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

Fire-Induced Thermal States and Structural Failure Analyses

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Objective

- No methodology is currently available for evaluating the capacity of *redundant structural systems with fire-induced thermal effects simulated by state-of-the-art (SOA) methods*.

- Our objective is to use SOA methods to achieve the most effective and realistic possible investigation of fire-thermal-structural effects – one that takes full advantage of the *interdisciplinary* nature of our methodology.

Tools (Thermal)

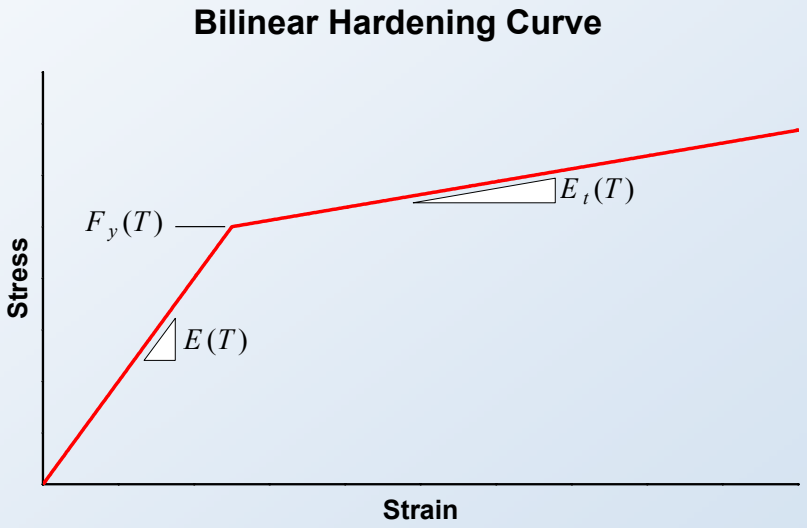
- Fire Dynamics Simulator – fire representations consistent with:
  - Observations (NIST photographic archive).
  - Best estimates of initial conditions.
- Physics-based nonlinear transfer functions converting *gas temperatures* due to fires in building interior to *mean temperatures and temperature gradients for each significant structural member*.

Tools (Structural)

- Nonlinear FEM software (ANSYS) for structure with specified:
  - Geometry (valid for both structural and thermal input).
  - Loads.
  - Temperature (mean and temperature gradient) time histories.
  - Section properties.
  - Nonlinear mechanical properties.
  - Thermal properties.

Material Properties

- Current model using *bilinear* hardening rule to characterize the post-yield stress-strain relationship.
  - Values of constants, e.g., $F_y(T)$, $E(T)$, $G(T)$, $E_t(T)$, $\alpha(T)$, and $\nu(T)$, provided by Project #3 (Gayle, Luecke, and Fields).
- Future calculations will use *Voce's nonlinear* isotropic hardening rule.
  - Material constants are currently being developed for 9 types of steel by Project #3.



Possible Collapse Scenarios

1. Connection or isolated member/element failures.

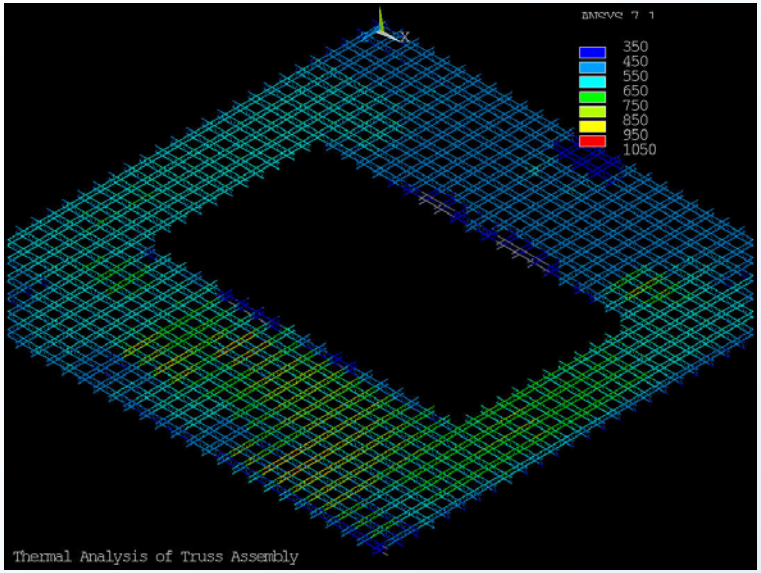
2. Collapse associated with floor system behavior; including buckling of exterior columns associated with thermally-induced sagging of joists.

