FIRESAFE BUILDING CONSTRUCTION AND MATERIALS

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1.0 SCOPE

This data sheet provides basic recommendations for firesafe building construction. It discusses the general areas of construction that can affect overall fire safety. Recommendations for specific items can be found in the data sheets referenced throughout this document and listed in Section 4.0. For added information on fire tests, see Data Sheet 1-4, *Fire Tests.*

1.1 Changes

October 2021. Interim revision. Added additional information on mass timber construction to Appendix A and Appendix C.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

In designing a new facility or building, give full consideration to all features that affect fire safety. The essentials of firesafe construction are described in this section.

2.2 Construction and Location

2.2.1 Use noncombustible and fire-resistant structural framework, such as reinforced concrete or protected steel frames, in high-rise buildings (see Data Sheet 1-3, *High-Rise Buildings*) and, whenever practical, in other multistory buildings, based on value or importance.

Where sprayed fire-resistive materials applied to structural members (protected steel-frame construction) are recommended, ensure they meet all applicable American Society for Testing and Materials (ASTM) test standards as outlined in Appendix C. Comparable standards available in countries outside the United States also may be used.

Ensure steel surfaces are free of dirt, oil, and loose scale. Provide guards and/or sheathing to protect exposed fireproofing that is subject to mechanical damage, and repair damaged areas of coating promptly.

Ensure fire-resistant material used for framing or spandrels on Maximum Foreseeable Loss (MFL) fire walls is durable enough so it cannot be easily scraped off.

2.2.2 Provide damage-limiting construction for processes having an explosion hazard due to ignitable liquids or gases, or combustible dusts, as defined in all applicable 7-series data sheets. Design these buildings according to Data Sheet 1-44, *Damage-Limiting Construction.* This will minimize damage to the building framing and the attached sprinkler system. Blast barricades may be needed for potential detonations (see Data Sheet 7-28, *Energetic Materials*).

2.2.3 If construction or contents are combustible, subdivide large areas or valuable contents, or separate manufacturing and storage areas with fire walls (see Data Sheet 1-22, *Maximum Foreseeable Loss*) that have adequately protected openings to limit fire damage.

2.2.4 Provide space between important buildings and adjacent property, and between individual important buildings, to reduce potential fire exposure. See Data Sheet 1-20, *Protection Against Exterior Fire Exposure* and Data Sheet 1-22.

2.2.5 In multistory buildings, enclose stairs, elevator wells, conveyors, and chutes with walls and doors having a fire rating suitable to that of the floors, or provide water spray protection at openings to help prevent spread of fire and smoke upward from story to story. Construct balconies entirely of noncombustible or limited-combustible materials (i.e., Class 1). Provide sprinkler protection (as outlined in Data Sheets 1-12, *Ceilings and Concealed Spaces*, and 2-0, *Installation Guidelines for Automatic Sprinklers*) for existing combustible balconies.

2.3 Occupancy

2.3.1 For industrial occupancies, choose construction that will not contribute to the spread of fire. Do not construct important buildings (those housing valuable contents or subject to significant business interruption) with wood walls, wood joisted floors or roofs, combustible hollow spaces, or quick-burning interior finishes (see Appendix C, Data Sheet 1-57, *Plastics in Construction*, and Data Sheet 1-60, *Asphalt-Coated/Protected Metal Buildings*). Basements and crawl spaces are more conducive to fire spread, have poor loss experience, and present problems of accessibility, ventilation, and drainage. Such spaces are unsafe for combustible storage and the fire spread potential is greatly increased if ignitable liquids or gases enter them.

2.3.2 Do not store or handle ignitable liquids in upper stories of multistory buildings or in basements. When unavoidable, provide containment (e.g., curbs, ramps), waterproof floors, and suitable drainage (see Data Sheet 1-24, *Protection Against Liquid Damage*, and Data Sheet 7-83, *Drainage Systems for Ignitable Liquids*).

Recommendations for the storage and handling of ignitable liquids can be found in 7-series data sheets.

2.4 Protection

2.4.1 Provide complete automatic sprinkler protection in accordance with applicable data sheets where needed, and practical, for combustible construction or occupancy. Provide security service and/or alarm systems as outlined in Data Sheet 9-1, *Supervision of Property*. For more information on protection of combustible construction, see Data Sheet 1-12, *Ceilings and Concealed Spaces*.

2.4.2 At properties where complete automatic sprinkler protection is impractical, provide a fire detection and alarm system (heat, smoke, or flame detection as appropriate) as outlined in Data Sheet 9-1.

2.5 Human Element

2.5.1 Ensure the area is kept clean during construction, alterations, and demolition operations, and that precautions (including the use of FM's *Hot Work Permit System*) are taken against fires from hot work operations such as cutting, heating of materials, welding, temporary space heaters, and other ignition sources. Provide reasonable temporary fire protection. Ensure the permanent protective systems are placed in service before the building is occupied. (See Data Sheet 1-0, *Safeguards During Construction, Alteration and Demolition*; and Data Sheet 1-33, *Safeguarding Torch-Applied Roof Installation*).

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 General Information

3.1.1 Fire Loading

Fire loading, or fuel loading, is sometimes used to express the probable maximum fire severity to which the structural elements of a building may be subjected in an uncontrolled fire.

3.1.1.1 United States (U.S.) System

Fire loading in the U.S. is sometimes expressed in terms of the weight of combustible building materials and contents. It is more desirable, however, to express it as possible energy content per unit floor area, with dimensions of Btu/ft^2 (MJ/m^2).

Figure 1 shows the weights per unit area of ordinary combustibles, such as wood and paper, required to produce fire severities approximating the ''ASTM E 119 Standard Time-Temperature (STT) Curve'' (see also Data Sheet 1-21, *Fire Resistance of Building Assemblies*) for various durations. For example, a fire loading of 10 psf (4.9 kg/m^2) of ordinary combustibles will approximate a 1 hour STT exposure. This curve is widely used as a standard measure of fire severity. It represents the maximum severity of fire likely to occur from the complete burnout of a brick and wood-joisted building and its contents.

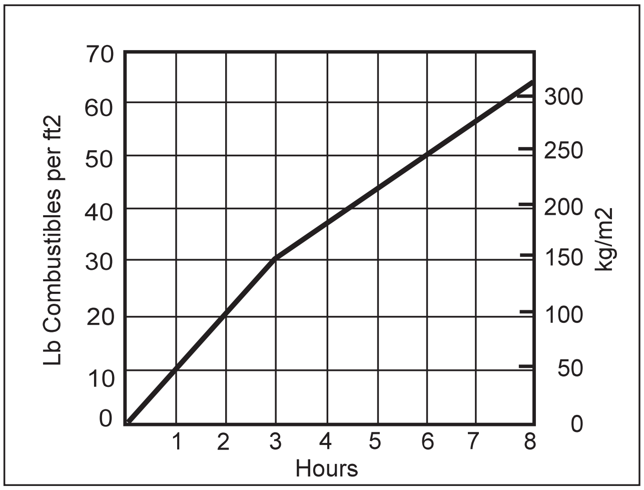

Fig. 1. Weights per square foot and square meters of ordinary (Class A) combustibles required to produce fire severities approximately the ASTM curve for various periods of duration. (Data from Bureau of Standards tests as reported in BM S92.)

In computing fire load in weight per unit area, plastics and ignitable liquids can be converted to equivalent weights of ordinary combustibles. One unit weight of plastic equals 1.5 to 2.5 units of ordinary combustibles, and 1 unit weight of ignitable liquid equals 2 units of ordinary combustibles.

To convert from fuel weight per unit area to energy content per unit area, the calorific value of ordinary combustibles can be taken as 8000 Btu/lb (18.6 MJ/kg). For estimating purposes, the calorific value (heat of combustion) for plastics can be taken from Table 1, and for ignitable liquids it can be taken as 16,000 Btu/lb (37.1 MJ/kg). A more exact estimate of ceiling temperatures in an actual fire can be made if the unit heat release rate (Btu/ft^2/sec, W/m^2) for the commodity in question were known. Limited data is available at this time.

Table 1. Calorific Value for Plastics (for estmating purposes)

Plastic	*Heat of Combustion Btu/lb (MJ/kg)*
Polystyrene	18,750 (43.6)
Polyethylene	20,100 (46.7)
Polypropylene	20,000 (46.5)
Polyvinyl-chloride	17,900 (41.6)
Polyurethane	14,700 (34.2)

3.1.1.2 British System

Under the British system, there are three fire load classes: low, moderate, and high. The following is an interpretation of British practice, to be used where applicable.

a) *Low fire load.* Combustible content, on the average, does not exceed 100,000 Btu/ft^2 (1140 MJ/m^2) of net floor area, or 200,000 Btu/ft^2 (2270 MJ/m^2) in limited, isolated areas. Necessary loadings in excess of these may be stored in limited areas enclosed by fire-resistive construction. Typical occupancies are lobbies and some places of public assembly. Such loading would produce the equivalent of a 1 hour ASTM exposure.

b) *Moderate fire load.* Combustible content, on the average, is between 100,000 Btu/ft^2 (1140 MJ/m^2) and 200,000 Btu/ft^2 (2270 MJ/m^2) of net floor area, but does not exceed 400,000 Btu/ft^2 (4550 MJ/m^2) in limited isolated areas. The provision for storage is similar to that for low fire loads. Typical occupancies are mercantile and industrial. Such loading would produce the equivalent of a 2 hour ASTM exposure.

c) *High fire load.* Combustible content, on the average, is between 200,000 Btu/ft^2 (2270 MJ/m^2) and 400,000 Btu/ft^2 (4550 MJ/m^2) of net floor area, but does not exceed 800,000 Btu/ft^2 (9090 MJ/m^2) in limited isolated areas. A typical occupancy is bulk storage. Such loading would produce the equivalent of a 4 hour ASTM exposure.

Burning rate or fire severity will vary depending on the arrangement and type of the fuel. For a given fire loading, an increased burning rate will result in a reduced burning time.

The area under any fire test time-temperature curve, expressed in degree-hours, is a reasonable measure of the fire exposure severity. In the example shown (see Fig. 2), the severity of the test fire for 60 minutes is roughly equivalent to that of the Standard ASTM Fire for 45 minutes.

