Fire-Structure Interaction: New Perspectives

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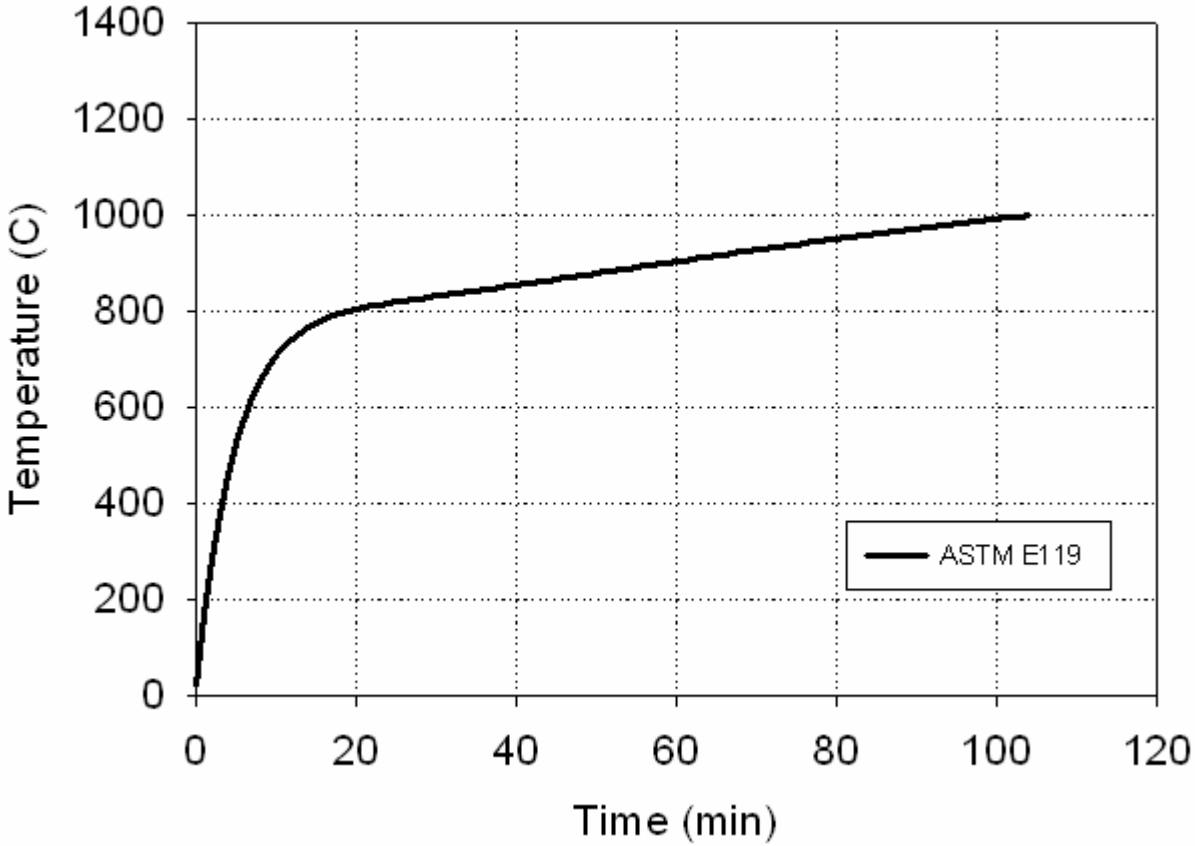
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Topics

- Motivation
- Interfaces
  - Fire-Thermal
  - Thermal-Structural
- Future Work

Motivation – WTC Disaster

ASTM E119 -- Prescriptive

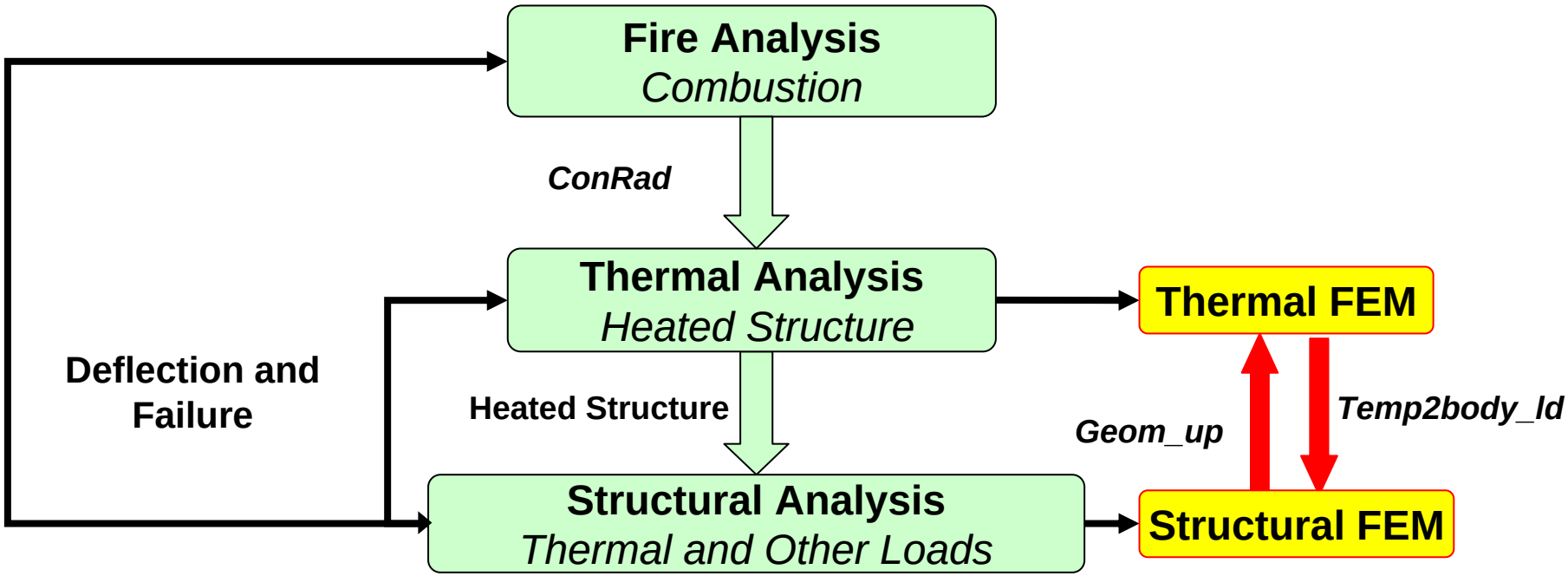


- prescribes a *standard exposing fire* of controlled extent and severity
- defines *performance* as the period of resistance for *building parts*
- *does not incorporate all factors required for fire hazard or fire risk assessment (e.g., behavior of complex structural system)*

Motivation

- Need to treat fire as a structural load, unlike E119
- NCST: enhance capabilities of available computational software to study the effect of fire on buildings and the design of fire protection systems
- Analyze complex structures under fire all the way to collapse
- Improve interfaces (complicated and limited to compatible elements)

Interfaces

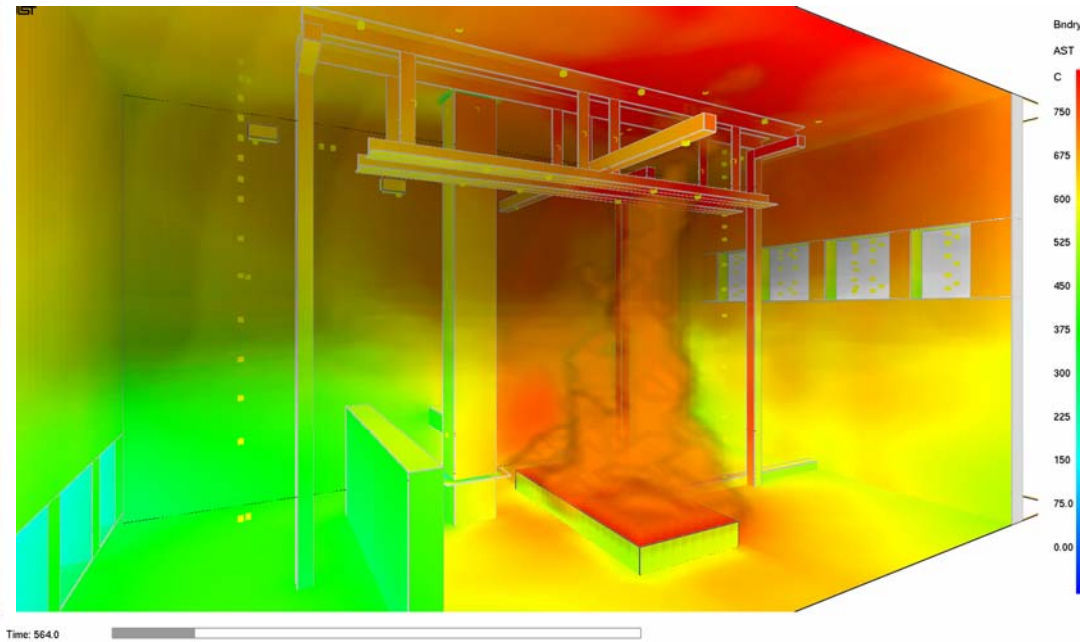

Fire Analysis
Combustion
ConRad
Thermal Analysis
Heated Structure
Thermal FEM
Deflection and Failure
Heated Structure
Geom_up
Temp2body_ld
Structural Analysis
Thermal and Other Loads
Structural FEM

Fire-Thermal Interface

- Transfers results of fire analysis as adiabatic surface temperatures (AST) or as measured by virtual plate thermometers (PT).

- Example: Compartment fire-thermal analysis of an insulated column and a truss.

Fire modeling



Heat transfer based on PT temperature

Radiation

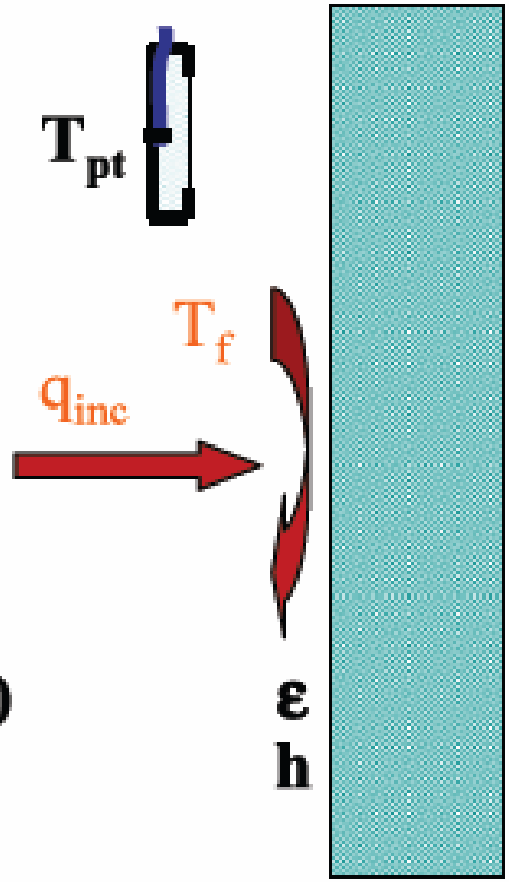
$$q_r = \varepsilon \sigma (\underline{T_{pt}}^4 - \underline{T_s}^4)$$

