

6.7 Analysis

A 3-D model was developed to better understand the performance of the building in response to impact from debris and to identify specific design features that contributed to this performance. The model was developed based on information obtained from the following sources: structural drawings (Rudderman 1971–1975), *Draft Structural Engineering Evaluation for the New York Department of Design and Construction* (Nordenson et al. 2001), and personal accounts (Smilow 2001).

All major structural entities were simulated within the ANSYS model: all major framing, intermediate framing in regions of damage, steel decking/slab, columns, and vertical bracing. Given the level of modeling detail required to simulate the behavior of the structure in the regions of damage, three levels of refinement were incorporated within the model to use analytical resources more efficiently:

Level 1: No visible structural damage

Level 2: Local structural damage

Level 3: Partial or imminent collapse

Because there are no eyewitness accounts available that can clarify the order of collapse of portions of the structure, two types of analyses were considered.

Nominally, the final state of the structure could be analyzed to determine the current state of stress redistribution within existing structural members. This analysis clarifies why the damage was arrested.

A more complex analysis could be performed, namely an analysis tracking the partial progression of damage. This type of analysis consists of parametric studies performed to determine the velocity of the impact debris that was required to:

- (a) collapse the region of slab between column lines C and D at the 16th through 21st floors;
- (b) remove the exterior column D-8 below the 16th floor; and
- (c) extend the region of damaged slabs to the two bays bounded by column lines C and E.

These calculations are based on engineering principles and methods. Although they attempt to quantify the extent of the damaged regions, they provide little intrinsic value to the understanding of the building performance. It is highly unlikely the calculations would indicate a unique sequence of events resulting in the observed collapse patterns. Analyses of the surviving structure are much more informative and indicate the redundancy of the steel moment-frame system. These calculations indicate why the collapse was arrested at the 8th floor and why the region of slab loss did not extend beyond the two exterior bays on either side of column line D. Calculations demonstrating the redistribution of load could be performed statically, allowing for inelastic deformations.

Two different types of girder-column moment connections failed as a result of the debris impact, and the performance of these connections had a major effect on the extent of collapse. These two connections were analyzed to better understand their capacity to resist extreme loading. Although the design drawings show some connection information and the observations of the damaged building (Smilow 2001) identified some critical dimensions, there was not enough information to develop detailed finite element models. Therefore, parametric evaluations based on engineering judgment were required to identify the trends in the reserve capacities of these critical connections.

At the time this report was published, a parametric study had been completed to determine the behavior of typical moment connection details in preparation for a subsequent suite of full 3-D frame parametric studies. This suite of calculations was not completed in time for inclusion in this report.