

**Fire Assemblies:
Performance and Application Using
Wood Trusses**

Overview

Revised 2/24/2017

SBCA

SBCA has been the voice of the structural building components industry since 1983, providing educational programs and technical information, disseminating industry news, and facilitating networking opportunities for manufacturers of roof trusses, wall panels and floor trusses. **SBCA** endeavors to expand component manufacturers' market share and enhance the professionalism of the component manufacturing industry.

Copyright © 2017 Structural Building Components Association.

Outline

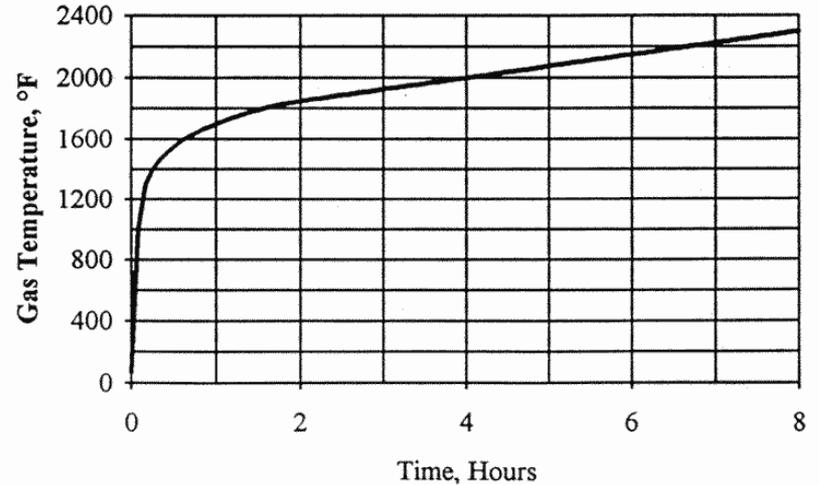
1. ASTM E119 Testing
2. Performance of Materials
3. Tested Assemblies & CAM
4. ASTM Test Furnace
5. Trusses after ASTM Testing & Fire
6. Unprotected Assembly Testing
7. Non-Combustible Materials
8. Key Points
9. Reference Sources

1.0 ASTM E119 Testing

- ASTM E119 is a standardized testing of assemblies for fire endurance rating in use since 1918
- The primary purpose of this testing was to develop one-hour through four-hour fire resistive assemblies to meet building code requirements.
- The key concept is not to suggest that an assembly is going to perform in a fire for one, two, or three hours – but to provide a benchmark for fire endurance performance that one can use to place into a building fire-rated assemblies that have a specific level of performance.

1.0 ASTM E119 Testing

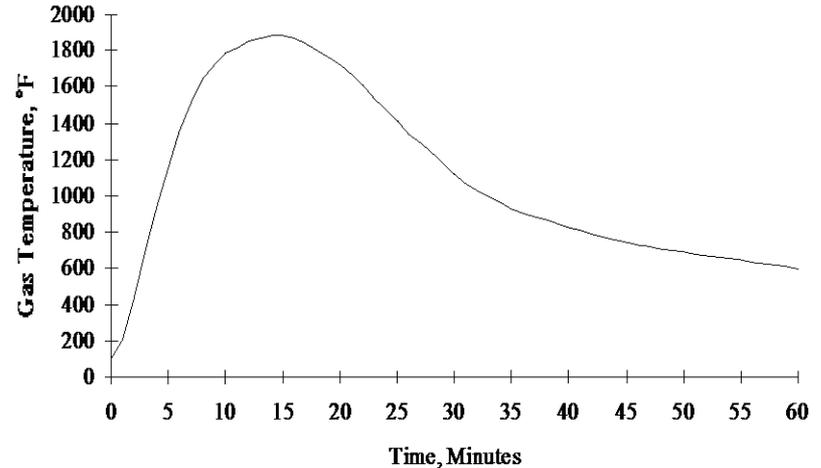
- In the test:
 - A representative assembly is constructed for each assembly to be tested.
 - The assembly is put under full design load, then burned following the ASTM time temperature curve.



ASTM E119 Time/Temperature Curve

1.0 ASTM E119 Testing

- There is concern within the fire service that this is not representative of a real fire.
- Frank Brannigan, for instance, suggests that the National Bureau of Standards (NBS) fire development curve would be preferred to ASTM E119 because it is more reflective of real fire behavior.

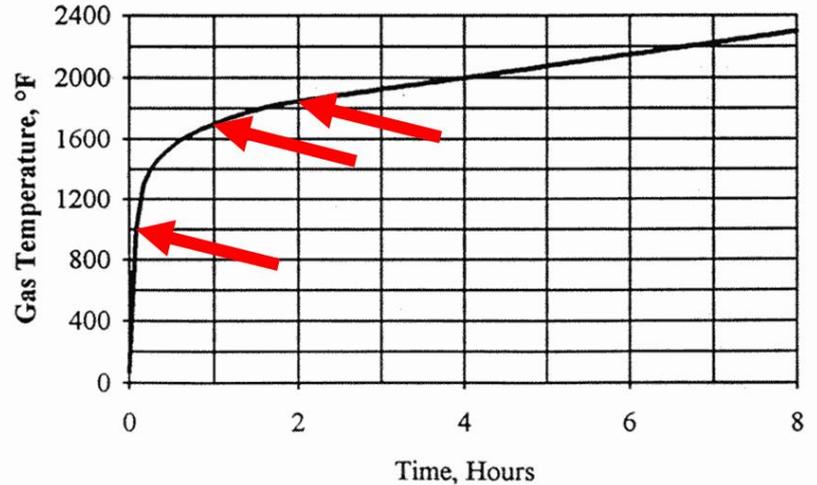


1.1 ASTM E119 Failure Criteria

- The failure criteria for an ASTM E119 test includes the following:
 - **Heat transmission**
 - Measured by nine thermocouples on the unexposed surface of the assembly.
 - The assembly fails if the average temperature on the unexposed surface increases more than 250 degrees F above the ambient temperature or if the temperature at any single thermocouple rises more than 325 degrees F above the initial temperature.
 - **Flame penetration**
 - Measured by placing cotton waste over the surface of the assembly.
 - If the cotton waste ignites, the assembly fails.
 - **Structural collapse**
 - Deemed to have occurred when the assembly is no longer able to carry the applied design load.

1.2 ASTM Time-Temperature Curve

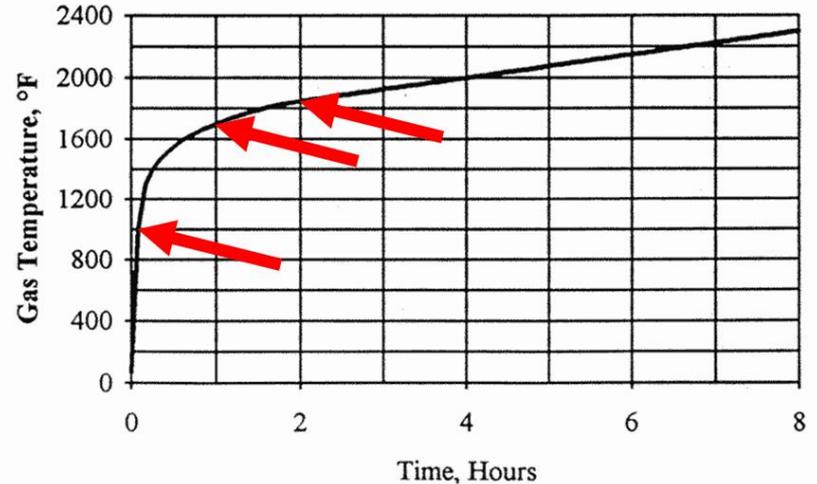
- In the first 5 minutes, the temperature increases to about 1000° F (**left arrow**)
- By 60 minutes into the test, the temperature increases to about 1700° F . (**middle arrow**)
- If the assembly needs to be tested for two hours, the temperature continues to increase up to 1800° F during the next hour. (**right arrow**)



ASTM E119 Time/Temperature Curve

1.2 ASTM Time-Temperature Curve

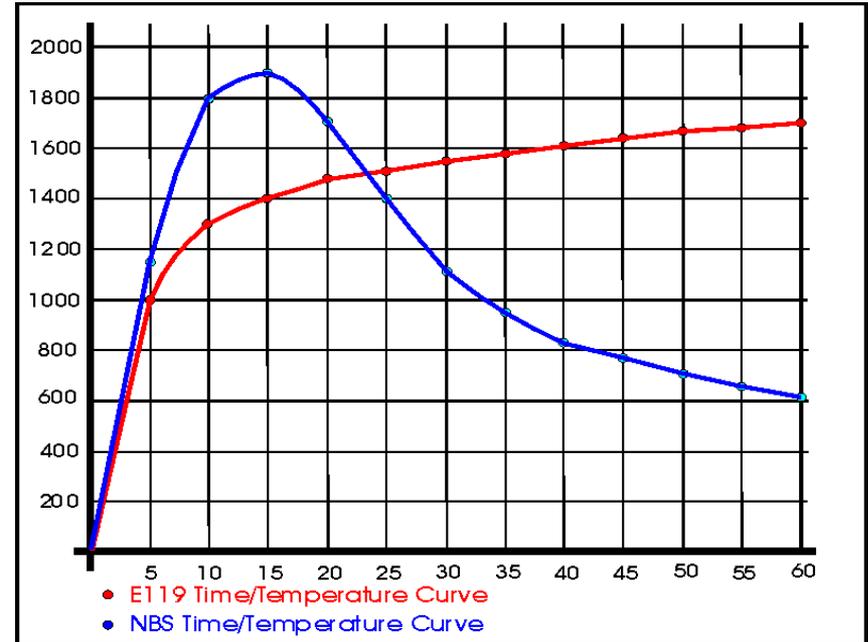
- The test furnace follows this time temperature curve as accurately as possible.
 - ASTM E119 has a formula to adjust endurance times if the furnace is to hot or too cool.
- This is a very severe test.
 - First, because of the rapid increase to 1000° F.
 - Second, because the temperature continues to increase until the assembly fails.



ASTM E119 Time/Temperature Curve

1.3 NBS Time-Temperature Curve

- Compare the NBS curve (blue) to the ASTM E119 curve (red).
- They are similar in the first 5 minutes where the temperature is about 1000° F
- The NBS curve increases to roughly 1800° F over the next five minutes, then drops off over the next 45 minutes, with the temperature falling to about 800° F by the 60 minute point.
- It is likely that if this time-temperature curve was used, assemblies would endure fire for longer periods of time than are seen in ASTM E119 tests due the severity differences — NBS high early, ASTM high to the end.



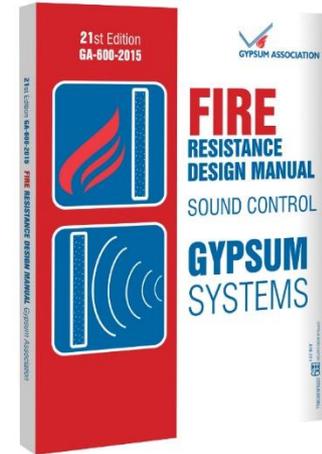
1.4 Comparisons

- Many in the industry believe that if the NBS time temperature curve were to be used as the standard, wood structural elements would still perform well because of the charring principle that provides structural performance protection for all wood members.
- This is due to the fact that the temperature rises so high so fast and then drops off.
- Wood charring would protect the wood structural member and would provide better performance for wood when compared to other materials that are more prone to structural weakness when subjected to temperatures in excess of 1000° F



1.5 IBC Fire Resistance

- ASTM E119 Testing
- IBC 104.11 Alternative materials, design and methods of construction and equipment
 - Approved sources
 - Prescriptive designs
 - Calculations
 - Engineering analysis
 - Alternative fire endurance assemblies

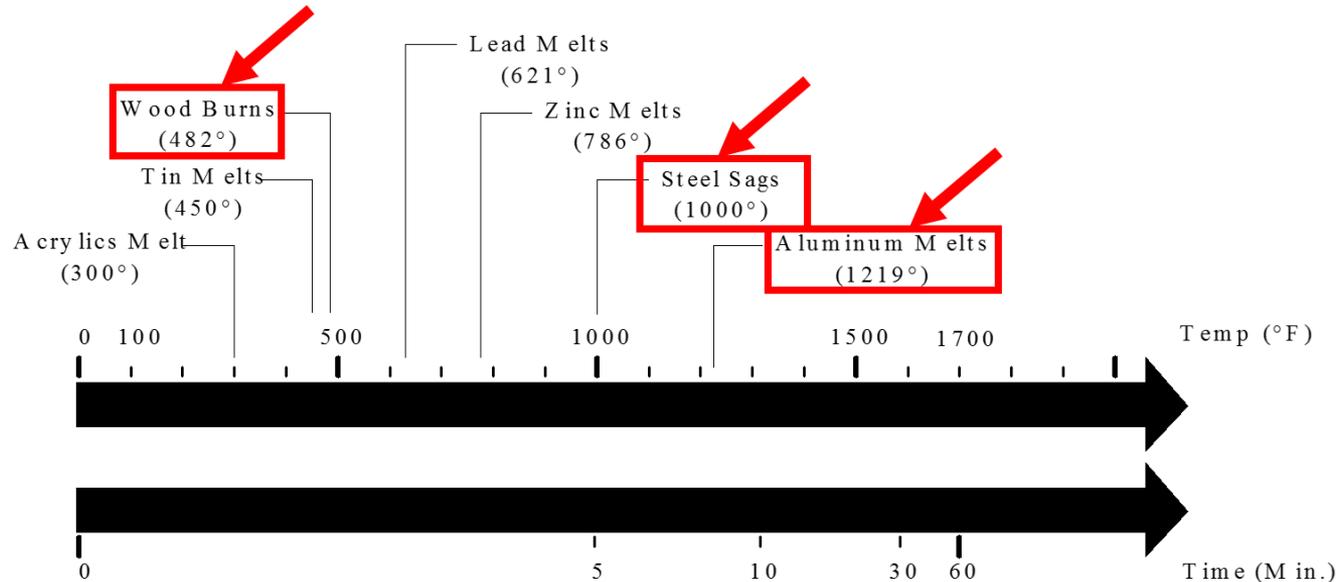


1.6 IBC Truss Protection

- IBC 704.5 Truss Protection - the thickness and construction of fire-resistance-rated assemblies enclosing trusses shall be based on one of the following options:
 - The results of full-scale tests
 - Combinations of tests on truss components
 - Approved calculations (which in turn are based on tests that satisfactorily demonstrate that the assembly has the required fire resistance.)