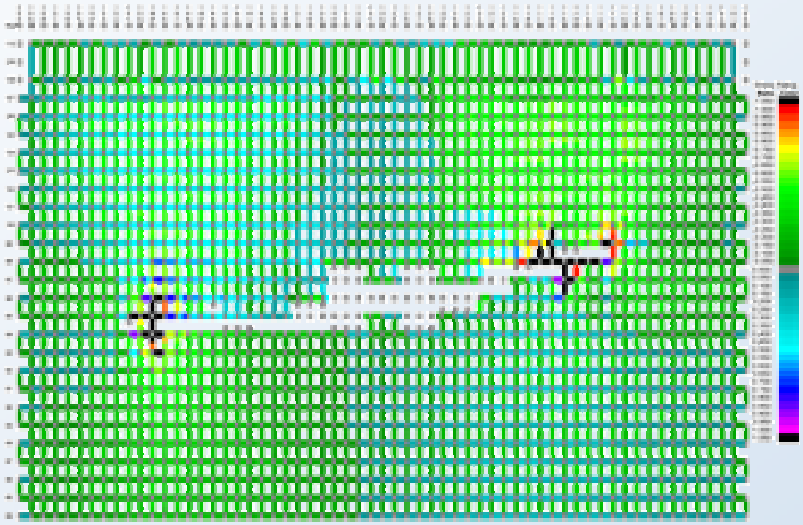
3. Collapse due to damage- and thermally-induced failure of core columns.