Convection

$$q_c = h (T_{pt} - T_s)$$

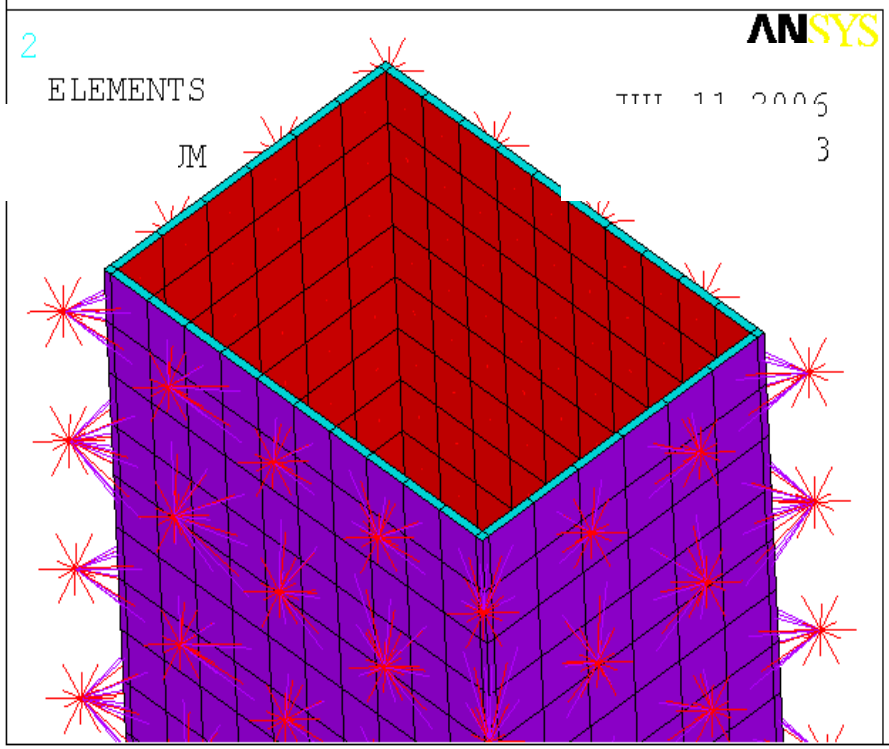
Total

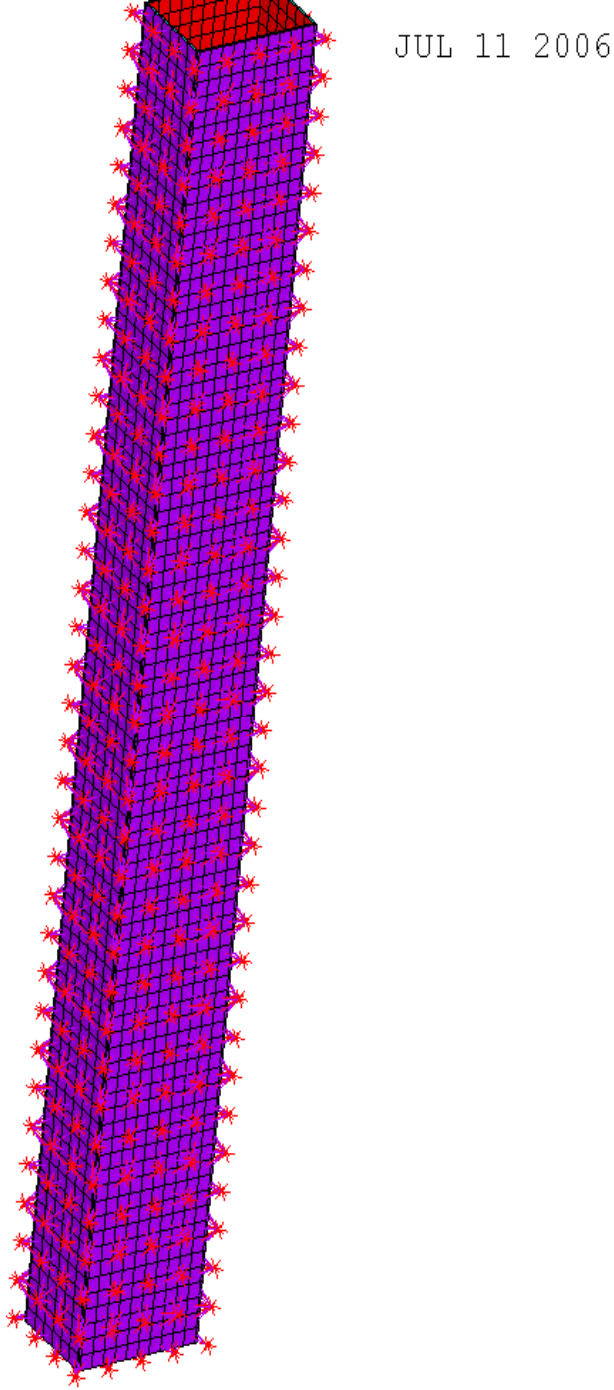
$$q = \varepsilon \sigma (\underline{T_{pt}}^4 - \underline{T_s}^4) + h (T_{pt} - T_s)$$



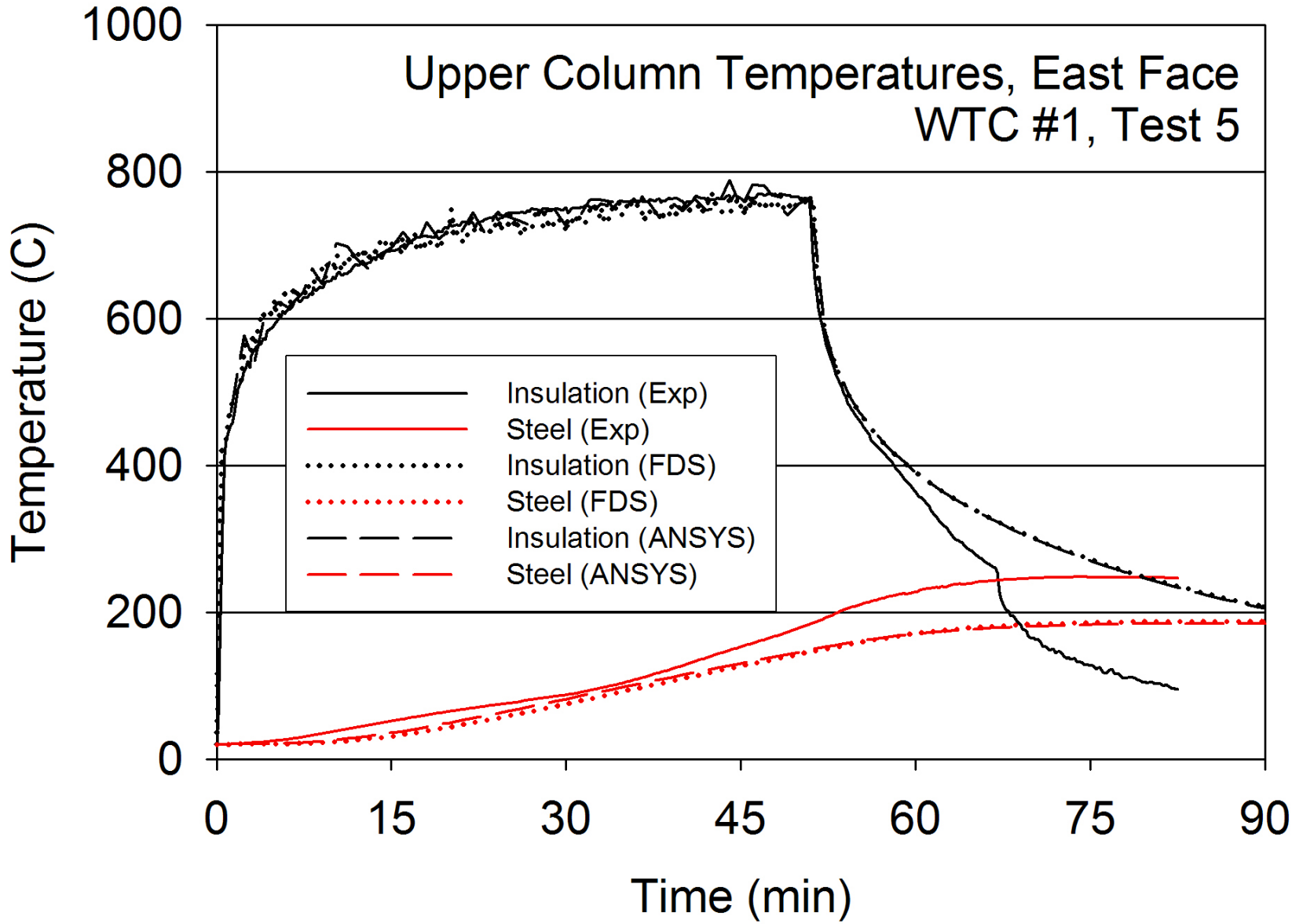
T_f = fire temperature, q_{inc} = incident radiative heat flux,
T_s = surface temperature. *From Ulf Wickstrom*

Reading AST (adiabatic surface temperatures)

