SBC ASSOCIATION

Research Report

Forest Products Laboratory Fire Performance Testing and Subsequent Fire Endurance Modeling of 2x10s

Relating this Knowledge to Metal Plate Connected Wood Truss Floor Assemblies Demonstrating Equivalent Fire Performance per *2012 IRC* Section R501.3

Background Research, Evaluation and Analysis

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Report Number: 1406-02

Research and Analysis Conducted: January 9 to May 5, 2013; June 2014

Final Report Issued: May 6, 2013, Revised June 8, 2014

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This research report is based on practical scientific research (literature review, testing, analysis, etc.), with the goal of supporting strategic needs for code and standards development and market expansion. This research report complies with the following sections of the building code:

- *IBC* Section 104.11.1 and Section 1703.4.2 – "**Research reports.** Supporting data, where necessary to assist in the approval of materials or assemblies not specifically provided for in this code, shall consist of valid research reports from *approved sources*."
- *IBC* Section 202 – "**APPROVED SOURCE.** An independent person, firm or corporation, *approved* by the *building official*, who is competent and experienced in the application of engineering principles to materials, methods or systems analyses."

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Introduction:

Object Statement

Questions have arisen regarding Forest Products Laboratory (FPL) 2x10 floor joist testing that has been used in the evaluation of 2x10 floor joist fire endurance performance as it relates to floor truss performance equivalency analysis and *International Residential Code* (*IRC*) Section R501.3.

Based on information provided in a National Fire Protection Research Foundation report (NFPRF report)[1] an Underwriters Laboratory (UL) literature review[2], the Illinois Fire Service Institute Testing (Chapter 4-1, page 77) referenced in the conclusions below, and the FPL ASTM E119 testing, it is clear that metal plate connected wood trusses can be classified as "other approved floor assemblies demonstrating equivalent fire performance."

The *IRC* states that "floor assemblies, not required elsewhere in this code to be fire resistance rated, shall be provided with a ½" gypsum wallboard (GWB) membrane, $^{5}/_{8}$" wood structural panel (WSP) membrane, or equivalent on the underside of the floor-framing member", with a few exceptions.

This code language is evaluated in the context of existing ASTM E119 standardized comparative equivalency fire endurance performance testing as confirmed in *Replicate Fire Endurance Tests of an Unprotected Wood Joist Floor Assembly* (FPL report)[3] by Robert H. White and E. L. Schaffer.

2012 IRC Section R501.3 states the following, in total:

> **R501.3 Fire protection of floors.** Floor assemblies, not required elsewhere in this code to be fire resistance rated, shall be provided with a ½" gypsum wallboard membrane, $^{5}/_{8}$" wood structural panel membrane, or equivalent on the underside of the floor framing member.
>
> Exceptions:
>
> 1. Floor assemblies located directly over a space protected by an automatic sprinkler system in accordance with Section P2904, NFPA13D, or other approved equivalent sprinkler system.
> 2. Floor assemblies located directly over a crawl space not intended for storage or fuel-fired appliances.
> 3. Portions of floor assemblies can be unprotected when complying with the following:
>   3.1 The aggregate area of the unprotected portions shall not exceed 80 square feet per story
>   3.2 Fire blocking in accordance with Section R302.11.1 shall be installed along the perimeter of the unprotected portion to separate the unprotected portion from the remainder of the floor assembly.
> 4. **Wood floor assemblies using dimension lumber or structural composite lumber equal to or greater than 2" by 10" nominal dimension, or other approved floor assemblies demonstrating equivalent fire performance.** [emphasis added]

Additional Background Research, Data Evaluation and Analysis:

The FPL report provide details of the FPL ASTM E119 testing and related analysis regarding 2x10 floor joist performance.

The FPL report states:

> The aim of this study was to determine the fire endurance performance of an unprotected wood joist floor for use in the model.

The ASTM E119 testing standard formed the basis for the testing.

> Eleven ASTM Standard E 119 floor tests were conducted. All the floors were 2 by 10 Douglas-fir wood joists, sixteen inches on center with 3/32-inch-thick plywood as the floor sheathing. In addition to one trial test, five tests were conducted using a live load of 11.35 lb/ft2. For the other five tests, the live load was 79.2 lb/ft2. Twenty joists were tested for modulus of elasticity and modulus of rupture.

The 2x10 joist properties were measured so that the exact design stress was known and the applied load could be compared to the design stress of the 2x10 joist.

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[1] http://www.carbeck.org/pdfs/NFPRF_Report_WTCA_version.pdf

[2] http://support.sbcindustry.com/docs/SRR_UL.pdf

[3] http://www.carbeck.org/pdfs/white83a.pdf

As a result of this study, fire-resistance performance of a wood floor is known for a specific population of wood joists with known structural properties. These results can be used to verify and revise the model for predicting fire endurance.

The joist population had a mean modulus of rupture of 5,280 lb/in.^{2} and a mean modulus of elasticity of 1,530,000 lb/in^2.

