RESTRAINED VS. UNRESTRAINED:

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As a result of confusing changes to the Underwriters Laboratories (UL) Fire Resistance Directory and various U.S. model building codes, many engineers are over-specifying fire protection for steel framed buildings, according to a new report by Richard Gewain of Hughes Associates, Inc., and Emile W.J. Troup, a consultant and structural engineer based in New England. In many cases the over-specification results in a 25-50% addition in fire protection, which adds as much as $0.25/sq. ft. to the cost of construction. These numbers become especially troubling in light of actual fire performance. According to Gewain and Troup's review of fire data, there is no evidence of any life safety problems due to structural failure during a fire in a modern steel-framed building in the U.S.

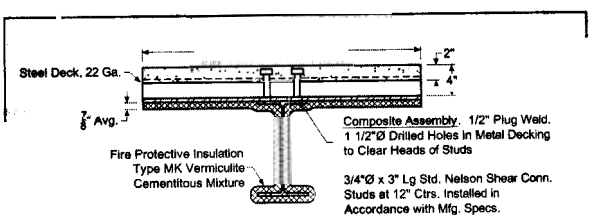
View of Cardington Test Building during fire exposure.

Beam in Cardington Tests after reaching temperature in excess of 1600°F.

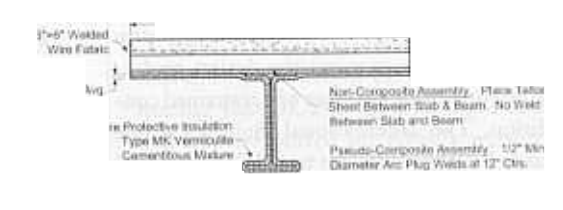
Much of the confusion rests with the concept of "restrained" and "unrestrained." Introduced in the late 1960s (and unique to North America), the concept of restraint as it relates to fire protection is poorly understood—and probably unnecessary. Although similar terminology is frequently used in structural design, in the context of fire engineering it should be emphasized that restrained ratings relate solely to resistance to thermal expansion. And, according to Gewain and Troup's review of actual fire data, full-scale fire tests and analytical modeling, steel-framed buildings should be classified as restrained for purposes of specifying fire protection. The new report, which was prepared in conjunction with the AISC-AISI Task Force for Fire Engineering of Structural Steel Buildings, provides information that will enable architects and engineers to satisfy code provisions requiring justification where fire resistance for steel beam floor and roof systems are based on "restrained assembly" ratings. The Task Force included a wide range of interdisciplinary experts from both the national and international fire safety and structural community.

When the dual classification was first introduced, the ASTM E-5 Fire Test Committee clearly recognized that architects, structural engineers, and building officials would have a hard time properly applying restrained and unrestrained ratings to the design of actual buildings. As a result, an appendix was added to ASTM E119 (Appendix X3) to provide guidance to designers and code officials.

Prior to 1992, the UL Fire Resistance Directory included a similar appendix. Unfortunately, in 1993 the appendix was deleted from the UL Directory in favor of an abbreviated discussion (interestingly, even today the Design Information Section Directory continues to directly reference the now deleted appendix). A careful review of the current (1999) Fire Resistance Directory indicates that UL has decided to concentrate on describing its own unique test conditions and to defer to nationally recognized standards for guidance on the application of restrained and unrestrained ratings,

