were spaced 24 in. on center. The floor consisted of a base layer of 3/4 in. Douglas fir plywood and a top layer of 3/8 in. Douglas fir exterior grade plywood. The ceiling consisted of a layer of 5/8 in. USG, Firecode C gypsum wallboard. The wallboard was attached by nails. The bridging was nominal 1 x 3 Southern Pine. Holes were drilled in each of the joist webs in accordance with a 1969 Trus Joist I-series publication.

The completed assembly was allowed to air dry in the normal atmosphere of the laboratory for a minimum of seven days to assure dryness of the joint compound.

A superimposed load of 1,389.6 lbs./joist was applied to the assembly at the start of the test. This load, in addition to the dead load of 192.4 lbs./joist, applied a design allowable shear of 791 lbs. to each joist, based upon data published by the sponsor.

Test Method Used: ASTM E119.

Report Observations: Exposed and unexposed surface observations surface temperatures, furnace temperatures, and deflection performance were all measured.

Report Summary: The test assembly failed to support the superimposed load at 48 min. Average deflection along the centerline of the assembly was 3.6 in. At the termination of the test, the center-most point of the assembly showed a deflection of 4.58 in. No unusual exposed or unexposed surface observations were made.

> **Comments:** THIS TEST ADDRESSES THE FIRE ENDURANCE PERFORMANCE OF I-JOISTS. THE TEST DURATION ALLOWS FOR A 45-MINUTE RATED ASSEMBLY. A CALCULATION OF THE FINISH RATING HAS BEEN MADE FROM THE TEST DATA, AND IS INCLUDED IN THE TABLE AT THE END OF THIS SECTION. THIS ALSO SHOWS PERFORMANCE SOMEWHAT SIMILAR TO WOOD JOISTS PROTECTED WITH A SINGLE LAYER OF GYPSUM BOARD, WHICH ALSO ACHIEVED A 45-MINUTE RATING. THE DIFFERENCE IS THE TYPE OF WALLBOARD USED—5/8-IN. TYPE C VERSUS 1/2-IN. TYPE X, WHICH IS SIGNIFICANT. UNFORTUNATELY, FAILURE TIMES ARE NOT PROVIDED FOR THE 1/2-IN. TYPE X DATA; THEREFORE, IT IS DIFFICULT TO DETERMINE JUST HOW SIGNIFICANT THIS PERFORMANCE DIFFERENCE IS.

4-2.4 Report: Floor/Ceiling Wood Truss Assembly Design FC-235

Author: W.R. Price and W.F. Shield, Factory Mutual Research

Sponsor: Truss Plate Institute

Date: August 6, 1976

Basic Test Description: The floor assembly consisted of floor trusses, 12 in. deep with nominal 2 x 4 wood chords and webs. The floor trusses were 17 ft., 5 in. long, and were spaced 24 in. on center. The floor was a single layer of 3/4 in. thick plywood with vinyl asbestos tile attached to it. The ceiling was a single layer of 5/8 in. Type FSW (or Type C) gypsum wallboard, produced by National Gypsum Company, and was secured directly to the bottom chords of the trusses.

Test Method Used: ASTM E119.

Report Observations: Observations were made of the exposed and unexposed surface, deflection measurements of the floor were made, and the temperature of the unexposed surface, plenum and furnace were measured.

Report Summary: The assembly was subjected to a uniformly distributed live load of 50.1 psf, which resulted in a combined live and dead load of 57.4 psf. The deflection at the center of the assembly at 50 min. was 3.5 in. There were no unusual occurrences based on the observations made for both the unexposed and exposed surfaces during the test. The test was terminated at 50 min. when the assembly failed to support the superimposed load. The finish rating was calculated to be 24 min.

> **Comments:** THIS TEST GIVES AN INDICATION OF THE PERFORMANCE OF METAL PLATE CONNECTED WOOD TRUSSES WITH SINGLE LAYER GYPSUM PROTECTION. THE GYPSUM BOARD USED WAS IDENTICAL TO THAT USED IN THE I-JOIST TEST ABOVE.

4-2.5 Report: Floor/Ceiling Truss Assembly Design FC-240

Authors: W.R. Price and W.F. Shield, Factory Mutual Research

Sponsor: Truss Plate Institute

Date: April 13, 1977

Basic Test Description: The floor assembly consisted of floor trusses 12 in. deep with nominal 2 x 4 wood chords and webs, and were 17 ft., 5 in. long. Trusses were spaced 24 in. on center. The floor was a single layer of 3/4 in. thick tongue-and-groove plywood. The ceiling was a single layer of 5/8 in. thick Firecode C gypsum wallboard manufactured by USG secured to furring channels attached to the bottom chords of the trusses. The furring channels, manufactured by USG and designated as RC-1 resilient channels, were installed perpendicular to the trusses, and located 16 in. on center.

Test Method Used: ASTM E119.

Report Observations: Observations of the exposed and unexposed surfaces were made, and the deflection of the floor, the temperature of the furnace, plenum, and unexposed surface, and time of failure of the assembly were recorded.

Report Summary: The assembly was subjected to a uniformly distributed live load of 50.7 psf, which resulted in a combined live and dead load of 57.8 psf. There were no unusual observations of either the exposed or unexposed surfaces during the test. The maximum deflection of the floor occurred at 58 min., where the center-most deflection was 2.13 in. The test was terminated at 58 min., when the assembly failed to support the superimposed load. The finish rating was calculated to be 26 min.

> **Comments:** THIS TEST HIGHLIGHT THE EFFECTS OF RESILIENT CHANNELS ON TRUSSES WITH ALL OTHER FACTORS BEING EQUAL. IN THIS CASE, THE RESILIENT CHANNEL ADDED APPROXIMATELY 6 MIN. TO THE PERFORMANCE OF THE ASSEMBLY, CALCULATED AS FOLLOWS:
>
> $$|(50 - 24) - (58 - 26)| = 6 \text{ MIN.}$$
>
> THIS CALCULATION ACCOUNTS ONLY FOR PERFORMANCE AFTER THE FINISH RATING WAS MET FOR THE MEMBRANE, AND IS CERTAINLY NOT ABSOLUTE FOR ALL CASES. IT ONLY PROVIDES AN INDICATION.

4-2.6 **Report:** Standard ASTM Fire Endurance Truss Test Project 4816

Authors: R.W. Bletzacker and J.G. Birle, Ohio State University

Sponsor: Trus Joist Corporation

Date: September, 1969

Basic Test Description: The joists tested were 14 in. deep, 15 ft., 10.25 in. long TJL-series joists. The joists were spaced 24 in. on center. The floor consisted of a base layer of 3/4 in. thick Douglas fir plywood and a top layer of 3/8 in. thick Douglas fir plywood. The ceiling consisted of a layer of nail-attached 5/8 in. thick USG sheetrock, Firecode C, gypsum wallboard. Bridging consisting of a 2 x 6 was placed perpendicular to the trusses.

The completed assembly was allowed to air dry in the normal atmosphere of the laboratory for a minimum of seven days to assure dryness of the joint compound. A superimposed design load of 199.8 lbs./lineal ft. was applied at the start of the test. The load was calculated to impose the maximum allowable working stress on the joist.

Test Method Used: ASTM E119.

Report Observations: Observations of both the unexposed and exposed surfaces of the test assembly were made; assembly deflection measurements, temperature of the furnace, plenum and unexposed surface were recorded during the test.

Report Summary: There were no unusual observations noted for the exposed or unexposed surfaces during the test. The center-most deflection at 45 min. was 1.03 in. The average deflection along the centerline of the test at 45 min. was .87 in. The assembly could no longer support the applied load at 48 min. The finish rating for this assembly was calculated to be 22 min.

> **Comments:** THIS TEST PROVIDES ADDITIONAL INFORMATION ON SINGLE LAYER GYPSUM PERFORMANCE ON ANOTHER ENGINEERED SYSTEM. IT APPEARS THAT SINGLE-LAYER 5/8 IN. TYPE X OR TYPE C SYSTEMS DIRECTLY ATTACHED TO THE STRUCTURAL MEMBER GENERALLY YIELD 45-MINUTE FIRE ENDURANCE RATINGS.

4-2.7 **Report:** Fire Endurance of Light-Framed Miscellaneous Assemblies, Taken from, "Investigation on Building Fires, Part V," By N. Davey and L.A. Ashton

Author: M. Galbreath

Sponsor: National Research Council of Canada

Date: June, 1966

Basic Test Description: The test consisted of regular 1/2 in. Gypsum board directly applied to 2 x 9[1] solid-sawn joists spaced 16 in. on center. One inch nominal tongue-and-groove boards were applied to the top of the joists. The joists were 12 ft. clear span, simply supported. The load applied to the test floor was 60 lbs./ft^2.

Test Method Used: It is assumed that the test method used was ASTM E119.

Report Observations: Thermocouples were used to measure the unexposed surface temperature between floor and the ceiling and the furnace temperature. Test duration, mode of failure, and behavior of the floor were all measured.

Report Summary: The test lasted 33 min., until there was an appearance of flame on the surface, and the assembly collapsed into the furnace. Gypsum board began to fall away from the joists at 18 min., and had completely fallen off the joist at 27 min.

> **Comments:** THIS TEST INCLUDED A VARIETY OF ASSEMBLIES. THIS TEST IS INCLUDED BECAUSE IT GIVES AN INDICATION OF THE CONTRIBUTION TO FIRE ENDURANCE OF 1/2 IN. REGULAR GYPSUM WALLBOARD. THE JOISTS APPEAR TO HAVE BEEN NOMINAL 2 X 10, BUT THEY MAY HAVE ACTUALLY HAD THE FULL 2 IN. DIMENSION RATHER THAN THE 1.5 IN. DIMENSION USED TODAY. ONE PROBLEM WITH USING OLDER DATA IS THAT THE STRUCTURAL WOOD JOISTS USED TODAY ARE SIZED DIFFERENTLY THAN THOSE USED IN 1966. THE JOISTS USED TODAY ARE ALSO DIFFERENT THAN THOSE USED 10 YEARS AGO,

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[1] Nominal 2 x 10 is assumed to be meant here.

DUE TO CHANGES IN TIMBER RESOURCES AND CHANGES IN DESIGN VALUES OVER THAT PERIOD OF TIME.

4-2.8 Report: BMS 92 Fire Resistance Classifications of Building Constructions

Authors: Subcommittee on Fire Resistance Classifications of the Central Housing Committee on Research, Design and Construction

Sponsor: United Stated Department of Commerce and the National Bureau of Standards

Date: October 7, 1942

Basic Test Description: Testing was performed on joists of 2 x 10 Southern Pine or Douglas fir #1 Common or Better Grade, using a subfloor of 3/4 in. wood sheathing, a diaphragm of asbestos paper, and finish tongue-and-groove wood flooring. The ratings apply for loadings developing not more than 1000 lbs./in^2 maximum fiber bending stress in the joists. Spacing is assumed to be 16 in. on center.

Test Methods Used: The fire tests were conducted in accordance with the Standard Specifications for Fire Tests of Building Construction and Materials, ASA No. A2-1934 (precursor to ASTM E119). The results of fire tests conducted at the National Bureau of Standards were used as a basis for the ratings. The ratings, in general, were taken directly from test results, and represent the lower average of results.

Report Observations: 1/2 in. thick gypsum wallboard secured with 1.75 in. No. 12 gauge nails spaced 6 in. on center was found to have a fire resistance rating of 25 min. and provide protection for the wood joists of 15 min. Two layers of 3/8 in. gypsum wallboard using 1.5 in. No. 15 gauge nails spaced 6 in. on center were found to have a fire resistance of 30 min. and provide protection for the wood joists of 20 min.

> **Comments:** THESE TESTS ADDED TO PROVIDE INFORMATION ON REGULAR GYPSUM WALLBOARD PERFORMANCE IN CONTRAST WITH TYPE X OR TYPE C THAT IS TYPICALLY APPLIED.

4-2.9 Report: Fire Performance of Selected Residential Floor Constructions Under Room Burnout Conditions, NBSIR 80-2134

Author: J.B. Fang

Sponsor: United States Department of Housing and Urban Development

Date: December, 1980

Basic Test Description: For general information, see **Section 4-1.13** in **Chapter 4-1: Fire Endurance Performance of Unsheathed Assemblies.**

Test 5: This assembly consisted of C-shaped 18 gauge galvanized steel joists, 7.25 in. deep spaced 24 in. on center. A 23/32 in. subfloor was applied to the top of the joist upon which was placed an Olefin carpet with foam rubber backing. The joists were protected with a 1/2 in. thick regular gypsum board ceiling.

Test 6: This assembly consisted of 12 in. deep x 3.5 in. wide x 11 ft., 8 in. long wood trusses with 2 x 4 wood chords and webs. Flat metal connector plates, fabricated from 20 gauge galvanized steel, were used to secure the webs to the chords. A single layer of 23/32 in. underlayment grade plywood was applied to the top of the trusses. An Olefin carpet with foam rubber backing was installed on top of the plywood. The ceiling was 1/2 in. thick regular gypsum wallboard.

Test 7: The floor framing consisted of nominal 2 x 8 kiln-dried Number 2 Southern Pine joists, spaced 24 in. on center. The joists were 11 ft., 8.5 in. long. The subfloor was 23/32 in. underlayment grade plywood. An Olefin carpet was secured to the plywood deck. The ceiling was 5/8 in., Type X gypsum wallboard.

Report Summary:

Test 5: Failure of the gypsum board ceiling occurred at 13 min., 9 sec. Penetration of flames through the test assembly to the unexposed surface occurred at 15 min., 58 sec. The maximum deflection was 12.8 in. at 16 min., 14 sec.

Test 6: The protective layer of gypsum board utilized as a ceiling finish for the assembly failed at 11 min., 51 sec. Flame penetration occurred at 17 min., 53 sec. near the center of the assembly. The temperature rise of one surface thermocouple positioned on the carpet exceeded 181° C at 17 min., 46 sec. The centrally located joist did not fail until 18 min., 34 sec. due to wood bridging fastened at mid-span. The maximum center point deflection was 12.8 in. at 18 min., 34 sec.

Test 7: The gypsum board ceiling began to fall away in random segments at 23 min., 6 sec. Passage of flames through the assembly to the unexposed surface was recorded at 35 min., 8 sec. Maximum floor deflection was 6 in. at 35 min., 26 sec. The maximum values of average and individual temperature rise on the unexposed carpet surface at the time of test termination were 150° and 108° C, respectively, since thermocouples were away from the burn-through region. Results are summarized in the following tables:

				Time from Flame Appearance to					
				Room Flashover					
				Ignition of					
Test No.	Initial Room Temp (°C)	Ambient Relative Humidity (%)	Time to Flame Appearance on Newspaper (min)	News-paper (min)	Filter Paper (min)	20 kW/m^2 on Floor (min)	Flames Emerging from Door-way (min)	Ignition of Carpet (min)	Termin-ation of Test (min)
5	25	43	0.17	1.73	1.75	1.43	1.51	2.00	16.23
6	24	30	0.10	1.60	1.62	1.42	1.50	1.75	18.80
7	22	42	0.17	1.68	1.70	1.59	1.60	1.97	35.43

Table 24. Test Results for NBSIR 80-2134.

	Structural Elements			Time to		Time to Unexposed Temperature Rise		Maximum Deflection	
Test No.	Floor Joists*	Gypsum Bd. Ceiling (in)**	Applied Load (psf)	Flame-Through (m:s)	Struct. Failure (m:s)	Avg. Temp 139° C (m:s)	1-Pt. Temp. 181° C (m:s)	Time (m:s)	Center Point (in.)
5	Steel	1/2	67	15:58	15:58*	15:57	15:55	16:14	12.9
6	Trusses	1/2	67	17:53	18:34	N.R.	17:43	18:34	12.8
7	Wood	5/8 (Type X)	40	35:08	35:18	N.R.	N.R.	35:26	6.0

* Wood Joists, nominal 2 x 8; Steel Joists, 1.75 x 7.25 in. x 18 gauge, Super-C; Wood Trusses, 3.5 x 12 in. prefabricated with 2 x 4 wood chords and webs; Span of all joists was 10.67 ft.; Thickness of plywood subfloors were 23/32 in. An olefin carpet with foam rubber backing was installed over the plywood subfloor. Joists were spaced at 24 in. on center, and loaded to 100% of maximum allowable stress.

** Gypsum board was painted

Table 25. Continuation of Test Results for Test Results for NBSIR 80-2134.

Report Summary: Under fire exposure, wood frame floors deflected at a slower rate as compared to steel frame floors. Ultimate collapse of wood frame floors is due to gradual reduction of the cross-section area of floor joists, caused by charring and burning of wood.

The use of a 1/2 in. thick regular or 5/8 in. thick Type X gypsum board ceiling increased the fire endurance time by 12 and 23 min., respectively, when compared to unsheathed steel and wood joists. No comparison can be made to floor trusses.

> **Comments:** Because 1/2 in. regular gypsum wallboard was not uniformly used for all joist assemblies, it is difficult to make clear comparisons between steel and wood joists. It can be observed that wood trusses lasted approximately 2 min. longer than steel joists when protected by 1/2 in. gypsum. Since theses were room burn tests, this also gives an indication of the performance of a protected assembly inside an actual fire. The membrane protection time for 1/2 in. regular wallboard appears to be between 15 and

20 MIN. ON STEEL AND WOOD TRUSSES. 5/8 IN. TYPE X GYPSUM WALLBOARD APPEARS TO PROTECT JOISTS FOR LONGER THAN 30 MIN. IN EACH CASE, HOWEVER, THERE WAS SIGNIFICANT DEFLECTION TOWARD THE END OF THE TEST, PROVIDING SOME WARNING OF STRUCTURAL COLLAPSE.

4-2.10 Report: Flame Endurance Tests of Selected Residential Floor Constructions, NBSIR 82-2488

Author: J.B. Fang

Sponsor: United Stated Department of Housing and Urban Development

Date: April, 1982

Basic Test Description: Except as noted, see **Section 4-1.14** in **Chapter 4-1: Fire Endurance Performance of Unsheathed Assemblies.**

For assemblies 1, 2 and 8, the floor framing consisted of 2 x 8 wood joists spaced 24 in. on center. Each joist was 9.17 ft. long. A single layer of 23/32 in. underlayment grade Douglas fir plywood was attached to the top of the joists. An olefin carpet with foam rubber backing was fastened to the plywood deck. The ceiling was a layer of 5/8 in. thick Type X gypsum wallboard. The wallboard was attached to the joists with nails.

Assemblies 1 and 8 used the new time/temperature curve, while Assembly 2 used ASTM E119.

Report Summary:

Test 1: Failure of the gypsum board ceiling was observed at 16 min., 25 sec. Penetration of flames through the unexposed surface occurred at 20 min., 6 sec. A maximum deflection of 1.85 in. was recorded at 20 min., 48 sec. The maximum temperature rise for the average and individual thermocouples attained on the unexposed surface during the test were 56 and 106° C, respectively.

Test 2: The protective layer of gypsum board began to fall at 30 min., 20 sec. Failure of the floor assembly was observed at 34 min. due to passage of flames through the unexposed surface. At 35 min., 4 sec. the floor reached maximum deflection of 13 in. prior to the collapse of the center joist. At 35 min., 8 sec., the average temperature rise was 241° C, and the individual temperature rise exceeded 181° C.

Test 8: The gypsum board ceiling began to fall at 15 min., 40 sec. Penetration of flames through the unexposed surface occurred at 24 min., 22 sec. The maximum deflection of 5.9 in. occurred at 26 min., 30 sec. The individual temperature rise on the unexposed surface exceeded 358° F at 25 min., 3 sec.

The results of these tests are summarized in the following table:

Test No.	Max. Allow. Stress (%)	Fire Exposure	Level of Excess Air	Time to		Time to Unexp. Temp. Rise		Maximum Deflection		Avg. Oxygen Conc.* (%)
				Flame-Through (m:s)	Struct. Failure (m:s)	Avg. Temp 139° C (m:s)	1-Point Temp. 181° C (m:s)	Time (m:s)	Center Point (in.)	
1[1]	100	New	High	20:06	N.R.	N.R.	N.R.	20:48	1.85	9.8
2[1]	100	ASTM E119	High	34:00	35:20	35:08	34:50	35:28	13.0	12.8
8[1]	93	New	Low	24:22	24:59	N.R.	25:23	26:30	5.9	6.4
Room[1]	—	—	—	—	35:08	—	—	—	—	0.7

[1] All assemblies were 2 x 8 wood joists with plywood subfloors of 23/32 in., gypsum board ceiling 5/8 in. Type X, joists spacing 24 in. on center, and an applied load of 54 psf.; N.R. = Not reached

* For assemblies, measured in the flue gas stream; for room, measured at the top of the doorway.

Table 26. Test Results for NBSIR 82-2488

Report Summary: A protective layer of 5/8 in. thick, Type X gypsum board increased the time to failure by approximately 15 min. for the high intensity, short duration fire exposure; and by approximately 18 min. for the standard ASTM E119 fire exposure when compared to the unsheathed joists under the same conditions.

In the case of the protected assemblies, a steep rise in furnace temperature was observed immediately after the combustible floor was involved in the fire.

Comments: THESE TESTS WERE A FOLLOW-UP TO ROOM FIRE TESTS OF **Section 4-2.9**. THE TESTING SHOWED THAT THE NEW TIME/TEMPERATURE CURVE WITH HIGH LEVELS OF EXCESS AIR CAUSED THE PROTECTED WOOD JOIST ASSEMBLY TO FAIL MORE QUICKLY THAN A SIMILAR ASSEMBLY TESTED USING THE ASTM E119 TIME/TEMPERATURE CURVE. THIS IS APPARENTLY DUE TO THE EXTREMELY HIGH TEMPERATURES ACHIEVED VERY EARLY IN THE TEST. WHEN THE NEW TIME/TEMPERATURE CURVE WAS USED WITH LOW LEVELS OF EXCESS AIR, THE ASSEMBLY ONLY INCREASED IN ENDURANCE TIME BY 4 MIN. OVER THE TEST WITH HIGH EXCESS AIR LEVEL. IT IS INTERESTING TO NOTE THAT THE ROOM TEST (NOT THE NEW TIME/TEMPERATURE CURVE) CAUSED STRUCTURAL FAILURE AT 35 MIN., 8 SEC., AND THE ASTM E119 CAUSED STRUCTURAL FAILURE AT 35 MIN., 20 SEC. IT WOULD APPEAR FROM THIS DATA THAT THE NEW TIME/TEMPERATURE CURVE IS MORE SEVERE THAN THE ROOM FIRE UPON WHICH THE TIME/TEMPERATURE CURVE WAS DEVELOPED, GIVEN THAT THE DIFFERENCE IN PERFORMANCE OF THE NEW CURVE AND THE ROOM BURN WAS 9 MIN., 9 SEC. ASTM SEEMS TO ACCURATELY PREDICT PERFORMANCE OF THE ASSEMBLY UNDER ROOM BURN CONDITIONS. CARE MUST BE TAKEN WHEN DRAWING CONCLUSIONS FROM THESE DATA, PARTICULARLY SINCE TEST CONDITIONS VARIED BETWEEN TESTS. THE ONLY MEANINGFUL COMPARISONS THAT CAN BE MADE ARE THOSE WHICH USE TESTS PERFORMED UNDER IDENTICAL CONDITIONS. BUT EVEN THEN, THE TESTING PERFORMED HAS LIMITED STATISTICAL SIGNIFICANCE.

Test Number	Structural Member[1]	Space O.C. (in.)	Gypsum Type	Ceiling Application	System Used Insulation	Applied Load (psf)[1]	Maximum Deflection (in.)	Finish Rating (min)	Assembly Rating (min)[2]	Standard Test Procedure
UL 506	2 x 10	16	1/2" X	Direct	No	FD	N/A	15	45	ASTM E119
UL 506	2 x 10	16	1/2" X	Direct	No	FD	N/A	20	45	ASTM E119
UL 520	2 x 10	16	5/8" C	R/C Chan.	Yes	FD	N/A	21	45	ASTM E119
BRL 5036	10" I	24	5/8" C	Direct	No	57.5 FD	4.58	23.5	45 (48)	ASTM E119
FM FC-235	12" MPCT	24	5/8" C	Direct	No	57.4 FD	3.5	24	45 (50)	ASTM E119
FM FC-249	12" MPCT	24	5/8" C	R/C Chan.	No	57.8 FD	2.13	26	45 (58)	ASTM E119
BRL 4816	14" TJL	24	5/8" C	Direct	No	99.9 FD	1.03	22	45 (52)	ASTM E119
PFS 88-03[3]	15" MPCT	24	5/8" C	Direct	Yes	FD	N/A	23	45 (52)	ASTM E119
Galbreath[3]	2 x 9	16	1/2" reg	Direct	No	60	N/A	N/A	33	ASTM E119
BMS 92[3]	2 x 10	16	1/2" reg	Direct	No	1000 max	N/A	N/A	25	ASA #A2-1934
BMS 92[3]	2 x 10	16	2-3/8" reg	Direct	No	1000 max	N/A	N/A	30	ASA #A2-1934
NBSIR 80-2131 (5)	7.5"steel C	24	1/2" reg	Direct	No	67 FD	12.9	N/A	16	Room Fire
NBSIR 80-2131 (6)	12" truss	24	1/2" reg	Direct	No	67 FD	12.8	N/A	18	Room Fire
NBSIR 80-2131 (7)	2 x 8	24	5/8" X	Direct	No	40 FD	6.0	N/A	35	Room Fire
NBSIR 80-2488 (1)	2 x 8	24	5/8" X	Direct	No	54 FD	1.85	N/A	20	New T/T
NBSIR 80-2488 (2)	2 x 8	24	5/8" X	Direct	No	54 FD	13.0	N/A	34	ASTM E119
NBSIR 80-2488 (8)	2 x 8	24	5/8" X	Direct	No	54 - 93%	5.9	N/A	24	New T/T

[1] I = I-joist; MPCT = Metal Plate Connected Truss; TJL = Trus Joist's Tubular Pin End Connected Truss; FD = Full Design; 1000 max. = 1000 psi max. bending stress (F_b) allowed for the joist.

[2] The numbers within parentheses indicate the total test duration

[3] Test reports for these data are unavailable

Table 27. Summary of Single Membrane Protected Assembly Tests

4-2.11 Evaluation of Single Membrane Protected Test Assembly Performance

In general, assemblies using lightweight wood components greater than 10 in. in depth and having directly applied 5/8 in. Type C gypsum wallboard have a fire endurance rating greater than 45 min. Resilient channels enhanced this performance by 6 min. (in one test). Also, in one assembly where insulation was applied in the truss cavity (only test summary data are available for this test), the assembly rating was 45 min. with structural failure occurring at 52 min., which means the addition of insulation did not radically alter the fire endurance performance of the assembly. Unfortunately, test reports and results from similar steel component assemblies (e.g., bar joists) are not available. The data do suggest, however, that a 7.5 in. steel C-joist will have fire endurance ratings similar to 12 in. trusses. This would have to be verified with additional testing before any clear conclusions could be drawn.

A single layer of 1/2-in regular gypsum board on lightweight wood components like steel joists and wood trusses contributes fire endurance of 16 and 18 min., respectively, in full-scale room tests (based on two tests). For 2 x 10 joists, 1/2 in. regular gypsum wallboard directly applied contributes 25 min. Based on the Canadian Building Code's Fire Endurance Assembly Calculation Method, if it is assumed that wood trusses contribute 5 minutes, and wood joists contribute 10 minutes of performance to an assembly, the contribution of 1/2 in. regular gypsum wallboard is 13 min. on trusses, and 15 min. on joists.[2] Applying this concept more broadly, it would appear that 1/2 in. of regular gypsum wallboard provides an additional 10 to 15 min. of performance to most lightweight structural members to which it is attached.

It is interesting to note, however, that under high levels of excess air, ASTM E119 predicted the results that were seen in the room fire tests in **Section 4-2.9**. The time/temperature curve based on the room fire tests predicted a far faster time to failure than was seen in the room itself. Unfortunately, it is not believed that enough testing has been done so that room tests are accurately represented by standardized time/temperature curves. Additionally, much of the testing cannot be directly compared due to changes in the test protocol between tests.

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[2] Canadian Wood Council, **Wood and Fire Safety**, 1991, p. 123.

Chapter 4-3: Fire Endurance Performance of Connections

Many of the lightweight component assemblies employ some type of connector to connect the smaller-dimension pieces used to form the component. Connection performance under fire conditions is pivotal to the performance of the structural system. The following test report summaries detail fire performance of connectors under specific test conditions:

4-3.1 **Report:** The Fire Resistance of Metal Connectors

Authors: R.H. Leicester, C.A. Seath and L. Pham

Sponsor: General Research

Date: After 1977 and prior to 1979

Basic Test Description: With little information available on the fire resistance of exposed joints fabricated with metal connectors, these tests were undertaken on typical timber tension joints. The joists were fabricated out of Blackbutt seasoned to 12% moisture content and having a cross section of 1.96 in. by 3.5 in. The four basic types of joints tested were:

- A nailed joint using 36 nails, each with a 0.17 in. diameter, 3.5 in. long.
- Two 14 gauge, metal connector plates, each being 2.95 x 9 in..
- A bolted joint using six 0.47-in. diameter bolts.
- A split-ring connector joint, using four 2.5-in. diameter split rings.

Test Methods Used: Each test joint was placed in the furnace and loaded in tension to the design working load specified in Australian Standard 1720. The furnace temperature was raised in accordance with Australian Standard 1530. Joint extension was recorded. Two tests of each joint were performed.

In a second set of tests, the load on the joints was reduced by 30%. The furnace temperature was controlled to produce a time/temperature relationship intended to simulate the temperatures measured by Rodack and Ingberg for a typical fire in a residential building.

Report Observations: The failure criterion of a joint for this study was a 0.39-in. joint extension. The time for each joint to reach failure was: 4 min. for the metal plate-connected joint, 11 min. for the split-ring joint, 14 min. for the bolted joint, and 33 min. for the nailed joint. In the second test, the bolted and nailed joints did not fail the joint extension criterion. The metal connector plate failed at approximately 24 min. and the split-ring joint failed at approximately 22 min.

Report Conclusions: Of the four types of joints tested, only the nailed joint showed satisfactory fire resistance characteristics. The mechanism for the poor characteristics of the other joints has been identified, and using this information it may be possible to design a joint with good fire resistance characteristics.

> **Comments:** THE DESIGN WORKING LOAD WAS NOT SPECIFIED, NOR ITS CALCULATION REVEALED, OTHER THAN BY REFERENCE TO THE AUSTRALIAN STANDARD 1720, FROM THE AUSTRALIA TIMBER ENGINEERING CODE. IT IS NOT KNOWN WHETHER THE DESIGN JOINTS WERE LOADED TO EQUIVALENT ALLOWABLE STRESSES ON EACH CONNECTOR, OR IF LUMBER WAS AT FULL DESIGN TENSION WORKING STRESS. WITHOUT THIS INFORMATION, IT IS DIFFICULT TO DETERMINE IF THE COMPARATIVE PERFORMANCE OF CONNECTORS BEING EVALUATED WAS ON AN EQUIVALENT STRESS BASIS. NOTE: THE TIME/TEMPERATURE CURVE USED IN TEST 1 IS NEARLY IDENTICAL TO THE ONE USED IN ASTM E119.

4-3.2 Report: The Fire Behavior of Timber in Wood-Based Products

Author: P.E. Jackman

Sponsor: Timber Research and Development Association (TRADA), High Wycombe

Date: 1980

Basic Test Description: Very little is known about the fire behavior of metal connections in conjunction with solid timber elements. The building code in England is, therefore, very conservative in this respect, and recommends that all connections be protected by sacrificial timber: either by burying the connection behind the assumed charring line, or by overcladding with adequate timber. TRADA evaluated the behavior of dense-nailed plywood gussets as a connection technique. A similar test on unprotected tooth plate connectors was performed.

Test Methods Used: The test methods were not delineated in the paper from which this information was taken. The standard time/temperature curve found in British Standard 476, Part A was used.[1]

Report Observations: The plywood gusset did not fail until the thickness was reduced, by charring, to a point where the stress in the gusset was close to the ultimate strength of the cold material.