For the five floors loaded to 11.35 lb/ft^2, the mean time for initial joist failure was 17.9 min with a coefficient of variation (COV) of 3.7%.

For the five floors loaded to 79.2 lb/ft^2, the mean time was 6.5 min with a COV of 11.6%.

Based on linear interpolation of these results, first joist failure would have occurred in 13.1 min if a 40 lb/ft^2 live load had been used, which is the typical live loading specified in the building codes for residential one- and two-family dwellings.

The loading conditions used for the 2x10 floor joist fire endurance testing were defined as follows (emphasis added):

We fire tested a total of eleven 14-foot by 18-foot unprotected joist floors that supported a maximum floor load as described in ASTM E 119 (79.2 lb/ft^2) or a load more typical of that encountered in a house (11.35 lb/ft^2) (Corotis and Doshi 1977).

The ASTM testing was conducted as follows:

The standard ASTM E 119 fire tests were conducted in a 14- by 18-foot floor furnace (Fig. 1). The floor furnace (Carlson and Hubbel 1969) is essentially a rectangular-shaped box in which the test specimens serve as the top closure. Gas burners within the furnace provide the standard fire exposure to the test specimen. A structural live load is imposed on the top of the specimen. In addition to visual observations, thermocouples record the temperatures within the furnace and on the test specimens, the atmospheric pressure within the furnace is recorded, and deflection of the floor is observed

Test specimens.-The test specimen was constructed with the nominal 2- by 10-inch joists and 23/32-inch-thick plywood (Fig. 2). Fourteen joists and two headers were used to construct the 14- by 18-ft frame (Fig. 3). The joists spanned the 13-ft 10.5-in. width and were spaced 16 inches on center along the 17-ft 9-in. length. Butt ends of the plywood sheets were located over joists. Plywood joints perpendicular to the joists were tongue and groove. Plywood was nailed to joists with 6d spiral thread nails spaced 6 inches on center along the panel edges and 10 inches on center at intermediate joists. There was no blocking or bridging.

The two levels of uniform live load used in the fire tests were 11.35 lb/ft^2 and 79.2 lb/ft^2. The 11.35 lb/ft^2 was the average live load found by Karman (1969) in surveys of 183 domestic dwellings in Budapest (Corotis and Doshi 1977). It is consistent with the 10.0 lb/ft^2 average live load found in later surveys of single family residences in the metropolitan Washington, D.C., area (Issen 1980).

The 79.2 lb/ft^2 represents a maximum loading condition as described in ASTM E 119. Using a span of 12 ft 11.5 in. and the average dimensions (1.47 in. by 9.11 in.) of the joists, the calculated extreme fiber stress in bending for a simple beam is 270 lb/in^2 for the 11.35 lb/ft^2 loading and 1,470 lb/in^2 for the 79.2 lb/ft^2 loading. If the standard dressed dimensions (1.5 in. by 9.25 in.) of the joists are used, the calculated outer fiber stress is 5% less.

The test results of the 2x10 joists that were tested to “represent a maximum loading condition as described in ASTM E 119” are listed below.

Test	Structural Member	Spacing (in o.c.)	Structural Failure (min : sec)	% Design Stress
FPL (R.H. White, 1983)	2 x 10; $^{23}/_{32}$" ply	16" o.c.	5:30	100%
FPL (R.H. White, 1983)	2 x 10; $^{23}/_{32}$" ply	16" o.c.	6:12	100%
FPL (R.H. White, 1983)	2 x 10; $^{23}/_{32}$" ply	16" o.c.	6:18	100%
FPL (R.H. White, 1983)	2 x 10; $^{23}/_{32}$" ply	16" o.c.	6:48	100%
FPL (R.H. White, 1983)	2 x 10; $^{23}/_{32}$" ply	16" o.c.	7:30	100%

Table 1: ASTM E119 FPL Unprotected 2x10 Joist Assembly Tests at Full Design Load[4]
ASTM Comparative Test Data Using 100% Design Load as the Common Denominator

The report describes the floor fire endurance performance of 2x10s loaded to 100% of the design load as required by ASTM E119.

> *Floor performance.* – In most of the tests, smoke was observed streaming from the butt joints in the plywood flooring within the first minute. These joints were located over the joists.
>
> In the high-load tests, the floor rippled at 3 to 6 min. Rippling was characterized by deflections of the sheathing along the lines of the application of the loading rams. This was followed by failure of the joists at 5 to 8 min (Table 2 [Table 1 above]). Fire penetration was associated with the failure of the joists.
>
> In the high-load tests, deflection increased steadily from ignition to 4 min into the tests (Fig. 10). From 4 to 8 min, rapid deflections (Fig. 10) associated with failure occurred. These deflection measurements basically agreed with the visual observations.