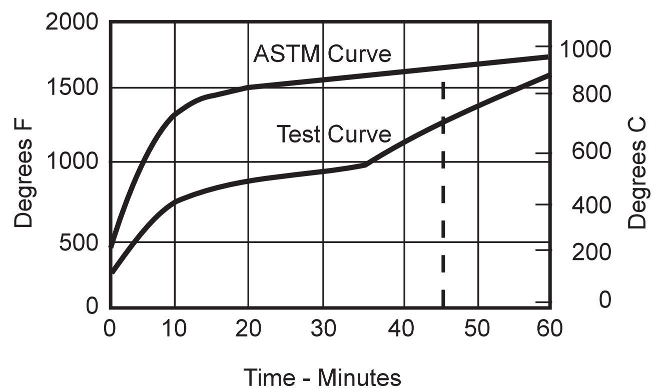

Fig. 2. The area, in degree-hours, under the test curve for 60 minutes is the same as the area under the ASTM curve for 45 minutes. Therefore, the severity of the fire exposure under both curves, up to these respective time limits, is approximately the same.

3.1.2 Dangerous Amounts of Combustibles

Figures 3, 4, and 5 give ceiling temperatures that would result from the burning of wood pallets and ignitable liquids in unprotected rooms of various heights. These temperatures occur when the combustibles are located in a corner. Lower temperatures would result if the combustibles were moved to an open area. A sustained ceiling temperature of 800°F (427°C) or higher can produce a self-propagating fire in a wood or Class 2 insulated metal deck roof.

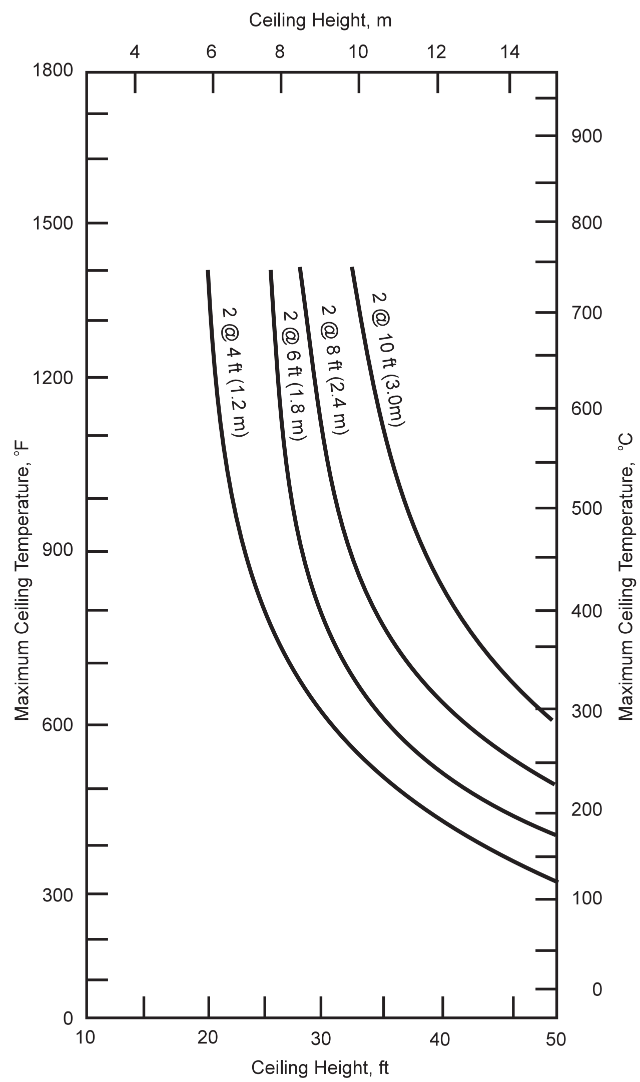

Fig. 3. Ceiling temperatures, double stacks of wood pallets.

3.1.3 Measuring the Combustibility of Building Materials

The potential flame spread from construction materials, particularly the interior finishes, greatly influences the fire hazard and need for automatic sprinkler protection when contents are wholly noncombustible.

Several tests are used to evaluate the relative combustibility of building materials, however, few relate to performance under actual fire conditions.

3.1.3.1 Tunnel Test

A widely used method for evaluating combustibility of building materials is the ‘‘Tunnel Test’’ prescribed in ASTM Standard E 84. FM Approvals is equipped to run this test as it is described in Data Sheet 1-4, *Fire Tests.* Flame spread and smoke developed are measured. These factors determine the product rating numerically on a scale where the flame spread for a cementitious board is 0 and red oak is 100. The testing laboratory makes no judgement of the product’s suitability. Recommendations on flame spread index for a particular application (for example, ceiling tiles in a corridor) are established in building codes. See Table 2 for typical test results.

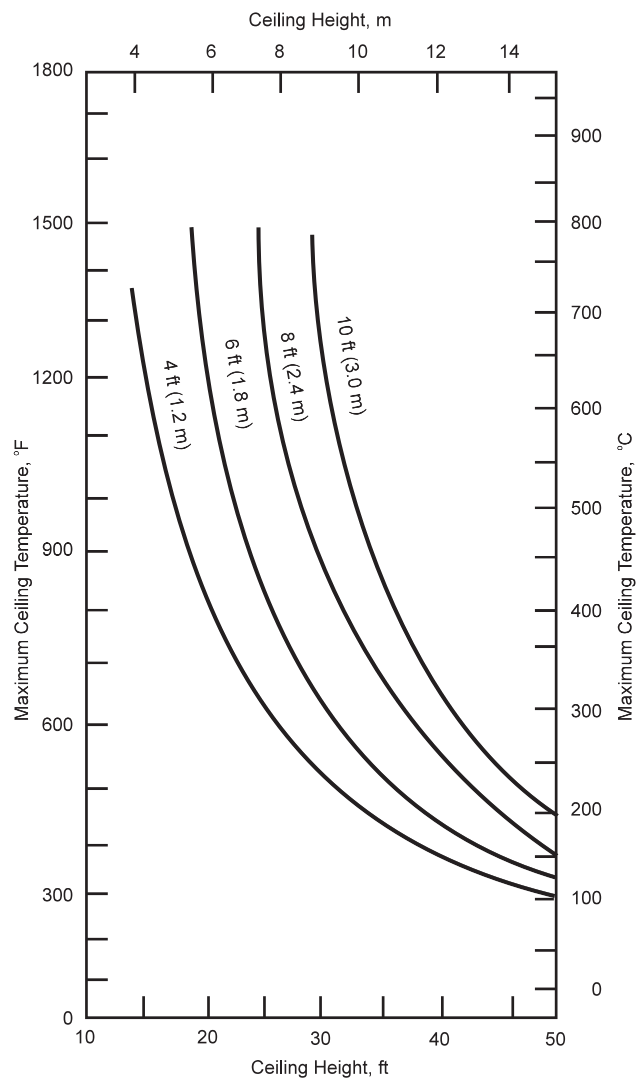

Fig. 4. Ceiling temperatures, single stacks of wood pallets.

Table 2. Typical ASTM E 84 Test Results on Combustibility of Selected Materials.

Product	*Flame spread*	*Smoke developed*
Cementitious board	0	0
Gypsum board	15	0
Protected metal	35–40	80
Acoustical tile		
Mineral	10–15	0–10
Wood fiber	160	105
Treated wood fiber	20	0
Painted glass fiber	10–15	0–10
Fir plywood:		
Untreated	138	60
Treated	15	0
Fiberboard	300	55
Red oak	100	100

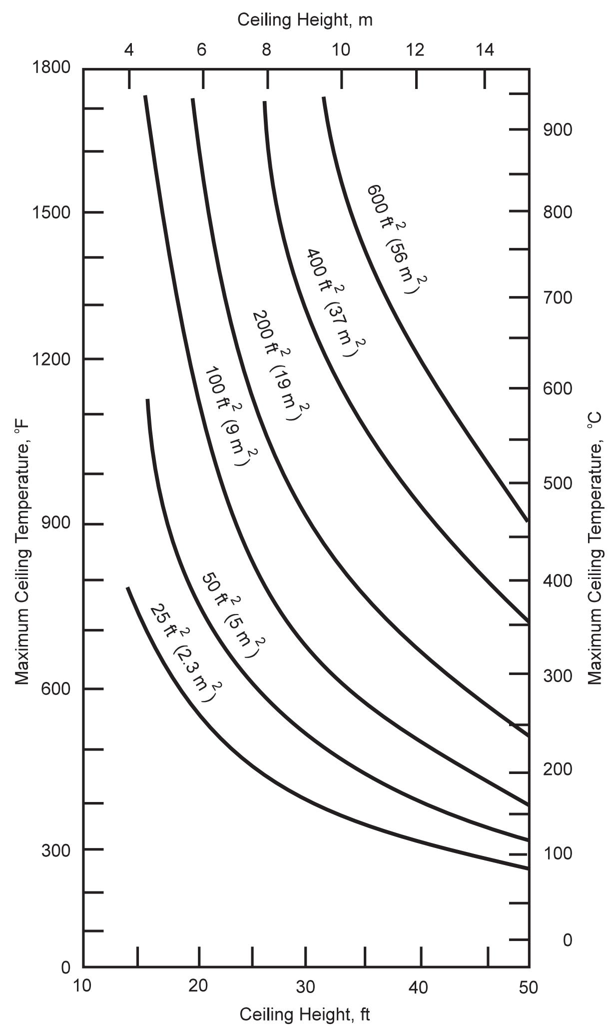

Fig. 5. Ceiling temperatures, ignitable liquid pool fires.

