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

WTC 7 Technical Approach and Status Summary

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NIST

WTC 7 Objectives

- Determine why and how WTC 7 collapsed;
- Determine what procedures and practices were used in the design, construction, operation, and maintenance of WTC 7; and
- Identify, as specifically as possible, areas in current building and fire codes, standards, and practices that warrant revision.

WTC 7 Investigation Approach

Obtain information on

- Building construction
- Building contents and layouts
- Debris damage to structure and fireproofing
- Fires
- Collapse sequence

Identify and evaluate possible initiating event scenarios – location and type of local failures that could have led to collapse as observed

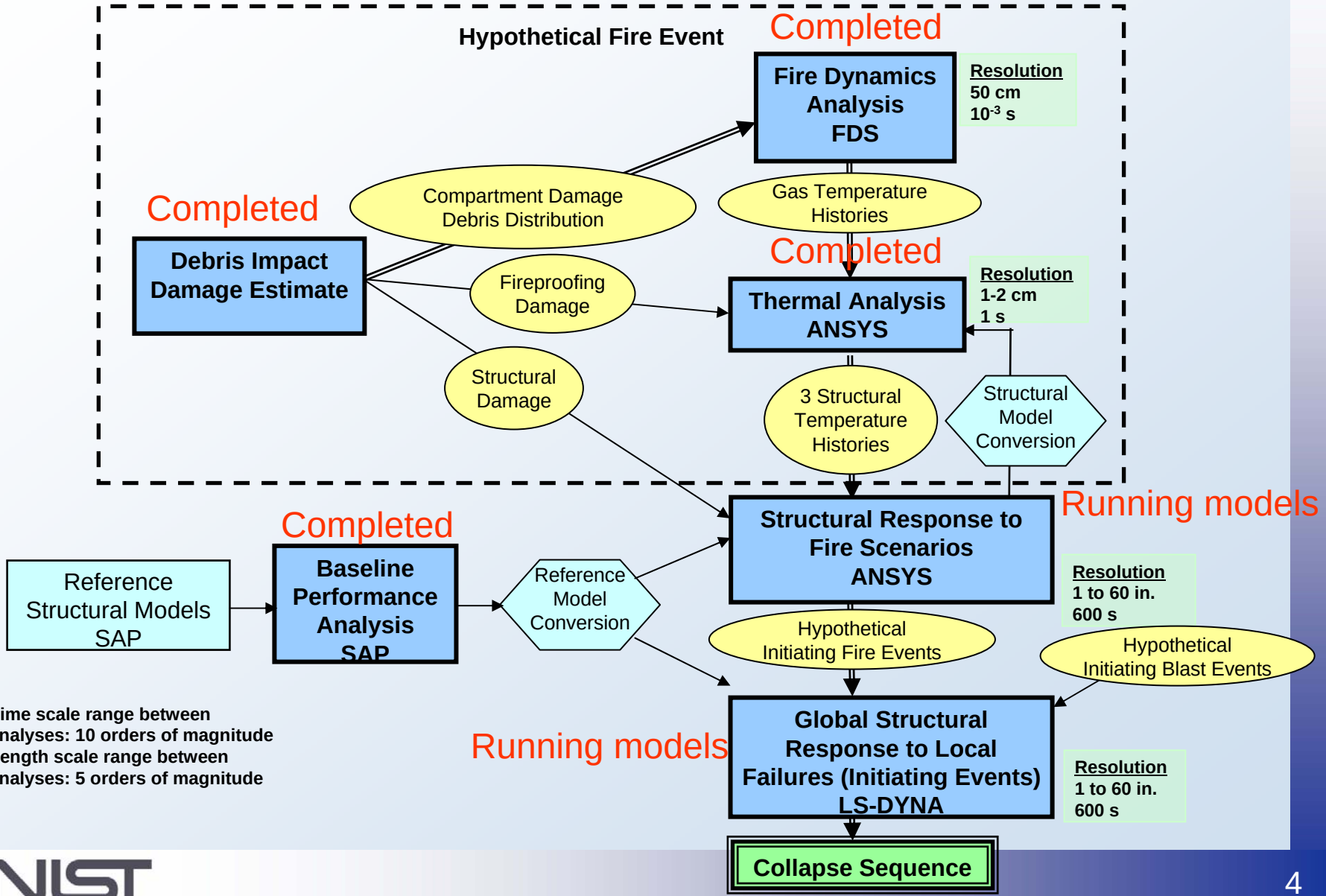
- Fire events
- Hypothetical blast events

Develop fire, thermal, and structural models and conduct analyses of

- Possible initiation mechanisms
- Fire growth and spread
- Heat transfer to structure
- Sequence of events leading to collapse

Determine probable collapse sequence

WTC 7 Critical Analysis Inter-dependencies



Significant Factors During the Investigation

- Review of additional 80 boxes of documents of modifications to WTC 7 and inspection reports.
- Elaboration of the initiating event sequence for the collapse hypothesis. Additional possible failure mechanisms required extensive analysis at the component and connection levels to ensure that these mechanisms were adequately captured.
- Acquired shop drawings (2565 drawings), which required extensive revision of connection details in the ANSYS and LS-DYNA structural finite element models.
- Significant time was required to develop, debug, enhance the efficiency of, verify, and validate the computational models of the thermal and structural response of WTC 7.

