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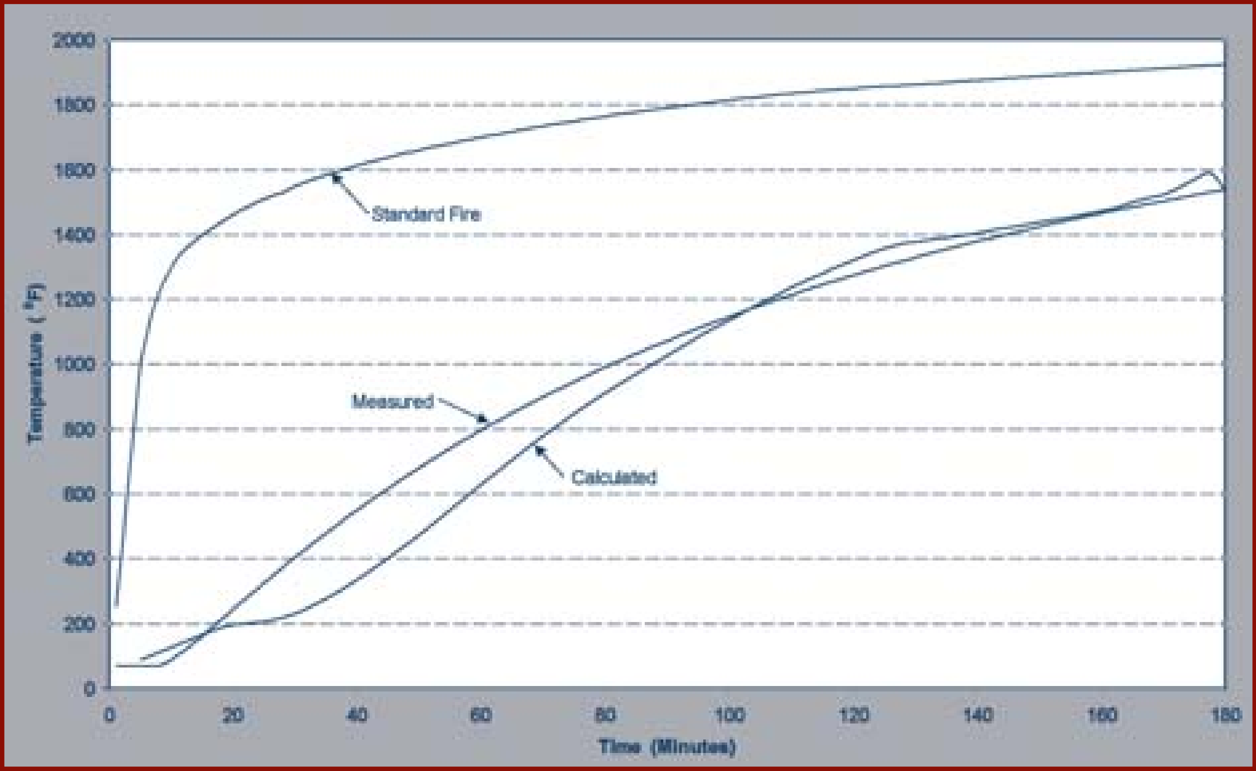
Steel Design Guide

Fire Resistance

of Structural Steel Framing



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Steel Design Guide

Fire Resistance
of Structural Steel Framing

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Section I
INTRODUCTION

I.1 GENERAL INFORMATION

An important objective of building codes and regulations is to provide a fire-resistive built environment. Thus, building fire safety regulations contain numerous provisions including directives for the minimum number of exits, the maximum travel distances to exits, minimum exit widths, fire compartment requirements, fire detection and suppression mandates, and the protection of structural members in buildings. The focus of this design guide is the fire protection of structural steel framing systems. The guide is arranged such that important information for fire protection design, including that for building codes and test standards, is repeated within the design chapters to allow them to function as self-containing, stand-alone sections.

Although structural steel offers the advantage of being noncombustible, the effective yield strength and modulus of elasticity reduce at elevated temperatures. The yield strength of structural steel maintains at least 85 percent of its normal value up to temperatures of approximately 800 °F (427 °C). The strength continues to diminish as temperatures increase and at temperatures in the range of 1,300 °F (704 °C), the yield strength may be only 20 percent of the maximum value[1]. The modulus of elasticity also diminishes at elevated temperatures. Thus, both strength and stiffness decrease with increases in temperature

Measures can be taken to minimize or eliminate adverse effects. An obvious approach is to eliminate the heat source by extinguishing the fire or by generating an alert so that an extinguishing action can be initiated. Extinguishing systems such as sprinklers and smoke and heat detection devices are responses to this approach, and are classified as active fire protection systems.

Another approach to improving the fire safety of a steel structure is to delay the rate of temperature increase to the steel to provide time for evacuation of the environment, to allow combustibles to be exhausted without structural consequence, and/or to increase the time for extinguishing the fire. This approach, which involves insulating the steel or providing a heat sink, is classified as a passive fire protection system. Figure I.1 is a photograph of a steel beam employing such a system using Spray-Applied Fire Resistive Material (SFRM). This design guide concentrates on the passive fire protection of structural steel framing.

The typical approach to satisfying the passive protection system objective is prescriptive. Buildings are classified according to use and occupancy by the building code. For each occupancy classification there are height and area limitations that are dependent upon the level of fire resistance provided. For instance, a building providing for business uses may have a height and floor area requiring building elements to be noncombustible and have a fire resistance rating of 2 hours. Then a tested floor assembly that provides a 2-hour fire resistance rating is identified and, as necessary, adjustments to the specifics of the tested assembly are made to match the actual construction. Thus, the required level of fire resistance is provided based on tests and extrapolation of test results. The process for identifying the appropriate tested assembly and making necessary adjustments is clarified within this design guide.

Improving the fire resistance of steel-framed structures using a passive system is only one of the strategies for providing fire-safe structures. Improvements in fire safety are most effective when used in conjunction with active systems.

An alternative approach to fire-safe construction is performance based. Under this option, calculations are prepared to predict a level of performance of the structure in a fire environment. Extensive research is progressing toward a thorough understanding of the behavior of steel-framed structures when exposed to fire, and an increase in the use of alternative design methods is inevitable.

I.2 MODEL BUILDING CODES

The standard frequently referenced in this guide is the 2000 version of the International Building Code (IBC)[2]. At the time of this writing, a 2003 version of the IBC has been released. Some of the provisions of

Fig I.1 Beam protected with SFRM.

IBC 2000 have been revised in IBC 2003. Since the adoption of a code version by a municipality may follow a code release by several years, it is probable that the IBC 2000 provisions will prevail in many locations for some time. Thus, the decision to use the provisions of IBC 2000 is purposeful, though not intended to preclude application of the principles herein in jurisdictions that have adopted IBC 2003 or another model building code.

The use of IBC provisions is not intended to indicate a preference for the IBC over the National Fire Protection Association (NFPA)[3] building code. Rather, one building code was selected to maintain a consistency in the design guide.

I.3 RESOURCES

Through the mid 1980's the American Iron and Steel Institute (AISI) served as a prolific and valuable resource for the design of fire protection for steel-framed structures. Design guides and directives were published by AISI addressing general steel construction[4, 5] as well as more focused treatments of beams[6], columns[7] and trusses[8]. In many instances the AISI guidance is still valid, but the AISI publications are currently out of print and more recent information has not been incorporated. This guide has incorporated, verified, expanded, and supplemented this data to provide a single resource for designing fire protection for steel-framed structures.

REFERENCES

[1] Lie, T.T. (1992), "Structural Fire Protection," *Manual and Reports on Engineering Practice,* ASCE, No. 78.

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[3] National Fire Protection Association (NFPA) (2003), *NFPA 5000: Building Construction and Safety Code,* 2003 Edition, Quincy, MA.

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[6] American Iron and Steel Institute (AISI) (1984), *Designing Fire Protection for Steel Beams*, Washington, D.C.

[7] American Iron and Steel Institute (AISI) (1980), *Designing Fire Protection for Steel Columns*, Third Edition, Washington, D.C.

[8] American Iron and Steel Institute (AISI) (1981), *Designing Fire Protection for Steel Trusses*, Second Edition, Washington, D.C.

Section II BUILDING CODE REQUIREMENTS

II.1 GENERAL INFORMATION

Model building codes are the resource for building guidelines adopted by a jurisdiction. Either by direct adoption or by reference, these codes provide a standardized set of rules and regulations for the built environment. The intent of these regulations is to provide minimum standards to ensure public safety, health and welfare insofar as they are affected by building construction. Although there is a general trend to provide regulations in terms of performance rather than providing a rigid set of specifications, the prescriptive nature of the current building regulations remains in use and will likely always be an accepted alternative.

II.2 BUILDING CODES

The predominant building and safety organizations in the United States are:

- Building Officials and Code Administrators (BOCA)
- Southern Building Code Congress International (SBCCI)
- International Conference of Building Officials (ICBO)
- International Code Council (ICC)
- National Fire Protection Association (NFPA)

In 1994, BOCA, SBCCI, and ICBO came together to create ICC. The purpose of this organization is to consolidate the different model code services and produce a single set of coordinated building codes that can be used uniformly throughout the construction industry. In 2000, ICC published a comprehensive set of 11 construction codes, including the International Building Code (IBC)[1]. As of January 2003, BOCA, SBCCI, and ICBO no longer function as individual entities, and have been completely integrated into the ICC organization[2].

There is still no complete consensus within the industry for a single national building code. In 2003, the NFPA developed and published its own set of building regulations, based on the American National Standards Institute (ANSI)-accredited process, with its building code NFPA 5000[3].

II.3 IBC FIRE RESISTANT DESIGN

The IBC allows both prescriptive and performance-based fire-resistant designs, although its current emphasis is clearly on the former. Section 719 of the code explicitly lists several detailed, prescriptive fire-resistant designs. However, the IBC also allows the designer to choose from other alternative methods for design as long as they meet the fire exposure and criteria specified in the American Society for Testing and Materials (ASTM) fire test standard ASTM E119[4].

> *703.3 Alternative methods for determining fire resistance.*
>
> 1. *Fire resistance designs documented in approved sources.*
> 2. *Prescriptive designs of fire resistance rated building elements as prescribed in Section 719.*
> 3. *Calculations in accordance with Section 720.*
> 4. *Engineering analysis based on a comparison of building element designs having fire resistance ratings as determined by the test procedures set forth in ASTM E119.*
> 5. *Alternative protection methods as allowed by Section 104.11.*

Notwithstanding the ability to use a performance-based design approach, this design guide's treatment of the building codes will generally be based on the application of the prescriptive provisions of the IBC.

II.4 REQUIRED FIRE RESISTANCE RATINGS

Fire-safe construction is a major focus of the building codes, which mandate certain levels of fire protection. The required fire protection for a building is determined by a combination of the following:

1. Intended use and occupancy
2. Building area
3. Building height
4. Fire department accessibility
5. Distance from other buildings
6. Sprinklers and smoke alarm systems
7. Construction materials

Once these factors have been resolved, the fire resistance rating requirements for a particular building can be determined. The ratings are given as a specified amount of time the building's structural elements are required to withstand exposure to a standard fire.

For a specific occupancy, the larger the building, the higher the probability is that it will experience a fire in its lifetime. Building codes often require a longer period of fire endurance for larger buildings than for smaller buildings of similar occupancy. Some occupancies are naturally at greater fire risk for inhabitants than others. For instance, occupants of a nursing home with non-ambulatory patients could be at a greater risk during fires than occupants of a similar office building. A greater period of fire resistance is required for the occupancies that present a greater life safety risk to occupants. The degree of protection can also vary with the type of building material, either combustible or noncombustible, and whether the building poses risk to neighboring buildings. Thus, the building code attempts to mandate the required level of fire protection considering numerous parameters.

Buildings are generally constructed to serve a specific function and several occupancy classifications may be required to satisfy functional needs. For instance, an education facility can have both classrooms (i.e. educational occupancy) and an auditorium (i.e. assembly). The building code addresses these mixed occupancy conditions by allowing the building to be constructed to meet the requirements of the more restrictive type of construction of either occupancy. Alternately, the uses may be separated by fire barrier walls and/or horizontal fire-rated assemblies. The size and height of the building evolves from creating space needed to allow the function to be performed within its enclosure. Early in the planning process, the occupancy, height, and area are established. These parameters are used to determine the level of fire resistance. The IBC occupancy classifications are listed in Table II.1.

The structural system is generally established in the early stages of project development. Often, the selection of the structural system is influenced by the height and area restrictions to the building code limited construction type. The construction types are defined in IBC Chapter 6. A tabulation of construction types with an abbreviated description is indicated in Table II.2.

Structural steel framing is noncombustible, and can be used in construction classified as Type I, Type II, Type III, or Type V. Type I and Type II construction allows only noncombustible materials to be used in construction. Type I permits greater building heights and areas to be used than Type II does, thus requiring a greater duration of fire resistance. Type III construction allows both combustible and noncombustible interior building elements with noncombustible exterior walls. Type V construction allows combustible materials in all building elements. For a specific occupancy classification, the allowable height and area for Type II construction always equals or exceeds the height and area allowable for Type III or Type V construction. The exterior wall fire resistance rating for Type III construction is more severe than that required for Type II construction. Therefore, since steel framing systems satisfy the noncombustible framing requirements, they are most efficiently used in Type II and Type I construction.

The height above the ground plane and area per floor limitations for the various types of construction are indicated in IBC Table 503. In addition to the area per floor limitation, the IBC also limits the maximum area of the building to be the area per floor as prescribed in IBC Table 503 multiplied by the number of stories of the building up to a maximum of three stories. The height and area limitations included in the IBC Table 503 can be increased if specific additional life safety provisions are included in the facility. Descriptions of these modifications are listed below.

II.4.1 Area Modifications. An increase in fire department accessibility (frontage) and/or incorporating an approved automatic sprinkler protection can modify the allowed building area. Requirements for using these area modifications are described in Section 506 of the IBC, and are illustrated in Example II.1 in this chapter.

II.4.2 Fire Wall Separations. A fire wall can often be used to divide the building into segments. Through the use of fire walls, height and area limitations can be applicable to the segment rather than the entire floor area. The segment area may permit the use of a construction type having less stringent fire resistance rating requirements than those for the entire building. In some cases the need for structural fire protection can be completely eliminated, as the non-combustible steel without protection will provide an acceptable level of fire safety. To qualify as a fire wall, specific requirements must be met, such as the stability condition defined in IBC paragraph 705.2:

> *Fire walls shall have sufficient structural stability under fire conditions to allow collapse of construction on either side without collapse of the wall for the duration of time indicated by the required fire resistance rating.*

Further construction requirements for fire walls are included in IBC Section 705.

Table II.1 IBC Use and Occupancy Classifications	
Group	**Use**
A	Assembly
B	Business
E	Educational
F	Factory
H	High-Hazard
I	Institutional
M	Mercantile
R	Residential
S	Storage
U	Utility and Misc.

II.4.3 Fire Partitions. A fire partition is a barrier to restrict the spread of fire and is used to separate dwelling units, guestrooms, tenant spaces in covered malls, and corridor walls. Fire partitions are often required to provide a 1-hour fire resistance rating. Generally, the structure supporting fire partitions should have a fire resistance rating equal to the rating of the fire resistive construction supported. However, the need to provide a 1-hour fire resistance rating for structures supporting a fire partition in Type IIB construction is exempted. The support of fire partitions in Type IIB construction is allowed without having to upgrade the structure's fire resistance rating to 1-hour as described in IBC Section 708.4.

II.4.4 Height Modifications. Maximum building height and story modifications are possible by incorporating the use of an approved automatic sprinkler system. Requirements for using these height modifications are described in Section 504 of the IBC, and are illustrated in Example II.1 in this chapter.

II.4.5 High-Rise Building Modifications. In lieu of area and height modifications, the IBC allows high-rise buildings (i.e. buildings with occupied floors located more than 75 ft (22.9 m) above the lowest level of fire department vehicle access) to have a reduction in the minimum construction type. The IBC requires that additional life safety provisions be made to use the reduced construction type. All the provisions included in IBC Section 403 High-Rise Buildings must be satisfied to use the reduction in minimum construction type. These provisions include automatic sprinkler protection, secondary water supplies, special sprinkler control and initiation devices, standby power, and several other requirements. The improved safety due to these enhancements is recognized by allowing a reduction in the fire resistance rating as follows:

Table II.2 IBC Construction Types	
Type	**Description of Materials**
I	Noncombustible
II	Noncombustible
III	Exterior walls-Noncombustible Interior building elements- Combustible or Noncombustible
IV	Heavy Timber, HT Exterior walls - Noncombustible
V	Combustible or Noncombustible

403.3.1 Type of construction. The following reductions in the minimum construction type allowed in Table 601 shall be allowed as provided in Section 403.3:

1. Type IA construction shall be allowed to be reduced to Type IB.

2. In other than Groups F-1, M and S-1, Type IB construction shall be allowed to be reduced to Type IIA.

II.4.6 Unlimited Area Buildings. IBC Section 507 permits unlimited areas for one-story and two story buildings of certain occupancies, where these building are surrounded and adjoined by public ways or yards of minimum specified widths.

II.4.7 Open Parking Garages. Parking garages that fit into the definition of open, according to IBC 406.3.2, constitute a reduced fire risk due to the good ventilation of the premises. In recognition of that, increased height and area limits for open parking garages are specified in IBC 406.3.

II.4.8 Special Provisions. IBC Section 508 provides for several other special case exceptions and modifications for height and area limits.

After the appropriate construction type has been established, the fire resistance rating requirements for specific structural elements may then be ascertained. Table 601 of the IBC lists fire resistance ratings in hours for various building elements as a function of the construction type. A summary of the fire resistance requirements for floor construction including supporting beams and joists for Type I and Type II is listed in Table II.3.