Table 3. Heat-release Rates and Burning Duration of Selected Products Based on the FM Global Research Construction Material Calorimeter Test

Product	Heat-release rate		Duration of burning, min	Metric-Heat-release rate	
	One min, Btu/ft²/min	Peak Btu/ft²/min		One min, MJ/m²/min	Peak MJ/m²/min
Cementitious board	0	0	0	0	0
Gypsum board	73	73	2	829	829
Protected metal (typical)	183	188	9	2,078	2,135
Acoustical tile:					
Mineral	125	134	6	1,420	1,522
Treated wood fiber	129	134	8-½	1,465	1,522
Plywood, elm face, treated core	270	340	9	3,066	3,861
Plywood, oak face, treated core	302	379	9	3,430	4,304
Red oak	508	531	9	5,769	6,030

Where a *non-plastic* material has an ASTM E 84 flame spread rating of 25 or less, the hazard of the material is low enough that automatic sprinkler protection is not needed for the material when used in a *horizontal plane.*

Omitting sprinklers based on ASTM E 84 test results alone does not apply to plastic materials, as the tunnel test does not give realistic results for such materials. In this test, plastics can release so much smoke that flame is choked. Some foam and high-density plastics melt before a flame front is established. Plastic materials listed by FM Approvals for use on walls and ceilings/roofs are Approved (see Appendix A for definition) on the basis of the FM Approvals Corner Test. This test is described in Data Sheet 1-4.

3.1.3.2 FM Global Research Construction Material Calorimeter

The FM Global Research Construction Material Calorimeter is used to determine a material's rate of heat release and duration of burning. These characteristics are significant for evaluating combustibility. Some materials are tested for 10 minutes and the maximum acceptable one-minute heat-release rate for this test is 200 Btu/ft^2/min (2270 MJ/m^2/min).

Some typical test results are shown in Table 3. The test is not meant for unfaced foamed plastics, but is appropriate for foamed plastics having thermal barriers. It also is used by FM Approvals to Approve protected metal panels.

This apparatus also is used for a 30 minute test of roof deck assemblies including insulated steel deck and fire-retardant treated wood. Maximum acceptable heat release rates are as follows:

Table 4. Maximum Acceptable Heat Release Rates

Time Interval min	*Max Fuel Contribution*	
	Btu/ft^2/min	*(kJ/m^2/min)*
3	410	(4656)
5	390	(4429)
10	360	(4088)
30 min	285	(3237)

Comparisons with large-scale tests show that a combustibility index based upon heat release rate is a reasonable method to approve construction materials as Class 1 or limited combustibility.

3.1.3.3 FM Global Research Susceptibility To Heat Damage Test

Heat alone can damage some materials. The FM Global Research Susceptibility to Heat Damage Test subjects a sample of material to the following temperatures (no direct flame).

0 min—ambient
5 min—425°F (218°C)
10 min—475°F (246°C)
15 min—500°F (260°C)
20 min—500°F (260°C)

The sample is removed at the end of 20 min and examined. Curling, bowing, melting, dimensional change, decomposition, or discoloration must be negligible. Damage to the bottom side of the material should not exceed ⅛ in. (3 mm) in depth.

This test is generally conducted for insulations used in metal deck assemblies.

3.1.3.4 ASTM E 108 Test

The potential for fire spread across the top surface of a roof may not be proportioned to the potential fire spread across the bottom of the roof deck within the building. Roof surface fire spread is affected by gravel or concrete paver block surfacing or other coatings, and the type of roof cover and insulation below it. A roof deck could be fire resistive or of limited combustibility, however, depending on the make-up of the above deck components, there could be a potential for severe fire spread across the top surface. Roof systems are fire rated A, B or C according to ASTM E 108.

4.0 REFERENCES

4.1 FM

Data Sheet 1-0, *Safeguards During Construction, Alteration and Demolition*
Data Sheet 1-3, *High-Rise Buildings*
Data Sheet 1-4, *Fire Tests*
Data Sheet 1-5, *Removal and Shipping of Roof Deck Samples for Calorimeter Testing*
Data Sheet 1-12, *Ceilings*
Data Sheet 1-17, *Reflective Wall and Ceiling Insulation*
Data Sheet 1-20, *Protection Against Exterior Fire Exposure.*
Data Sheet 1-21, *Fire Resistance of Building Assemblies*
Data Sheet 1-22, *Maximum Foreseeable Loss*
Data Sheet 1-24, *Protection Against Liquid Damage*
Data Sheet 1-28, *Wind Design*
Data Sheet 1-29, *Above Deck Roof Components*
Data Sheet 1-30, *Repair of Wind Damaged Roof Systems*
Data Sheet 1-31, *Metal Roof Systems*
Data Sheet 1-32, *Inspection and Maintenance of Roof Assemblies*
Data Sheet 1-33, *Safeguarding Torch-Applied Roof Insulation*
Data Sheet 1-44, *Damage-Limiting Construction*
Data Sheet 1-57, *Plastics in Construction.*
Data Sheet 1-59, *Fabric and Membrane Structures*
Data Sheet 1-60, *Asphalt-Coated/Protected Metal Buildings*
Data Sheet 1-61, *Fire-Retardant Treated Wood.*
Data Sheet 7-28, *Energetic Materials.*
Data Sheet 7-29, *Ignitable Liquid Storage in Portable Containers.*
Data Sheet 7-32, *Ignitable Liquid Operations.*
Data Sheet 7-83, *Drainage Systems for Ignitable Liquids.*
Data Sheet 9-1, *Supervision of Property.*

Approval Guide, a publication of FM Approvals.

FM Hot Work Permit, Form 2630

4.2 NFPA Standards

National Fire Protection Association (NFPA)

NFPA 220, *Types of Building Construction, 1999.*

NFPA 259, *Test Method for Potential Heat of Building Materials, 1998.*

4.3 Others

American Society for Testing and Materials (ASTM)

ASTM E 84—91, *Standard Test Method for Surface Burning Characteristics of Building Materials.*

ASTM E 108—91, *Standard Test Methods for Fire Tests of Roof Coverings.*

ASTM E 119—95, *Method for Fire Tests of Building Construction and Materials.*

ASTM E 136—92, *Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C.*

ASTM E 605—77 (1982), *Standard Test Methods for Thickness and Density of Sprayed Fire-Resistive Material Applied to Structural Members.*

ASTM E 736—86 (1991), *Test Method for Cohesion/Adhesion of Sprayed Fire-Resistive Materials Applied to Structural Members.*

ASTM E 759—86 (1991), *Test Method for Effect of Deflection of Sprayed Fire-Resistive Material Applied to Structural Members.*

ASTM E 760—86 (1991), *Test Method for Effect of Impact on Bonding of Sprayed Fire-Resistive Material Applied to Structural Members.*

ASTM E 761—86 (1991), *Test Method for Compressive Strength of Sprayed Fire-Resistive Material Applied to Structural Members.*

ASTM E 859—82, *Test Method for Air Erosion of Sprayed Fire-Resistive Materials Applied to Structural Members.*

Building Officials & Code Administrators (BOCA®)

National Building Code.

International Conference of Building Officials

Uniform Building Code.

National Research Council of Canada

National Building Code.

Southern Building Code Congress International (SBCCI)

Standard Building Code.

Similar standards available in countries outside the United States also may be utilized.

APPENDIX A GLOSSARY OF TERMS

A brief description of some terms are described below. For a more detailed description, examples and illustrations, see Appendix C.

Approved: references to ''Approved'' in this data sheet means the product and services have satisfied the criteria for FM Approval. Refer to the *Approval Guide* for a complete listing of products and services that are FM Approved.

Boards-on-joist construction: consists of wood floor deck supported by closely spaced wood joists.

Fire-resistive construction: consists of materials that will withstand fire for the rated period without structural failure.

Limited-combustible construction: consists of materials that will not release sufficient fuel so as to allow a self-propagating fire.

Mass timber construction: consists of large-sized engineered wood products for the majority of the structural framing system.

Noncombustible construction: consists of materials that will not allow for a self-propagating fire, contribute a negligible amount of fuel, but are not necessarily fire resistive.

Plank-on-timber construction: also known as ''heavy timber'', ''mill'' or ''slow-burning construction''. It consists of large wood members.

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

October 2021. Interim revision. Added additional information on mass timber construction to Appendix A and Appendix C.

April 2020. Interim revision. Added information on mass timber construction to Appendix A and Appendix C.

April 2012. Terminology related to ignitable liquids has been revised to provide increased clarity and consistency with regard to FM Global's loss prevention recommendations for ignitable liquid hazards.

January 2011. Minor editorial changes were made. Deleted references to Data Sheet 1-19, *Fire Walls, Subdivisions and Draft Curtains*, that was made obsolete.

September 2007. Minor editorial changes were made.

January 2005. Deleted references to obsolete Data Sheet 8-0, *General Storage Safeguards*.

May 2003. Minor editorial changes were made for this revision.

May 2002. Minor changes were made to emphasize the use of noncombustible or limited combustible materials.

September 2000. This document has been reorganized to provide a consistent format. Only editorial and no major changes from May 1998 edition were made.

APPENDIX C CLASSIFICATION OF CONSTRUCTION

C.1 Major Types of Construction

Building framework often is categorized by relative fire hazard and resistance. These categories include: *fire resistive, noncombustible* or *limited-combustible, plank-on timber, board-on-joists* and *wood frame*. Building components of these types also can be combined in ways that result in construction types that do not fit neatly into any of the categories.

In the U.S., model building codes have a more specific definition of types of construction. Prior to the year 2000, there were three model building codes in the U.S. They are the BOCA® National Building Code (NBC), the Standard Building Code (SBC) and the Uniform Building Code (UBC). Individual states generally use one of these as a model for their state codes, however, the most current model building code is not always adopted immediately. Building codes have requirements for fire resistance ratings of all structural members, including walls, partitions, columns, floors and roofs. The National Fire Protection Association (NFPA) Standard 220, *Types of Building Construction*, contains similar criteria. Construction is broken down into five general categories.

Type I construction is noncombustible, and structural framework is protected (fire resistive).

Type II construction is noncombustible and is either protected to a lesser degree than Type I, or unprotected.

Type III construction may have protected or unprotected wood structural elements.

Type IV construction allows unprotected wood framing, such as heavy timber (heavy timber is Type III construction per SBC).

Type V construction allows any material acceptable to the code.

The SBC also specifies Type VI construction.

Factors that influence the type of construction required by the applicable building code include the number of stories or building height, floor area and the occupancy.

Table 5 lists major structural components and the range of fire resistance requirements required by the four U.S. codes or standards mentioned above. In some cases, there may be considerable differences between various codes. There also are many exceptions to the normal requirements, such as reductions in fire resistance ratings if sprinklers are provided, that are not noted in this table.