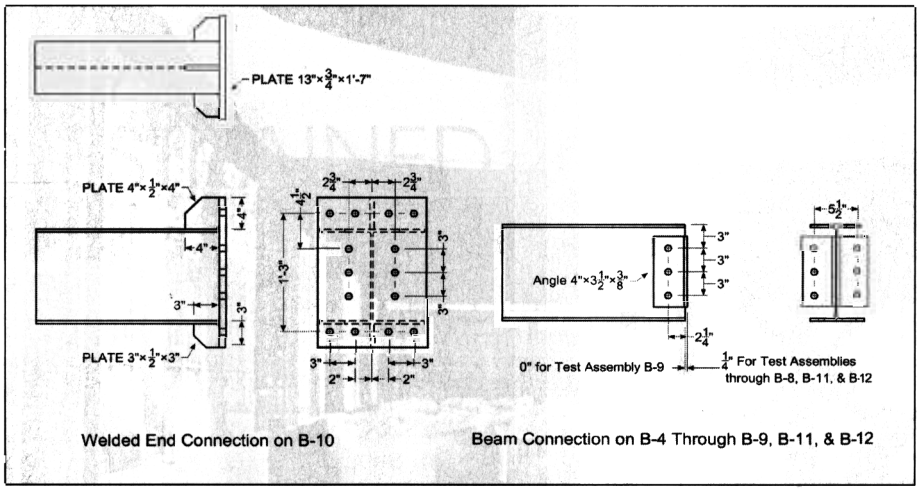


Beam and Deck Test Assembly

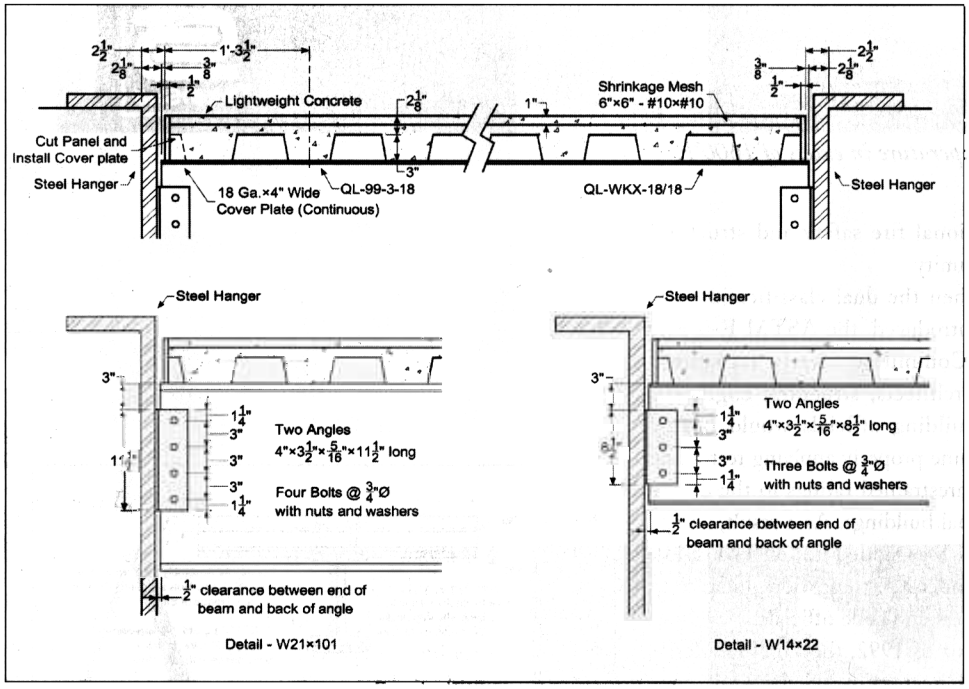


Beam and Deck Test Assembly

Details of construction of steel beam and floor assemblies in the Ohio State University fire tests.



Connection details for the beam assemblies in the Ohio State University fire tests.



Steel beams in Underwriter's Laboratories, Inc. fire tests.

Gewain and Troup point out. While the Standard and National Building Codes adopt ASTM E119 by reference, the Uniform Building Code requires the design professional to provide evidence of a restrained condition. The International Building Code takes a slightly different tack. While the IBC references the ASTM E119 Standard Fire Test, it also states that for an assembly to be considered restrained, evidence satisfactory to the building official must be furnished. Fortunately, a long history of fire testing and actual fire performance provides substantial evidence that steel-framed buildings should be considered as restrained construction.