Table II.3 IBC Fire Resistance Requirements for Building Floor Construction (From IBC Table 601)		
Construction Type		Rating (hours)
Type I	A	2
	B	2
Type II	A	1
	B	0

Table II.4 IBC Fire Resistance Requirements for Building Structural Frames (From IBC Table 601)		
Construction Type		Rating (hours)
Type I	A	3
	B	2
Type II	A	1
	B	0

A summary of the structural frame requirements taken from the IBC for construction Type I and Type II is listed in Table II.4. The structural frame is defined in a footnote to IBC Table 601 as:

The structural frame shall be considered to be the columns and the girders, beams, trusses and spandrels having direct connections to the columns and bracing members designed to carry gravity loads.

II.4.9 EXAMPLE II.1

Determine the structural frame fire resistance rating for a steel framed building given the following:

Medical Office Building
Height = 50 ft (15.2 m), 4 stories
Footprint = 200 ft x 250 ft = 50,000 ft^2 (4,650 m^2)
Total Area = 50,000 x 4 =200,000 ft^2 (18,600 m^2)
Building Perimeter, P = 900 ft (274 m)
Perimeter fronting public way, F = 450 ft (137 m)
Access way width, W=25 ft (7.6 m)
Note: the minimum width to qualify as a public way access is 20 ft (6.1 m).
Automatic sprinkler system throughout
Noncombustible construction

IBC Section 304 lists buildings housing professional services such as dentists and physicians as Business Group B.

Given the initial floor area (50,000 ft^2 or 4650 m^2) and building height (50 ft or 15.2 m, 4 stories), without considering area or height increases, construction Type I B would be required by IBC Table 503. IBC Table 601, summarized in Table II.3 of this section, requires the structural frame for this building to achieve a 2-hour fire resistance rating.

The presence of a fire suppression system and the amount of perimeter access to a public way improve the fire safety of the building. This improvement is acknowledged by the IBC by allowing increases in the area per floor allowed for a specific construction type.

Therefore, one method of identifying an acceptable construction type is to determine a minimum acceptable base area that can be read directly from the base area table. This approach will be followed.

Area modification (IBC Section 506):

$$A_a = A_t + \left[\frac{A_t * I_f}{100}\right] + \left[\frac{A_t * I_s}{100}\right] \qquad \textbf{(II-1)}$$

where
A_a = Allowable area per floor (ft^2).
A_t = Tabular area per floor in accordance with Table 503 (ft^2).
I_f = Area increase due to frontage (percent) as calculated in accordance with Section 506.2 and shown below.
I_s = Area increase due to sprinkler protection (percent) as calculated in accordance with Section 506.3.

Frontage Increase:

$$I_f = 100 * \left[\frac{F}{P} - 0.25\right] * \frac{W}{30} \qquad \textbf{(II-2)}$$

where
I_f = Area increase due to frontage (percent).
F = Building perimeter which fronts on a public way or open space having 20 ft (6.1 m) minimum width.
P = Perimeter of building.
W = Minimum width of public way or open space.

$\therefore I_f$ = 100*(450/900 – 0.25)*(25/30)
= 20 percent

Automatic sprinkler system increase:

Section 506.3 of the IBC allows buildings protected with an approved automatic sprinkler system to have an area increase of:

200 percent (I_s = 200 percent) for multi-storied buildings
300 percent (I_s = 300 percent) for single-story buildings

$\therefore I_s = 200$ percent

SUMMARY

	Percent
Base Area	100
Frontage Increase	20
Sprinkler Increase	200
Area after Increase	320

Structural steel framing is non-combustible and complies with the requirements of Type I and Type II construction. The following tabulations summarize the tabular area from the IBC, the allowable area for this example, and the maximum building area for this example. The second table lists the area limits in SI units.

Construction Type	Tabular Floor Area (ft^2)	Allowable[a] Floor Area (ft^2)	Maximum[b] Building Area (ft^2)
I A	UL	UL	UL
I B	UL	UL	UL
II A	37,500	120,000	360,000
II B	23,000	73,600	220,800

Construction Type	Tabular Floor Area (m^2)	Allowable[a] Floor Area (m^2)	Maximum[b] Building Area (m^2)
I A	UL	UL	UL
I B	UL	UL	UL
II A	3,480	11,100	33,300
II B	2,140	6,850	20,500

UL = Unlimited
[a] = 320 percent times Tabular area
[b] = Stories x Allowable floor area (max. 3 stories)

Construction Type IIB satisfies both the floor area and maximum building area limitations.

Building height limitations are also prescribed. The benefits of sprinklers are again recognized in IBC by allowing height increases. Section 504.2 of the IBC allows buildings protected with an approved automatic sprinkler system to have an allowable tabular height increase of +20 ft (6.1 m) and an allowable tabular story increase of +1.

The tabulated story limit and height limit for Type IIB construction are 4 and 55 ft (16.8 m) respectively. Thus, the adjusted limits are 5 stories (4 + 1) and 75 ft (55 + 20) or 22.9 m (16.8 + 6.1). The height limitations are satisfied with Type II B construction.

In accordance with IBC Table 601, for Type IIB construction, **0-hour** fire resistance rating is required, therefore no protection is required for the structural steel frame.

II.4.10 EXAMPLE II.2

Determine the structural frame fire resistance rating requirements for a steel framed building given the following:

Apartment Building
Building height = 96 ft (29.3 m), 8 stories
Height of highest occupied floor = 84 ft (25.6 m)
Footprint = 150 ft x 150 ft = 22,500 ft^2 (2,090 m^2)
Automatic sprinkler system with sprinkler control valves according to IBC 403.3

IBC Section 310 lists apartment buildings as Residential Group R-2.

IBC Section 403 classifies most buildings, including Residential Group R-2 buildings, having occupied floors located more than 75 ft (22.9 m) above the lowest level of fire department vehicle access as "High-Rise" buildings. High-Rise buildings must comply with the requirements of IBC Section 403 including an automatic sprinkler system, automatic fire detection, standby power, etc. Additionally, it bears noting that Group R-2 buildings of Type IIA construction not classified as "High-Rise" buildings, but still meeting the requirements of IBC 508.7, may have their height limitation increased to 9 stories and 100 ft.

Given the initial floor area (22,500 ft^2 or 2,090 m^2) and building height (96 ft or 29.3 m, 8 stories), IBC Table 503 requires an initial construction of Type IB for occupancy group type R-2, as shown in Tables II.5a and II.5b. IBC Table 601, summarized in Table II.3 of this section, requires the structural frame for this building to achieve a 2-hour fire resistance rating.

For high-rise buildings such as in this example, the IBC recognizes the protection afforded to the building by the additional life safety provisions required for high-rise buildings and a reduction in the fire resistance rating is allowed. For occupancy group R-2, section 403.3.1 of the IBC allows a reduction from Type IB construction to Type IIA. Therefore, the structural frame of the building is required to have a fire resistance rating requirement of **1 hour**.

Table II.5a Allowable Height and Building Areas for Occupancy Type R-2 (Derived From IBC Table 503)			
Constr. Type	**Height (ft)**	**No. Stories**	**Area (ft^2)**
Type IA	UL	UL	UL
Type IB	160	11	UL
Type IIA	65	4	24,000
Type IIB	55	4	16,000
Type IIIA	65	4	24,000
Type IIIB	55	4	16,000
Type IV HT	65	4	20,500
Type VA	50	3	12,000
Type VB	40	2	7,000

Table II.5b (SI Units) Allowable Height and Building Areas for Occupancy Type R-2 (Derived From IBC Table 503)			
Constr. Type	**Height (m)**	**No. Stories**	**Area (m^2)**
Type IA	UL	UL	UL
Type IB	48.8	11	UL
Type IIA	19.8	4	2,230
Type IIB	16.8	4	1,490
Type IIIA	19.8	4	2,230
Type IIIB	16.8	4	1,490
Type IV HT	19.8	4	1,910
Type VA	15.2	3	1,120
Type VB	12.2	2	650

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[1] International Code Council, Inc. (ICC) (2000), *International Building Code, 2000,* Falls Church, VA.

[2] International Code Council, Inc. (ICC) (2003), *News Releases*, <http://www.iccsafe.org>.

[3] National Fire Protection Association (NFPA) (2003), *NFPA 5000: Building Construction and Safety Code,* 2003 Edition, Quincy, MA.

[4] American Society for Testing and Materials (ASTM) (2000), *Standard Test Methods for Fire Tests of Building Construction and Materials*, Specification No. E119-00, West Conshohocken, PA.

Section III
STANDARD FIRE TEST

III.1 GENERAL INFORMATION

A standardized method of conducting a fire test of controlled duration and severity is essential to accurately compare results from different investigations. This issue was initially addressed in 1903 with proposals presented by the British Fire Prevention Committee and adopted at the International Fire Congress in London. These proposals were later modified for practice in the United States, and in 1918, at a joint conference between the American Society for Testing Materials (ASTM) and the National Fire Protection Association (NFPA), the first U.S. standards were adopted. Underwriters Laboratories Inc. (UL) followed shortly thereafter, publishing the first edition of a separate standard in 1929 that was approved by the American National Standards Institute (ANSI)[1].

Today, ASTM E119[2], NFPA 251[3], and ANSI/UL 263[1] have become the standards for fire resistance testing of construction elements in the United States. They provide uniform testing methods for walls and partitions, columns, beams, and roof and floor assemblies. The procedures and requirements for elements tested under each of the three standards are virtually identical to each other. For the purposes of this guide, ASTM E119 will be referenced.

III.2 PROCEDURE

The procedure begins with choosing a specimen that represents the construction to be tested and assembling it within or above a test furnace that is capable of subjecting the specimen to increasing temperatures in accordance with a standard time-temperature relationship. A typical furnace for roof and floor systems is shown in Figure III.1. Thermocouples are attached to the element, and, if appropriate, fire protection is applied. Specimens representing floor and roof assemblies are always subjected to a superimposed force, normally equal to their full design capacity. A reduced load condition is allowed, but the assembly in practice must also have the same limit placed on load capacity. Standard test methods allow columns to be tested with or without load. However, columns are almost always tested in an unloaded condition due to the limited number of facilities available for loaded column testing.

The element is then subjected to furnace temperatures conforming to the standard time-temperature curve. The test is conducted under a slight negative furnace pressure for the safety of the laboratory personnel. Depending on the standard's specific criteria for the type of element tested (wall, column, roof, floor, or beam) and the rating desired (restrained or unrestrained), the test is completed when either a limiting temperature criteria is met or the element can no longer support its design load. A list of limiting criteria for ASTM E119 is shown in Table III.1. The standard also provides alternative test procedures for elements without the application of design loads.

Walls undergo an additional hose stream test that consists of discharging a pressurized stream of water upon the wall and observing its impact and cooling effects. The hose stream test may be applied to the tested specimen immediately following the fire endurance test, or may be applied to a duplicate specimen subjected to a fire endurance test for one-half of its classification rating. A fire resistance rating, expressed in hours, is derived from the standard fire test by measuring the time elapsed until a failure criterion is reached.

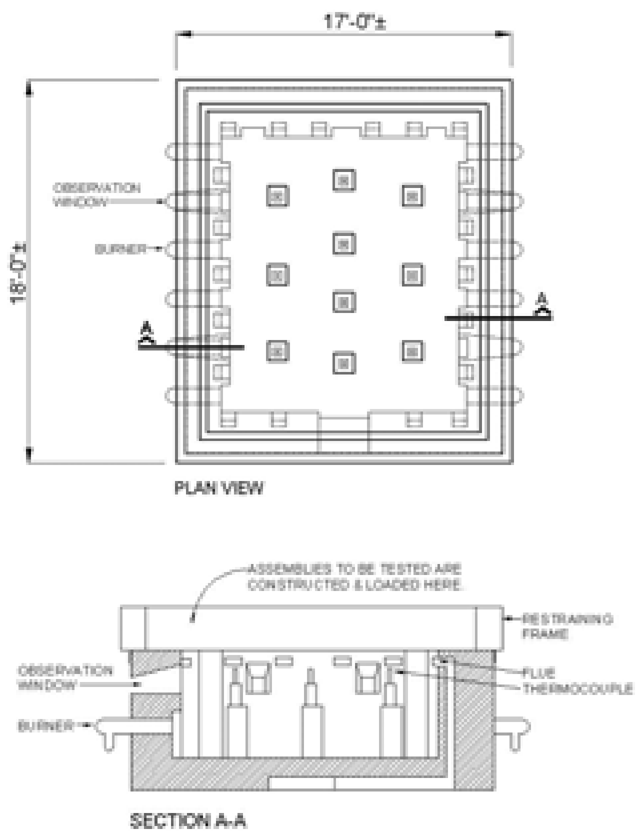

Fig. III.1 Typical Furnace for Roof and Floor Assembly Testing[11]

Table III.1 **ASTM E119 Limiting Criteria**	
Load-Bearing Walls and Partitions	The element can no longer sustain its superimposed load.
	The ignition of cotton waste on the unexposed surface.
	An opening develops permitting a projection of water beyond the unexposed surface during the hose stream test.
	The temperature on the unexposed surface at any point rises more than 325 °F (181 °C).
	The average temperature on the unexposed surface rises more than 250 °F (139 °C).
Non-bearing Walls and Partitions	The ignition of cotton waste on the unexposed surface.
	An opening develops permitting a projection of water beyond the unexposed surface during the hose stream test.
	The temperature on the unexposed surface at any point rises more than 325 °F (181 °C).
	The temperature on the unexposed surface rises more than 250 °F (139 °C).
Loaded Columns	The element can no longer sustain its superimposed load.
Unloaded Columns	The average temperature exceeds 1,000 °F (538 °C).
	The temperature at any one point exceeds 1,200 °F (649 °C).
Restrained Roof and Floor Assemblies and Loaded Beams	The element can no longer sustain its superimposed load.
	The ignition of cotton waste on the unexposed surface. (Assembly ratings only)
	At the larger of ½ the rated time or 1 hour, the average steel temperature exceeds 1,100 °F (593 °C)
	At the larger of ½ the rated time or 1 hour, the temperature at any one point exceeds 1,300 °F (704 °C)
Restrained Roof and Floor Assemblies and Loaded	The temperature on the unexposed surface at any point rises more than 325 °F (181 °C). (Assembly ratings only)
	The temperature on the unexposed surface rises more than 250 °F (139 °C). (Assembly ratings only)
Unrestrained Roof and Floor Assemblies and Loaded Beams	The element can no longer sustain its superimposed load.
	The ignition of cotton waste on the unexposed surface. (Assembly ratings only)
	The average temperature recorded by four thermocouples exceeds 1,100 °F (593 °C). (Specimens employing members spaced more than 4 ft on center only)
	The temperature at any one point exceeds 1,300 °F (704 °C). (Specimens employing members spaced more than 4 ft on center only)
	The average temperature recorded by all thermocouples exceeds 1,100 °F (593 °C). (Specimens employing members spaced 4 ft or less on center only)
	The temperature on the unexposed surface at any point rises more than 325 °F (181 °C). (Assembly ratings only)
	The temperature on the unexposed surface rises more than 250 °F (139 °C). (Assembly ratings only)
	The average temperature recorded by all thermocouples located on any one span of steel floor or roof decks exceeds 1,100 °F (593 °C). (Units intended for use in spans greater than those tested only)
Unloaded Steel Beams and Girders	Average temperature exceeds 1,000 °F (538 °C).
	Temperature at any one point exceeds 1,200 °F (649 °C).

III.3 STANDARD TEST FIRE

The standard test fire is identical for ASTM E119, NFPA 251, and ANSI/UL 263. The test fire has remained virtually unchanged since it was first documented in the United States in 1918[2]. The rate at which the test fire is applied is governed by the standard time-temperature curve, shown in Figure III.2. Characteristics of this curve include a rapid temperature increase and a long duration. Temperatures continually increase with time, and there is no cooling period.

Furnace temperatures are adjusted to match the curve based on readings taken at least every 5 minutes during the first 2 hours of the test and every 10 minutes thereafter. The accuracy of the test is obtained by comparing the area under the applied time-temperature curve to the standard time-temperature curve. Tests for systems with ratings of 1 hour or less are considered successful if the areas are within 10 percent of each other, ratings 2 hours or less require 7.5 percent accuracy, and ratings greater than 2 hours require 5 percent accuracy.

In addition to the standard test fire, ASTM also provides a procedure to test elements exposed to hydrocarbon pool fires. This Standard, designated as ASTM E1529[4], includes an even greater rate of temperature rise and severity than the standard test fire.

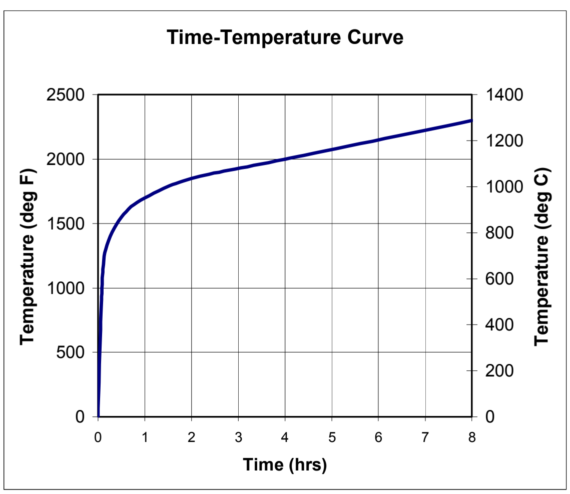

Fig. III.2 Standard Time-Temperature Curve

III.3.1 LIMITATIONS OF THE STANDARD FIRE TEST

The standard fire test provides a working baseline for the comparison of the performance of different fire resistant constructions. However, due to assumptions and constraints inherent within it, the test should not be misconstrued to predict the behavior of an element under actual building fire conditions. In this regard, the standard fire test is subject to several limitations.