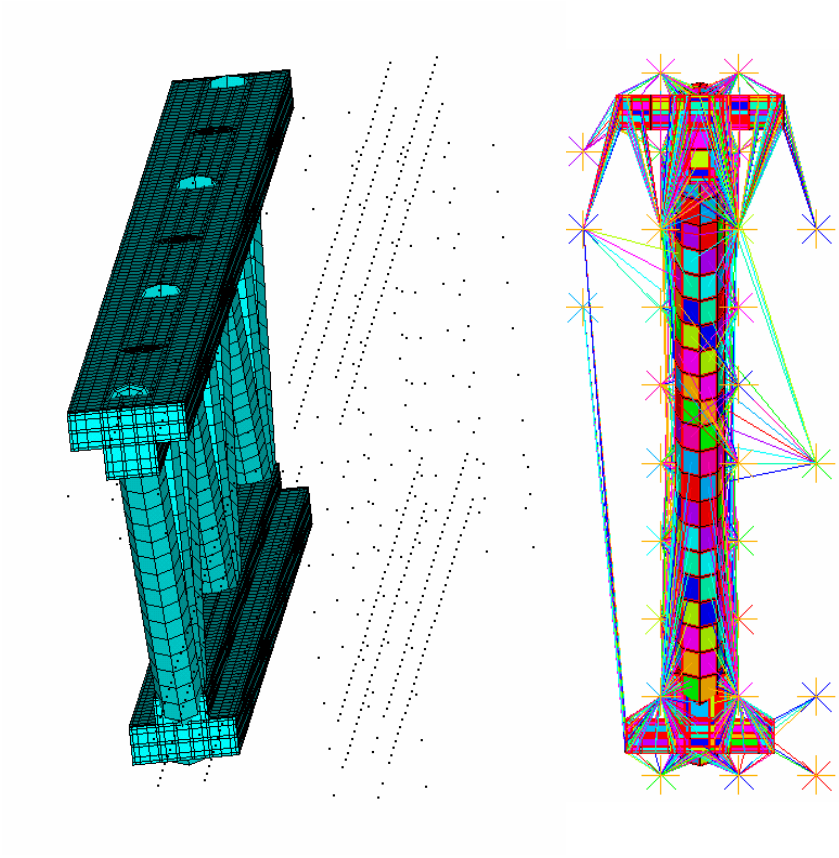


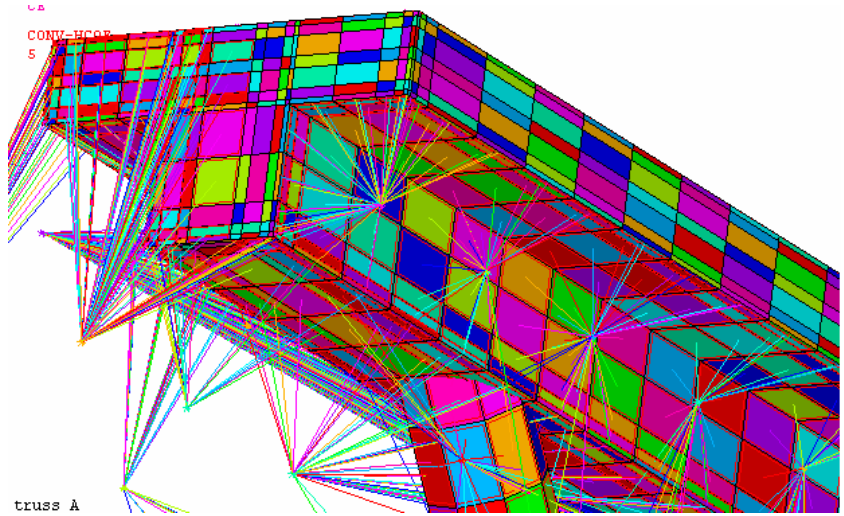


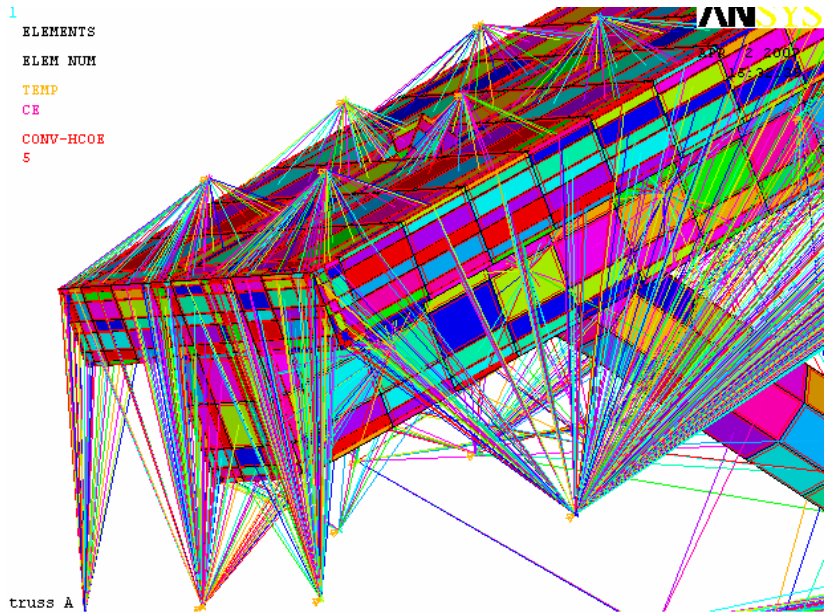
Insulated column

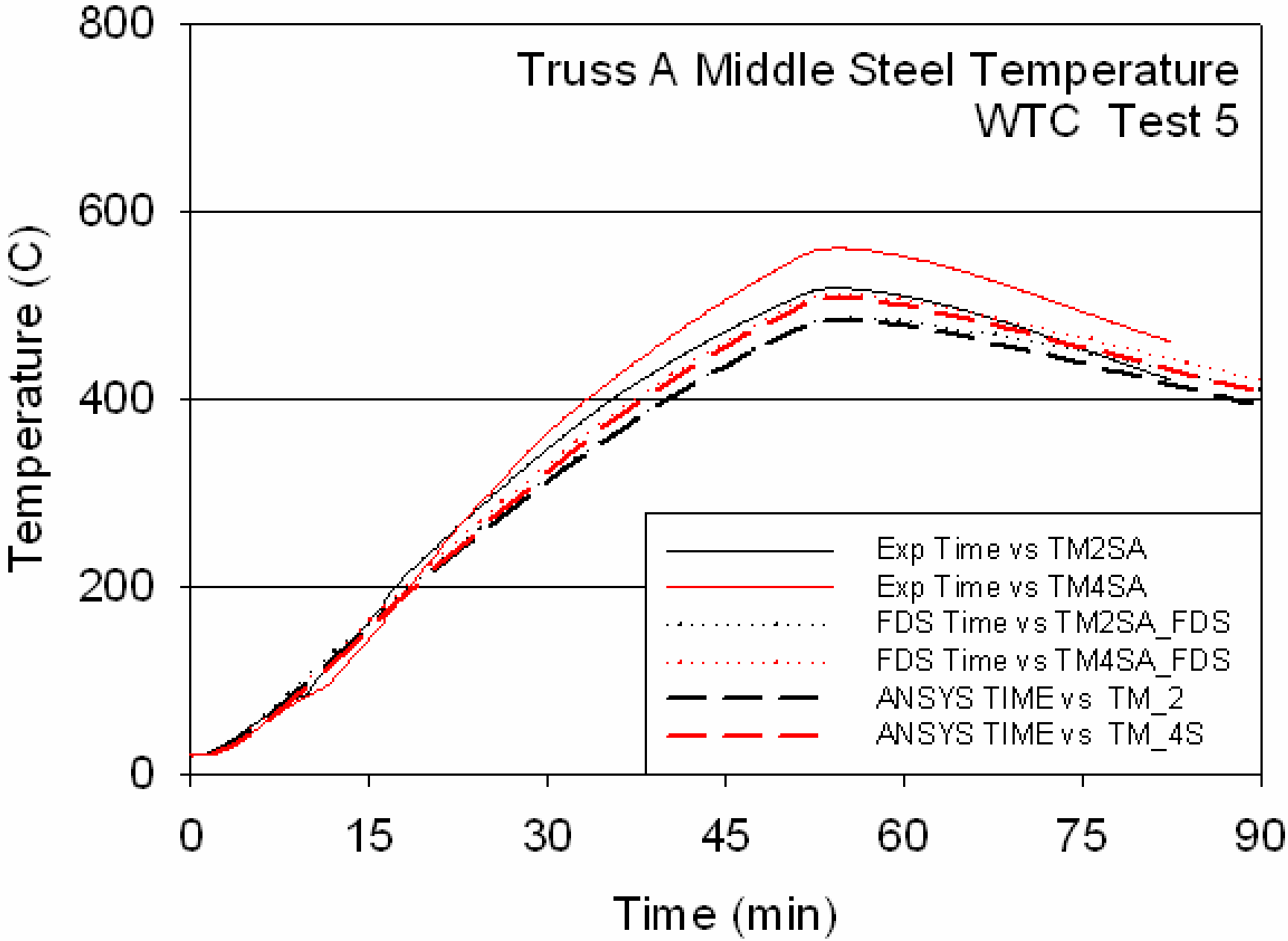


Reading AST




CONV-HCOE
5
truss A

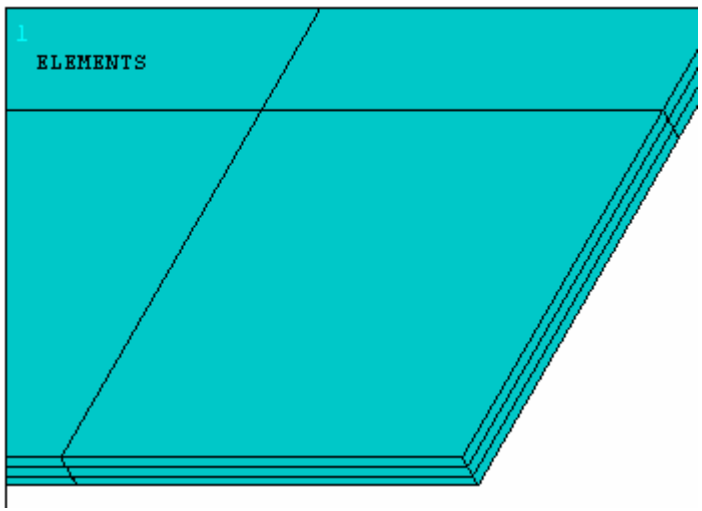

1
ELEMENTS
ELEM NUM
TEMP
CE
CONV-HCOE
5
truss A

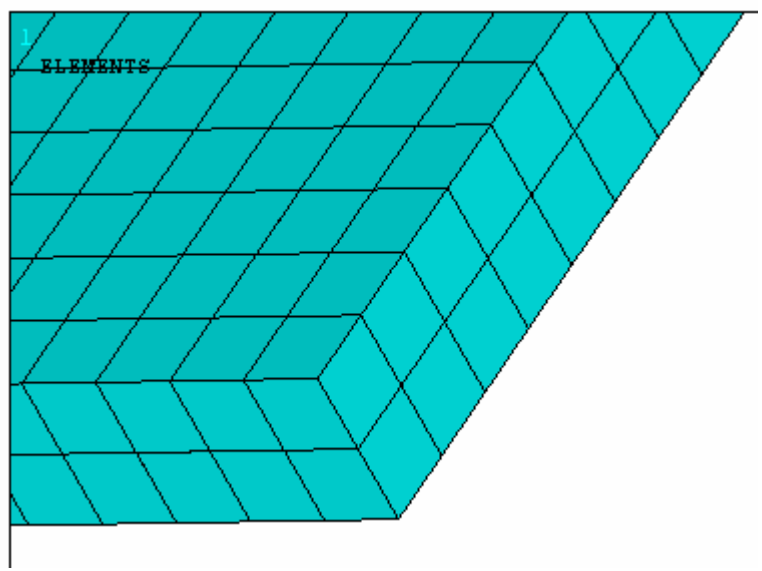

Truss A Middle Steel Temperature
WTC Test 5
Temperature (C)
Time (min)
800
600
400
200
0
0
15
30
45
60
75
90
Exp Time vs TM2SA
Exp Time vs TM4SA
FDS Time vs TM2SA_FDS
FDS Time vs TM4SA_FDS
ANSYS TIME vs TM_2
ANSYS TIME vs TM_4S

Thermal-Structural Interface

- Temp2Body_ld
  - Maps temperatures from thermal to structural model
- Geom_up
  - Maps deflections and strains from structural onto thermal model
  - Accounts for insulation damage