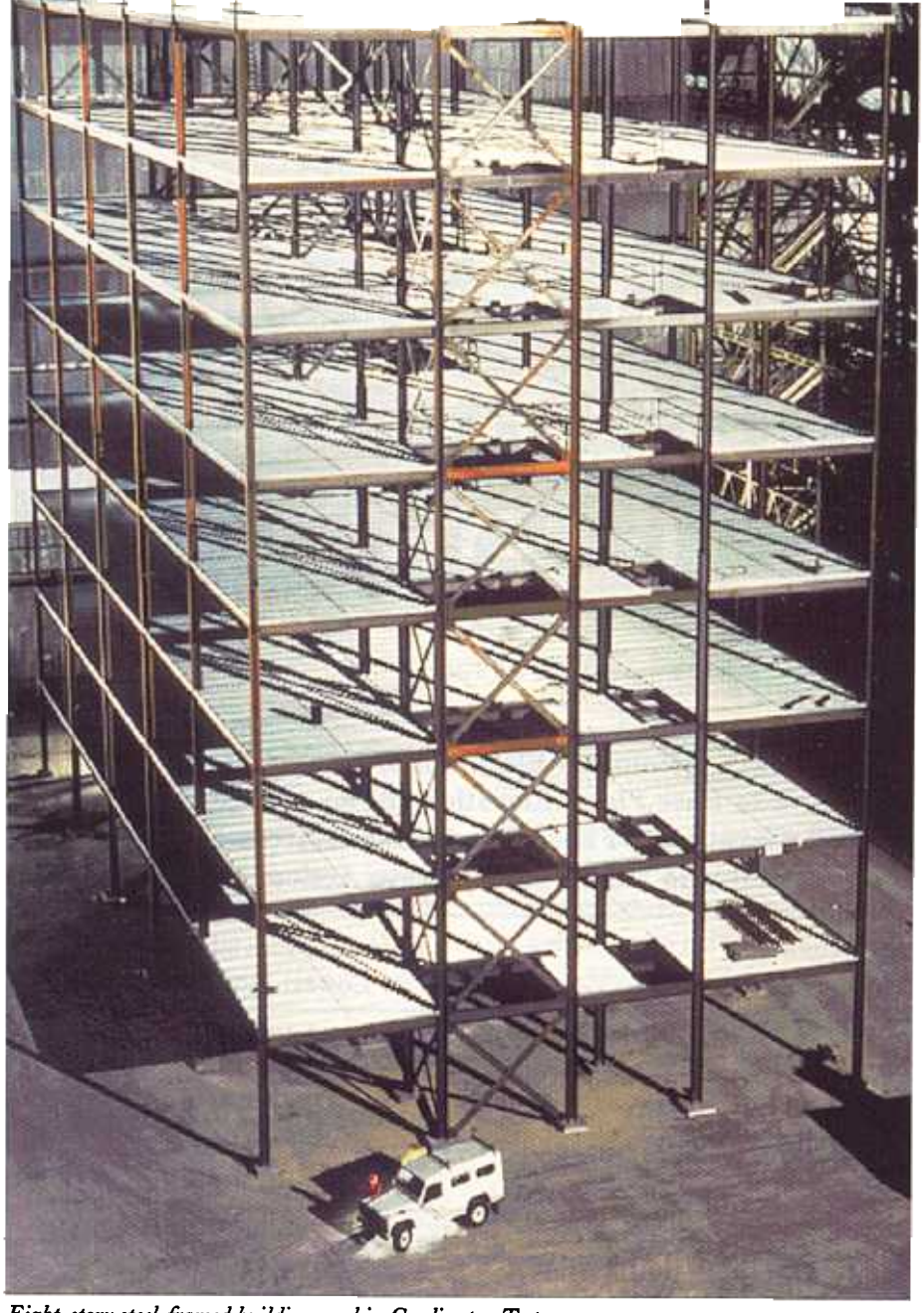
For example, test assemblies fire tested at Ohio State University in 1965 were instrumented with strain gages placed on the steel beams loaded according to ASTM E119. The vertical loads calculated by accepted engineering procedures to impose design allowable stresses in the steel beams actually imposed measured initial working stress in the range of 18 to 36 percent below the design stresses for the beam assemblies involved in this study. These measured stresses are consistent with measured working stresses observed in ASTM E119 fire tests of floor or roof and beam assemblies. Thus it was shown that extended fire endurance experienced with some E119 tested floor assemblies must have resulted from load or moment redistribution. The boundary conditions in a building at the time a fire occurs are different than those in the ASTM E119 fire test. In actual buildings, it can be expected that these stress levels will be even lower since the tested beams in the OSU fire tests only had a steel deck/concrete slab not more than 3' wide. Very little if any load redistribution takes place in the ASTM E119 beam-only tests, unlike the beam loading in the E119 floor test or in actual building fires. Again, for all practical purposes, as long as the floor slab is more than 3'-wide, steel-framed buildings can be considered restrained, according to Gewain and Troup.

