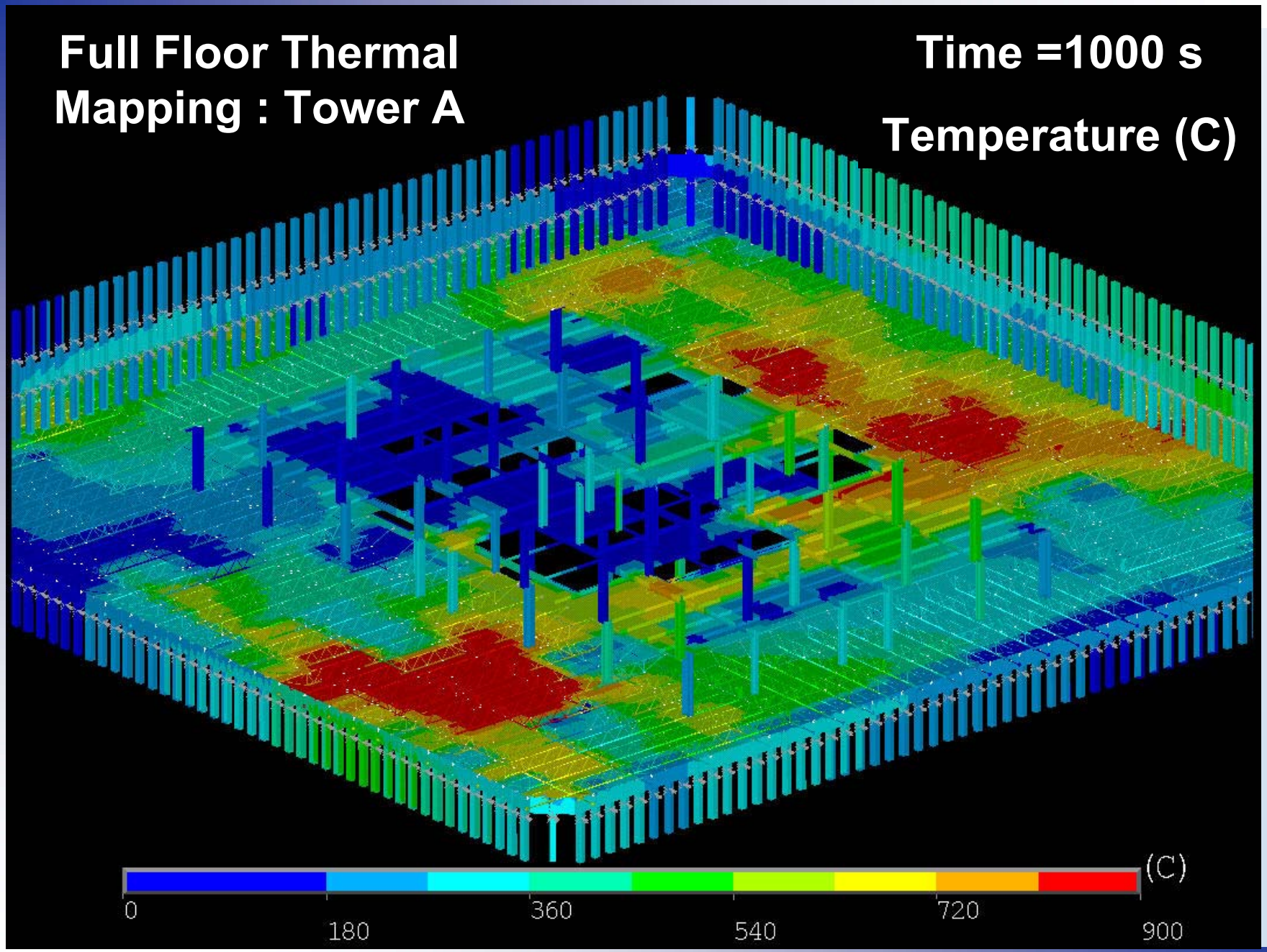
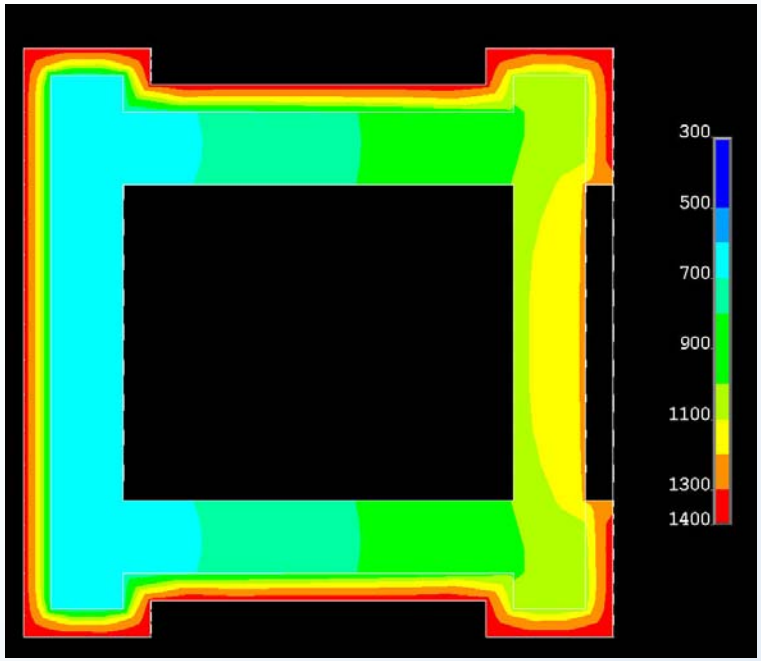