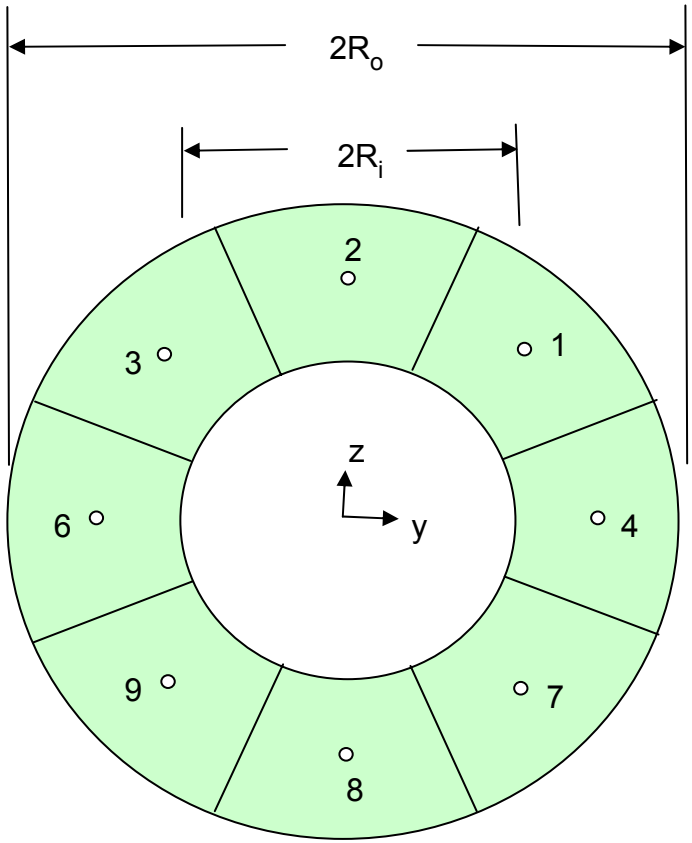
Temp2Body_ld shells

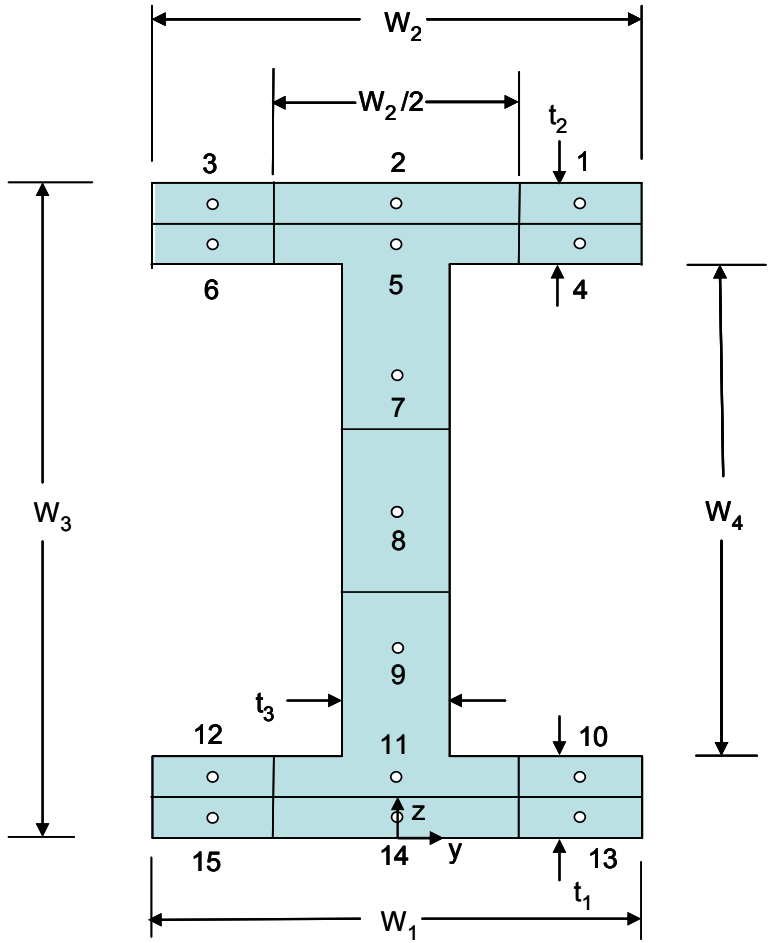




Temp2Body_Id Transfer Nodes

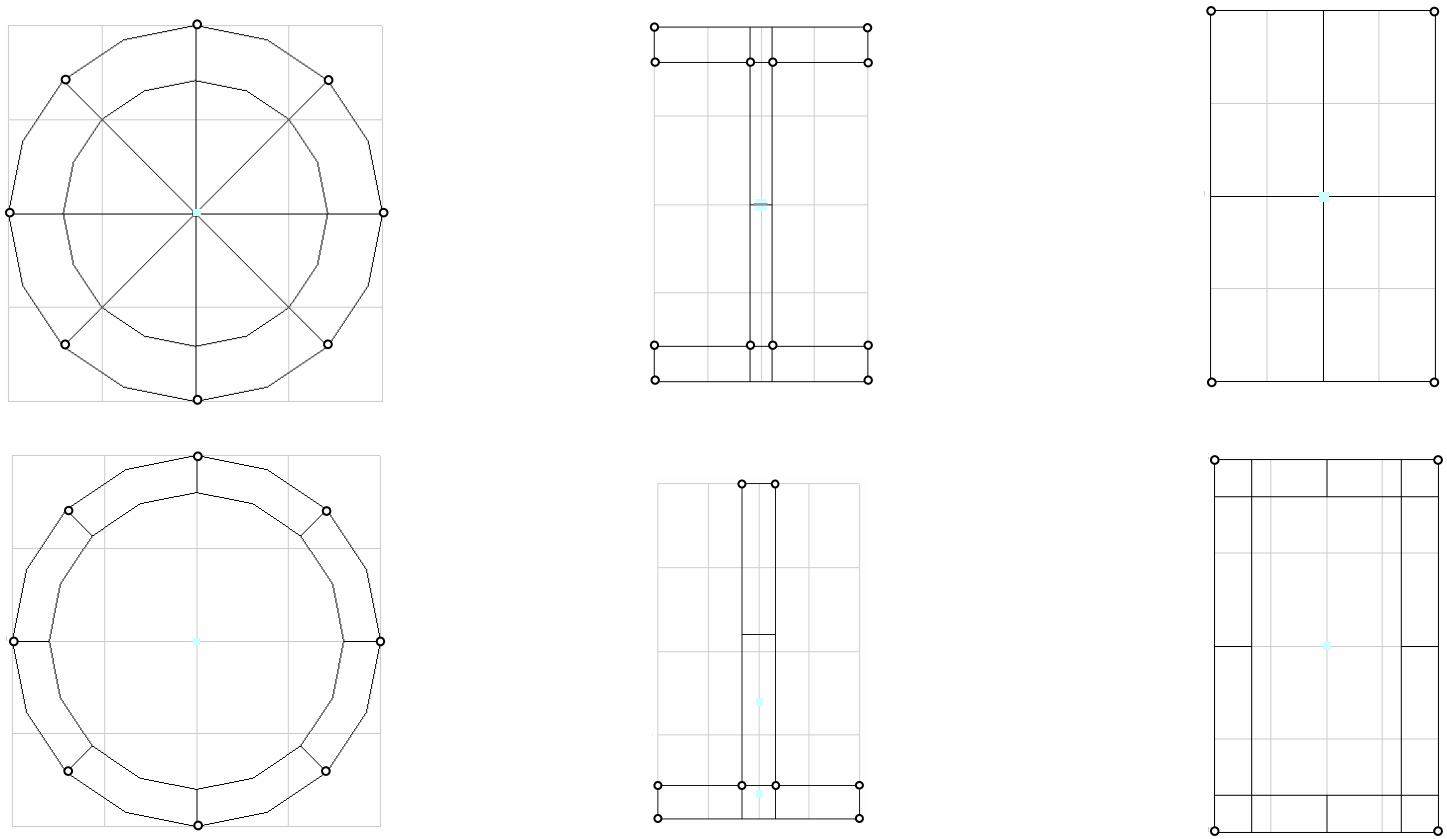
- beams





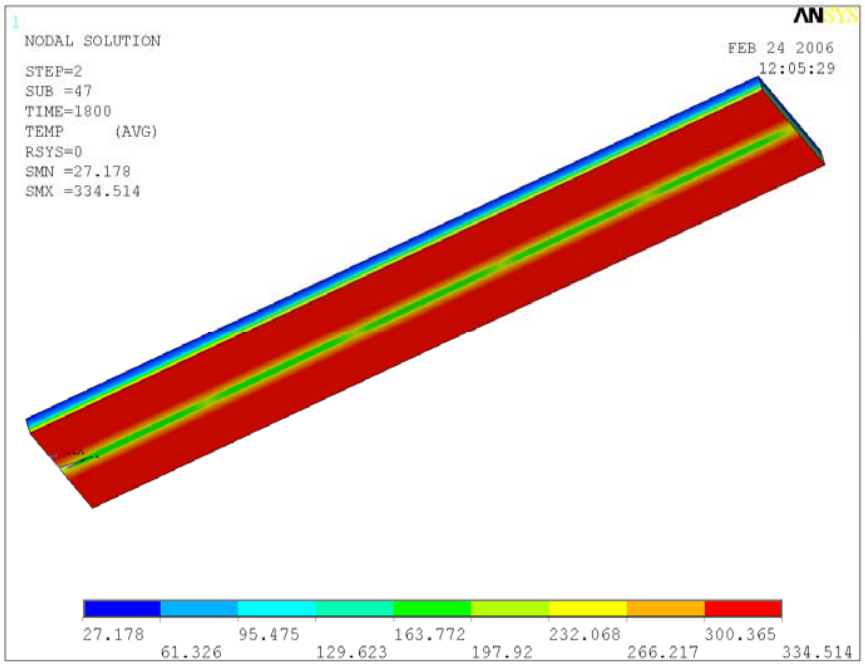
Common cross sections

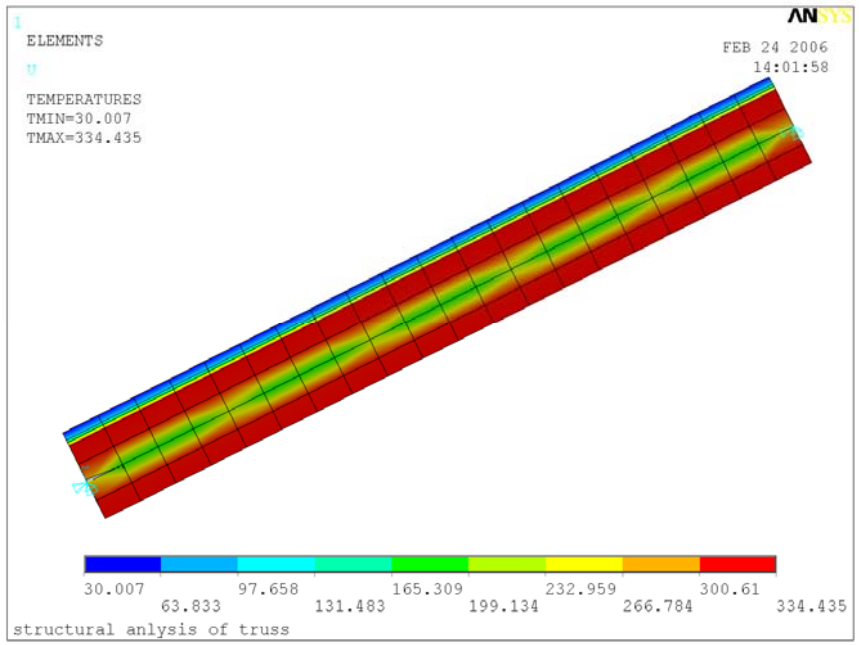
- Cells and strain transfer nodes



Floor Slab Supported by Open Web
Thermal and Structural FEM

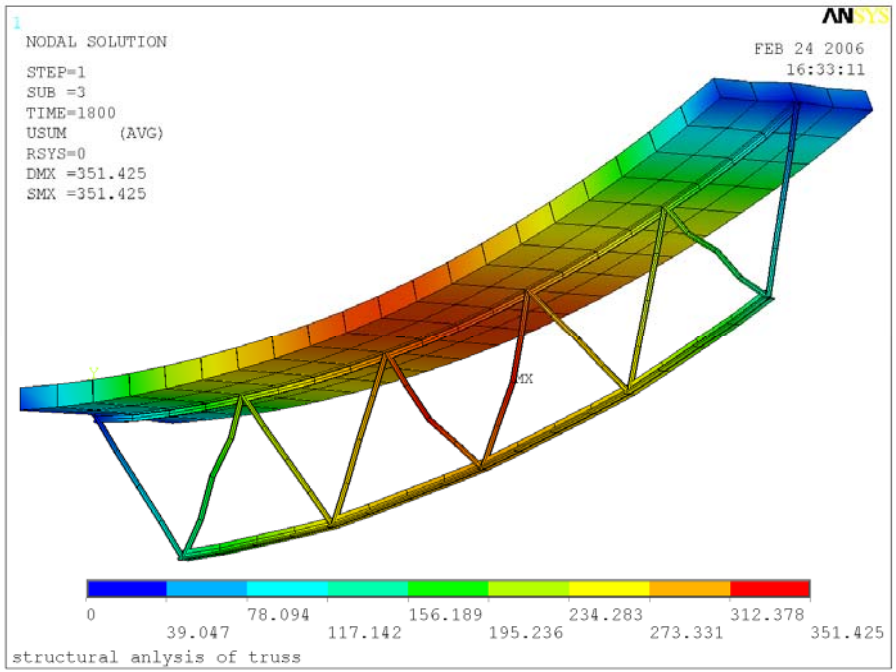
Temperature Solution and Thermal Body Loads - Slab