Another relevant fire test involved three simply supported beams with pin connections (simple clip angle bolted connections). These were found to perform equivalently to beams jammed into the UL restraining frame. The UL Test Report concluded:

"Summarizing, there does not appear to be significant differences in the fire resistance performance of restrained beams that are shimmed against the test frame as compared to restrained beams that are bolted to clip angles in the manner described in this Report. Thus, this test confirmed that beams with bolted connections should be considered as restrained beams."

During the 1980s, AISI funded an analytical study by Wiss, Janney Elstner and Associates (WJE) to review the OSU fire data. WJE, utilizing FASBUS II software, validated the practical classification of restrained construction for structural steel in ASTM E119, Table X3.1.

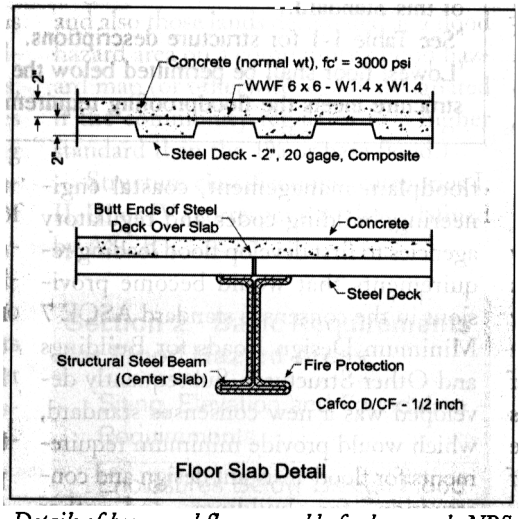
Two more recent studies, the Cardington Fire Tests in 1995-1996 and a 1997 analytical study of restrained/unrestrained fire ratings by Socrates Iaonnides and Sandeep Mehta of Structural Affiliates International both add further credence to the conclusion that essentially all steel-framed construction should be considered as restrained. In fact, Iaonnides and Mehta's work went so far as to conclude that, considering the combination of factors that occur in real buildings during real fires, steel beams, protected with spray-



Eight-story steel-framed building used in Cardington Tests.

applied fire protection material thicknesses for "restrained" beams, can have sufficient load-carrying capacity without even counting on any restraint.

While there is limited data on actual fires in high-rise steel-framed buildings in the U.S., the available studies do support a restrained rating for steel construction. One of the most comprehensive reports was prepared by Robert Dexter, now with the University of Minnesota, and Le-Wu Lu of Lehigh University. The report studied an intensive 1991 high-rise fire in an east coast city that caused a complete burnout of eight upper stories over an 18-hour period—being halted only at the 30th floor by sprinklers that were being retrofitted into the building from the top floor downward. Although there was considerable distress to steel floor assemblies (originally fire-protected based upon a restrained rating classification), there were no reported floor collapses.



Details of beam and floor assembly for large scale NBS tests.

Based on analysis of more than a quarter century of research and development, Gewain and Troup's report presents the following conclusions:

The "unrestrained assembly" fire resistance rating for structural steel beam floor and roof systems, based on ASTM E119 temperature criteria only, has no relevance to the behavior of these systems under uncontrolled fires in real buildings.

The fire endurance of structural steel beam floor and roof construction under uncontrolled fire is enhanced by the interaction of the beams with the other structural elements and constructions that are integral with or surround the exposed assembly.

All steel beam connections to other structural steel members exhibit both axial and rotational restraint. The least stiff connection is adequate to develop restrained assembly performance under uncontrolled fire exposure.

Conclusions drawn from the fire research and computer modeling that have been performed by various agencies, including Underwriters Laboratories, Inc., support the conclusion that a restrained assembly classification and fire protection design is most appropriate for steel beam floor and roof assemblies, and verify the guidance contained in ASTM E119-00, Appendix X3.

The performance of structural steel beam and concrete floor systems exposed to uncontrolled fires observed during the research and analysis studies conducted during the past 25 years largely explains the excellent performance of these systems during severe fire exposures in un-sprinklered, modern high-rise buildings.

Gewain and Troup's full paper is scheduled to be published in the AISC's Engineering Journal, 2nd Quarter 2001 and will also be posted on AISC's website **www.aisc.org.**