1. The time-temperature curve for the standard test fire is characterized by a rapid temperature rise followed by continually increasing temperatures. Research has shown that, in reality, a building fire can behave quite differently[5]. Instead of a rapid temperature rise as in the standard time-temperature curve, building fires may build temperatures relatively slowly during the initial ignition phase. From this stage, some building fires go through rapid temperature elevations in a phenomenon called "flashover" where nearly every combustible object in the compartment simultaneously ignites. These fires further progress to a fully developed stage where temperatures can become greater than those of the standard time-temperature curve. Fires that do not advance to "flashover" condition result in less severe heat exposure conditions through the fire plume or hot smoke layer. Other fires lacking sufficient oxygen or fuel necessary to reach the flashover point may remain localized and develop temperatures well under the standard curve. Lastly, whereas temperatures in the standard time-temperature curve continually increase with time, building fires eventually go through a cooling phase as building contents are exhausted or otherwise extinguished by active fire protection measures. A schematic plot of how the standard fire test compares to typical building fires is shown in Figure III.3.

2. The test bay used for the standard fire test has different ambient conditions than those found in an actual building fire. During the test, specimens are tested under negative pressure for the safety of laboratory personnel. Under actual building fire conditions, pressures are typically positive[3]. The specimen is also tested with sufficient ventilation to provide for full combustion. The ventilation during an actual building fire may be limited.

3. Load-bearing elements are generally tested under their full superimposed dead and live design loads. If limited loading design criteria are specified for the assembly, the corresponding reduced load is applied. The standard gives no assessment to the low probability of the entire design load occurring during an extraordinary fire event. In *Minimum Design Loads for Buildings and Other Structures* by The American Society of Civil Engineers (ASCE)[6], a significant reduction is allowed in design live loads for members experiencing extraordinary events. A similar reduction is also provided for in the *Model Code on Fire Engineering* published by the European Convention for Constructional Steelwork (ECCS)[7].

4. Because standard furnaces are limited in size, members with lengths greater than the test frame cannot be accommodated. ASTM E119 acknowledges this limitation, and alerts the designer that the test does not provide "full information as to the performance of assemblies constructed with components or lengths other than those tested."

5. The standard fire resistance test does not address the contribution of combustible construction (to fire intensity) that sometimes results in significantly lower fuel consumption in order to maintain the ASTM E119 time-temperature regime in the furnace. This effect somewhat undermines the intended purpose of the standard to provide a uniform "comparative" evaluation method for different types of construction under the "same" fire exposure, as tests of similar duration on combustible and noncombustible specimens consume different amounts of furnace fuel.

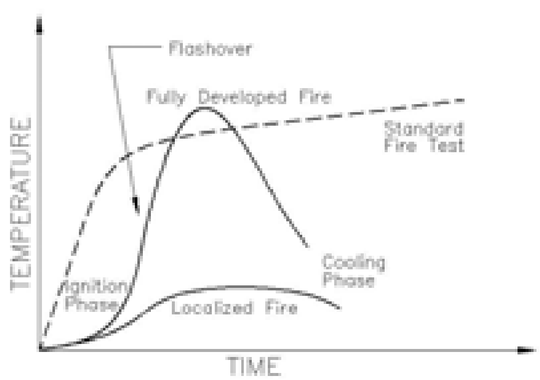

Fig. III.3 Time-Temperature Curve of Standard Fire Test vs. Typical Building Fires

6. Results from ASTM E119 do not account for the effects that some conventional openings, including electrical outlets and pipe penetrations have on the overall performance of the assembly. Although penetrations can be included in the test, they seldom are. Standard ASTM E814[8] is usually used to test penetrations in fire resistive assemblies because smaller samples can be tested. The test is also not designed to simulate the behavior of joints between floors and walls, or connections between columns and beams.

7. Not necessarily a limitation of ASTM E119, but an appropriate clarification is to note that ASTM E119 does not test for the ability of wall or floor assemblies to limit the generation and migration of smoke and toxic gases – the major causes of fatalities and injuries in fire incidents. Combustible construction, even when rated for fire resistance, can significantly contribute to smoke generation when exposed to fire.

III.4 THERMAL RESTRAINT

Test specimens used in the standard fire test are chosen to be representative of the building constructions for which the test results will be applied. For roof and floor systems (and for individual beams), this representation also includes perimeter restraint conditions (end restraint conditions for beams) with respect to the test frame where the specimen is mounted. In 1970, ASTM E119 was amended to take into account two different conditions defined as restrained and unrestrained. This dual classification system is used for design within the United States and Canada. Prior to 1970, a simpler rating system was used, as the perimeter (or end) conditions were not specified in the standard. However, the beneficial effect of perimeter restraint for floor and roof assemblies was well known by specialists, and most of the rated specimens were tested in the restrained condition.

The restrained classification models the continuity provided by the roof or floor construction, and by the structural frame, in actual construction. ASTM E119 defines building construction as restrained when the "surrounding or supporting structure is capable of resisting substantial thermal expansion throughout the range of anticipated elevated temperatures." This condition is representative of most field conditions. Appendix X.3 of ASTM E119 lists the few cases where steel beams, girders, joists, and steel-framed floors or roofs do not qualify for the restrained classification.

Current test practices simulate the restrained condition by constructing the specimen tight against the test frame, e.g. by pouring the concrete slab tight against test frame boundaries, or with the use of steel shims at beams ends. Restrained ratings in beam tests are governed by the length of time the specimen maintains the ability to support its superimposed design load under fire exposure. Restrained ratings for steel-framed floors with concrete slabs are usually governed by the time when the temperature rise on the unexposed surface exceeds the specified limits (unless, in rare cases, the ability to support the test load is lost earlier). Nearly all steel-framed roof and floor assemblies, as well as all loaded individual beams, are tested in this restrained condition.

The unrestrained classification theoretically represents a condition where an element's ends are free to rotate and expand when heated. Ratings for this condition are not based on actual load-carrying capabilities of the system. Rather, the unrestrained classification is based on the realization of limiting temperature criteria. These conservative criteria represent temperature levels at which, it is believed, a member with unrestrained end supports may no longer be able to sustain its design load. The time when this limit is first reached is recorded as the unrestrained rating. The test is then continued until a restrained rating is reached. Both restrained and unrestrained ratings are determined from the same test.

Unrestrained classifications often require greater amounts of fire protection than restrained classifications do for the same time rating, frequently by as much as 50 percent to 100 percent. Therefore, to maximize the fire protection system's cost effectiveness, restrained ratings should be specified wherever the design allows and is acceptable to the authority having jurisdiction.

ASTM E119 provides guidance for the use of restrained and unrestrained classifications in its Appendix X3 guidelines. Table X.3 in this appendix classifies all types of bolted, welded, and riveted steel-framed systems as restrained. More detailed information and guidance on the use of restrained and unrestrained classifications was provided by Gewain and Troup[10].

III.5 SUMMARY

Despite limitations presented in this chapter, ASTM E119 continues to function as an invaluable reference for comparing the relative fire resistive performances of different structural components and assemblies in the United States. However, it remains important that the designer understand the assumptions upon which results from this test are founded and the extent to which they remain valid when applying them to building design.

REFERENCES

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[2] American Society for Testing and Materials (ASTM) (2000), *Standard Test Methods for Fire Tests of Building Construction and Materials*, Specification No. E119-00, West Conshohocken, PA.

[3] National Fire Protection Association (NFPA) (1999), *NFPA 251 Standard Methods of Tests of Fire Endurance of Building Construction and Materials*, 1999 Edition, Quincy, MA.

[4] American Society for Testing and Materials (ASTM) (2000), *Standard Test Methods for Determining Effects of Large Hydrocarbon Pool Fires on Structural Members and Assemblies*, Specification No. E1529-00, West Conshohocken, PA.

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[7] European Convention for Constructional Steelwork (ECCS) – Technical Committee 3 (2001), *Model Code on Fire Engineering, First Edition,* Brussels, Belgium.

[8] American Society for Testing and Materials (ASTM) (2002), *Standard Test Method for Fire Tests of Through-Penetration Fire Stops*, Specification No. E814-02, West Conshohocken, PA.

[9] International Code Council, Inc. (ICC) (2000), *International Building Code, 2000,* Falls Church, VA.

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Section IV
RATED DESIGNS

IV.1 GENERAL INFORMATION

Fire-resistant construction assemblies (walls, floors, roofs) and elements (beams, columns), that perform satisfactorily in standard fire resistance tests[3,6,7], are documented in building codes, standards, test reports and special directories of testing laboratories. Over the years, a considerable amount of accumulated test data allowed the standardization of many fire-resistant designs involving generic (non-proprietary) materials, such as steel, wood, concrete, masonry, clay tile, "Type X" gypsum wallboard, and various plasters. These generalized designs and methods are documented in building codes and standards, such as in the International Building Code (IBC)[4] sections 719 and 720 with detailed explanatory figures, tables, formulas, and charts. Fire resistant designs that incorporate proprietary (pertaining to specific manufacturers and/or patented) materials are documented by test laboratories in test reports and special directories. The major sources of documented construction designs rated for fire resistance are described below.

IV.2 ASCE/SFPE 29

In a joint effort, the American Society of Civil Engineers (ASCE) and the Society of Fire Protection Engineers (SFPE) have produced a standard document designated ASCE/SFPE 29 *Standard Calculation Methods for Structural Fire Protection*[2]. This document is a consensus standard that has been subjected to an approval process involving technical reviews and affirmations through balloting. The document covers the standard methods for determining the fire resistance of structural steel construction in addition to concrete, wood, and masonry construction. The calculation methods generally involve the interpolation or extrapolation of results from the American Society for Testing and Material standard fire test ASTM E119[3], and are mostly the same as the procedures contained in the IBC. The 2003 edition of the IBC and the National Fire Protection Association (NFPA)[5] code both list the ASCE/SFPE 29[2] as a referenced standard.

IV.3 UL DIRECTORY

The Underwriters Laboratories Inc. (UL) was founded in 1894 as a not-for-profit organization dedicated to testing for public safety. The UL conducts tests of various building components and fire protection materials. The tests are initiated by a sponsor, and an assembly is constructed to closely match the intended construction. The assembly is tested under recognized testing procedures, including ASTM E119[3], ANSI/UL 263[6], and NFPA 251[7], all of which are essentially the same and are described in Chapter III Standard Fire Test. When the assembly complies with the acceptance criteria of the fire test standard, a detailed report is provided to the test sponsor including its description and performance in the test, pertinent details, and specifications of materials used. A summary of the important features is produced and given a UL designation, which is then added to the UL Directory. The UL Directory is ever-growing, and is published annually in three volumes. Volume 1 containing hourly fire resistance ratings for beams, floors, roofs, columns, and walls and partitions, Volume 2 containing ratings for joint systems and through-penetration firestop systems. Volume 3 containing ratings for dampers and fire door assemblies. Volume 1 continues to be the largest single source of fire-resistant designs for construction assemblies and elements that use proprietary fire protection materials.

IV.4 OTHER SOURCES

In addition to UL, several other accredited laboratories in United States, such as Intertek Testing Services (ITS) and Omega Point Laboratories (OPL), conduct standard fire resistance tests and publish details of fire resistant designs in their directories[8,9].

REFERENCES

[1] Underwriters Laboratories Inc. (UL) (2003), *Fire Resistance Directory, 2003*, Vol. 1, Northbrook, IL.

[2] American Society of Civil Engineers (ASCE)/ Society of Fire Protection Engineers (SFPE) (2000), *Standard Calculation Methods for Structural Fire Protection*, No. ASCE/SFPE 29-99, New York, NY.

[3] American Society for Testing and Materials (ASTM) (2000), *Standard Test Methods for Fire Tests of Building Construction and Materials*, Specification No. E119-00, West Conshohocken, PA.

[4] International Code Council, Inc. (ICC) (2000), *International Building Code, 2000,* Falls Church, VA.

[5] National Fire Protection Association (NFPA) (2003), *NFPA 5000: Building Construction and Safety Code,* 2003 Edition, Quincy, MA.

[6] Underwriters Laboratories Inc. (UL) (2003), *Fire Tests of Building Construction and Materials,* Thirteenth Edition, Standard No. UL 263, Northbrook, IL.

[7] National Fire Protection Association (NFPA) (1999), NFPA 251 Standard Methods of Tests of Fire Endurance of Building Construction and Materials, 1999 Edition, Quincy, MA.

[8] Intertek Testing Services NA Inc. (ITS) (2003), *Directory of Listed Products*, Cortland, NY.

[9] Omega Point Laboratories Inc. (OPL) (2003), *Directory of Listed Building Products, Materials and Assemblies*, Elmendorf, TX.

Section V
FIRE PROTECTION MATERIALS

V.1 GENERAL INFORMATION

The functional abilities of all conventional structural materials begin to degrade when subjected to the elevated temperatures of building fires. Therefore, the proper selection and arrangement of fire protective materials are essential to preserving the integrity of the structure for fire-fighting operations and building evacuation. Historically, this protection has been provided through the use of hollow clay tile, brick, and concrete masonry blocks. Currently, newer methods and materials, such as spray-applied fire resistive materials (SFRM) and intumescent coatings, are more commonly used. The focus of this chapter is to highlight the thermal properties and insulating mechanisms of frequently used fire protection materials.

V.2 GYPSUM

Gypsum is a fire resistive material that is used widely throughout the construction industry. The mineral consists of calcium sulfate chemically combined with water ($CaSO_4$ + $2H_2O$). Gypsum is acquired by mining natural gypsum rock sources, or by capturing byproducts of combustion processes[1].

The ability to maintain and release chemically bound water is essential to gypsum's fire resistance. Roughly one-fifth of the weight of pure gypsum crystals can be attributed to water[1]. When exposed to fire, gypsum-based materials undergo a process known as calcination, where they release the entrapped water in the form of steam, providing a thermal barrier. The gypsum material immediately behind this thermal barrier will rise in temperature to only slightly more than 212 °F (100 °C), the boiling point of water, well below the range where structural steel begins to lose its strength. After the process of calcination has terminated, gypsum enclosures retain a relatively dense core, providing a physical barrier to fire.

V.2.1 Gypsum Board. The manufacture of gypsum board begins with a series of crushing, grinding, heating or "calcined" steps that transform the raw gypsum into a uniform, dry powder. The powder is then mixed with water, forming a slurry, before being sandwiched between two sheets of paper and dried[2]. The board is available in nominal thicknesses of ¼ in. (6.4 mm) to ⅝ in. (15.9 mm), and in lengths of 4 ft (1.2 m) to 12 ft (3.7 m).

Gypsum boards are provided with "regular" or "Type X" designations. The American Society for Testing and Materials (ASTM) standard ASTM C36[3] designates boards labeled "Type X" as special fire resistant products that ensure the required fire-resistance ratings for specified benchmark wall assemblies. Additionally, some manufacturers also produce a "Type C" or "Improved Type X" board that exhibits superior fire performance compared to "Type X." Most fire resistant gypsum boards include glass fibers that reduce shrinkage and cracking under fire exposure.

V.2.2 Gypsum-Based Plaster. Gypsum-based plaster consists of calcined gypsum combined with lightweight vermiculite and perlite aggregates, sand, and/or wood fibers that harden upon drying. Vermiculite and perlite are siliceous materials that undergo large volumetric expansions in the presence of high temperatures. This expansion insulates protected elements from elevated temperatures. This insulation, combined with gypsum's natural ability to create a steam barrier, make gypsum-based plasters very efficient fire-protective materials.

ASTM C28[4] regulates the composition, setting time, and compressive strengths gypsum-based plasters are required to achieve. The plaster may be applied either directly to the steel member surface, or to metal lath fixed around the member, depending on the requirements of the fire-rated assembly.

V.3 MASONRY

Creating barriers of concrete masonry blocks, bricks, and hollow clay tiles were some of the first methods used to protect building elements from fire. Historically, fire-ratings for specimens protected with masonry have been obtained from the results standard fire tests such ASTM E119. Research conducted at the National Research Council of Canada now provides designers with the ability to determine the fire resistance of masonry enclosures with calculations of the heat flow through the material[5]. These calculations are based on empirical data derived from the density, aggregate type, thermal conductivity, thickness, core grouting, finish, and moisture content of the masonry. Proprietary manuals in conjunction with building codes may be referenced for techniques of protecting elements with masonry enclosures.

V.4 CONCRETE

Concrete is a mixture of cement, mineral aggregates, sand, and water. Its ability to delay the transfer of heat can be utilized to protect specimens either through exterior encasement of the section, or by filling hollow elements such as HSS members.

The type of aggregate used in concrete can greatly affect its fire resistive properties. Lightweight aggregates such as vermiculite, perlite, expanded clay, and shale have a greater insulating effect than denser, heavier aggregates, thus providing greater fire resistance. Additionally, research has found that concrete made using a siliceous aggregate exhibits lower fire resistance than concrete made with carbonate aggregate, such as limestone[6].

Free and chemically bound moisture within concrete (similar to gypsum) brings about a cooling effect as high temperatures induce steam emission. Fully hydrated concrete typically contains approximately 16 to 20 percent water[6]. Drier concrete has less water available for evaporation; therefore the onset of temperature increase comes about more quickly. Concrete containing high moisture contents is susceptible to "explosive spalling" with the sudden loss of concrete cover.

Finally, concrete serves as a physical barrier between the intense heat of a building fire and the structural member. Studies have shown that thickness is the factor that contributes most to the fire resistance of concrete-protected members[6].