Report Summary: It was anticipated before the test series that the plywood gusset failure would occur due to the nails losing their fixity from heat conduction into the timber substrate. This did not occur. The nails were still fixed adequately enough to

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[1] It is assumed this time/temperature relationship is similar to ASTM E119.

provide the required shear strength for the joint to remain firm up to the point where the plywood failed.

Unprotected tooth plate connectors were tested under pure tension and failed in under ten minutes under identical test conditions. Since tooth plate connectors are limited to roof construction (which is not required to have fire resistance), their performance was felt to be satisfactory.

Report Conclusion: It can be seen that with the present state of the art, timber can meet all the requirements expected of a modern building material. In some sections of the building industry there is suspicion for the use of combustible materials. Performance of wood products must be proven and reproven, and backed up with necessary education. Wood and wood based products can make an important contribution to fire safe building construction.

> **Comments:** FEW SPECIFICS ARE AVAILABLE ON THE TESTING THAT WAS PERFORMED, AS THIS INFORMATION WAS TAKEN FROM A PAPER ALREADY SUMMARIZING THE RESULTS. IT INDICATES THAT, AS IN THE PREVIOUS REPORT, NAILED CONNECTIONS PERFORM BETTER THAN TRUSS-PLATE JOINTS UNDER FULL DESIGN LOAD AND E119 CONDITIONS. BASED ON THE TWO PREVIOUS REPORTS, TRUSS PLATES APPEAR TO HAVE A FIRE ENDURANCE PERFORMANCE OF LESS THAN 10 MIN. UNDER STANDARDIZED TEST CONDITIONS.

4-3.3 **Report:** Flame Exposure Tests of a Ceramic Covering System for Truss Plate-Connected Wood Members

Authors: Proprietary

Sponsor: Proprietary

Date: July 6 - August 6, 1990

Basic Test Description: Testing was performed using experimental test procedures employing both a control and test specimen. Each lumber piece was cut so that one cut edge would be used to form a joint for both the control and test specimen. Two other two-foot sections attached to the common cut joint were also from the same lumber piece. Lumber selected for joint fabrication was Spruce Pine Fir. To include a broad range of lumber densities, ten pieces each of 2100F-1.8E MSR, 1650 F-1.5E MSR, and visually graded #3 were used in the testing. (MSR stands for Machine Stress Rated lumber, and visual graded means lumber grades were assigned by a human lumber grader.)

The covering that was applied over the metal connector plate for protected specimens was a 3.5 x 4 in. proprietary ceramic covering, 0.040 in. thick (tolerance being greater than 0.000 and less than 0.009 in.). The metal connector plates used were a 3 x 3.5 in. truss plate.

Test Methods Used: A total of 120 specimens were tested: 60 (20 in each grade) with the 1.5 in. face of the lumber exposed to flame, and 60 with the 3.5 in. face of the lumber exposed to flame. Thirty control and thirty covered specimens were tested in each exposure condition. The 3.5 x 4 in. covering was stapled over both truss plates in each test specimen. The splice was centered between supports, and a gas burner was mounted below the splice to produce a 1500° F flame impingement on the specimen. A 40 lb. dead weight was positioned on the centerline of each splice. The test duration consisted of the time elapsed from initial flame exposure until the specimen deflected a distance of 1-3/8 in.

Report Observations:

Horizontal (3.5" Face) Placement Over Flame	**Number Specimens Tested**	**Average Failure Time (min.)**	**Ratio-Test Over Control (%)**
#3 SPF Control	10	2.88	
#3 SPF Test	10	6.00	208
1650F SPF Control	10	3.00	
1650F SPF Test	10	6.47	216
2100F SPF Control	10	3.22	
2100 F SPF Test	10	6.88	214
Vertical (1.5" Face) Placement Over Flame			
#3 SPF Control	10	4.04	
#3 SPF Test	10	7.08	175
1650F SPF Control	10	4.65	
1650F SPF Test	10	8.67	186
2100F SPF Control	10	5.83	
2100 F SPF Test	10	11.27	193
Total Specimens Tested	**120**		

Table 28. Test Results for Proprietary Coating Tests.

Report Summary:

Description	Placement Over Flame	
	Horizontal	**Vertical**
Average Improved Performance over Control	212%	185%
Standard Deviation	0.279	0.182
Coefficient of Variation	0.078	0.033
Maximum Improvement	298%	228%
Minimum Improvement	140%	146%
Estimated 5th Percentile Improvement	165%	156%

Table 29. Summary of Results for Proprietary Coating Tests.

Comments: THE DATA PRESENTED IN THIS TEST WERE USED TO EVALUATE THE PERFORMANCE OF THE TRUSS CONNECTOR PLATE CERAMIC COATING ONLY. THE DATA DO NOT PROVIDE ANY MEASURE OF THE PERFORMANCE OF A METAL TRUSS CONNECTOR PLATE IN AN ACTUAL FIRE ENDURANCE SITUATION. THIS TESTING DOES, HOWEVER, PROVIDE SIGNIFICANT INFORMATION ON THE ABILITY OF A COATING TO PROTECT A METAL CONNECTOR PLATE AND IMPROVE ITS PERFORMANCE IN A FIRE ENDURANCE ENVIRONMENT.

UNFORTUNATELY, THESE DATA CANNOT BE RELATED TO ANY OF THE OTHER DATA ON CONNECTOR PERFORMANCE TESTS.

4-3.4 **Report:** Fire Behavior of Metal Connectors in Wood Structures

Author: O. Carling

Sponsor: Royal Institute of Technology, Stockholm, Sweden

Date: 1991 International Timber Conference, London, England.

Basic Test Description: Instead of testing a full-scale connection in a traditional fire test, the behavior of a single connector was studied under electrically generated temperatures that relate to fire conditions. The main difference between this and a furnace test is that only the contact surface is exposed to thermal degradation, while the remaining surface is unaffected.

Two bolt diameters—0.47 in. and one which was unspecified—were tested. A prismatic steel plate was also tested, in order to study the influence of the radius of curvature of the contact surface.

Only one type of nail was tested: annular ring shank nails. The nails had a diameter of 0.15 in. Two lengths were tested: 1.57 and 2.63 in. Nail spacing was 1.18 in. for all tests. Nail edge and end distance were greater than 1.57 in.

Test Methods Used: The tests were carried out in a universal press. The wood specimen was fixed to a base plate. Compressive load was applied to the top of the connection. The bolt and the steel plate were electrically heated, and the temperature at the contact surface was continuously recorded. The displacement between the bolt or steel plate and the wood specimen was recorded. Wood specimens were made of Swedish Pine. The average density was 26.21 lb./ft^3. Before testing, the wood specimens were conditioned in a climate providing a moisture content of approximately ten percent. Most boards were sawn from the center of the log, which includes a high percentage of juvenile wood. This may have affected results in an unfavorable way. Three different rates of temperature increase were studied:

- 20° K/min. up to 572° F, then constant.
- 40° K/min. up to 707° F, then constant (667° F for nail tests).
- 60° K/min. up to 842° F, then constant (752° F for nail tests).

There were 270 bolt and 180 nail tests performed. Failure was defined as the moment the rate of displacement exceeded 0.39 in./min., or the total displacement exceeded 0.69 in.

Report Observations: Specific data summaries are not provided in this report.

Report Summary: The following conclusions were made regarding bolted connections:

The rate of displacement depends on:

- The angle between load and grain direction.
- The bolt bearing stress.
- The rate of temperature increase.

The critical temperature may be lower than the normal charring temperature of wood (approximately 572° F). The critical temperature is lower when load is perpendicular to grain than when load is parallel to grain. When all other circumstances are similar, the rate of displacement is higher:

- When load is parallel rather than perpendicular to grain.
- The higher the bolt bearing stress.
- The higher the steel temperature.
- The smaller the bolt diameter.

The time to failure (in minutes) may be estimated by the following expression:

$$t_{cr} = \frac{T_0 - 20}{\Delta T} + \frac{15}{\Delta T}(14 - \sigma)\left(1 - \frac{5}{\Phi}\right)$$

where ΔT = bolt temperature increase (K/min)

$$T_0 = \begin{cases} 280 \text{ when load is parallel to grain} \\ 340 \text{ when load is perpendicular to grain} \end{cases}$$

σ = bolt bearing stress (MPa)

Φ = bolt diameter (mm)

Nailed Connections

The following conclusions can be made for nailed connections:

- The rate of displacement is higher when load is perpendicular to grain than when it is parallel to grain.
- The rate of displacement is higher for connections made with 1.57-in. long nails than with 2.63-in. long nails.
- When all other conditions are equal, the time to failure is approximately the same, whether load is parallel or perpendicular to grain.
- Within the maximum test time (approximately 25 min.), failure was achieved only for connections with 1.57-in. long nails.

The time to failure (in minutes) for 1.57-in. long nails may be estimated with the following expression:

$$t_{cr} = \begin{cases} \left(7.5 - 0.04\sqrt{30F - 5700}\right)^2 & \text{for } \Delta T = 60 \text{ K/min.} \\ \left(10.3 - 0.055\sqrt{30F - 6500}\right)^2 & \text{for } \Delta T = 40 \text{ K/min.} \\ > 25 & \text{for } \Delta T = 20 \text{ K/min.} \end{cases}$$

Where ΔT = steel-plate temperature increase (K/min.)

F = nail load (Newtons per nail)

Comments: THESE TESTS WERE DEVELOPED SPECIFICALLY FOR THE REFERENCED PROJECT. THEY WERE NOT BASED ON STANDARDIZED TEST PROCEDURES. FORMULA VERIFICATION HAS NOT BE PERFORMED.

4-3.5 **Report:** The Fire Performance of Unloaded Nail-On Gusset Connections For Fire Rated Timber Members

Authors: P.K.A. Yiu and A.B. King

Sponsor: Building Research Association of New Zealand (BRANZ)

Date: 1988

Basic Test Summary—Unloaded tests: The starting point for this study was a series of fire tests of unloaded nailed connections. Blocks of glue-laminated timber had steel and plywood gusset plates nailed to one side. The gussets were then protected with gypsum plaster board, solid timber, or intumescent paint before exposure to a standard fire in the BRANZ pilot furnace. Temperatures were measured between the various layers during the test. It was found that steel gussets with no protection had a rapid rise in temperature, leading to charring around the gussets and around the nails. Plywood gussets with no protection charred layer by layer—much faster than would be expected for solid wood. Solid wood and gypsum plaster board gave good protection to both steel and plywood gussets, with a slow but steady temperature rise in the gusset. Intumescent paint gave some protection, with a faster temperature rise than for gypsum plaster board.

> **Comments:** THESE TESTS PROVIDE GENERAL INFORMATION ABOUT PROTECTION OF CONNECTIONS USING COVERINGS. THESE DATA REINFORCE RESULTS FROM THE PROPRIETARY TEST DISCUSSED EARLIER.

4-3.6 Report: Behavior of Nailed Gusset Connections Under Simulated Fire Exposure

Authors: A.H. Buchanan, R. Chinniah and P.J. Moss

Sponsor: Building Research Association of New Zealand

Date: 1988

Test Methods Used: Steel and plywood gussets were nailed to blocks of glue-laminated timber and loaded in shear. A horizontal orientation was used in order to get uniform heating over the gusset plate. This required a pulley system to transfer the horizontal load to the vertical action of the testing machine. A heating box with a domestic electric stove heating element and thermostat was used to raise the temperature of the gusset plates. Temperatures in the test specimens were measured with thermocouples. The time/temperature curves followed were from the unloaded BRANZ test, and were non-standardized.[2]

Basic Test Description: Glue-laminated radiata pine timber 3.54 in. thick was used for all tests. Moisture content was in. the range of 10 - 13%. For the steel gusset plates, plain steel nails—2.95 in. long by 0.124 in.—were used for most tests. Galvanized nails—1.18 and 1.51 in. by 0.124 in. and 1.77 by 0.17—were also used. Nail heads were driven to just making contact with the steel gusset in order to eliminate friction effects. For the plywood gussets, 3.34 x 0.13-in. gun nails were used. The steel gussets were 0.19-in. thick mild steel plate, pre-drilled with six holes. The plywood gussets were

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[2] Yiu, P.K.A. and King, A.B., 1989, "Fire Performance of Unloaded Nail-on Gusset Connections for Fire Rated Timber Members," Draft Study Report, Building Research Association.

0.71-in. thick construction plywood. All gussets were nailed to the glue-laminated timber with six nails.

Three types of protection were tested: one layer of 0.75-in. Fyreline Gibraltar Board, two layers of 0.57-in. Fyrestop Gibraltar Board, and intumescent paint. Both cold tests under increasing load, and constant load tests with increasing temperature were performed.

Report Observations: Ultimate load and load slip curves were recorded for each test performed.

Report Summary: Under simulated fire conditions, the nail slip in steel plate gusset connections increased with increasing load, and also with increasing gusset temperature. For plywood gussets, only one thickness of protection was simulated. Nail slip increased with increasing load. Measured nail slips for plywood gussets were generally larger than for steel gussets with the same protection.

For the same protection (one layer of 0.75-in. Fyreline Gibraltar Board) a nail load of 86.5 lbs. (1.8 times the basic nail load for 0.124-in. diameter nails), the slip after one hour of exposure was 0.03 in. for the steel gusset and 0.08 in. for the plywood gussets. The ultimate load capacity of nails was approximately ten times the basic nail load under cold conditions, and six times the basic nail load after one hour of simulated fire exposure.

> **Comments:** THE VALUE OF PROTECTION FOR CONNECTION SYSTEMS IS SHOWN IN IMPROVED FIRE PERFORMANCE, WHICH WAS ALSO NOTED IN THE PREVIOUS TWO REPORTS.

4-3.7 **Report:** Bolted Steel Plate Joints in Timber Structures Under Fire Conditions

Authors: O. Holmijoki, J. Majamaa and E. Mikkola

Sponsor: Fire Technology Laboratory, VTT, Finland

Date: 1991 International Timber Engineering Conference

Basic Test Description: Ignition and charring models for wood were applied to mechanical bolted steel plate joints of timber structures. A calculation method was developed to determine the rate of temperature increase of the steel plate, and the time to charring conditions in wood under different fire exposures. Experimental results using Cone Calorimeter tests gave the charring rate values under the steel plate and effect of bolts on charring.

Test Methods Used: The tests were carried out using the Cone Calorimeter equipment of the Fire Technology Laboratory of the Technical Research Center of Finland. All wood specimens were the same size: 3.93 x 3.93 x 2.99 in. Specimens were wrapped in a thin aluminum foil (except the upper surface), and the lower edge was insulated using fire resistant Kaowool insulation blanket. Three specimens were tested. The first was a single block of laminated veneer lumber. The second was a block of laminated veneer lumber with a steel plate covering the top of the specimen. The third was a block of laminated veneer lumber with only a steel bolt penetrating the specimen from the top to the bottom.

Test specimens were exposed to a constant heat flux of 25, 50 or 75 kW/m^2. The temperature in the specimens was measured by thermocouples located on the surface, and at various depths within the specimen. The time to ignition and the rate of mass loss were also measured. The duration of any single test was 30 to 60 min.

Report Observations: Test results were collected, and values for time for charring to start (t_i) were calculated. Here, d is the thickness of the steel plate.

Test Specimen	q (cone) (kW/m^2)	d (mm)	t_i (Test) (min:sec)	t_i (Calc.) (min:sec)
Wood	25	—	1:48	2:11
	50	—	0:15	0:15
	75	—	0:07	0:06
Wood & Steel Plate Covering (no bolt)	25	8	13:20	13:05
	50	5	3:40	3:57
	50	8	5:20	5:59
	50	12	8:20	8:37
	75	8	4:20	3:50

Table 30. Test Results for Fire Technology Laboratory.

In the steel bolt test, charring of the wood was observed to be slower in contact and near the steel bolt than elsewhere in the wood specimen. At a heat flux level of 50 kW/m^2, it took thirty minutes before heat transfer through the steel bolt caused a higher charring rate near the bolt than elsewhere in the specimen.

Report Summary: As shown by the test results, a steel plate covering a wood specimen causes protection of the wood by delaying the initiation of charring, and reducing the charring rate, as compared to free burning situations(those without steel plates). This effect is closely related to the thickness of the steel plate. Increasing the thickness of the steel plate increases the protection effect. On the basis of this study, it can be stated that the charring rate of wood under steel plate joints can be calculated from the rate of mass loss and temperatures.

> **Comments:** THIS REPORT APPEARS TO CONFIRM THE THEORY THAT STEEL GUSSET PLATES CAN PROTECT WOOD FROM CHARRING AS RAPIDLY AS UNPROTECTED WOOD. RESULTS ALSO SHOW THAT STEEL BOLTS PENETRATING WOOD DO NOT CAUSE THE SURROUNDING WOOD TO CHAR MORE RAPIDLY.

> THESE RESULTS MIGHT APPEAR TO CONTRADICT LOGIC AND, THEREFORE, MAY BE DIFFICULT TO ACCEPT. ADDITIONAL WORK NEEDS TO BE DONE TO DETERMINE IF THIS PHENOMENON HAS ANY MEANINGFUL EFFECT ON THE FIRE PERFORMANCE OF AN ASSEMBLY, AND IF IMPROVEMENTS IN PERFORMANCE CAN BE MADE USING THESE CONCEPTS.

4-3.8 Report: None Yet Available

Authors: R.H. White, S.M. Cramer, R.W. Wolf

Sponsor: National Forest Products Association

Date: Committee on Research and Evaluation (CORE) Report, April 4, 1991

Basic Test Description: Testing was performed on metal connector plates. The plates were 20 gauge, Grade A steel with 9.4 teeth/in^2. Each tooth was approximately 0.3 in. long. Two types of plates were used in the testing: one with teeth slots parallel to the grain of lumber, measuring 2.95 x 7.5 in., having 96 teeth; the other with teeth slots perpendicular to the grain of lumber, measuring 2.96 x 6.88 in. and having 91 teeth. Joints were made using two plates with teeth removed from the middle 0.66-in. of the plate over the butt joint. The lumber used was #1 DNS (Dense) Southern Pine Visual Grade and 2100F-1.8E SPF MSR.

Test Methods Used: There were two test methods used: one called "ramp load to failure," and the other, "fire exposure to failure". Under ramp load, a constant temperature was placed on the specimen. The temperatures used were: room temperature, 100, 200, 250, 275, 300, and 325° C. Exposure times were typically 30 min., but some 60 min. exposures were made. Under fire exposure to failure, the ASTM E119 time/temperature curve was used. The test specimens were stressed to 50- and 100% of design load. Pure tension and tension moment stresses were placed on the specimen. These data will be used to verify the thermal degrade model.

Report Observations: The final report on these data has not been completed.

> **Comments:** THE DATA DEVELOPED FROM THIS STUDY WILL PROVIDE THE GREATEST AMOUNT OF INFORMATION TO DATE ON THE FIRE PERFORMANCE OF TRUSS CONNECTOR PLATES. THESE DATA ARE BEING USED TO REFINE A COMPUTER MODEL THAT WILL PREDICT THE FIRE ENDURANCE PERFORMANCE OF A SINGLE TRUSS. FROM THIS, THE METHODOLOGY WILL BE EXPANDED TO MODEL THE FIRE PERFORMANCE OF AN ENTIRE TRUSS ASSEMBLY.

Connector Test Summary Table

Testing Designation	Structural Member	Connection Type	Test Temperature	Load Condition	Average Time To Failure	Comments
Aus. Tests I	2 x 4	3 x 9 MPC**	ASTM E119	Design working load	4 min.	0.39" Jt. Ext. = Failure
Aus. Tests I	2 x 4	4-2.5" Split Rings	ASTM E119	Design working load	11 min.	0.39" Jt. Ext. = Failure
Aus. Tests I	2 x 4	6 - .5" Bolts	ASTM E119	Design working load	14 min.	0.39" Jt. Ext. = Failure
Aus. Tests I	2 x 4	36-.17x3.5" long nails	ASTM E119	Design working load	33 min.	0.39" Jt. Ext. = Failure
Aus. Test II	2 x 4	3 x 9 MPC	Res. time/temp	70% Design level	approx. 24 min.	0.39" Jt. Ext. = Failure
Aus. Test II	2 x 4	4 - 2.5" split rings	Res. time/temp	70% Design level	approx. 22 min.	0.39" Jt. Ext. = Failure
Aus. Test II	2 x 4	6 - .5" bolts	Res. time/temp	70% Design level	> 125 min.	0.39" Jt. Ext. = Failure
Aus. Test II	2 x 4	36 - .17"x3.5" long nails	Res. time/temp	70% Design level	> 125 min.	0.39" Jt. Ext. = Failure
TRADA Test	2 x 4	MPC's	BS 476	Tension loads	< 10 min.	All Data Not Available
TRADA Test	2 x 4	Dense Nailed Ply. Gusset	BS 476	Tension Loads	N/A	All Data Not Available
Finnish Tests	3.9 x 3.9 x 3"	Wood Only	25 kW/m2	none	1.8 min.	Time to Start of Charring = Failure
Finnish Tests	3.9 x 3.9 x 3"	Wood Only	50 kW/m2	none	.25 min.	Time to Start of Charring = Failure
Finnish Tests	3.9 x 3.9 x 3"	Wood Only	75 kW/m2	none	.11 min.	Time to Start of Charring = Failure
Finnish Tests	3.9 x 3.9 x 3"	.5 in. Steel Plate Cover	25 kW/m2	none	13.33 min.	Time to Start of Charring = Failure
Finnish Tests	3.9 x 3.9 x 3"	.19 in. Steel Plate Cover	50 kW/m^2	none	3.6 min.	Time to Start of Charring = Failure
Finnish Tests	3.9 x 3.9 x 3"	.3 in. Steel Plate Cover	50 kW/m^2	none	5.3 min.	Time to Start of Charring = Failure
Finnish Tests	3.9 x 3.9 x 3"	.47 in. Steel Plate Cover	50 kW/m^2	none	8.3 min.	Time to Start of Charring = Failure
Finnish Tests	3.9 x 3.9 x 3"	.3 in. Steel Plate Cover	75 kW/m^2	none	4.33 min.	Time to Start of Charring = Failure
FPL Tests	N/A	2.95 x 7.5 in., 96 Teeth MPC	Constant Temp	ramp load	N/A	Data Not Yet Available
FPL Tests	N/A	2.95 x 6.88 in., 91 Teeth MPC	ASTM E119	50 & 100% design load	N/A	Data Not Yet Available
Proprietary*	2 x 4	3 x 3.5 MPC	1520 ° F	40 lbs.	3.06 min.	avg. 4x2 unprot. control
Proprietary*	2 x 4	3 x 3.5 MPC	1520 ° F	40 lbs.	4.86 min.	avg. 4x2 unprot. control
Proprietary*	2 x 4	3 x 3.5 MPC	1520 ° F	40 lbs.	6.43 min.	avg. 4x2 prot. test
Proprietary*	2 x 4	3 x 3.5 MPC	1520 ° F	40 lbs.	9.00 min.	avg. 4x2 prot. test

* Proprietary tests are protected (prot.) control vs. protected (prot.) tests under load and fire.

** MPC = Metal Plate Connector, Ply. = plywood.

Table 31. Summary Table of Connection Fire Endurance Tests.

4-3.9 Evaluation of Connection Fire Endurance Testing Performance

Connection systems form a critical element in any structural system. In all likelihood, the connection will fail prior to any other element of a structural member under most loading schemes, including those due to fire degradation. The Australian tests raise concerns about metal plate and split ring connections when compared to bolts and nails. However, it is not known if these tests were run under equivalent connection stresses. The TRADA test reinforces the data available on metal plate connectors. The proprietary metal plate connector tests show only the effect of coatings, and do not represent connection failure times for comparative purposes. The FPL tests are the most comprehensive tests performed on metal plate connectors and should provide the basis for performing more significant analyses. The Finnish tests reinforce the concept that steel coverings can protect wood prior to conduction and wood charring. The char rate is shown to be lower under steel plates and adjacent to steel bolts.

At this time, not enough information on connection system fire endurance performance is available to allow broad-based conclusions to be made about their impact on structural system performance under fire exposure. The FPL testing should provide this information, and the model developed should allow for better prediction of the performance of metal plate connected truss systems.

Chapter 4-4: Fire Endurance Performance of Operation Breakthrough Assemblies

Operation Breakthrough was initiated by the Department of Housing and Urban Development (HUD) in May 1969 to demonstrate industrialized housing techniques that could be used for high volume production. As part of its research, HUD conducted numerous fire tests of assemblies to determine and demonstrate fire performance. The following summarizes the tests and results obtained when these assemblies were evaluated.

4-4.1 **Report:** Feedback - Operation Breakthrough, Volume 5, Part 3, Fire Endurance: Roofs/Ceiling, Floor/Ceiling and Floor Assemblies

Author: United Stated Department of Housing and Urban Development

Sponsor: United Stated Department of Housing and Urban Development

Date: Initiated in May, 1969

Test Method Used: All tests were performed using the ASTM E119 time/temperature curve. The loading used was specific to the test being performed.

Reference: Fire test reports RC-168, RC-169, and RC-171, National Gypsum Company Research Center, January and February 1972 (Unpublished).

Report Summary:

Double Wood Joists, Plywood and Gypsum Board System: The ceiling assembly consisted of 2 x 4 wood joists spaced 16 in. on center, with one layer of 1/2 in. Type X gypsum wallboard and one layer of 3 1/2 in. thick fiberglass insulation between the joists. The end of the joists were nailed to a double 2 x 6 edge beam, on top of which was built a 16 ft. x 16 in. high parapet wall, constructed with 2 x 4 studs, 24 in. on center. Both sides of the stud wall were sheathed with 1/2 in. plywood. The roof assembly consisted of 2 x 6 wood joists, 16 in. on center, nailed to 2 x 6 edge beams. The roof sheathing material was 1/2 in. plywood.

Testing: Three tests were conducted on three separate test assemblies. Each assembly measured 11 ft., 9 1/2 in. x 17 ft., 5 in.

Test 1: Described above.

Test 2: This test was identical to Test 1 except that the ceiling assembly was insulated with two layers of 3 1/2 in. thick glass fiber batts instead of one. A 1/4 in. bead of adhesive was applied to each joist before the wallboard was nailed.

Test 3: This test was identical to Test 2 except that an additional layer of 1/2 in. Type X gypsum board was added to the ceiling surface.

Each test had a superimposed load of 30 lbs./ft^2 applied to the roof joists. The ceiling joists had dead load applied only.

Test Results:

Test 1: Structural collapse occurred at 34 min., 30 sec.

Test 2: At 45 min., 10 sec., excessive temperature rise was recorded at one thermocouple. Flamethrough followed at 45 min., 20 sec.

Test 3: At 83 min., 40 sec., flamethrough occurred on the unexposed side of the roof system.

Reference: Son, B.C., "Fire Endurance Test of a Roof/Ceiling Construction of Paper, Honeycomb and Gypsum Board," NBSIR 73-167, National Bureau of Standards, January, 1973

Test Description: This roof/ceiling assembly consisted of two panels: each 8 ft., 11 in. wide and 13 ft., 5 in. long, butted together on the long sides to produce a test panel 13 ft., 5 in. by 17 ft., 10 in. The nominal overall thickness of the assembly was 7 1/4 in. The sandwich panels consisted of flame retardant treated paper honeycomb core with 5/8 in. Type X Gypsum on both sides. The edge of each honeycomb core had 3 x 6 in. beams consisting of 4 layers of 3/4 in. plywood. A 5 in. wide strip of 5/8 in. Type X gypsum board covered the joint between the test panels. A uniform load of 15.9 lbs./ft^2 was applied to the test specimen. This produced a bending moment equivalent to that produced by a conventional design load of 20 psi over a 12 ft. span.

Test Results: Failure occurred at a corrected time of 37 min., 13 sec., by flamethrough of the unexposed surface through a joint in the gypsum boards. At 37 min., 23 sec., a local load failure occurred.

Reference: Fire Test Report FC-156, National Gypsum Company (Unpublished)

Test Description: Construction of this assembly was identical to that of Report NBSIR 73-167, above, except that the gypsum board strip covering the panel joint on the exposed side was 6 in. wide instead of 5 in. Type C wallboard was used instead of Type X on the fire exposed side of the panel. A uniform load of 17 lbs./ft^2 was applied during the test.

Test Results: Flamethrough at the panel joint occurred at 29 min.

4-4.2 **Reference:** Fire Test Report FC-159, National Gypsum Company (Unpublished)

Test Description: The sandwich panel was produced identically to that in NBSIR 73-167 except that two layers of 5/8 in. Type C gypsum board were applied to the ceiling side of the roof system. Type C board was used instead of Type X on the roof side as well. The exposed layer was bonded to the under layer with 3/16 in. beads of adhesive spaced 12 in. on center, and stapled with 1 1/2 in. long staples. Staples were spaced 24 in. on center along each edge and down the center of each board, and 12 in. on center at end joints. A uniform load of 18.5 lbs./ft^2 was applied to the test specimen.

Test Results: Flamethrough at a gypsum board joint on the unexposed surface occurred at 64 min., 45 sec.

Reference: Son, B.C., "Fire Endurance Test of Steel Sandwich Panel - Exterior Wall and Roof/Ceiling Constructions," NBSIR 73-135.

Test Description: The construction of this roof/ceiling system consisted of a 3 in. thick paper honeycomb core partially filled with solid polyurethane foam, and 26 gauge sheet steel facings on both sides. The test assembly consisted of four 4 ft. x 13 ft., 5 in. deep sandwich panels and one 1 ft., 10 in. x 13 ft., 5 in. deep panel. Long edges of the panel were closed with a 1-1/2 x 5-1/4 in. tongue-and-groove wood closure. A 26 gauge, galvanized sheet metal cap was applied over the top of this closure. Overall dimensions of the test assemblies were: 13 ft., 5 in. x 17 ft., 10 in. A uniform load of 28.6 lbs./ft^2 was applied during the test, which is equivalent to 40 lbs./ft^2 over a 12 ft. span.

Test Results: A maximum temperature rise of 325° F occurred at one thermocouple on the unexposed side at 9 min., 9 sec.

Reference: Report Number 5067, "Standard ASTM Fire Endurance Test on a Roof and Ceiling Assembly," Building Research Laboratory, Ohio State University (Unpublished)

Test Description: The test specimen was composed of 0.151 in. thick glass fiber reinforced polyester skins bonded to the top and bottom of truss type stiffeners made of the same material. The cavities formed by the stiffeners were filled with proprietary insulation material. 2 x 6 wood rim joists provided a surround for the nominal 6 in. thick roof panel. The stiffeners and external surfaces of the rim joists were coated with an intumescent paint. The test specimen, 11 ft., 7-1/2 in. x 16 ft., was loaded at eight load points to a uniform live load of 20 lbs./ft^2.

Test Results: The test assembly could not sustain the applied load after 48 min. of exposure to fire.

4-4.3 **Reference:** Project 5234, "Report of a Standard ASTM Fire Endurance Test of a Limited Load Bearing Roof and Ceiling Assembly," Building Research Laboratory, Ohio State University, March, 1972 (Unpublished).

Test Description: The roof/ceiling system consisted of 20 gauge, galvanized sheet steel, interlocking pans, 4 in. deep x 16 in. wide x 12 ft., 5 in. long. The pans were installed with their vertical legs up. Unfaced, 3 1/2 in. thick glass fiber insulation batts were placed in the recesses formed by the vertical legs, and a 1 in. thick rigid glass fiber insulation was installed over the entire assembly. Roof sheathing was 1/2 in. exterior grade plywood. The ceiling consisted of 1/2 in. Type X gypsum board, which was attached to steel furring channels, 24 in. on center, perpendicular to the steel pans. A 12 ft., 5 in. x 16 ft. test specimen was loaded to produce a uniform load of 30 lbs./ft^2 over an 11 ft., 11 in. clear span.

Test Results: After 42 min. of exposure to fire, hydraulic load jacks were no longer able to apply load due to the deflection of the specimen. When the test was terminated at 47 min., the system had deflected more than 8 in. No flamethrough was observed, nor were any excessive temperature rises recorded on the unexposed surface.

4-4.4 **Reference:** "Report on a Fire Endurance Test of a Floor and Ceiling Construction," UL File R6946-1, Underwriters' Laboratories, Incorporated, February, 1972 (Unpublished).