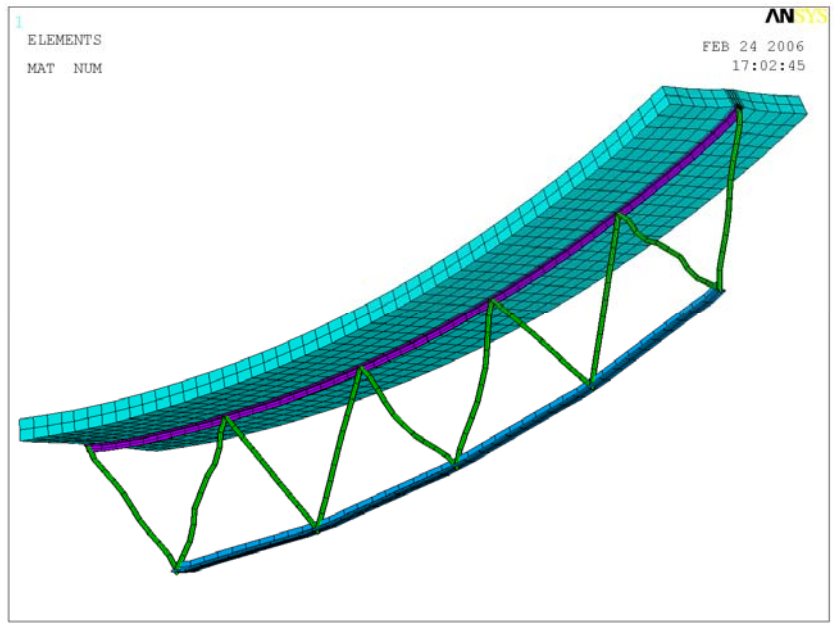




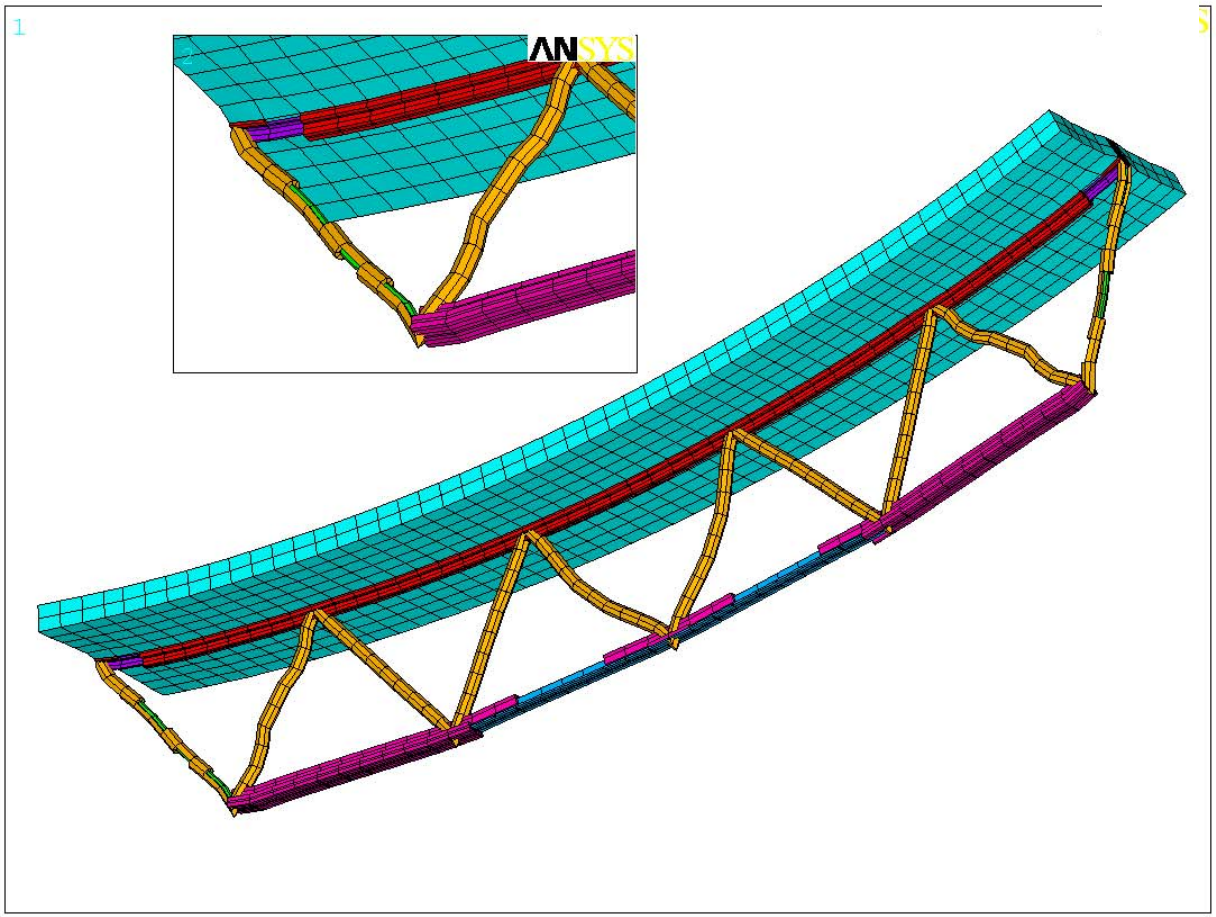
Floor Slab Supported by Open Web Structural and Thermal FEM

- Deflected and Updated Shapes





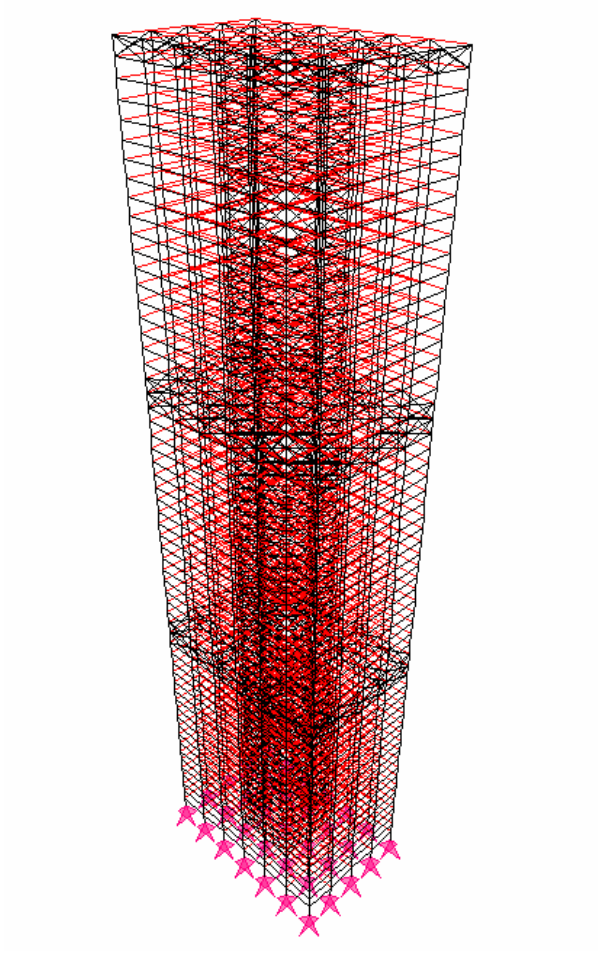
Failed Insulation of Thermal Model (Removed)