V.5 SPRAY-APPLIED FIRE RESISTIVE MATERIALS

Spray-applied fire resistive materials may be categorized into two basic groups, cementitious and fiber-based. Despite what these categories suggest, a Portland or gypsum-based cement provides cohesion to both types of SFRM.

V.5.1 Fibrous SFRM. Fibers created by melting rock or iron slag and spinning the materials into wool produces a filamentous mass with lightweight and noncombustible properties. An insulating fire protection material is created by combining the wool with a binder. Application of fibrous SFRM consists of the mixing of bonding agents and dry fibers with water at the nozzle of the hose, then spray-applying the material to coat the member to be protected. ASTM C1014[7] outlines pertinent fire resisting requirements of fibrous SFRM protection.

V.5.2 Cementitious SFRM. Most cementitious SFRM protections contain gypsum mineral that provides fire protection to structural elements through the release of gypsum's chemically combined water in the form of steam. Additional protection is also provided through the inclusion of vermiculite or perlite aggregates, which expand and insulate under extreme heating conditions. Cementitious SFRM is prepared by mixing the slurry in a hopper and delivering the SFRM under pressure into a nozzle for spray application. In lieu of spraying, the slurry may be trowelled into place.

V.6 MINERAL FIBERBOARD

Mineral fiberboard is created by spinning and compressing volcanic rock, resins, mineral fibers, or wools into boards. These boards form fire resistant barriers that may be cut and placed to form a tight seal around structural elements. Mineral fiberboard has the advantage of being able to be placed in outdoor weather conditions, and is not significantly affected by the surface conditions of the steel it is protecting. This advantage allows the fiberboard to be placed in locations where clearances are tight, or for retrofit conditions. A variety of precut sizes and surface finishes are available from manufacturers. ASTM C612[8] specifies maximum use temperature limits, density, and relevant thermal and physical characteristics of standard board types.

V.7 INTUMESCENT COATINGS

Intumescent coatings are thin chemical films that include a mixture of binders, resins, ceramics and refractory fillers. These films expand under high temperatures and form a durable, adherent, fire resisting cellular foam layer as gases within the film attempt to escape. Research has estimated that while the foam layer chars, its low thermal conductivity creates a reduced thermal capacity that acts to retard heat flow to the steel. The foam layer acts as an appreciable heat sink during intumescence, then as a reasonable insulator. Intumescent systems applied to steel members typically consist of a base coat, containing elements with the ability to create the foam layer, placed on top of the steel primer. A top coat is then placed over the base coat. This layer provides the film with desired aesthetic qualities, while providing protection from humidity, abrasion, and chemicals. The coatings are placed in a similar manner to paint, and may be applied with rollers, brushes, or spray equipment. Some applications require the use of a glass fiber reinforcing mesh between layers of intumescent coatings. Coating thickness can range from ⅛ in. to ⅝ in. and fire resistance ratings up to 3 hours are possible.

REFERENCES

[1] Walker, Jerry A. (2002), *"*All Things Gypsum-The Moisture in Gypsum," *Walls & Ceilings*, <www.wconline.com>.

[2] National Gypsum Company (2002), *How Wallboard is Made,* <www.nationalgypsum.com>.

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[4] American Society for Testing and Materials (ASTM) (2000), *Standard Specification for Gypsum Plasters*, Specification No. C28/C28M-00, West Conshohocken, PA.

[5] National Concrete Masonry Association (NCMA) (1998), *Tek Manual for Concrete Masonry Design and Construction*, Herndon, VA.

[6] Schultz, Neil (1985), *Fire and Flammability Handbook,* Van Nostrand Reinhold Company, Inc., New York, NY.

[7] American Society for Testing and Materials (ASTM) (1999), *Standard Specification for Spray-Applied Mineral Fiber Thermal or Acoustical Insulation*, Specification No. C1014-99, West Conshohocken, PA.

[8] American Society for Testing and Materials (ASTM) (2000), *Standard Specification for Mineral Fiber Block and Board Thermal Insulation*, Specification No. C612-00, West Conshohocken, PA.

Section VI
FIRE PROTECTION FOR STEEL COLUMNS

VI.1 GENERAL INFORMATION

The performance criterion for a column exposed to fire is that it remain functional for a specified duration when subjected to a temperature rise caused by fire. Since mechanical properties decrease at elevated temperatures, the length of time the column can continue to function can be extended by retarding the rate of heat transfer to the steel. The rate of heat transfer to the steel can be reduced by providing a means for absorbing the thermal energy. For example, this mechanism has been used in water-filled tubular steel columns to increase fire endurance time by utilizing the water's capacity for heat absorption. Concrete has higher heat storage capacity and lower thermal conductivity properties than steel. Thus, concrete and steel can be combined to improve the performance of the column at elevated temperatures. Concrete-filled tubular sections and concrete shells around core steel sections are examples of combined systems. However, the usual approach for effecting the heat transfer delay is to protect the column with an insulating material. Using this method, adequate fire endurance for a steel column is produced by applying the appropriate amount of insulating material. The thickness of protection that will extend the time before a limiting temperature is reached can be determined analytically or by referencing test data.

VI.2 TEMPERATURE CRITERIA

Temperature data from tests of loaded columns subjected to fire indicate that the column failure can be reasonably predicted based on the temperature attained by the steel cross section. The ability of a column to continue to carry load has been confirmed as long as the fire exposure does not cause the average temperature at any cross section to elevate above 1,000 °F (538 °C)[1,2]. Fire test standards impose an additional temperature limit of 1,200 °F (649 °C) at any one location along the member[3,4]. This 1,200 ºF (538 ºC) temperature is often referred to as the critical temperature which typically represents the temperature when a 50 percent strength loss occurs. These temperature limits can be used as the basis for a heat transfer analysis and they can represent the failure criteria for a test of an insulated column.

VI.3 ASTM E119 ANSI/UL 263

The ability of a column to remain functional when subjected to a temperature rise caused by fire can be determined by tests in accordance with the American Society for Testing and Materials (ASTM) standard E119[3]. The test requirements for ASTM E119 are virtually the same as the provisions of the American National Standards Institute (ANSI) accredited standard ANSI/UL 263[4]. The provisions in each of these tests allow the column to be tested in either loaded or unloaded condition.

Most column tests are performed using unloaded sections. Nonetheless, procedures for testing a loaded column are prescribed. Using the loaded option, the maximum design load or a restricted (some percentage of the maximum) load is applied. The column section is constructed vertically in the test furnace, a protection is applied to the column, and the furnace temperature is increased at a rate to follow a standard time-temperature curve. The protection is acceptable for the required fire resistance rating as long as the column continues to carry the load for the duration of the rating time.

Acceptable performance under the unloaded test option is based on temperature. A protected column section at least 8 ft (2.4 m) in length is placed vertically in the furnace. The column is instrumented with at least three thermocouples at each of four levels along the column length and subjected to a temperature increase on all sides. The rate of furnace temperature increase is controlled to follow the standard time-temperature curve. The column protection is acceptable if the average temperature at any level does not increase above 1,000 °F (538 °C) or the temperature at any one measurement point has not increased above 1,200 °F (649 °C). The unloaded test condition is the more common column test procedure in the United States.

VI.4 TEST FACILITIES

Performance characteristics of building materials and systems can be determined by fire tests. The tests are conducted for material manufacturers to qualify the use of their products. There are several laboratories, including Interteck Testing Services/Warnock Hersey, Omega Point Lab, Inc., VTEC Laboratories, Inc., Southwest Research Institute (SwRI) and Underwriters Laboratories (UL) who provide testing services for building materials. Certifications of conformance can be provided by the manufacturer for tested building materials and systems and, in many instances, a directory of tested building materials and systems is available.

VI.5 UL DIRECTORY

The most common reference for fire test data is the Underwriters Laboratories (UL) Inc. Fire Resistance Directory[5]. The UL Directory is produced annually in three volumes. Column fire protection tests, performed under the provisions of ANSI/UL 263, are listed with assembly designations having a prefix of X or Y. A group of rapid fire tests, performed under the provisions of ANSI/UL 1709 *Rapid Rise Fire Tests of Protection Materials for Structural Steel*[19], are included in the UL Directory with designations having a prefix of XR. Column designs having the XR prefix are intended for use in areas such as petrochemical production facilities, which may develop fire temperatures at a more rapid rate than assemblies using the standard test. A three digit number is used after the X or Y prefix for each specific column test designation. This numeric component of the designation is assigned in accordance with the type of protection as outlined in Table VI.1.

VI.6 IBC DIRECTORY

The International Building Code (IBC)[6], published by the International Code Council (ICC), includes a listing of fire-rated column assemblies independent of the UL Directory. Sections 719 (Prescriptive Fire Resistance) and 720 (Calculated Fire Resistance) of this code contain several useful fire resistant designs of steel columns. These designs utilize many different fireproofing systems, including lath and plaster, gypsum board, masonry, and concrete, including some designs that cannot be found in any other directory.

VI.7 *W/D* and *A/P* CRITERIA

The rate of temperature change in a body is a function of its mass and the area of its surface exposed to the temperature difference. Therefore, a factor influencing the steel column's fire resistance is *W/D*. *W* is defined as the weight per unit length of the steel member. *D* is defined as the inside perimeter of the fire protection material, as shown in Figures VI.1a and VI.1b. For tubular sections, the *A/P* (steel section area over perimeter) ratio is commonly used in lieu of *W/D*.

The larger the *W/D* (or *A/P*) ratio, the slower the rate of temperature change. Therefore, as a general rule of thumb, steel sections with higher *W/D* (or *A/P*) ratios perform better in fire tests than similarly protected sections with smaller *W/D* (or *A/P*). Hence, the terminology of "smaller" and "larger" steel section in fire protection design pertains to *W/D* (or *A/P*), ratio, and not to the geometrical size.

It is generally permitted to use "larger" columns in fire designs instead of tested "smaller" columns of the same shape. Listed fire resistant column designs always specify a minimum steel section "size" implying that only sections with higher *W/D* (or *A/P*) ratios can be used, unless a special adjustment is permitted. *W/D* and *A/P* ratios are also common parameters in experimentally derived correlations used to determine fire resistance ratings or to adjust the thickness of fire protection.

Values of *D* provided by AISC and reproduced in Appendix A of this guide include the effects of rounded fillets at the corners of steel sections, therefore, they are more accurate and slightly lower than those found from the approximate formulas in Figures VI.1a and VI.1b. This difference results in slightly higher *W/D* values in Appendix A than those calculated using the *D* values from the equations in the figure.

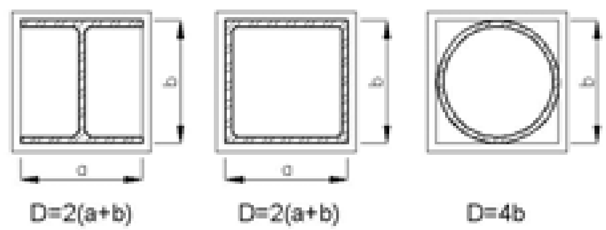


Fig. VI.1a D Factor Formulas (Box Protection)

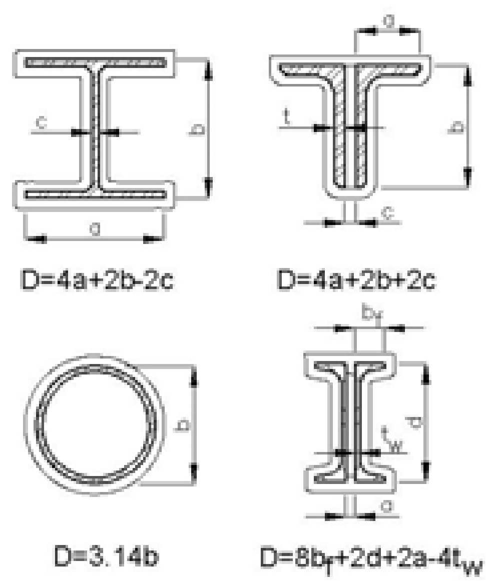


Fig. VI.1b D Factor Formulas (Contour Protection)

Table VI.1 – UL Protection Types	
Number Range	**Protection Type**
000-099	Building units consisting of prefabricated panels (limited material suppliers)
100-199	Prefabricated fire resistant jacket (concrete-filled metal jackets around a steel core)
200-299	Endothermic wrap (endothermic heat absorbing wrap) and ceramic wrap systems
300-399	Mineral fiber board (single and multiple layer systems)
400-499	Lath and plaster systems (vermiculite and perlite plaster systems)
500-599	Gypsum board systems (direct applied or metal stud supported multiple layer board)
600-699	Mastic coatings (intumescent and subliming mastic coatings)
700-899	Spray-Applied Fire Resistive Materials
900-999	Masonry protection

VI.8 COLUMN FIRE PROTECTION SYSTEMS

VI.8.1 Prefabricated Building Units (000-099). Fire resistance can be provided using patented prefabricated panels. These systems are limited and have not seen extensive use. A critical component of the protection is the panel-to-panel and panel-to-column attachment mechanism. The availability of the system should be checked prior to specifying.

VI.8.2 Prefabricated Fireproof Columns (100-199). Prefabricated steel columns, with 2 to 4 hour ratings, consist of a core steel W-shape or tubular section surrounded by lightweight cementitious protection and a steel jacket. Columns are prefabricated with cap plates, base plates, and intermediate connection components as required. The protection shell is held back from connection areas, so the fire resistance must be provided at connection locations on site after erection.

VI.8.3 Endothermic & Ceramic Mat Materials (200-299).
The endothermic wrap blocks heat penetration by chemically absorbing heat energy. At high temperatures, it releases chemically bound water to cool the outer surface. Endothermic wraps can achieve fire resistance ratings of 1, 2, and 3 hours. The fire rating is a function of the number of layers of endothermic mat applied around the column. Seams and terminations of the wrap must be treated with endothermic caulk and foil tape. Endothermic wraps are held in place by steel banding straps and further protected with stainless steel jackets. Similar designs incorporating insulating ceramic wraps are also included within this division. Ratings of up to 2 hours can be achieved, depending on the thickness of the ceramic blanket and the *W/D* ratio of the column section.

VI.8.4 Mineral Board Enclosures (300-399). Mineral fiber board enclosures can be used to create fire endurance ratings up to 4 hours. Tests of mineral fiber board protected columns are included in the UL Directory and have designations X307 through X314. These systems are proprietary and the specific details of each tested configuration must be followed explicitly. The number of layers, the corner lap condition, and the corner fasteners in the actual installation must conform to the tested configuration. Some of the UL listings have an equation for the determination of the mineral board thickness as a function of *W/D* ratio and the required hourly rating. The heated perimeter, *D*, is defined as the inside surface of the mineral board protection enclosing the column. Other listings have board thickness requirements shown explicitly.

A synopsis of the UL designations is provided in Table VI.2. The protection is required for the full height of the columns and, if the floor protection system is also mineral board, tight joints are required between horizontal and vertical mineral boards. If dissimilar materials are used between the horizontal protection and the column protection, a minimum 16 in. (406 mm) overlap is required. Mineral boards are available prefinished or with a surface suitable for finishing. Figure VI.2 is an isometric sketch of the mineral board placement for UL Design No. X312 for a wide flange column shape. Mineral board sections called noggings are tightly fitted between column flanges and boards are secured with corkscrew-like fasteners.

Table VI.2 – Mineral Board Column Designs			
Designation	Rating Hours	Section Types	Equation or Explicit
X307	1, 1½, 2, 3, and 4	W, Tubular, Angles, Pipe	Equation and explicit
X309	1, 1½, 2, and 3	W	Equation
X310	1, 1½, 2, and 3	W	Equation
X311	1, 1½, 2, and 3	Pipe or Tubular	Explicit
X312	3	W	Explicit
X313	1, 1½, and 2	W	Explicit
X314	1, 2, 3, and 4	W	Explicit

VI.8.4.1 EXAMPLE VI -1

A 3-hour fire resistance rating is required for a W14x109 using mineral wool board protection in accordance with UL Design No. X307,

Required thickness is determined by equation:

$$h = \frac{1.08\ R}{1.13\left(\frac{W}{D}\right) + 0.47} \qquad \textbf{(VI - 1)}$$

where
h = Board Thickness (in.)
R = Fire Resistance Rating (hours)
W = Column weight (lbs per ft)
D = Inside perimeter of the mineral board (in.)

D = 2 x 14.3 + 2 x 14.6 = 57.8

W/D = 109/57.8 = 1.88
Alternatively, use W/D = 1.89 listed in Appendix A.

$$h = \frac{1.08\,(3)}{1.13\,(1.88) + 0.47} = 1.25$$

use 1¼ in. (31.8mm)

VI.8.5 Lath and Plaster Enclosures (400-499).
Plaster is normally a composition of sand, water, and lime that hardens on drying. If the sand is replaced with expanded minerals such as perlite or vermiculite, the insulating properties are enhanced and the resulting lightweight plaster can be used to provide fire protection for steel columns. The column section is wrapped with metal lath or paperbacked wire fabric to create a substrate for the plaster. Columns protected with lath and plaster enclosures are reported in the UL Directory and have designations X401 through X413. Fire protection ratings up to 4 hours have been confirmed. Plaster fire protection systems can often be applied directly to lath around the column. However, some systems require a 1¼ in. (31.8 mm) stand-off from the column using lath spacers. The required plaster thickness varies with the rating and needs to be confirmed by referencing the UL listing. Representative plaster thicknesses are 1 in. (25.4 mm) for 2 hours, 1⅜ in. (34.9 mm) for 3 hours and 1¾ in. (44.5 mm) for 4 hours.