Test Description: The floor consisted of 7-1/2 in. steel C-joists, spaced 24 in. on center, covered with a 3/4 in. tongue-and-groove interior grade plywood underlayment. One-half of the floor was covered with pad and shag carpet, the other half with 1/16 in. vinyl asbestos tiles. One layer of 1/2 in. Type SF-3 gypsum board was attached directly to the bottom flanges of the joist. The ceiling consisted of 1/2 in. Type SF-3 gypsum board attached to 7/16 in. deep steel furring channels, spaced 12 in. on center, running perpendicular to the joist span. A 12 ft., 5 in. x 16 ft., 6 in. assembly was loaded with 45 lbs./ft^2.

Test Results: At 52 min., flamethrough occurred on half of the exposed floor surface that was covered with vinyl floor tile. This was followed by structural collapse at 52 min., 45 sec.

Reference: Fire Test Report FC-170, National Gypsum Company Research Center, February, 1972 (Unpublished)

Test Description: The floor system consisted of 2 x 8 wood joists, spaced 16 in. on center, with 5/8 in. plywood subflooring. The ceiling system was made up of 2 x 4 joists, spaced 16 in. on center, with one layer of 5/8 in. Type X gypsum board applied to the bottom side of the joist. Paper-faced, 3 1/2 in. glass fiber insulation bats were installed between the ceiling joists. A uniform load of 40 lbs./ft^2 was applied to the 10 ft., 10 1/2 in. x 17 ft., 5 in. test assembly.

Test Results: Flamethrough occurred on the unexposed side of the joists at 45 min., 30 sec.

Reference: Fire Test Report FC-166 and FC-167, National Gypsum Company Research Center, December, 1971 and January, 1972 (Unpublished - Tests 1 and 2 below); and Son, B.C., "Fire Endurance Tests of Plywood and Steel Joist Floor Assemblies Without Ceilings," NBSIR 73-141, March, 1973 (Test 3 below).

Test Description:

Test 1: (FC-166) The floor system consisted of 6 in. deep, 18 gauge galvanized steel C-joists, spaced 24 in. on center, with 3/4 in. tongue-and-groove plywood subflooring attached to the joists. The ceiling assembly was composed of 3 in. deep, 18 gauge galvanized steel C-joists, spaced 24 in. on center. The ceiling membrane consisted of 3/8 in. plywood attached to the underside of the steel joists. 5/8 in. Type C gypsum board was applied over the 3/8 in. plywood. Glass fiber blanket insulation, 2 in. thick, was laid over the top of the ceiling joists. A 40 lbs./ft^2 load was applied to an 11 ft., 8 in. x 17 ft., 4 in. specimen.

Test 2: (FC-167) This test was identical to Test 1 except that the ceiling membrane consisted of two layers of 1/2 in. Type C gypsum board.

Test 3: (NBSIR 73-141) This test was similar to Tests 1 and 2 except that it was slightly larger in size: 11 ft., 9 in. x 17 ft., 11 in. The ceiling membrane was a single layer of 5/8 in. Type X gypsum board and a continuous 3 in. wide, 24 gauge steel bracing strap, which was welded to the top of the ceiling joists at mid span.

Test Results:

Test 1: Flamethrough occurred at 50 min.

Test 2: This test was terminated at 70 min., 30 sec., when structural failure appeared imminent.

Test 3: Failure occurred at 30 min. by flamethrough on the unexposed floor surface.

4-4.5 **Reference:** Son, B.C., "Fire Endurance Test of a Steel Sandwich Panel Floor Construction," NBSIR 73-164, National Bureau of Standards, April, 1973.

Test Description: The structural frame of the floor assembly consisted of 6 x 3 in., 14 gauge steel C-joists. The joists were spaced 48 in. on center. The overall size of the assembly was 10 ft., 7 1/4 in. x 17 ft., 11 in. The steel C-joists were unsheathed.

Sandwich panels were placed over the C-joists. The sandwich panels were 3 in. thick, paper honeycomb core, with a top surface of 3/8 in., CD interior grade plywood, and a bottom surface of 26 gauge, galvanized sheet steel. Three 4 ft. wide panels were placed in. the center of the test assembly with one 2 ft., 11 1/2 in. panel on either side of these, for a total of five panels. Joints between the panels were sealed with 3/8 in. wide Butyl sealant strips. A 40 lbs./ft^2 load was applied to the floor assembly.

Test Results: Failure by flamethrough occurred at a joint between two sandwich panels at 8 min., 45 sec., followed by structural failure at 9 min.

Test Number	Structural Member	Spacing	Gypsum Type	Ceiling Application	Insulation System Used	Applied Load (psf)	Assembly (min:sec)
RC-168 NG	2x4 joists / 2x6 rafters	16" o.c.	1/2" X	Direct	3 1/2" glass	30	34:30
RC-169 NG	2x4 joists / 2x6 rafters	16" o.c.	1/2" X	Direct	7" glass	30	45:20
RC-171 NG	2x4 joists / 2x6 rafters	16" o.c.	2-1/2" X	Direct	7" glass	30	83:40
NBSIR 73-167	3x6 beams (4 lyr. 3/4" plywd.)	8'11"	5/8" X	Direct	Honeycomb core	15.9	37:13
FC-156 NG	3x6 beams (4 lyr. 3/4" plywd.)	8'11"	5/8" C	Direct	Honeycomb core	17	29:00
FC-159 NG	3x6 beams (4 lyr. 3/4" plywd.)	8'11"	2-5/8" C	Direct	Honeycomb core	18.5	64:45
NBSIR 73-135	Steel-faced paper honeycomb	48" o.c.	none	26 ga. steel faces	honeycomb foam	28.6	9:09
BRL 5067	Glass Fiber/ Polyester Panel	16'0"	none	0.151" poly. skin	proprietary	20	48:00
BRL 5243	20 ga. steel pans	16" o.c.	1/2" X	R/C Channel	glass	30	47:00
UL R6946-1	7 1/2" steel joists	24" o.c.	2-1/2" SF-3	R/C Channel	none	45	52:45
FC-170 NG	2x8 / 2x4 joists	16" o.c.	5/8"	Direct	glass	40	45:30
FC-166	6" 18 ga C / 3" 18 ga C steel	24" o.c.	3/8" ply./5/8"X	Direct	glass	40	50:00
FC-167	6" 18 ga C / 3" 18 ga C steel	24" o.c.	2-1/2" C	Direct	glass	40	70:30
NBSIR 73-141	6" 18 ga C / 3" 18 ga C steel	24" o.c.	5/8" X	Direct	glass	40	30:00
NBSIR 73-164	3x6 14 ga C-joists / sndw. pan.	48" o.c.	none	26 ga. steel faces	Honeycomb	40	8:45

Table 32. Summary of Operation Breakthrough Reports

4-4.6 Evaluation of Fire Testing of Operation Breakthrough Assemblies

Operation Breakthrough testing produced a wide variety of information with very little standardization upon which to make comparisons. In the two fire tests (NBSIR 73-135 & 73-164) that used unsheathed steel joists or a steel sandwich panel, the results were similar to other unsheathed tests (described in **Chapter 4-1**) with the assembly lasting under 10 min. in both cases. When the steel joists were protected by gypsum wallboard, the fire performance increased commensurate with the protection. It should be noted that in the test that used two layers of 1/2 in. Type C gypsum board, the performance of the steel joist assembly was 70 min., 30 sec. It is generally assumed that virtually any system that uses two layers of Type X or Type C gypsum board attached directly to the bottom of the component will result in a fire endurance time greater than 60 min. Based on available test reports, this is applicable for engineered wood assemblies, steel joists, and 2 x 4/2 x 6 joist rafter assemblies as well.

Unfortunately, it is extremely difficult to make more than general observations about the HUD tests, as not enough is known about the specifics of each. However, this information can be used to provide additional data on some of the performance characteristics of a variety of assemblies and effects such as gypsum board type, combinations of gypsum board, glass fiber insulation, and the use of resilient channels. Any further reliance on these data would be unrealistic.

Chapter 4-5: Fire Endurance Performance of Coatings

The literature search did not produce significant information on the fire endurance performance of coatings, as that was not its focus. The information included in this chapter provides data for discussion and illustrates the potential for improving fire performance of lightweight products through use of coatings.

4-5.1 Report: Flame Exposure Tests of a Ceramic Covering System with Truss Plate Connected Wood Members

Authors: Proprietary

Sponsor: Proprietary

Date: July 6 - August 6, 1990

Basic Test Description and Test Method Used, See **Chapter 4-3: Fire Endurance Performance of Connections.**

Report Observations:

Horizontal Placement (3.5" Face) Over Flame	**Number Specimens Tested**	**Average Failure Time (min.)**	**Ratio Test Over Control (%)**
#3 SPF Control	10	2.88	
#3 SPF Test	10	6.00	208
1650F SPF Control	10	3.00	
1650F SPF Test	10	6.47	216
2100F SPF Control	10	3.22	
2100 F SPF Test	10	6.88	214
Vertical Placement (1.5" Face) Over Flame			
#3 SPF Control	10	4.04	
#3 SPF Test	10	7.08	175
1650F SPF Control	10	4.65	
1650F SPF Test	10	8.67	186
2100F SPF Control	10	5.83	
2100 F SPF Test	10	11.27	193
Total Specimens Tested	**120**		

Table 33. Results of Proprietary Covering Tests.

These data from the table above are represented graphically in Figures 31 and 32:

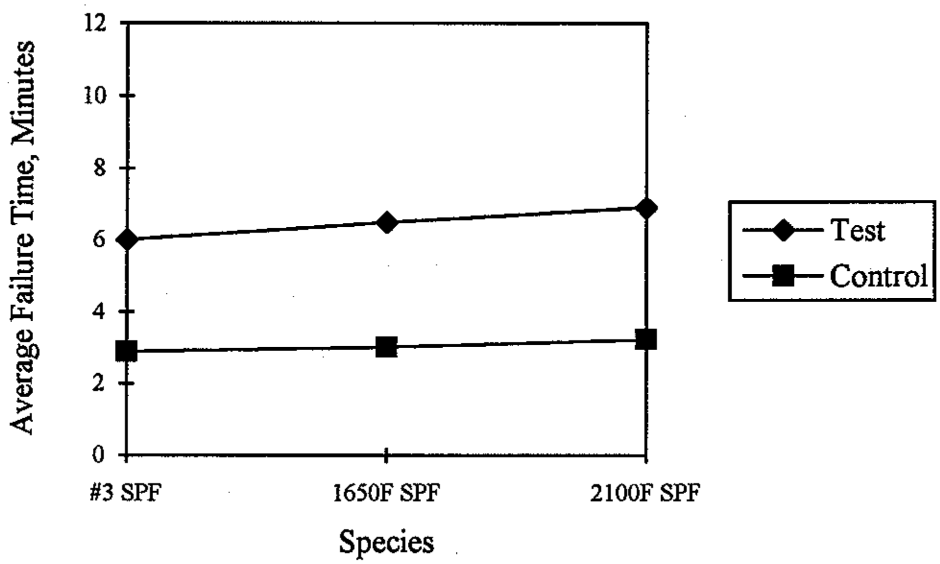

Figure 31. Average Failure Time for Horizontal Specimens

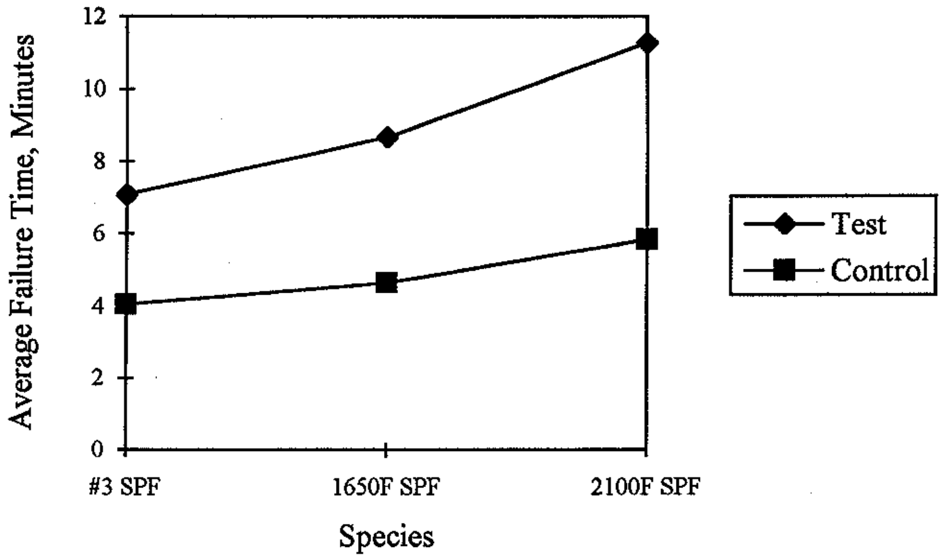

Figure 32. Average Failure Time for Vertical Specimens

Report Summary:

Description	Placement Over Flame	
	Horizontal	**Vertical**
Average Improved Performance over Control	212%	185%
Standard Deviation	0.279	0.182
Coefficient of Variation	0.078	0.033
Maximum Improvement	298%	228%
Minimum Improvement	140%	146%
Estimated 5th Percentile Improvement	165%	156%

Table 34. Summary of Results for Proprietary Coating Tests.

> **Comments:** THE FIRE DATA PRESENTED IN THIS TESTING INDICATES THAT PROTECTION OF THE CONNECTOR IMPROVES THE FIRE PERFORMANCE OF THE CONNECTION ASSEMBLY. THE CONCEPT OF IMPROVED CONNECTION PERFORMANCE USING A HEAT RESISTANT COVERING OR COATING CAN PROBABLY BE SUCCESSFULLY APPLIED TO MOST CONNECTION TYPES. IF AN ADEQUATE COVERING OR COATING IS APPLIED TO THE CONNECTION, ONE CAN THEREFORE ANTICIPATE IMPROVEMENT IN FIRE ENDURANCE PERFORMANCE.

4-5.2 **Report** Fireball Tests of Open Webbed Steel Joists

Author: T.E. Waterman, IIT Research Institute

Sponsor: General Services Administration

Date: May 15, 1977

Basic Test Description and Test Method Used: These are identical to that found in **Chapter 4-1: Fire Endurance Performance of Unsheathed Assemblies in Section 4-1.18.**

Report Observations: Unsheathed Joists generally reach temperatures between 1400 and 1600° F when exposed to the Factory Mutual Research Corporation Test F time/temperature curve.

> **Test 1**: None of the unsheathed joists in this test met the temperature limitation of 1100° F.
>
> **Test 2:** These were joists protected with two coats of intumescent paint: Each joist was brush painted with one coat of Pratt and Lambert primer at a rate of 700 ft.^{2}/gal., followed by two coats of Pratt and Lambert fire retardant white paint (intumescent type) at a rate per coat of 200 ft.^{2}/gal. On each joist, the upper chord nearly met the 1100° F limit, except where ceiling corrugations exposed unsheathed surfaces. Webs

and lower chords all exceeded the limit, but were kept cooler than the unsheathed joists of Test 1.

In general, the unprotected surface temperatures ranged from 1400 to 1600° F. The intumescent coated surfaces ranged from 1200 to 1400° F.

Test 3: These joists were protected with four coats of intumescent paint: The joists were prepared with one coat of primer and four coats of intumescent paint as described in Test 2. The intumescent coats were inadvertently brushed out thinner than before, so that the four coats were equivalent to three coats of the recommended thickness of 200 $ft.^2/gal$. Improvement in protection was marginal, at best. Temperatures were more erratic than before and, in some cases, poor performance resulted. It is suspected that the benefit of additional coating thickness was nullified by coating losses during intumescence. Further consideration of brushed on intumescent coatings was abandoned.

Test 4: These were joists protected with Jet-Sulation Type 400—a commercial sprayed fiber fireproofing. Experienced applicators coated the joist using a low pressure gun. The applicators were instructed to put on the thinnest coat practical. It is estimated that 1/4 in. of material would be adequate, but it was found difficult to apply such a thin coating.

Adequate protection was achieved in all cases except for one round lower chord, where the applied coating was less than 1/16 in. thick. Thickness ranged from 1/4 in. to 1 3/4 in. of Jet-Sulation.

Test 5: Albi-Clad 89-S—an intumescent fireproofing mastic—was professionally applied to the joists using heavy-duty pneumatic spray equipment. A wet film thickness of 1/16 in. was applied to Joists A, C and D; 1/8 in. to Joists B and E. During the early stages of the fire exposure, the coating intumesced to a thickness of approximately 1 in. Some flaming near the coating was noted as it intumesced, and it appeared to separate from the joists in localized areas. Neither thickness of Albi-Clad offered adequate protection for the joists, and little difference in protection was observable between the two applied thicknesses.

Test 6: Joists protected with Cafco products: Two coatings were professionally applied for this test. Two joists were coated with Cafco Blaze-Shield D C/F, and three others with Cafco Deck-Shield C/F. Both coatings are insulative in nature. Blaze-Shield is described as mineral fibers in a cementitious binder, designed for application to rigid structural assemblies. Deck-Shield is described as cementitious in nature, designed for roof and wall assemblies. Both are applied with a low pressure gun which incorporates a small amount of water during application. The applicators were instructed to apply the thinnest coat practical. Upper chords were protected by the applied coatings, suggesting that as little as 1/4 in. is adequate at the ceiling. A coating thicknesses of 1/4 in. was adequate in protecting all webs and the round lower chord. Coating thickness of approximately 1/2 in. were necessary to protect the thinnest lower chords, with lesser amounts needed for thicker sections.

Report Conclusions: Based on this testing, the use of spray-on fireproofing insulation appears to be the best coating to protect joists in GSA Records buildings from fire temperatures achieved prior to sprinkler operation. Coating thicknesses near the minimum compatible with commercial application techniques appear suitable. Since these coatings could significantly reduce heat losses if applied to the entire ceiling, GSA might consider this combined benefit by coating the entire ceiling and support system. It is probable that coatings of greater insulative quality and lesser fire resistance would also offer the fire resistance necessary for this purpose, while increasing energy savings.

A summary of this testing is presented in the following table:

Test Number	Structural Member	Spacing (in o.c.)	Treatment	Comments
IITRI J6397 1	12" deep Joist A-E	12	none	Failed; joist temp>1000° F FM "F" curve
IITRI J6397 2	12" deep Joist A-E	12	2 coats intum. paint 200 ft.^{2}/gal.	Failed; joist temp>1000° F FM "F" curve
IITRI J6397 3	12" deep Joist A-E	12	4 coats intum. paint 200 ft.^{2}/gal.	Improvement marginal over #2
IITRI J6397 4	12" deep Joist A, D	12	Jet-Sulation Type 400	Met 1100° F criter., i.e, FM "F" curve
IITRI J6397 5	12" deep Joist B-E	12	Albi-Clad 89-S, 1/8" & 1/16"	Failed; joist temp>1100°F, FM "F" curve
IITRI J6397 6	12" deep Joist A-E	12	Cafco Blaze-Shield D C/F	Passed, 1/4" for TC* webs, 1/2" for BC*
IITRI J6397 6	12" deep Joist A-E	12	Cafco Blaze-Shield C/F	Passed, 1/4" for TC* webs, 1/2" for BC*

* TC = Top Chord; BC = Bottom Chord

Table 35. Results of Fireball Tests.

Comments: AGAIN, COATINGS ARE SHOWN TO PROVIDE IMPROVED FIRE PERFORMANCE. THE IMPROVEMENT REALIZED IS DIRECTLY DEPENDENT ON COATING TYPE USED AND ITS APPLICATION. THIS DATA IS PRESENTED FOR GENERAL INFORMATION ONLY.

4-5.3 Evaluation of Fire Testing of Coatings

Information on coating performance for fire protection of structural members is very limited. Much of the testing has been done on structural steel columns with spray-applied fire insulation or the application of wallboard. These protection systems have been applied to structural steel beam and joist elements as well. Calculation methods have been developed for this protection.[1] Proprietary testing has also been performed using the ASTM E119 test to provide the details necessary for specific coating materials to meet a variety of ratings.[2] Most of this testing has been done to facilitate regulatory

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[1] See Chapter 31 of the Southern Building Code and Uniform Building Code Standard 43-9 for model code methods of calculating fire resistance of structural assemblies.

[2] ASTM E119 ratings for steel also have temperature limits, as noted in **Chapter 4.**

acceptance of structural systems where a fire resistance of one hour or greater is specified.

Available tests and calculation procedures indicate that coatings already have a place in fire protection for structural elements. More data are needed to evaluate how coatings may best be used. It can be expected that the greater use of coatings will be dependent upon economics and the establishment of performance requirements for the intended application. Without these criteria, the full potential of coatings may not be easily realized.

Chapter 5: Sprinkler Testing

5.1 Overview

In **Quick Response Sprinklers: A Technical Analysis,**[1] it is revealed that the primary focal point of sprinkler testing to date has been on sprinkler performance and their ability to contain a fire under a variety of fire load conditions. Little attention has been placed on structural elements holding up the sprinklers. However, one of the current questions, from a fire service perspective, is what will be the performance of lightweight engineered wood products with sprinklers attached after a fire has begun. The key elements of this question are:

- Will structural members fail before the sprinklers can activate to control the fire or protect the structure?
- Does the arrangement of the sprinklers and their attachment to the structural element effect a sprinkler's ability to protect the structure?
- Does the spacing, depth, and arrangement of the structural element influence the sprinklers' ability to protect the structure?

This chapter will report on the available test data specific to fire performance of lightweight engineered components supporting sprinklers. Unfortunately, data on this specific issue is limited. The test reports found in the literature search are on wood systems exclusively.

5.2 **Report:** Fireball tests of Open-Webbed Steel Joists.

Author: T.E. Waterman, IIT Research Institute

Sponsor: General Services Administration

Date: May 15, 1977

Report Details: See **Section 4-1.18** of **Chapter 4-1** for report details.

> **Comments:** THE FIREBALL TESTS OF OPEN WEBBED STEEL JOISTS IN **Chapter 4-1** ALSO DISCUSSED THE PERFORMANCE OF STEEL BAR JOISTS PRIOR TO SPRINKLER ACTIVATION. THE CRITERION USED FOR ACCEPTABLE PERFORMANCE WAS PREVENTION OF TEMPERATURES GREATER THAN 1100° F

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[1] Fleming, Russell P. "Quick Response Sprinklers: A Technical Analysis", National Fire Protection Research Foundation, April 1985.

ANYWHERE ON THE STEEL JOISTS. THIS TEST IS INCLUDED FOR GENERAL INFORMATION.

5.3 **Report:** Sprinkler Tests for Protection of Parallel Chord Wood Trusses

Authors: D. Burkhart, K. Powell, and R.B. Coker

Sponsor: Fort Worth Fire Prevention Bureau

Date: 1988

Basic Test Description: The City of Fort Worth investigated sprinkler coverage in concealed truss spaces. Trusses tested were 16 in. deep wood webbed, metal plate connected trusses. The test assembly consisted of a 30 x 30 ft. area that had trusses spaced 2 ft. on center. A 3/4 in. tongue-and-groove plywood deck was used as sheathing. The sprinkler system consisted of a tree system with a 2 in. cross main and riser nipple, and 1-1/2 in. branch lines to reduce friction loss. Outlets were arranged to allow for installation of 8 x 8, 10 x 10, and 12 x 12 ft. spacing (standard and staggered), both in the upright and pendent positions. Horizontal distances from truss members were random.

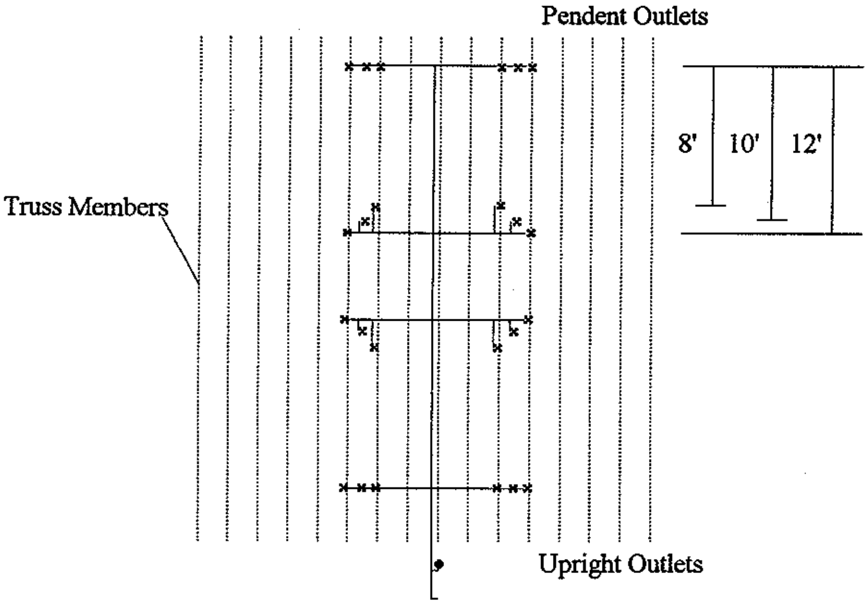


Figure 33. Test Assembly Layout

Distribution Criteria: The criteria established for successful distribution were wetting of the lower chord members in the entire sprinkler effectiveness area, and some wetting of the deck, established by visual inspection.

Test Results: The first test series used 12 x 12 ft. spacing with standard sprinklers installed in standard positions. Tests were performed using operating pressures of 7, 15, and 25 lbs./in.^{2}. The established criteria were not met.

The next series of tests were the same as Test 1, but used standard sprinklers installed in their reverse position. This meant that upright sprinklers were installed in pendent position and the pendent sprinklers were installed in the upright position. This resulted in excellent wetting of the deck, but not of truss members.

The third test reduced spacing to 10 x 10 ft. With standard sprinklers installed in normal positions, the established criteria were not met. The criteria were also not met when standard sprinklers were installed in reverse positions.

The final series of tests was run with standard sprinklers and staggered 10 x 10 ft. spacing. Satisfactory results occurred with standard sprinklers in reverse positions, and an operating pressure of 7 lbs./in.^{2}. Satisfactory results also occurred with conventional sprinklers in upright and pendent positions, at an operating pressure of 7 lbs./in.^{2}.

Fire Tests: The same assemblies for the distribution tests were used in the fire tests, except that in fire tests a 1/2 in. standard drywall ceiling was attached to the bottom chords of the trusses. The sides and ends were enclosed to limit air circulation in the concealed space. The sprinkler system was charged with water, and the control valve was closed. Upon activation of the first sprinkler, the valve was opened to the desired pressure. Although this caused a slight delay, pressures were more accurately controlled. The pass/fail criterion was total extinguishment. The fuel used for each test was 16 ounces of naphtha placed in an 18 in. diameter pan 2 in. deep. This amount of fuel was used as the ignition source for the wood truss only, not as fuel to contribute to burning.

Test Results: The first test used 10 x 10 ft. staggered sprinkler spacing. The fuel was located in the same channel as the sprinkler, but in the geometric center between the three sprinklers. The test used pendent sprinklers in the upright position. The fire was extinguished within 10 sec. One sprinkler activated, with an operating pressure of 7 lbs./in.^{2}.

In the next series of tests, conventional sprinklers were used in the pendent and upright positions. The fires were also extinguished in less than 10 sec., with a single sprinkler activating with 7 lbs./in.^{2} water flow.

Two tests were also performed with the fire located in a channel adjacent to the sprinklers. In all cases, the fire was extinguished in less than 10 sec. with one sprinkler activating with 7 lbs./in.^{2} water flow.

Finally, fire tests performed with standard sprinklers in normal positions failed to extinguish the fires with water pressures less than 25 lbs./in.^{2}.

Report Summary: The acceptable arrangements were:

- Standard sprinklers staggered at 10 x 10 ft., installed in the reverse position with a minimum operating water pressure of 7 lbs./in.[2]
- Conventional sprinklers installed either upright or pendent, staggered at 10 x 10 ft., with a minimum operating water pressure of 7 lbs./in.[2]

Report Conclusion: A proposal was made to amend the local fire code to designate the spacing of sprinklers in parallel chord wood truss construction to a maximum 10 x 10 ft. staggered spacing, with standard sprinklers in the reverse position, or conventional sprinklers in either position, operating at a minimum of 7 lbs./in.[2] water flow.

> **Comments:** The Fort Worth Tests were performed to provide information about sprinkler distribution patterns within a truss concealed space. This testing was undertaken to determine whether sprinkler head spacing and positioning designated in National Fire Protection Association's NFPA 13 standard was satisfactory to extinguish a concealed space fire within wood trusses.[2] The report does not state whether or not there are other viable options for sprinkler placement, positioning, or the use of different sprinkler heads that would allow other spacing combinations. Additional testing is desirable. It would also be desirable to have a test procedure with objective and quantitative criteria to evaluate sprinkler system spacing within the concealed space. Without these criteria, performance acceptability is undefined.
>
> These data were submitted to the NFPA 13 committee. The committee chose not to change the standard believing that the criterion for extinguishment of fire was excessive. Given this, there appears to be the de facto establishment of at least one performance criterion for sprinkler tests—*control* of the fire. The committee did, however, change the definition of trusses.
>
> The City of Fort Worth fire code was changed, adding the following sprinkler placement requirements and revised truss definition (Note: these requirements do not apply to all situations, and are not to be used as general sprinkler placement requirements. See **Chapter 7.3.6** for additional discussion.):
>
> - When wood trusses are present in concealed spaces, sprinklers shall be placed at a maximum protection area of 100 ft.[2].

---

[2] NFPA 13R, **Standard for the Installation of Sprinkler Systems in Residential Occupancies up to Four Stories in Height**, 1989 ed.

- SPRINKLER HEADS SHALL BE PLACED NOT CLOSER THAN 6 FT., NOR FARTHER THAN 10 FT. FROM ADJACENT HEADS.
- SPRINKLER HEADS SHALL NOT BE CLOSER THAN 6 IN. TO TRUSS MEMBERS.
- SPRINKLER HEADS SHALL BE INSTALLED IN THE REVERSE POSITION—PENDANT SPRINKLERS IN UPRIGHT POSITION OR UPRIGHT SPRINKLERS IN PENDANT POSITION.
- WOOD TRUSS CONSTRUCTION SHALL MEAN PARALLEL WOOD CHORD BEAMS WITH WOOD WEBBING SUPPORTING A ROOF OR FLOOR DECK. TRUSSES WITH STEEL WEBBING SIMILAR TO BAR JOIST CONSTRUCTION HAVING WOOD CHORDS SHALL BE CONSIDERED AS COMBUSTIBLE BAR JOIST CONSTRUCTION.

5.4 **Report:** Fire Sprinklers in Exposed Deep Prefabricated Wood I-Joists Floor/Roof Systems

Authors: J. Piscione and J. Vogt

Sponsor Trus Joist Corporation and Willamette Industries

Date: February, 1989

Basic Test Description: Three separate fire tests were conducted:

Test 1: The floor assembly consisted of five 24 in. deep TJI 350X I-joists and five 24 in. deep WSI 424 I-joists spaced 32 in. on center and spanning 30 ft. The ends of the joists were attached to a rim beam, which provided firestopping, at the end of each channel for the full depth of the joists. The length, depth and spacing of the joists resulted in a volume of 160 $ft.^3$ per joist channel. This volume represents the maximum allowed by the Insurance Services Organization (ISO). Six Viking Micromatic Model M standard response glass bulb spray sprinkler heads, with 1/2 in. orifices, were mounted on two parallel branch lines, located approximately 6 ft., 11-1/2 in. on either side of the assembly centerline. These sprinkler heads have a nominal sprinkler temperature rating of 155° F, and a response time index of 300. The sprinklers were spaced at 9 ft., 4 in. intervals along each branch line, and provided a protection area per sprinkler of 130 $ft.^2$. The spacing was chosen according to the maximum per head protection area allowed in NFPA 13 for an ordinary hazard occupancy classification. Sprinklers 1 and 6 were located at the center of a joist channel, 2 and 5 directly beneath an I-joist, and 3 and 4 located 16 in. beyond the floor assembly. All sprinkler head deflectors were 25 in. beneath the assembly deck.

An inactive sprinkler branch line was also installed under the floor assembly, approximately 6 in. from one of the active branch lines. Five standard response and two quick response sprinklers were attached to the inactive line. This line was positioned 18 in. beneath the deck. This allowed comparisons to be made between the response of the sprinklers positioned at 18 in., and those at 25 in. beneath the deck.