WTC 7 Working Collapse Hypothesis

- The current NIST working collapse hypothesis for WTC 7 is restated here:
  - An initial local failure occurred at the lower floors (below floor 13) of the building due to fire and/or debris-induced structural damage of a critical column (the initiating event) which supported a large-span floor bay with an area of about 2,000 square feet;
  - Vertical progression of the initial local failure occurred up to the east penthouse, and as the large floor bays became unable to redistribute the loads, it brought down the interior structure below the east penthouse; and
  - Triggered by damage due to the vertical failure, horizontal progression of the failure across the lower floors (in the region of floors 5 and 7 that were much thicker and more heavily reinforced than the rest of the floors) resulted in a disproportionate collapse of the entire structure.
- The working hypothesis for the initiating event sequence that characterizes the initial local failure is based on fire-induced failures initiating in the tenant floors:
  - Floor beams, slabs, and connections heat more quickly and to higher temperatures than the columns.
  - Elevated temperatures in the floor elements lead to thermal expansion, sagging, and weakening that result in failure of floor connections and/or buckling of floor beams.
  - Sufficient floor component failures (connections and/or beams) result in at least one long unsupported column at the lower floors, which leads to the initiation of global collapse.
- While NIST has found no evidence of a blast or controlled demolition event, it is evaluating the magnitude of hypothetical blast scenarios that could have led to the structural failure of one or more critical elements.
- The working hypothesis is based on an initial local failure caused by normal building fires, not fires from leaking pressurized fuel lines or fuel from day tanks.
- This hypothesis may be supported or modified, or new hypotheses may be developed, through the course of the continuing investigation.

Improvements to Structural Models

The ANSYS and LS-DYNA structural models are highly rigorous to capture complex failure mechanisms. NIST's use of these FEA models is advancing the state-of-the-art of computational analysis, in terms of software and hardware. Significant improvements made to the structural models include:

- Identified and incorporated possible failure mechanisms:
  - Bolt shear, weld fracture, tearout and block shear failures in connection plates or angles, beam/girder walk-off of a bearing seat, and shear stud failure
  - Lateral torsional buckling of beams and buckling of columns
- Developed (1) 18 types of user-defined break elements for the ANSYS model on floors 8 to 14, and (2) 31 types of connection sub-models for the LSDYNA model.
- Each break element contained multiple failure mechanisms, which were modeled using beam elements, contact elements, nonlinear springs, and rigid links, for:
  - 3 types of shear connections for beam-to-beam framing
  - 7 types of bearing connections for girders framing into columns
  - 1 type of shear stud connection between the steel beams and concrete slab
- To include connections (1) a total of 12,866 elements were added to the ANSYS model, and (2) 13,920 connection sub-models were added to both ends of all floor beams and girders in the LSDYNA model from floor 4 to the roof.
- The addition of connections and identified failure beam/column failure mechanisms greatly increased computational demand, slowing down the analysis when a large number of break elements failed.
- The level of detail in the models was optimized to maintain sufficient modeling fidelity, adequately capture failure mechanisms, and minimize computational times.

Accomplishments

- Elaborated the initiating event sequence for the working collapse hypothesis.
- Reviewed Manhattan Dispatch tapes for much of the day of September 11, 2001.
- Completed FDS analyses of fires on floors 7 through 13.
  - Based on observed fires in photos and videos and known floor layouts and contents
- Completed thermal analyses to transfer FDS results to structural analyses for two of three possible cases for both structural models.
  - Three possible fires are based on FDS results (gas temperatures) and +/-10% adjustment to the gas temperatures (Cases A, B, C)
- Completed hypothetical blast analysis.
- Completed analysis of 5th floor fire scenarios.
- Added possible failure mechanisms to both structural models that required extensive analysis at the component and connection levels to ensure that these mechanisms were adequately captured.
- Incorporated steel framing connection data into both structural models.
- Structural analysis of initiating events for two of three possible thermal cases nearing completion.
- Structural analysis of vertical and horizontal progression of failure in progress.

Remaining Tasks

Initiating event

- For Case A, B, and C temperatures
  - Complete 16-story analysis
  - Identify initiating event(s)

Transfer ANSYS Data to LS-DYNA Model

- Temperature files for 47-story model at time of initiating event
- List of damaged and failed connections and components from ANSYS analyses

Propagate failure through the 47-story building

- For each identified initiating event, i.e., 1 and 2:
  - Complete 47-story analysis with impact damage, temperatures, and thermally-induced damage to connections and components

Develop probable collapse sequence based on final analysis results

Write reports

- A number of report sections have been drafted and are in various stages of review and editing by the technical staff