VI.8.6 Gypsum Board Systems (500-599).
Gypsum board assemblies are noncombustible systems that protect columns by releasing chemically combined water in the form of steam when subjected to intense heat. The steam creates a thermal barrier known as the plane of calcination. The gypsum material immediately behind the barrier rises to temperatures only slightly greater than 212 ˚F (100 ˚C), the boiling point of water. This temperature is well below the point at which steel begins losing strength. ASTM C36 mandates strength and endurance requirements for both regular and the more heat resistive "Type X" gypsum boards. Many manufacturers also produce an "Improved Type X," also called "Type C"

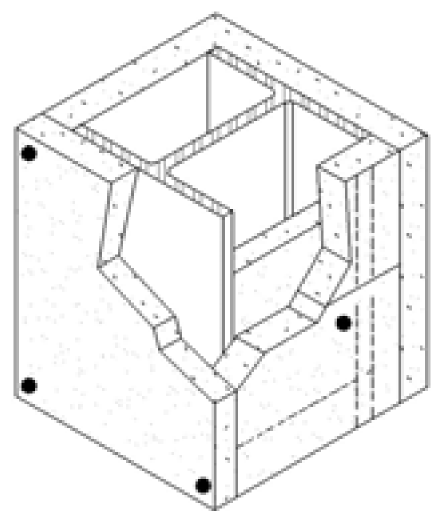


Fig. VI.2 Sketch of Mineral Board Placement[5] gypsum board that is specially formulated to meet the requirements of “Type X” and incorporate additional fire resistive properties[11].

The UL and Gypsum Association list both proprietary and generic column fire assemblies of gypsum board for up to 4 hours. Typically, higher assembly ratings are achieved by applying multiple board layers. The ratings for the assemblies are either explicitly tabulated or presented in equation form directing the total thickness of the wallboard.

In most instances, a minimum column size is specified for a particular test. Columns with larger *W/D* ratios can be substituted for the column section tested as long as the same protection is applied to the substitute column as used on the test column. The UL listing does not provide a procedure for adjusting protection requirements for substituted column sections when protection is provided using gypsum board systems.

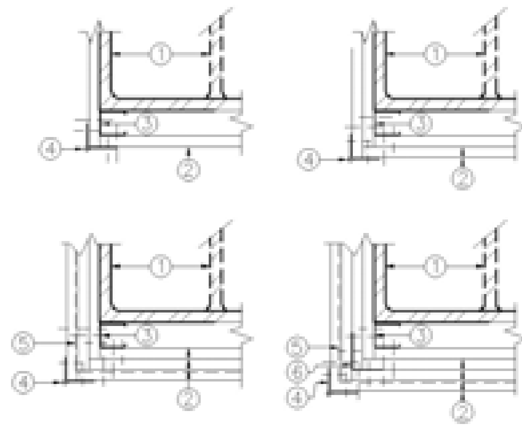
Column protection using “Type X” gypsum board enclosures is covered in the International Building Code (IBC) section 720.5.1.2. The protection requirements are directed by the equation:

$$R = 130\left[\frac{h\left(W'/D\right)}{2}\right]^{0.75} \qquad \textbf{(VI} - \textbf{2)}$$

where
- h = Wallboard Thickness (in.)
- R = Fire Resistance Rating (min.)
- D = Inside perimeter of gypsum (in.)
- W = Steel column weight (lbs per ft)
- W' = Column and gypsum wallboard weight
  = W + 50 h D/144 (lbs per ft)

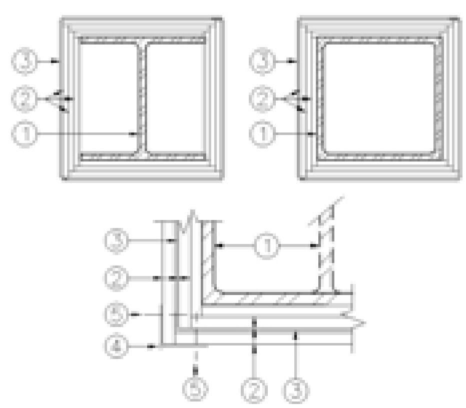
The integrity of the gypsum wallboard attachment is an important component of the fire resistive enclosure and specific details for the enclosure must be incorporated in the construction. For columns designed under IBC 720.5.1.2 for fire resistance durations of 4 hours, a stainless steel cover is required to hold the wallboard in place. Similarly, in designs for 3 hours or less, steel tie wires spaced at 24 in (610 mm) along the length of the column, are required to hold in place multiple-layer protection (3 or 4 layers). Figure VI.3 is a general illustration of this construction for a 3-hour or less fire resistive rating. Figure VI.4 is a general illustration of the details of the construction for a 4-hour or less fire resistive rating that requires a metal shell. For specific requirements for fasteners, board placement, seams, etc., the requirements in the IBC should be reviewed.

Gypsum board systems often require support studs or clips at column corners, also the minimum column sizes could vary from one design to another. A tabulation of the minimum column size and the corner support requirements provided in the UL Directory is provided in Table VI.3.



1 - Steel Column
2 - Gypsum Wallboard
3 - Steel Stud
4 – Corner Bead
5 – Tie Wire
6 – Corner Steel Angle

Fig. VI.3 Gypsum Wallboard Attachment for a 3-Hour or Less Fire Resistive Rating[5]



1 – Steel Column
2 – Gypsum Wallboard
3 – Metal Shell
4 – Corner Bead
5 – Screw

Fig. VI.4 Gypsum Wallboard Attachment for a 4-Hour or Less Fire Resistive Rating[5]

Table VI.3 – Gypsum Board Column Designs				
Designation	**Ratings**	**Corner Support**	**Minimum Column**	**Remarks**
X501	4	Steel Studs	W10X49	
X502	4	Gypsum Blocks	W10X49	
X504	4	Gypsum Blocks	W10X49	
X507	4	Steel Studs	W14X228	
X508	3	None	W10X49	
X509	3	Steel Studs	W10X49	
X510	3	Steel Studs	W10X49	
X513	3	Steel Studs	W14X228	
X514	3	Steel Studs	W14X228	
X515	3	Steel Studs	W10X49	
X516	2	None	W10X49	
X517	2	Steel Studs	W10X49	
X518	2	Steel Studs	W10X49	
X520	2	Steel Studs	W14X228	
X521	2	Steel Studs	W14X228	
X522	4	Clips (Steel)	W14X228	
X523	2	Clips (Steel)	W14X228	
X524	1, 2	Steel Studs	Varies	Girt connection to column considered
X525	2, 3, 4	Steel Studs	W8X28	Requires SFRM and Independent studs
X526	1, 2, 3, 4	None	Multiple	Both W and HSS sections considered and a steel cover is required
X527	2, 3, 4	Steel Studs	W8X28	Requires SFRM and Independent studs
X528	1, 2, 3	Steel Studs	Multiple	Both W and HSS sections
X530	1, 2	Steel Studs	Cold Formed	
X531	1½	Steel Studs	4½ in. Pipe	
X533	4	Steel Studs	W14X228	
X534	3	Steel Studs	W14X228	
X535	4	Clips (Steel)	W10X49	
X536	1,2,3,4	Clips (Steel)	W10X49	

VI.8.6.1 EXAMPLE VI -2

A 3-hour fire resistance rating is required for a W12x87 using gypsum wallboard protection in accordance with IBC equation:

$$R = 130\left[\frac{h\left(W'/D\right)}{2}\right]^{0.75}$$

where
h = Board Thickness (in.)
R = Fire Resistance Rating (min.)
W' = Column and wallboard weight (lbs per ft)
D = Inside perimeter of wallboard (in.)

D = 2 x 12.5 + 2 x 12.1 = 49.2

Try h = 1½ in.

W' = 87 + 50 x 1.5 x 49.2/144 = 113

$$R = 130\left[\frac{1.5\left(113/49.2\right)}{2}\right]^{0.75} = 195 \text{ min}$$

Use 1½ in. "Type X" gypsum wallboard

VI.8.7 Mastic Coatings (600-699). This category covers intumescent mastic coatings that expand (intumesce) when heated to create an insulation barrier and to reflect heat. Thin coatings, generally less than ⅝ in. (15.9 mm), are often sufficient to satisfy the required fire resistance rating. The coating surface is durable and often suitable for the application of a final finish. Fire resistance ratings up to 3½ hours are attainable. The coatings are generally applied in multiple layers and a reinforcing material within the mastic is often required. Reinforcing materials must be similar to those used in the test, and can be glass fiber mesh or galvanized welded wire mesh. The reinforcing can be continuous throughout the coating or provided only at flange edges in the case of W-shaped sections.

A minimum column size is always specified for each test. Only columns of the same configuration with the same or larger *W/D* (or *A/P*) ratios and the same thickness of coating as that tested can be used. For example, if the test report indicated a minimum W10x49 (*W/D* = 0.840) column section, the test would be an appropriate reference for a W8x40 (*W/D* = 0.849) column section. However, several designs in this category, e.g. X641 and X649, provide equations for the adjustment of protection thickness, depending on the *W/D* ratio and the required fire resistance.

VI.8.8 Spray-applied Fire Resistive Materials (700-899). The most common method of insulating columns is through the use of Spray-Applied Fire Resistive Materials (SFRM). The UL Directory alone lists over 90 tests for SFRM protection of columns, and in many instances, more than one member cross section is included in a listing. The sheer volume of information makes the task of identifying the appropriate thickness and details for construction formidable. The tests are initiated by a material manufacturer to confirm the function of their particular product. Thus, the tests are proprietary and can be referenced as evidence for conformance when the tested product is used. As with other material tests, one or more minimum column sizes are indicated with the test. Column sections with larger *W/D* ratios can be substituted for the tested column to provide the same level of endurance as the tested column as long as the same thickness and details are followed in the actual construction.

The fire resistance is influenced by the thermal properties of the insulating material, such as specific heat and conductivity. Therefore, some test reports include an equation reflecting the thermal properties that facilitate calculation of the appropriate material thickness, which can differ from the thickness tested.

The UL Directory contains an equation for adjustments to the tested thickness for substituting wide-flange sections protected with SFRM that have *W/D* ratios smaller than the tested column.

$$X_2 = 1.25\,(X_1)\left(\frac{W_1}{D_1}\right)\left(\frac{D_2}{W_2}\right) \qquad \textbf{(VI – 3)}$$

where

X_1 = SFRM thickness on the tested column (in.)
X_2 = SFRM thickness on the smaller substituted W-shape column (in.)
W_1 = Tested column weight (lbs per ft)
W_2 = Substitute column weight (lbs per ft)
D_1 = Perimeter of the tested column at the interface with the SFRM (in.)
D_2 = Perimeter of the substitute column at the interface with the SFRM (in.)

Section 720.5.1.3 of the IBC includes an equation for the determination of the required SFRM thickness as a function of the fire rating *R*, the *W/D* ratio of the column and coefficients reflecting the thermal properties of the insulating material.

$$R = \left[C_1\left(\frac{W}{D}\right) + C_2\right]h \qquad \textbf{(VI – 4)}$$

where

h = SFRM Thickness (in.)
R = Fire Resistance Rating (hours)
W = Column weight (lbs per ft)
D = Perimeter of the column at the interface of the SFRM (in.)
C_1 & C_2 = Material dependent constants

The UL listing for columns that include an equation for SFRM thickness determination are of the same form as equation VI-4 and explicitly list values for C_1 and C_2. Table VI.4 is a tabulation of those constants extracted from the explicit equations. The values of C_1 and C_2 to be used in the IBC equation should be confirmed by the material supplier.

The SFRM thickness can be determined by direct reference to a test, by adjusting the test thickness for W-shapes smaller than the test column, by an equation included in the test listing (when available), or by use of the IBC equation. Example VI-3 demonstrates how different results can be obtained under each option.

Table VI.4 – Representative SFRM Material Constants		
Material	C_1	C_2
Grace MK6 All W/D	1.05	0.61
Isolatek 800 All W/D	0.86	0.97
Isolatek 280 W/D 0.33 to 2.51	1.25	0.53
Isolatek 280 W/D 2.51 to 6.68	1.25	0.25
Isolatek D-C/F W/D 0.55 to 7.00	1.01	0.66
Isolatek D-C/F W/D 0.30 to 0.55	0.95	0.45

VI.8.8.1 EXAMPLE VI-3

Determine the thickness of SFRM for a W14X109 column (W/D = 1.27) to provide a 2-hour fire resistance rating.

UL X701

Minimum column size W10X49 (W/D = 0.83)

The W14X109 has a larger W/D than the tested W10X49, and the required thickness of material can be read from the listing:

h **= 1⅛ in.** (28.6 mm) of MK-6

UL X704

Minimum column size W14X228 (W/D = 2.44)

The W14X109 has a smaller W/D than the tested W14X228, and the required thickness of material can be determined by adjusting the listed thickness using the UL equation.

X_2 = 1.25 (9⁄16) (2.44) (1/1.27) = 1.35 in.

h **= 1⅜ in.** (34.9 mm) of MK-6

UL X722

Minimum column size W6X16 (W/D = 0.57)

The W14X109 has a larger W/D than the tested W6X16 and the required thickness of material can be read from the listing:

h **= 1¹¹⁄₁₆ in.** (42.9 mm) of MK-6

UL X723

Minimum column size W8X28 (W/D = 0.67)

The W14X109 has a larger W/D than the tested W8X28 and the required thickness of material can be read from the listing:

h **= 1⅜ in.** (34.9 mm) of MK-6

UL X772

Several column sections are listed and results can vary depending on the test column referenced.

Reference: W10X49

The W14X109 has a larger W/D than the tested W10X49 and the required thickness of material can be read from the listing:

h **= 1⅛ in.** (28.6 mm) of MK-6

Reference: W14X228

The W14X109 has a smaller W/D than the tested W14X228 and the required thickness of material can be reduced from the listing using the adjustment equation:

X_2 = 1.25 (9⁄16) (2.44) (1/1.27) = 1.35 in.

h **= 1⅜ in.** (34.9 mm) of MK-6

UL 772 has an associated thickness equation:

$$h = \frac{R}{1.05\left(\frac{W}{D}\right) + 0.61} \qquad \textbf{(VI – 5)}$$

$$h = \frac{2}{1.05\,(1.27) + 0.61} = 1.02\text{in.}$$

h **= 1¹⁄₁₆ in.** (27 mm) of MK-6

The material constants for MK-6 are C_1 = 1.05 and C_2 = 0.61. When these constants are used with the IBC equation, the calculated thickness is the same as that resulting from the UL equation.

The appropriate thickness is **1¹⁄₁₆ in.** (27 mm) since it would be excessive to provide more material than necessary.

The preferred approach to avoid finding the minimum among these multiple options is to use the equation included with the listing when available. These listed equations have the appropriate material constants included in the equation. If an equation is not provided in the particular UL design being referenced, the IBC equation with the appropriate material constants should be used. The values for the material related constants should be verified with the material supplier.

VI.8.9 Concrete-Filled HSS Columns. Concrete-filled Hollow Structural Sections (HSS) can effectively sustain load during a fire exposure without benefit of external protection. The concrete mass provides an increased capacity for absorbing the heat caused by the fire and thereby extends the duration for load resistance. Research conducted at the National Research Council of Canada provided a basis for establishing an empirical equation to predict the fire resistance of concrete-filled round and square HSS sections[12,13,14]. The equation is presented in ASCE/SFPE 29-99[15] as follows:

$$R = 0.58\, a \frac{(f'_c + 2.90)}{(KL - 3.28)} D^2 \left(D/C\right)^{0.5} \qquad \textbf{(VI-6)}$$

where

R = Fire Resistance Rating (hours)

a = Shape and material parameter

- 0.07 - circular section with siliceous aggregate concrete fill
- 0.08 - circular section with carbonate aggregate concrete fill
- 0.06 - square or rectangular section with siliceous aggregate fill
- 0.07 - square or rectangular section with carbonate aggregate concrete fill

f_c' = 28 day concrete compressive strength (ksi)

KL = Column effective length (ft)

D = Outside diameter of circular HSS (in.)
Outside dimension of square HSS (in.)
Least outside dimension of rectangular HSS (in.)

C = Column compressive force due to unfactored dead load and live load (kips)

The fire performance of a concrete-filled HSS column improves when heat absorption occurs as the moisture in the concrete is converted to steam. The heat absorbed during this phase change is significant, however the resulting steam must be released to prevent the adverse effects of an internal pressure build-up. Thus, vent holes need to be provided in the steel section. Two ½ in.(12.7 mm) diameter holes should be placed opposite each other at the top and bottom of the column. The bottom holes should be rotated 90° relative to the top holes.

The application of the formula is limited. Since it is based on actual column tests, the application must fit within the range of the parameters considered in the testing. The following restrictions are placed on the use of the equation:

1. The calculation is limited to columns requiring a fire resistance rating of 2 hours or less.

2. The 28 day compressive strength of the fill concrete must be between f_c'=2.9 ksi (20 MPa) and f_c'= 5.8 ksi (40 MPa).

3. The column effective length must be between 6.5 ft (2 m) and 13 ft (4 m).

4. Round sections must have a D between 5½ in. (140 mm) and 16 in. (406 mm).

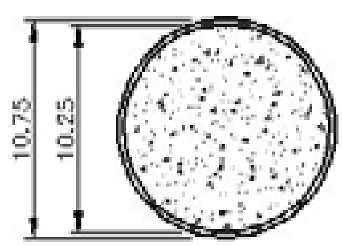
5. Square and rectangular sections must have a D between 5½ in. (140 mm) and 12 in. (305 mm).

6. Compressive force C shall not exceed the design strength of the concrete core at ambient temperatures determined in accordance with the AISC LRFD Specification for Structural Steel Buildings.