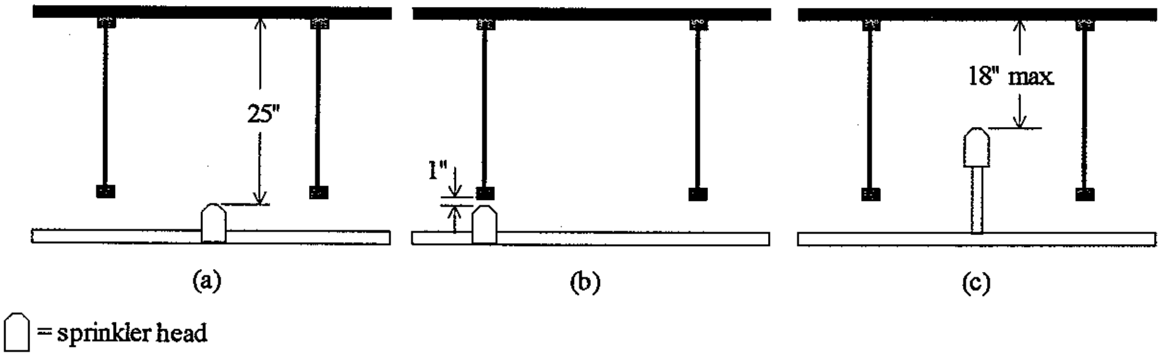


Figure 34. Active sprinkler head placement in test assembly: at center of joist channel (a) and one inch below bottom flange (b). Placement of inactive standard response sprinkler heads at 18 inches beneath the deck (c).

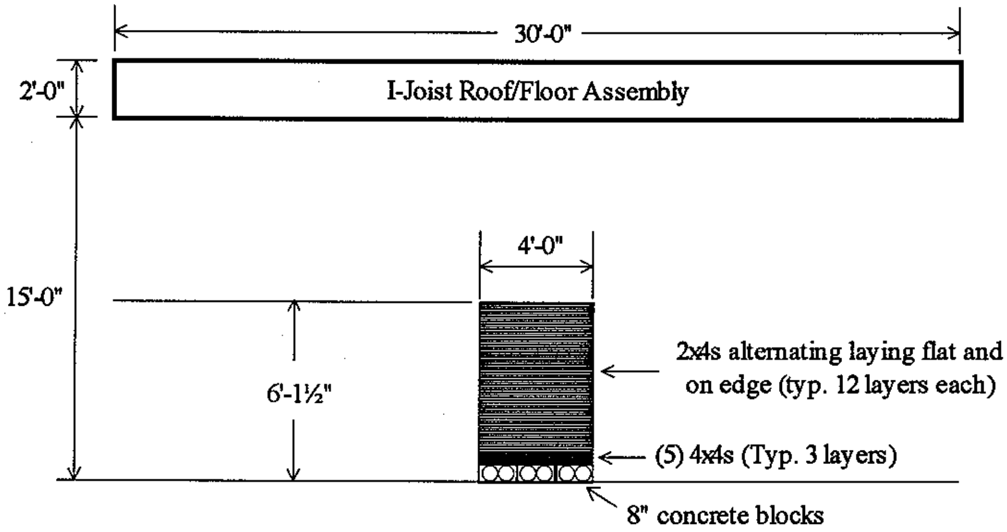


Figure 35. Cross-section of wood crib and floor assembly.

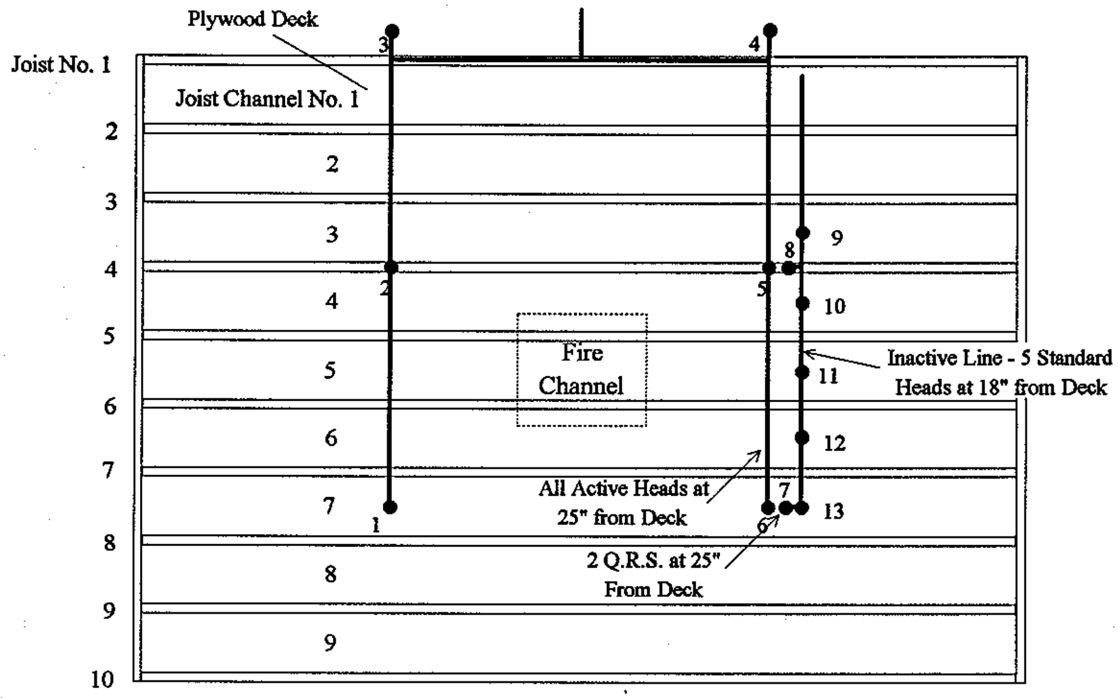


Figure 36. Diagram of Test 1.

Test 2: The second fire test was the same as the first, except that the spacing of the branch lines was at 15 ft., and active sprinkler heads were 10 ft., 8 in. apart. This represented the maximum spacing allowed (130 ft.^{2} per head) in NFPA13 for ordinary hazard occupancies. ('Ordinary' indicates certain construction types and combustible contents using lightweight engineered construction.)

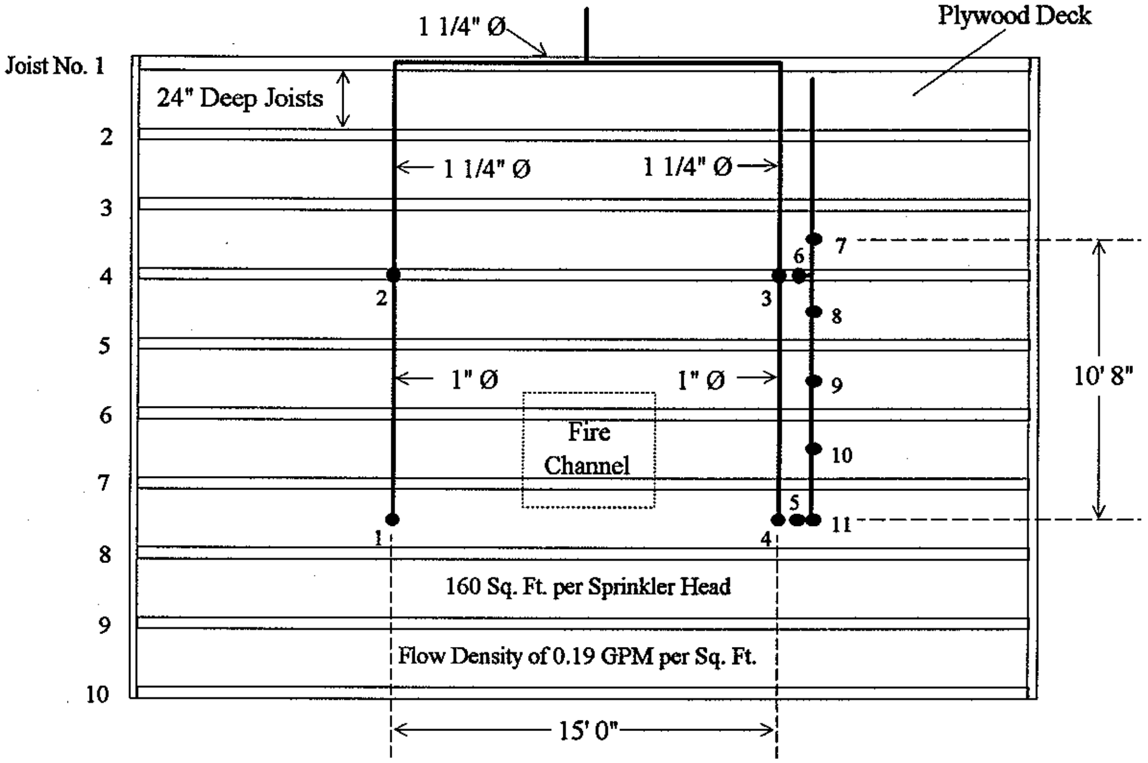


Figure 37. Diagram of Test 2.

Test 3: This test was identical to the second, except that the effective joist depth was increased to 30 in. All active sprinkler heads were centered between the joists, with deflectors positioned 31 in. beneath the deck.

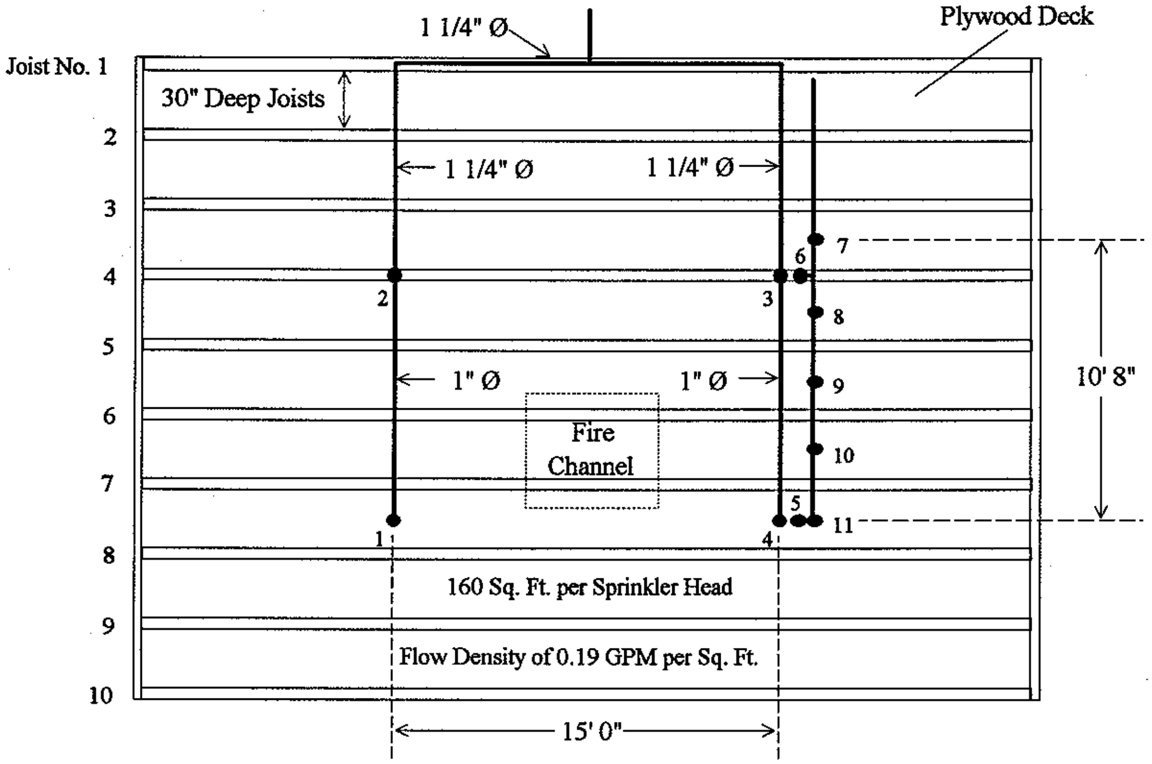


Figure 38. Diagram of Test 3.

Test Methods used: Water supply for the sprinkler system was provided by a pumping system capable of delivering 1680 gal./min. All pipe sizes used in this sprinkler system were selected in accordance with NFPA 13 specifications. The flow density per sprinkler head during the first test was calculated to be 0.35 gal./min/ft.^{2}. This was reduced to 0.19 gal./min/ft.^{2} for Tests 2 and 3.

The fire source used in each test was provided by a wood crib containing 528 bd.-ft. of dimension lumber. The crib design was similar to that used by Underwriters Laboratories to evaluate the effectiveness of sprinkler heads, but contained over 3-1/2 times the amount of wood. The crib used in Test 1 was positioned directly under joists at the center of the assembly, while the cribs used in Tests 2 and 3 were positioned under joist 6 and 7 in the center of the assembly. The crib placement in each test was considered to be in the worst location with respect to active sprinkler head sensitivity.

Report Observations: Temperature measurements were made in various locations throughout the assembly. Observations were also made during each test.

Report Summary:

Test 1: The exposed surface of the deck at the center of the assembly began to burn in less than 2 min. from crib ignition. The first sprinklers to respond were the uncharged standard response sprinklers 18 in. below the deck at 1 min., 54 sec., and 1 min., 57 sec. An uncharged quick response sprinkler was the next to respond at

2 min., 7 sec., and was located 25 in. below the deck. One more uncharged standard response sprinkler 18 in. below the deck responded before the charged sprinklers. The first charged active response sprinkler activated 2 min., 26 sec. into the test. Within one second, the second standard response sprinkler activated. At 2 min., 34 sec., all fire in the assembly had been completely extinguished. The flames were confined to the wood crib 4 min., 10 sec. into the test, and by 5 min., 40 sec., the fire had been completely extinguished.

Damage to the floor assembly was minimal, and was confined to the center joist channel only. Charring, 1/16 in. thick, was observed on the deck and I-joists of the center channel to a distance of approximately 2 ft. on either side of center. Beyond this distance damage was limited to surface charring and discoloration.

Test 2: This test progressed in a manner similar to Test 1. Three uncharged standard response sprinklers 18 in. below the deck, and two uncharged quick response sprinklers 25 in. below the deck responded before any of the charged sprinklers.

The response time of the charged sprinklers in this test was approximately 3 min., 26 sec. into the test--one minute longer than the response times of the charged sprinklers in Test 1. However, the charged sprinklers in Test 2 were located approximately 50 percent further away from the fire. At approximately 4 min. from activation of the two standard response sprinklers, the fire in the floor assembly had been completely extinguished. At 4 min., 30 sec., flames were confined to the wood crib. By 8 min., 30 sec., the fire was completely out, and the test concluded. Damage to the floor assembly was similar to that observed in Test 1. Charring of approximately 1/16 and 1/8 in. was observed on the I-joists and the exposed surface of the deck on the portion of the joist channel which was located directly over the wood crib. Some charring was noted beyond this area, but was limited to surface charring. Minor discoloration was also noted.

Test 3: As in the two previous tests, two uncharged quick response sprinklers and three uncharged standard response sprinklers activated before any of the charged sprinklers.

Two charged standard response sprinklers activated at 4 min., 10 sec. and 4 min., 11 sec. into the test. These were soon followed by two more activations at 4 min., 15 sec. and 4 min., 21 sec., respectively. At 4 min., 31 sec., all fire in the floor assembly had been extinguished. At 13 min., 56 sec., the fire in the wood crib was completely out, and the test concluded. Damage to the floor assembly during Test 3 was minimal, and confined to that portion of the joist channel located directly above the wood crib. Damage to the assembly beyond the central portion of this channel was limited to surface discoloration.

Report Findings:

- The sprinkler coverages and flow densities used in each test were effective in controlling and extinguishing the fire.

- Temperatures in the I-joist channels located away from the fire were generally higher at sprinklers beneath the joist than at sprinklers inside the joist channel. Sprinkler head sensitivity would thus be optimized by placing the sprinklers below the joists.
- Temperatures appear to be the same at a given elevation and horizontal distance from the fire source. Sprinkler heads, therefore, can be placed directly beneath the I-joists or in the center of the joist channel without jeopardizing sensitivity. The temperature drop in each successive joist channel away from the fire is significant. Therefore, in a larger assembly with a greater number of sprinklers, it is not likely additional sprinklers would be activated.
- Joist channels should be blocked to a maximum of 200 ft.^{3}, which is based on a 30 in. deep joist channel.

Comments: This testing was ad hoc, as there was no defined test procedure, performance requirements or performance criteria. The only criterion for acceptable performance seems to be that the fire is controlled and/or extinguished. Even though temperature measurements were made throughout the assemblies, there is no pass/fail criteria for a temperature rise in any location on an assembly. Previously we have seen that 1100° F was the criterion used for determining the acceptable performance of a steel joist. The Fort Worth test also used fire extinguishment as the only criterion for success or failure of the system. This area needs further development.

5.5 **Report:** Fire Sprinklers in Exposed 30 in. Deep Prefabricated I-joist Floor/Roof Systems, Phase 2

Authors: J. Piscione and P. Pintar

Sponsors: Trus Joist Corporation and Willamette Industries

Date: November, 1989

Basic Test Description: Six separate tests were conducted in Phase 2. Four tests were reported in detail.

The floor/roof assembly consisted of fourteen 30 in. deep TJI/350X I-joists and twelve 30 in. deep WSI-424 I-joists spaced 32 in. on center. Thirteen joists spanned a 30 ft. section of the structure. The remaining joists spanned a 45 ft. section, creating an overall structure 75 ft., 7 in. in length. The rim joists provided firestopping around the perimeter of the joists. Additional firestops were placed 15 ft. from the outer edge of the 45 ft. joists. The length, depth and spacing of the joist channels resulted in a volume of 200 ft.^{3} per joist channel. Plywood 5/8 in. thick was used for the deck.

Branch lines were located 7 ft., 9-1/2 in. from the ends of the assembly, and spaced 15 ft. apart. Sprinkler heads had a nominal sprinkler temperature rating of 155° F, and a response time index of 300. The sprinklers were spaced at 8 ft., 8 in. intervals along each branch line, and provided a protection area per sprinkler of 130 ft.². The branch line elevations were adjusted so that all sprinkler head deflectors were 34 in. beneath the deck of the assembly for Test 2, and 31 in. below the deck for Tests 1-2, 3 and 4.

An inactive branch line was also installed approximately 6 in. laterally from each active branch line. Quick response sprinklers were placed on the inactive branch line, that had a rating of 155° F and a response time index of 65.

> **Test 1-2:** The fire source was located on the center-most sprinkler line, between two sprinkler heads. This location was selected in response to a concern that the critical fire location was between two heads, close to a firestop.
>
> No standard response sprinklers were used; only six quick response sprinkler heads were allowed to activate during the test.

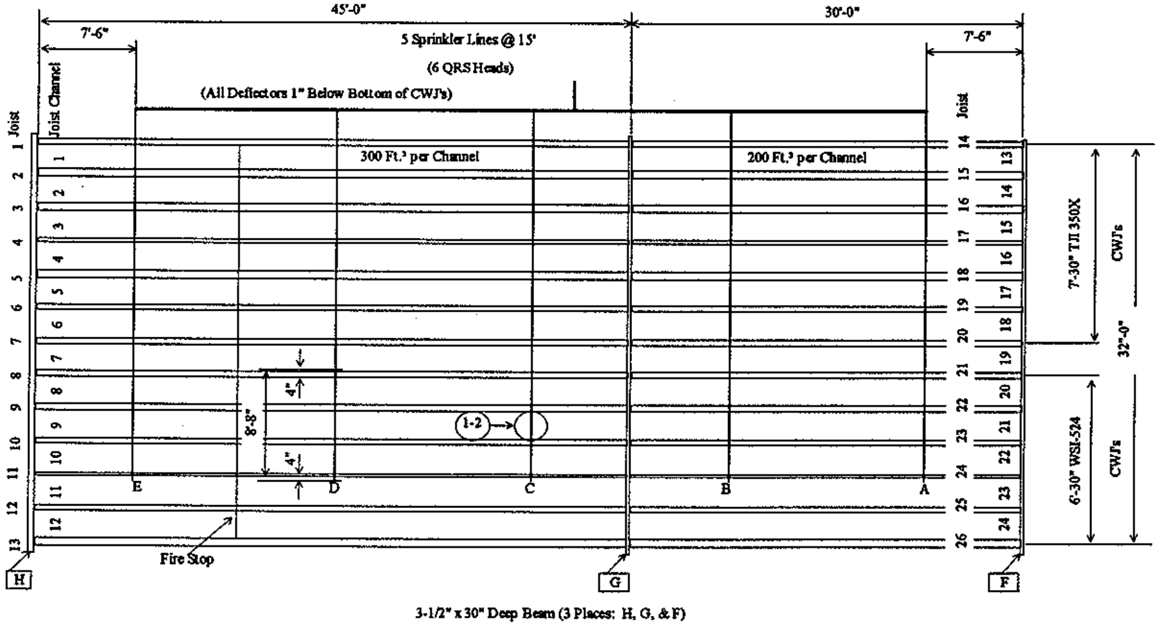


Figure 39. Plan View of Test 1-2

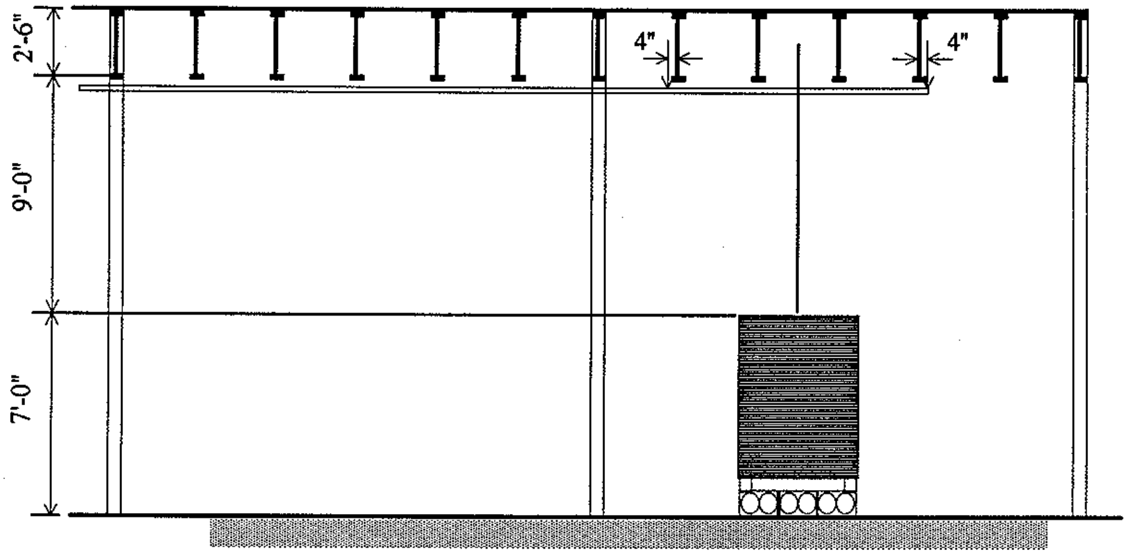


Figure 40. Elevation View of Test 1-2

Test 2: The fire source was located under the center-most sprinkler head of the branch line next to the center beam under the 30 ft. joists. This fire location was selected in response to a concern that the critical fire location was beneath one sprinkler. Active standard response sprinklers were used. The sprinkler head deflectors were located 34 in. below the bottom of the deck. Fifteen standard response and fifteen quick response sprinklers were deployed.

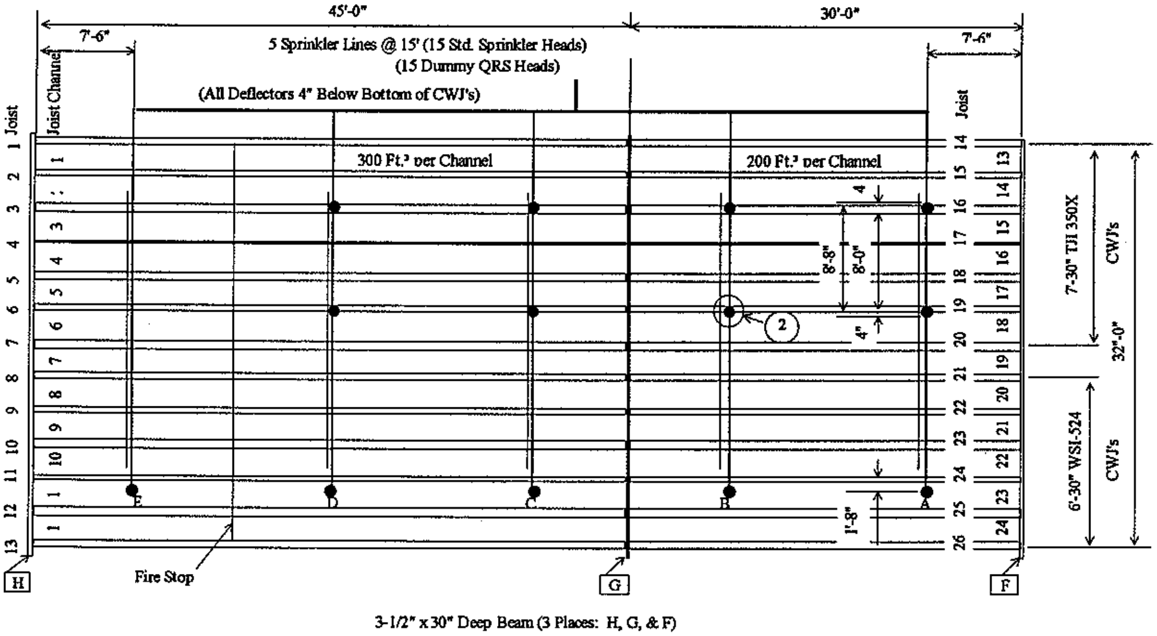


Figure 41. Plan View of Test 2

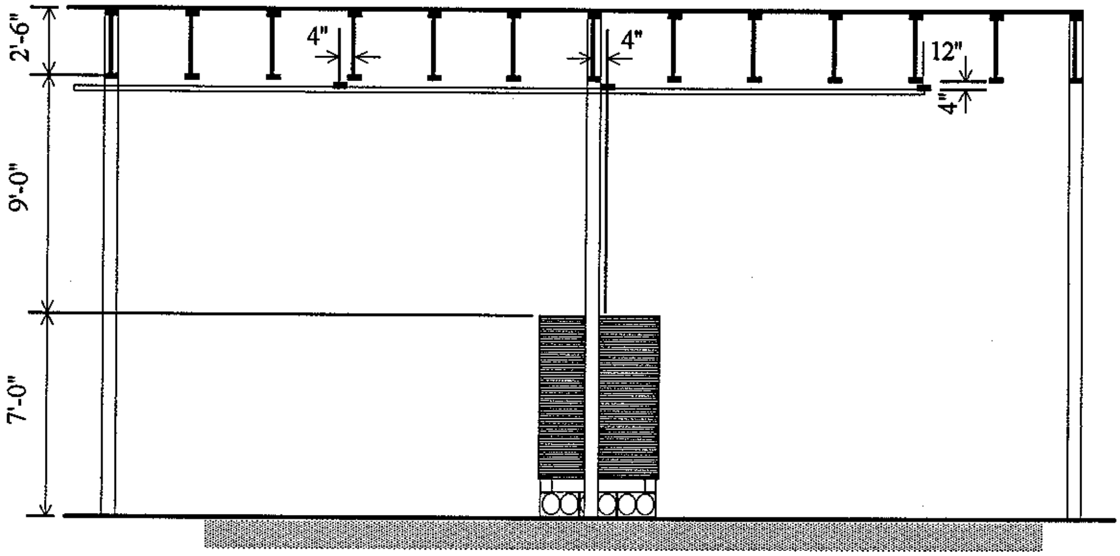


Figure 42. Elevation View of Test 2

Test 3: This test was developed in response to a concern about the performance of sprinkler heads in a 45 ft. channel with the fire source located between four sprinklers. Blocking panels were removed from the 45 ft. section to increase the channel volume to 300 ft.^{3}. The sprinkler head deflectors were located at 31 in. below the bottom of the deck. Fifteen standard response and 15 quick response sprinklers were deployed.

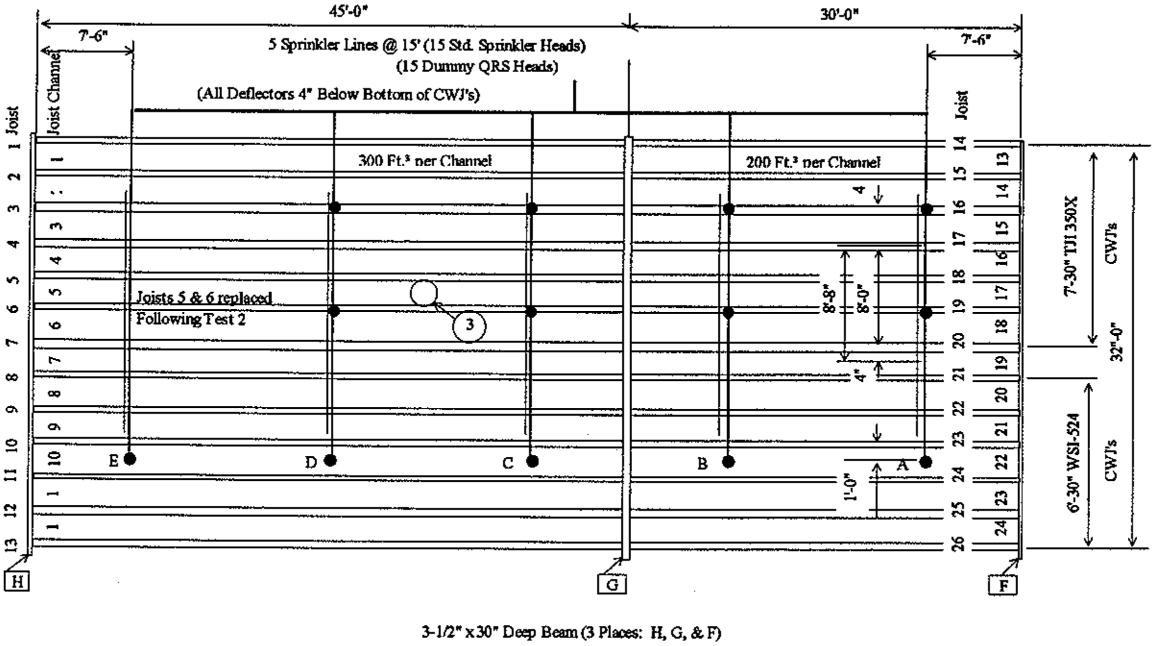


Figure 43. Plan View of Test 3

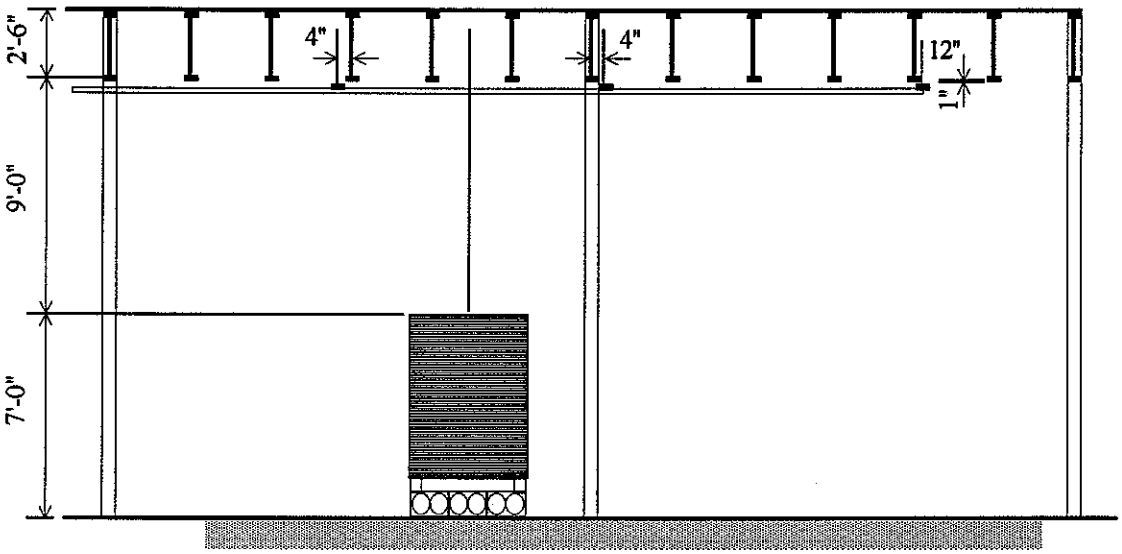
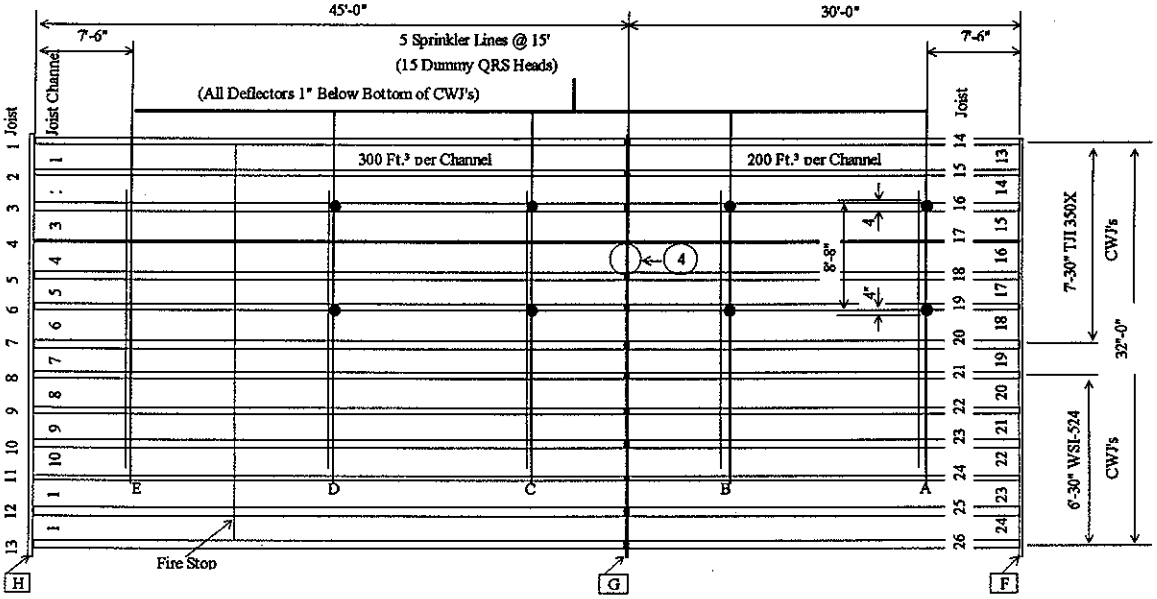


Figure 44. Elevation View of Test 3

Test 4: This test was developed based on a concern that the critical fire location was directly below a firestop. The rest was similar to the general assembly, except that branch lines were located 32 in. to the side of the original locations. The sprinkler head deflectors were located 31 in. below the bottom of the deck. Fifteen inactive quick response and eight active standard response sprinklers were deployed.