Table 5. Fire Resistance Requirements for Type I through Type VI Construction (In Hours)

	Type I	*Type II*	*Type III*	*Type IV*	*Type V*	*Type VI*[2]
Exterior Bearing Walls[3]						
Supporting more than one floor, columns or other bearing walls	*3-4*	*NC-4*	*1-4*	*1-4*	*0-1*	*1/0*
Supporting one floor only	*3-4*	*NC-4*	*1-4*	*1-4*	*0-1*	*1/0*
Supporting a roof only	*3-4*	*NC-4*	*1-4*	*1-4*	*0-1*	*1/0*
Interior Bearing Walls						
Supporting more than one floor, columns, or other bearing walls	3-4	NC-3	0-2	0-2	0-1	1/0
Supporting one floor only	2-3	NC-2	0-1	0-1	0-1	1/0
Supporting a roof only	2-3	NC-2	0-1	0-1	0-1	1/0
Column						
Supporting more than one floor, bearing walls, or other columns	3-4	NC-3	0-1[4]	1,NC or HT	0-1	1/0
Supporting one floor only	2-3	NC-2	0-1[4]	1,NC or HT	0-1	1/0
Supporting a roof only	2-3	NC-2	0-1[4]	1, NC or HT	0-1	1/0
Beams, Girders, Trusses & Arches						
Supporting more than one floor, bearing walls, or columns	3-4	NC-3	0-1[4]	1, NC or HT	0-1	1/0
Supporting one floor only	2-3	NC-2	0-1[4]	1, NC or HT	0-1	1/0
Supporting a roof only	1-½-3	NC-2	0-1[4]	1, NC or HT	0-1	1/0
Floor Construction	2-3	NC-2	0-1[4]	HT	0-1	1/0
Roof Construction	NC-2	NC-1	0-1[4]	HT	0-1	1/0
Exterior Nonbearing Walls[3]	NC-4	NC-4	0-4	0-4	0-3	1/0

NC—Noncombustible
HT—Heavy Timber
[1]There are many exceptions to this table. For example, fire resistance ratings may be reduced in some cases if sprinklers are provided.
[2]Only SBC has Type VI requirements, rating on left is for 1 hour protected construction, rating on right is for unprotected construction.
[3]Separation distances between exterior fire exposures may govern.
[4]SBC allows Heavy Timber in these cases.

C.2 Fire-Resistive Construction

Fire-resistive construction consists of materials that will withstand fire within the building, insulating as necessary, for the rated period without structural failure.

Concrete (see Fig. 6) and protected steel-frame (see Fig. 7) construction are two types of fire-resistive construction.

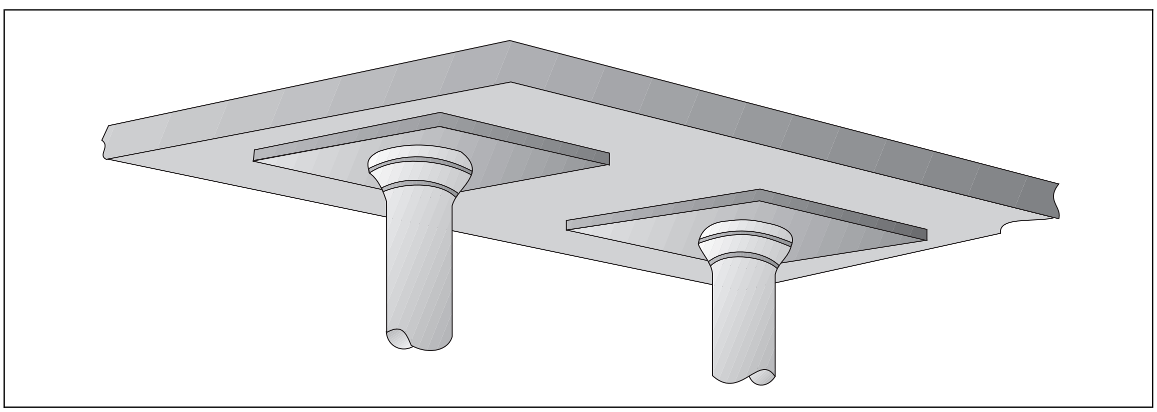

Fig. 6. Concrete frame construction.

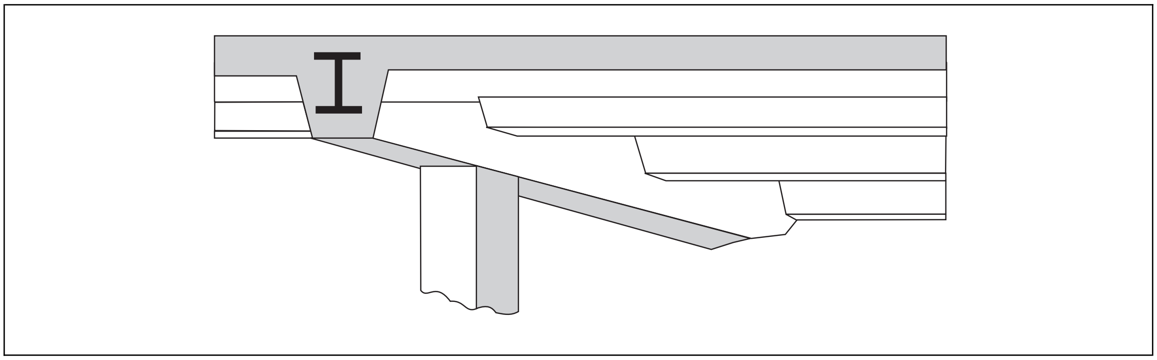

Fig. 7. Concrete on protected steel construction.

Concrete may be cast in place or precast. Concrete also may be prestressed by either pre-tensioning or post-tensioning.

Pretensioned concrete is reinforced with high strength steel tendons, which are stretched between external anchorages in the form prior to pouring the concrete. When the concrete reaches sufficient strength and has bonded to the steel, the tensioning force is released.

Pretensioned concrete can be used for various structural purposes including wall, floor and roof construction. It is found in various shapes including double or single tees (usually 8 ft [2.4 m] wide), solid or hollow core flat slabs and rectangular, L-shaped and inverted tee beams (see Figs. 8a. through e.). Columns and piles also can be prestressed. Because it must be transported, pre-tensioned concrete often is limited to 8 or 10 ft (2.4 to 3.0 m) widths and 60 ft (18.3 m) lengths. With post-tensioned concrete, hollow conduits placed in the framework prevent the concrete from bonding to the tendons (see Fig. 9). After the concrete has hardened and reached sufficient strength, the tendons are then stretched by jacking against the concrete. Post-tensioning is most commonly used for beams, and floor slabs of multi-story buildings, however, pretensioning is used more often than post-tensioning.

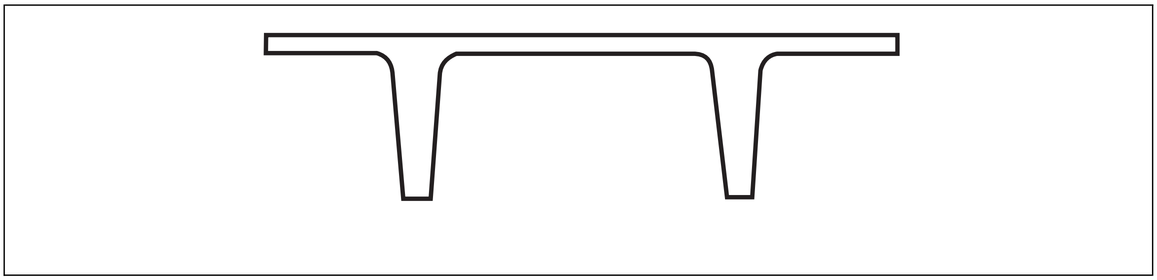

Fig. 8a. Double Tee.

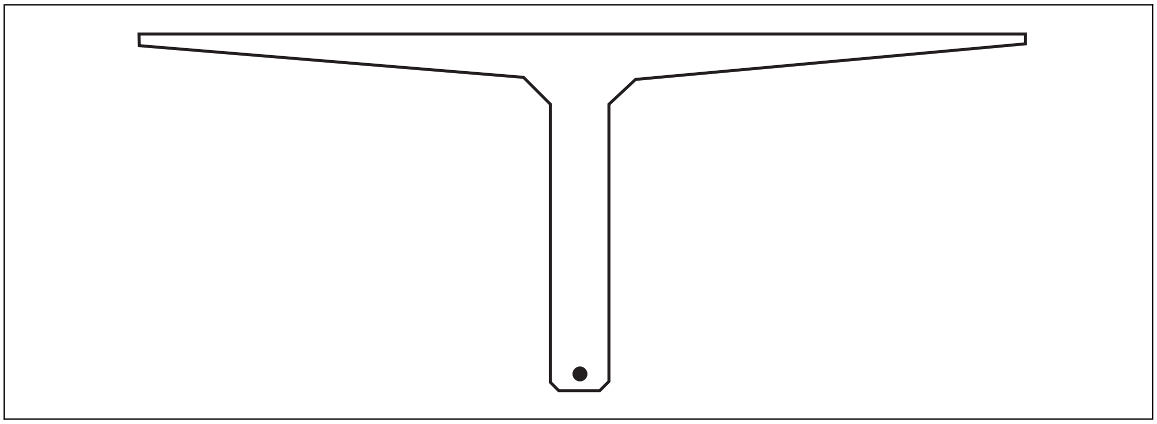

Fig. 8b. Single Tee.

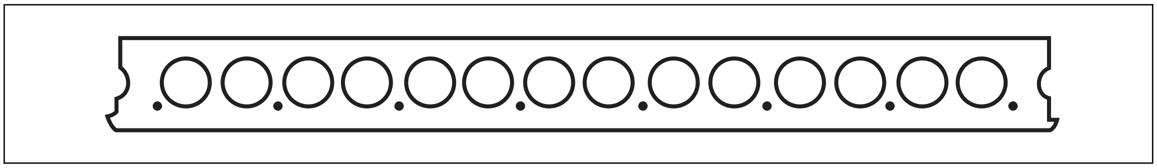

Fig. 8c. Hollow Core Flat Slab.