7. Vent holes must be provided at the top and bottom of the column section to relieve steam pressure.

VI.8.9.1 EXAMPLE VI-4

Determine the fire resistance rating of a round concrete-filled HSS 10.75 x 0.25 having an effective length (KL) of 10 ft (3.05 m) subjected to an unfactored dead load of 45 kips (200 kN) and an unfactored live load of 35 kips (156 kN). Carbonate coarse aggregate is used in the concrete fill that has a 28 day compressive strength of 4,000 psi (27.6 MPa).



$a = 0.08$
$f_c' = 4{,}000$ psi
$KL = 10$ ft
$D = 10.75$ in.
$C = 45 + 35 = 80$ kips

HSS 10.75 x 0.25

$A_s = 7.70 \text{ in.}^2$

$r = 3.72 \text{ in.}$

$$R = 0.58\,(0.08)\,\frac{(4 + 2.90)}{(10 - 3.28)}\,10.75^2\,\left(10.75/80\right)^{0.5}$$

$R = 2.02$ hours

The capacity of the core concrete at ambient temperature can be verified using the provisions of the LRFD Specification[16] Chapters E and I as follows:

$$\frac{A_c}{A_s} = \frac{\pi\,(10.25)^2\;/\;4}{7.7} = 10.7 \qquad \textbf{(VI-7)}$$

where

A_c = Concrete core area (sq. in.)

A_s = Steel area (sq. in.)

Calculate the modified yield strength and modified modulus of elasticity for the composite column in accordance with Chapter I of the LRFD Specification.

$$F_{ym} = F_y + c_2\; fc'\left(\frac{A_c}{A_s}\right) \qquad \textbf{(VI-8)}$$

where

F_{ym} = Modified yield strength (ksi)

F_y = Steel yield strength (ksi)

f_c' = 28 day concrete strength (ksi)

c_2 = numerical coefficient

= 0.85 for concrete-filled HSS

$$F_{ym} = 46 + 0.85\,(4)\,10.7 = 82.4 \text{ ksi}$$

$$E_m = E_s + c_3\; E_c\left(\frac{A_c}{A_s}\right) \qquad \textbf{(VI-9)}$$

where

Es = Steel modulus of elasticity (ksi)

E_m = Modified modulus of elasticity (ksi)

E_c = Concrete modulus of elasticity (ksi)

$= w^{1.5}\sqrt{fc'}$

where w is the concrete weight (pcf)

f_c' = 28 day concrete strength (ksi)

c_3 = numerical coefficient

= 0.4 for concrete-filled HSS

$$E_m = 29{,}000 + 0.4\,(3{,}500)\,10.7 \approx 44{,}000 \text{ ksi}$$

Calculate the composite column capacity using the LRFD provisions of Chapter E.

$$\lambda_c = \frac{KL}{r\pi}\sqrt{\frac{F_{ym}}{E_m}} \qquad \textbf{(VI-10)}$$

where

K = effective length factor

L = lateral unbraced length (in.)

r = governing radius of gyration (in.)

$$\lambda_c = \frac{10\,(12)}{3.72\,\pi}\sqrt{\frac{82.4}{44{,}000}} = 0.44$$

$$\lambda_c{}^2 = 0.20$$

$$F_{cr} = \left(0.66^{\lambda_c{}^2}\right)F_{ym}$$

$$F_{cr} = \left(0.66^{0.20}\right)82.4 = 75.8 \text{ ksi}$$

$$P_n = A_s\; F_{cr}$$

$$P_n = 7.7\,(75.8) = 584 \text{ kips}$$

$$\phi\, P_n = 0.85\,(584) = 496 \text{ kips}$$

Calculate the non-composite column capacity using the LRFD provisions of Chapter E.

$$\lambda_c = \frac{KL}{r\pi}\sqrt{\frac{F_y}{E}}$$

$$\lambda_c = \frac{10\,(12)}{3.72\,\pi}\sqrt{\frac{46}{29{,}000}} = 0.41$$

$$\lambda_c{}^2 = 0.17$$

$$F_{cr} = \left(0.66^{\lambda_c{}^2}\right)F_y$$

$$F_{cr} = \left(0.66^{0.17}\right)46 = 42.9 \text{ ksi}$$

$$P_n = A_s\ F_{cr}$$

$$P_n = 7.7\,(42.9) = 330\text{ kips}$$

$$\phi\ P_n = 0.85\,(330) = 281\text{ kips}$$

Therefore, the design strength of the concrete core is:

$$\begin{aligned} \text{Composite } \phi\ P_n &= 496\text{ kips} \\ -\,\text{NonComposite } \phi\ P_n &= 281\text{ kips} \\ \hline & 215\text{ kips} \geq 80\text{ kips} \end{aligned}$$

The concrete core capacity is greater than the compressive force of the unfactored load on the column and the column does provide a fire resistance rating of 2 hours.

The fire resistance of concrete-filled columns can be improved further by adding reinforcing steel or steel fibers within the concrete fill. Although not included in ASCE/SFPE 29-99[15], the benefits of and specific provisions for using fiber or reinforcing within the concrete core can be determined by referring to research performed at the National Research Council of Canada[12].

VI.8.10 Masonry Enclosures. An insulating enclosure can be provided for the steel column section using concrete masonry units or clay masonry units. For columns tested in an unloaded condition, ASTM E119 limits the average temperature rise to 1,000 °F (538 °C) for any section or 1,200 °F (649 °C) for any single point. The fire resistance provided by concrete masonry and clay masonry is based on heat flow through the masonry material. The heat flow can be predicted based on several parameters, including the equivalent thickness of the masonry, the thermal conductivity of the masonry, the density of both the masonry and the steel, the heated perimeter of the steel, and the inside perimeter of the masonry. Research conducted at the National Research Council of Canada is the basis for an empirical equation for calculation of the fire resistance of a masonry enclosed column[17]. IBC Section 720.5.1.4.5 lists the following equation for columns protected with masonry enclosures:

$$R = 0.17\left(W/D\right)^{0.7} + \left[0.285\left(T_e^{1.6}/K^{0.2}\right)\right] \times \left[1.0 + 42.7\left\{\left(A_s/d_m T_e\right) \div \left(0.25\,p + T_e\right)\right\}^{0.8}\right] \qquad \textbf{(VI-11)}$$

where

R = Fire-resistance rating of column assembly (hours)

W = Average weight of steel column (lb/ft)

D = Heated perimeter of steel column (in.)

T_e = Equivalent thickness of concrete or clay masonry unit (in.)

K = Thermal conductivity of concrete or clay masonry unit (Btu/hr. ft °F)

A_s = Area of steel column (in.^{2})

d_m = Density of the concrete or clay masonry unit (pcf)

p = Inner perimeter of concrete or clay masonry protection (in.)

The thermal conductivity of masonry is a function of the density of the materials as tabulated in the IBC and shown in Tables VI.5a and VI.5b.

Per IBC Section 720.4.1.1, the equivalent thickness of masonry is calculated by multiplying the average percent solid of a unit by the actual width of the unit. For example, a 55 percent solid 8 in. masonry unit has the following equivalent thickness:

T_{ea} = 0.55x7.62 = 4.19 in. (106mm)

The remaining parameters of the fire resistance rating equation involve the geometry of the enclosure and the column as illustrated in Figure VI.4.

VI.8.10.1 EXAMPLE VI-5

Determine the fire resistance rating of a W12x72 column enclosed using standard modular brick (3⅝ in. x 2¼ in. x 7⅝ in. (92.1 mm x 57.2 mm x 194 mm) units constructed to provide a finished enclosure dimension of 24 in. x 24 in. (610 mm x 610 mm). The brick units will have a density of 120 pcf (1,920 kg/m^3) and will be solid, thus, the equivalent thickness will be 3⅝ in. (92.1 mm).

Table VI.5a – Masonry Thermal Conductivity	
Density, *D* (pcf)	**Thermal Conductivity, *k* (Btu/hr ft °F)**
Concrete Masonry Units	
80	0.21
85	0.23
90	0.25
95	0.28
100	0.31
105	0.34
110	0.38
115	0.42
120	0.46
125	0.51
130	0.56
135	0.62
140	0.69
145	0.76
150	0.84
Clay Masonry Units	
120	1.25
130	2.25

Table VI.5b – Masonry Thermal Conductivity (SI Units)	
Density, *D* (kg/m^3)	**Thermal Conductivity, *k* (W/m °K)**
Concrete Masonry Units	
1,280	0.36
1,360	0.39
1,440	0.44
1,520	0.48
1,600	0.53
1,680	0.59
1,760	0.65
1,840	0.72
1,920	0.79
2,000	0.88
2,080	0.97
2,160	1.07
2,240	1.19
2,320	1.31
2,400	1.45
Clay Masonry Units	
1,920	2.16
2,080	3.89

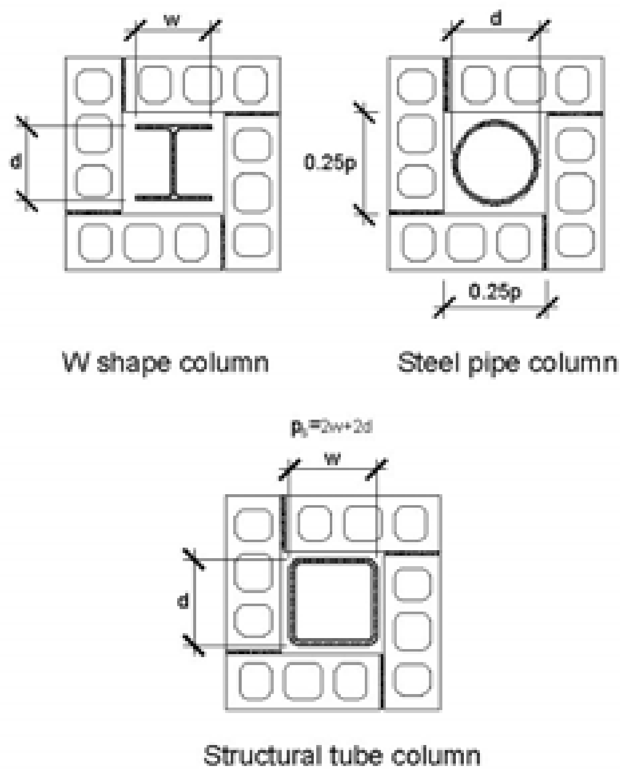
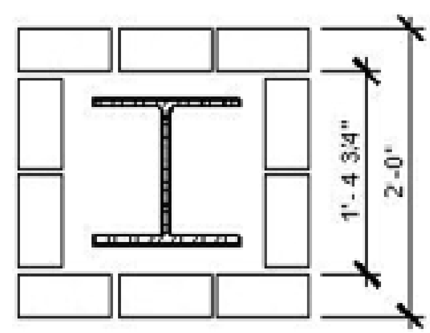


Fig. VI.4 Masonry Protected Steel Columns[6]

EXAMPLE VI-5, cont.



Parameters:

W = 72 lbs/ft
D = 70.3 in.
T_e = 3.63 in.
K = 1.25 Btu/hr. ft °F
A_s = 21.1 in.^{2}
d_m = 120 pcf
p = 67 in.

$$R = 0.17\left(\frac{72}{70.3}\right)^{0.7} +$$
$$\left[0.285\left(\frac{3.63^{1.6}}{1.25^{0.2}}\right)\right]\times$$
$$\left[1.0 + 42.7\left\{\left(\frac{21.1}{120(3.63)}\right) \div \left(0.25\,(67) + 3.63\right)\right\}^{0.8}\right]$$

$R = 3.05$ hours

The IBC 2000 includes a tabulation of the required equivalent masonry thickness to achieve 1, 2, 3 and 4-hour fire resistance ratings. The tabulation includes equivalent masonry thickness requirements for protection for numerous W-shapes, square steel tubes (HSS sections), and steel pipes. Both concrete masonry and clay masonry materials (IBC Tables 720.5.1(5) and 720.5.1(6), respectively) are included and a range of material densities are listed.

VI.8.11 Concrete Protection. Both cast-in-place and precast concrete encasements are often used to extend the time that a column can continue to sustain load by using the thermal capacity of the concrete to the column's advantage. The capacity of concrete to absorb heat is influenced by the moisture content of the concrete. Therefore, the fire resistance can be determined by equations in two steps. First, the fire endurance with zero moisture content is determined, and then that fire endurance is increased as a function of the actual moisture. IBC item 720.5.1.4 lists the equation for fire endurance at zero moisture as:

$$R_0 = 10\left(\frac{W}{D}\right)^{0.7} + 17\left(\frac{h^{1.6}}{k_c^{\;0.2}}\right) x \left[1 + 26\left(\frac{H}{\rho_c\, c_c\, h\,(L+h)}\right)^{0.8}\right] \qquad \textbf{(VI–12)}$$

where
R_0 = Fire endurance rating at zero moisture content (min.)
W = Weight of steel column (lbs/ft)
D = Inside perimeter of the fire protection (in.)
h = Thickness of concrete cover (in.)
k_c = Ambient temperature thermal conductivity of concrete (Btu/hr ft °F)
H = Ambient temperature thermal capacity of the steel column = 0.11 W (Btu/ft °F)
ρ_c = Concrete density (pcf)
c_c = Ambient temperature specific heat of concrete (Btu/lb °F)
L = Interior dimension of one side of a square concrete box protection (in.)

Some of the parameters should be adjusted to be consistent with the actual configuration of the encasement, with reference to Figure VI.5, as follows:

- When the inside perimeter of the concrete protection is not square, L shall be taken as the average of L_1 and L_2.
- When the thickness of the concrete cover is not uniform, h shall be taken as the average of h_1 and h_2.
- When the space between the flange tips and web is filled with concrete (i.e. full encasement), the thermal capacity of the steel column, H, can increased as follows:

$$H = 0.11\,W + \left(\frac{\rho_c\, c_c}{144}\right)\left(b_f\, d - A_s\right) \qquad \textbf{(VI–13)}$$

where
b_f = Steel column flange width (in.)
d = Steel column depth (in.)
A_s = Steel column area (sq. in.)

The fire endurance increases as the moisture content of the concrete increases. Therefore, the fire endurance at zero moisture is increased as follows:

$$R = R_0\,\left(1 + 0.03\; m\right) \qquad \textbf{(VI – 14)}$$

where
R = Fire endurance rating at the actual moisture condition (min.)
m = Actual moisture content of concrete by volume (percent)

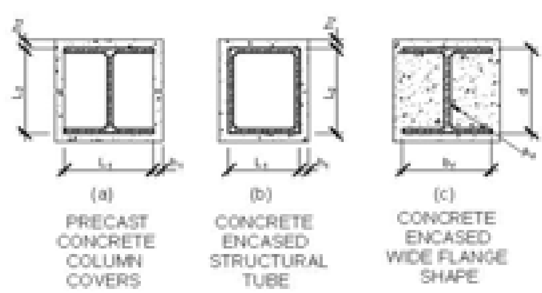
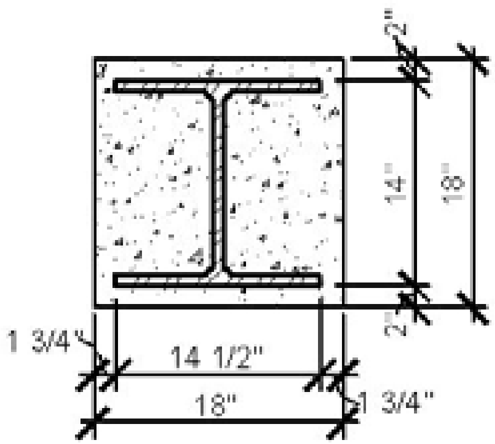


Fig. VI.5 Structural Steel Columns with Concrete Protection[6]

The concrete properties to be used in the resistance equation can be determined by test or tabulated values in the IBC, shown in Tables VI.6a and VI.6b, can be used.

VI.8.11.1 EXAMPLE VI-6

Determine if a 3-hour fire endurance is provided by a W14x90 column encased with normal weight concrete, creating an 18 in. x 18 in. (457.2 mm x 457.2 mm) enclosure.



$W = 90$ lb/ft
$D = 84.6$ in.
$W/D = 1.06$
$A_s = 26.5$ in.^{2}
$h = (h_1 + h_2) / 2 = (2+1.75) / 2 = 1.88$ in.
$k_c = 0.95$ Btu/hr ft °F
$\rho_c = 145$ pcf
$c_c = 0.20$ Btu/lb °F
$L = (L_1 + L_2) / 2 = (14+14.5) / 2 = 14.25$ in.

$$H = 0.11\,(90) + \left(\frac{145\,(0.20)}{144}\right)(14.5\,(14) - 26.5)$$

$$= 45.5$$

$$R_0 = 10\,(1.06)^{0.7} + 17\left(\frac{1.88^{1.6}}{0.95^{0.2}}\right) x$$

$$\left[1 + 26\left(\frac{45.5}{145\,(0.20)\,1.88\,(14.25 + 1.88)}\right)^{0.8}\right]$$

$$= 172 \text{ min.}$$

The resistance time at zero moisture is adjusted for the equilibrium moisture content of the concrete by volume in percent.

$R = 172 * (1 + 0.03\,(4))$
$= 193$ min. ≥ 180 min.

Alternatively, for concrete encasement of steel columns with all re-entrant spaces filled, IBC Tables 720.5.1(7) and 720.5.1(8) may be used to determine the thickness of concrete cover required for various fire endurance ratings. It also bears noting that, under the prescriptive requirements of IBC Table 719.1(1), the column in this example will need only 1 in. of concrete cover to achieve a 3-hour rating.

