

## 11.6 SUMMARY OF FINDINGS

A finite element model of WTC 7 was developed in ANSYS to evaluate the building structural response to the fire environment and to determine the sequence of events that led to an initial failure event (or collapse initiation event). The ANSYS model consisted of the lower 16 stories of the building. The ANSYS model included nonlinear effects, such as: nonlinear temperature-dependent material properties including thermal expansion, plasticity and creep; nonlinear geometry; and user-defined elements that captured the details of temperature dependent connection failures. The following findings are based on the ANSYS finite-element analysis of the structural response of WTC 7 to the fires observed between Floors 7 to 14:

- The failures in the floor systems were caused by the following structural responses to elevated temperatures:
  - At temperatures less than approximately 400 °C, restrained thermal expansion of beams and girders caused axial compressive forces to develop in the beams and girders, which led to the following connection failures:
    - bolt shear failure in fin, knife, and seated connections,
    - girder walk off of seated connections after all the bolts had sheared at Columns 79 and 81, and
    - failure of header connection welds.
  - The failure of the girder-to-column seated connection at Columns 79 and 81 occurred in two stages: (1) horizontal loss of support occurred when the bolts at the seated connection were sheared, primarily due to thermal expansion of the floor beams in the east floor system, and (2) further thermal expansion of the floor beams pushed the girder off the bearing seat.
  - Many floor beams on Floors 12, 13, and 14 in the east floor region had buckled prior to beam temperatures reaching 400 °C (averaged over the beam length). Floor beams buckled under the combined effects of
    - loss of lateral restraint due to failure of the majority of shear studs,
    - increased axial loads due to thermal expansion that was restrained by the exterior and interior structural frame, and
    - gravity loads from the floor slab.
  - The girders that framed into interior columns on Floor 12, 13, and 14 failed by either
    - buckling due to the combined effects of gravity loads from the floor beams, lateral displacement due to the thermal expansion in the floor beams, and increasing axial loads due to thermal expansion in the girder, or