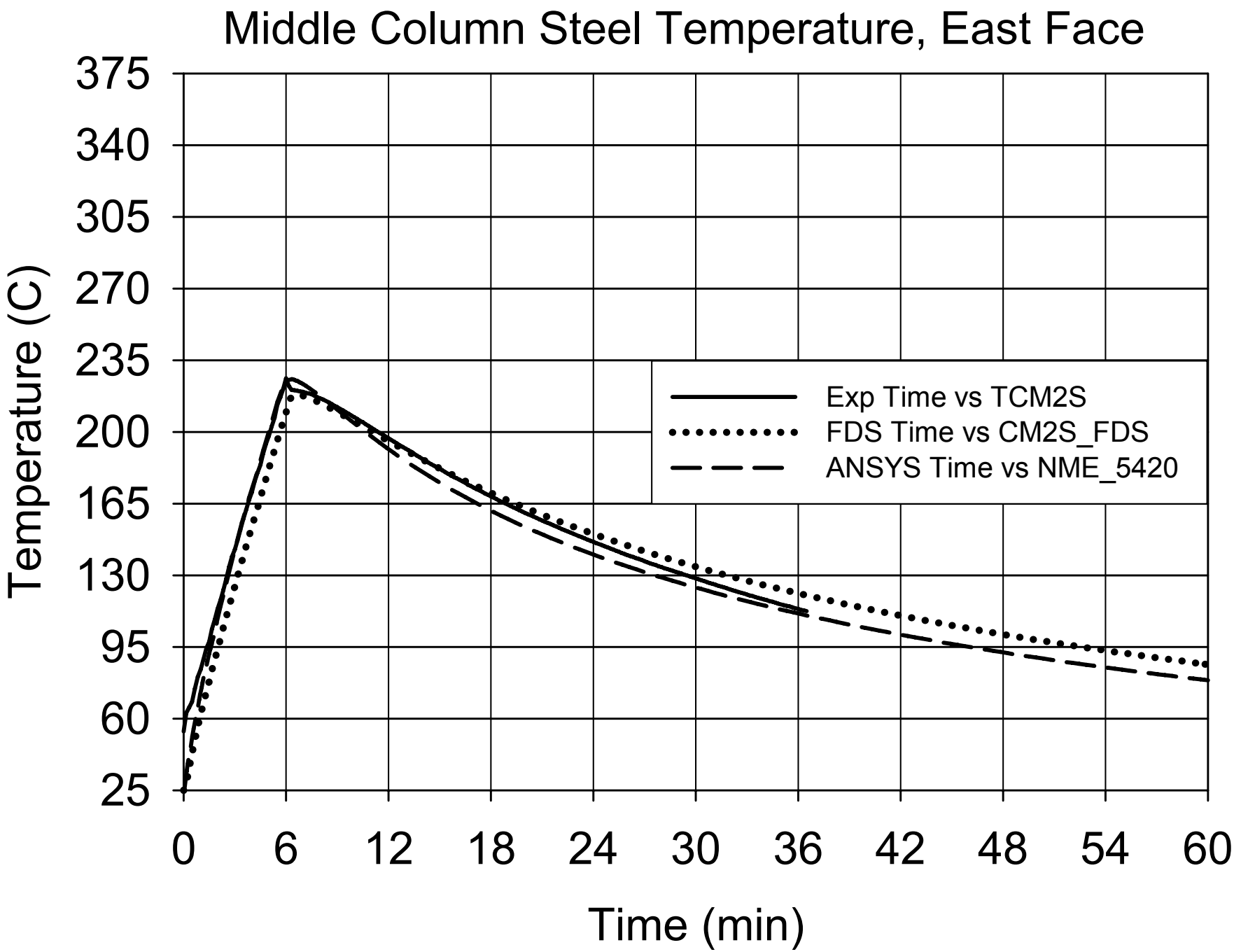


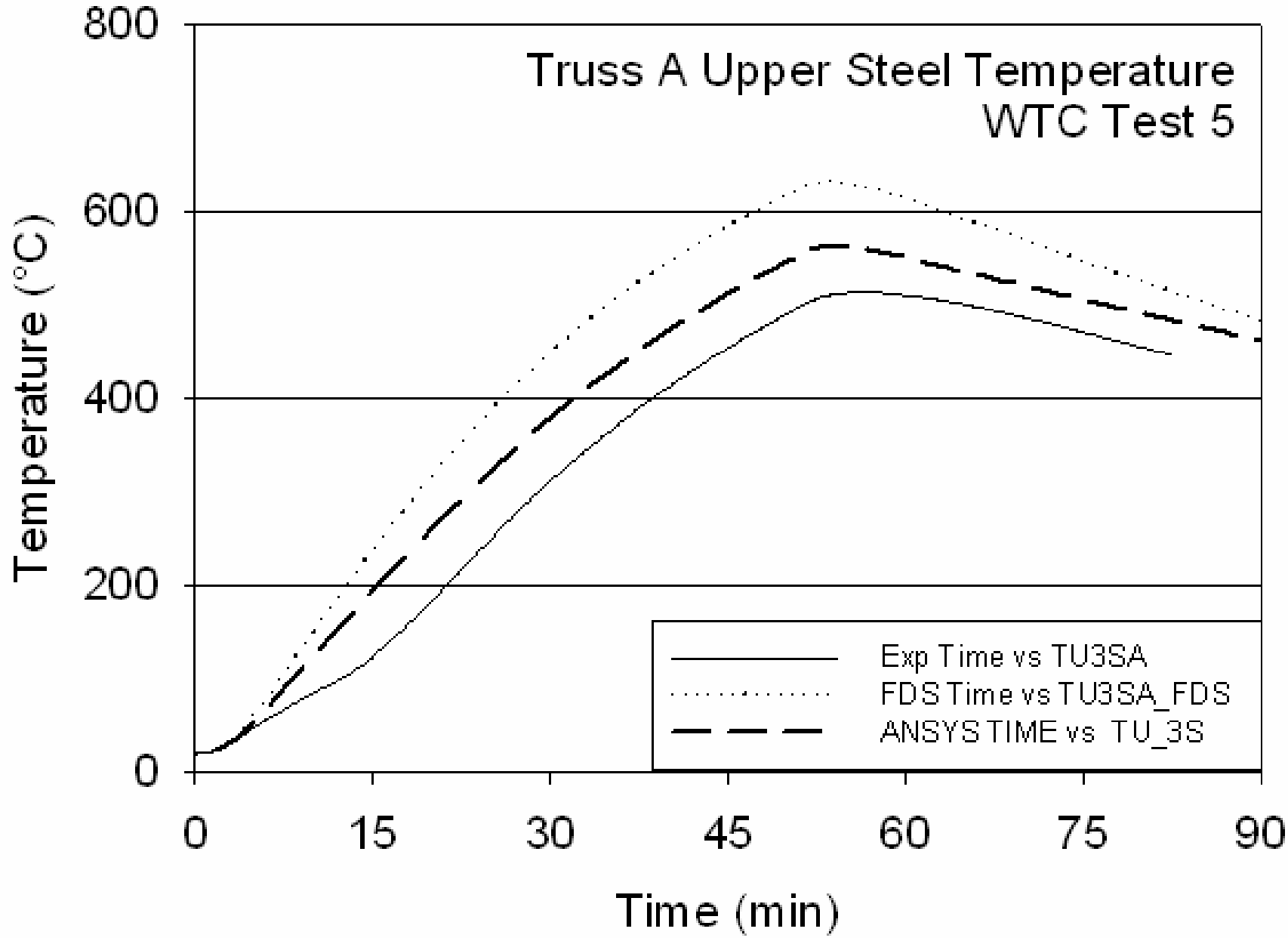
Future Work

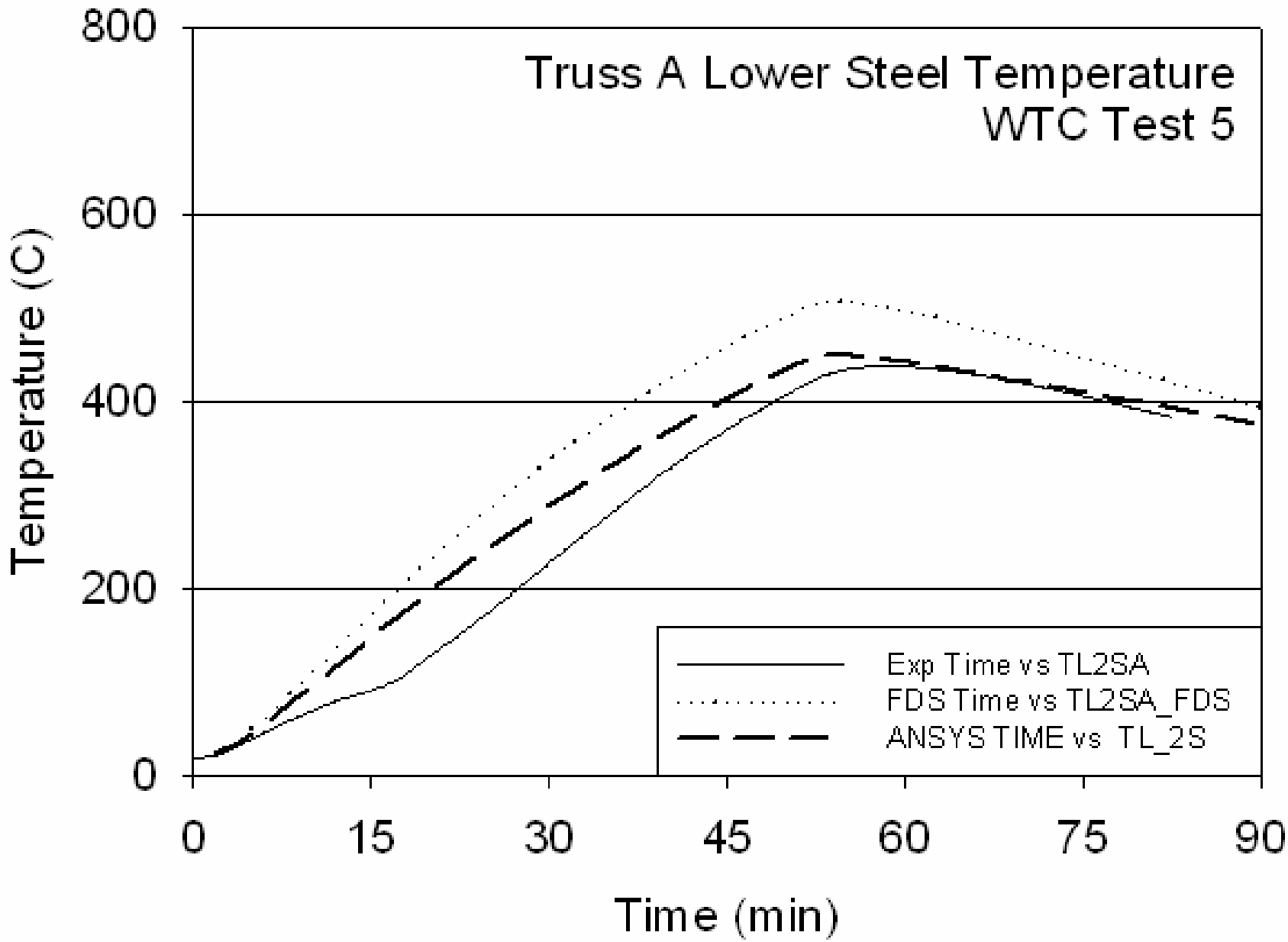
- Better failure criteria for insulation (experiments)

- Computational criteria for predicting structural failure




Middle Column Steel Temperature, East Face
375
340
305
270
235
200
165
130
95
60
25
Temperature (C)
0
6
12
18
24
30
36
42
48
54
60
Time (min)
Exp Time vs TCM2S
FDS Time vs CM2S_FDS
ANSYS Time vs NME_5420


Truss A Upper Steel Temperature
WTC Test 5
Temperature (°C)
800
600
400
200
0
0
15
30
45
60
75
90
Time (min)
Exp Time vs TU3SA
FDS Time vs TU3SA_FDS
ANSYS TIME vs TU_3S


Truss A Lower Steel Temperature
WTC Test 5
Temperature (C)
800
600
400
200
0
0
15
30
45
60
75
90
Time (min)
Exp Time vs TL2SA
FDS Time vs TL2SA_FDS
ANSYS TIME vs TL_2S

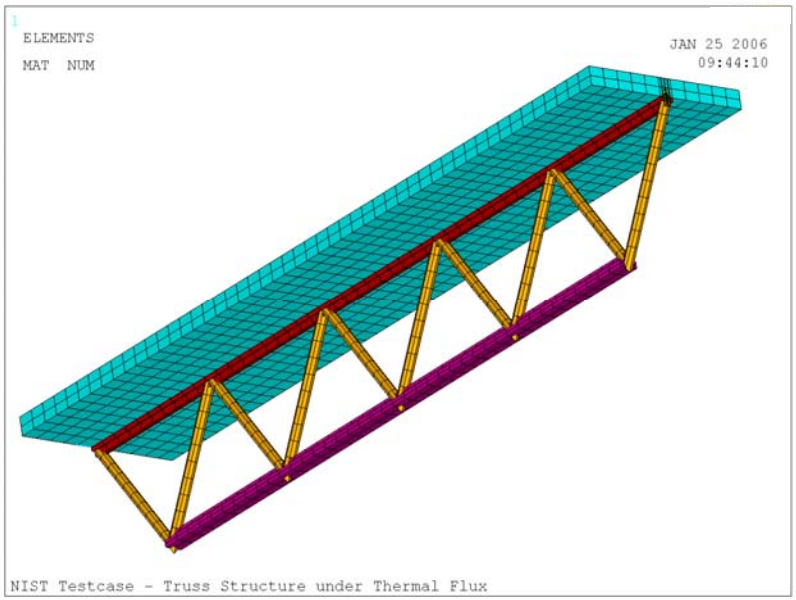
Thermal-Structural Interface

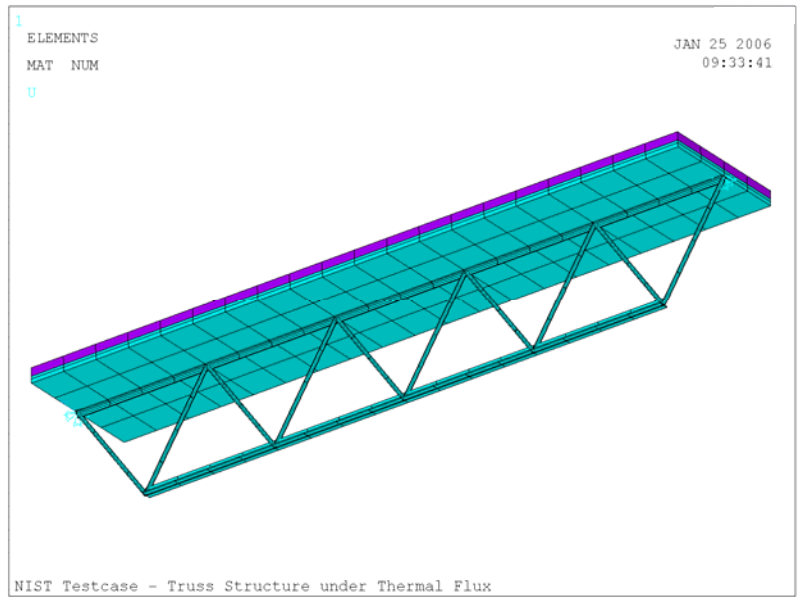
- Temp2Body_ld
  - Maps temperatures from thermal to structural model
  - Calculates gradient and defines body load
  - Uses area-weighted averages, transfer nodes and same global coordinate system

- Geom_up
  - Maps deflections and strains from structural onto thermal model
  - Uses kinematic relationship for deflections

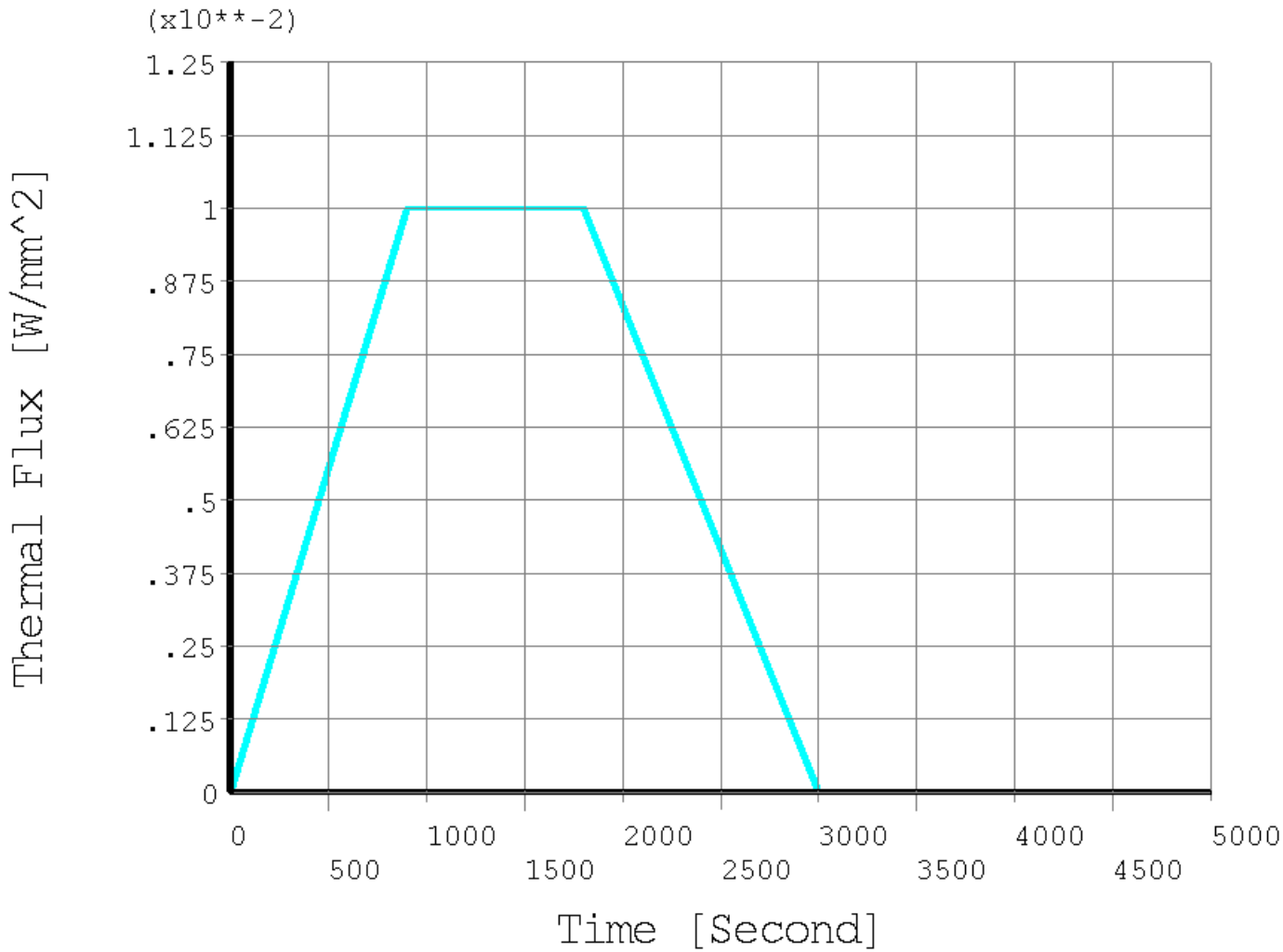
    $\boldsymbol{U} = \boldsymbol{u} + \boldsymbol{r} \times \boldsymbol{d}$
  - Interpolates strains from selected cross section cell nodes of structural onto thermal model to account for insulation damage

