

- loss of vertical support due to girder walk off the bearing seat, or due to thermally-induced failure of a connection.
- Loss of lateral support to Columns 79, 80, and 81 resulted from the failures of the girders to the north, west, and south, and the floor beams to the east, where
 - girders between Columns 79 and 80 and Columns 80 and 81 buckled on Floor 13, due to the combined effects of thermal expansion and the lateral displacement caused by the thermal expansion in the east floor beams,
 - girders west of Column 79 failed due to tensile weld failures in the knife connections on Floors 10, 11, and 12 from restrained thermal expansion on other floors,
 - girder west of Column 80 failed due to weld failures in the header connections on Floor 14,
 - girders between Columns 44 and 79 and Column 26 and 81 failed due to girder walk off of the bearing seat,
 - The buckling failure of the east floor beams and exterior columns was caused by restrained thermal expansion and failure of the shear studs along the beam length.
- Restrained thermal expansion of slabs, particularly in locations where fires were directly heating the slab, resulted in a compressive failure of the concrete slab (crushing) and reduced slab stiffness.
- The simple shear connections used in the typical floor framing were not able to resist the axial compressive forces that developed in the floor framing due to thermal expansion effects that were restrained by the structural system.
- The failure of the girder-to-column seated connection at Columns 79 and 81 was primarily caused by thermal expansion of the long span floor beams in the east tenant floor.
- Additional factors that contributed to the girder failures were the absence of shear studs that would have provided lateral restraint and the one-sided framing of the east floor beams, which pushed laterally on the girders.
- Columns 79, 80, and 81 were not thermally weakened by elevated temperatures since temperatures in the columns rarely exceeded 300 °C.
- An increase in the SFRM thickness on the floor beams, from 0.53 in. to 0.625 in. or 0.75 in., would have delayed heating of the floor beams by 10 min to 20 min, which was unlikely to have prevented the heating, thermal expansion, and damage of the floor system that led to collapse initiation.
- The temperature differences between Case B and C were not sufficient to produce different failure patterns, and both cases resulted in similar damage (i.e., location and degree) to the floors with a time lag between the two solutions.