

By 4.0 h of heating, there was substantially more damage in the WTC 7 structural system, particularly the loss of lateral support to Column 79 after the failure of girder connections at Floors 10, 11, 12, and 13. Floor beams, girders and floor slab sections at Floors 8, 10, 11, 12, 13, and 14 were damaged in the vicinity of Column 79, primarily from the effects of thermal expansion within the structural system. All the north-south girders framing into Columns 79, 80, and 81 on Floor 13, and the east floor beams, had been damaged. The girder between Columns 44 and 79 had walked off the bearing seat at Column 79 on Floor 13, and all 4 bolts had failed on Floor 14 and two to three bolts had failed on Floor 12 at this seated connection. The girder between Columns 79 and 80 and Columns 80 and 81 had buckled on Floor 13. The girder between Columns 81 and 26 had buckled and walked off the bearing seat on Floor 12. Approximately one-half to three-quarters of the east floor beams had a connection damage level of 0.75-0.99 on Floors 11, 12, and 14.

Thermal Effects on Columns

None of the columns reached temperatures over 300 °C and, therefore, did not buckle due to fire-induced thermal weakening (thermal weakening occurs at temperatures greater than about 500 °C). The interior columns were not thermally restrained, so they could not develop increased loads due to thermal expansion. The exterior columns had some restraint to thermal expansion, due to the moment frame construction of the exterior framing. However, the exterior columns tended to have lower temperatures than the interior columns as they were only heated on one side and the heat was dissipated to the outside. Thermal expansion of either interior or exterior columns had little or no effect on the failure mechanisms that occurred in the floor systems.

Thermal Expansion Effects on Shear Studs

Before the floor beams could exert an axial force on the interior girders, the shear studs had to have failed. Shear stud failures in WTC 7 were found to be primarily due to differential thermal expansion effects as the floor beams heated more quickly than the concrete slab. The capacity of a shear stud connector in a concrete slab was found to be 19.4 kip (Section 11.2.3). For 28 shear studs on each floor beam, the shear force required to fail all of the shear studs was approximately 545 kip.

The interior girders connecting Columns 44, 79, 80, 81, and 26 were non-composite and floor beams framed into one side of these girders. The less stiff interior girders allowed the floor beams to thermally expand toward the girders, but the concrete slab was restrained by the surrounding floor slab. When a northeast corner floor beam was heated to an average temperature of 100 °C, the floor beam exerted an axial force of up to 950 kip on its shear studs, significantly greater than the capacity of 545 kip.

Shear stud failures also occurred when fires caused local thermal expansion in the concrete slab (the floor surface where the fire was burning) such that compressive failure by concrete crushing occurred in the slab, causing the shear studs to become ineffective. This type of failure occurred in the southwest floor slab of Floor 11 where fires burned on the slab surface. There were fin connection failures along the girder between Columns 26 and 81 and a buckled floor beam, even though there were no fires on Floor 10.

Once the shear studs failed, the floor beams were no longer laterally restrained. Clearly, this was the case if the shear stud connector failed at its weld. If a shear connector failed through crushing of the concrete