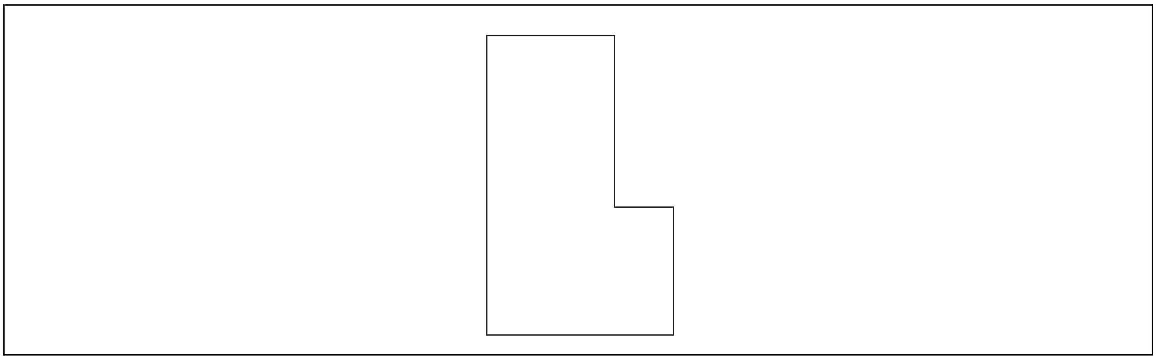

Fig. 8d. L-Shaped Beam.

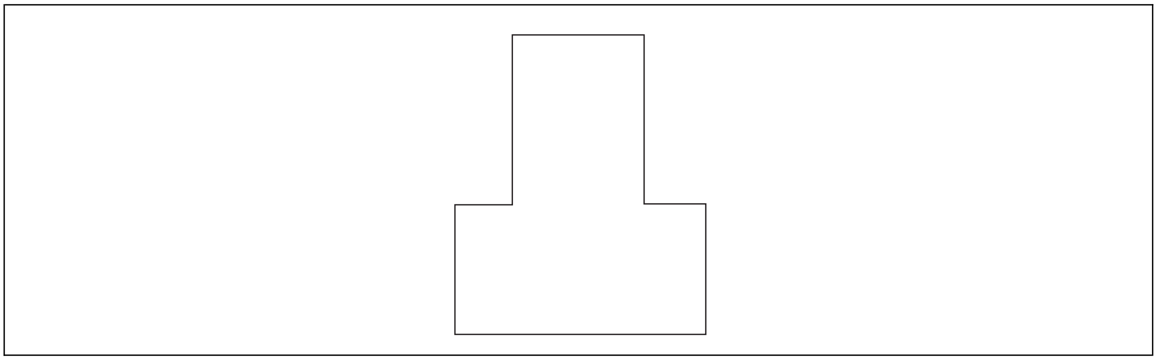

Fig. 8e. Inverted Tee Beam.

Tilt-up concrete is often used when wider wall panels are utilized. The concrete is poured into formwork at the job site and lifted into place after the concrete has reached sufficient strength. Panels are usually one bay wide (20 ft [6.1 m] or more).

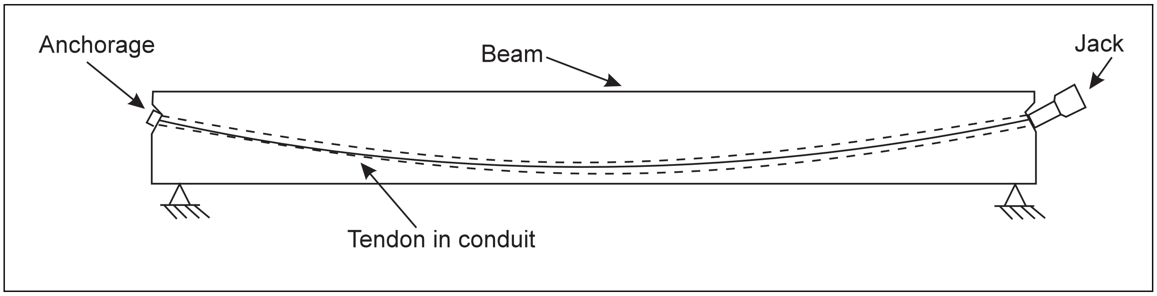

Fig. 9. Post-tensioned concrete beam.

With proper thickness and detailing, concrete cover over cables, and reinforcing bars etc., prestressed (pretensioned or post-tensioned) concrete can have the same fire resistance as monolithic concrete. In any case, deterioration such as spalling of the concrete surface can expose reinforcing steel to a fire causing it to weaken and fail prematurely.

A two-way concrete slab is sometimes used in floor construction and has steel reinforcement placed in two directions. The slab acts as the deck and secondary and primary framing. It may be either flat or ribbed in two directions on its underside.

C.3 Protected Steel-Frame Construction

In protected steel-frame construction, the structural steel is provided with a fire resistant covering. Floors and roofs are usually concrete or concrete fill on steel deck, with fireproofed supporting steel framework. If the steel deck and concrete are integrated to form a composite roof system, or if additional insulation against fire is needed, fireproofing of the deck may be applied as well. Sprayed fire-resistive materials applied to structural members are particularly sensitive to application procedures and environment. A number of ASTM test standards are applicable to such products and are listed in Section 4.0, of this data sheet. ASTM E 119 fire testing is conducted in order to establish the needed fire resistance rating of the assembly. Other tests noted in Section 4.0, are intended to test physical properties. ASTM E 759 (deflection), E 760 (impact resistance), E 761 (compressive strength) and E 859 (air erosion) are conducted in the laboratory and the manufacturer should certify that the materials meet these standards. ASTM E 605 (thickness and density), and E 736 (cohesion/adhesion) may be conducted in the laboratory or the field and *are recommended as a check of all new field installations.* ASTM E 859 is particularly critical if the sprayed material is located in a return air plenum (on the underside of a roof/floor deck in the space above a suspended ceiling). Areas adjacent to air inlets may be most vulnerable due to higher air velocities. If a sealer is applied over the fire-resistive material to prevent erosion, it should be a type that has been tested and listed with the fire-resistive material to ensure that it does not detract from the noncombustibility or fire-resistance rating. An independent laboratory should certify that these tests have been conducted and recommend repairs as needed. Similar standards available in countries outside the U.S. may also be utilized.

Field testing of these sprayed applied products is necessary to ensure, among other things, that the amount of air-entraining material used in the formulation is not excessive. This could result in inadequate density and impact resistance. Improper surface preparation can lead to inadequate adhesion and insufficient thickness also will result in protection that is less than recommended. After mechanical work has been completed, but before suspended ceilings are installed, visual examinations of fireproofing should be made and bare spots/spalled areas should be repaired.

Buildings constructed prior to 1940 may have the steel frame encased in concrete that is poured in forms, with decks of reinforced concrete (see Fig. 7). For added details on fire resistance, see Data Sheet 1-21, *Fire Resistance of Building Assemblies*. Listings for ‘‘Wall and Floor Penetration Fire Stops’’ can be found in the *Approval Guide*.

The basic function of automatic sprinkler piping is to reliably carry water under pressure to all sprinkler heads. When piping is supported by exposed steel, the structural system is a major factor affecting reliability.

With exposure to excessive atmospheric temperatures for even short periods of time, steel softens and weakens. At the same time, the steel is attempting to expand under the effect of the heat. If a degree of restraint to expansion is present, permanent distortion will result.

When a structural member is exposed to a fire, the interplay between softening, expansion, and restraint produces a very complex behavior. To further complicate the behavior where there is direct exposure to high temperatures, the top of horizontal members will be hotter that the bottom.

Tests have been run with loaded structural beams exposed to short term high temperatures of a nature that will result in borderline conditions for sprinkler lines. Typically, the structural beam will deflect upward initially. This is because the top of the member is expanding more than the bottom. At temperatures of a few hundred degrees, the strength of the steel is reduced and deformations that offset the expansion occur. The steel member settles to the starting position or slightly below.

With the approximate temperature-time relationship shown in Figure 10, deflections of structural members sufficient to break fittings of sprinkler piping are probable. Exposures releasing great amounts of heat can produce such ceiling temperatures if the proper sprinklers with water supplies sufficient to control the fire are not provided as outlined in the appropriate data sheet. Typical of such exposures are high-piled combustible pallets, high-piled roll paper and many plastics. The appropriate data sheet also will indicate when exposed steel needs fireproofing in addition to adequate sprinklers and water supplies to provide protection from specific exposures.

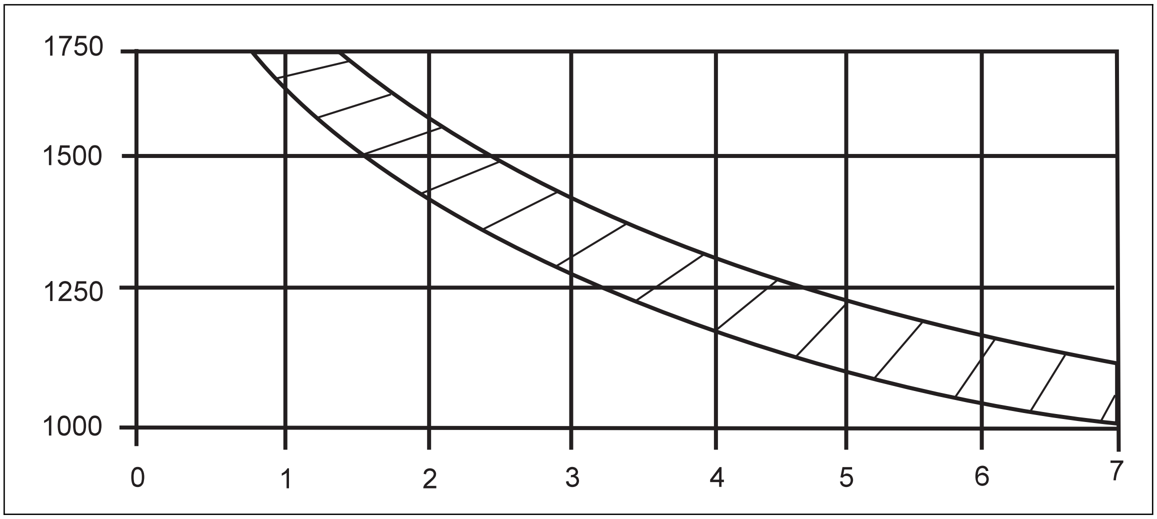

Fig. 10. Exposure required to distort structural steel to the point where breakage of sprinkler pipe fittings will occur.