Precast concrete enclosures of steel columns can be used to create fire endurance using the same calculation procedure as that for cast-in-place concrete. The thermal capacity of the steel column would not be adjusted for the concrete mass created when the space between the flanges is filled. Also, the joints in the precast concrete enclosure need to be protected with a ceramic fiber blanket having a thickness of one-half the precast concrete thickness or 1 in. (25.4 mm), whichever is greater. IBC Tables 720.5.1(9) and 720.5.1(10) indicate minimum cover for steel columns with precast covers.

VI.8.12 Exterior Columns. Section 713.5 of the IBC states that the fire protection required for an exterior column is at least the same as that required for an exterior wall. This fire resistance rating can be different than that required for an interior column and the specific requirements for exterior columns should be confirmed.

Occasionally, the exterior columns are located beyond the exterior wall and, under this condition, the column exposure is much different than either an interior column or an exterior column within the building enclosure. In fire conditions, whereas interior building columns are surrounded by flames and the heated surfaces of enclosing compartments, exterior columns are exposed to radiation from the windows in the facade. Depending on their size and position, exterior columns outside the building wall may not need any protection.

The American Iron and Steel Institute supported research that culminated with the publication of a design guide titled *Fire-Safe Structural Steel*[18]. This reference is a resource for calculating the temperature in an exterior column based on numerous parameters, such as column position relative to exterior windows, window size, ventilation and fire load. The publication includes equations and tables that allow calculation of the temperature of the steel column. This temperature can be compared to a critical temperature to verify the adequacy of the column. A temperature of 1,000 °F (538 °C) is suggested as the critical temperature at or below which the column can be considered safe.

Table VI.6a Concrete Properties		
Property	Normal Weight Concrete	Light Weight Concrete
Thermal Conductivity (k_c)	0.95 Btu/hr ft °F	0.35 Btu/hr ft °F
Specific Heat (c_c)	0.20 Btu/lb °F	0.20 Btu/lb °F
Density (ρ_c)	145 lbs/ft^3	110 lbs/ft^3
Free Moisture (m)	4 percent	5 percent

Table VI.6b Concrete Properties (SI Units)		
Property	Normal Weight Concrete	Light Weight Concrete
Thermal Conductivity (k_c)	1.64 (W/m °K)	0.61 (W/m °K)
Specific Heat (c_c)	837 J/kg °K	837 J/kg °K
Density (ρ_c)	2,320 kg/m^3	1,760 kg/m^3
Free Moisture (m)	4 percent	5 percent

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Section VII
FIRE PROTECTION FOR STEEL ROOF AND FLOOR SYSTEMS

VII.1 GENERAL INFORMATION

The capacity for a building to remain functional for a specified length of time during a fire is of utmost importance for life safety and fire department access. However, all conventional construction materials begin to degrade when exposed to elevated temperatures for prolonged periods of time. Therefore, it is often necessary to provide means of fire protection to the building's structural elements in order for them to properly carry load during this important time period.

Building fire protection may be categorized into two main systems, active and passive. Active protection relies on devices requiring external activation to alert occupants of a fire and to control building fire conditions. Automatic sprinkler systems, smoke detectors, and fire department suppression are all examples of active systems. Alternatively, passive protection provides fire protection by relying on in-place elements, and requires no external activation. Examples of passive protection include fire-rated ceilings, gypsum board or lath and plaster systems, spray-applied fire resistive materials (SFRM), and mastic coatings. Designing passive protection systems for steel roof and floor assemblies that adequately meet building code requirements is the focus of this chapter.

VII.2 TEMPERATURE CRITERIA

Conventional construction material properties, including steel, begin to deteriorate when subjected to elevated temperatures. At temperatures around 1,000 - 1,100 °F (538 – 593 °C) the strength and stiffness of hot rolled steel are approximately one-half of their room temperature values[1]. However, the length of time a steel roof or floor system can remain functional during exposure to these temperatures may be substantially lengthened by retarding the rate of thermal energy transferred to the system.

Numerous tests have been conducted on loaded roof and floor assemblies subjected to elevated temperatures - far more than for any other building element in the United States. These tests have demonstrated that the steel temperature throughout the beam section is a reasonable indicator of its ability to continue to support its design load. The tests have confirmed that assemblies retain the capacity to support the design load when no point along the steel beam member reaches a temperature above 1,300 °F (704 °C) or where the average beam temperature does not exceed 1,100 °F (593 °C). Generally, steel-framed structures can continue to sustain load beyond these limiting temperatures. The effective yield strength is diminished but not completely lost at these temperatures. Nonetheless, these temperature limits have been used to specify the minimum fire resistance criteria for steel roof and floor systems.

VII.3 ASTM E119 ANSI/UL 263

The provisions of ASTM E119[2] are virtually identical to the requirements listed in ANSI/UL 263[3]. Each determines the ability of a roof or floor system to support its design load and remain functional for a specified time when subjected to elevated temperatures. Two different standardized tests are specified in these listings, one for the entire loaded roof or floor assembly and one for a loaded steel beam only. In addition, an alternative test may be used for a steel beam in an unloaded condition.

VII.3.1 Thermal Restraint. Roof and floor assemblies as well as individual beams can be classified as having one of two different end support conditions, either restrained or unrestrained. ASTM E119 defines thermal restraint as when "the surrounding or supporting structure is capable of resisting substantial thermal expansion throughout the range of anticipated elevated temperatures." Unrestrained elements are defined as having supports being "free to rotate and expand" when subjected to elevated temperatures. Most common types of steel-framed construction are classified as thermally restrained[4]. Appendix X3 of ASTM E119 lists the few instances where individual steel beams and girders, or steel framed floor and roof assemblies, are classified as unrestrained.

VII.3.2 Steel Assembly Test. In most cases, the entire loaded assembly, including roof or floor construction, steel beams, girders, and applied fire protection is tested. The assembly is constructed such as to represent the system anticipated at the building site. The required minimum specimen area exposed to the furnace is 180 ft^2 (16.7 m^2), with a minimum dimension of 12 ft (3.7 m) on any side. The assembly is loaded to its maximum load condition unless a lesser load is used and the reduced load is imposed as a condition of applicability. The assembly is restrained against the perimeter test frame with steel shims. Sets of four thermocouples are attached at sections along the length of the structural members to record the temperature. The entire roof or floor assembly is subjected to increasing furnace temperatures following a standard time-temperature relationship and tested until a failure criterion is reached. A single restrained test is usually conducted to evaluate ratings for the two classifications, restrained and unrestrained. The unrestrained rating for the assembly is usually determined from the following temperature criteria:

1. For assemblies with structural steel members (beams, joists, etc) spaced more than 4 ft on center, the average temperature recorded by four thermocouples at any section exceeds 1,100 °F (593 °C), or any in single point along the member reaches 1,300 °F (704 °C).
2. For assemblies with structural steel members (beams, joists, etc) spaced 4 ft or less on center, the average temperature recorded by all beam or joist thermocouples exceeds 1,100 °F (593 °C).
3. For assemblies with steel floor or roof deck units intended for use in spans greater than those tested, the average temperature recorded by all thermocouples located on any one deck span exceeds 1,100 °F (593 °C).

The fire test is then continued until a desired rating is achieved, or until any failure criterion for the restrained assembly rating, as listed below, is reached.

4. The unexposed surface of the assembly develops conditions that ignite cotton waste (due to passage of hot gases or flames through cracks in the assembly).
5. The average temperature rise on the unexposed surface of the assembly exceeds 250 °F (139 °C).
6. The assembly could no longer support the superimposed load.

Where any of the temperature criteria in item 1 (for members spaced more than 4 ft on center) or Item 2 (for members spaced 4 ft or less on center) is reached in less than 1 hour, the restrained rating is determined based on that temperature criterion. Where any of the temperature criteria in items 1 or 2 is reached in 1 hour or more, the restrained assembly rating is determined based on criteria 4, 5, or 6, however, the restrained rating is not allowed to be more that twice longer than the time based on criteria 1 or 2. It bears noting that the restrained assembly rating is not subject to the temperature criterion in item 3 that applies to unrestrained assembly ratings only.

In addition, ASTM E119 (and ANSI/UL 263) also provides for an unrestrained beam rating to be determined from the same assembly test. This unrestrained beam rating is based on the temperature criteria in item 1, regardless of the spacing of structural steel members.

Ratings published from a roof or floor assembly test usually include a restrained assembly rating, an unrestrained assembly rating, and an unrestrained beam rating.

VII.3.3 Loaded Steel Beam Test. Conducting all of the necessary complete assembly tests that fully encompass every combination of beam sizes, sections, and profiles in conjunction with different fire protection methods is not practical or feasible. Therefore, ASTM E119 and ANSI/UL 263 also provide for a beam-only test. In this test, the steel beam specimen is constructed, together with a representative floor slab strip, such that the derived fire resistance ratings may be applicable when the beam is used within a roof or floor assembly having an equal or greater heat dissipation capacity. For floors with concrete slabs, a greater heat dissipation capacity is achieved with higher concrete density or with higher concrete volume per unit floor area. Usually, the slab strips used in the beam-only tests are of a minimum (about 2½ in. or 63.5 mm) thickness, so the designer may conservatively substitute beam-only rating results into complete roof or floor assembly tests of similar composition.

The beam specimen is constructed as thermally restrained against longitudinal expansion. ASTM E119 stipulates that the tested beam shall not be less than 12 ft (3.7 m) long and limits the width of the floor slab not to exceed 7 ft (2.1 m). If the roof or floor slab is part of the "complete beam as designed", i.e. composite, the effective design width of the slab is also to be constructed as restrained at beam ends. If not, then the slab is to be constructed as unrestrained, and only the steel beam is constructed as restrained. The specimen shall endure a superimposed load representing its maximum loading condition throughout the length of the test, unless a reduced load condition is intended for the rating. The test is continued until a desired restrained rating is achieved, or until the specimen can no longer support the superimposed load.

In loaded beam tests, the unrestrained beam rating is determined based on the temperature criteria of item 1 in the previous section. Where the unrestrained beam rating is less than one hour, the restrained beam rating is equal to the unrestrained beam rating. Where the unrestrained beam rating is 1 hour or more, the restrained beam rating is based solely on the beam's ability to sustain the applied load. However, the restrained beam rating is not allowed to be more than twice longer than the unrestrained beam rating.

No complete assembly ratings are published from beam-only tests as the complete roof or floor assembly is not tested. Therefore, only a restrained beam rating and an unrestrained beam rating are listed.

VII.4 TEST FACILITIES

As previously noted, testing facilities have conducted a far greater amount of fire protection research for roof and floor assemblies than for any other building element. Results from these standardized tests allow the performance of building construction assemblies to be quantified. Several testing facilities have conducted fire endurance tests, with Underwriters Laboratories Inc. (UL) being the most prolific in the United States. Results from these tests are often published in a directory that may be referenced for building design. Additionally, material certifications of conformance can be directly provided by the manufacturer.

VII.5 UL DIRECTORY

The UL Fire Resistance Directory[5] is the most commonly referenced directory for published fire test data in the United States. Listings for both complete roof and floor assembly tests as well as for beam-only tests are included. All published test results are grouped together and designated with specific prefixes shown here in Table VII.1.

The UL Directory further subdivides each specific prefix designation with a three-digit number representing the type of fire protection system used in the assembly as shown in Table VII.2.

VII.6 BUILDING CODES

Building construction in the United States is regulated either directly by one of the national model building codes, or by local provisions that often are only modifications to of one of the national codes. Historically, the three major national building codes are the Basic Building Code (BOCA), the Standard Building Code (SBC), and the Uniform Building Code (UBC). In 2000, these three major organizations cooperated to produce a combined national code, designated the International Building Code (IBC)[6]. After the creation and publication of the IBC, the National Fire Protection Association (NFPA) also produced a separate national building code. Currently, the IBC and NFPA are the two primary national building codes in the United States. The fire protection design examples in this guide are based upon the 2000 IBC, however, the design procedures used are characteristic of most building codes and may be readily adapted.

VII.6.1 Level of Protection. Building codes mandate the amount of fire protection required for buildings based on probabilistic data of building failure and life safety. Therefore, the level of protection required varies with the combustibility of the building materials (construction type), the number of occupants and type of occupancy the construction will house, and the building height and area. Building codes also recognize the influence that automatic sprinkler systems and perimeter fire department access provide in the protection of a building. Allowances for these systems are further discussed in Chapter II of this guide.

Building codes regulate the required fire endurance for roof and floor assemblies by listing time ratings through which assemblies are to remain functional during fire conditions. The IBC mandates different levels of protection for roof and floor members depending on their importance to maintaining structural integrity. Structural frame elements sometimes require a greater rating than do typical roof or floor beams. The definition of the structural frame occurs as a footnote to Table 601 of the IBC:

> *The structural frame shall be considered to be the columns and girders, beams, trusses and spandrels having direct connection to the columns and bracing members designed to carry gravity loads.*

Fire resistance rating requirements for building elements are published in Table 601 of the IBC. Ratings for the structural frame and for roof and floor construction are summarized in Table VII.3.

VII.6.2 Individual Member Protection. The IBC directs the type of fire protection that may be used on specific elements according to their importance to the overall structural integrity of the building.

Structural members supporting certain building elements are required to have individual fire protection. This type of protection is defined as having members protected “on all sides for their full length with materials having the required fire resistance rating.” Section 713 of the IBC states that a member must be individually protected if it supports the following:

Table VII.1 UL Construction Groups		
Constr. Group	**Prefix**	**Description**
Floor/ Ceiling Assembly	A	Concrete and Cellular Steel Floors
	D	Concrete and Steel Floor Units
	G	Concrete and Steel Joist Assemblies
Beam-Only	N	Floor/Ceiling Beam-Only Designs
Roof/ Ceiling Assembly	P	Steel Beam and Joist Roof Assemblies
Beam-Only	S	Roof/Ceiling Beam-Only Designs

Table VII.2 UL Protection Types	
Number Range	**Protection Type**
000-099	Concealed Ceiling Grid Systems
100-199	Reserved for Future Expansion
200-299	Exposed Ceiling Grid Systems
300-399	Mineral and Fiber Board Systems – All Groups Except A Reserved for Future Expansion – Group A
400-499	Metal Lath Systems with Plaster or Spray-Applied Fire Resistive Materials
500-599	Gypsum board systems
600-699	Mastic coatings (intumescent and subliming mastic coatings) – Groups N and S Miscellaneous – Group P
700-899	Spray-Applied Fire Resistive Materials
900-999	Unprotected Deck Systems

1. More than two floors.
2. More than one floor and one roof.
3. A load-bearing wall of any height.
4. A nonload-bearing wall more than two stories high.

A fire-rated ceiling membrane is not an acceptable method of fire protection for members supporting these building elements.

Table VII.3 IBC Fire Resistance Requirements for Structural Frame, Floor and Roof Construction (hours)				
Constr. Type		**Struct. Frame**	**Floor Constr.**	**Roof Constr.**
Type I	A	3	2	1½
	B	2	2	1
Type II	A	1	1	1
	B	0	0	0
Type III	A	1	1	1
	B	0	0	0
Type V	A	1	1	1
	B	0	0	0

The IBC allows structural members supporting conditions other than these to be protected by a ceiling membrane as well as all other approved methods of construction, including individual encasement, membrane protection, or a combination of both.

VII.6.3 Fire Resistant Design. As noted in Chapter II, evidence of compliance with the building code can be based on test results conducted in accordance with the ASTM E119 standard. A compilation of testing that is based on ASTM E119 and acceptable to the building official can be referenced as evidence of compliance. The UL Directory is a compilation of tested assemblies giving the designer much flexibility in choosing a fire protection system for the structure. Therefore, the designs and examples in this guide will meet all IBC code requirements, but will be based on UL test assemblies.

The IBC also addresses restrained and unrestrained construction in fire resistance design. The code defines assemblies classified as restrained according to the following:

> *703.2.3 Restrained classification. Fire resistance rated assemblies tested under ASTM E119 shall not be considered to be restrained unless evidence satisfactory to the building official is furnished by the registered design professional showing that the construction qualifies for a restrained classification in accordance with ASTM E119. Restrained construction shall be identified on the plans.*

The UL Directory is an approved design source based upon the ASTM E119 standard. The UL Directory defines restraint conditions as those meeting Appendix C of Standard ANSI/UL 263. This listing as well as Table X3.1 of the appendix of ASTM E 119 qualifies most common types of steel-framed construction as restrained.

VII.7 CONSTRUCTION FACTORS INFLUENCING FIRE RESISTANCE RATINGS

Many factors affect the endurance and heat transfer of a fire resistive assembly. Therefore, the composition of tested fire protection systems is very specific and purposeful. When choosing an assembly, the building composition should closely match that as described in the listed assembly. Combinations or substitutions are generally not acceptable except for those designs, such as beam-only tests, that are specifically intended for substitution into another assembly. Even in assemblies such as these, specific requirements allowing the substitution must be met.

Factors having a significant influence on fire resistive assemblies are:

1. Concrete Strength and Unit Weight
2. Composite / Non-composite Beams
3. Steel Deck Properties
4. Unprotected/Protected Steel Decks
5. Roof Insulation

VII.7.1 Concrete Strength and Unit Weight. Concrete slab properties can have a significant influence on the heat transfer of a fire resistive assembly. Designs in the UL Directory indicate required compressive strengths. The minimum concrete strength allowed, without invalidating the use of the assembly rating, is the specified assembly design slab strength less 500 psi (3.45 MPa). There is no maximum concrete strength limit.

The unit weight of the concrete slab is also a very specific property of the assembly and must be met. Normal weight concrete test assemblies may not be referenced in lightweight concrete building systems. The greater insulating properties of the lightweight system allow less heat to be dissipated away from the steel member, creating higher member temperatures than those tested. Similarly, lightweight concrete test assemblies may not be referenced in normal weight concrete building systems. The greater heat conducting properties of the normal weight slab can create higher unexposed surface temperatures than those developed during the test.