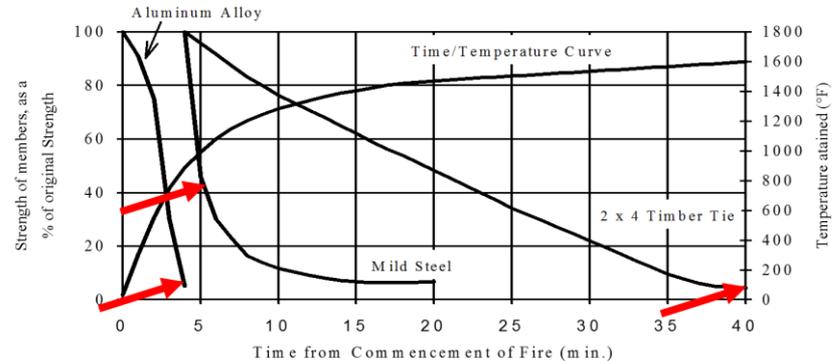
2.0 Materials Begin to Melt or Burn

- It is instructive to take a look at where different materials begin to have performance problems under fire conditions.



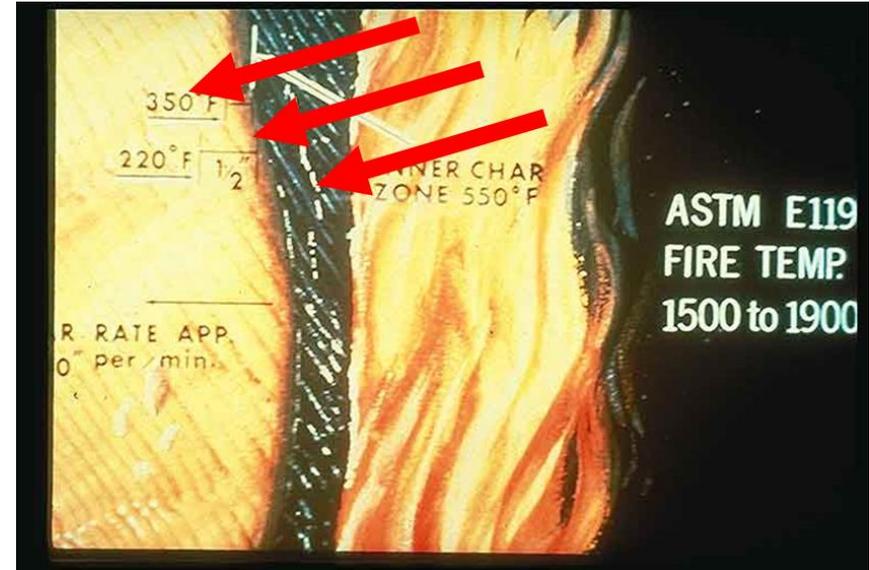
2.1 Strength

- Testing was undertaken on various materials using the ASTM time temperature curve to compare the performance of unprotected structural materials:
 - The aluminum member fails in about 4 minutes
 - Mild steel loses yield strength rapidly in 5 minutes, is at 20% of its strength at 7 minutes and fails in 20 minutes
 - The 2x4 is at 20% of its strength at 30 minutes and fails at 40 minutes.



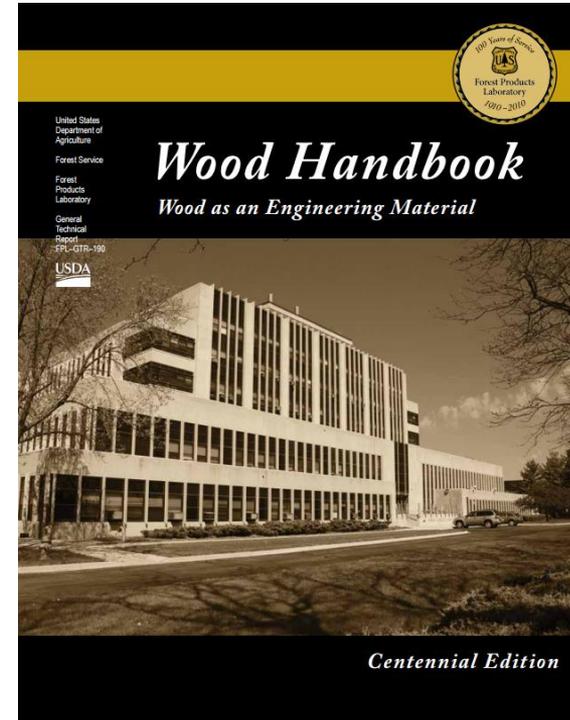
2.1 Strength

- As the wood burns a char layer is developed that protects the wood below this layer of char from degrading.
- Recall that under ASTM E119 testing conditions the temperature of the testing furnace goes from 0 to 1000° F in 5 minutes and then increases more slowly until it reaches 1700° F at 60 minutes.
- The charring rate of wood is a valuable fire protection feature of this engineering material.
 - The temperature at the inside of the char zone is 550° F
 - $\frac{1}{4}$ " in the temperature is only 350° F
 - $\frac{1}{2}$ " in the temperature is only 220° F



2.2 Wood Reactions

- Under ASTM E119 fire test exposures, wood ignites in approximately two minutes.
- According to Forest Products Laboratory, "Wood Handbook: Wood as an Engineering Material,"
 - Charring then proceeds at a rate of 1/30 inch per minute for the next eight minutes
 - Thereafter, the char layer has an insulating effect, and the rate decreases to 1/40 inch per minute after 8 minutes
 - This translates to about 1-1/2 inches of charring per hour of burning, depending on the species of wood



2.3 Fire Performance

- Regardless of testing methodology it is virtually impossible to model the way a fire will perform in any given structure.
- Although materials perform predictably, fire performs unpredictably due to the multitude of variables including:
 - Type of structure and the materials and methods used in construction
 - Location of the contents and the contribution they might make to fire and smoke intensity and spread
 - Availability of oxygen
 - Ability of heat to be dissipated from the structure
 - Fire origin location and start time.

3.0 Tested Assemblies

- Testing assemblies is an expensive (\$15-25,000) and time consuming process.
- Most of the available tested assemblies have been tested by and are available from one of the following:
 - Underwriters Laboratories – US and Canada
 - Intertek Testing Service under the Warnock Hersey or ETL labels
 - PFS Corporation
 - Factory Mutual (FM)
- Or they are recorded in the Gypsum Association Fire Manual or in National Evaluation Service Reports (for example, NER-392)

3.1.1 UL

- Underwriters Laboratories Fire Resistance Directory
 - Available in both printed and online version

 **ONLINE CERTIFICATIONS DIRECTORY** [Quick Guide](#) [Contact Us](#) [UL.com](#)

BEGIN A BASIC SEARCH

To begin a search, please enter one or more search criteria in the parameters below.

Company Name [\(options\)](#)

City

US State

US Zip Code

Country

Region

Canadian Province:

Postal Code (non-US)

UL Category Code [\(options\)](#)

UL File Number [\(help\)](#)

Keyword

We want your feedback!

Try the beta version of the Enhanced Online Certifications Directory.

TRY IT NOW

ABOUT THE ONLINE CERTIFICATIONS DIRECTORY

You can use the UL Online Certification Directory to:



3.1.2 UL Fire Resistance Directory

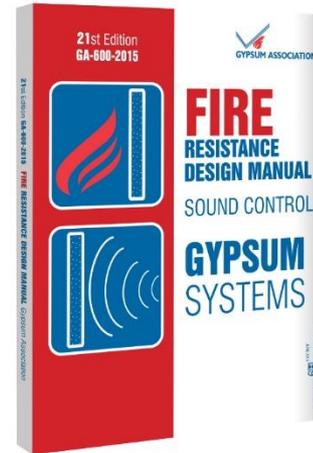
- All ratings are based on the assumption that the stability of structural members supporting the assembly are not impaired by the effects of fire.
- The extent of damage of the test assembly at the rating time is not a criteria for the rating.

703.2 Fire-resistance ratings.

The *fire-resistance rating* of building elements, components or assemblies shall be determined in accordance with the test procedures set forth in ASTM E119 or UL 263 or in accordance with Section 703.3. The *fire-resistance rating* of penetrations and fire-resistant joint systems shall be determined in accordance Sections 714 and 715, respectively.

3.2.1 GA 600-2000

- Gypsum Association
- Fire Resistance Design Manual
 - GA 600
 - 21st edition
 - Free to view online



3.2.2 Gypsum Types

- Regular
- Type X
- Improved Type X
 - (often referred to as Type C)
- UL CKNX Category



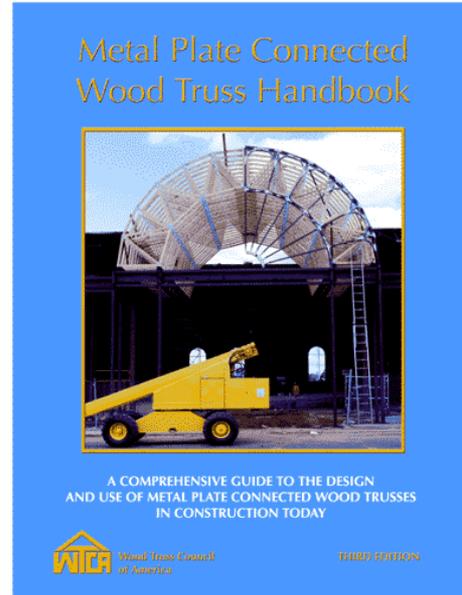
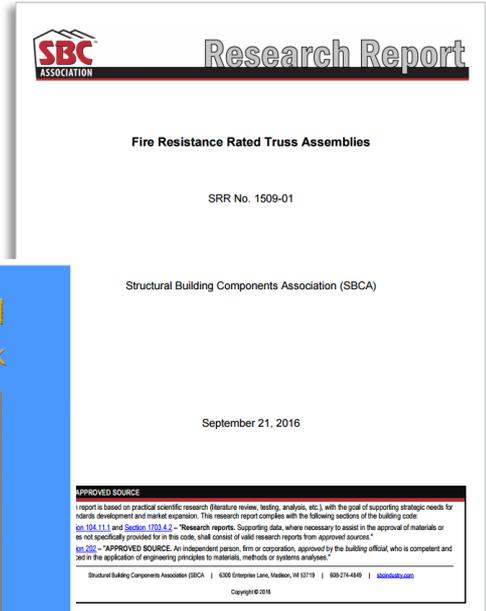
3.3 ITS

- Intertek Testing Services
- Directory of Listed Building Products
 - ETL Semko
 - Warnock Hersey



3.4 Wood Trusses

- TPI & SBCA
- Fire Resistance Rated Truss Assemblies
- Metal Plate Connected Wood Truss Handbook
 - 3rd Edition
 - Section 17, Fire Performance of Trusses



3.5 Alternates in Assemblies

GA File No. FC 5406 & RC 2601

GA FILE NO. FC 5406	GENERIC	1 HOUR FIRE	35 to 39 STC SOUND
<p style="text-align: center;">WOOD JOISTS, GYPSUM WALLBOARD</p> <p>Base: layer 1/2" type X gypsum wallboard applied at right angles to 2 x 10 wood joists 24" o.c. with 1 1/2" Type W or G drywall screws 24" o.c. Face: layer 1/2" type X gypsum wallboard or gypsum veneer base applied at right angles to joists with 1 1/2" Type G drywall screws 12" o.c. at joints and intermediate joists and 1 1/2" Type G drywall screws 12" o.c. placed 2" back on either side of end joints. Joints offset 24" from base layer joints. Wood joists supporting 1/2" plywood with exterior glue applied at right angles to joists with 8d nails. Ceiling provides one hour fire resistance protection for wood framing, including trusses.</p>			<p>Approx. Ceiling Weight: 5 psf Fire Test: FM PD 175, 3-25-73 Sound Test: Estimated</p>