The summary of this ASTM E119 testing states:

> For a population of 2- by 10-inch Douglas-fir joists with known structural properties, a total of 11 ASTM E 119 tests were conducted of an unprotected wood joist floor system. The joist population had a mean MOR of 5,280 lb/in^2 and mean MOE of 1,530,000 lb/in^2.
>
> For the five floors loaded to 11.35 lb/ft^2, (note: ASTM E119 non-standard design stress test) the mean time for initial joist failure was 17.9 min with a coefficient of variation of 3.7%.
>
> For the five floors loaded to 79.2 lb/ft^2, (note: 100% design stress) the mean time for initial joist failure was 6.5 min with a coefficient of variation of 11.6%.
>
> There was one trial test using a load of 11.35 lb/ft^2.
>
> Visual and acoustic observations of joist failures were generally consistent with deflection measurements. Fire resistance and load-carrying capacity by the floor sheathing itself and load sharing between joists were evidenced in the data and visual observations.

[4] http://www.carbeck.org/pdfs/NFPRF_Report_WTCA_version.pdf, page 29.

Concluding Comments:

The FPL floor fire endurance performance testing performed on 2x10s loaded to 100% of the design load as required by ASTM E119 follows with a comparison to 12" metal plate connected wood truss performance that is performed using 100% of the design load per ASTM E119.

Test	Structural Member	Spacing (in o.c.)	Structural Failure (min : sec)	Loading (psf) (% Design Stress)
FPL (R.H. White, 1983)	2 x 10; $^{23}/_{32}$" ply	16" o.c.	5:30	79.2 (100%)
FPL (R.H. White, 1983)	2 x 10; $^{23}/_{32}$" ply	16" o.c.	6:12	79.2 (100%)
FPL (R.H. White, 1983)	2 x 10; $^{23}/_{32}$" ply	16" o.c.	6:18	79.2 (100%)
FPL (R.H. White, 1983)	2 x 10; $^{23}/_{32}$" ply	16" o.c.	6:48	79.2 (100%)
FPL (R.H. White, 1983)	2 x 10; $^{23}/_{32}$" ply	16" o.c.	7:30	79.2 (100%)
FM FC 250 (Factory Mutual Research, 1977)	12" wood truss; $^{3}/_{4}$" ply	24" o.c.	10:12	60.0 (100%)

As a point of comparison using a more typical loading condition, the demonstrative testing conducted by the Illinois Fire Service Institute, 1986, provided the following comparative results confirming metal plate connected wood truss performance equivalency to 2x10s using a loading condition of 31 psf (with emphasis added).

Authors: J. Straseske and C. Weber
Sponsor: Illinois Fire Service Institute at the University of Illinois
Date: Fall, 1986
Test Methods Used: The floor systems used for demonstrations were:

1) Conventional 2 x 10 joists on 16 in. centers.
2) Wood I-beams on 24 in. centers.
3) Open-web trusses with wood members and gusset plates on 24 in. centers.
4) Open-web trusses with a stamped out steel webs on 24 in. centers.
5) Open-webbed trusses with a wooden top and bottom chord and pipe web members on 24 in. centers.

All decks were identical in size, manner of loading and ignition source. The decks were built 8 x 9 ft., and were set up on 8 in. concrete blocks, three layers high. Block foundations enclosed each system on three sides. Each deck was placed on a 2 x 6 sill plate mounted on top of the blocks.
The 2 x 10 system used a 2 x 10 box sill.

The openwebbed truss systems were enclosed on the outside perimeter of the deck by 3/4 in. plywood to enclose the box sill. All deck systems were sheathed with 3/4 in. tongue-and groove waferboard that was nailed down with 8 penny, coated nails.

A live load of 31 psf, consisting of concrete blocks, was distributed across each deck.

The fuel for the fire was contained in cut-off 55 gal. barrels approximately 12 in. high. The ignition fuel source was 4 gal. of diesel fuel, 1 gal. of gasoline, and 5 gal. of water.

Report Observations: The 2 x 10 platform began to sag at 8 min., and burned through the sheathing at 9 min. No further significant damage occurred, and the fire was extinguished at 13 min. **The 2 x 10 system continued to carry its load after the 13 min. burn.** The system gave ample warning that a structural problem was developing: it sagged, but the system did not fail entirely.

The metal plate connected wood truss system began sagging at approximately 8 min., and burned through the sheathing at 9 min. The sagging of the floor was very evident, **but the system continued to carry the load until the fire was extinguished at 15 min., 45 sec.** By sagging, this system gave a definite indication of structural problems.

At 4 min., 40 sec., the wooden I-beam platform failed completely. There was no sagging or warning noises to indicate a structural problem. The system carried the load until failure. The failure of the wood I-beam system to sag prevents firefighters from determining if the building is in structural trouble.

The metal web wood truss began sagging at 6 min. Most notable was that the metal web failed to carry the load. As the web failed, the top and bottom chords came together. The fire was extinguished at 7 min., 30 sec., when the fire burned through the sheathing.

Burn through of the sheathing of the pin-end steel webbed wood trusses occurred at 6 min., 50 sec. At burn through there was no noticeable sag. At approximately 8 min., parts of the bottom chord were hanging down into the fire. At 9 min., 45 sec., the system failed without any warning or sagging.

[redacted]