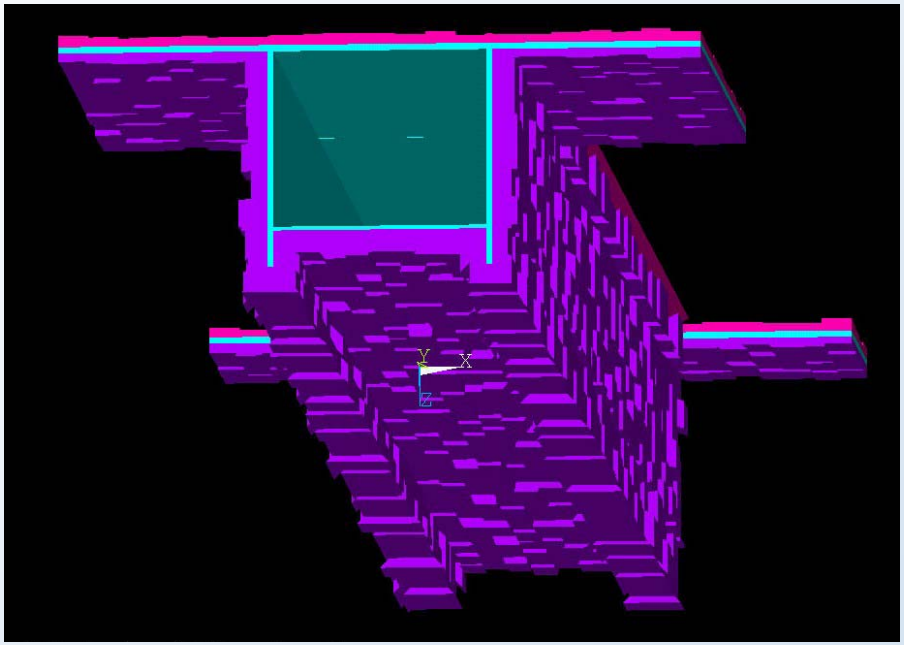
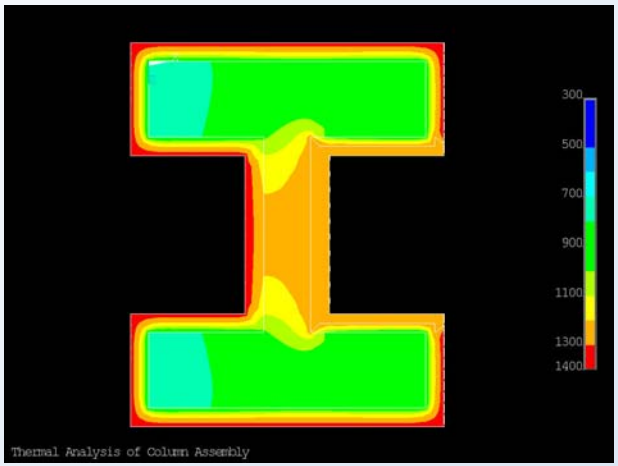