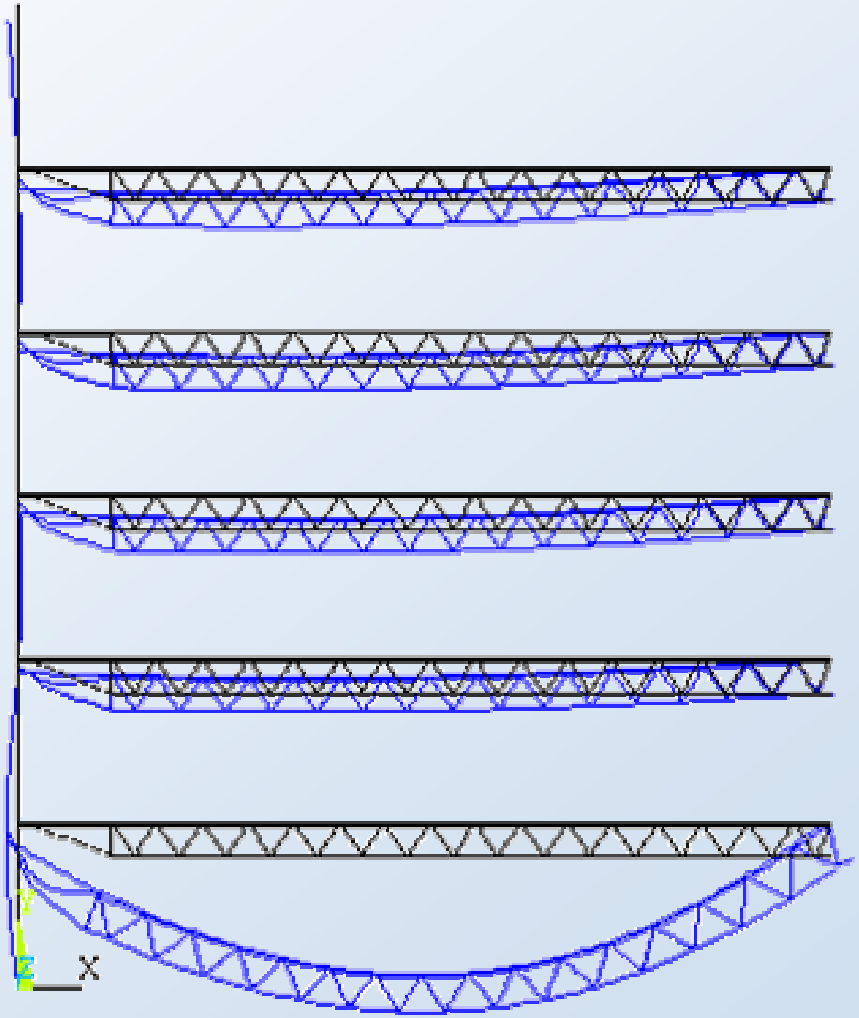
Status of 2-D Modeling and Analysis

- 2-D model developed to analyze sagging of joists and external column buckling, considering:
  - Fire representation.
  - Member sizes.
  - Material properties.
  - Nonlinear analysis.
- Ongoing analysis using simplified 2-D model to:
  - Evaluate role of sagging of joists and column buckling in undamaged structure.
  - Examine that role for a damaged structure.
  - Evaluate sensitivity to:
    - Various types of plausible fires.
    - Effect of creep at high temperatures.