3-1/2" x 30" Deep Beam (3 Places: H, G, & F)

Figure 45. Plan View of Test 4

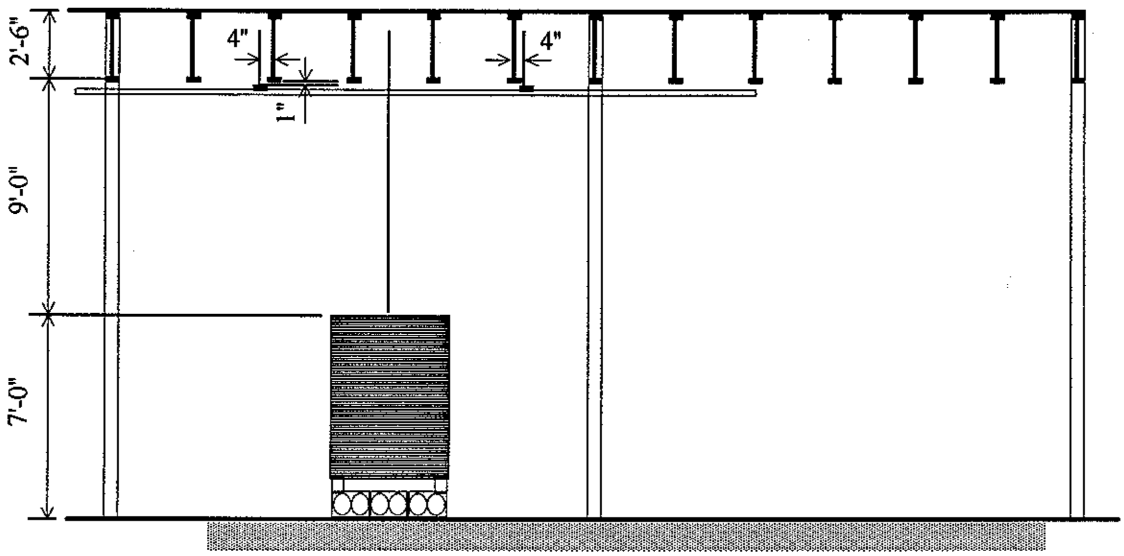


Figure 46. Elevation View of Test 4

Water Supply: The water supply was capable of delivering 1680 gal./min. A static water pressure of 134 lbs./in.^{2} was measured, and a flow density of 0.19 gal./ft.^{2} was maintained throughout each test.

Fire Source: The fire in each test was provided by a wooden crib containing 528 bd. ft. of dimension lumber, as in the previous test. The crib design was similar to that used by Underwriters Laboratories, but contained more than 3-1/2 times the amount of wood.

Report Observations: Temperatures at various locations in the assembly were monitored throughout each test. Visual observations and time to extinguishment were also collected.

Report Summary: Test 1 and 1-1 used the same test configuration as Test 1-2. This configuration was tested three times due to the inability of the sprinkler system to control the crib fire. Test 1 was discounted due to pressure problems noted during the critical first second after activation. Test 1-1 was performed under identical conditions, except deflectors were moved to 31 in. below the deck, instead of 34 in. This scenario also failed to provide adequate fire control.

Test 1-2: This test used only charged quick response sprinkler heads, to determine if an earlier response time would be effective in controlling the fire. The QRS sprinklers activated 45 sec. earlier than standard sprinklers from the previous tests, but the system could not control the crib fire. In Test 1-2, the first QRS sprinkler activated at 2 min., 2 sec., at a temperature of 223° F. This sprinkler was located 4 ft., 4 in. to the left side of crib center. Within 22 sec., three additional sprinklers activated. Despite the activation of four sprinklers, the fire increased in intensity, and the joist channel ignited at 2 min., 51 sec. Two additional QRS sprinklers activated, but did not aid in controlling the fire. Manual assistance was required to extinguish the flames.

Test 2: At 1 min., 1 sec., the charged quick response sprinkler over the fire activated. The charged standard response sprinkler directly over the crib activated at 1 min., 17 sec. This second activation was solely responsible for controlling of the fire. Ten additional charged QRS and four charged standard response sprinklers activated during the course of extinguishment.

The fire was confined to the crib and was allowed to burn for 13 min. before excessive smoke forced manual extinguishment of the fire source. 355 lb. of wood was consumed during the 13 min. fire period. Charring of the joist channel above the fire of 1/16 in. was evident, and some discoloration was also noted. The ultimate load obtained on the most charred joist was 5,866 lb. per reaction. An uncharred control joist was tested to an ultimate load of 7,055 lb. per reaction. This represents a 16.8% reduction in strength.

Test 3: The fire reached the assembly deck at 1 min., 45 sec. into the test. At 2 min., 40 sec., the 45 ft. channel was engulfed in flames. At this point, eight uncharged QRS heads activated. Two charged standard response sprinklers activated at 2 min., 48 sec., soon followed by four additional charged standard response activations. The first four sprinkler heads that activated were those adjacent to the fire. The remaining two standard sprinkler response heads that activated were adjacent to the channel above the fire. The flames within the channel were extinguished by the sprinkler system within 1 min. after activation of the first charged standard response sprinkler head. The fire was confined to the crib. Manual assistance was used to extinguish the fire to prevent excessive smoke buildup in the building.

98 lbs. of wood from the crib burned during the test. Fire damage to the joists due to charring was limited to the 45 ft. section. Two joists experienced charring to a depth of 1/16 in., and there was some discoloration and minor charring on the two joists and the beam. No other damaged was observed. The ultimate strength of the charred joist was 4,748 lbs. of reaction. This compared to an uncharred control joist that had a 5,303 lb. reaction. This represents a 10.5% reduction in strength.

Test 4: The fire source was located directly under the center beam. This forced the fire to burn into both the 45 ft. and 30 ft. channels. At 1 min., 45 sec., flames began to touch the bottom of the joists. At approximately 3 min., six uncharged QRS heads activated. At 3 min., 30 sec., the channels were fully engulfed in flames. Two additional uncharged QRS heads activated at 3 min., 20 sec. Two charged standard response heads activated at 3 min., 40 sec. These heads were the center-most heads, with one head being adjacent to the fire, and one being one line away from the fire. At 3 min., 45 sec., two additional heads activated on the same lines that initially activated. The two heads that activated on the line adjacent to the fire were successful in extinguishing the flames. In total, eight charged standard response sprinklers activated. A line of charged standard response sprinklers directly adjacent to the crib did not activate at all. Two hundred pounds of wood was consumed during the test. Fire damage to the structure was minimal, and remained confined to the channels directly above the fire source. The maximum depth of char noted was 1/8 in. Ultimate strength was measured on three joists, and resulted in strength decreases of 11, 13, and 2.2 percent.

Report Summary:

- When the fire is directly between sprinklers spaced 8 ft., 8 in. apart, the sprinklers are ineffective in controlling the fire. Very little water got to the crib. Any structure type may be threatened under this specific condition. Further evaluation may be desirable, such as the relationship between the sprinkler density of 0.19 gal./min/ft.^{2} and the 850 lb. wood crib.
- In the other three fire scenarios, the sprinklers controlled the crib fire, and the sprinklers protected the structure.
- When the sprinklers controlled the fire, they also protected the structure.

Comments: THE LAST TWO TESTS CONTRIBUTED TO A CHANGE IN THE NFPA 13 STANDARD THAT ALLOWS MAXIMUM DEFLECTOR DISTANCE TO BE 22 IN. BELOW THE FLOOR OR ROOF DECK. THIS WOULD ALLOW I-JOISTS 22 IN. DEEP TO BE USED UNDER THIS PROVISION. THIS HAS CAUSED CONCERN ON THE PART OF THOSE WHO BELIEVE THAT THIS DEFLECTOR DISTANCE IS TOO GREAT, GIVEN THAT THE PERFORMANCE RELIABILITY OF THIS DEPTH JOIST HAS NOT BEEN PROVEN. PART OF THIS CONTROVERSY ARISES FROM THE FACT THAT THREE OF THE SIX TESTS ABOVE FAILED TO CONTROL THE FIRE.

THE TESTS SUGGEST THAT WHEN A FIRE OCCURS DIRECTLY BETWEEN STANDARD OR QUICK RESPONSE SPRINKLERS SPACED 8 FT., 8 IN. APART, WATER DISTRIBUTION PATTERNS DO NOT CONTROL THE FIRE. ONE COULD CONCLUDE THAT THIS IS DUE TO THE JOIST DEPTH, YET THE QUICK RESPONSE SPRINKLER ACTIVATED AT 2 MIN., 2 SEC. IN TEST 1-2. IN THE OTHER TESTS, STANDARD RESPONSE SPRINKLERS ACTIVATED BETWEEN 1 MIN., 17 SEC. AND 3 MIN., 40 SEC., AND STILL CONTROLLED THE FIRE. THIS SUGGESTS THAT THE CRIB FIRE SIZE AND ITS PLACEMENT BETWEEN SPRINKLERS CREATES A WATER DISTRIBUTION PROBLEM THAT DOES NOT CONTAIN AND SUPPRESS THE FIRE. THIS ALSO SUGGESTS THAT JOIST DEPTH IS INDEPENDENT OF THIS WATER DISTRIBUTION PATTERN.

THESE SERIES OF TESTS PROVIDE DATA NEEDED TO UNDERSTAND SPRINKLER PERFORMANCE AT GREATER DEFLECTOR DISTANCES. THESE TESTS ALSO RAISE A CONCERN OVER WATER DISTRIBUTION PATTERNS UNDER ONE FIRE LOAD AND SPRINKLER SPACING CONDITION. ADDITIONAL TESTING WOULD ENHANCE UNDERSTANDING OF THIS ANOMALY.

5.6 Evaluation of Sprinkler Performance

All sprinkler testing described above was performed under ad hoc conditions. The sprinklers were spaced in accordance with the NFPA 13 standard and determination was made whether the fire was controlled or extinguished with the particular type of sprinkler, sprinkler orientation, sprinkler water distribution pattern, sprinkler spacing, water flow, and deflector distance, etc. This appears to be one method upon which sprinkler performance is assessed. However, test procedures are not standardized. The development of a consensus standard for sprinkler performance with specific structural member, temperature, and fire control criteria is needed.

Until a standard test protocol and performance criteria are developed, performing additional testing would only provide interesting information. However, there will continue to be the significant possibility that testing like this will be unacceptable to regulatory authorities. This is due to the perception that the tests are biased, or that the testing performed does not meet expectations on how the tests should have been performed. Therefore, it is extremely important for there to be agreement on what constitutes acceptable performance.

Chapter 6: Building Code Requirements

6.1 Model Codes

Three major model building codes in the United States define construction:

- **Uniform Building Code** (UBC) by the International Conference of Building Officials (ICBO)
- **National Building Code** by Building Officials and Code Administrators International (BOCA)
- **Standard Building Code** by Southern Building Code Congress International (SBCCI)

There are also state and local building codes and other jurisdictions that have their own code provisions. Canada has a building code that is different from any of those in the United States. One major difference in the Canadian code that addresses the fire endurance performance of assemblies is an allowance for 45-minute rated assemblies in certain applications.

A mechanism to aid in the use of alternate materials of construction is called an Evaluation Report. Manufacturers of products that do not fall within the specific context of the code can submit test data that will be evaluated by the model code groups for suitability and equivalence with existing code provisions. A report is produced based on their findings, which may allow the product to be used as an alternate method of compliance.

Ultimately, the responsibility for the decision to allow a specific construction type, method or material is determined by the local jurisdiction or building official working on the project.

6.2 Uniform Building Code

While a number of model building codes are produced, and countless other local codes exist, the 1991 edition of the **UBC**, produced by ICBO, has been used here for defining code requirements for structural members.

6.2.1 Type I—Fire Resistive Buildings

Structural elements in Type I Fire Resistive (FR) buildings shall be of steel, iron, concrete or masonry. Under certain conditions within the code, heavy timber members can be used as structural framework or roof framing in Type I buildings, usually for buildings with only one story. In cases where the structural framing is greater than 25 ft. above any floor, every part of the roof frame including the structural frame may be unprotected. In other cases, where every part of the structural steel framing is between 18 and 25 ft. high, the structural members shall be protected by ceiling assemblies of not less than 1-hour FR construction. Generally, Type I construction has no limits on allowable floor area or building heights.

6.2.2 Type II Buildings

The structural elements in Type II-FR buildings shall be of steel, iron, concrete or masonry. The structural elements of Type II-1-hour or Type II-N (N = No fire resistance requirements) buildings shall be of non-combustible materials. Walls and partition systems in both Type II-FR and Type II-1-hour buildings have provisions for the use of fire retardant treated wood stud framing. The allowable grade floor area for Type II-FR ranges from 12,400 ft.^{2} to 59,900 ft.^{2}; for Type II-1-hour from Not Permitted to 27,000 ft.^{2}; and for Type II-Not Protected from Not Permitted to 18,000 ft.^{2}. A maximum height for Type II-FR is 160 ft., for Type II-1-hour is 65 ft., and for Type II is 55 ft. The number of stories is also limited: Type II-FR is limited to 12 stories; Type II-1-hour, to 4 stories; and Type II-N, from Not Allowed to 3 stories.

6.2.3 Type III Buildings

Structural elements in Type III buildings may be of any materials permitted by the code. Type III-1-hour buildings shall be of 1-hour FR construction throughout. The allowable floor area for Type III-1-hour buildings range from Not Permitted to 27,000 ft.^{2}, and for Type III-N from Not Permitted to 18,000 ft.^{2}. The building height for Type III-1-hour buildings is limited to 65 ft., and 55 ft. for Type III-N (not protected) Buildings. The maximum number of stories for Type III-1-hour is four and for Type III-N from Not Permitted to 3 stories. Type III buildings are often referred to as ordinary construction, and are typically built with masonry walls and wood floors and roofs.

6.2.4 Type IV Buildings

Structural elements of Type IV buildings may be of any materials permitted by the code. Type IV construction shall conform to heavy timber construction requirements, except that partitions and members of the structural frame may be of other materials, provided they have a fire resistance of not less than 1-hour. Type IV construction has a range of allowable floor areas from Not Permitted to 27,000 ft.^{2}. The allowable building height is 65 ft. The number of stories ranges from Not Permitted to 4.

6.2.5 Type V Buildings

Type V buildings may be of any material allowed by the code. Type V-1-hour buildings shall be of 1-hour FR construction throughout. The allowable floor area in Type V-1-hour ranges from Not Permitted to 21,000 ft.^{2}. Type V-N ranges from Not Permitted to 12,000 ft.^{2}. The allowable building height for Type V-1-hour is 50 ft. and Type V-N is 40 ft. The number of stories ranges from Not Permitted to three stories for both classifications.

6.3 Allowable Heights and Areas

The code permits area and height increases for all construction types where alternative fire safety features have been provided. These include sprinklers, increased open space, and use of fire walls.

For all construction types under R-3 construction (one- and two family dwellings and lodging houses), the maximum allowable floor area is unlimited, and the maximum allowable number of stories is three.

Sprinkler and standpipe systems are generally detailed in the sections of the code addressing allowable area increases and maximum building height. In general, the areas specified in the code may be tripled in one story buildings, and doubled in buildings with more than one story, if the building is provided with an approved automatic sprinkler system throughout. Also, the building height may be increased by one story. Sprinkler systems are required to be installed in accordance with **UBC** Standards 38-1 and 38-3, which are the 1989 edition of NFPA 13, "Standard for the Installation of Sprinkler Systems," and NFPA 13R , "Standard for the Installation of Sprinkler Systems in Residential Occupancies up to Four Stories in Height," respectively, with minor revisions.

6.4 Comments

As can be seen in this cursory overview of code provisions, each type of construction within the building code allows structural systems to be built without rated fire resistance. This means that in many of those buildings the structural system is not protected by any kind of fire rated membrane or coating. It appears that when such systems are constructed from lightweight building components, there can be concern that fire performance has been compromised in some manner. The code recognizes the increased possibility of greater fire damage in unprotected buildings, and restricts their allowable areas and heights. As greater protection is installed (i.e., 1-hour rated assemblies and sprinklers), greater allowable building sizes and heights can be used. Greater building separation from adjacent buildings allows for increased building areas as well. In general, where fire rated assemblies are used, they are required to have a minimum 1-hour rating. Mixed occupancies necessitate the use of fire resistant assemblies with greater hourly ratings for both walls and floor/ceiling assemblies. The following tables, taken from the **1991 Uniform Building Code**, summarize the fire resistance provisions of the code as it relates to mixed occupancy, allowable areas and heights:

	Types of Construction[1]								
	I	II			III		IV	V	
Occupancy	F.R.	F.R.	1-hour	N	1-hour	N	H.T.	1-hour	N
A-1	Unlimited	29,000	Not Permitted						
A-2-2.1[2]	Unlimited	29,900	13,500	Not Perm.	13,500	Not Perm.	13,500	10,500	Not Perm.
A-3-4[2]	Unlimited	29,900	13,500	9,100	13,500	9,100	13,500	10,500	6,000
B-1-2-3[3]	Unlimited	39,900	18,000	12,000	18,000	12,000	18,000	14,000	8,000
B-4	Unlimited	59,900	27,000	18,000	27,000	18,000	27,000	21,000	12,000
E-1-2-3	Unlimited	45,200	20,200	13,500	20,200	13,500	20,200	15,700	9,100
H-1	15,000	12,400	5,600	3,700	Not Permitted				
H-2[4]	15,000	12,400	5,600	3,700	5,600	3,700	5,600	4,400	2,500
H-3-4-5[4]	Unlimited	24,800	11,200	7,500	11,200	7,500	11,200	8,800	5,100
H-6-7	Unlimited	39,900	18,000	12,000	18,000	12,000	18,000	14,000	8,000
I-1.1-1.2-2	Unlimited	15,100	6,800	Not Perm[8]	6,800	Not Perm.	6,800	5,200	Not Perm.
I-3	Unlimited	15,100	Not Permitted[5]						
M[6]	See Chapter 11								
R-1	Unlimited	29,900	13,500	9,100 [7]	13,500	9,100 [7]	13,500	10,500	6,000[7]
R-3	Unlimited								

[1] For multistory buildings, see Section 505(b).

[2] For limitations and exceptions, see Section 602.

[3] For open parking garages, see Section 709.

[4] See Section 903.

[5] See Section 1002(b).

[6] For agricultural buildings, see also Appendix Chapter 11.

[7] For limitations and exceptions, see Section 1202(b).

[8] In hospitals and nursing homes, see Section 1002(a) for exception.

N = No requirements for resistance F.R. = Fire Resistance H.T. = Heavy Timber

Table 36. Basic Allowable Floor Area for Buildings One Story in Height (In Square Feet)

	A-1	A-2	A-2.1	A-3	A-4	B-1	B-2	B-3[1]	B-4	E	H-1	H-2	H-3	H-4-5	H-6-7[2]	I	M[3]	R-1	R-3
A-1		N	N	N	N	4	3	3	3	N		4	4	4	4	3	1	1	1
A-2	N		N	N	N	3	1	1	1	N		4	4	4	4	3	1	1	1
A-2.1	N	N		N	N	3	1	1	1	N		4	4	4	4	3	1	1	1
A-3	N	N	N		N	3	N	1	1	N		4	4	4	3	2	1	1	1
A-4	N	N	N	N		3	1	1	1	N		4	4	4	4	3	1	1	1
B-1	4	3	3	3	3		1	1	1	3		2	1	1	1	4	1	3	1
B-2	3	1	1	N	1	1		1	1	1		2	1	1	1	2	1	1	1
B-3[3]	3	1	1	1	1	1	1		1	1		2	1	1	1	3	1	1	1
B-4	3	1	1	1	1	1	1	1		1		2	1	1	1	4	N	1	1
E	N	N	N	N	N	3	1	1	1			4	4	4	3	1	1	1	1
H-1	Not Permitted in Mixed Occupancies. See Chapter 9																		
H-2	4	4	4	4	4	2	2	2	2	4			1	1	2	4	1	4	4
H-3	4	4	4	4	4	1	1	1	1	4		1		1	1	4	1	3	3
H-4-5	4	4	4	4	4	1	1	1	1	4		1	1		1	4	1	3	3
H-6-7[1]	4	4	4	3	4	1	1	1	1	3		2	1	1		4	3	4	4
I	3	3	3	2	3	4	2	3	4	1		4	4	4	4		1	1	1
M[2]	1	1	1	1	1	1	1	1	N	1		1	1	1	3	1		1	1
R-1	1	1	1	1	1	3	1	1	1	1		4	3	3	4	1	1		N
R-3	1	1	1	1	1	1	1	1	1	1		4	3	3	4	1	1	N	

For multistory buildings, see Section 505(b).

[1] Open parking garages are excluded, except as provided in Section 702(a)

[2] For special provisions on highly toxic materials, see Fire Code.

[3] For agricultural buildings, see also Appendix Chapter 11

Table 37. Required Separation in Buildings of Mixed Occupancy (In Hours)

Occupancy	Types of Construction								
	I	II			III		IV	V	
	F.R.	F.R.	1-hour	N	1-hour	N	H.T.	1-hour	N
	Maximum Height in Feet								
	Unlimited	160	65	55	65	55	65	50	40
	Maximum Height in Stories								
A-1	Unlimited	4	Not Permitted						
A-2-2.1	Unlimited	4	2	Not Perm.	2	Not Perm.	2	2	Not Perm.
A-3-4[1]	Unlimited	12	2	1	2	1	2	2	1
B-1-2-3[2]	Unlimited	12	4	2	4	2	4	3	2
B-4	Unlimited	12	4	2	4	2	4	3	2
E[3]	Unlimited	4	2	1	2	1	2	2	1
H-1[4]	1	1	1	1	Not Permitted				
H-2[4]	Unlimited	2	1	1	1	1	1	1	1
H-3-4-5[4]	Unlimited	5	2	1	2	1	2	2	1
H-6-7	3	3	3	2	3	2	3	3	1
I-1.1[5]-1.2	Unlimited	3	1	Not Perm.	1	Not Perm.	1	1	Not Perm.
I-2	Unlimited	3	2	Not Perm.	2	Not Perm.	2	2	Not Perm.
I-3	Unlimited	2	Not Permitted[6]						
M[7]	Unlimited	See Chapter 11							
R-1	Unlimited	12	4	2[8]	4	2[8]	4	3	2[8]
R-3	Unlimited	3	3	3	3	3	3	3	3

Table 38. Maximum Height of Buildings

To go into greater detail on code requirements for specific occupancies or mixed uses in order to delineate where protected assemblies are used is beyond the scope of this chapter.

6.5 Current Code Environment

In response to concerns about the fire performance of lightweight construction, there have been a variety of recent code changes proposed on both protected and unprotected systems. A description of a few of the proposals that have been under consideration follow:

- In Pointe-Claire, Quebec, a code change that requires 5/8 in. Type C gypsum wallboard on all standard wood joists was passed. Additionally, all other types of floor joists are to be protected on all levels with a minimum of 5/8 in. Type C wallboard, and shall also have all levels equipped with interconnected smoke alarms (including basements, garages and all floor levels), and shall provide fire curtains for every 215 ft.^{2} of concealed space.
- State of Massachusetts' House Bill 820 sought to prohibit the use of trusses in residential construction. Trusses are defined by a legislative committee as I-joists, metal plate connected trusses, and other engineered truss types. This particular bill is currently in committee, and no action has been taken on it at this time.
- The state of New Jersey recently enacted a law that requires an identifying emblem be attached to the front of structures with truss construction. The emblem shall be

bright and of reflective color or made of reflective material. The shape of the emblem shall be an isosceles triangle, and the size shall be 6 in. high by 12 in. long. An 'F' inside the triangle will specify a floor truss, 'R' a roof truss, and 'FR' both construction types. Detached one- and two-family dwellings that are not part of a planned real estate development are exempt from these provisions. Individual structures and dwellings that are part of a planned real estate development shall not be required to have an identifying emblem if there is an emblem affixed to the development. The governing body of the municipality may require, by ordinance, that emblems be affixed on any structure using truss construction. This law left truss construction undefined, so it applies to all "trusses". The bill was developed in response to an automobile dealership fire in New Jersey.

- The city of Rockford, Illinois, was considering an ordinance that would require all structured elements used in floor or roof systems to have fire endurance performance equivalent to solid-sawn joists. As of December, 1991, no action had been taken.
- A provision exists in Palatine, Illinois, that requires 1/2 in. Type X gypsum wallboard to be applied on all lightweight components used in floor or roof assemblies. This provision does not apply to solid-sawn joists.
- In British Columbia, a proposed change to the provincial building code would require nails or staples to be installed on the metal plates of trusses, to prevent them from falling out in a fire. This concept was rejected by the Code Committee in December, 1991.
- A code change was proposed at the 1991 BOCA code change hearings that would have excluded metal plate connected roof trusses from buildings in Use Group R (residential construction), unless the building was equipped throughout with an automatic sprinkler system in accordance with the appropriate BOCA sprinkler sections. This code change did not pass.
- The city of Glen Cove, New York ratified an amendment to its building code that stated that all new or modified construction utilizing prefabricated support structures consisting of wood truss members with steel plate connectors in floor/ceiling assemblies shall require the formal notification of the city building department administrator. Wherever wood truss members with steel plate connectors are used, buildings shall be equipped with a sprinkler system (which sprays both up and down) in all voids and attic spaces in accordance with NFPA 13. The status of enforcement of this provision is unknown at this time.
- A proposed code change in Laval, Quebec, would require that buildings having roofs or floors constructed out of metal web trusses, I-joists, or other similar construction systems be sprinklered in conformance with NFPA 13, 13D, or 13R.
- The city of Long Grove, Illinois, among others, requires that all residential construction be built with sprinkler system protection.

When the evidence submitted by the code change proponent is reviewed, it is easy to conclude that many of these proposals are in response to the articles reviewed in **Chapter 2** of this report. Much of the substantiating language and thoughts appear to be taken directly from some of the fire service articles reviewed. An example of this is seen in the proposed 1991 BOCA code change submission, B 253-91:

> *Lightweight wood trusses from the construction perspective all share the same basic advantages, but there are disastrous disadvantages for fire fighters. By engineering calculations and practical fire fighting experience, lightweight trussed rafters may be expected to collapse after approximately ten minutes in a fully involved fire. During a fire it takes time for the fire to deteriorate the rafters (in this type of construction) to a point where they give way. This gives fire fighters enough time to perform ventilation on a roof that is strong enough to hold several fire fighters at one time. The lightweight wood truss is a fast burner. This is compounded by the problem that if one part of the truss fails, the entire truss fails. Whereas, the failure of one rafter will not cause the failure of any other element.*
>
> *Lightweight wood truss construction involves large interconnected areas in which fire can be hidden and explosive or back draft heated gases can accumulate. It is possible to have a serious fire in a roof void with little or no smoke visible in a building. If a fire enters any attic or other concealed space it will spread rapidly and involve the entire area. A solid wood framing member will cause fire blocking for a period of time, there is no such fire blocking with the open construction of a lightweight wood truss.*
>
> *Lightweight wood trusses themselves are often manufactured with the use of sheet metal surface fasteners. These fasteners only connect the outer one-half inch wood. Truss design as an architectural design can be defended but the use of sheet metal fasteners cannot. This device is a dangerous structural connection.*[1]

Another factor used to justify code changes is often performance experience. Actual and perceived poor performance causes local code authorities to request that changes be made to the local building code.

6.6 Evaluation of Building Code Requirements

As noted, building codes allow unprotected construction to be used in a variety of occupancy types with a variety of building heights and areas. Thus, lightweight component construction elements can be used in many buildings. Use of fire rated assemblies results from code requirements. The broadest category is 1-hour rated assemblies. As there is no requirement in the code for a fire resistive rating for

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[1] Prepared by Arnold R. Hamilton, East Lake Fire Department, East Lake, Ohio as a BOCA code change proposal. The proposal is printed verbatim.

unprotected assemblies, very little standardized testing has been performed. None has been performed for model code compliance.

Incorporation of sprinkler systems generally allows building size to be increased in both unprotected and protected (i.e., fire-resistance rated) construction.

The 1990 edition of the BOCA **National Building Code** recognizes a life safety benefit of sprinklers by requiring installation in R-1 (hotels, motels, boarding houses, etc.); R-2 (apartments, dormitories, etc.); A-1, A-2, and A-3 (assembly); high hazard; institutional, mercantile S-1 (storage) and F-1 (factory) buildings, albeit with exceptions. The BOCA code routinely allows the reduction of area-separation fire-rated-assembly duration requirements when sprinklers are used. For example, a 2-hour fire separation assembly used in multi-family construction can be reduced to a 1-hour fire separation assembly with an approved automatic sprinkler system. In certain applications, a recent BOCA code change allows for the use of a 30-minute rated assembly with sprinklers in lieu of a 1-hour rated assembly with sprinklers or 2-hour fire separation assembly requirement in multi-family building dwellings, provided that sprinklers are installed in all closets located against tenant separation walls and in all bathrooms. This code change indicates a BOCA recognition that sprinklers have a proven performance history of containing and suppressing fires, ultimately saving lives and property. It also recognizes that the majority of fires begin inside an area that is compartmentalized.