WOOD JOISTS, GYPSUM WALLBOARD

Ceiling provides one hour fire resistance protection for wood framing, including trusses. (a maximum of 24" on center)

ER-1632

2 hour with 18" deep wood trusses (UL556)

3.6 ASTM E119 Finish Rating

- The time it takes on the unexposed surface of a material:
 - for the average temperature to rise more than 250°F or
 - an individual temperature rise of 325°F at a single thermocouple
- Not the same as the 'assigned time' in the CAM method

3.7 Penetrations

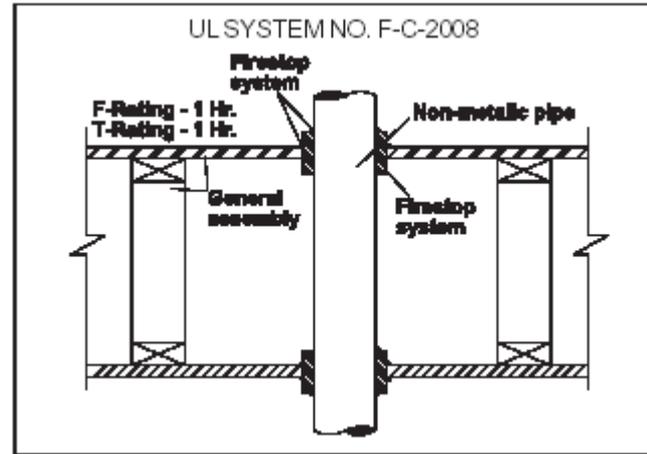
- IBC Section 714 (Through Penetrations or Membrane Penetrations)
- Examples:
 - Light fixtures
 - Ducts & Dampers
 - Firestop Systems

3.7.1 Light Fixtures

- IBC 714.4.1.1 Installation
- IBC 714.4.2 Membrane penetrations:
 - Recessed fixtures shall be installed such that the required fire resistance will not be reduced.
- UL CDHW Luminaires Classified for Fire Resistance

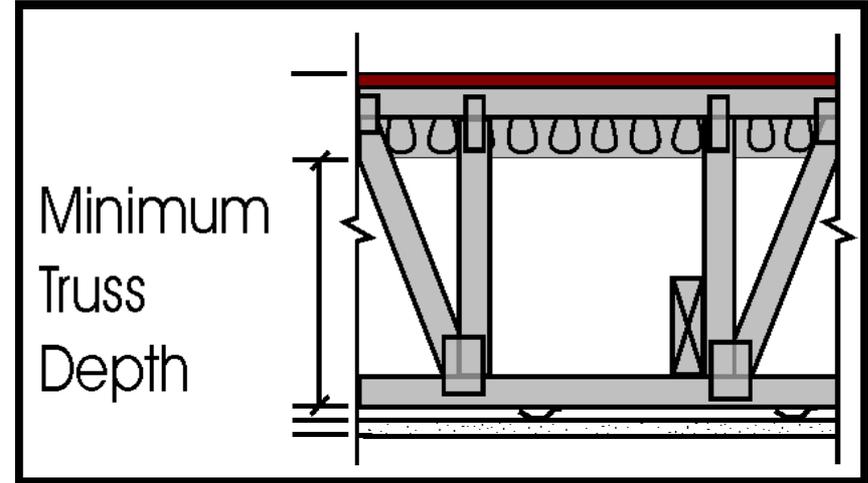
3.7.2 Firestop Systems

- F = floor
- W = wall
- C = ceiling



3.8.1 Insulation

- In assemblies tested with insulation
 - Follow tested assembly
- In assemblies tested without insulation
 - Evaluate impact
 - Place away from gypsum
 - Plenum depth greater or equal to tested

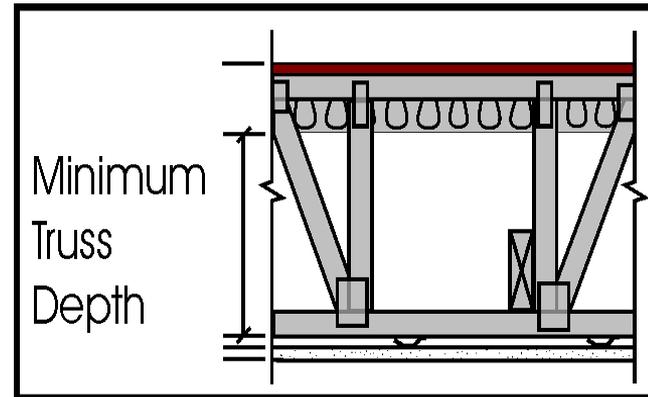
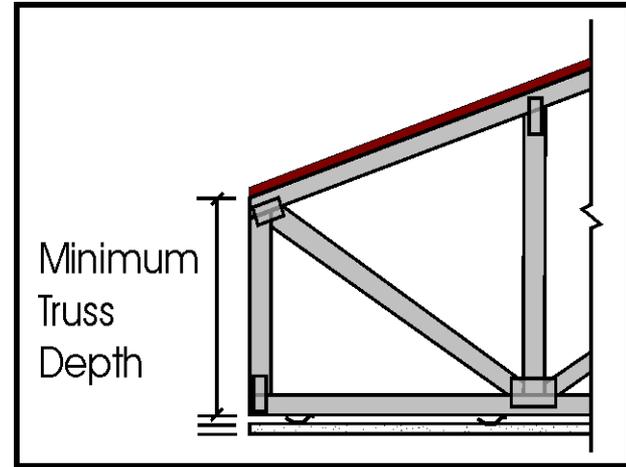


3.8.2 Insulation

- Assemblies tested with insulation:
 - Attached to surface furthest away from fire source
 - Laid directly on the protective membrane
 - Laid on resilient channel
 - Held up with stay wires or furring strips
- Review by professional engineer and code official

3.9 Depth of Assemblies

- Depth of Assembly
 - Minimum depth given
 - Increasing depth may enhance assembly performance
- Pitched vs. Flat assemblies
 - As long as minimum depth is maintained



3.10.1 Calculated Assemblies

- AWC Design for Code Acceptance 4
 - [Component Additive Method \(CAM\) for Calculating and Demonstrating Assembly Fire Endurance](#)
 - Describes a methodology for calculating the fire endurance of load bearing and non-load bearing floor, wall, ceiling and roof assemblies. In its most current version it includes floor and roof trusses at 24” o.c. spacing.
- IBC Section 722
 - Used in lieu of testing
 - Extrapolated from tests
 - CAM background

3.10.2 CAM

- CAM:
 - Is used when it is clear the fire-resistance rating of an assembly depends strictly on the specification and arrangement of materials for which nationally recognized standards exist
 - Is also used to assign a fire-resistance rating of up to 1-Hour (US, 90 minutes in Canada).
 - Can be applied to wood-stud walls and partitions and wood floor and roof joists up to 16" oc (DCA-4, BOCA, and CWC include 24" oc)
 - Results in conservative estimates

3.10.2 CAM

- The Component Additive Method calculation takes 3 items into account:
 - The time given for the protective membrane on the fireside
 - The time assigned to the structural framing
 - The time for insulation (only allowed in walls, not floor/ceiling or roof/ceiling assemblies)
- No value is given to the membrane on the non-fire side of the assembly, because it is assumed that the unexposed membrane will collapse when the structural framing fails.
 - The membrane must provide a contribution to fire resistance of at least 15 minutes.

Membrane	Rating (minutes)
5/8" Type X gyp with at least 3" of mineral wool batt insulation	30
Double 5/8" Type X gyp	60

3.10.2 CAM

TABLE 722.6.2(1) TIME ASSIGNED TO WALLBOARD MEMBRANES^{a, b, c, d}

DESCRIPTION OF FINISH	TIME ^e (minutes)
³ / ₈ -inch wood structural panel bonded with exterior glue	5
¹⁵ / ₃₂ -inch wood structural panel bonded with exterior glue	10
¹⁹ / ₃₂ -inch wood structural panel bonded with exterior glue	15
³ / ₈ -inch gypsum wallboard	10
¹ / ₂ -inch gypsum wallboard	15
⁵ / ₈ -inch gypsum wallboard	30
¹ / ₂ -inch Type X gypsum wallboard	25
⁵ / ₈ -inch Type X gypsum wallboard	40
Double ³ / ₈ -inch gypsum wallboard	25
¹ / ₂ -inch + ³ / ₈ -inch gypsum wallboard	35
Double ¹ / ₂ -inch gypsum wallboard	40

$2 \times 15 = 30$

3.10.2 CAM

TABLE 722.6.2(2) TIME ASSIGNED FOR CONTRIBUTION OF WOOD FRAME ^{a, b, c}

DESCRIPTION	TIME ASSIGNED TO FRAME (minutes)
Wood studs 16 inches o.c.	20
Wood floor and roof joists 16 inches o.c.	10

For SI: 1 inch = 25.4 mm.

- a. This table does not apply to studs or joists spaced more than 16 inches o.c.
- b. All studs shall be nominal 2 × 4 and all joists shall have a nominal thickness of not less than 2 inches.
- c. Allowable spans for joists shall be determined in accordance with Sections 2308.4.2.1, 2308.7.1 and 2308.7.2.

Wood roof and floor truss assemblies, 24" on center	5
--	----------

3.10.2 CAM

TABLE 722.6.2(4) FLOORING OR ROOFING OVER WOOD FRAMING^a

ASSEMBLY	STRUCTURAL MEMBERS	SUBFLOOR OR ROOF DECK	FINISHED FLOORING OR ROOFING
Floor	Wood	$15/32$ -inch wood structural panels or $11/16$ -inch T & G softwood	Hardwood or softwood flooring on building paper resilient flooring, parquet floor felted-synthetic fiber floor coverings, carpeting, or ceramic tile on $1/4$ -inch-thick fiber-cement underlayment or $3/8$ -inch-thick panel-type underlay Ceramic tile on $1 1/4$ -inch mortar bed
Roof	Wood	$15/32$ -inch wood structural panels or $11/16$ -inch T & G softwood	Finished roofing material with or without insulation

For SI: 1 inch = 25.4 mm.

a. This table applies only to wood joist construction. It is not applicable to wood truss construction.

3.10.2 CAM

TABLE 722.6.2(5) TIME ASSIGNED FOR ADDITIONAL PROTECTION

DESCRIPTION OF ADDITIONAL PROTECTION	FIRE RESISTANCE (minutes)
Add to the <i>fire-resistance rating</i> of wood stud walls if the spaces between the studs are completely filled with glass fiber mineral wool batts weighing not less than 2 pounds per cubic foot (0.6 pound per square foot of wall surface) or rockwool or slag material wool batts weighing not less than 3.3 pounds per cubic foot (1 pound per square foot of wall surface), or cellulose insulation having a nominal density not less than 2.6 pounds per cubic foot.	15

3.10.2 CAM

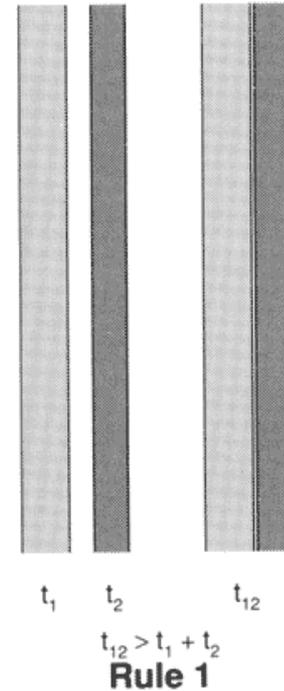
- Comparisons of the calculated fire-resistance ratings with experimental results show the calculated values as conservative, being almost 30% underestimated in some cases.
- It is a simplified method for use by individuals not qualified to provide engineering analysis.
- Engineering analysis is still allowed
 - IBC 703.3 Methods for determining fire resistance (#4)

3.11 Extrapolation

- The extrapolation of data from fire-resistance tests is based upon Harmathy's 10 Rules of Fire Endurance.
- This provides a means of assessing the fire endurance of various assemblies since it is impossible to test all assemblies in use today.
- The illustrations of Harmathy's rules in the following slides are from Figure 10.12 in the Canadian Wood Council, Wood Reference Handbook.

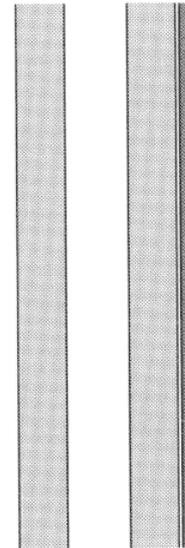
3.11.1 Rule 1

- The thermal fire endurance of a construction consisting of a number of parallel layers is greater than the sum of the “thermal” fire endurance characteristics of the individual layers when exposed separately to a fire.



