

Fully developed building fires can generally attain average gas temperatures throughout the room containing the fire in excess of 1,000 °C (1,800 °F). The temperature measurements acquired in experiments involving office furnishings conducted by DeCicco, et al. (1972) in the Hudson Terminal Building (30 Church Street, New York), along with the two time-temperature curves from the standard tests is presented in Figure A-3. Temperature development in the first 5 minutes in the room space is notably similar in the experiment with that in ASTM E1529, UL 1709, and the bare thermocouple temperatures for ASTM E119.

Greater temperatures may be acquired locally in a room and especially within flames. Research has indicated that, in the center of flames generated by relatively small fires, temperatures may approach 1,300 °C (2,400 °F) (Baum and McCaffrey 1988). For larger fires, where radiation losses may be reduced, it is conceivable that fire temperatures could reach 1,400 °C (2,550 °F), although this has not been confirmed experimentally.

A.3.1.7 Factors Affecting Performance of Steel Structures in Fire

Several factors influence the behavior of steel structures exposed to fire. The more significant factors are discussed in the following sections.

Loading: One of the major factors that influence the behavior of a structural steel member exposed to fire is the applied load (Fitzgerald 1998, Lie 1992). A loss of structural integrity is expected when the applied loading exceeds or is equal to the ultimate strength of the member. The limiting temperature and the fire resistance of the member increases if the applied load decreases. Traditional fire resistance tests apply a load that results in the maximum allowable stress on the structural member resistance.

Connections: Beam-to-column connections in modern steel-framed buildings may be either of bolted or welded construction, or a combination of these types. Most are designed to transmit shears from the beam to the column, although some connections are designed to provide flexural restraint between the beam and column, as well, in which case they are termed “moment resisting.” When moment-resisting connections are not provided in a building, diagonal bracing or shear walls must be provided for lateral stability. When fire-induced sagging deformations occur in simple beam elements with shear connections, the end connections provide restraint against the induced rotations and develop end moments, reducing the mid-span moments in the beams, as well as the tensile catenary action. The moment and tension resisted by connections reduces the effective load ratio to which the beams are subjected, thereby enhancing the fire resistance of the beams as long as the integrity of the connection is preserved. This beneficial effect is more pronounced in large multi-bay steel frames with simple connections. Connections are generally not included as part of the assembly tested in traditional fire resistance tests. Further, most modeling efforts assume that the pre-fire characteristics of a connection are preserved during the fire exposure.

The investigating team observed damaged connections in WTC 5. For example, distorted bolts and bolt holes were found. The performance of connections seem to often determine whether a collapse is localized or leads to progressive collapse. In the standard fire tests of structural members, the member to be tested is wedged into a massive restraining frame. No connections are involved. The issue of connection performance under fire exposure is critical to understanding building performance and should be a subject of further research.

End Restraint: The structural response of a steel member under fire conditions can be significantly enhanced by end restraints (Gewain and Troup 2001). For the same loading and fire conditions, a beam with a rotational restraint at its ends deflects less and survives longer than its simply supported, free-to-expand counterpart. The addition of axial restraint to the end of the beam results in an initial increase in the deflections, due to the lack of axial expansion relief. With further heating, however, the rate of increase in deflection slows.