2-D Structural Model and Analysis



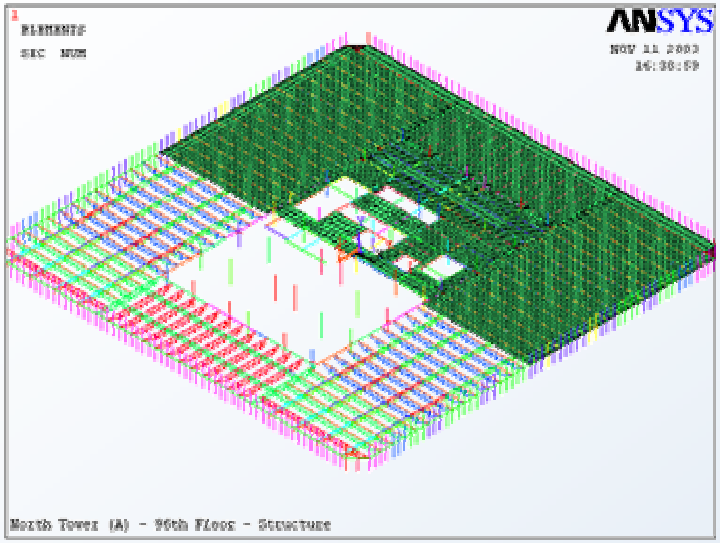


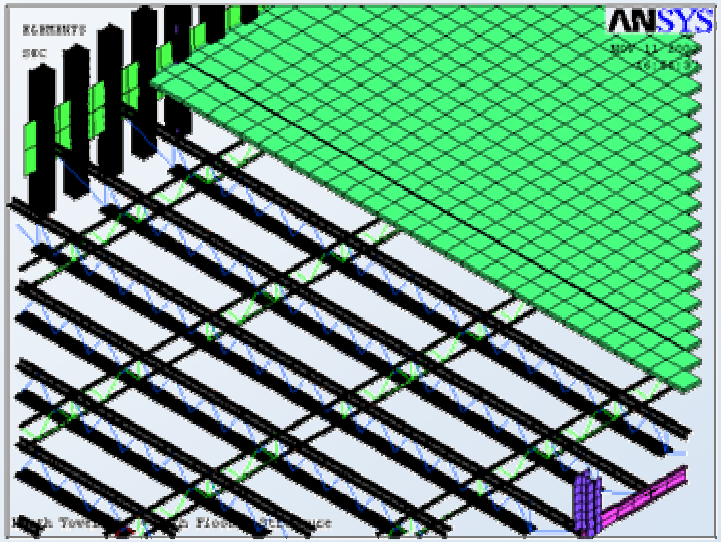


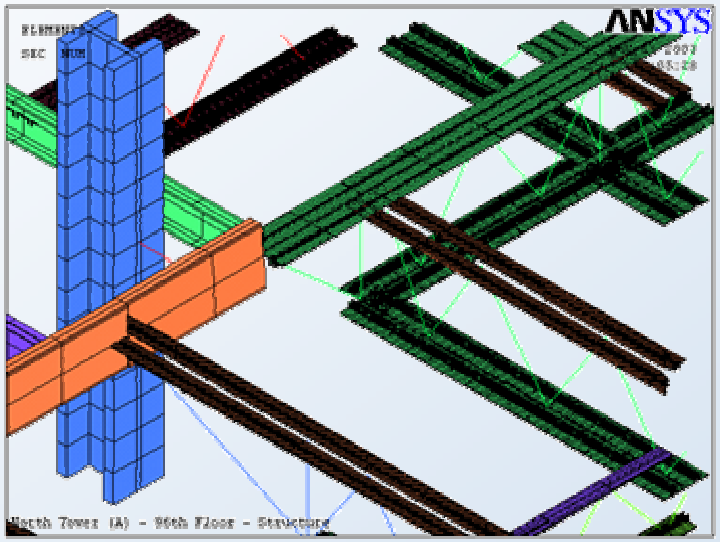
Simplified 3-D Modeling and Analysis

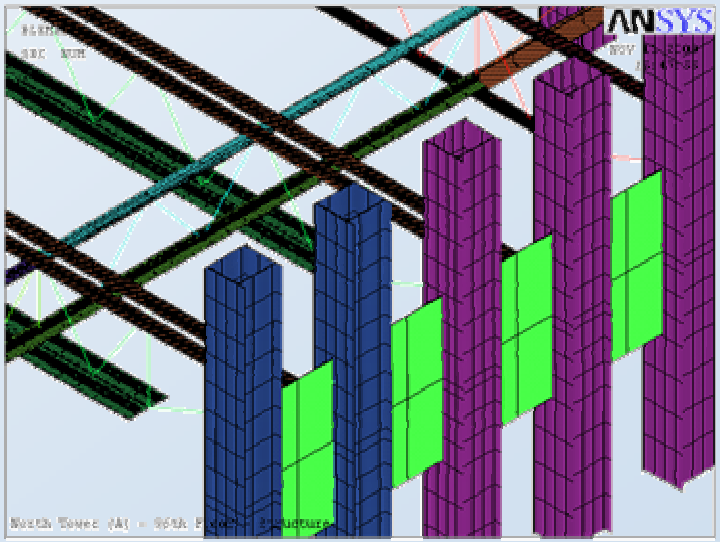
- 3-D models being developed to:
  - Validate or improve existing results on:
    - sagging of joists.
    - core columns failure scenario.
  - Examine effects of different fire scenarios, including spatial distribution, on global structural response.
  - Examine the effects of structural damage, including damage to members in the core, on global structural response.

Simplified 3-D Model









Future work

- Various fireproofing scenarios.
- Various fire scenarios consistent with observations.
- Various damage scenarios.
- Various sets of material property parameter values.
- Reliability estimates.

Summary

- Our work will:
  - Provide credible insights into failure scenarios based on quantitative, physics-based fire/structural analyses unprecedented in structural engineering.
  - Use fire/structural engineering as a unified, interdisciplinary tool.
  - Examine various hypotheses for probability estimation purposes.
  - Allow NIST to monitor contractor's work from a position of knowledge and experience.