3.11.2 Rule 2

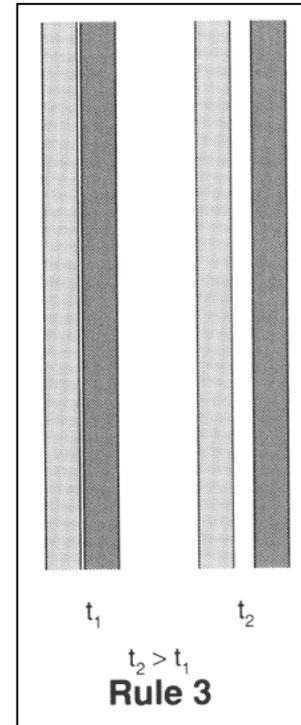
- The fire endurance of a construction does not decrease with the addition of further layers.



t_1 t_2
 $t_2 > t_1$
Rule 2

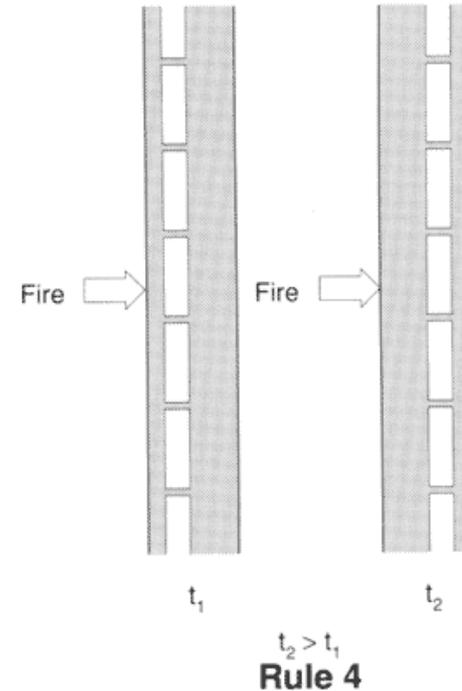
3.11.3 Rule 3

- The fire endurance of constructions that contain continuous air gaps or cavities is greater than the fire endurance of similar constructions of the same weight, but containing no gaps or cavities.



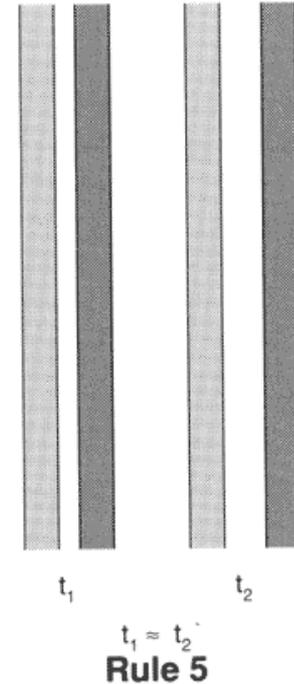
3.11.4 Rule 4

- The farther an air gap or cavity is located from the exposed surface, the more beneficial is its effect on fire endurance.



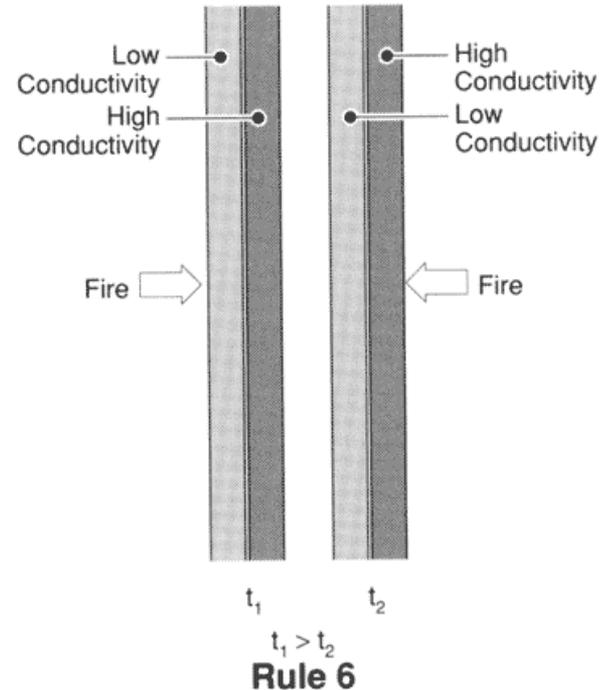
3.11.5 Rule 5

- Increasing the thickness of a completely enclosed air layer cannot increase the fire endurance of a construction.



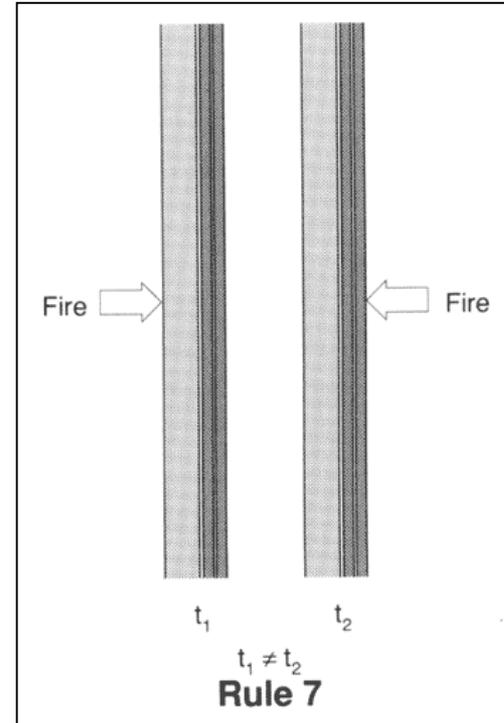
3.11.6 Rule 6

- Layers of materials of low thermal conductivity are better utilized on that side of the construction on which fire is more likely to happen.



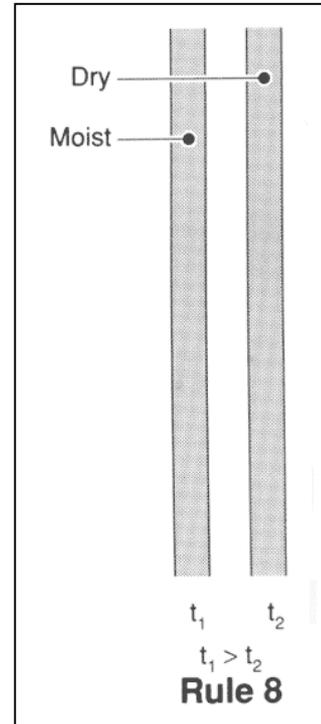
3.11.7 Rule 7

- The fire endurance of asymmetrical constructions depends on the direction of heat flow.



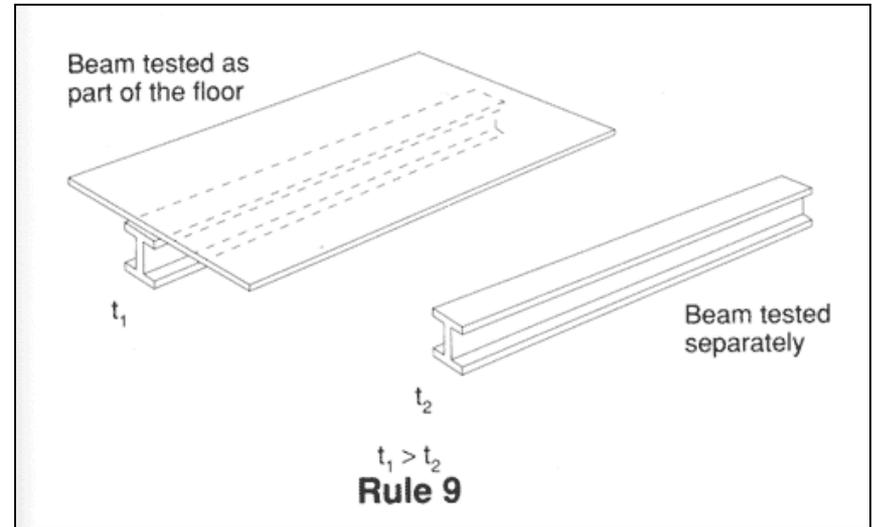
3.11.8 Rule 8

- The presence of moisture, if it does not result in explosive spalling, increases the fire endurance.



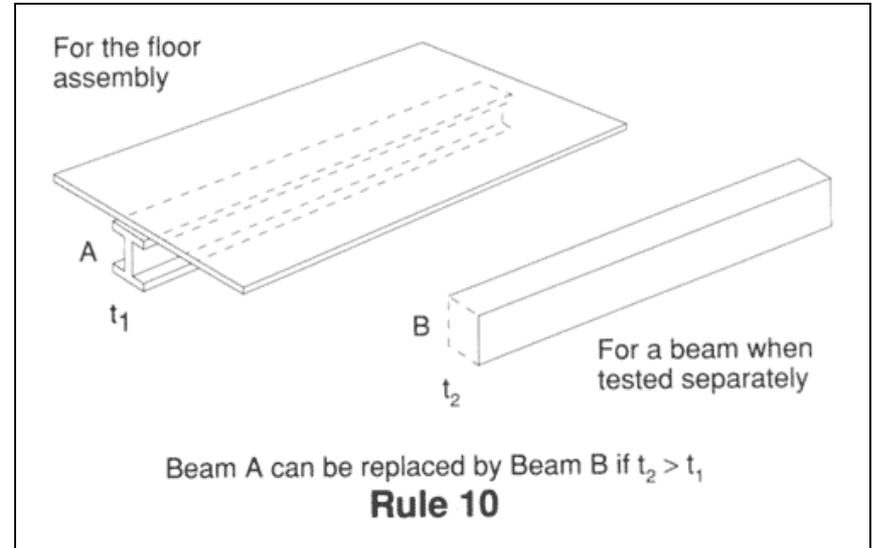
3.11.9 Rule 9

- Load-supporting elements, such as beams, girders and joists, yield higher fire endurance's when subjected to fire endurance tests as parts of floor, roof, or ceiling assemblies than they would when tested separately.



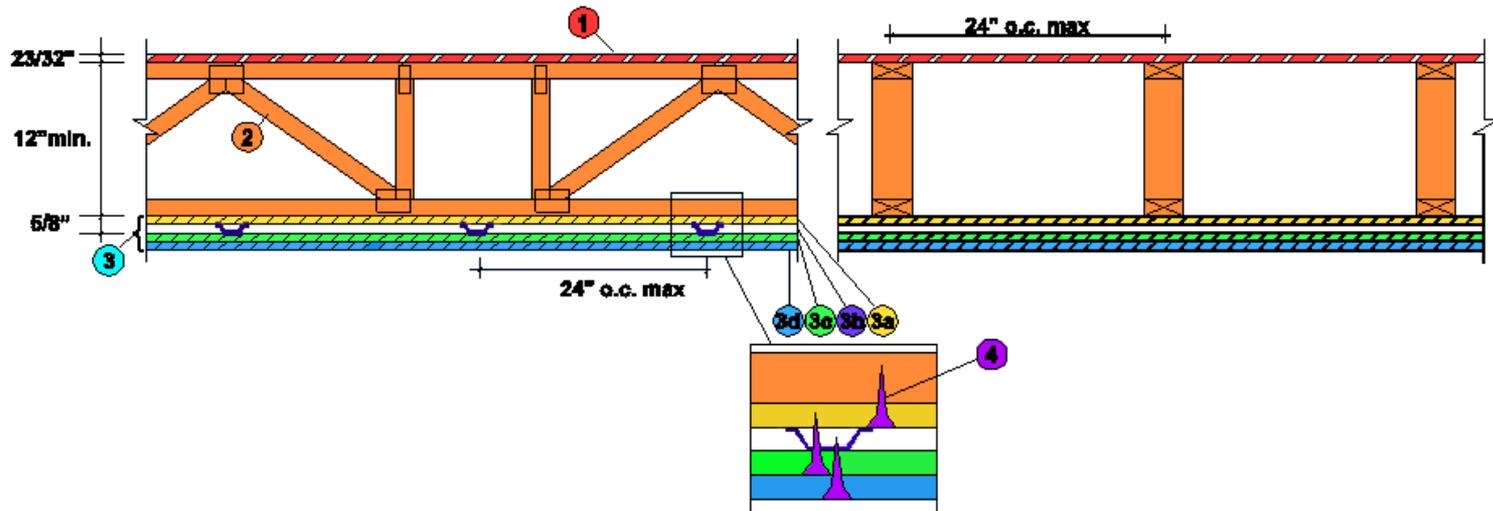
3.11.10 Rule 10

- The load-supporting elements (beams, girders, joists, etc.) of a floor, roof, or ceiling assembly can be replaced by such other load-supporting elements which, when tested separately, yielded fire endurance's not less than that of the assembly.