There have been attempts to restrict the use of lightweight components through the code change process. Generally this has been done at the local level, but proposals are being made at the model code level as well. It is often easier for local codes to be changed because of a lack of a formalized code change process. A concern that must be considered is that, in general, those involved with local code changes are not as knowledgeable about the technical details of the variety of products that are available for construction. Their decisions are also heavily influenced by the current published literature on the topic. Therefore, it is imperative that facts be presented accurately on technical topics.

At the model code level, a code change proponent must provide detailed substantiation and reasoning for a code change to be adopted. The code change must then face a consensus vote of the entire voting membership of the model code body (typically limited to building officials only). This process is meant to screen and evaluate code change proposals, and adopt those that are technically supportable. The BOCA code change described above (B253-91) is an example of a change that was not adopted because of the absence of adequate substantiating evidence.

Nonetheless, the code change trend is a concern, given the number of code changes being submitted with little substantiating data. This is particularly true for changes proposed at the local level, where there is often less of a need for substantiating data, and no formalized consensus-based code change process in place to require technical rigor. This can lead to costly, ineffective, and technically unsound public policy decisions.

Chapter 7: Discussion

7.1 Lightweight Building Component Fire Performance Issues

The following discussion is based on the data found in the preceding chapters. Because the breadth of this subject is great, it is difficult to reduce it to a few simple points. Statistics, test data, and model code considerations are discussed first, followed by a discussion of the concerns brought forward by the fire service.

7.2 Fire Loss Statistics

As was seen in **Chapter 3**, the majority of fires in the United States occur in residences (one- and two-family dwellings and apartments). The majority of those fires begin in living areas (e.g., kitchen, living room, bedroom, etc.) that are typically compartmentalized. This means that structural support members for walls, floors and ceilings are sheathed, and therefore protected. For walls and ceilings, this protection is typically provided by gypsum wallboard. Floors are generally constructed of plywood, concrete, or gypcrete. Given the statistics, the focus on fire performance of lightweight engineered building components ought to be directed more toward the various fire performance aspects of protected assemblies, than other areas of potential study.

Since most fires begin in compartmentalized living spaces, the addition of sprinklers would prevent losses of life and property in many of the fires that occur, and reduce the risk to the fire service. This confirms what has been known for a long time. There are two key fire safety measures that will reduce loss of life in fires: the use of smoke detectors and the use of sprinkler systems.

Finally, a risk assessment should be performed that considers the various causes of firefighter fatalities. This risk assessment can then be used to develop firefighting tactics that will help reduce the risk of fatality. Ideally, the risk of death on the fireground should be reduced to as close to zero as is reasonably possible.

7.3 Summary of Testing

In **Chapter 4**, available testing performed on engineered components has been compiled and reviewed. A discussion of each section of **Chapter 4** follows:

7.3.1 Unsheathed Assemblies (Chapter 4-1)

Testing described in **Section 4-1.1** concluded that each of the lightweight building component members tested resulted in early failure.[1] However, "early failure" is not yet

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[1] Mittendorf, J., "Lightweight Construction Tests Opens Fire Service Eyes to Special Hazards," **Western Fire Journal**, January, 1982.

well defined, and the test procedures were not standardized, so that comparative performance of the structural elements cannot be accurately assessed.

The Illinois Fire Service Institute tests provide some indications of warning signals that may be available for each of the structural components tested.[2] Those tests noted that:

- 2 x 10s gave ample warning by the sagging of the structural system.
- MPC wood trusses sagged, giving a definite indication of structural problems.
- Metal web wood trusses sagged early, giving an indication of structural problems.
- Wooden I-joists did not sag or produce warning noises to indicate there were structural problems.
- Pin-end connected steel webbed wood trusses also failed without sagging or providing any warning.

However, since this testing was also performed without standardized test procedures, only a qualitative assessment of potential differences between components can be made.

When standardized tests at full design load are studied (See Table 22, page 108), it can be seen that deflection at failure is significant for the truss assembly and the two steel C-joist assemblies. The deflection at failure is 11-1/2 inches for the truss assembly, and 7 and 10 inches for the steel C-joist assemblies. The 2 x 10 deflection performance was in the range of 2.7 to 4 inches at failure. Given this, it could be concluded that the failure warning signals for trusses and steel C-joists may be more significant, in terms of deflection, than typical joist construction. It was also noted in the testing that as the loading decreased, the associated deflection near failure decreased as well. This may indicate that under typical room loading conditions (which are typically far less than design load), the warning that exists through deflection performance may not be as noticeable. This has significant ramifications on the fireground.

Room fire tests are interesting as they provide data intended to represent performance under more realistic fire load conditions. This testing also indicated that the deflection performance of both steel joists and 2 x 8 wood joists is significant near failure. However, in all cases, the load applied to the system was near the maximum allowable design load, which could overstate the deflection that would be seen at a typical fire scene.

None of the standardized tests record indications or warning signals that could be expected prior to collapse, because information of this nature is not typically noted in these test reports. If this information is desired, specific test procedures should be developed to detail the warning signals available prior to failure of the tested assembly.

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[2] Straseske, J. and Weber, C., "Testing Floor Systems," **Fire Command**, June, 1988.

A time/temperature curve was developed to represent typical room fire-load conditions, which are defined in the test report.[3] This new curve caused failure to occur much more quickly than in the room burns it represented. At this time, it is difficult to evaluate the usefulness of the new time/temperature curve. More testing should be performed, and the curve should be calibrated to actual room fire test results, so it can be assured that it accurately represents a realistic room fire.

Finally, the available test data that allows for direct comparison between assemblies can be reduced to eight tests (see Table 22, page 108). These tests indicate that in unsheathed assemblies, wood joists have greater fire endurance than steel C-joists. The data also indicate that MPC trusses have fire endurance times that fall close to the range of performance for 2 x 10 joists. However, the MPC truss assembly tested did not have a splice plate located in the bottom chord of the truss. It is expected that this would reduce the time to failure, although it is unknown by what amount.

There are currently no fire endurance performance criteria available or that must be met for unsheathed assemblies based on this literature review. It is expected that this lack of performance criteria, and the fact that there has never been a requirement or proposal to test unsheathed assemblies, are the reasons for the small amount of standardized test data available on unsheathed fire endurance assemblies.

7.3.2 Single Membrane Protected Assemblies (Chapter 4-2)

The testing of a single gypsum wallboard membrane directly attached to structural elements yielded the following results:

- Assemblies with 1/2-inch fire rated Type X gypsum wallboard applied directly to 2 x 10 joists typically have a 45 minute assembly rating.
- Assemblies with 5/8-inch fire rated Type C gypsum wallboard applied directly to wooden I-joists, MPC trusses or pin end connected steel web trusses have a 45-minute assembly rating.

In each case, the assembly's performance duration was determined by structural failure.

In all tests performed with a single membrane applied directly to the structural element, there was deflection prior to collapse, ranging from very little to quite noticeable. This deflection ranged from 1.03 to 12.9 inches for trusses and I-joists, and 1.85 to 13.0 inches for 2 x 10 joists. Unfortunately, collapse warning signals (e.g., rate of deflection) were not recorded as part of the test procedure. Therefore, it is difficult to determine the types of collapse warning signals that may exist prior to collapse, other than the system deflection, which is only valuable when the deflection magnitude is

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[3] Fang, J.B., Fire Endurance Tests of Selected Residential Floor Constructions, NBSIR 82-2488, U.S. Department of Housing & Urban Development, April 1982. See summary in **Sections 4-1.14** and **4-2.10** of this report.

significant. In the cases where the deflection is less than 2 inches, the value of deflection as a warning signal is not as great.

If a fire begins in a properly constructed compartment which has 5/8-inch thick fire-rated gypsum wallboard on horizontal lightweight engineered components, the rating for this compartment will typically be 45 minutes. For solid sawn joist construction, the equivalent rating is achieved with a 1/2-inch thickness of fire-rated gypsum wallboard.

Any compartment with 1/2-inch regular gypsum wallboard attached to the structural elements should have fire resistance performance of at least 15 minutes, since the gypsum wallboard membrane provides a 15 minute membrane rating.[4,5] The fire endurance performance of the structural members will add to the 15 minute membrane performance. Thus, most residences will have protection slightly greater than 15 minutes, should a fire start in a living area that has wallboard sheathing. This suggests that the fire performance of any unsheathed system can be increased to at least 15 minutes by attaching a single layer of 1/2-in. regular gypsum wallboard directly to the unsheathed structural system. This concept is supported by the test data found in this chapter.

The most "realistic" data found in the literature were three protected tests performed by the National Bureau of Standards using actual room fire conditions.[6] Additional testing of this type would probably be very valuable for the fire safety community in terms of developing the warning signals that occur prior to collapse, collapse mechanisms, failure modes and the deflection performance of the various assemblies under more realistic fire conditions. This type of testing has excellent potential for being very valuable, if test methods are developed to specifically yield results that provide information that can be used to improve tactical fireground approaches.

7.3.3 Connections (Chapter 4-3)

Firefighters are concerned with the performance of different types of connections in fire conditions. The literature revealed six test reports that were concerned specifically with the fire endurance performance of connections. This testing was not standardized, and presently, there are no standardized test procedures or performance requirements for evaluating only connections placed under fire test conditions. Since engineering design does not take into account the fire performance of connections alone, additional data must be developed to draw any relevant conclusions on their fire performance.

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[4] 1991 U.B.C. Standards, "Method for Calculating Fire Resistance of Steel, Concrete and Wood Construction," U.B.C. Standard 43-9, Table No. 43-9-W-A, Pg. 1518.

[5] 1988 Standard Building Code, "Calculating Fire Resistance," Chapter 31, Table 3106.2A, Pg. 469.

[6] Fang, J.B., Fire Performance of Selected Residential Floor Constructions Under Room Burnout Conditions, NBSIR 80-2134, December, 1980. See **Sections 4-1.13** and **4-2.9** of this report.

Predicting performance using these small sets of data would not be recommended, as comparative results would be questionable due to the lack of statistical significance.

Currently, connections are always evaluated as an integral part of the fire endurance assembly being tested.

The fire endurance performance of connections is an area where additional data would be useful to better evaluate and understand performance characteristics.

7.3.3.1. Truss Plate Connectors

Testing performed on metal plate connectors (MPCs) generally indicates performance of less than 10 minutes. Testing currently being conducted at the United States Department of Agriculture Forest Products Laboratory holds great promise for adding to the MPC fire performance database, and for creation of a model that will predict the performance of a single MPC truss element under fire load conditions.[7] From this, the capability of predicting the performance of an entire truss assembly is expected to follow.

7.3.4 Operation Breakthrough Assemblies (Chapter 4-4)

The objective of Operation Breakthrough was to test the fire endurance performance of many systems that could potentially be used in the manufactured housing environment. Therefore, little standardized testing was done for purposes of direct comparison, but rather, a variety of tests were performed to determine the performance of specific easily manufactured assemblies.

Operation Breakthrough did yield some information about systems using double layers of 1/2-inch fire-rated gypsum. These systems showed performance of a joist-rafter assembly and a steel C-joist assembly that go well beyond a 60 minute rating. This finding is typical for double layer 1/2-inch Type X gypsum wallboard fire endurance assemblies. When existing data (e.g., industry test data not included in this report) on two-layer 1/2-inch fire rated gypsum assemblies are combined with these data, it becomes apparent that a two-layer 1/2-inch Type X gypsum wallboard system generally provides at least one hour of fire resistance performance when attached to almost any structural floor framing system. However, this performance will be dependent on secure attachment of the two layers of wallboard to the framing members.

The Operation Breakthrough data can only be used for general observations, and to gain knowledge regarding the performance of the specific types of assemblies under the fire endurance conditions described in the test report.

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[7] White, R.H., Cramer, S.M., and Wolf, R.W., National Forest Products Association Committee on Research and Evaluation Report, April 4, 1991.

7.3.5 Coating Performance (Chapter 4-6)

The literature search produced a very small amount of information regarding the tested performance of coatings on MPC connections and steel bar joists. It is well known, however, that there is a body of data available, and that model building codes have developed calculation procedures for insulating steel beams, columns and joists from fire through the use of coatings. Concrete is also used as a protective coating.

From the limited testing available, coatings enhance the performance of connection and structural systems under fire load conditions. Additional testing will be necessary to determine the degree of performance improvement and how coatings can be economically employed to improve lightweight building component fire endurance systems.

7.3.6 Sprinkler Performance (Chapter 5)

The literature reveals that there is no standardized test procedure available to evaluate the performance of sprinklers attached to a given structural framing system, or for sprinklers employed within a concealed space. The available testing provides only a small base of information upon which to evaluate the performance of sprinkler systems used with wooden I-joists and MPC trusses. Unfortunately, no pass/fail criteria have been defined for these types of tests; therefore, no measure of acceptable performance is available. Without such criteria, any testing performed is subject to criticism, and may be considered unacceptable. A consensus standard and associated performance acceptance criteria for the testing of structural elements that support sprinkler systems may be needed.

The I-joist testing demonstrated that there may be a fire load size and placement that current sprinkler technology does not adequately contain or extinguish. This condition is a cause for concern, and should be more thoroughly evaluated, since there may be certain field applications that are at risk.

The quoted tests performed by the City of Fort Worth were used to make a local code change (See **Section 5.3** for test details). The sprinkler layout and positioning are not supported or rejected by this project's Technical Advisory Committee because they may not result in adequate sprinkler protection for the building or the structural support system.

Test methods and evaluation criteria need development, and testing will need to be performed in the future to address sprinkler performance when used with lightweight building components.

An additional concern of the fire safety community is the manner in which sprinklers can be installed. When NFPA 13[8] is followed, it is presumed the building is sprinklered throughout. NFPA 13R[9] and 13D[10] allow for there to be some areas of the building that are not sprinklered. For example, NFPA 13R and 13D allows sprinklers to be omitted from the following areas:

- Bathrooms not exceeding 55 sq.ft., with non-combustible plumbing fixtures.
- Small clothes closets where the least dimension is 3 ft., the area doesn't exceed 20 sq.ft., (24 sq.ft. in 13D) and the walls and ceiling are surfaced with non-combustible or limited-combustible materials.
- Open attached: porches, balconies, corridors, and stairs.
- Attics, penthouses, equipment rooms, crawl spaces, floor/ceiling spaces, elevator shafts, and other concealed spaces that are not used or intended for living purposes or storage.
- Sprinklers may be omitted from entrance foyers which are not the only means of egress (13D only).

Should a fire begin in one of these areas, it is uncertain how the remaining sprinklers will function in controlling the fire, if it is controlled at all.[11,12]

7.3.7 Summary of Test Data

To gain an appreciation for where test data is and is not available, the following tables have been prepared:

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[8] NFPA 13, **Installation of Sprinkler Systems**, 1987 ed.

[9] NFPA 13R, **Standard for the Installation of Sprinkler Systems in Residential Occupancies up to Four Stories in Height**, 1989 ed.

[10] NFPA 13D, **Sprinkler Systems - One- and Two-Family Dwellings**, 1984 ed.

[11] NFPA 13R, *loc. cit.*

[12] NFPA 13D, *loc. cit.*

Description[1]	**Full Design Load**[2]	**Restricted Load**[3]	**Small-Scale**[4]	**Ad-Hoc**	**Room Burn**	**Full Bldg.**	**Other (e.g., ISO 834)**
Wood Joists	9*	5*	1*	1*	2[1]	N/A	3 Room T/T
MPC Trusses	1*	*	1*	3*	N/A	N/A	N/A
MPCMW Trusses	N/A	N/A	1*	1*	N/A	N/A	N/A
I-Joists	N/A	N/A	1*	2*	N/A	N/A	N/A
PECMW Trusses	N/A	N/A	N/A	2	N/A	N/A	N/A
Steel Bar Joists	N/A*	1*	N/A	1*	N/A	N/A	N/A
Steel Joists	3*	3*	N/A	N/A	2	N/A	1 Room T/T
Heavy Timber	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Glulam	1	N/A	N/A	N/A	N/A	N/A	N/A
Panelized	N/A	N/A	N/A	1*	N/A	N/A	N/A
Sandwich Panel	3	1	N/A	N/A*	N/A	N/A	N/A
Steel Beams	1*	N/A*	N/A*	N/A*	N/A*	N/A*	N/A
Truss Plate Con. Joists	N/A	4*	N/A	N/A*	N/A	N/A	1 ISO 834

* More tests may be available from proprietary sources.

[1] For report details, see **Chapter 4-1: Fire Endurance Performance of Unsheathed Assemblies.**

[2] Follows the standard ASTM E119 test method using time/temperature curve and the maximum allowable design load.

[3] Follows the ASTM E119 standard test method using the time/temperature curve and a less-than-maximum allowable design load with actual load applied recorded.

[4] Uses the ASTM E119 time/temperature curve in a small size furnace at typically much less than full design load conditions. In some cases, with no load at all.

N/A No tests available through the literature search process. May be available from proprietary sources.

Table 39. Number of Tests Performed on Unsheathed Assemblies from the Test Reports Available.

Description[1,5]	**Full Design Load[2]**	**Restricted Load[3]**	**Small-Scale[4]**	**Ad-Hoc**	**Room Burn**	**Full Bldg.**	**Other (e.g., ISO 834)**
Wood Joists	7 [6]	*	N/A	N/A	1	N/A	2 Room T/T
MPC trusses	3*[6]	*	N/A	N/A	1	N/A	N/A
MPCMW Trusses	*	N/A	N/A	N/A	N/A	N/A	N/A
I-Joists	1*[6]	N/A	*	N/A	N/A	N/A	ISO 834[7]
PECMW Trusses	Few*	*	*	N/A	N/A	N/A	N/A
Steel Bar Joists	*[6]	*	*	N/A	N/A	N/A	N/A
Steel Joists	5*	N/A	*	N/A	1	N/A	N/A
Heavy Timber	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Glulam	*	N/A	N/A	N/A	N/A	N/A	N/A
Panelized	*	N/A	N/A	N/A	N/A	N/A	N/A
Sandwich Panel	*	N/A	N/A	N/A	N/A	N/A	N/A

* More tests may be available from proprietary sources.

[1] For report details, see **Chapter 4-2: Fire Endurance Performance of Single Membrane Protected Assemblies.**

[2] Follows the standard ASTM E119 test method using time/temperature curve and the maximum allowable design load.

[3] Follows the ASTM E119 standard test method using the time/temperature curve and a less-than-maximum allowable design load with actual load applied recorded.

[4] Uses the ASTM E119 time/temperature curve in a small size furnace at typically much less than full design load conditions. In some cases, with no load at all.

[5] Some cells have information in them that is not discussed in this report.

[6] Many more tests are available with a variety of protection systems from proprietary sources.

[7] This is an APA test performed at UL.

N/A no tests available through the public literature search process. May be available through proprietary sources.

Table 40. Number of Tests Performed on Protected Assemblies from the Test Reports Available.

Description[1]	**Full Design Load**[2]	**Restricted Load**[3]	**Small-Scale**[4]	**Ad-Hoc**	**Other (e.g., ISO 834)**
Steel Connection Systems	N/A	N/A	N/A	N/A	N/A
Truss Plates	2	1	N/A	4*	N/A
Bolts	1	N/A	N/A	3*	N/A
Nails	1	N/A	N/A	2*	N/A
Split Rings	1	N/A	N/A	1*	N/A
Lag Screws	N/A	N/A	N/A	N/A	N/A
Steel Pins	N/A	N/A	N/A	N/A	N/A
Plywood Gusset	1	N/A	N/A	2*	N/A
Steel Gusset	N/A	N/A	N/A	3*	N/A

* More tests may be available from proprietary sources.

[1] For report details, see **Chapter 4-3: Fire Endurance Performance of Connections.**

[2] Follows the standard ASTM E119 test method using time/temperature curve and the maximum allowable design load.

[3] Follows the ASTM E119 standard test method using the time/temperature curve and a less-than-maximum allowable design load with actual load applied recorded.

[4] Uses the ASTM E119 time/temperature curve in a small size furnace at typically much less than full design load conditions. In some cases, with no load at all.

N/A no tests available through the public literature search process. May be available through proprietary sources.

Table 41. Number of Tests Performed on Connections from the Test Reports Available.

Description[1]	**Ad-Hoc**	**Room Burn**	**Full Bldg.**	**Other (e.g., ISO 834)**
Wood Joists	*	*	N/A	N/A
MPC Trusses	12	N/A	N/A	N/A
MPCMW Trusses	N/A	N/A	N/A	N/A
I-Joists	9	N/A	N/A	N/A
PECMW Trusses	N/A	N/A	N/A	N/A
Steel Bar Joists	*	*	N/A	N/A
Steel Joists	N/A	N/A	N/A	N/A
Heavy Timber	N/A	N/A	N/A	N/A
Glulam	N/A	N/A	N/A	N/A
Panelized	N/A	N/A	N/A	N/A
Sandwich Panel	N/A	N/A	N/A	N/A

* Many tests have been done with these structural members, but are not included in this report. No test standard is available; therefore, these are all considered to be ad hoc tests.

[1] For report details, see **Chapter 5: Sprinkler Testing.** Some cells have information in them that is not discussed in this report.

N/A no tests available through the public literature search process. May be available through proprietary sources.

Table 42. Number of Tests Performed on Sprinklers from the Test Reports Available.

As can be seen from the summaries, the majority of data available comes from tests performed on protected assemblies. The data presented in this report are only a small fraction of the data available on protected systems. This is logical, since building codes mandate protection of assemblies for a given period of time using ASTM E119 as the standard method of acceptance. Manufacturers wanting to have their product used must comply with code requirements, resulting in an abundance of code compliance testing.

There is relatively little test information on the fire performance of connections and unsheathed assemblies. This is due to the fact that there are no specific code-mandated performance requirements in these areas. Therefore, testing has only been done for evaluation of a specific problem or for general scientific purposes.

Unsheathed tests may provide very useful information for fire service personnel. Results would give a sense for the modes of failure, warning signals prior to collapse and deflection performance of lightweight building components, and provide a basis upon which to build a tactical response. However, the usefulness of unsheathed test information detailed in this report is limited primarily to the data generated from standardized test procedures (See Table 22, page 108). Each of these tests was performed for a specific purpose, and many of the tests were performed years ago. If a test program is to be developed for unsheathed assemblies, it would be best to perform all testing at a single test facility, under identical test protocols.

The connection test data generated from standardized test procedures included in this report do *not* allow for the evaluation of the performance of both connectors in assemblies and connections within a building structural element in a fire. By testing single connections, one can learn about relative performance and begin to estimate the impact of the connection on the fire performance of the structural member, and ultimately, on the fire performance when the connector is part of an assembly.

Many sprinkler tests have been performed with wood joists and steel bar joists as the structural member supporting the sprinkler system. The testing conducted, however, was intended to examine sprinkler distribution patterns and their ability to control or suppress the fire. Therefore, there is very little information on the fire performance of the structural element supporting the sprinkler system under fire conditions. Currently, the attachment of sprinkler systems to structural members is defined by NFPA 13, and the physical connection strengths required can be calculated through the use of traditional engineering formulas. The base of knowledge on the fire performance of structural members with attached sprinklers should be more fully developed, as sprinklers will be a more prevalent fire suppression method and life safety tool in the future.

7.4 Model Code Considerations

As seen in **Chapter 6: Building Code Requirements**, the provisions of the model building codes allow for the use of unprotected assemblies. The only constraint on the use of these assemblies in building construction is the type of building and its allowable area and height. Allowable building areas and heights increase with increased protection, for example, through the use of fire endurance rated assemblies for fire compartmentation and sprinklers.

The model building codes recognize the fire safety benefit of sprinklers. ICBO requires sprinklers in apartments, congregate residences and hotels three or more stories in height with the additional provision for number of occupants or dwelling units. The BOCA building code requires sprinklers in residential occupancies such as hotels, motels, boarding houses, apartments and dormitories. A recent BOCA code change allows for the use of a 30-minute rated assembly with sprinklers in certain applications, which is deemed to provide equal to, or more, protection than a typical 1-hour assembly. This is a reduction from the previous one-hour fire-rated assembly with sprinklers or two-hour rated assembly requirements. This code change acknowledges that sprinklers have a proven history of performance in containing and suppressing fires.

Finally, codes are beginning to be changed to restrict the use of lightweight building components due to concern over their fire performance characteristics. There is a concern that code changes may be made without the use of detailed substantiating test or other relevant data. This is particularly true for changes being made in codes at the local level, where there is no formalized code change process requiring the use of substantiated technical data. Code changes should only be made where there is a solid technical basis for the change. To make a code change on any other basis will lead to costly, ineffective and technically unsound public policy decisions.

7.5 Review of Firefighting Concerns

The literature often contains emotional language (e.g., "firefighter's enemy," killer connector," etc.) to make a point about firefighter safety. This emotion is used to motivate all firefighters to become aware of potential dangers, and to avoid a complacency in learning about the hazards of burning construction and safe firefighting precautions and methods. This approach is useful from a safety awareness standpoint, but must be used with discretion because it can easily be misinterpreted. Understanding all of the technical aspects of this issue is crucial to making valid decisions on the fire performance of engineered components.

7.5.1 Product Design and Effect of Mass

It is clear that engineered products are designed to maximize strength and minimize the amount of material going into the product. This minimizes mass. Therefore, to the extent that this mass reduction can create a fire endurance performance problem, engineered products are effected. Many times, however, design for serviceability (e.g., deflection performance—common for component floor assemblies where spans exceed 16 to 18 ft.) is a more significant engineering criterion than design for strength (for all construction elements). This means that the mass of the engineered component will be greater than is actually needed to carry design loads. This may provide reserve strength, which will benefit the fire performance of members. It is also common for structures to be designed to carry greater loads than those that actually occur in the field. This also provides reserve strength that may be beneficial under fire conditions.

Testing of unsheathed wood 2 x 10 joist systems and metal plate connected (MPC) trusses suggests that the mass effect is at best a minor factor in fire endurance performance *when comparing solely these two member types*. For example, tests outlined in **Chapter 4-1**—Mutual Corporation Design FC-250 in **Section 4-1.8**, the Forest Products Laboratory tests in **Section 4-1.7**[13], Factory Mutual Design FC-209 in **Section 4-1.4**, and FC-212 in **Section 4-1.5**—show that unsheathed 12 in. deep parallel chord trusses have a fire endurance performance time of 10 min., 12 sec., and unsheathed 2 x 10 joists have an endurance time of 6 min., 30 sec.[14]; 13 min., 34 sec.; and 12 min., 6 sec.; respectively. The fact that these tests were run under identical fire (ASTM E119), spacing, sheathing, and full design load conditions suggests that the mass difference of the trusses was a minor factor in their fire endurance performance. This is probably due to the fact that the char rate of wood is fairly consistent among wood species, and that in the case of the truss, the ability to carry the applied load will remain until the char layer is deep enough to cause the remaining uncharred wood to fail in bottom chord tension. The same concept is true for a 2 x 10 joist. The dimensions of the bottom chord of the truss are 3.5 in. by 1.5 in., and for the 2 x 10 are 1.5 in. by 9.25 in. In both cases the 1.5 in. dimension is the critical dimension for fire endurance performance. Once the char reduces the 1.5 in. dimension enough the member will fail; hence, similar failure times for these two products.

Mass does become a consideration when comparing 2 x 10 joists with 6 x 20 glulam beams, for example. A 6 x 20 beam will perform much better under fire conditions. It will also be a consideration with engineered components, should *the effective* fire resisting mass decrease. The actual mass effect on fire performance of the engineered components under study needs to be documented more thoroughly, however, because there is not a solid base of data available to accurately evaluate mass effects upon the fire endurance performance of all the components under study.

7.5.2 Building Design

Current design requirements involve the application of loads that are assigned by the building code. The codes often reference ASCE standard 7-88, "Minimum Design Loads for Buildings and Other Structures." As the title suggests, this standard provides guidance for all *structural* loading conditions that apply to buildings, including live, dead, snow, earthquake, wind, roof live, rain, ponding, lateral soil, and fluid loads. The strength degradation due to fire, which could be considered a structural loading condition, is not considered in this design process, and consequently, members are sized to handle only the loads that directly apply to the structure from a building code

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[13] Questions surround the results of this testing. Comparative analysis should be done with discretion.

[14] Ibid.

perspective. If structural elements can safely meet the building code defined loads, they are allowed to be used because they conform to the code requirements.

Other sections of the code apply directly to the fire safety aspects of the building. The major model building codes do not specifically address the structural design and load capacity consequences of fire on a structure or, as a result, firefighter safety issues after a fire has begun within a structure. However, these codes do recognize that standard fire tests that they reference employ representative fire loads for evaluating the comparative performance of structural assemblies.

Fortunately, severe fires seldom occur at the same time as full structural design loading. This will benefit the fire endurance performance of structural members.

7.5.3 Building Codes

No type of construction (e.g., Type I, II, etc.) provides absolute protection for firefighters after building contents have ignited. As noted above, this is especially true from a structural design perspective, since the effects of a fire on structural member performance are not specifically part of the design process. The codes do, however, adjust the size of the building based on occupancy, the potential fire load generated by that occupancy, and the type of construction. Certain features of the building codes aid firefighters in the suppression of building fires and, hence, their safety. These include: fire-rated compartmentation, fire doors, draft- and firestopping, sprinklers, egress, emergency lighting, and other requirements.

In some cases, code requirements are violated during the construction process. This may occur by failing to construct a fire endurance assembly in accordance with the test assembly requirements, or the cutting of holes by HVAC, electrical, or plumbing contractors that violate code provisions or a manufacturer's recommendations. Construction practices that are cause for concern from the point of view of structural and fire performance integrity can be seen on many construction job sites. These situations can contribute significantly to the poor performance of a structural element in an actual fire condition. Improved code enforcement and more widespread code compliance education is needed (e.g., for the builder, electrician, plumber, code official, architect, etc.).

7.5.4 Truss Plate Connections

All steel connections conduct heat into the wood at some point in a fire. Truss plate connections, being steel, do as well. However, they also reflect heat for a period of time during a fire, which protects the wood below those connections. A fire test assembly videotape taken of a small-scale MPC assembly shows the fire performance of a truss plate splice joint under a less-than-design test load following ASTM E119 time/temperature fire conditions.[15] The video distinctly shows the phases a truss plate goes through under fire conditions. Initially, the truss plate reflects radiant fire energy and provides protection to clear wood below the truss plate. This lasts for approximately three minutes (which is not a long period of time), at which point wood below the plate begins to char. The wood ***not protected*** by the plate begins to char approximately one minute into the test, which is two minutes less than the wood that is protected. Once the plate gets hot enough, it conducts heat, and contributes to the charring of wood below the plate and, presumably, around the truss plate teeth. Eventually, charring becomes significant enough that the truss plate loses its holding power and fails. At no time does the plate warp or curl up and fall away from the joint. The time frames found in this testing will not apply to all tests or to actual fires. They only provide a relative comparison of the radiant energy protection that an MPC truss provides. When the char becomes great enough, the load on the truss plate connection causes the wood member to pull away from the truss plate. When this occurs, the plate is often left connected to the other wood member, and does not necessarily fall away from the joint. The existence of this phenomenon is corroborated by tests performed at the Fire Technology Laboratory in Finland, described in **Section 4-3.7** of this report. Here, steel plates are also shown to protect the wood from charring.

There has also been concern over the structural performance of the truss plate, and, consequently, truss performance. Engineering design can make the truss plate connection *structurally* equivalent to many other connection types (e.g., nails, split rings, bolts, etc.).

There has been a very small amount of fire testing performed on the various structural connection types. Engineering design does not take connection fire performance into account. Additional standardized data on the fire performance of connections must be obtained in order to draw any valid conclusions or to be able to perform fire performance-based engineering design with consideration for connections.

7.5.5 Truss Member (Chord or Web) Failure

The concept of one truss member (chord or web) failing, causing an entire truss to fail is *not* an accurate concept for today's lightweight truss construction (e.g., MPC trusses, MPCMW trusses, steel bar joists, etc.). In a theoretical truss, where all joints are a series of frictionless pin-end connected members, this would be the case. In actuality, none of the pre-engineered truss systems are manufactured like this theory suggests. All commonly made trusses today have continuous chords that provide structural continuity and provide a certain amount of additional stiffness; and all connections have a degree of friction and, thus, load carrying capacity. A truss has technically failed when a single member is cut, but cutting a single member by itself will ***not necessarily*** cause catastrophic collapse (see Figure 48 below). In fact, in some cases the truss will still

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[15] Performed by Weyerhaeuser's Fire Technology Laboratory.

carry substantial loads. Total collapse will be dependent on load amount, span, spacing and diaphragm conditions.

