

Thermal Effects on Concrete Floors

Thermal expansion of concrete floors was restrained by the surrounding unheated slab sections, the interior and exterior columns, and shear studs at the floor beams and exterior spandrel beams. Restraint of thermal expansion led to compressive failure of the concrete slab through crushing, which softened the slab in tenant floor areas, and also led to loss of composite action with the floor beams. This failure mechanism usually occurred at slab surface locations where fires were burning, which led to much higher slab temperatures in a localized area.

Slab tensile failures were related to the response of floor beams and girders to thermal effects. When beams and girders failed at their connections, affected slab section cracked under tensile stresses where reverse curvature in the slab occurred over adjacent intact girders.

Floor Failures Leading to an Initial Failure Event

After 4.0 h of heating, the floor framing and slabs at Floors 8 to 14 were weakened by fires, and Columns 79, 80, and 81 had lost lateral support at several floors due to the failure of connections, floor beams, and girders. The fire-induced failures of the floor framing resulted in increased unsupported column lengths for Columns 79, 80, and 81, as shown in Figure 11–49, where floor beams or girders that failed (by either buckling or end connection failure) are shown as red and intact members are shown as blue.

In the east-west direction, Columns 79 and 80 were laterally supported by one member that was directly connected to the columns at each floor, while Column 81 had two members providing lateral support, as shown in Figure 11–49. The east floor beams could only provide lateral support to Columns 79, 80, and 81 as long as the girders were intact. The floor beams with fin connections provided indirect lateral bracing to Columns 79 and 80, as the beams framed into the girders at locations close to the columns. In the north-south direction, Columns 79, 80, and 81 were laterally supported by two girders that were directly connected to the columns. Neglecting the lateral support provided by the east floor beams at Columns 79 and 80, the unsupported lengths for these columns at 4.0 h can be described as follows: Column 79 was laterally unsupported at three floors in the east-west direction and one floor in the north-south direction, Column 80 was laterally unsupported at one floor in the east-west and north-south directions, and Column 81 was laterally unsupported at one floor in the north-south direction. (Even though there were three failed girders on the south side, there was one failed girder on the north side, so lateral support was still provided at the floors above and below the failed girder.)

As noted previously, the ANSYS analysis used a non-linear static procedure with an implicit solution algorithm that solved for equilibrium at each time step, but did not account for the dynamic effects of falling debris from framing failures in the floor systems. Based on engineering judgment and preliminary analyses in LS-DYNA, which included the effects of dynamics caused by debris impact from failed floor sections, the level of failures, damage, and thermal weakening in ANSYS at 4.0 h was identified as likely to result in an initiating event in an LS-DYNA analysis. The procedures used for transferring the ANSYS data to LS-DYNA are discussed in Section 11.5.