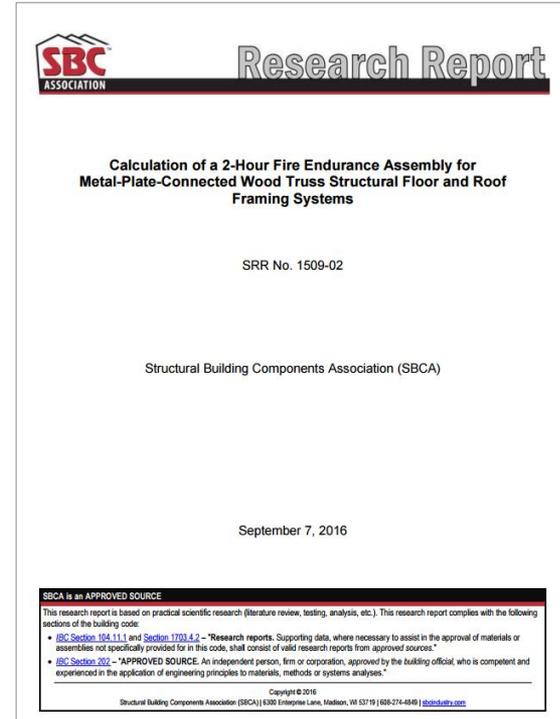
3.12 Calculated 2-Hr Assembly

- Uses Harmathy's Rules
- Component times are additive.
- Uses Test Data to Confirm Performance



3.12 Calculated 2-Hr Assembly

- The assembly summary is as follows:
 - Finish floor = 5/8" sheathing - Plywood or OSB
 - Structural members = wood truss, Minimum 12" deep, Maximum 24" on center
 - Ceiling membrane = 3 layers 5/8" Type C gypsum wallboard, Furring channel between layer 1 and 2.
- Note that the 40 minute value given for a single layer of 5/8" Type X gypsum would be exceeded both by the use of enhanced type X plus the use of multiple layers plus additional value for the furring channel and air space.
- See [SRR 1509-02](#) for complete details

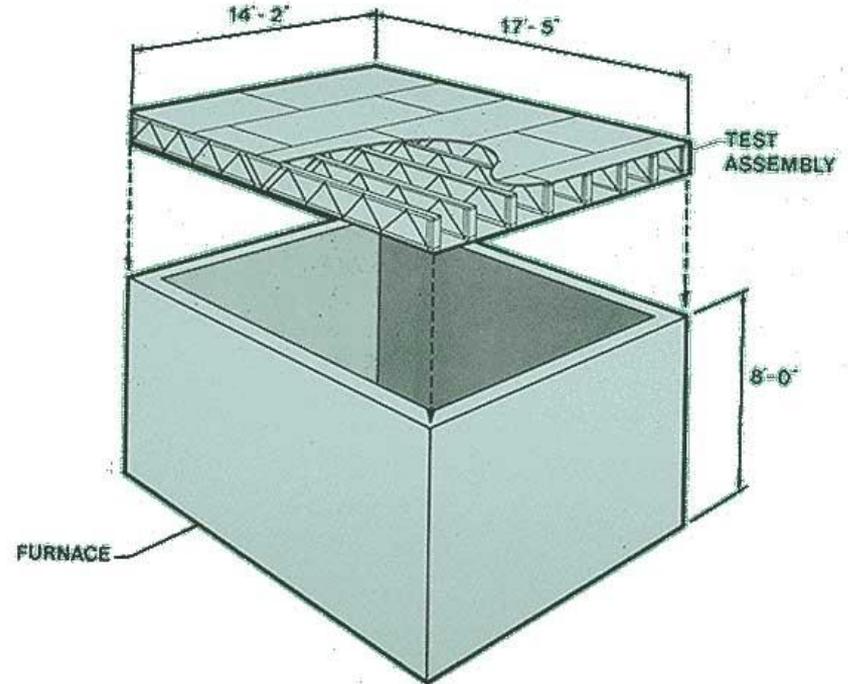


3.13 Wood Truss Advantages

- Wood trusses have advantages over other materials, even other wood structural material:
 - They perform well under fire
 - They are cost effective
 - They are made from a renewable material
 - Wood is a familiar product to the light frame construction industry
 - Trusses can be custom engineered to meet a wide range of span and load design criteria.

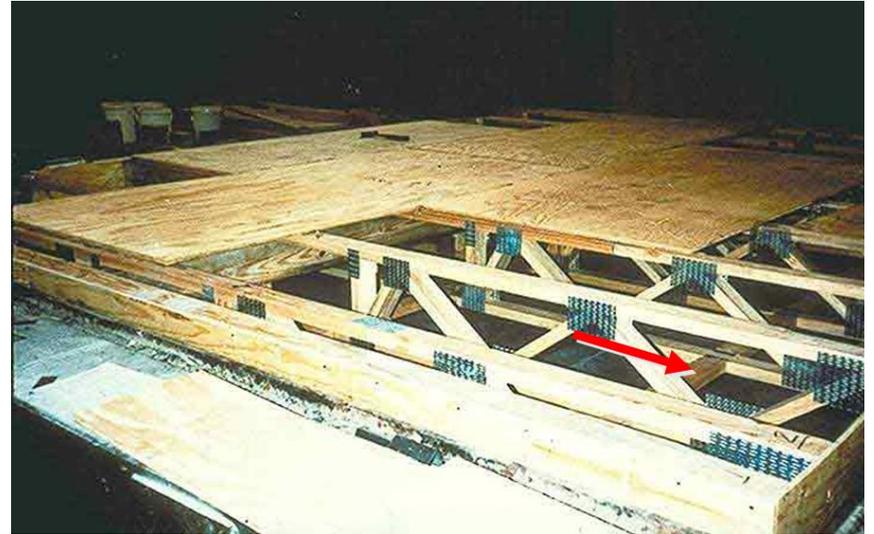
4.0 ASTM E119 Test Furnace

- Let us take a look at how a floor truss assembly was tested.
- For all full-scale fire endurance assembly testing the test assembly is designed for a 14' x 17' furnace.



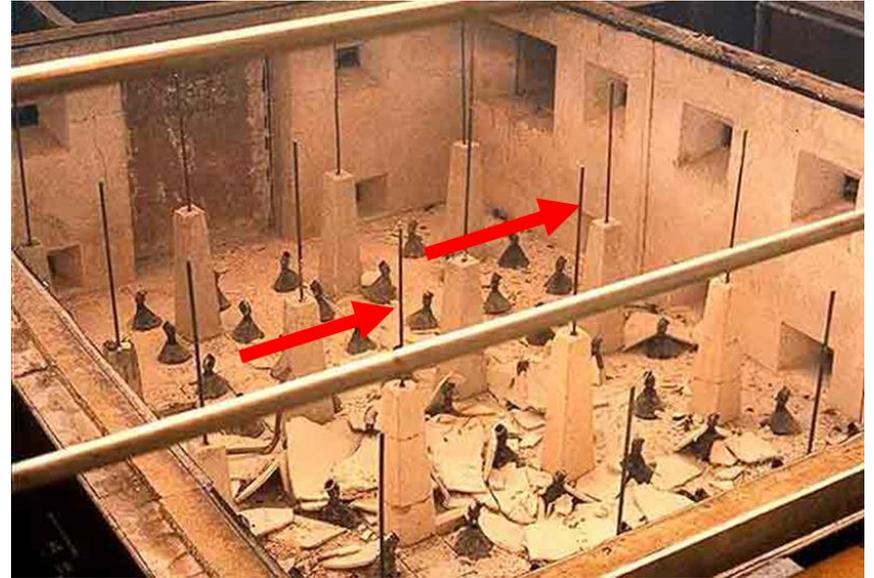
4.1 Assembly Being Constructed

- For each ASTM test a representative assembly is constructed.
- This is a metal plate connected wood truss assembly test just prior to the sheathing being finished.
- This test is PFS 86-10 on which GA FC5517 is based.
- Although the following slides show wood floor truss testing, the process would be similar for any product.
- Note the 2x4 wood blocking required for backing the gypsum butt joints in this particular assembly.



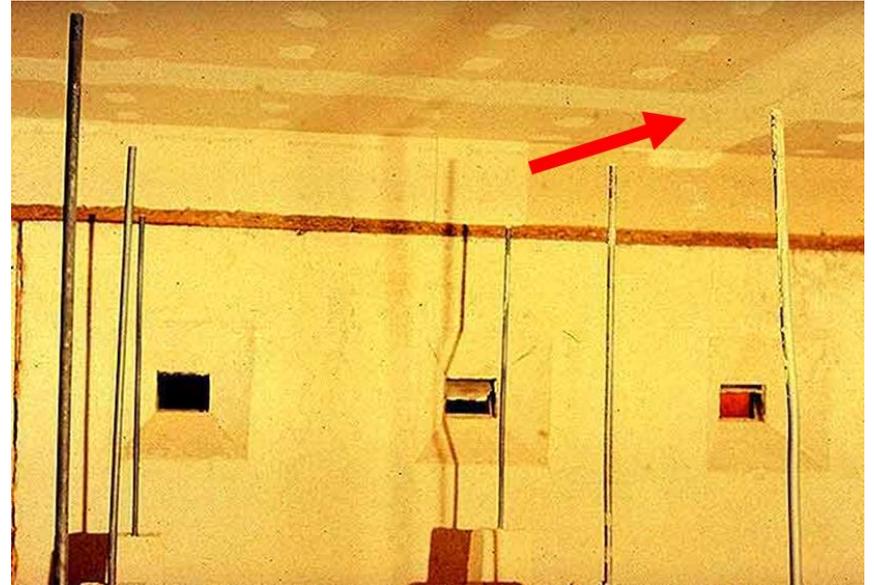
4.2 ASTM E119 Test Furnace

- In the test furnace one can see:
 - The gas burners at the bottom.
 - The long poles are the thermocouples that measure the temperature and control the amount of gas added to ensure that the ASTM E119 time temperature curve is followed throughout the test.



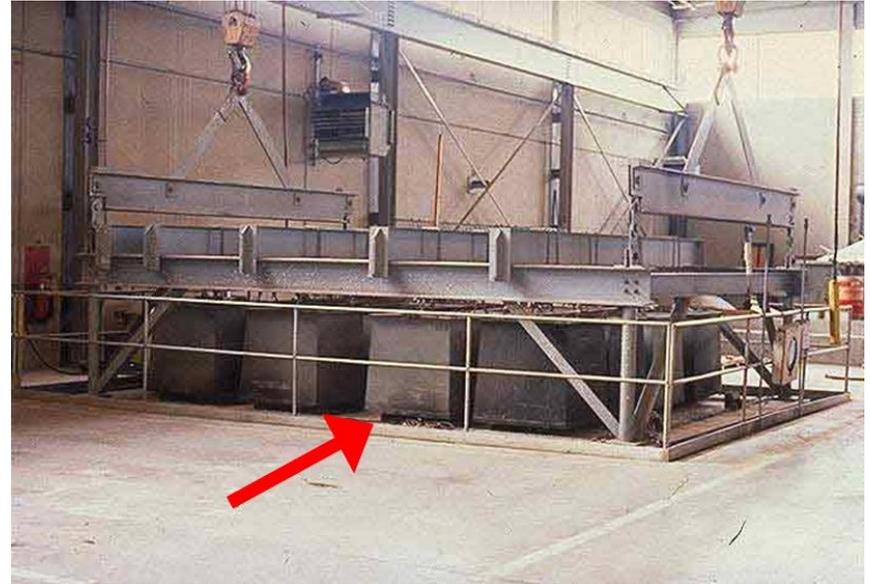
4.3 Ceiling Prior to Testing

- The gypsum ceiling is installed to the assembly specifications and all joints are taped and mudded and all screws are mudded as well.



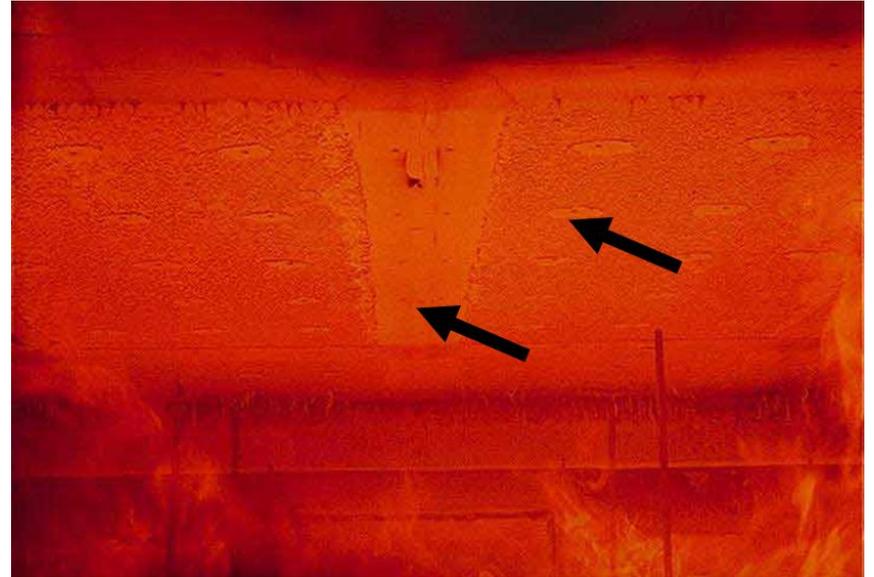
4.4 Load application before testing

- This shows the assembly with the load applied just prior to the test being started.
- A unique feature of the ASTM E119 test is that the assembly is loaded to its full design capacity.
- The rectangular containers filled with water apply the loads to the assembly.
- It is interesting to note that the typical residential floor system in our industry is designed to carry 40 psf of live load.
- The typical actual live load in a residential floor is about 11.35 psf.
- The typical full design live load or total floor live load capacity used in a fire test assembly is 60-70 psf.