C.4 Noncombustible or Limited-Combustible Construction

The primary elements of noncombustible construction are noncombustible materials that fail to meet the full requirements of fire-resistive construction. Generally, noncombustible construction has exposed steel supporting members.

The principal fire-safety advantage of noncombustible or limited-combustible (Class 1) construction, as compared with combustible construction, is their limited fire spread. It does not contribute significant fuel to a fire originating in the contents of the building or allow fire spread via the construction where there is only a localized fire exposure. A serious disadvantage in several varieties is the inability to withstand fire temperatures for more than a few minutes without damage or structural failure.

A wide variety of roof materials is used in noncombustible construction. Examples are corrugated sheet metal, corrugated cementitious panels, precast concrete plank, concrete tile and poured gypsum. Class l insulated steel deck (see Fig. 11, and Data Sheet 1-28, *Wind Design*, and Section C.10 of this data sheet) and fire-retardant lumber (Data Sheet 1-61, *Fire-Retardant Treated Wood*) have limited combustibility, as defined by the FM Global Research Roof Deck Calorimeter Test.

Floors in buildings of noncombustible construction are either reinforced concrete or concrete on cellular or corrugated metal panels.

Typical materials used for noncombustible walls are brick, concrete masonry units, corrugated metal, gypsum board, corrugated cement. Approved insulated metal wall and ceiling/roof panels are of limited-combustibility as defined by the FM Approvals Corner Test.

Cladding and framework for metal buildings are generally of noncombustible construction. These buildings are usually constructed of exposed steel frame with steel or aluminum siding and roofing.

C.5 Combustible Materials in Noncombustible Construction

Some combustible materials are frequently used for siding, suspended ceilings, and interior finish in buildings classified as fire resistive or noncombustible. When these materials are of limited combustibility, such as Class 1 steel deck they do not challenge the integrity of the building. Even when combustible elements create a fire hazard requiring sprinkler protection, the classification of the construction is unchanged. For example, a reinforced concrete building with combustible, suspended, wood-fiber ceilings would still be called fire resistive, but automatic sprinkler protection would be needed to protect the ceiling, as it would be similarly needed to protect a combustible occupancy. Combustible ceilings are not recommended for high-rise buildings, regardless of the presence of automatic sprinklers.

Adding combustible components to otherwise noncombustible materials can result in a combustible, composite assembly. For example, mopping above deck roofing materials to the top surface of a corrugated,

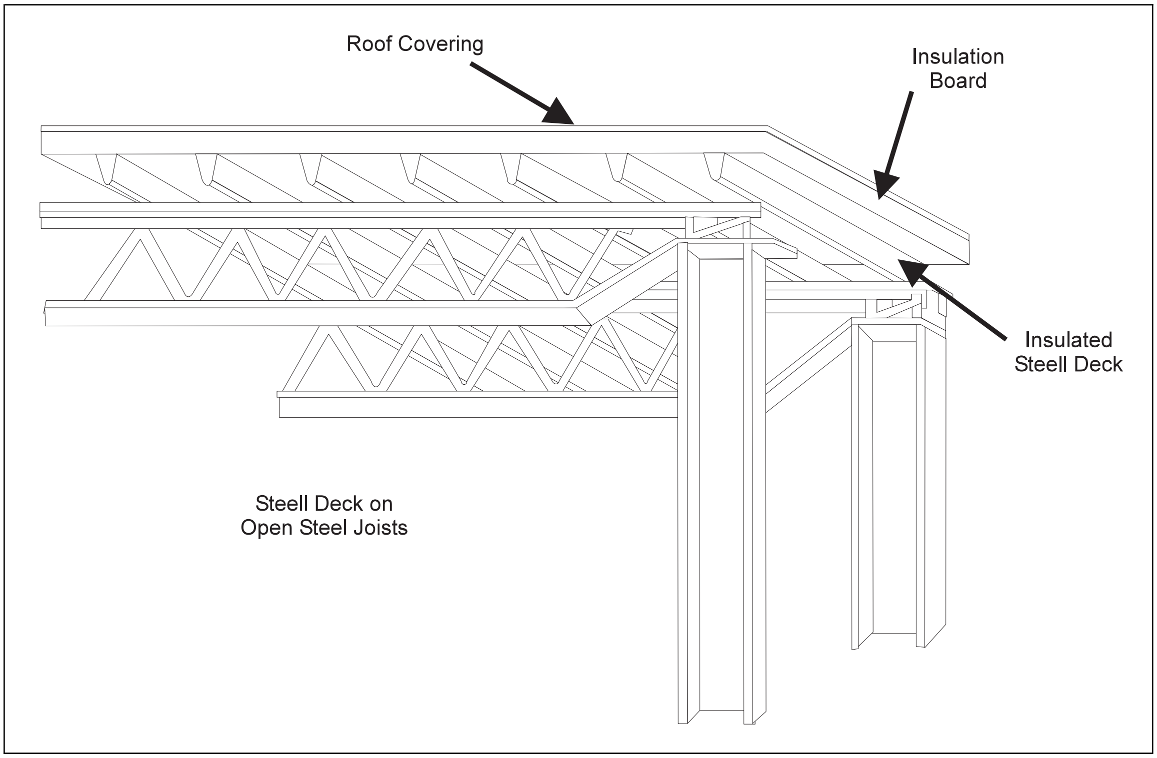

Fig. 11. Insulated steel deck on steel framing.
(Note: above deck assembly should be of limited combustibility—see Section C.4)

cementitious roof panel with hot asphalt may result in a Class 2 (combustible) roof assembly due to potential burning of flammable vapors forced down through joints in the deck sections.

C.6 Plank-On-Timber Construction

Plank-on-timber construction is also known as ''heavy timber,'' ''mill'' or ''slow-burning'' construction and should not be confused with mass timber construction. It consists of masonry walls with plank floors and roof on heavy timber supports (see Fig. 12). Floors of minimum 3 in. (76 mm) plank with a hardwood overlay have an estimated fire endurance of 45 minutes available for fire fighting before a fire ''breakthrough'' into the area above can be expected. The wide dimensions and spacing of beams, and the floor thickness are key factors that make this construction slow burning. Beams are generally 6 to 12 in. (150 to 300 mm) wide and spaced 6 to 12 ft (1.8 to 3.6 m) on center. Wood floor or roof framing with lesser dimensions are generally considered to be board-on-joist. There is little new construction of this type.

Heavy timber construction was used extensively prior to the invention of the concrete flat slab in 1906. It was implemented in multistory textile mills, one-story warehouses containing baled fibers and general manufacturing and storage occupancies. Little new construction is of this type.

C.7 Wood Joist Construction

Board-on-joist construction is a type of floor or roof construction in which boards are supported by closely spaced wood joists. Floors are generally constructed of two-plies, (each ½ in. [13 mm] to 1 in. [25 mm] thick) of sheathing boards and have an estimated fire-resistance rating of about 10 to 15 minutes. Joists are usually 1-½ in. (38 mm) in width, are usually 8 to 10 in. (200 to 250 mm) deep and spaced 12 or 16 in. (300 or 400 mm) on center and usually span 12 to 14 ft (3.7 to 4.3 m). Plywood-on-joist construction is very similar except that plywood is used in lieu of boards as decking. In heavy joist construction the joists are usually deeper and/or wider to accommodate heavier floor loads or longer spans.

Open-joist construction (see Fig. 13), with no interior sheathing or wood structural members, is frequently used where appearance is not important. The main disadvantages of open-joist construction, as compared with heavy timber, are the smaller size of the structural members, the greater combustible surface exposed

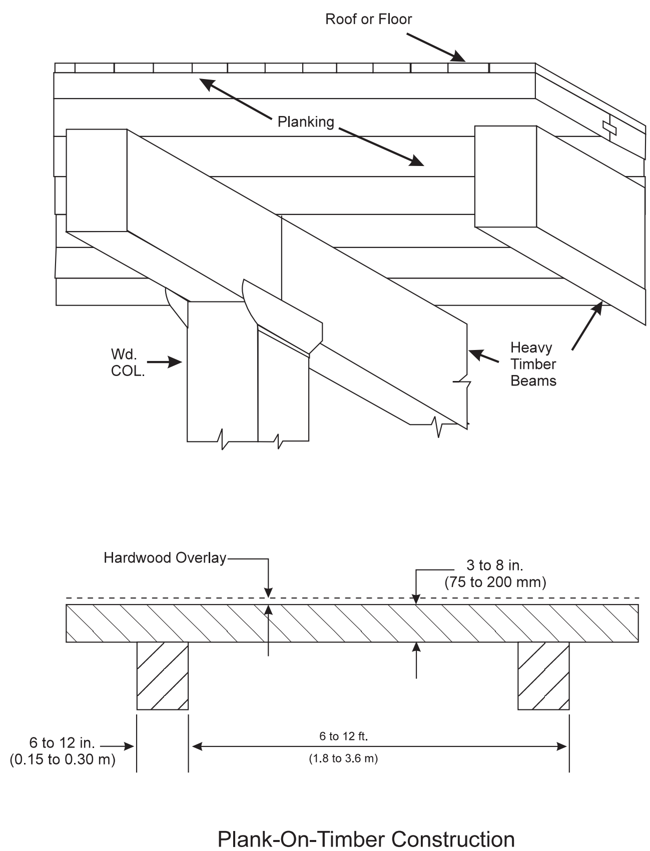

Fig. 12. Plank-on-timber construction.

and the close spacing of supports which re-radiates additional heat. All contribute to the rapid spread of fire. However, with complete automatic sprinkler protection and no other unfavorable factors, this type of construction has reasonable loss experience.

In hollow-joist construction, the underside of the joist is sheathed. It is less desirable than open-joist construction because of the concealed spaces through which fire can spread, shielded from sprinklers. Adequate firestopping is essential. For further details, refer to Data Sheet 1-12, *Ceilings.*

C.8 Wood Frame Construction

If floors and walls are of board-on-joist or wood truss construction and the structural members of the walls are wood, the construction is called wood frame (see Fig. 14). Sheathing may be noncombustible such as gypsum board, brick, or metal. The combination of rapid burning floors and combustible wall framing makes this construction framework type more susceptible to fire spread. Wood framing is not desirable in multi-story buildings.