Slab Supported by Open Web
Thermal FEM – Solid Elements
Structural FEM – Beam and Shell Elements



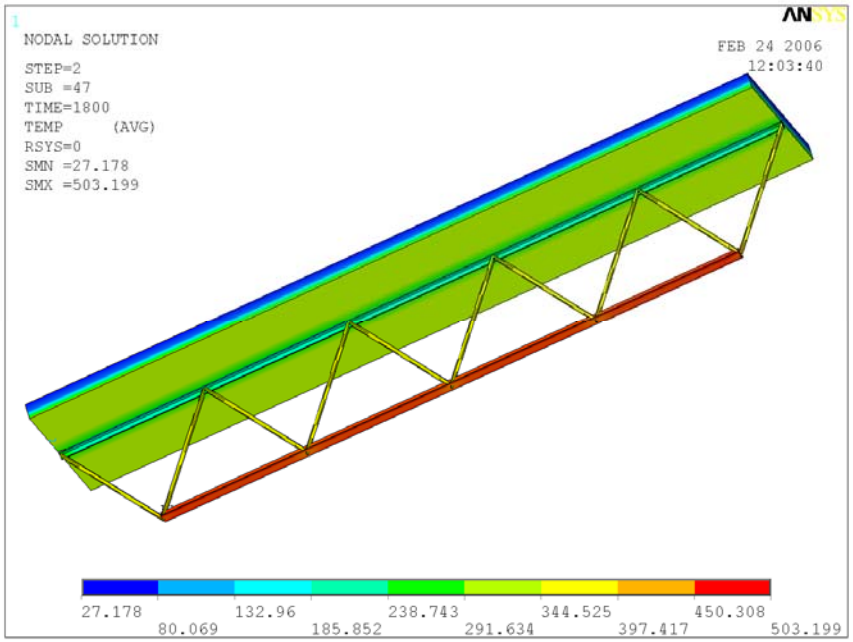


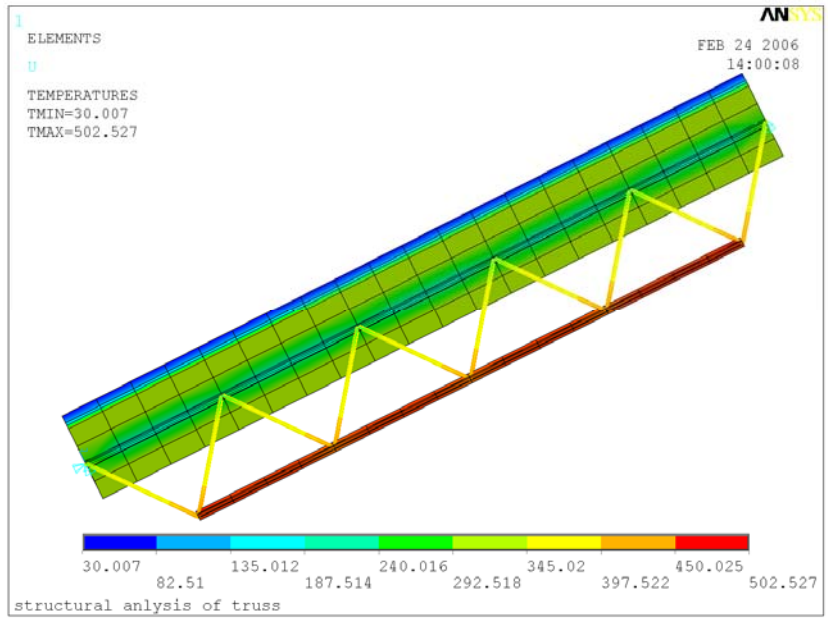
Thermal Finite Element Model – Thermal Flux



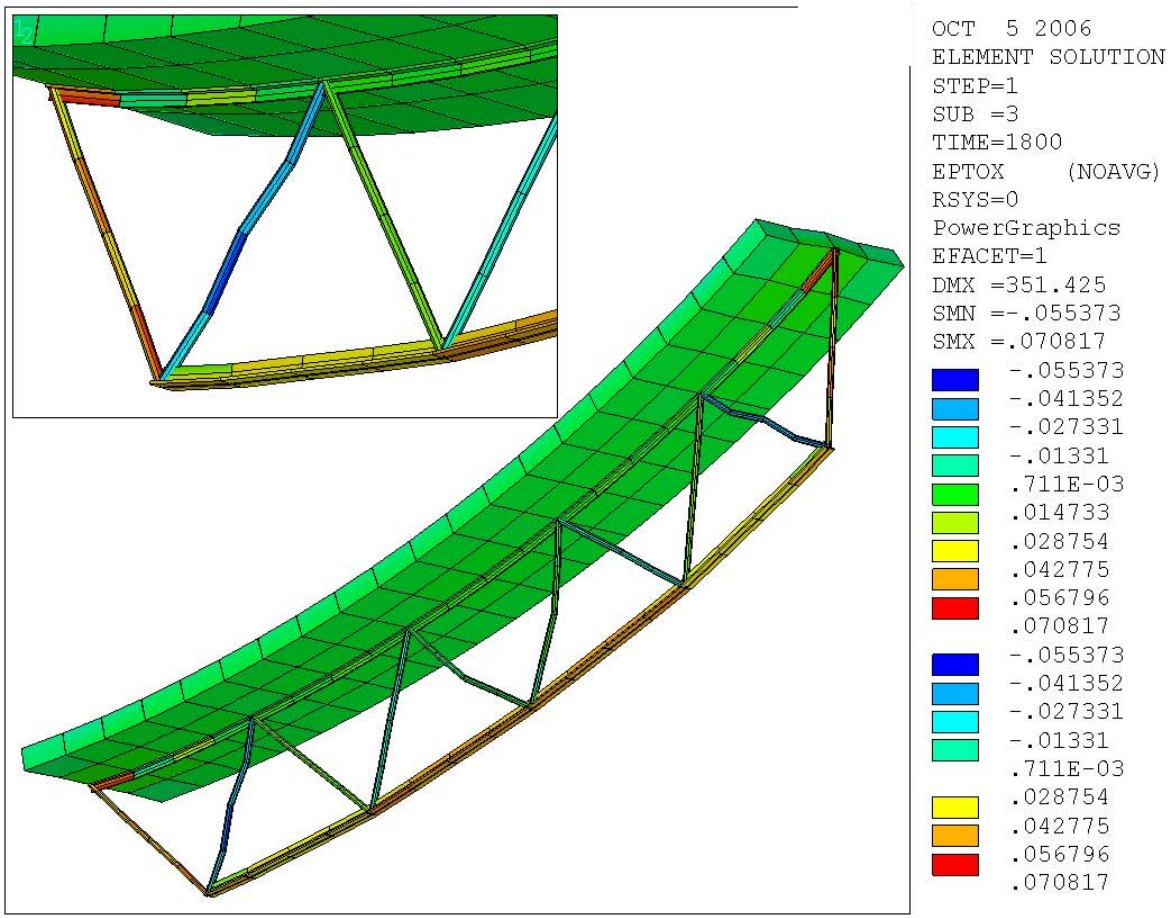
Floor Slab Supported by Open Web
Thermal and Structural FEM