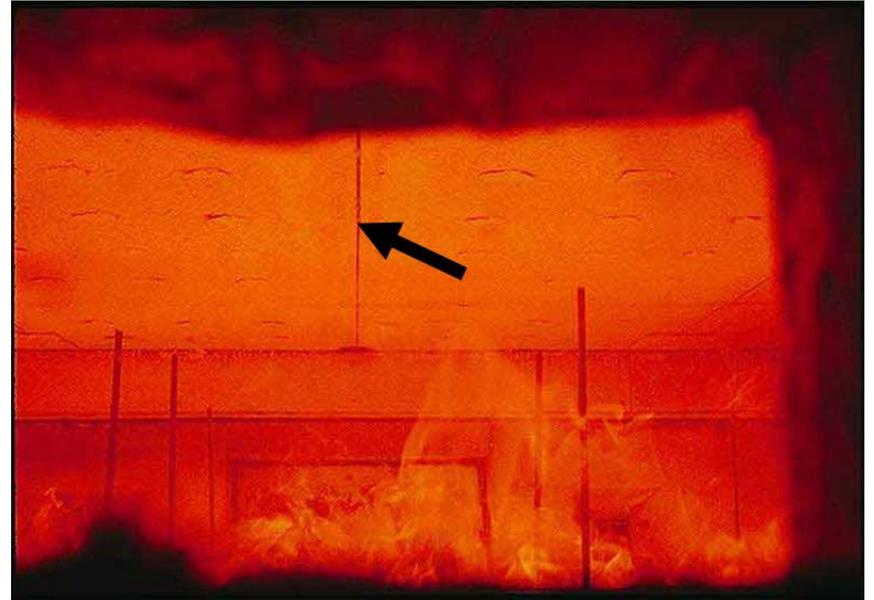
4.5 Five minutes into test

- This is a view inside the furnace at about five minutes into the test.
- One can readily see that the gypsum paper has already burned off.
- The mud and tape is still on the joints and screws.
- The temperature is well in excess of 500°F at this point.



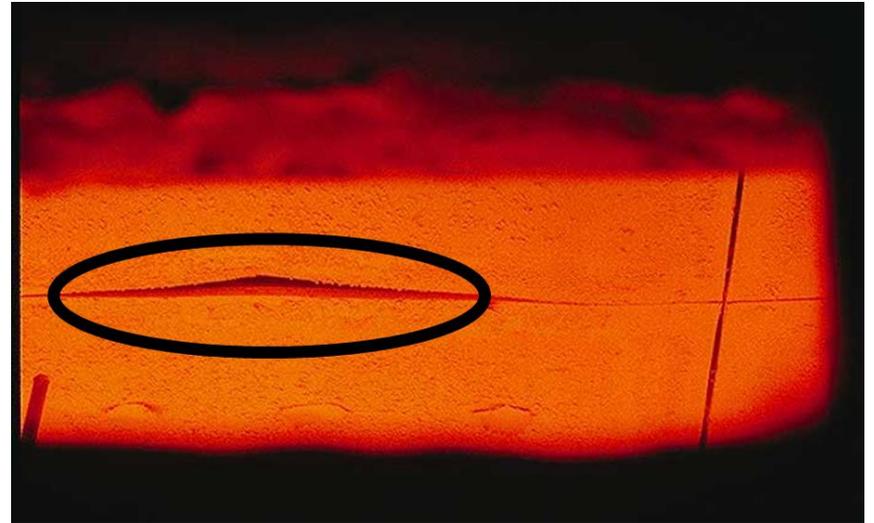
4.6 Ten minutes into test

- This is the assembly at about 10 minutes into the test.
- Notice that the joint compound and tape covering the joints has now fallen into the furnace.
- This allows heat to transfer into the plenum space.
- It is at this stage that the temperatures begin to rise in the plenum space causing structural members to show the structural degradation effects of higher temperatures.



4.7 About 25 minutes into test

- This is the assembly at approximately 25 minutes into the test.
- Notice that the gypsum wallboard has begun to show signs of stress under the fire conditions due to the water in the gypsum wallboard evaporating and causing the gypsum to shrink.
- For any assembly to achieve a 1-hour rating it is critical that the gypsum stays intact for at least 30-40 minutes or more.
- Once the gypsum fails there is rapid failure of structural members.
- Because the furnace is at such a high temperature, most structural members will fail within 15 minutes after the gypsum falls off.



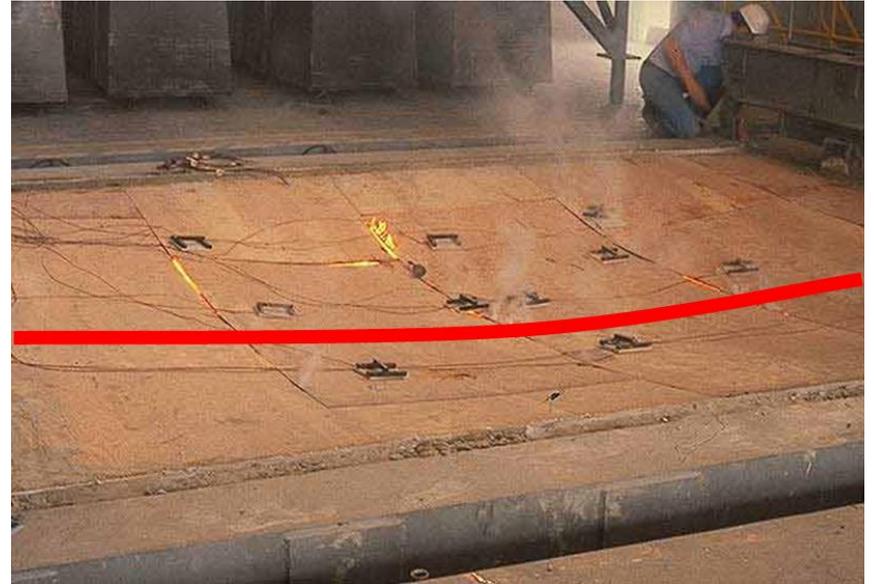
4.8 Load Application

- Note the curvature of the floor system after the completed test.
- Toward the end of this ASTM E119 fire test there is a high degree of visible warning prior to failure.



4.9 After 60 minutes

- This immediately after the one-hour test is completed and the loading buckets have been pulled away from the assembly.
- Notice the severe deflection of the structural members in this assembly which means that structural collapse was the failure mode.
- In real-life, however, the visible deflection would be much less because there may be very little live load actually applied to the structure.



4.10 Lifting after 60 minutes

- As the fire endurance assembly is pulled up and off from the furnace, severe burning of the assembly occurs due to the flood of oxygen.
- When viewing the assembly after the fire has been extinguished, consideration needs to be made for the additional 10-15 minutes of burning after the test has completed.



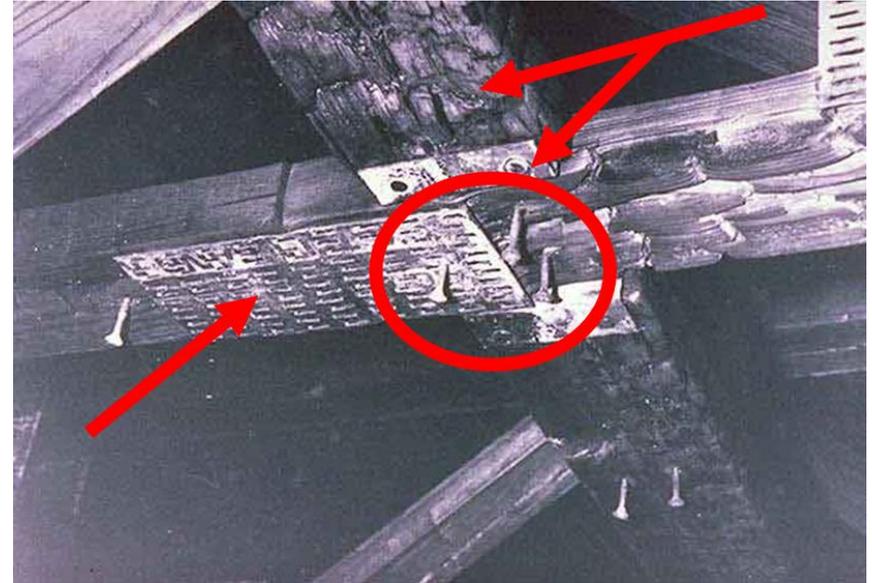
4.11 Lifting after 60 minutes

- The assembly is being raised into a position so that the fire can be extinguished.



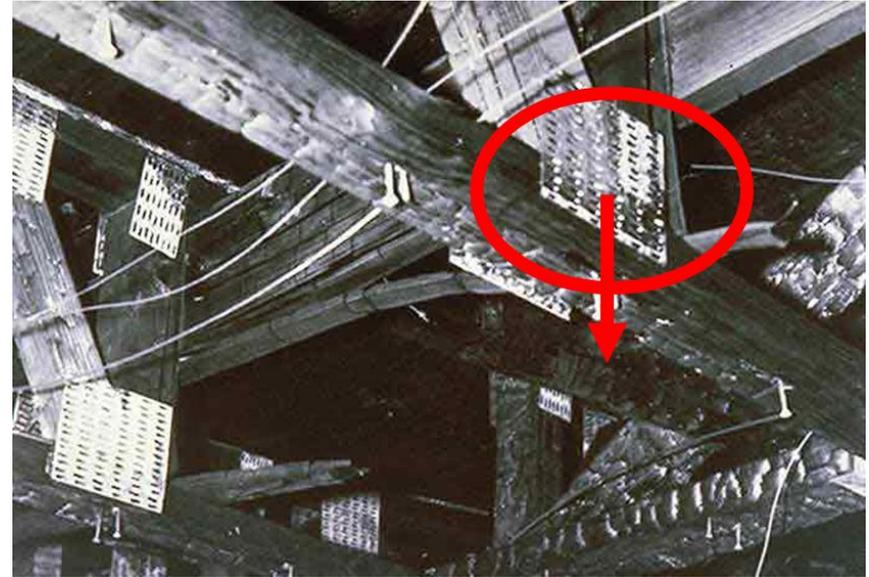
5.0 Truss splice plate after test

- This is a truss splice plate in the bottom chord of the truss after the test assembly has cooled down.
 - The plate is intact except for the charring of the wood around it.
- The screws in the truss plate and the bottom chord are the screws that were holding the gypsum in place.
 - In this case the charring of the wood did not go deep enough to cause the splice plate to fail.
- The wood blocks and metal clips are not part of the truss system.
 - They are a part of the tested assembly and are used to provide additional support for the end joints of the gypsum sheathing.
 - This blocking is not required in all fire rated truss assemblies.



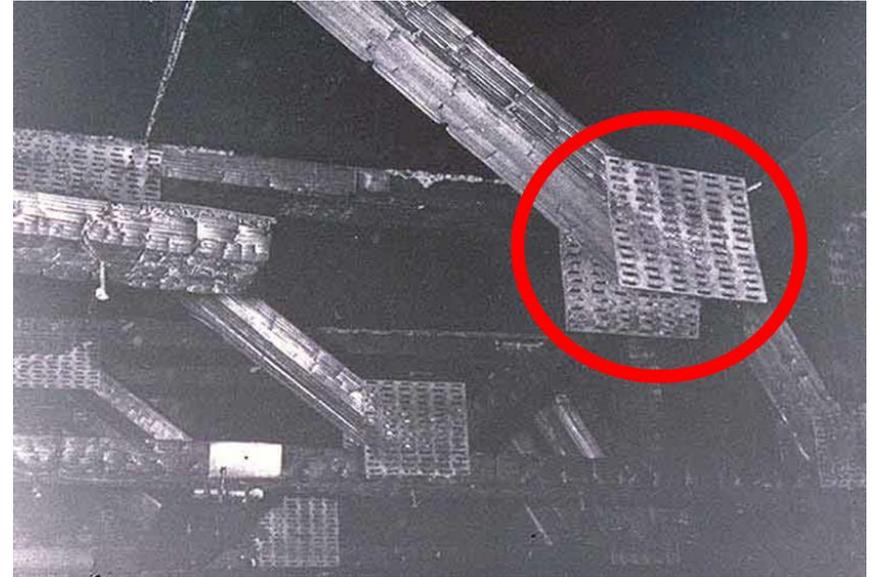
5.1 Trusses after the test

- This is the same assembly showing the structural failure location.
 - Notice that the truss plate at the joint location has curled somewhat away from the bottom chord.
 - This shows the typical withdrawal resistance failure mode of the truss plate as the bottom chord pulls away from the web members or conversely the web members pull away from the bottom cord under the applied loads.
 - The plate retains its curled shape due to the softness of the steel under the high temperatures and then it become hard again when water was applied to the assembly after the test was completed.



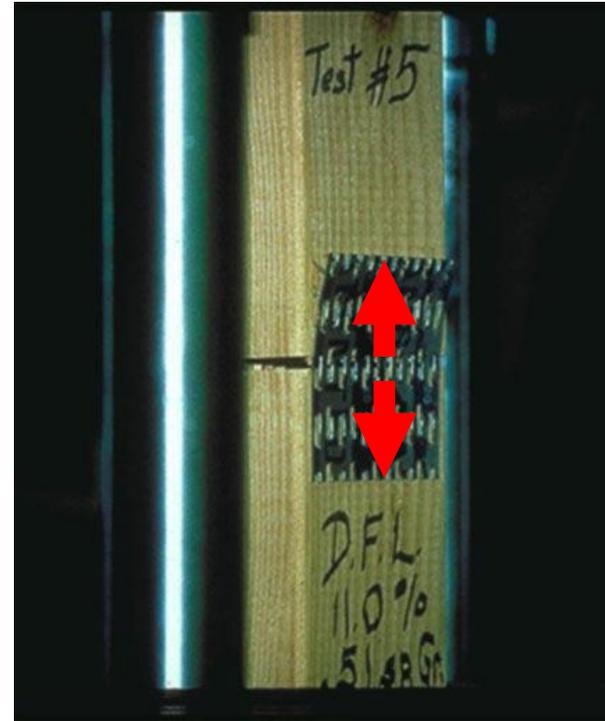
5.2 Trusses after the test

- This is another of the structural failure locations.
- Here the bottom chord has completely pulled away from the web member joint.
- Again the plate is curled slightly due to the bottom chord pulling away from the joint under the applied load.