C.9 Plywood Diaphragm Roof

Another type of wood roof construction that is popular in some areas is the plywood diaphragm roof (see Fig. 15). The roof system acts as a thin, deep beam that resists lateral loads, such as wind or earthquake, in the place of the member.

In this type of construction, a plywood deck is supported on 2×4 in. (51×102 mm) sub-purlins spaced approximately 2 ft (0.6 m) on center (o.c.). The sub-purlins butt into and are supported by 4 in.×12–24 in. (102 mm × 305–610 mm) purlins spaced approximately 8 ft (2.4 m) o.c. These, in turn, butt into and are supported by 7 in.×24–40 in. (178 mm×610–10200 mm) glue-laminated beams. The ‘‘glu-lam’’ beams are usually spaced 20 to 24 ft (6 to 7 m) apart. Member sizes and spacing may vary somewhat in individual

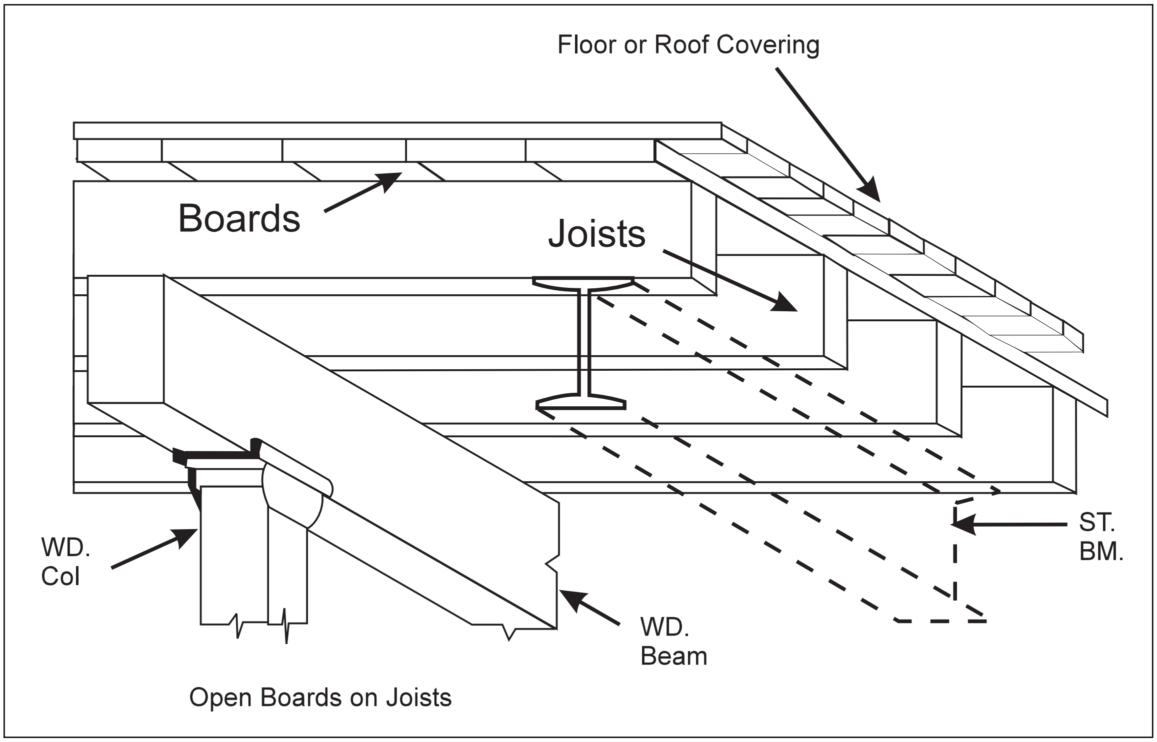

Fig. 13. Open boards on joists.

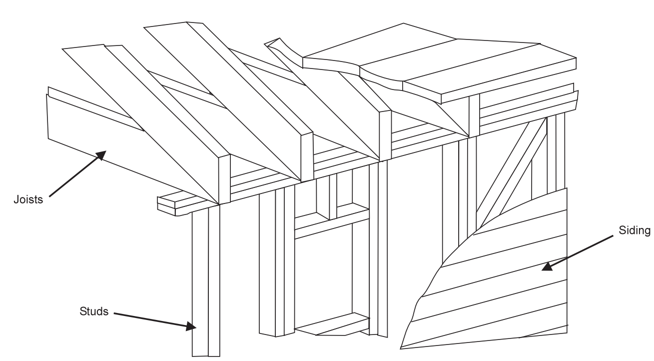

Fig. 14. Wood frame construction.

installations. In some installations, the glu-lam beams run in both directions. In some plywood deck constructions, the sub-purlins and/or purlins do not butt into their respective supporting members but are continuous over them. Because of the spacing of the sub-purlins, this is considered equivalent to boards-on-joist construction from a fire standpoint.

Reflective ceiling insulation is most commonly encountered with this type of construction and can in some cases be a fire hazard. A detailed description and recommendations for reflective ceiling insulation can be found in Data Sheet 1-17, *Reflective Wall and Ceiling Insulation.*

C.10 Other Construction Types

Some construction types do not fit neatly into the above categories, but still represent a sizeable portion of modern construction types. These include mass timber, plank-on-steel, asphalt-coated metal, protected metal and Class 2 insulated metal deck.

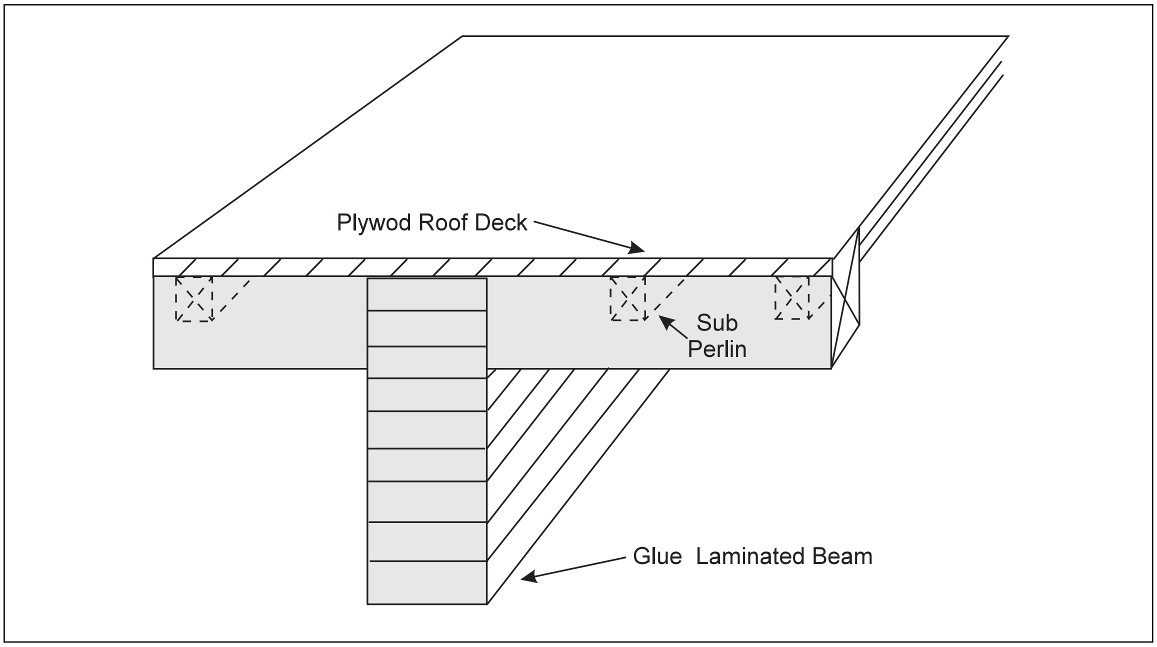

Fig. 15. Typical plywood diaphragm roof deck (not to scale).

Plank-on-steel construction consists of 4 to 8 in. (102 to 203 mm) thick wood plank on steel or wood beams attached to steel girders. Plank-on-steel construction is combustible and is subject to early collapse in an uncontrolled fire.

Mass timber construction is built using a category of engineered wood products of a large size for columns, beams, roof, floor, and wall panels. Mass timber wood products are engineered for high strength, comparable to steel and concrete, but are lighter in weight. A building is considered mass timber construction when the majority of the vertical and horizontal structural framing system is comprised of engineered mass timber wood products (see Figure C-10). Mass timber construction can be a hybrid with other materials, such as heavy timber, steel and concrete. In the US building code, mass timber is considered Type IV construction, provided the wood members meet minimum dimensions.

Mass timber engineered wood products are comprised of multiple wood pieces laminated (glued) or nailed together to form larger, stronger members with various functions including columns, beams, roofs, floors, walls, etc. They are typically built off-site and include:

- Nail-laminated timber (NLT): Multiple laminations of lumber stacked on edge and successively nailed perpendicular to the face to form a wood panel.
- Dowel-laminated lumber (DLT): Similar to NLT but laminations are held together with wood dowels to form a wood panel.
- Cross-laminated timber (CLT): At least three layers of lumber that are cross-oriented and bonded with adhesives to form a wood panel.
- Glue-laminated timber (Glulam): Multiple wood laminations oriented parallel with the member's length and bonded together with adhesives to form beams or columns.
- Laminated-veneer lumber (LVL): Multiple layers of thin wood (veneers) stacked in parallel and bonded with adhesives to form beams or headers.
- Timber-concrete composite (TCC): CLT or DLT panels with a poured in-place concrete slab on top connected with metal screws or dowels to form a roof or floor.
- Post-tensioned timber (PTT): Engineered wood beam or column used in combination with steel post-tensioning cables to place the member in a state of precompression, increasing the load carrying capacity.

Asphalt-Coated Metal (ACM). ACM buildings are steel-frame buildings having metal siding and/or roofing that has been coated on both sides with asphalt. The coating increases the fire hazard substantially. Buildings of this type are discussed in detail in Data Sheet 1-60, *Asphalt-Coated/Protected Metal Buildings.*

Fig. C-10 Mass timber construction

Protected Metal (PM). PM buildings are similar to ACM buildings except that roofing and siding panels have considerably less asphaltic coating or they are coated with paint at 5 mils (0.13 mm) or less, or are coated with zinc or zinc-aluminum alloys (galvanized). This also is discussed in Data Sheet 1-60.