Full Floor Thermal Mapping : Tower A
Time =1000 s
Temperature (C)
0
180
360
540
720
900
(C)

Heavy Core Column

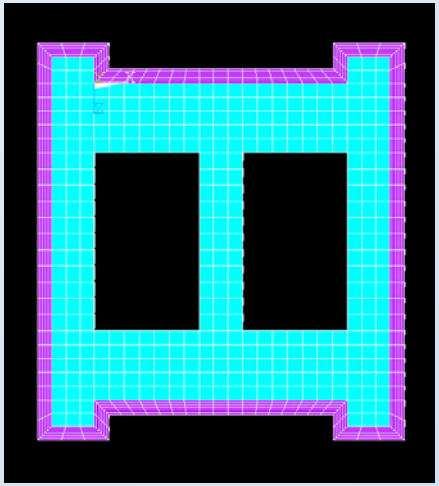


Perimeter Column





Wide Flange Columns



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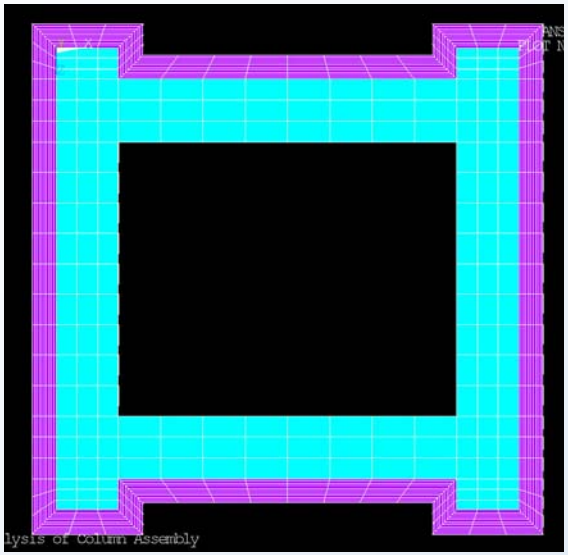
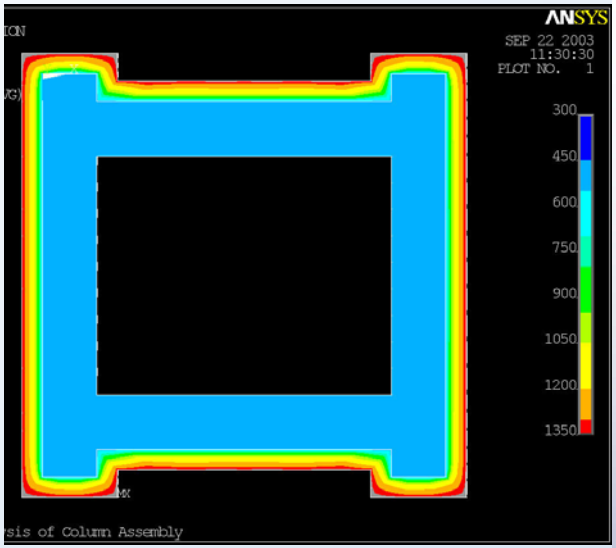
Core Column