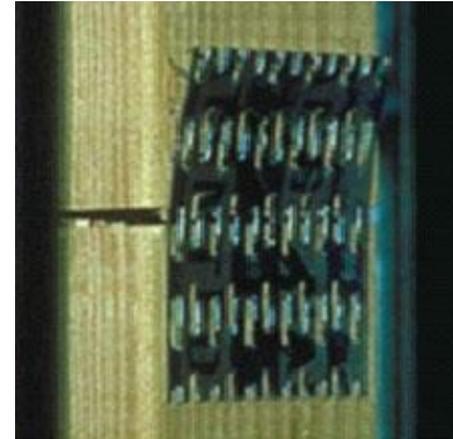
5.3.1 Connector Plate Testing

- This demonstrates withdrawal resistance failure mode
 - Notice how the plate has begun to pull out of the wood after the load is applied.
 - The plate has taken on a cupped shape.



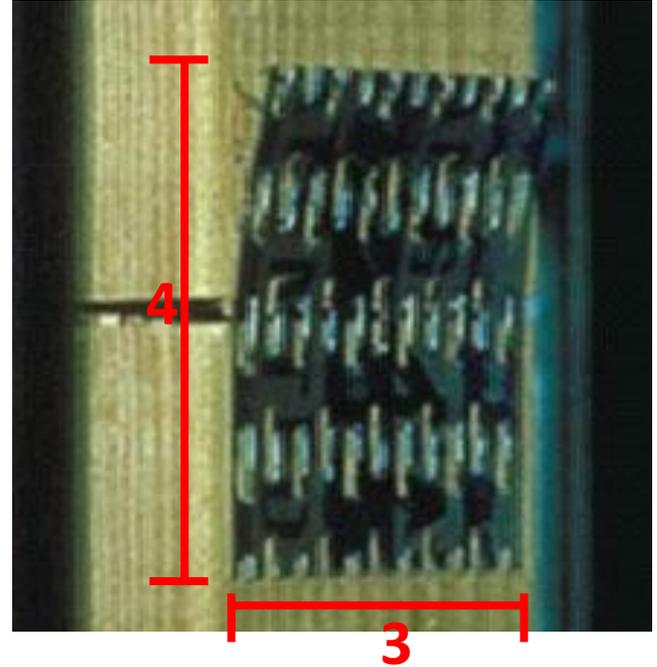
5.3.2 Connector Plate Testing

- This is a close-up of the plate in the previous slide.
- The withdrawal of the plate from the wood under the applied load caused the plate to cup.
- No fire was involved in this test.
- However, because this withdrawal is observed at fire scenes, the assumption is made that the plates curled and withdrew because of the fire or heat applied to the plate.
- The plate withdraws because of excessive loads applied to the truss in a location where it was not designed to carry that load.
- This excessive load could be the result of a weakened truss member or additional load from debris.
- When trusses are no longer able to carry the loads applied to them, the truss plates withdraw from the joint – some even fall to the ground.



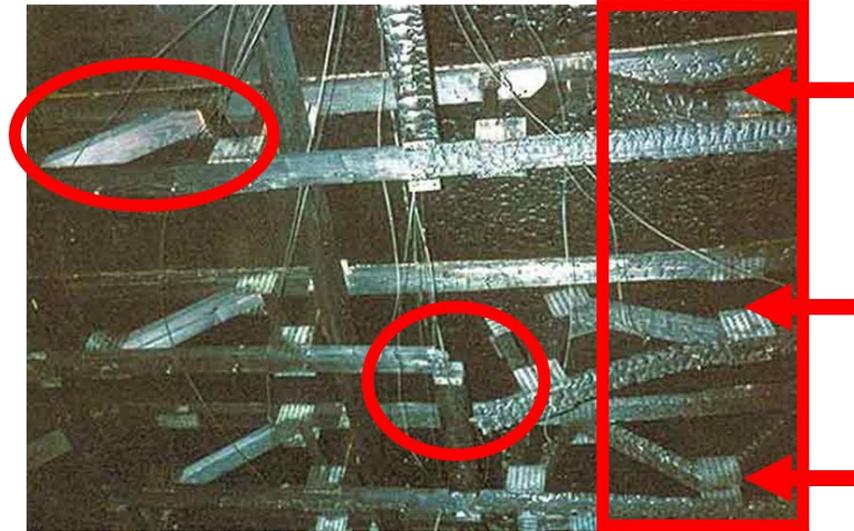
5.3.3 Connector Plate Testing

- The typical truss plate in our industry has a 0 degree design withdrawal resistance of 200 psi
- The joint shown above with a 3x4 plate has a design capacity of about 2400 lb.
- And with a factor of safety of 3.2 has an ultimate strength capacity of about 7680 lb.



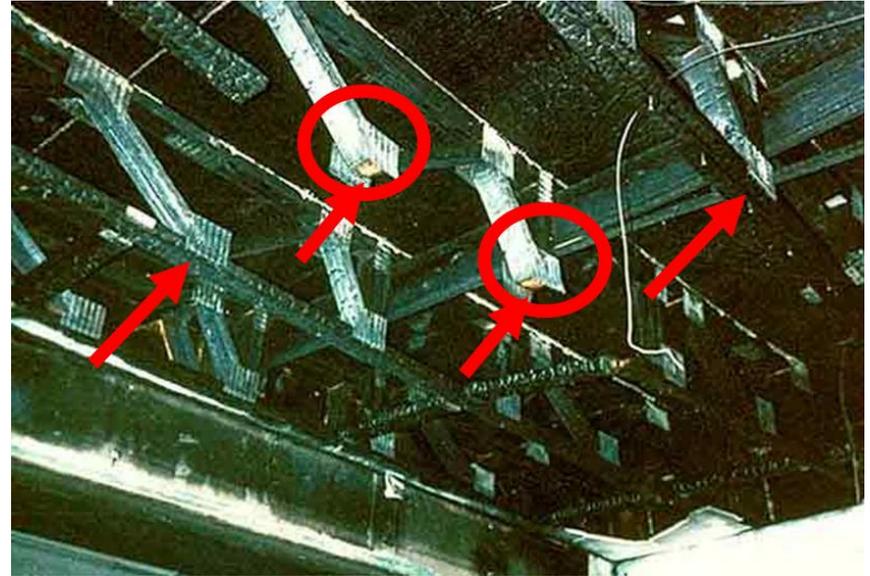
5.4 Trusses after the test

- This is a broader view of the trusses after the test.
 - Notice in the center of the photograph that a splice plate failed causing the truss to fail completely and severely deflect at that failure point.
 - In the upper left-hand corner there's still lumber that has remained un-charred even though this assembly burned for more than 60 minutes.
 - On the right, there has been severe charring of the wood, but all the truss plates remain attached to the web and chord members.
 - The truss at the top of the photograph, in all likelihood, is still carrying some amount of load. When this truss failed it caused the adjacent trusses to carry more of the load.
- All the trusses in the assembly would fail eventually had the fire been allowed to burn long enough.



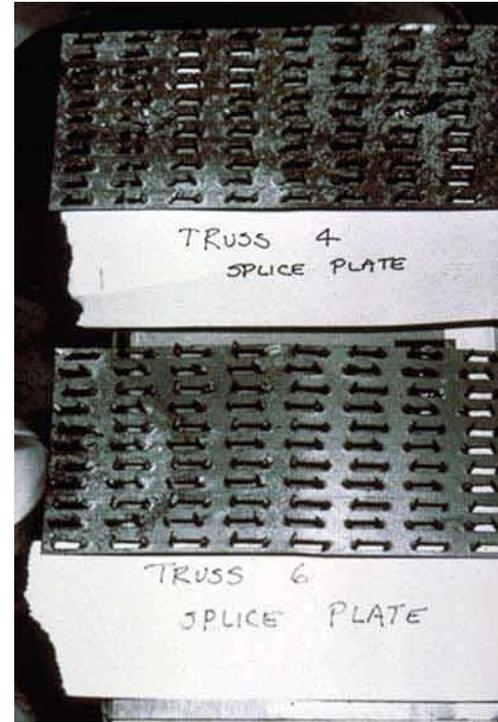
5.5 Trusses after the test

- This is another view of a bottom chord failure in this truss system.
 - Notice the plates are cupped where the bottom chords pulled away from the web members.
 - Notice also the bright normal colored wood near each plate that has remained un-charred and still has load carrying capacity.
 - The trusses adjacent to the failed truss are still intact and retain some of their structural capacity, however, at this point probably not enough strength to be walked on.



5.6 Truss plates after the test

- These are the splice plates from trusses 4 and 6.
- The plates show no distress and look no different from normal plates other than the charred wood remaining on the teeth and some discoloration.



5.7.1 Trusses & Fire

- The following series of pictures are from a 1992 fire in a church in Marshfield, WI., where 66 foot scissor trusses were cut by the fire department.
- The fire started in the ceiling/roof cavity caused by a canister light fixture.

5.7.2 Church Fire

- In this case it was determined that the trusses were sturdy enough [oval] that the fire service personnel could work on the structure by standing within the trusses themselves as the only means of support.
- In this case [arrow] the trusses that are being cut are also supporting the weight of those that are standing inside of them, doing the cutting.
- Please note the location of the ceiling fan immediately below the firefighter's feet at the bottom left corner of the photo. The ceiling fans serve as a reference point indicating the ceiling ridge. [arrow]



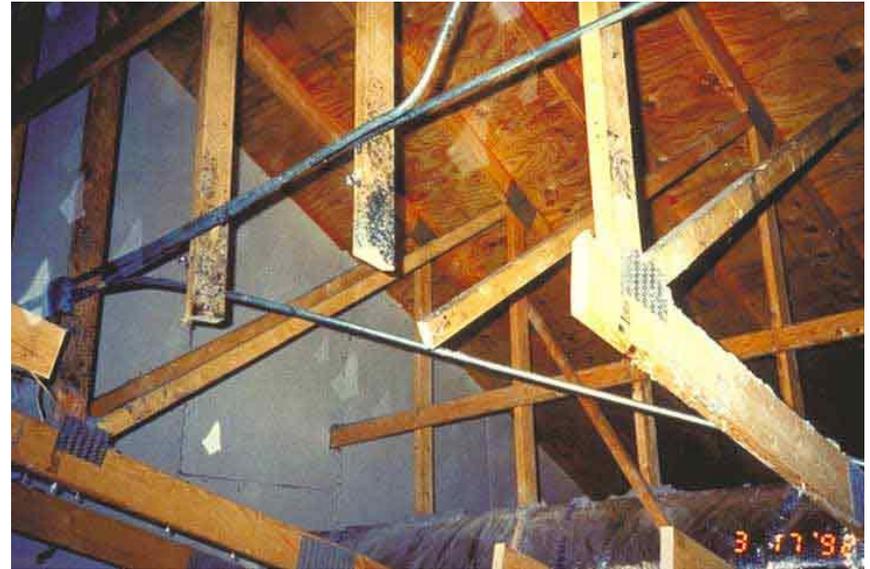
5.7.3 Church Fire

- This shows the completed cutting operation. There are a total of 11 trusses (22') whose bottom chords and web members have been cut out in order to stop any further spread of smoldering fire.
- Note again the ceiling fan in the lower right corner as a reference point.



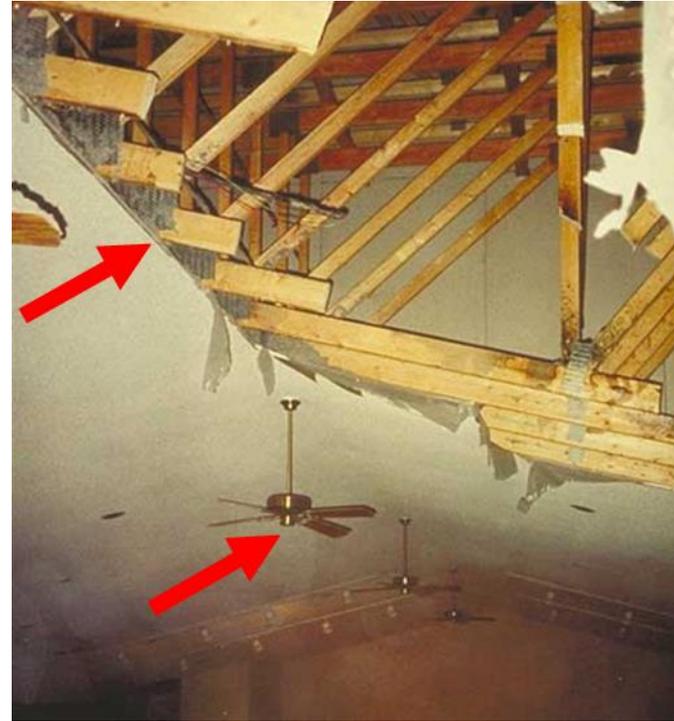
5.7.4 Church Fire

- Here is a close-up of the cut chord and web members and gives some indication of how much of the bottom chord and web members had to be cut to eliminate further smoldering.



