

8.3.5 Structural Response and Collapse Analysis

- The core columns were weakened significantly by the aircraft impact damage and thermal effects. Thermal effects dominated the weakening of WTC 1. As the fires moved from the north to the south side of the core, the core was weakened over time by significant creep strains on the south side of the core. Aircraft impact damage dominated the weakening of WTC 2. With the impact damage, the core subsystem leaned to the southeast and was supported by the south and east perimeter walls via the hat truss and floors. As the core weakened, it redistributed loads to the perimeter walls through the hat truss and floors. Additional axial loads redistributed to the exterior columns from the core were not significant (only about 20 percent to 25 percent on average) as the exterior columns were loaded to approximately 20 percent of their capacity before the aircraft impact.
- The primary role of the floors in the collapse of the towers was to provide inward pull forces that induced inward bowing of perimeter columns (south face of WTC 1; east face of WTC 2). Sagging floors continued to support floor loads as they pulled inward on the perimeter columns. There would have been no inward pull forces if the floors connections had failed and disconnected.
- Column buckling over an extended region of the perimeter face ultimately triggered the global system collapse as the loads could not be redistributed through the hat truss to the already weakened building core. As the exterior wall buckled (south face for WTC 1 and east face for WTC 2), the column instability propagated to adjacent faces and caused the initiation of the building collapse. Perimeter wall buckling was induced by a combination of thermal weakening of the columns, inward pull forces from sagging floors, and to a much lesser degree, additional axial loads redistributed from the core.
- The WTC towers would likely not have collapsed under the combined effects of aircraft impact damage and the extensive, multi-floor fires that were encountered on September 11, 2001, if the thermal insulation had not been widely dislodged or had been only minimally dislodged by aircraft impact.
- In the absence of structural and insulation damage, a conventional fire substantially similar to or less intense than the fires encountered on September 11, 2001, likely would not have led to the collapse of a WTC tower.
- The insulation damage estimates were conservative as they ignored possibly damaged and dislodged insulation in a much larger region that was not in the direct path of the debris but was subject to strong vibrations during and after the aircraft impact. A robust criterion to generate a coherent pattern of vibration-induced dislodging could not be established to estimate the larger region of damaged insulation.
- For WTC 1, partitions were damaged and insulation was dislodged by direct debris impact over five floors (floors 94, 95, 96, 97, and 98) and included most of the north floor areas in front of the core, the core, and central regions of the south floor areas, and on some floors, extended to the south wall.