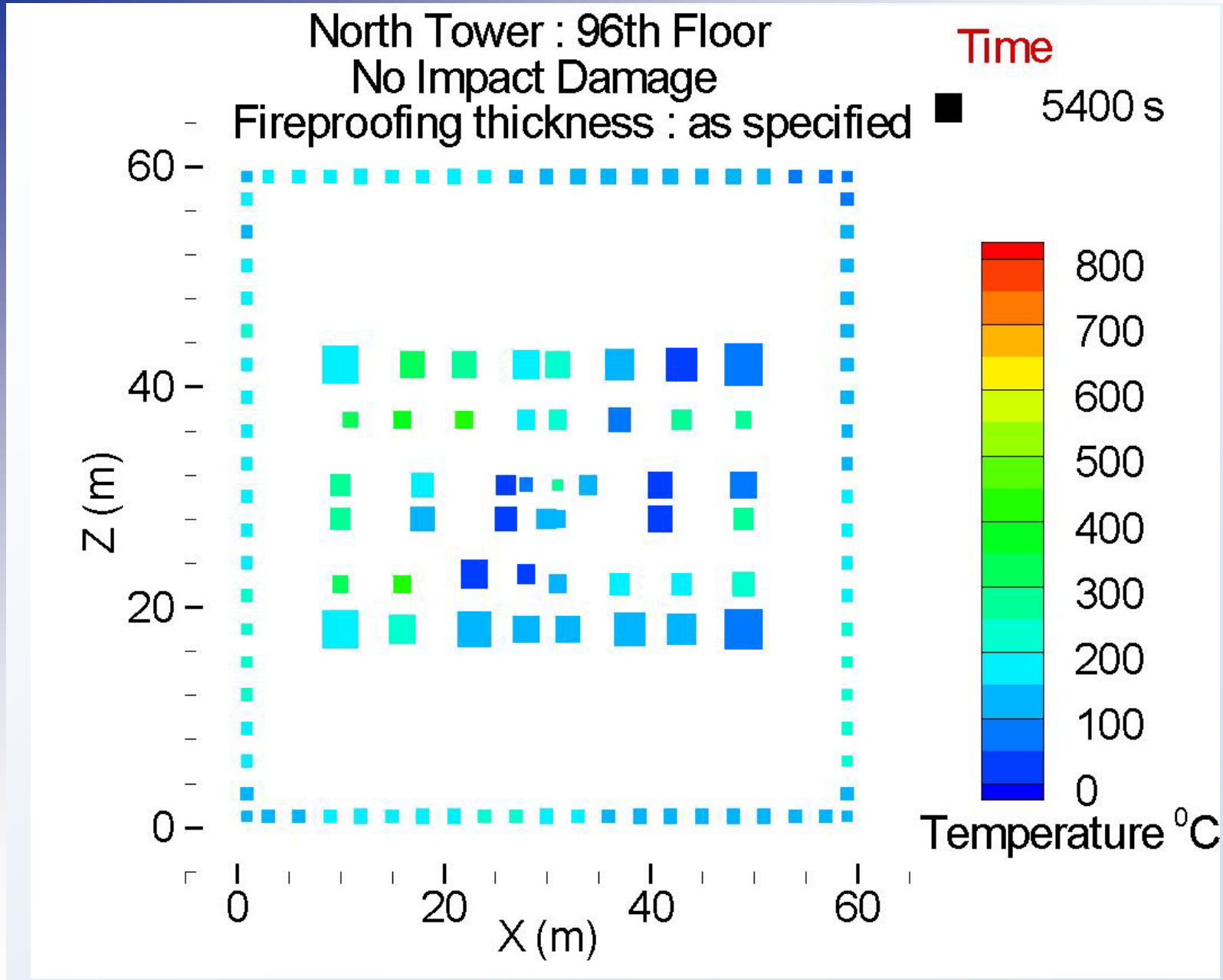
- Box Shape : Heavy
- 22” x 22” x 3”
- A36 Steel
- Insulation:

  Blaze-Shield 1 1/8”





GasTemperature, Critical Temperature							
	C	900/538	900/600	900/700	1100/538	1100/600	1100/700
	F	1653/1000	1653/1112	1653/1292	2012/1000	2012/1112	2012/1292
THICKNESS		**Time in hours**					
(INCHES/MM)							
0.0/0.0		0.34	0.41	0.58	0.15	0.22	0.26
0.5/12.7		5.7	7.1	10.2	3.8	4.72	6.4
1 1/8, 29.0		12.7	15.8	23.3	8.8	10.5	14.1
Damaged		6.3	7.9	11.6	4.8	5.9	8.0


North Tower : 96th Floor
No Impact Damage
Fireproofing thickness : as specified
Time
5400 s
800
700
600
500
400
300
200
100
0
Temperature °C
Z (m)
60
40
20
0
0
20
40
60
X (m)