5.7.5 Church Fire

- This is another view of the cut out section of trusses.
 - Notice the ceiling fans are at the center peak of the bottom chords of the scissors truss. The trusses for this church sanctuary are 66 foot clear span scissors trusses
 - The area of burning took place just to the right of the bottom chord peak.
 - This center peak joint is the area of highest stress in the bottom chord of any scissors truss.



5.7.6 Church Fire

- All of the cut trusses were repaired by manufacturing identically configured sections of scab trusses that were slid in next to the original fire damaged trusses and nailed and bolted into place.
- Then the gypsum was replaced, and the ceiling was restored to its original condition.
- This is a great example of the extraordinary performance of trusses even when damaged by fire.
- It also demonstrates that trusses may be easier to repair than many people expect.



6.0 Unprotected Assemblies

- A key area of concern for the fire service is in residential basements where the floor framing often has no gypsum protection.
- Unprotected assemblies, like this, are allowed by code, in residential construction.
- Wherever a single layer of ½" gypsum is installed, it affords at least 10 min of fire protection (industry standards list the time at 15 min).
- There are no fire endurance assembly requirements for residential construction primarily because the model codes address fire spread between occupancies or containment within a compartment, and in single family dwellings there is only one occupancy.
- There is a scarcity of testing on unprotected assemblies because there is no testing requirement to use unprotected assemblies in a structure.



6.1 Unprotected Assembly Tests

- This table shows the results of some tests of unprotected assemblies done between 1971 and 1983.
 - Five 2x10 tests, three with the joists spaced 16” oc and two with the joists spaced 24” oc.
 - One metal plate connected truss test with the trusses spaced 24” oc.
 - Two 7¼” steel C-joist tests that are spaced 24” oc.

Test	Structural Member	Spacing (in. o.c.)	Assembly Rating (min:sec)	Structural Failure (min:sec)	Avg. Defl. at Floor (in.)	Loading (psf) % Design Stress	Comments
FM FC 209	2X10; 23/32" ply w/vnl	24	N/A	13:34	2.83	62.1 (100%)	ASTM E 119
FM FC 212	2X10; 23/32" ply w/cpt	24	N/A	12:06	3.58	62.4 (100%)	ASTM E 119
NBS 421346(2)	2x10	16	N/A	11:38	2.70	63.7 (100%)	ASTM E 119
NBS 421346(4)	2x10; 2-1/2" ply	16	N/A	11:38	3.30	63.7 (100%)	ASTM E 119
FPL	2x10	16	N/A	6:30	4.00	79.2 (100%)	ASTM E 119
FM FC 250	12" MPCT ¹	24	7:30	10:12	11.50	60.0 (100%)	ASTM E 119
FM FC 208	7 1/4" Steel C-Joist	24	7:24	7:30	7.00	69.8 (100%)	ASTM E 119
FM FC 211	7 1/4" Steel C-Joist	24	5:12	5:12	10.00	69.8 (100%)	ASTM E 119

¹ Assembly rating is due to deck burn through. MPCT = Metal Plate Connected Truss.

6.1 Unprotected Assembly Tests

- In all cases the tests were run in accordance with ASTM E119 test procedures with their full design load applied, allowing us to compare performance directly
 - For the 2x10 tests, the design load ranged from roughly 62-79 psf.
 - For the truss test the design load was 60 psf.
 - For the steel C-joist tests the design load was 69 psf.

Test	Structural Member	Spacing (in. o.c.)	Assembly Rating (min:sec)	Structural Failure (min:sec)	Avg. Defl. at Floor (in.)	Loading (psf) % Design Stress	Comments
FM FC 209	2X10; 23/32" ply w/vnl	24	N/A	13:34	2.83	62.1 (100%)	ASTM E 119
FM FC 212	2X10; 23/32" ply w/cpt	24	N/A	12:06	3.58	62.4 (100%)	ASTM E 119
NBS 421346(2)	2x10	16	N/A	11:38	2.70	63.7 (100%)	ASTM E 119
NBS 421346(4)	2x10; 2-1/2" ply	16	N/A	11:38	3.30	63.7 (100%)	ASTM E 119
FPL	2x10	16	N/A	6:30	4.00	79.2 (100%)	ASTM E 119
FM FC 250	12" MPCT ¹	24	7:30	10:12	11.50	60.0 (100%)	ASTM E 119
FM FC 208	7 1/4" Steel C-Joist	24	7:24	7:30	7.00	69.8 (100%)	ASTM E 119
FM FC 211	7 1/4" Steel C-Joist	24	5:12	5:12	10.00	69.8 (100%)	ASTM E 119

¹ Assembly rating is due to deck burn through. MPCT = Metal Plate Connected Truss.

6.1 Unprotected Assembly Tests

- Structural failure for the 2x10 assemblies took place in the 6:30 to 13:34 range.
- The truss test failed at 10:12.
- The two steel C-joist tests performed for 5:12 and 7:30.
- In the steel and metal plate connected truss tests structural failure took place after the assembly rating was achieved due to the fact that there was only a single layer of plywood attached to the top of the assembly which resulted in the assembly failing one of the two ASTM E119 unexposed surface temperature requirements.

Test	Structural Member	Spacing (in. o.c.)	Assembly Rating (min:sec)	Structural Failure (min:sec)	Avg. Defl. at Floor (in.)	Loading (psf) % Design Stress	Comments
FM FC 209	2X10; 23/32" ply w/vnl	24	N/A	13:34	2.83	62.1 (100%)	ASTM E 119
FM FC 212	2X10; 23/32" ply w/cpt	24	N/A	12:06	3.58	62.4 (100%)	ASTM E 119
NBS 421346(2)	2x10	16	N/A	11:38	2.70	63.7 (100%)	ASTM E 119
NBS 421346(4)	2x10; 2-1/2" ply	16	N/A	11:38	3.30	63.7 (100%)	ASTM E 119
FPL	2x10	16	N/A	6:30	4.00	79.2 (100%)	ASTM E 119
FM FC 250	12" MPCT ¹	24	7:30	10:12	11.50	60.0 (100%)	ASTM E 119
FM FC 208	7 1/4" Steel C-Joist	24	7:24	7:30	7.00	69.8 (100%)	ASTM E 119
FM FC 211	7 1/4" Steel C-Joist	24	5:12	5:12	10.00	69.8 (100%)	ASTM E 119

¹ Assembly rating is due to deck burn through. MPCT = Metal Plate Connected Truss.

6.1 Unprotected Assembly Tests

- Another interesting column of information is the deflection performance of each of the assemblies.
- Notice that the trusses deflected 11 1/2", the steel C-joists deflected 7 and 10" respectively and the 2x10 joists deflected from 2.7-3.58".
- This suggests that both the truss assembly and the steel C-joint assemblies show warning signals of impending collapse faster than a 2x10 joist assembly would.

Test	Structural Member	Spacing (in. o.c.)	Assembly Rating (min:sec)	Structural Failure (min:sec)	Avg. Defl. at Floor (in.)	Loading (psf) % Design Stress	Comments
FM FC 209	2X10; 23/32" ply w/vnl	24	N/A	13:34	2.83	62.1 (100%)	ASTM E 119
FM FC 212	2X10; 23/32" ply w/cpt	24	N/A	12:06	3.58	62.4 (100%)	ASTM E 119
NBS 421346(2)	2x10	16	N/A	11:38	2.70	63.7 (100%)	ASTM E 119
NBS 421346(4)	2x10; 2-1/2" ply	16	N/A	11:38	3.30	63.7 (100%)	ASTM E 119
FPL	2x10	16	N/A	6:30	4.00	79.2 (100%)	ASTM E 119
FM FC 250	12" MPCT ¹	24	7:30	10:12	11.50	60.0 (100%)	ASTM E 119
FM FC 208	7 1/4" Steel C-Joist	24	7:24	7:30	7.00	69.8 (100%)	ASTM E 119
FM FC 211	7 1/4" Steel C-Joist	24	5:12	5:12	10.00	69.8 (100%)	ASTM E 119

¹ Assembly rating is due to deck burn through. MPCT = Metal Plate Connected Truss.

6.1 Unprotected Assembly Tests

- Performance of all the tested assemblies is similar, with the steel C-joist at the low end and the 2x10 joists at the high end, but all products typically falling within 5-13 minutes of performance in an unprotected application condition.
- This testing shows that sheathing performance is often the critical element in the performance of an assembly, often failing far before the structural member fails, because the sheathing is so much thinner than the structural member it is attached to.

Test	Structural Member	Spacing (in. o.c.)	Assembly Rating (min:sec)	Structural Failure (min:sec)	Avg. Defl. at Floor (in.)	Loading (psf) % Design Stress	Comments
FM FC 209	2X10; 23/32" ply w/vnl	24	N/A	13:34	2.83	62.1 (100%)	ASTM E 119
FM FC 212	2X10; 23/32" ply w/cpt	24	N/A	12:06	3.58	62.4 (100%)	ASTM E 119
NBS 421346(2)	2x10	16	N/A	11:38	2.70	63.7 (100%)	ASTM E 119
NBS 421346(4)	2x10; 2-1/2" ply	16	N/A	11:38	3.30	63.7 (100%)	ASTM E 119
FPL	2x10	16	N/A	6:30	4.00	79.2 (100%)	ASTM E 119
FM FC 250	12" MPCT ¹	24	7:30	10:12	11.50	60.0 (100%)	ASTM E 119
FM FC 208	7 1/4" Steel C-Joist	24	7:24	7:30	7.00	69.8 (100%)	ASTM E 119
FM FC 211	7 1/4" Steel C-Joist	24	5:12	5:12	10.00	69.8 (100%)	ASTM E 119

¹ Assembly rating is due to deck burn through. MPCT = Metal Plate Connected Truss.

7.0 Non-Combustible Materials

- ALL construction materials have performance problems under fire conditions – timber depletes by charring, concrete cracks and spalls, and steel quickly loses its load bearing capacity.
- Non-combustible materials do not preclude structural collapse and fire loss
 - McCormick Place
 - General Motors Plant in Livonia, MI
 - World Trade Center

7.1 Non-Combustible Materials

- General Motors Plant, 1953
 - Non-combustible building & non-combustible contents, yet completely collapsed.
 - The fire was caused by a welder on the roof who ignited the roofing material.
 - The fire caused the steel to buckle after it exceeded 1000°F, causing the roof to collapse into the building pulling down the walls along with it.



8.0 Key Points

- Wood trusses are not just pieces of wood and sheet metal assembled in truss manufacturing operations.
 - They are highly engineered products that have been subjected to a great deal of structural and fire testing.
 - To meet fire rated code requirements, wood trusses have been subjected to the rigorous testing protocol set out in ASTM E119 to verify performance in accordance with a benchmark.
 - Testing has shown that as wood chars, the charring actually protects the wood for a predictable period of time. Wood loses its strength slowly due to charring. A 2x4 took 40 minutes to completely fail.

8.1 Key Points

- Although cold-formed steel is non-combustible, it loses strength fairly quickly when subjected to the heat of a fire.
- The IBC allows alternative methods to full-scale testing for rating assemblies but all methods generally go back to the results determined from full-scale testing.
- There are a large number of full-scale tested assemblies addressing most common construction situations.
- Substitutions should be accepted by the code authority when good engineering judgment is used in conjunction with tested results.

8.2 Key Points

- Unprotected assemblies are allowed by code in residential construction.
- Sheathing fire performance is more critical than structural member fire performance, since once the sheathing goes, strength and stability go.
- The fact that a building structure is designed with non-combustible materials does not preclude collapse or fire loss.

8.3 Wood Truss Facts

- Cutting one truss member doesn't cause truss failure
- Truss plates don't curl up when heated and fall off the truss
- Large area collapse less likely with 2' o.c. conditions
- Trusses don't always collapse in fires
- Trusses don't always collapse suddenly
- Are structures that use trusses really the most dangerous structures fire fighters face?

9.1 Resources

- [Underwriters Laboratory \(ULI\)](#)
- [National Fire Protection Association \(NFPA\)](#)
- [US Fire Administration](#)
- [National Fire Sprinkler Association \(NFSA\)](#)
- [Operation Life Safety](#)
- [The Gypsum Association](#)
- [Forest Products Laboratory](#)
- [Truss Plate Institute](#)
- [Carbeck Structural Components Institute](#)
- [National Engineered Lightweight Construction Fire Research Project](#)
- [Fire Ratings of Archaic Materials and Assemblies](#) (HUD, February 2000)
- [“Summary Report for Consortium on Fire Resistance and Sound Insulation of Floors, Sound Transmission Class and Impact Insulation Class Results,”](#) (CNRC

9.2 SBCA Educational Programs

- [1509-01 Fire Resistance Rated Truss Assemblies](#)
- [1509-02 Fire Endurance Calculation for Wood Truss Structural Framing Systems: 2-Hour Assembly](#)