- Temperature Solution and Thermal Body Load

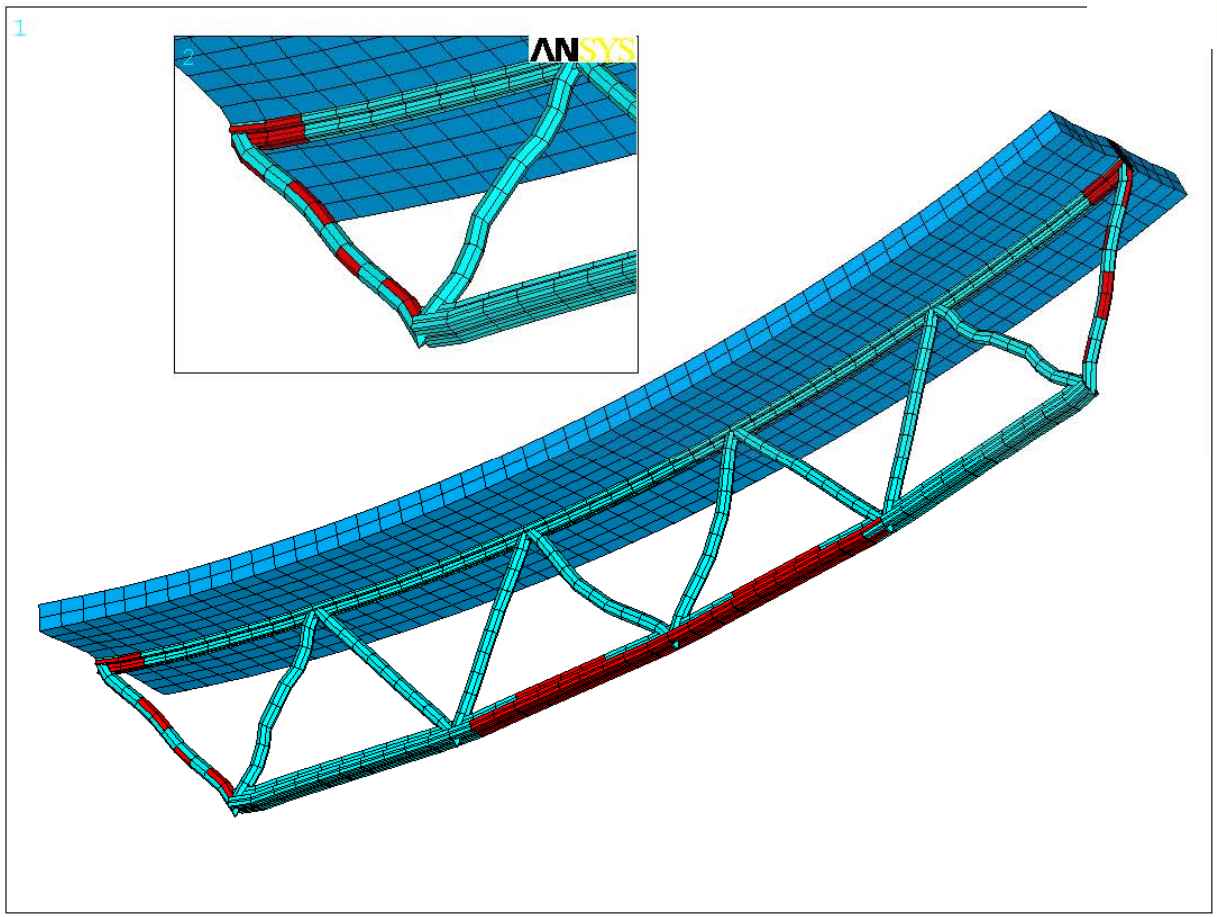




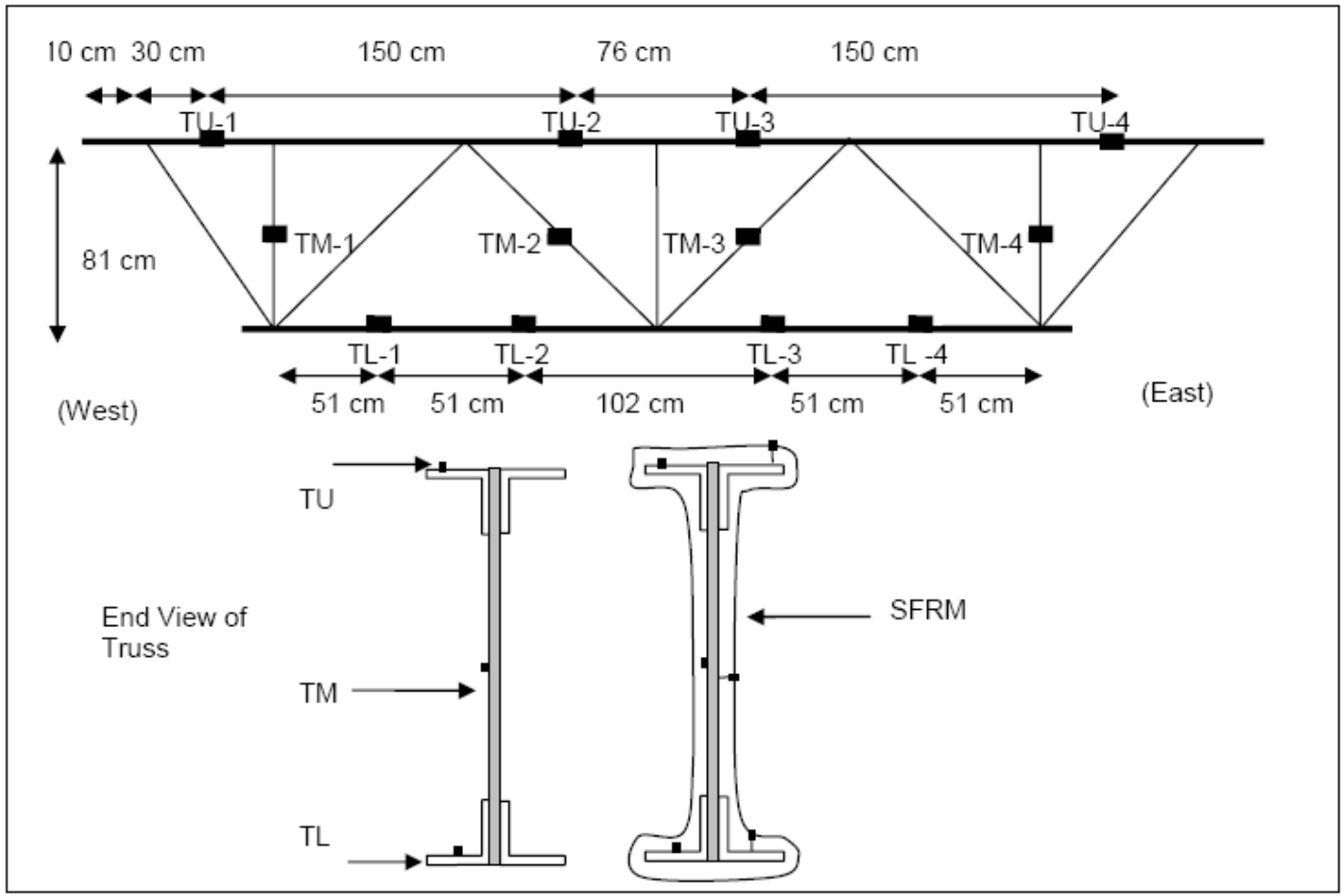
Structural strains ε_{xx} at 1800 s



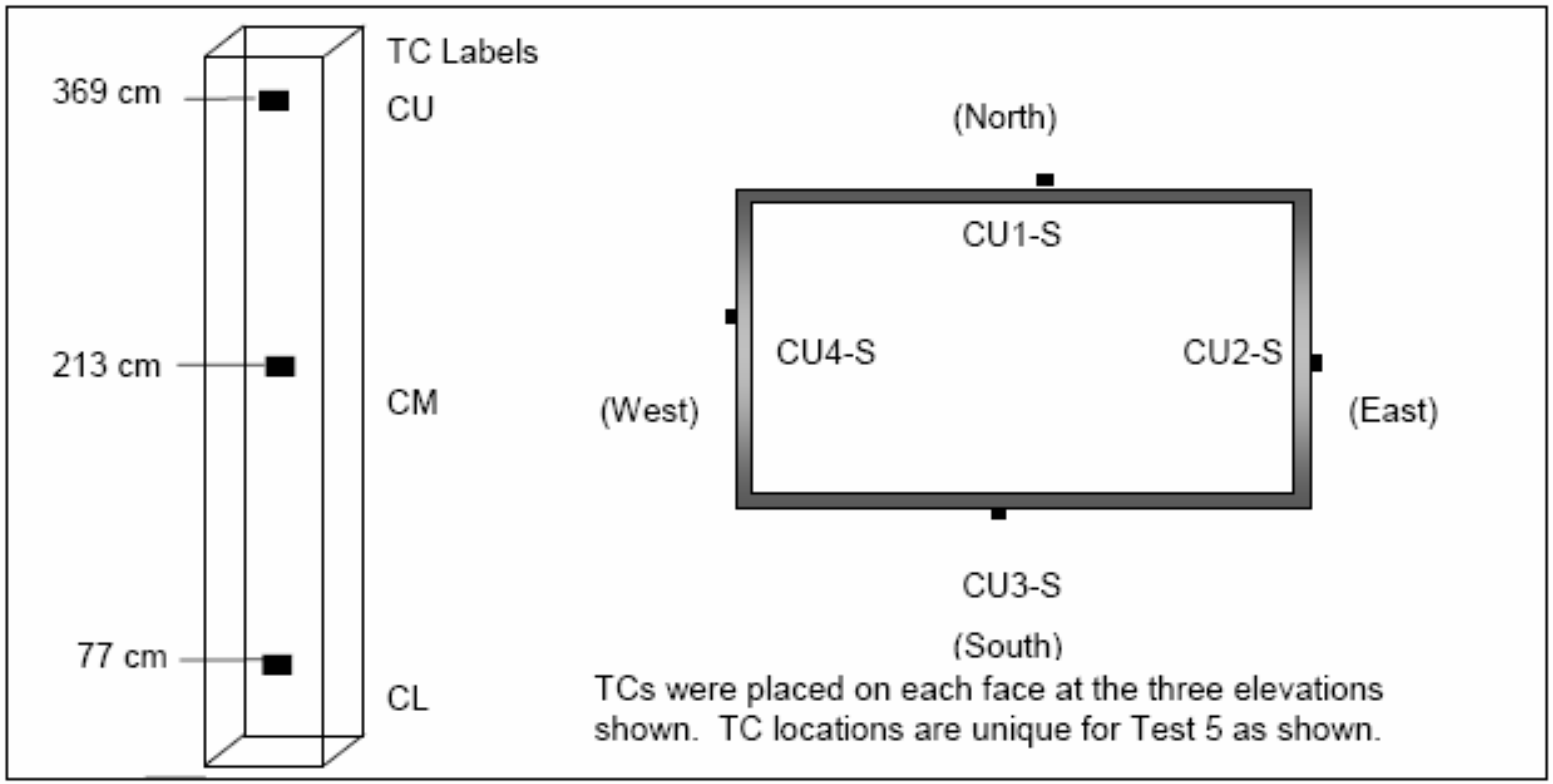
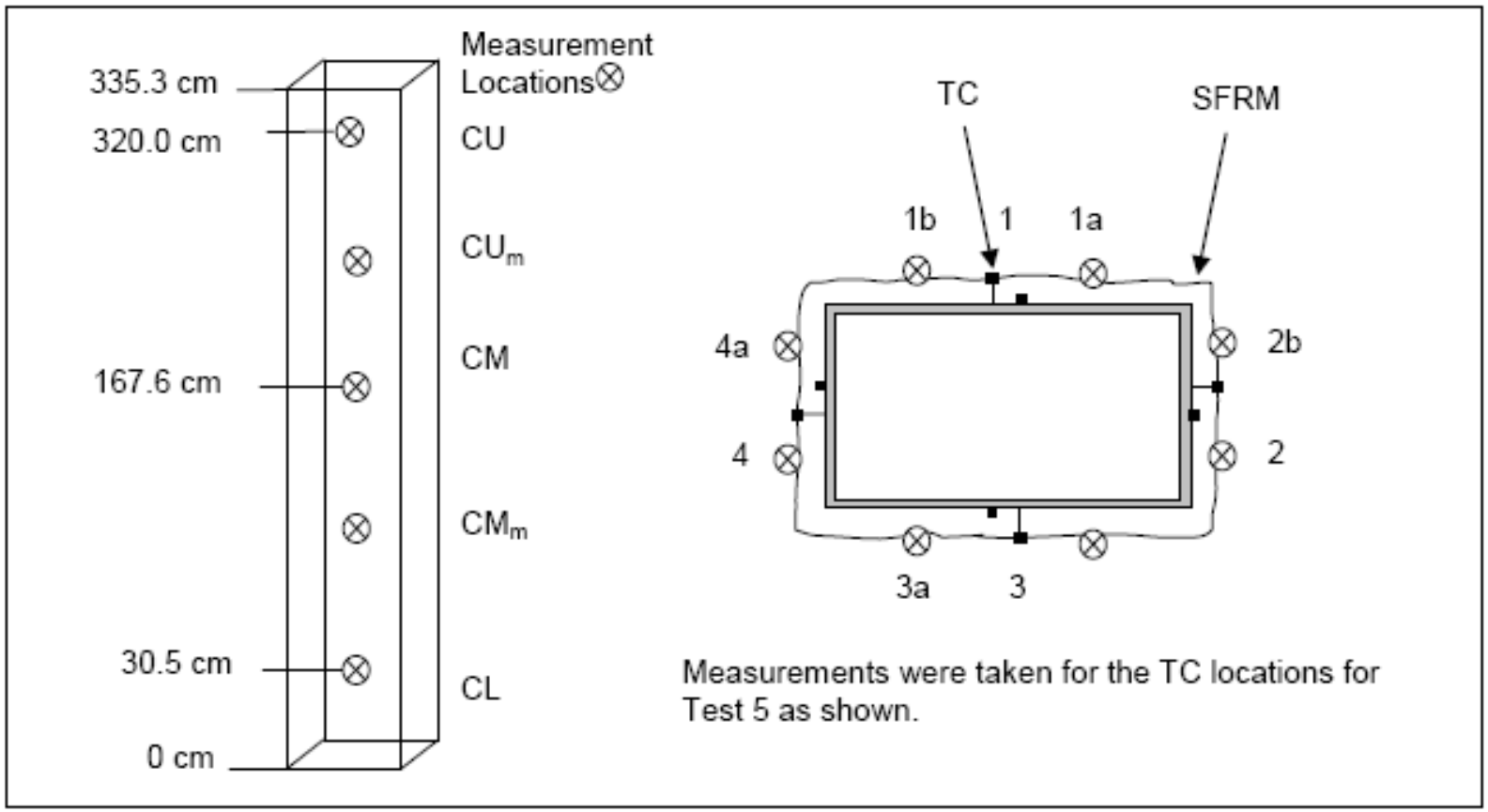
Failed Insulation of Thermal Model (Red)



Location of thermocouples on truss



Location of thermocouples on column



Location of thermocouples on column insulation