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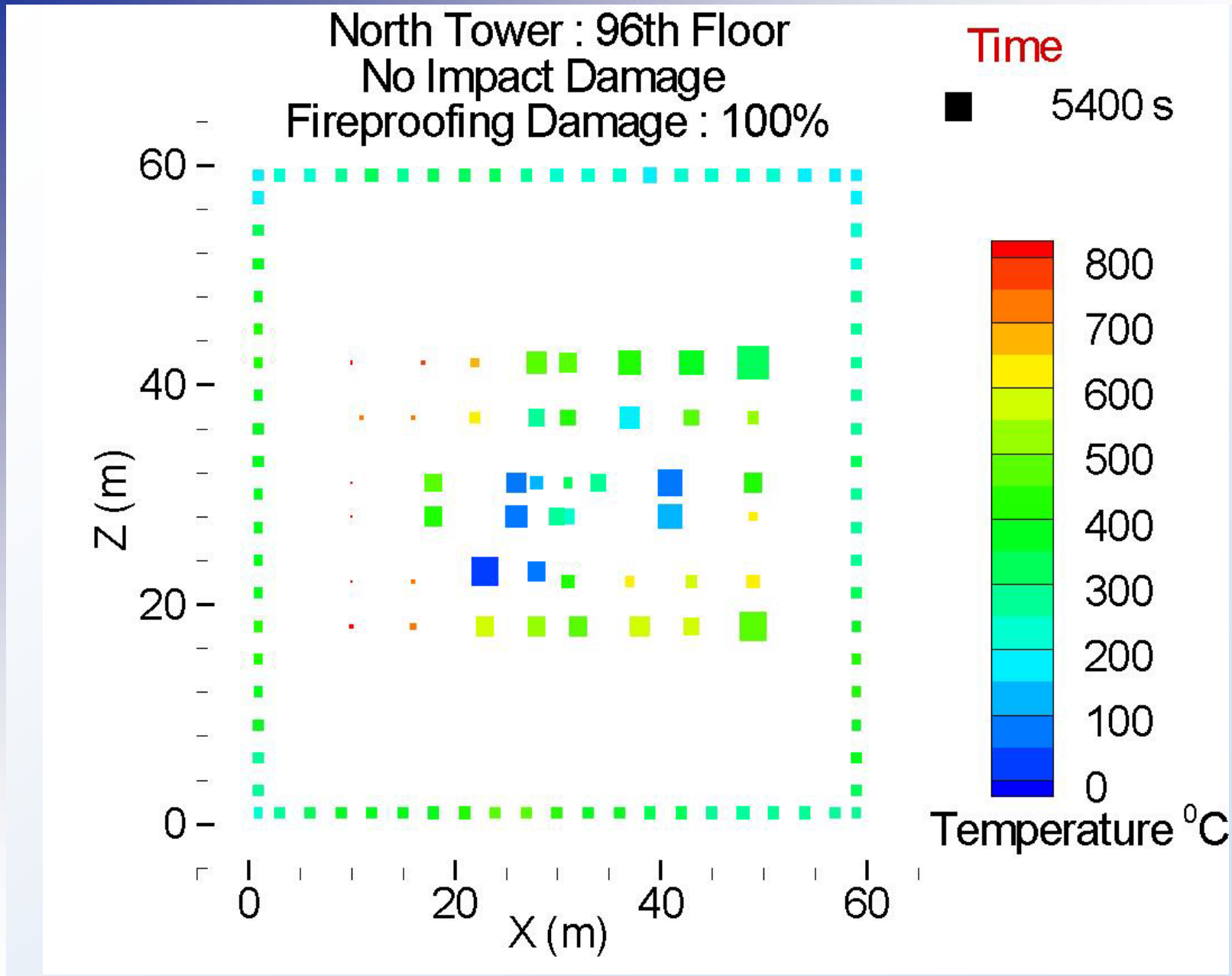
North Tower : 96th Floor
No Impact Damage
Fireproofing Damage : 100%
Time
5400 s
60
40
20
0
Z (m)
0
20
40
60
X (m)
800
700
600
500
400
300
200
100
0
Temperature °C