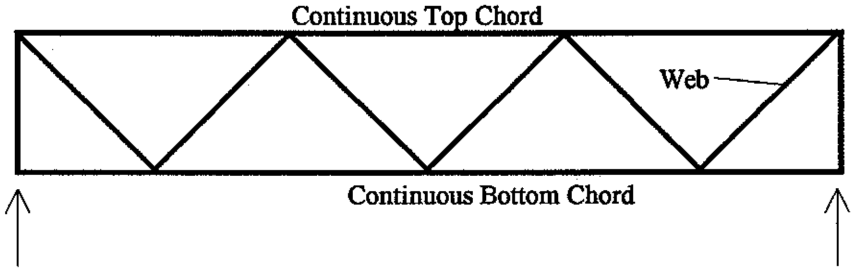

Figure 47. Standard truss with continuous chords and load-carrying joints similar to MPC trusses or steel bar joists.

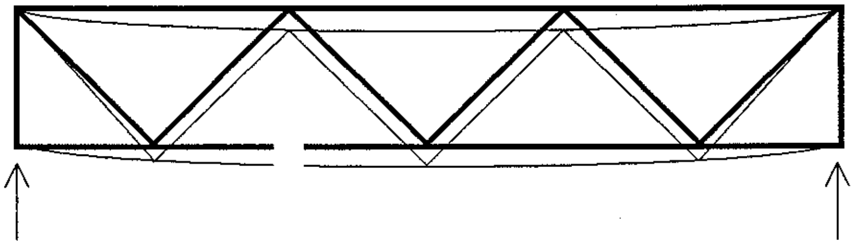

Figure 48. Standard truss showing deflected shape after the chord is cut. This truss will still carry loads due to the strength capacity of the connections and the continuity of the chords.

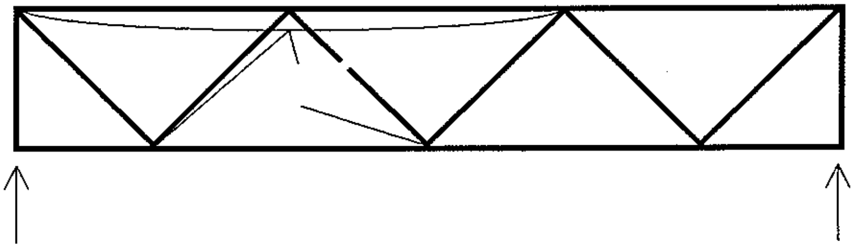

Figure 49. Standard truss showing deflected shape after the web is cut. This truss will still carry substantial loads.

For example, if a structural member is spaced two feet on center or less, has a stiff sheathing material (e.g., 5/8-in. plywood) on the top chord, and is braced properly, the system is said to be redundant. When one member fails or is cut through, deformation occurs, the magnitude of which is dependent upon the load applied to the structural system. Under dead load conditions only, cutting through the truss bottom chord would not be noticeable in a redundant system. This is because the structural elements adjacent to the cut member pick up the loads transferred to them through the sheathing material beyond what the cut truss can continue to carry.

The reason that trusses have better load carrying capacity than expected is that most engineered truss types have connections that typically have the capacity to carry loads.

Therefore, by cutting a member in a truss, the load is distributed through the connections to other members that are still sound, which transfers the load to the bearing points. The cut truss will be much more flexible or "spongy" than before it was cut; but the cut will most likely not lead to catastrophic failure.

A forensic videotape clearly shows that cutting the bottom chord of a pitched chord MPC truss does not lead to catastrophic failure, even when the applied load is the weight of two men and the truss spacing is greater than two feet on center (non-redundant conditions).[16]

7.5.6 Girder Versus Redundant Framing Methods

Any structural member that has other structural members framing into it has the potential to cause a large area to collapse under fire conditions. A member to which other members are attached is typically called a girder. If the girder fails in a fire, its failure contributes to the failure of all structural members attached to it. For example, consider a girder truss that is 80 feet long and has eight foot long members framing into it from both sides. Should the girder truss collapse, an area of roof 16 feet wide and 80 feet long (an area of 1280 ft.^{2}) will collapse with it. An example of heavy timber bowstring truss girder framing performance under fire conditions was seen in an automobile dealership fire in New Jersey.[17]

In contrast to this, many lightweight building systems have structural member spacings of two feet on center or less. Using the example above (i.e., 80 ft. span, 2 ft. on center spacing), should one member fail, an area of 320 ft.^{2} could potentially collapse. However, this entire area is less likely to collapse due to the sheathing and lateral bracing that is attached to the members and the load sharing that will take place in the adjacent structural members. This load sharing property is enhanced by a stiff sheathing material (e.g., 5/8-in. plywood) that interacts with the structural elements, creating a diaphragm. In certain cases, a single structural element could completely fail and would continue to be held in place by the structural members adjacent to it, because of the stiffness of sheathing element and continuous lateral bracing.

In some instances, chord and web members have actually failed in existing buildings, and the roof or floor structural system withstood the dead and live loads that were being applied at the time. In a few cases, there have been more than one fractured truss member found within the same truss. Several fractured trusses were also found within the same roof system. This shows that the strength of the roof or floor assembly, including the plywood sheathing and gypsum ceiling, is much greater than the strength of

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[16] Truss load tests at Fish Building Supply Company by Stadelman Engineering, Inc., Menominee Falls, WI, April 20, 27 and 28, 1985 and May 12, 1989.

[17] Klem, Thomas J., **Summary Investigation Report - Five Fire Fighter Fatalities, Hackensack New Jersey**, Fire Investigations Division, National Fire Protection Association, July 1, 1988.

an individual structural element or connection that makes it up. It also reinforces the concept of structural member load sharing or redundancy.

The only situation in which a larger area would fail under redundantly framed conditions would be when several structural elements reach their point of failure at approximately the same time. This phenomenon *doesn't* occur in protected ASTM E119 tests that have been witnessed.[18] Here, one member fails first, which usually begins progressive failure. It may occur in actual fire situations, however, which could be the reason for some of the pancake type failures seen with lightweight building components. Another possible explanation would be the simultaneous failure of the bearing connections, which has to do with the structural integrity and fire performance of the wall system and end connections.

There are no data on the fire performance of girder structural framing contrasted to redundant structural framing. There are also no data on pancake failures of whole floor or roof systems, or its cause. These areas could be developed more thoroughly.

7.5.7 Wooden I-Joist Performance

One of the concerns over I-joist performance is with the use of adhesives in their manufacture. The adhesives used are thermosetting adhesives designed to be very durable when exposed to high moisture conditions. Additional discussion on this is found in **Section 7.5.15.**

There is very little test data available on the fire endurance performance of I-joists. Unsheathed testing is limited to non-standardized and semi-standardized ad hoc tests that can only shed limited light on fire performance characteristics of these products. From this testing, though, it can be surmised that I-joists will perform less well under fire conditions than an equivalent sized solid-sawn member. This is intuitively obvious, given the differences in the cross sections of each. Solid-sawn sections have more "fat" to burn through. To gain fire performance information that will provide the needed information for firefighting tactics, only standardized testing should be performed.

There is one test using 5/8 in. Type C gypsum wallboard directly applied to the bottom flanges of I-joists. This test shows a fire endurance performance of 48 min., which yields an assembly rating of 45 min. This assembly rating is typical for 5/8 in. Type C gypsum wallboard directly applied to engineered components like I-joists or trusses.

7.5.8 Concealed Spaces

The concealed space issue is very important from a firefighting tactics perspective, as it relates to the fire performance of lightweight components. Different components react

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[18] The author of this report has witnessed more than 15 ASTM E119 tests, and been involved in writing the reports for more than 30.

differently under identical fire scenarios. This can create difficult suppression problems if the building does not have a complete pre-fire plan. Concealed spaces are of particular concern for open web component systems in either a floor or roof. For all truss-type construction (wood trusses, steel bar joists, etc.), a floor system concealed space is a wide open area that fire, heat and smoke can easily move through. When comparing this with solid-sawn (e.g.,2 x 10) joist construction, wooden I-joists, or steel C-joists that have *no* holes for HVAC or plumbing, and have a direct applied ceiling, a solid web provides better protection against the lateral spread of fire. However, the performance of solid web members is more like open web construction when the web is penetrated for HVAC, electrical, or plumbing. When a dropped ceiling is used, it creates a concealed space for *all* lightweight building components.

In roof construction, all pitched roof systems have an open area through which smoke, heat and fire can move without encumbrance. Flat roof systems, however, are just like floors as described above.

The *major* issue surrounding concealed space fire performance and the spread of fire is the application of code-conforming fire- and draftstopping. If these methods for preventing fire spread are not applied, misapplied, or cut through, the building becomes more vulnerable to structural element and total building collapse caused by fire. Therefore, thorough building inspection is important, that plumbing, electrical, and HVAC holes are sealed and that there is ongoing education on the importance of following fire- and draftstopping requirements and making fire safe penetrations.

Consideration must also be given to the adequacy of the current code requirements for fire- and draftstopping. Changes may have to be made in the codes if they are found to be inadequate. No information is available detailing the adequacy or inadequacy of the code fire- and draftstopping requirements. This needs to be developed.

As noted in **Chapter 3: Fire Loss Statistics**, the majority of residential (49.1%) and apartment (70.9%) fires begin in living areas that are compartmentalized. Only 3.1% and 0.70%, respectively, begin in a structural concealed space, floor, or roof assembly. This reinforces the point that sound compartmentation practices in buildings will contain many fires to a local area, where it can be suppressed most easily. Thoughtless penetration of the compartment or fire- and draftstopping will only aid in earlier fire performance failure of structural building components.

Finally, concealed spaces within roof assemblies (attics) may be used by the building occupant for storage.[19] This results in two problems: the structural element may not be designed for this storage load, which creates a more highly stressed structural member than the design allowed for or is expected; and stored items can also become projectiles once a fire begins, falling through the ceiling to the ground and injuring firefighters

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[19] The automobile dealership fire in Hackensack, New Jersey, is an example of a situation where a concealed space was loaded by storing automobile parts and combustible products in the truss space. See footnotes 28 - 30 on Page 204 for references.

during fireground operations. The extra loading applied will be a factor in how long the structural member remains in place during the fire. This can contribute to a collapse that is *faster*, or more extensive, than would normally be expected.

7.5.9 Surface Burning Area

There is greater surface burning area in an MPC wood web truss or a wooden I-joist when compared to the surface burning area of a solid sawn joist. For example, the surface area of a 2 x 10 joist is 25 in.^{2} per inch of length. The surface area of a typical 10 in. deep parallel chord truss measured through a diagonal web is 30 in.^{2} per inch of length. A typical 9-1/2 in. I-joist has a surface area of 25.25 in.^{2} per inch of length. Given this, trusses have the greatest amount of surface area to burn, yet this doesn't necessarily predict poorer fire endurance performance.

As noted In **Section 7.5.1**, when discussing mass effects, 2 x 10 joists and 12-inch deep trusses provide roughly the same unsheathed fire endurance performance time, which leads one to conclude that the greater surface area of the truss did not play a major role in relative fire endurance performance. This conclusion may not apply to other lightweight components, and certainly would not apply to heavy timber components. There is no known testing that relates the effect of surface burning to the ultimate fire endurance performance of the various products under study. Data on this relationship will have to be developed to evaluate this in more depth.

7.5.10 Wood Char Rate

The charring rate of wood is a valuable fire protection feature of this engineering material. Under **ASTM E119** fire test exposures, wood ignites in approximately two minutes. Charring then proceeds at a rate of approximately 1/30 in. per minute for the next eight minutes. Thereafter, the char layer has an insulating effect, and the rate decreases to 1/40 in. per minute.[20] With this information, one can often calculate the approximate time that a wood-based system will fail under standard ASTM E119 fire exposures. A graphic example of the effect that charring has on a 2 x 4 member follows in Figure 50.

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[20] Forest Products Laboratory, "Wood Handbook: Wood as an Engineering Material," Agricultural Handbook 72, Washington D.C., U.S. Department of Agriculture, revised 1989, p. 15-3.

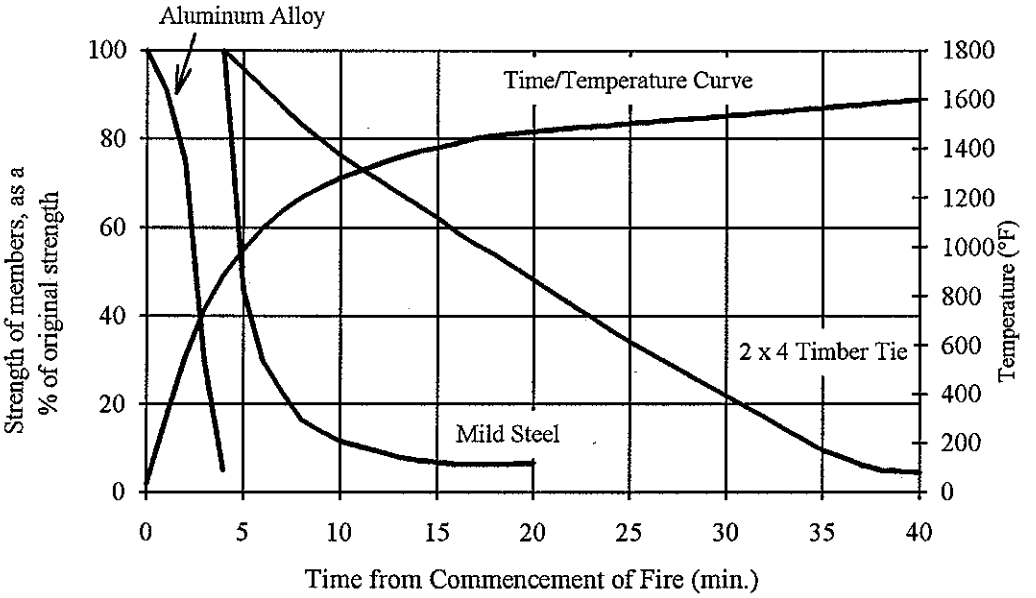

Figure 50. Strength of Steel, Aluminum, and Timber in Relation to the Standard Fire Test. AITC Data[21]

The char rate information shows why heavy timber construction performs so well under fire conditions, and has a separate code classification. It takes a long period of time to burn a 6 in. x 14 in. wood member to a point where it is unable to sustain its load.

7.5.11 Balcony Design

Frank Brannigan brings out a very important point about structural member layout safety. When a structural member is continuous, supporting the living area and the outside common balcony area, any fire that enters the structural compartment will weaken the member supporting the balcony. Since the member is continuous, the concealed space may also allow for spread of the fire into the balcony area if not properly firestopped. This creates a potentially dangerous situation for occupants trying to exit and firefighters trying to enter and exit. This particular construction practice ought to be thoroughly evaluated from a fire performance perspective. Specific installation and fire- and draftstopping recommendations for this application condition should be made.

7.5.12 Truss Collapse

The literature reporting actual fire experience (reviewed in **Chapter 2)** suggests that trusses collapse without warning, and that multiple truss collapses are the rule, not the exception. Reports on actual fires state that there have been cases where truss roofs and floors have collapsed 10 to 15 minutes after the arrival of the fire department. These

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[21] Dock & Harbour Authority, London, England, "What About Fire?", American Institute of Timber Construction, 1972, p. 3.

collapses include both wood- and steel-based lightweight components. In other known cases, trusses and other lightweight components have had endurance times of greater than 30 minutes, or may not collapse at all. The collapse experience that is observed must be viewed in the context of the individual fire scenario. A few questions that need to be asked include:

- How long was the fire burning before the firefighters arrived?
- How heavy was the fire load within the building?
- How heavily was the assembly loaded (dead/live load conditions)?
- Did the roof self-vent?
- Did the structure use redundant member construction or girder construction?
- Were there any warning signals that indicated the potential for a collapse?
- Was there a pre-fire plan in place to determine the type of construction involved?

7.5.13 Collapse Warning Signals

Warning signals prior to collapse is a difficult subject, because they may or may not be present in every fire situation. Recognition of a warning signal is dependent on a firefighter being in the correct place to recognize the signal, and being able to warn others. Some of the warning signals known about for lightweight building construction include:

- A spongy feeling to the floor or roof.
- Floor sag.
- Fire burning through the exterior siding at the floor level, indicating the floor concealed space is on fire. This could also apply to the roof concealed space.

Clearly, this is an area of great concern and has perhaps the greatest life safety implication for the fire service. If there are key warning signals that predict when a collapse will take place, tactics can be developed that will aid in recognition of these warning signals, and allow the fire service to fight a fire with increased safety. The key to this is in developing a solid base of information on warning signals that are visible or audible prior to collapse. (There is currently very little information—other than word-of-mouth experience from firefighters—that provides guidance in this area.) This needs to be developed more fully so that firefighter safety on the fireground can be improved, because there may be many collapse warning signals that aren't currently recognized.

7.5.14 Long-Term Truss Performance

A study was performed by the Forest Products Laboratory in Madison, Wisconsin, on the long-term strength performance of a variety of wooden truss types.[22] The conclusion drawn from ten years of long-term loading of these trusses was:

> *There appeared to be no appreciable effect upon strength and stiffness as determined by laboratory evaluation after five and ten years of exposure, with the exception of the nailed plywood gusset truss rafters, which had a 30% reduction in stiffness. All the truss rafters still met acceptable short-term performance criteria.*

From a practical standpoint, there are residential and commercial structures that were built with MPC trusses that are now 30 years old that have had no field performance problems. In fact, there are examples of satisfactory long term field performance for all components reviewed in this study.

7.5.15 Steel Structural Member Performance

> *Steel is non-combustible and does not contribute fuel to the fire, which often leads to unwarranted confidence in its fire-resistance properties. Like all engineering materials, it has structural properties that react adversely to high temperature conditions. Steel loses approximately 35% of its original yield strength and modulus of elasticity at 1000 °F. Steel also has high thermal conductivity, which means it transfers heat away from a localized heat source very quickly. This property, along with its thermal capacity, allows steel to act as a heat sink. When steel can transfer heat to cooler regions, it can take a long time for a member to reach a critical temperature. However, an intense fire that distributes heat evenly along a steel member will reduce this time considerably.*
>
> *Mass and surface area are the most significant factors in determining the fire endurance performance of steel. Heavy, thicker sections have greater resistance to fire than do lighter, thinner ones. Unprotected lightweight sections like those found in bar joists can collapse after five to ten minutes of exposure. Steel's high coefficient of expansion may also cause problems under fire exposure by buckling, twisting, and causing lateral movement in structural elements it is attached to. As an example, a 50-ft. long steel beam heated uniformly to 972° F will increase in length 3.9 in.*[23]

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[22] "Longtime Performance of Trussed Rafters With Different Connection Systems: 10-Year Evaluation," U.S. Department of Agriculture Forest Service, Forest Products Laboratory, Madison, WI, Research Paper FPL 204, Revised 1978.

[23] National Fire Protection Association, "Fire Protection Handbook," Quincy, MA, 1991, pp. 6-62 - 6-66.

Finally, due to steel's high strength, members are often spaced at wide intervals (i.e., six feet or more on center, which typically constitutes a non-redundant condition). This condition requires special consideration during fireground operations so that safe operating conditions are maintained.

7.5.16 Adhesive Fire Performance

The premise that adhesives soften during a fire is erroneous. The adhesives used in engineered wood components (I-joists, LVL, glulam beams, etc.) are typically thermo-setting adhesives that do not soften when subjected to high temperatures. In fact, they get harder. Most often, these adhesives are formulated for durability and resistance to delamination when placed in exterior exposure conditions (i.e., outdoors). These adhesives are typically phenol-formaldehyde or phenol-resorcinol based, and have a char rate that is equal to or better than that of the wood they are bonding.[24] Generally, these adhesives do not ignite at the bond line, but do pyrolyze. Glue laminated beams using these adhesives types are used under heavy timber code classifications, which means they have been proven to have extremely good fire endurance performance behavior.[25]

7.5.17 Fire Testing

There are currently no standardized fire tests that replicate realistic or actual fire scene conditions from a firefighting perspective. The test used most frequently to assess the comparative fire endurance performance of building assemblies is ASTM E119. However, this test method is not intended to predict performance times in actual fire situations. The rated time period (e.g., 1-hour) is relative, not absolute. It is not viewed as reliable in predicting realistic fire endurance performance of structural components by the fire safety community. This is clearly an area where agreement on a standardized approach to testing could provide the fire community with additional knowledge. Such information on warning signals and failure modes is needed to aid in the development of firefighting tactics in buildings constructed with specific types of lightweight building components. Refining test methodologies could aid in the assessment of the performance of lightweight components in the following areas:

- Warning signals prior to failure.
- Redundant versus non-redundant system fire endurance performance.
- Performance after a ventilation hole is cut into the system.
- Firefighter safety when operating on assemblies near vent holes or near the fire area.

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[24] Schaffer, E.L. and River, B., conversation on fire performance of adhesives, Forest Products Laboratory, May, 1992, Madison, WI.

[25] "Design of One-Hour Fire Resistive Wood Members (6-inch Nominal or Greater)", Council of American Building Officials Report No NER-250, NFoPA.

- Various modes of failure for a structural element, connection, or entire structural system.
- Structural element fire performance strength decay in vented versus unvented structures.
- Modes of failure for concealed space fires.
- The effects of draft- and/or firestopping on assembly fire endurance performance.
- The effects of membrane and fire- and draftstopping penetrations.
- The effects of various fire intensities, replicating as accurately as possible realistic fireground fire conditions and fire growth.

7.5.18 Firefighting Tactics

Firefighting tactics are influenced greatly by the general tenets of firefighting, which are:

- Firefighters are expected to rescue trapped occupants in buildings.
- Firefighters are expected to confine a fire to the area of its origin in most cases.
- Firefighters are expected to extinguish a fire with the least possible damage to the building/contents.
- Interior firefighting is the most effective and efficient method of fire extinguishment.
- Firefighters expect a building (including its components) to perform adequately in order for them to perform their duties. The building must remain intact for a reasonable period of time after firefighter arrival.[26]

Given these tenets, the fire service has developed some initial strategies (found in the literature) to address changes taking place in the design and use of lightweight building components within structural systems. However, knowledge in this area needs to be expanded. Firefighters have recognized that the tactics used to suppress fires may have to change when these components are used. The ability to recognize the structural systems and determine the best tactical approaches is extremely difficult. As a start, this process should include:

- Active pre-fire planning for each building in the jurisdiction, particularly during the initial construction process. Clearly, the more that is known about a building, the easier it will be to fight a fire in it.
- Changes to ventilation procedures.
- Opening up concealed spaces quickly.

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[26] Corbett, G.P., "Lightweight Wood Trusses and Fire Notes," March 30, 1992.

- Being aware of the time factor by always asking, "How long has the fire been burning?" prior to arrival and while on the fireground.
- Being aware of warning signals of impending collapse, and communicating information frequently to fireground command.

> *"All assemblies can pose serious dangers to firefighters.* Any *assembly can be fatal if the proper ratios of fire load, time, construction type, penetrations to compartments, and fire- or draftstopping are combined. The amount of time remaining to failure cannot be predicted for* any *assembly type, and should not be attempted on the fireground. Finally, it is a fact that any assembly can be dangerous and collapse unpredictably during the early stages of a fire.'*[27]

7.5.19 Education and Training

Education and training may be the single most important short- and long-term activity that the fire safety community can immediately undertake to enhance life-safety on the fire scene. The lightweight component industry must recognize their important role in this educational process. Information about their products and their structural and fire endurance performance must be communicated to the fire community. It follows that the fire community must take facts—those currently available, as well as those which will be ascertained cooperatively—and integrate them into their training programs, pre-fire plans, and tactics.

7.6 Lightweight Component Industry Perspective

The lightweight component construction industry is concerned that the negative attitudes that exist toward such construction only serve to create conflict despite the fact that the components and assemblies conform to the current model code requirements for building construction. When facts regarding engineered products are misunderstood or when the products are blamed for firefighter deaths without thorough analysis, the conflict is increased.

Some deaths and injuries have occurred because the fire performance characteristics of different construction systems were not recognized. Because firefighters may have difficulty recognizing that particular structural systems are incorporated into the construction of a burning building, a pre-fire plan would be beneficial for quick assessment.

For example, an automobile dealership fire in New Jersey, where truss failure was implicated in the deaths of five firefighters, did not use lightweight components as part of the construction. This building was constructed in the late 1940's using bowstring wood trusses, and was renovated extensively in 1973. Reports indicate that the collapse took

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[27] Mittendorf, J. and Brannigan, F., "The Timber Truss: Two Points of View," **Fire Engineering**, May, 1991.

place between 30 and 45 minutes after the fire alarm office received report of the fire. Changes to the use of the building, inappropriate storage of combustible materials in the truss space, building alterations, mixed use, lack of effective communications on the fireground, and other unforeseen elements at the fire scene all contributed to this loss of life.[28,29,30] To place the responsibility for this incident on the fact that trusses were the major structural element is a gross oversimplification.

Currently, all lightweight building components must comply with applicable building code requirements. In complying, there is an expectation that these products will be allowed to be used in any structure where they meet the intent of the code, where sound engineering principles are utilized, and are in demand by consumers. It is important that products be economical to use in building construction, yet effective where life-safety is an issue. Currently, life-safety issues raised with respect to lightweight building construction appear to be limited to firefighter safety. The safety issues arise due to the general tenets of firefighting given above. This is definitely a concern, but one that is not addressed by the model building codes. There are currently no performance requirements that lightweight components must meet that take into account fireground safety issues.

The manufacturing industry wants to work with the fire service to address product fire performance issues. This should be done in a factual, systematic, and standardized way in order for the lightweight component industry to embrace and promote any measures that may be developed. The best outcome will result when such measures are developed and implemented cooperatively through a consensus process.

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[28] Demers, P.R. and David, P., Fire Incident Analysis Five Firefighter Fatalities. Hackensack, New Jersey, July 1, 1988. Prepared for International Association of Firefighters.

[29] Klem, Thomas J., **Summary Investigation Report - Five Fire Fighter Fatalities, Hackensack New Jersey**, Fire Investigations Division, National Fire Protection Association, July 1, 1988.

[30] Corbett, Glenn P., "Five Fall in Hackensack," **Fire Engineering**, October 1988

Chapter 8: Conclusions and Recommendations

8.1 Conclusions

The preceding chapters of this report have sought to review the readily available literature found during the literature search, digest the information, concisely report on its content, and then analyze it for accuracy and relevance. As a result of this process, the following conclusions have been drawn:

- Lightweight building components are the structural elements of the future and the trend is for their use to increase. As concern increases over environmental impacts of products and the dwindling natural resources that are available, the use of lightweight building products like those described in this report will only increase, because of their efficient use of valuable natural resources.
- Progress on increasing fire ground safety will be made with continued education and training of the fire safety community. Articles in the firefighting literature should encourage increased learning about building construction. This educational process should incorporate all of the engineering and fire performance facts available. This is an area where lightweight component manufacturers should work with the fire community so that all relevant technology is transferred as factually as the current state of knowledge will allow.
- Engineered products, as the name implies, are highly engineered. The purpose of structural engineering is to provide structural elements that can carry expected loads safely while at the same time, be manufactured economically and use engineering materials efficiently. This is precisely why engineered products (e.g., bar joists, trusses, I-joists, etc.) are so often used as structural elements.

  Associated with this, structural engineering design and code requirements (e.g., ASCE 7-88 Minimum Design Loads for Buildings and Other Structures) do not factor increased loading due to fire degradation of the structural member into design procedures. This means that engineered components are made of lightweight materials that, when combined through engineering analysis, have very high strengths under gravity loads, but not necessarily under attack by fire. This has ramifications on fire endurance performance and, consequently, on the fire service.
- Product mass and surface burning area definitely influence the fire endurance performance of products when one compares a large cross-sectional beam versus a lightweight beam of any material. These effects are dramatically reduced when comparing materials having similar mass and surface area. The key to evaluating the effects of mass and surface area lie in analyzing the components that are effectively resisting fire degradation. For example, in evaluating a 2 x 10 joist and a 2 x 4 truss, the key fire performance resistance dimension is 1.5 in. Test results show similar fire endurance performance of these two products. The critical dimension usually degrades at a similar rate.

- The fire safety community has stated that it has experienced fire scenarios where lightweight building construction structural elements have collapsed more rapidly than would typically be expected. This has led to a major concern over the fire performance of these products.[1] There is a real need to learn as much as possible about the fire performance of the products under study—particularly modes of failure and observable/audible warning signals prior to collapse—so that fireground tactics can be reviewed and safety enhanced.
- Determining the warning signals of lightweight components prior to collapse is a subject area that needs much more research and development. There may be collapse warning signals available that aren't currently recognized, and there may be situations where no warning signals are present. There is not a large body of information to work with to evaluate this effectively.
- The standardized comparative testing of unsheathed assemblies to date is limited to 2 x 10 joists, MPC trusses, and Steel C-joists as shown in Table 22 in **Chapter 4-1**, page 108. There are no tests available for wooden I-joists, MPCMW trusses, PECSW trusses, and steel bar joists. Standardized comparative tests do exist for protected assemblies for all lightweight components, due to model code requirements. The codes do not require this for the application of unsheathed assemblies.
- Open webbed truss-type components are very useful in construction for running HVAC ductwork, plumbing, and electrical distribution systems through the structural assembly. However, this construction method results in a concealed space when a ceiling is applied. The same is true for I-joists and solid-sawn joists when holes are drilled through these systems, although the spread of fire and gases will not be as rapid. A dropped ceiling creates a concealed space condition for all lightweight building systems.

  The concealed space issue is very important. Different components react differently under identical fire conditions. This can create serious suppression problems. A thorough pre-fire plan can be instrumental in the successful suppression of the fire and aid in fire ground safety.

  Concealed space fire performance will be a concern where structural elements are continuous (and not firestopped) and support the living area as well as an outside balcony area. This creates a dangerous situation by potentially weakening the balcony, which may be the only means of entry and egress for occupants and firefighters. This situation should be thoroughly evaluated, and proper firestopping requirements implemented.

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[1] There is a real need for in-depth documentation of fast collapse fire scenarios so that these situations can be thoroughly evaluated for solutions. The literature does not have much detailed information on this.

The key to preventing spread of fire in a concealed space is to apply code-complying fire- and draftstopping. A major problem, however, is a lack of construction of this fire- and draftstopping, or its penetration by the HVAC, plumbing, or electrical trades. Once penetrated, the fire- and draftstopping ceases to be of value, and will allow fire to spread to other areas of the building unchecked. A major educational effort should be undertaken within code enforcement bodies and construction trades so that the importance of applying code complying fire safety requirements are reinforced and implemented.

- Trusses built today are not built in accordance with frictionless pin-end connection theory, upon which theoretical truss design is based. The chords are often continuous, and the connections at the web member locations often transfer substantial amounts of load. This means that when one member of a truss is cut, whether it be a chord or web, the truss will generally not collapse, even under relatively high load conditions.

  The same concept is true for connections. Should one connection fail, in general, the entire truss will not collapse. Rather, the load is redistributed to other load-carrying elements and connections. Depending on the size of the load, a truss will deflect abnormally, signaling the existence of a structural problem.

  However, it must be remembered that a cut truss has failed in that it will probably not support the full design load. It won't necessarily collapse, however.

- There is a difference in structural failure performance for systems that use framing that is non-redundant as opposed to redundant. The non-redundant systems—often called girder systems—are more complex in their fire response. Should a girder system fail, a large area of roof or floor supported by the girder may fail with it. Girders also carry higher load levels, which means that the structural members that make up the girder are often of larger dimensions. Heavy timber trusses, for example, are typically employed as girders with smaller members framing into them to support a roof or ceiling. (The automobile dealership in New Jersey, which was constructed with 78-foot-long bowstring, segmental trusses spaced approximately 16 feet on center is an example of girder construction. These trusses were high load carrying, non-redundant structural members. Thus, the failure of a single truss would cause a large section of the roof to collapse. As noted in one report, the collapse "was not solely a function of the fire burning the truss. It was, rather, a result of the combination of fire, heavy structural load (stored auto parts), and, possibly, water that may have collected in the truss loft."[2,3,4])

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[2] Demers, P.R. and David, P., Fire Incident Analysis Five Firefighter Fatalities. Hackensack, New Jersey, July 1, 1988. Prepared for International Association of Firefighters.