Class 2 Insulated Metal Roof Decks. In the types of construction described above, combustibility of the roof is generally determined by the physical characteristics of the roof deck and supporting structure. Fire tests and experience show that critical quantities of some combustible above-deck components (e.g., the insulation, adhesive, vapor retarder and roof covering) will result in a Class 2 steel deck. If exposed to fire even locally and not protected, this could allow a spreading interior fire due to the above-deck construction alone. Prior to the 1980s, hot asphalt was often mopped to the deck to secure above deck components. This generally resulted in a Class 2 assembly.

Insulated metal deck usually consists of a water-resistant covering on insulation, with or without a vapor retarder (barrier), which is secured to a metal roof deck. The water-resistant covering generally consists of several plies of felt, or a single-ply membrane, either smooth or with a gravel surface (see Fig. 16). For additional information on above deck roof components, refer to Data Sheet 1-28, *Wind Design* ; Data Sheet 1-29, *Above-Deck Roof Components*; Data Sheet 1-30, *Repair of Wind Damaged Roof Systems*; Data Sheet 1-31, *Metal Roof Systems*; Data Sheet 1-32, *Inspection and Maintenance of Roof Assemblies*, and the *Approval Guide*.

An assembly should be considered Class 2 if the above deck components are not Approved in specific combination, unless a calorimeter test is conducted to prove otherwise (see Data Sheet 1-5, *Removal and Shipping of Roof Deck Samples for Calorimeter Testing*).

In some cases, variations from the *Approval Guide* or Data Sheet 1-28 can affect wind resistance, and may or may not affect the fire hazard. A first layer of insulation that is thinner than Approved may adversely affect wind resistance, or may increase the fire hazard and result in a Class 2 roof. (**Note:** manufacturers also specify minimum insulation board thickness for structural strength to span rib openings in the steel deck. See the *Approval Guide* and Data Sheet 1-28.) The use of aluminum deck instead of steel generally results in a Class 2 metal deck because of the relatively low melting temperature of aluminum.

Steel deck has a melting temperature of about 2650°F (1450°C), and consequently does not melt in either a typical fire or in a calorimeter test. The contribution to fire spread due to fire exposure on the underside of the deck is limited to flammable vapors forced through joints in the deck. Aluminum deck has a melting temperature of about 1050°F (565°C) and, consequently would melt in a typical fire or in the calorimeter test.

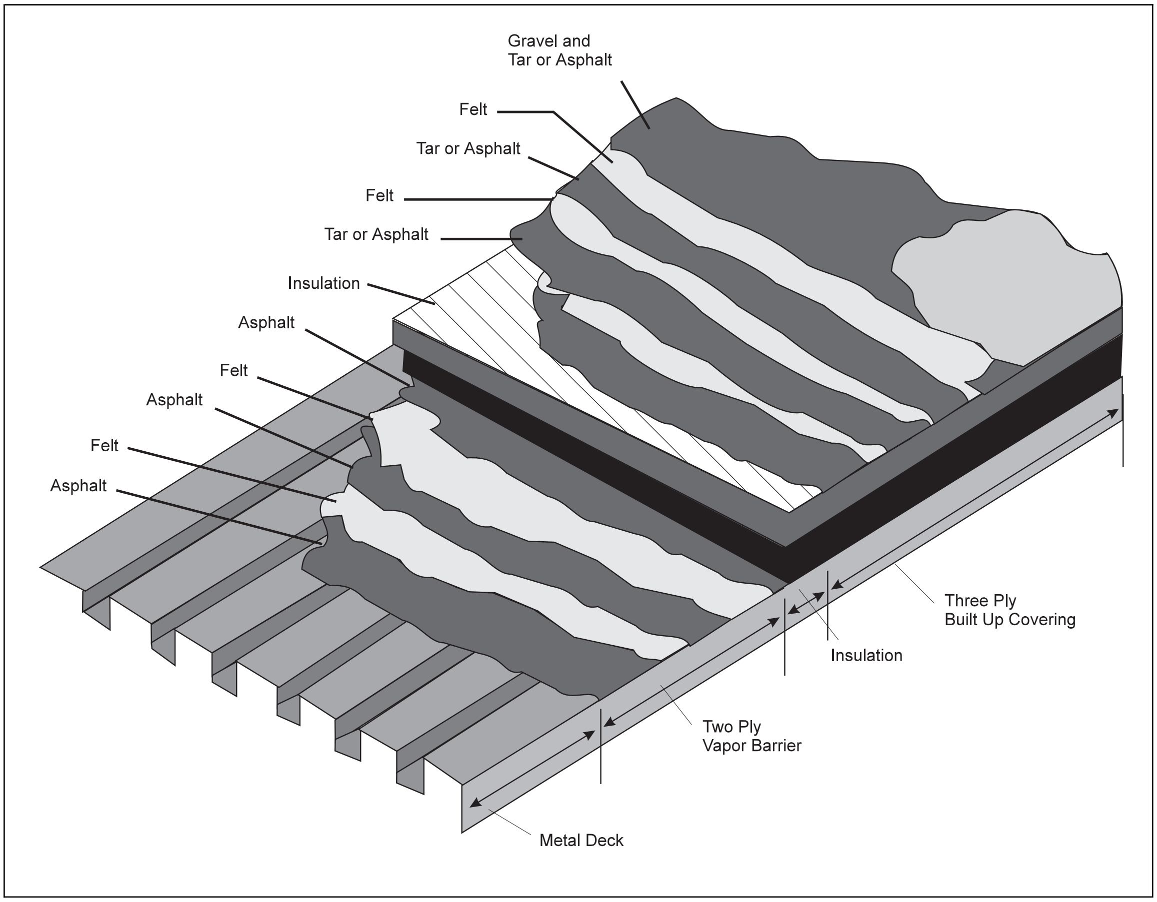

Fig. 16. Typical Class 2 insulated metal roof deck construction with vapor barrier.

This would directly expose most of the underside of the combustible above deck components in the flame impingement area. That would greatly increase the fuel contribution rate of the above deck components and result in a Class 2 roof.

Sprinkler protection is generally recommended below Class 2 roofs, however, for exceptions refer to Data Sheet 1-12. An Approved undercoating applied to the underside of the deck is an acceptable alternative to sprinklers if the occupancy is noncombustible.

Class 1 Insulated Metal Roof Decks. A roof deck calorimeter test is conducted to determine the heat release rates of the above deck components. Assemblies that have rates that do not exceed the acceptable criteria will have a limited fire spread and are categorized as Class I (limited combustible) insulated steel deck. Assemblies that qualify for Class 1 are listed in the *Approval Guide* and described in Data Sheet 1-29 and do not, by themselves, necessitate sprinkler protection.

Since the early 1980's, insulated steel deck has generally been constructed using mechanical fasteners to secure insulation to the deck. In this case the limited combustibility of the insulation, and its ability to act as a thermal barrier to limit fuel contribution from other components above, is necessary to maintain a Class 1 fire rating. Prior to the 1980's, adhesives were often used to secure the insulation to the deck (see Fig. 17) and it was necessary to limit the quantities of adhesives as well in order to maintain a Class 1 fire rating. Such construction is no longer recommended due to adverse wind loss experience (see Data Sheet 1-29).

Insulated metal decks are not used for floor construction. Consequently, when metal deck is noted below an upper floor it is generally being used as a form deck (for concrete) which will remain in place.

Stucco on wood or metal lath is sometimes used for wall construction. This should not be confused with EIFS noted in Section C.5.

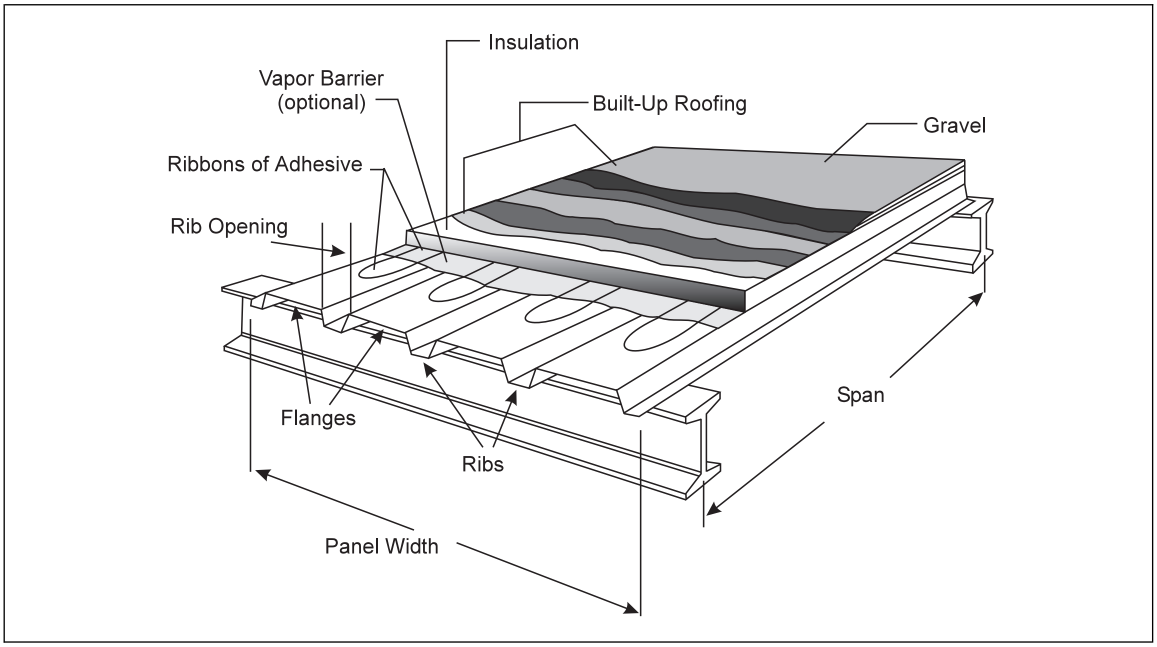

Fig. 17. "Old Style" Class 1 insulated steel deck roof using limited quantities (ribbons) of adhesive to secure insulation and vapor barrier.