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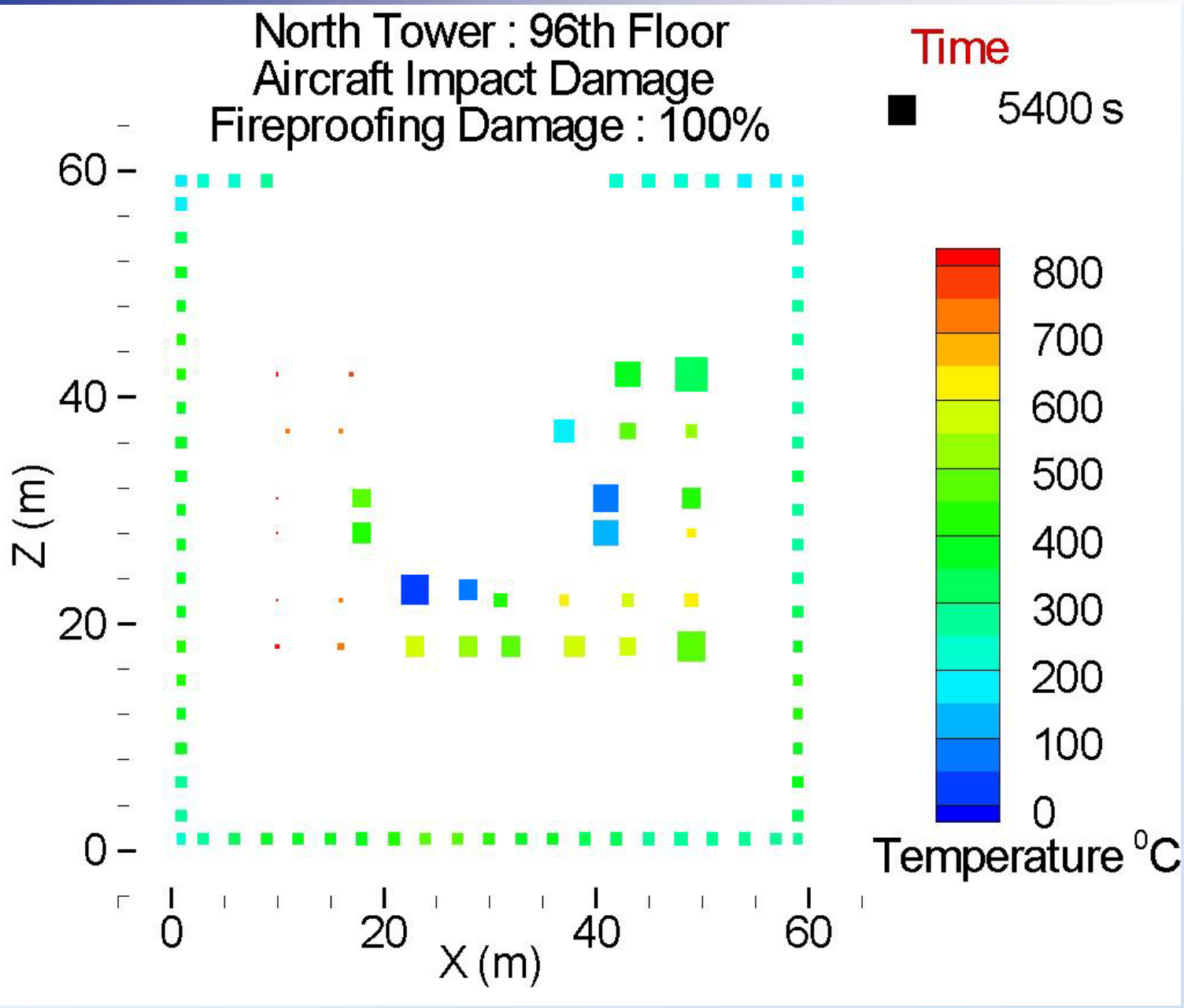
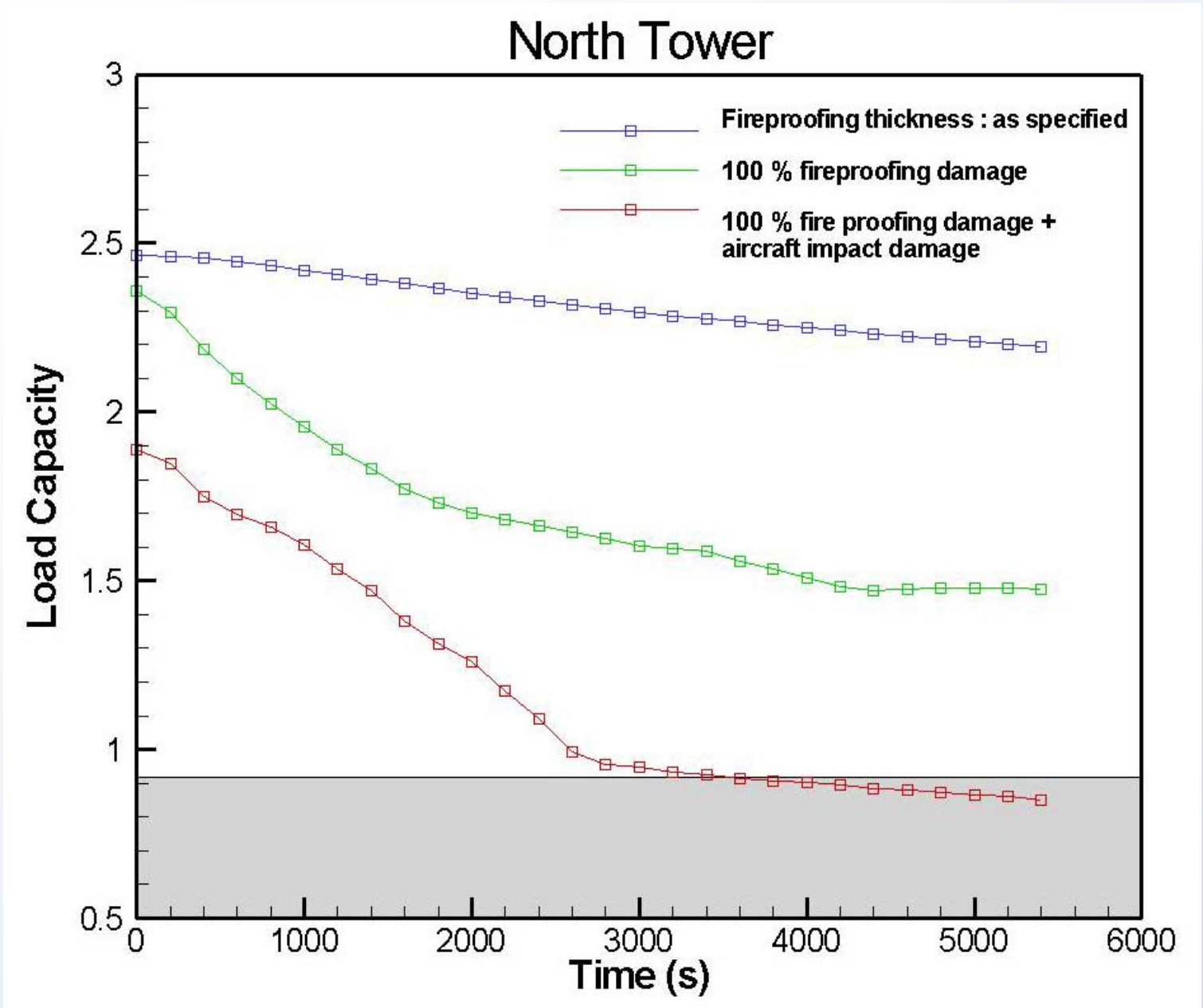

North Tower : 96th Floor
Aircraft Impact Damage
Fireproofing Damage : 100%
Time
5400 s
800
700
600
500
400
300
200
100
0
Temperature °C
Z (m)
60
40
20
0
0
20
40
60
X (m)


North Tower
Fireproofing thickness : as specified
100 % fireproofing damage
100 % fire proofing damage + aircraft impact damage
Load Capacity
Time (s)
3
2.5
2
1.5
1
0.5
0
1000
2000
3000
4000
5000
6000

Status:

- Fire Structure Interface (FSI) - completed
- Sensitivity to model parameters – completed
- Thermal analysis of wall model – completed
- Standard cases for evaluating collapse hypotheses – underway
  - FDS-generated fires
  - Varied insulation thickness (0”, 0.6”, 2.2”)

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Thank you

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