[3] Klem, Thomas J., **Summary Investigation Report - Five Fire Fighter Fatalities, Hackensack New Jersey,** Fire Investigations Division, National Fire Protection Association, July 1, 1988.

[4] Corbett, Glenn P., "Five Fall in Hackensack," **Fire Engineering,** October 1988

Structurally redundant systems typically have elements spaced 2 feet on center or less, and carry much lighter loads. A system is redundant if adjacent structural members can be expected to share load. For instance, if one member fails, the two adjacent members will pick up the load originally resting on the failed member. Much of the load sharing capability comes from the sheathing diaphragm; therefore, even greater on-center spacings may share load and be considered redundant, depending on the strength of this sheathing material and the resulting diaphragm. As spacings become greater than 2 feet on center, the systems will typically have increasingly less structural member redundancy, and begin to fall into a girder classification.

Understanding the difference between these two framing methods and if possible, recognizing the construction type in the building will benefit fireground command decision-making capabilities.

- Truss plate connectors do reflect radiant fire energy during the initial phases of a fire and then progress into a conduction phase that results in charring below the plate and the eventual degradation of the strength of the joint. The fire will not cause the plate to pull or curl away from the joint, but the load on the wood members will.

  Where these connections have been fire tested; fire endurance performance is less than 10 minutes, based on the small amount of test data available. Additional standardized data on the fire performance of connections must be obtained in order to draw any valid conclusions.

- The charring rate of wood can be beneficial to the fire endurance performance of all wood-based systems. The char layer acts as an insulator of uncharred wood below the surface, allowing the wood to continue to carry the applied loading until the char layer becomes too deep, and the applied stress causes member failure. This process is more significant in large cross-sectional members than in small cross-sectional members. The concepts apply to all wood members, however. It is because of the wood charring process that there is a section in most building codes on the use of heavy timber.

- There is very little data available to make an accurate assessment of the fire performance of wooden I-joists. The reduced cross-section of the I-joist causes concern within the fire service because the fire performance will not be the same as a traditional joist (intuitively, it will be less). The exact differences in fire performance are not known. However, I-joists have been tested using gypsum wallboard protection. They have been found to perform similarly to other engineered products (e.g., trusses) when gypsum protection is directly applied.

- The adhesives used in engineered components are thermosetting adhesives which do not soften or lose their bonding capabilities during a fire. In fact, under heat, the bond becomes stronger. Under fire conditions, the adhesives will char in a manner similar to that of solid wood.

- Each type of construction in the building code allows the use of unprotected non-fire resistance rated structural systems. The codes do recognize the increased possibility of fire damage in unprotected buildings, and restrict the allowable areas and heights for this construction. As protection is installed, allowable areas and heights increase.

- Building code provisions are developed so occupants can evacuate safely, and so that the fire service has adequate access (clear path for trucks, etc.) to the building to suppress a fire. The focus of building codes is not to protect those who enter a building once a fire has gotten out of control in a building.
- All changes that are made in building code requirements (both model and local) should be based on technically valid substantiating evidence. Without this, costly, ineffective and technically unsound public policy decisions may be made.
- Lightweight engineered trusses and other composite engineered products have a solid history of structural performance in field applications in a variety of building types. It is estimated that there are several billion steel and wood trusses still supporting their applied loads in construction completed over the last 30 to 40 years.
- The general tenets of fighting fires place firefighters at risk and influence the strategy and tactics used on the fireground. The fire service has proposed some changes in procedures that could help prevent disasters at the fire scene. These include:
  - Pre-planning all structures. (This may not always be possible or practical yet should be considered a very valuable method of obtaining fire performance related information.)
  - Venting the roof using only proper safety precautions.
  - Opening concealed spaces quickly to determine current fire location.
  - Being aware of the time factor by always asking, "How long has the fire been burning?" prior to arrival and while on the fireground.
  - Communicating all abnormalities to fireground command.
  - Watching for indications of structural deterioration.
  - Broadly disseminating new tactical safety concepts learned from each fire.

  This is only the beginning, however. With the help from industry, new tactical procedures must be developed continuously, taking into account new construction methods, to increase fireground safety.
- Education and training may be the single-most important collective activity the fire safety community and lightweight building products industry can jointly immediately undertake to enhance life safety on the fire scene.
- Statistics reviewed for this report suggest that the firefighter life safety efforts ought to be on protected lightweight building construction elements. This is due to the fact that the majority of fires begin in compartmentalized spaces. There is some experiential data, however, that suggest that there may be a life safety issue with unsheathed (i.e., unprotected) lightweight building assemblies and when these

assemblies support sprinkler systems. There is not a good statistical base of information to corroborate the experiential data, however.

Since most fires begin in compartmentalized living spaces, the addition of smoke detectors and the use of sprinklers will save civilian lives and go a long way toward protecting firefighters on the fireground. Firefighter safety will be enhanced because civilians will be out of the building and/or the fire will be contained and possibly extinguished.

In most sprinkler activations, one head usually controls the fire. Generally, this activation occurs in a room that is compartmentalized (e.g., a protected assembly). Given this, there is no question that the use of functioning and well-maintained sprinklers will reduce life and property loss. There is also the strong possibility that sprinklers will reduce fireground fatalities, as they contain and then extinguish fires prior to the arrival of the fire department. The fire safety community is concerned over sprinkler applications where certain building areas are exempt from being sprinklered. Should a fire start in one of these areas, it is difficult to predict what will happen.

A risk assessment should be performed to fully address the risks associated with fatalities directly related to structural member collapse. One firefighter death directly attributable to engineered components is one too many. The focus should be to reduce this risk to as small as is reasonably possible given the relative risks.

- Finally, when available test information on components and sprinklers is reviewed, it reveals a lack of product performance test standards and acceptance criteria for the components under study, under the following conditions:
  - **Fire performance of unsheathed component assemblies:** There is currently no standardized test procedure to evaluate the fire performance of unsheathed components that is acceptable to both the fire service and the building component industry. The fire safety community desires a test procedure that replicates "realistic" fire conditions. Currently, the most widely accepted test procedure is ASTM E119, which uses a standard time/temperature relationship to allow comparison of performance. A consensus standardized test method that incorporated the fire safety community's need for information would be very beneficial.

    Beyond this is the issue of there being no fire endurance performance requirements for the use of unsheathed fire endurance assemblies mandated by the model code groups. Because of this, no testing is being conducted on these assemblies for use in code complying construction. Hence, no large body of test data is available on unsheathed fire endurance performance.

    A consensus standard test method that focuses on failure modes and audible/visual warning signals prior to collapse would be useful to improve fireground tactics. Associated with this will be the need for criteria that states what is acceptable product performance. Once this consensus is developed, a body of test data would be available to guide fireground tactical response.

- **Fire endurance performance of components when a fire originates in a concealed space:** Similar to unsheathed assemblies, there do not appear to be standardized test procedures or performance criteria that can be used to evaluate the performance of a component when fire begins in a concealed space.[5] There are also no model code requirements that establish acceptable performance. A consensus standard focusing on fire performance in concealed spaces would be useful. Associated with this will be the need for criteria that state what is acceptable performance, so that the tactical response in the majority of cases will be effective.
- **Fire endurance performance of lightweight components that support sprinkler systems:** As with the preceding two points, there are no standardized test procedures or performance criteria that can be used to evaluate the fire endurance performance of structural members supporting sprinklers when a fire begins below a structural member and its attached sprinklers. There are also no acceptance criteria that can be used to determine satisfactory fire endurance performance of lightweight components as they support sprinklers.

  There are, however, standards that have been developed specifically to assess sprinkler head performance. These standards include UL 199, "Automatic Sprinklers for the Fire Protection Service;" UL 1626, "Quick Response Sprinklers for the Fire Protection Service;" and UL 1767, "Early Suppression, Fast Response Sprinklers."

  The application of lightweight components in buildings using sprinkler systems is fully developed by NFPA 13, 13R or 13D. The connection of sprinkler systems to components can easily be performed using traditional engineering calculations or through tests that have been run on connecting systems.

  The express concern, however, is whether the structural elements, in certain applications, will maintain their load carrying capability long enough for sprinklers to contain or extinguish a fire that begins under a sprinkler system or within a concealed space. This is where a consensus test standard and criteria may be needed.

In contrast to the above three points where standardized test procedures and acceptance criteria are not available, is the protected fire endurance compartment. Here, there is a commonly accepted test procedure (ASTM E119) and code-mandated performance criteria for protected assemblies and penetrations of those protected assemblies. Because of this, the lightweight building component industry has developed various assemblies that meet these code requirements.

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[5] A test method to measure the performance of an assembly within a concealed space above the ceiling exists in Germany.

It appears that agreement on consensus-based standardized testing procedures and performance criteria for the areas defined above is a primary need for both the lightweight building components industry and the fire service, in order to resolve issues surrounding the fire endurance performance of these products. Once standards and acceptance criteria are defined, there will be no question on how the testing should be performed, and what acceptable performance will be. If these standards and performance criteria are established through a partnership between manufacturers and the fire service, all concerns regarding product performance can be addressed. Industry will know the fire performance expectations of its products, and the fire service can formulate the appropriate suppression tactics and fireground strategies based upon this known performance.

8.2 Recommendations

From these concluding comments, the following activities should be undertaken to continue the process of resolving the issues surrounding the fire performance of lightweight building construction:

- Representatives from the fire service, lightweight building component industry, model codes, and other groups should form a committee. This committee can develop initial test protocols and performance criteria that can be used to evaluate unsheathed, concealed space, and sprinkler performance of the lightweight building components described herein. This would entail collecting all testing protocols that may be used or have useful sections, and integrating them into a draft test protocol. Performance criteria could be developed in the same manner. Testing could then be undertaken following these prepared guidelines. The goal would be to begin to fill in the knowledge gaps that have been identified in this literature review and technical analysis with particular emphasis on firefighting safety and the various tactical responses that could be undertaken.
- As noted in the conclusions above, the need for education and training is significant. There is an immediate need for development of several technology transfer activities that would provide factual information surrounding the performance of lightweight engineered building components. The content could include:
  - Engineering principles that apply to these building components.
  - Explanation of the fire performance of building components that are used in construction systems.
  - Explanation of fire endurance testing procedures.
  - Explanation of the use of mathematical fire endurance models as they are developed for construction components.
  - The importance of code-conforming construction, and how violations of fire- and draftstopping influence fire performance of building components.
  - Strategy and tactics that are developed for fighting fires in buildings that employ lightweight building components. This includes developments based

  on current knowledge, and would include knowledge gained through testing and experience.

- Developing the database technology that would support pre-fire planning. This could then be expanded to gather detailed information on the fire performance of lightweight components in buildings that use them.

With a broad base of fire service and industry support working cooperatively in educational and standards activities as described above, credibility of the work product within the fire service and lightweight engineered product industry would be immediate. This would provide the greatest possible positive impact on knowledge about product fire endurance performance, and hence, general life safety, as well as improve safety for the firefighter on the fireground.

Appendix A: Glossary of Terms

Preface

Pertinent definitions have been taken from the ASTM Standard E176-91d, "Standard Terminology Relating To Fire Standards."

ASTM Standard Definitions

Combustible, adj - capable of undergoing combustion.

> **Discussion:** The term combustible is often delimited to specific fire-exposure conditions. For example, building materials are considered combustible if they are capable of undergoing combustion in air at pressures and temperatures that might occur during a fire in a building. Similarly, some materials that are not combustible under such conditions may be combustible when exposed to higher temperatures and pressures, or to an oxygen-enriched environment. Materials that are not combustible in bulk form may be combustible in finely divided form.

Fire endurance, n - a measure of the elapsed time during which a material or assemblage continues to exhibit fire resistance.

> **Discussion:** As applied to elements of buildings, et shall be measured by the methods and to the criteria defined in Test Methods E119, E152, E163, or E814.

Fire hazard, n - the potential for harm associated with fire.

> **Discussion:** A fire may pose one or more types of hazard to people, animals, or property. These hazards are associated with the environment and with a number of fire-test-response characteristics of materials, products, or assemblies including but not limited to ease of ignition, flame spread, rate of heat release, smoke generation and obscuration, toxicity of combustion products, and ease of extinguishment. (1989)

Fireproof, adj - an inappropriate and misleading term. Do not use.

> **E176 Non-Mandatory Commentary:** This term was originally used to describe buildings having all non-combustible structural elements and some degree of fire resistance. However the term has been misunderstood to mean an absolute or unconditional property, and therefore the use of the term, fireproof, is inappropriate and misleading. (1985)

Fire resistance, n - the property of a material or assemblage to withstand fire or give protection from it.

Discussion: As applied to elements of buildings, it is characterized by the ability to confine a fire or to continue to perform a given structural function, or both.

Fire resistive, adj - having fire resistance.

Fire-retardant barrier, n - a layer of material which when secured to a combustible material or otherwise interposed between the material and a potential fire source, delays ignition and combustion of the material, when the barrier is exposed to fire.

Fire-retardant coating, n - a fluid-applied surface covering on a combustible material which delays ignition and combustion of the material when the coating is exposed to fire.

Fire risk, n - the probability that a fire will occur and the potential for harm to life and damage to property resulting from its occurrence.

E176 Non-Mandatory Commentary: Fire risk is a quantitative description of the potential for injury or loss. The risk of loss of property will depend upon the probability of an ignition occurring, the fire-test-response and fire performance characteristics of the materials, product, and assemblies in a given situation, and the existence of fire containment or extinguishing systems. Where the risk is that of injury or death, consideration must also be given to the probability of human exposure and the physiological and psychological responses of persons to the fire. Risk is a scalar quantity that may have any one of a range of values, and does not describe the acceptability of that value to an individual or society. Two persons, when presented with the same risk situation, might reach different conclusions relative to their willingness to accept that risk.

Fire test exposure severity, n - a measure of the degree of fire exposure, specifically in connection with test methods E119, E152, and E163, the ratio of the area under the curve of the average furnace temperature to the area under the standard time/temperature curve, each from the start of the test to the end or time of failure, and above the base temperature 68° F (20° C).

Fire-test-response characteristics, n - a response characteristic of a material, product, or assembly, to a prescribed source of heat or flame, under controlled fire conditions; such response characteristics may include, but are not limited to, ease of ignition, flame spread, heat release, mass loss, smoke generation, fire endurance, and toxic potency of smoke.

Discussion: A fire-test-response characteristic can be influenced by variables of exposure, such as ignition source intensity, ventilation, geometry of item or enclosure, humidity, or oxygen concentration. It is not an intrinsic property, such as specific heat, thermal conductivity, or heat of combustion, where the value is independent of test variables.

A fire-test-response characteristic may be described in one of several terms. Smoke generation, for example, may be described as smoke opacity, change of opacity with time, or smoke weight. No quantitative correlation need exist between values of a fire-test-response characteristic for different materials, products, or assemblies, as measured by different methods, or tested under different sets of conditions for a given method.

Flame resistance, n - the ability to withstand flame impingement or give protection from it.

Flame-retardant coating, n - a fluid-applied surface covering on a combustible material which delays ignition and reduces flame spread when the covering is exposed to flame impingement.

Flame-retardant treatment, n - the use of a flame-retardant chemical or a flame-retardant coating.

Flame spread index, n - a number or classification indicating a comparative measure derived from observations made during the progress of the boundary of a zone of flame under defined test conditions.

Ignition, n - the initiation of combustion.

Discussion: The combustion may be evidenced by glow, flame, detonation, or explosion. The combustion may be sustained or transient.

Ignition temperature, n - the lowest temperature at which sustained combustion of a material can be initiated under specified conditions.

Discussion: While the phenomenon of combustion may be transient or sustained, in fire testing practice the ignition temperature is considered reached when combustion continues after the pilot source is removed.

Mass burning rate, n - mass loss per unit time by materials burning under specified conditions.

Noncombustible, n - not combustible.

Pyrolysis, n - process of simultaneous phase and chemical species change caused by heat (compared to **smoldering**).

Smoldering, n - Combustion of a solid without flame, often evidenced by visible smoke.

Discussion - Smoldering can be initiated by small sources of ignition, especially in dusts or fibrous or porous materials, and may persist for an extended period of time after which a flame may be produced.

Standard time/temperature curve, n - *in fire testing*, a graphical representation derived from prescribed time/temperature relationships, and used to control furnace temperature with progressing time.

Discussion: One example is found in Test Method E119.

Superimposed load, n - force applied to a specimen or structure other than that associated with its own mass.

Technical Advisory Committee (TAC) Definitions

I-Joist Definitions

Wooden I-joist, n - a structural member manufactured using sawn or structural composite lumber flanges and structural panel webs, bonded together with exterior exposure adhesives, forming an "I" cross-sectional shape. These members are primarily used as joists in floor and roof construction.

I-joist flange, n - this material consists of solid sawn lumber or laminated veneer lumber. The lumber is machined in a variety of sizes and then routered for web attachment. The sizes include 1-1/2" by 1-3/4", 1-1/2" by 2-1/4", 1-1/2" by 3-1/2" and other sizes per proprietary design. (See figure below.)

I-joist web, n - this material is placed between the flanges of an I-joist. The width of this material varies with the depth of the truss. The web material also comes in a variety of thicknesses which include; 3/8", 7/16", 1/2", etc. The web material may be oriented strandboard, hardboard, plywood, or other proprietary composite material. (See figure below.)

Oriented strandboard, n - A type of particle panel product composed of strand-type flakes which are purposefully aligned in directions which make a panel stronger, stiffer, and with improved dimensional properties in the alignment directions than a panel with random flake orientation.

Plywood, n - A glued wood panel made up of relatively thin layers of veneer with the grain of adjacent layers at right angles, or of veneer in combination with a core of lumber or of reconstituted wood.

Truss Definitions

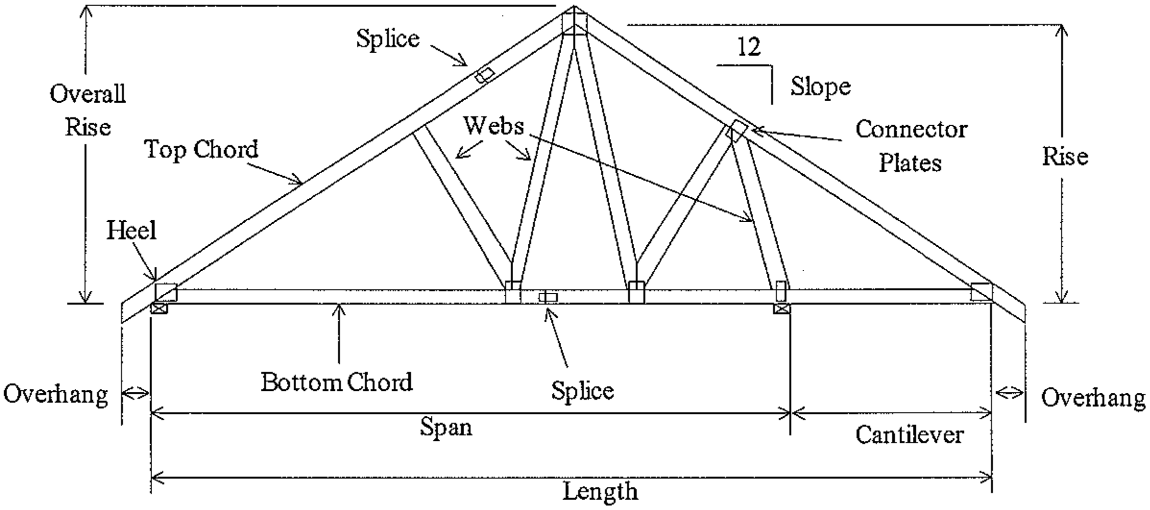
Metal connector plate, n - a connector made from a specific gauge and specific strength steel sheet that is punched with a specific tooth pattern. Each tooth pattern represents a proprietary product. These stamped metal connectors come in a variety of sizes and are pressed into two or more wood members to form a joint which resists axial, moment, and eccentrically applied forces.

Metal plate connected (MPC) wood truss, n - a series of dimension lumber members typically assembled to form a series of planar triangles. The chord members are connected to each other and to web members through the use of metal plate connectors.

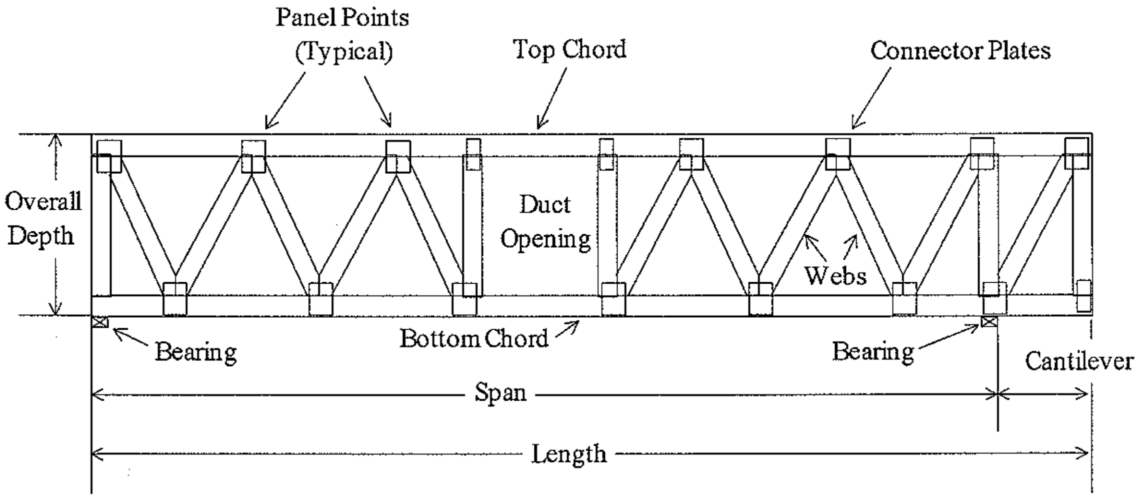
Bottom chord, n - a dimension lumber member that forms the bottom perimeter of the truss. (See figure below.)

Web members, n - dimension lumber members that form the interior members of the truss. (See figure below.)

Pitched chord truss, n - the top chord singly or the top and bottom chords together slope to provide a surface that is at some angle to the horizontal plane. (See figure below.)



Parallel chord truss, n - the chord members of this truss are at a constant distance from each other throughout the length of the truss. (See figure below.)



Pin-end connected metal web (PECMW) truss, n - this truss has steel pins running through wood chords that connect steel webs between the top and bottom chord.

Metal plate connected metal web (MPCMW) truss, n - this truss has wood chords connected with metal webs that have punched metal connectors on the top and bottom of the web.

Metal plate connected metal web (MPCMW) truss, n - this truss has wood chords connected with metal webs that have punched metal connectors on the top and bottom of the web.

Steel bar joist truss, n - this truss is made up of a series of steel top and bottom flanges and steel web members welded together to form a truss.

Steel joist, n - this is a joist of specified gauge and strength that is typically formed into a C-shape and used as a joist or rafter element in floor and roof systems.

Other Definitions

Composite Wood Joist, n - a wooden joist that is made up of composite materials such as waferboard or oriented strandboard for the web material and parallel strand lumber or laminated veneer lumber for chords. This element has dimensions like solid-sawn joists, and is used in a manner similar to solid sawn joists for joists and rafters.

Connection systems, n - these are the locations within a structure that join one structural element to another. This can include nails, bolts, steel side plates, light gauge metal hangers, bearing clips, etc.

Dimension lumber joists, n - lumber manufactured from the natural wood fiber in trees, cut and dried to nominal dimensions such as 2 x 6, 2 x 8, 2 x 10, 2 x 12, etc., which are used in floor and ceiling systems.

Dimension lumber rafter, n - lumber manufactured from natural wood fiber cut from trees and dried to nominal dimensions such as 2 x 6, 2 x 8, 2 x 10, 2 x 12, etc., which are used in roof systems.

Glue laminated beams, n - a structural element made up of laminations consisting of dimension lumber and/or LVL and/or PSL. The individual laminations are adhesive bonded under heat and pressure and ordered so that a specific composite strength results.

Laminated veneer lumber (LVL), n - a composite of wood veneer sheet elements with wood fibers primarily oriented along the length of the member. Veneer thickness shall not exceed 0.25 inches (6.4 mm) (Per 11th draft of Structural Composite Lumber Standard.)

Light-frame construction, n - any method of construction utilizing dimension lumber joists, MPC trusses, MPCMW trusses, PECMW trusses, steel bar joist trusses, wooden I-joists, or composite wood joists as floor or roof system structural elements.

Parallel strand lumber (PSL), n - a composite of wood strand elements with wood fibers primarily oriented along the length of the member, bonded together under heat and pressure with exterior durable adhesives. The least dimension at the strands shall not exceed 0.25 inches (6.4 mm) and the average length shall be a minimum of 300 times the least dimension.

Structural Composite Lumber, n - Structural composite lumber is either laminated veneer lumber (LVL) or parallel strand lumber (PSL). These materials are intended for structural use and they shall be bonded with an exterior adhesive, qualified in accordance with ASTM D2559 and, in Canada, conforming to the appropriate section of CSA standards for wood adhesives.

Appendix B: Biographies of Fire Service Personnel

REFERENCES IN THIS APPENDIX ARE LISTED IN ALPHABETICAL ORDER BY LAST NAME.

Francis L Brannigan

Francis L. Brannigan has had a lifetime of varied professional fire protection experience. During World War II he directed a naval fire fighting school, commanded a seagoing fire fighting unit, and served as a district chief in the unique Army-Navy-Pancanal fire protection organization. He remained with the Navy after the war to help develop a competent fire service for the Naval Shore Establishment.

He served for many years as the Public Safety Liaison Officer of the federal Atomic Energy Commission. He developed the Chain Reaction Training Program for fire officers in the correct handling of radiation accidents, and the Fire Loss Management program for the protection of life and property from fire.

At Montgomery College, Rockville, MD, he developed a model Fire Science Program, assembling an outstanding adjunct staff, each a nationally recognized expert in his field. He is currently a member of the adjunct staff of the National Fire Academy, Emmitsburg, MD and the Fire and Rescue Institute, University of Maryland, College Park, MD. In association with his wife, Maurine, he has assembled extensive collections of slides on all aspects of building construction and fire loss management. Jointly they conduct seminars across the country.

He was honored by the Society of Fire Protection Engineers with full membership, despite the fact that his degree was not taken in engineering. He served for many years on National Fire Protection Association Technical committees. He received the Fire Angel Award from the Cleveland firefighters and the Training Officers Conference Award.

The Chesapeake Chapter of the International Society of Fire Service Instructors founded the Francis L. Brannigan Instructor of the Year Award in his honor.

Excerpted from ***Building Construction for the Fire Service,*** *2nd Edition, Francis Brannigan, 1982.*

Allen B. Clark, Jr.

Allen B. Clark, Jr., began his fire service career in Virginia by serving on U.S. Forest Service pickup crews. He joined the Bell Township department in 1975 and, after intensive training, became assistant chief and training officer in 1979 and chief in 1980.

Referenced from "The Bare Facts on Hidden Dangers," ***Fire Command Magazine,*** *July 1984.*

Glenn P. Corbett

Glenn P. Corbett is the administrator of engineering services for the San Antonio [Texas] Fire Department. He has a bachelor's degree in fire science from John Jay College of Criminal Justice in New York City and is working on a graduate degree in fire protection engineering at Worchester Polytechnic Institute in Worchester, Massachusetts. His fire service background includes seven years as a volunteer firefighter in northern New Jersey.

Referenced from "Lightweight Wood Truss Floor Construction: A Fire Lesson," ***Fire Engineering Magazine****, July 1988.*

Bruce E. Cutter

Bruce E. Cutter is a Captain with the Boone County Fire Protection District, Missouri. He is also an Associate Professor of Forestry at the University of Missouri at Columbia where he teaches courses in wood technology, wood utilization and wood engineering.

Excerpted from "Working Together," ***WoodWords****, May, 1990.*

Vincent Dunn

Vincent Dunn, who has been with the City of New York Fire Department for 31 years, is deputy chief in command of midtown Manhattan, one of the most densely populated areas in the U.S. He holds a master's degree in fire administration and teaches at the National Fire Academy and Manhattan College. Chief Dunn is the author of the text and video series **Collapse of Burning Buildings**, published by Fire Engineering Books.

Excerpted from "Firefighter Death and Injury: 50 Causes and Contributing Factors", ***Fire Engineering Magazine****, August 1990.*

John W. Mittendorf

John W. Mittendorf is a battalion chief and 27-year veteran of the Los Angeles City Fire Department. He has an associate's degree in fire science. Chief Mittendorf is the author of the books **Ventilation Methods and Techniques** and **Facing the Promotional Interview**, published by Fire Technology Services.

Excerpted from "The Timber Truss: Two Points of View," ***Fire Engineering Magazine****, May 1991.*

William Peterson

William Peterson is currently fire chief for the City of Plano, Texas, and is former fire marshal for the City of Bolingbrook, Illinois.

J. Gordon Routley

J. Gordon Routley, a registered professional engineer, is former Assistant to the Fire Chief of Phoenix, Arizona; Fire Chief for the Shreveport, Louisiana Fire Department; and Chair of the Health and Safety Committee of the International Association of Fire Chiefs. He is also Secretary of NFiPA's Technical Committee on Fire Service Occupational Safety. Among his duties with the Phoenix Fire Department is the on-scene evaluation of the structural integrity of burning buildings. He is currently a consultant for the fire service and Chairperson of the NFPRF Technical Advisory Committee for the National Engineered Lightweight Construction Research Project.

Excerpted in part from ***Fire Journal Magazine****, January/February 1989, p. 83.*

Appendix C: Comparative Risk Statistics

To put the risk of firefighter fatality due to lightweight components into comparative perspective, Table 43 delineates fatalities per year for firefighters, agricultural workers, construction workers, mining workers, and police officers. This will provide a basis upon which to ascertain the level of risk firefighters face in their workplace.

Year	Agricultural[a]	Construction[a]	Mining[a]	Police[b]	Firefighters[c]
1980	2000	2500	500	165	137
1981	1900	2200	600	157	135
1982	1800	2100	600	164	123
1983	1800	2000	500	152	112
1984	1600	2200	600	147	119
1985	1600	2200	500	148	126
1986	1700	2100	400	133	118
1987	1500	2200	200	158	130
1988	1300	2100	300	155	135
1989	1300	2100	300	146	116

a Source: Accident Facts, National Safety Council, 1981-1990 eds.
b Source: Statistical Abstract of the United States, 1991 ed.
c Source: NFPA Journal, August 1991.

Table 43. Fatalities in Selected Fields, 1980-1989

In order to get a better idea of how fatalities compare between these occupations, Table 44 contains the same data normalized to show fatalities per thousand people in each occupation.

Year	Agricultural[a]	Construction[a]	Mining[a]	Police[bc]	Firefighters[ad]
1980	61	45	50	0.38	0.12*
1981	54	40	55	0.35	0.12*
1982	52	40	55	0.37	0.11*
1983	54	37	50	0.34	0.10
1984	46	39	60	0.31	0.11
1985	49	37	50	0.31	0.12
1986	52	33	50	0.28	0.11
1987	49	35	38	0.33	0.12
1988	48	34	25	0.32	0.13
1989	40	32	43	0.29	0.11

a Source of fatality statistics: Accident Facts, National Safety Council, 1981-1990 eds.
b Source of fatality statistics: Statistical Abstract of the United States, 1991 ed.
c Source of total number of police officers: U.S. Department of Justice, Federal Bureau of Investigation, "Crime in the United States," 1980-1989 eds.
d Source of total number of firefighters: Michael J. Karter, Jr., "U.S. Fire Department Profile Through 1990," Fire Analysis and Research Division, NFiPA, November 1991.
* Total number of firefighters was not available for these years. Data were extrapolated.

Table 44. Fatalities in Selected Occupations per 1000 People in Each Occupation in the U.S., 1980-1989

Appendix D: Obtaining the NFPRF Bibliography

The bibliography of articles discussed in **Chapter 2** contains approximately 2,000 entries, and can be obtained from the NFPRF by writing to:

NFPRF
1 Batterymarch Park
Quincy, MA 02269-9101

or by calling:

617/770-3000,

and asking for the Research Foundation.

The bibliography comes in two formats: printed or on floppy disk.