VII.7.2 Composite/Non-Composite Beams. When subjected to elevated temperatures, composite beams deflect more than non-composite beams when loaded to their maximum allowable stress. Therefore, under UL provisions, composite beams may not be substituted into non-composite beam designs, however, non-composite beams may be substituted into composite beam designs.

VII.7.3 Steel Deck Properties. The UL directory requires the steel deck properties of the roof and floor test assembly referenced to match those used in the construction. These properties include:

1. Deck type, including cellular, form, or fluted.
2. Minimum deck thickness.
3. Deck attachment and support.
4. Finish type, either painted or galvanized. SFRM is usually applied to galvanized floor decks, however it may be applied to primed or painted decks provided it has passed bond tests in accordance with ASTM E736. Certain SFRM manufacturers provide lists of pre-approved paints passing ASTM E736.

VII.7.4 Unprotected/Protected Steel Deck. Assemblies with an unprotected steel deck transmit more heat to the beam section than do protected deck assemblies. Therefore, the deck protection used in the building should match the protection required in the tested assembly. However, an additional requirement applies when incorporating beam-only designs with sprayed steel decks into complete assembly designs with unprotected steel decks. In this substitution, a minimum width of 12 in. (305 mm) of the deck on each side of the beam is required to be oversprayed with the same thickness and fireproofing material as that on the beam. Beam-only designs with unprotected decks may be directly substituted into complete assembly designs with protected or unprotected steel decks without additional overspray.

When both the beam-only and complete assembly design call for protected decks, the SFRM thickness to be used for the 12 in. (305 mm) deck width on each side of the beam shall be the lesser of the specified thickness required for either the beam or the deck in the beam-only test. However, this thickness shall not be less than that required for the deck in the assembly listing. When both the beam-only and complete roof or floor assembly design call for unprotected decks, no overspraying is required.

VII.7.5 Roof Insulation. Roof insulation types or thicknesses different from those specified in the assembly can create adverse effects similar to those created when substituting different concrete weights. A greater roofing thickness or insulating material property can result in higher beam temperatures than those tested. A decrease in the roofing thickness or insulating material property can result in greater unexposed surface temperatures.

VII.8 FIRE RESISTANT ASSEMBLY SYSTEMS

As mentioned, fire protection systems may be classified as active systems requiring some method of external activation, or passive systems requiring no external activation. Passive protection systems for roofs and floors may be further divided into two categories:

1. Fire-rated Ceiling Systems
2. Individual Protection Systems

The designer should note that the authority having jurisdiction might limit the acceptable methods of passive protection based on what the member is supporting, as listed in VII.6.2 Individual Member Protection.

VII.8.1 Fire-Rated Ceiling Systems. Fire-rated ceiling systems protect the structure from elevated temperatures by creating a protective envelope below the roof or floor construction. Construction of this envelope commonly consists of attaching a horizontal layer of gypsum boards, mineral and fiber boards, or lath and plaster to the bottom of the structure. Alternatively, a fire-rated ceiling assembly can be suspended from the members above. The ceiling panels used in these assemblies are not in themselves rated but must be a component listed with the description of the complete assembly. All details relevant to the assembly should be closely followed to ensure the integrity of the envelope is not compromised. The cost of providing these items is not trivial and should be carefully weighed against the cost of providing individual member protection. Details for fire-rated ceiling assemblies may include:

- Protecting all light fixture penetrations with batts and blankets, gypsum board, or acoustical material.
- Limiting the maximum aggregate area of the light fixtures to be used.
- Limiting the number and size of duct penetrations through the ceiling.
- Requiring protected ductwork for air returns.
- Furnishing fire dampers with fusible links within air ducts.
- Providing Teflon coating to in-ceiling communication wiring.
- Requiring hold-down clips for acoustical panels unable to withstand a one pound per square foot uplift.
- Constructing additional support members at ceiling edges.
- Providing special ceiling control joints at panel-to-panel interfaces.
- Limiting the maximum allowable spacing of ceiling hanger wire.

VII.8.2 Individual Protection Systems. Individual protection systems differ from ceiling systems in that they preserve the integrity of the structural system by protecting specific elements of the construction. The two primary types of individual protection systems are insulated beam enclosures and direct-applied protective coatings. Fire-rated enclosure systems are constructed with mineral and fiber boards, lath and plaster, or gypsum board. Insulated beam enclosures are often used where the beam protrudes into the architectural space or where other aesthetics are of concern. Direct-applied protective coatings include SFRM and intumescent mastic coatings. In locations where the element is located such that aesthetics are not of primary concern, SFRM is the most economical option. Mastic coatings may be used where aesthetics are of interest or where exterior applications are required.

VII.9 *W/D* CRITERIA

Tests based on heat transfer principles indicate that important parameters influencing the rate of thermal transfer through a body are the body's surface area exposed to a thermal gradient and its mass. Results from these tests show that the rate of temperature change is directly proportional to the beam's exposed surface area and inversely proportional to its mass[7]. This relationship may be expressed by the term W/D, where W is the weight of the member in pounds per linear foot and D is the inside perimeter of the fire protection material in inches. Elements with a higher W/D ratio are more resistant to thermal transfer than members with a lower W/D given the same material properties. Values of D for common beam sizes are listed by AISC and reproduced in Appendix A of this guide. Formulas for two common profiles for roof or floor applications are listed in Figure VII.1. It is important to note these values are listed for the <u>heated</u> perimeter. Therefore when designing the fire protection for roof or floor beams, only three sides are considered in the computation. Additionally, values of D listed in Appendix A accurately include the effects of rounded beam fillets and are slightly lower than those found from the approximate formulas in Figure VII.1. This difference provides slightly higher *W/D* values than those calculated using the figure equations.

VII.10 SFRM THICKNESS ADJUSTMENT

In tests where SFRM is used, the UL Directory lists the size of the tested element as a minimum beam size (i.e. minimum *W/D* ratio). Many of these members are shallow, heavy W-sections that are rarely found in an economical structural design. Therefore, a procedure is necessary to convert SFRM thickness requirements from these tests to suit the member actually used in the design. SFRM thickness adjustments for both complete roof and floor assembly tests and beam-only tests can be made in one of two ways:

1. Larger *W/D* Substitution
2. SFRM Thickness Adjustment Equation

VII.10.1 Larger *W/D* Substitution. By listing a minimum beam size, each assembly essentially prescribes a minimum *W/D* ratio to be met. Any beam section with a larger *W/D* value than that listed may be directly substituted into the assembly without changing the SFRM thickness[7]. However, because the listings often specify shallow, compact members with relatively high *W/D* ratios, this method may not be suitable for many economical beam sections. In these cases the thickness adjustment equation must be used. Even in instances when an element does have a larger *W/D* ratio than that listed and may be directly substituted, it is advisable to check the thickness adjustment equation as a smaller amount of fireproofing may be permitted.

VII.10.2 SFRM Thickness Adjustment Equation. Results of UL fire tests of beams with varying SFRM thickness show a strong relationship between the time until a limiting temperature or beam failure is reached to the thickness of SFRM applied and the member's *W/D* ratio. This relationship, shown in equation VII-1, provides a logical approach for varying the thickness

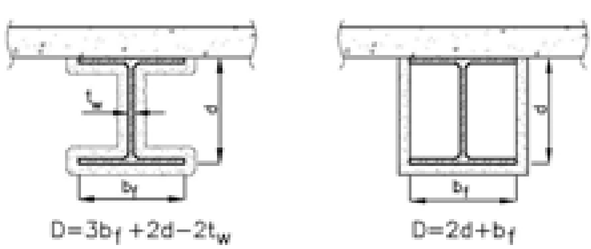

Fig. VII.1 D Factor Formulas for Wide-Flange Steel Beams

of SFRM applied to a substituted beam based on its *W/D* ratio. The UL Directory allows the formula to be utilized in both restrained and unrestrained cases as long as the restrained beam is classified as compact.

SFRM Thickness Adjustment Equation:

$$T_1 = \frac{\left(\frac{W_2}{D_2} + 0.6\right) * T_2}{\left(\frac{W_1}{D_1} + 0.6\right)} \qquad \textbf{(VII–1)}$$

where

T	=	Thickness (in.) of spray applied material
W	=	Weight of beam (lb / ft)
D	=	Perimeter of protection, at the interface of the protection material and the steel through which heat is transferred to steel (in.)
Subscript 1	=	Refers to desired beam size and required material thickness.
Subscript 2	=	Refers to given beam size and material thickness shown on the individual design.

The beam substitution equation is subject to the following qualifications:

1. *W/D* values for the beam must not be less than 0.37.
2. T_1 values must not be less than ⅜ in. (9.5 mm).
3. The Unrestrained Beam Rating is not less than 1 hour.
4. The Restrained Beam Rating is not less than 1 hour.
5. When used to determine the thickness to be applied to a restrained beam, the desired beam must be classified as compact as per Part B5.1 and Table B5.1 of the AISC LRFD Specification for Structural Steel Buildings [7]. For A992 steel W-shapes, relatively few sections (W21x48, W14x99, W14x90, W12x65, W10x12 W8x31, W8x10, W6x15 and W6x8.5) are classified as non-compact.

VII.10.3 EXAMPLE VII-1

Determine the thickness of SFRM required to meet IBC Construction Type IB requirements for the example floor plan shown in Figure VII.2. For economy, an unprotected deck design is to be used.

Table VII.3 shows that for Construction Type IB, the IBC requires a 2-hour rating for both the structural frame and floor construction. Steel-framed structures are classified as restrained; therefore a UL assembly supporting a 2-hour restrained rating must be found. In addition, the assembly must support the use of composite beams, lightweight concrete and fluted deck. UL tests D902 and D925, utilizing SFRM materials from Isolatek International and W. R. Grace & Co., respectively, are commonly referenced unprotected deck designs. In this example, UL design D902, shown in Figure VII.3, will be evaluated.

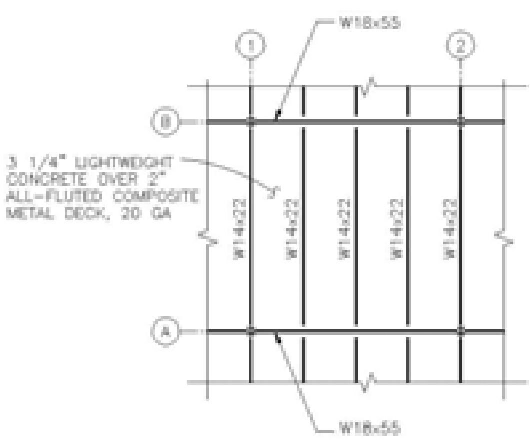

Fig. VII.2 Example Floor Plan

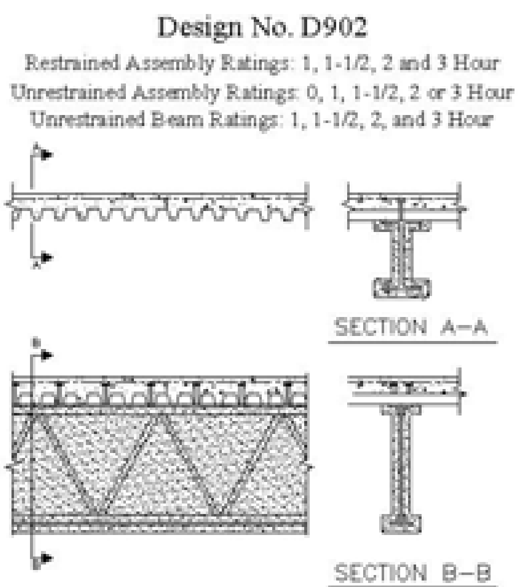

Fig. VII.3 UL Design D902[5]

Slab Design: UL D902 supports the use of both normal weight and lightweight concrete. The assembly requires a 3¼ in. (82.6 mm) lightweight concrete deck for a 2-hour restrained assembly rating. The compressive strength of the concrete shall be 3,000 psi (20.7 MPa). The unit weight of the concrete used in design should fall within the range of 107-116 pcf (1,710-1,860 kg/m^3) as specified in the assembly. Differences in the unit weight of the concrete may adversely alter the insulating properties of the slab from those tested.

Deck Design: The assembly allows both composite and non-composite fluted decks. Fluted units may be either galvanized or phosphatized/painted. The deck is to have a gauge 22 MSG minimum thickness.

SFRM Thickness: Figure VII.4 shows a summary of the SFRM thickness amounts required by UL D902 for a W8x28 beam coated with Isolatek Type D-C/F material. UL D902 lists several unrestrained beam ratings for each restrained assembly rating. For instance, the 2-hour restrained assembly rating used with lightweight concrete systems provides 1-, 2-, and 3-hour unrestrained beam ratings requiring ⅜ in. (9.5 mm), 1 in. (25.4 mm), and 1⁹⁄₁₆ in. (39.7 mm) of material thickness, respectively. A 2-hour restrained assembly rating with a 1-hour unrestrained beam rating is an acceptable solution for this example and requires the least amount of fireproofing material. Therefore, a ⅜ in. (9.5 mm) thickness applied to the W8x28 test beam will be chosen.

Restrained Assembly Rating (Hr)	Unrestrained Beam Rating (Hr)	Concrete Type	Thickness (in.) for W8x28 with All Fluted Deck
1	1	NW	3/8
1-1/2	1	NW	3/8
2	1	NW	3/8
2	2	NW	3/4
2	3	NW	1-3/16
3	1-1/2	NW	1/2
3	2	NW	3/4
3	3	NW	1-3/16
1	1	LW	3/8
1-1/2	1	LW	3/8
2	1	LW	3/8
2	2	LW	1
2	3	LW	1-9/16
3	1-1/2	LW	11/16
3	2	LW	1

Fig. VII.4 UL D902 SFRM Thickness Requirements[5]

In order to use the SFRM adjustment formula, the beam member must be compact. Both the W14x22 and W18x55 are classified as compact sections.

W14x22, *W/D* = 0.53

The W14x22 has a *W/D* less than that of the tested W8x28 beam (*W/D* = 0.82), therefore the SFRM thickness adjustment equation must be used.

$$T_1 = \left(\frac{0.82+0.6}{0.53+0.6}\right) * 0.38 = 0.47$$

use ½ in. (12.7mm)

W18x55, *W/D* = 0.96

The W18x55 has a *W/D* greater than that of the tested W8x28 beam, therefore the ⅜ in. (9.5 mm) thickness of fire protection material required for the W8x28 beam may be directly used on the W18x55 beam. It is always good practice to check with the thickness adjustment equation as a lesser amount of fire protection may be allowed. However, in this case, the ⅜ in. (9.5 mm) thickness coincides with the minimum value allowed by the equation, so there is no adjustment.

In summary, the following SFRM thicknesses are required:

Steel Deck – No Protection Required

W14x22 – ½ in. (12.7 mm) of Isolatek Type D-C/F

W18x55 – ⅜ in. (9.5 mm) of Isolatek Type D-C/F

Alternatively, the D-902 table in Appendix B in this design guide may be used to determine fireproofing thicknesses. SFRM values of ½ in. (12.7 mm) for the W14x22 and ⅜ in. (9.5 mm) for the W18x55 can be obtained directly from the tabulation.

VII.10.4 EXAMPLE VII-2

Determine the SFRM thickness requirements for the floor layout in Example VII-1 using a protected deck design. IBC Construction Type IB requirements are to be used.

As in Example VII-1, a 2-hour restrained rating will be used to meet the IBC Construction Type IB requirements. A tested UL assembly supporting the use of composite beams, lightweight concrete, and a protected 2 in. fluted deck is needed. UL design D858, shown in Figure VII.5, will be evaluated for these requirements.

Slab Design: UL D858 supports the use of both normal weight and lightweight concrete, calling for a 2½ in. (63.5 mm) thickness over the flutes of the deck. The compressive strength of the concrete shall be 3,000 psi (20.7 MPa). Because this specific example supports both normal and lightweight concrete, the upper bound of the concrete unit weight is that of normal weight concrete (153 pcf or 2,450 kg/m^3), and the lower bound unit weight is that of lightweight concrete (108 pcf or 1,730 kg/m^3).

Deck Design: The assembly supports composite design of fluted decks. Fluted units are to be galvanized only. The assembly requires the deck to have a minimum thickness of gauge 22 MSG.

SFRM Thickness Applied to the Deck: Figure VII.6 lists several restrained and unrestrained ratings for various steel floor deck units, concrete weights, and SFRM thicknesses. Values for a 2-hour restrained assembly may be read directly from the table. A thickness of ⅜ in. (9.5 mm) is to be applied to both the crests and valleys of the deck.

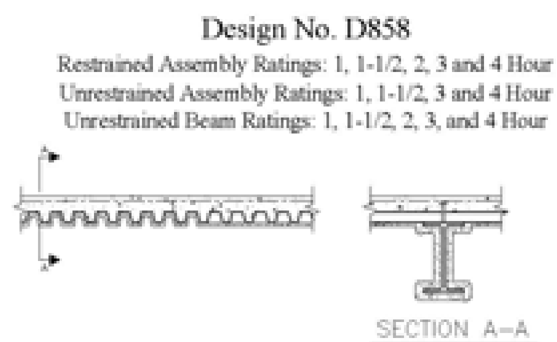

Fig. VII.5 UL Design D858[5]

Restrained Assembly Rating (Hr)	Unrestrained Assembly Rating (Hr)	Steel Floor Unit Depth (in.)	Concrete Type	Thickness (in.) for Crests / Valleys
1	0	2 or 3	LW	0 / 0
1	1	1-1/2	LW or NW	3/8 / 3/8
1, 1-1/2 or 2	1, 1-1/2 or 2	2 or 3	LW or NW	3/8 / 3/8
3	1-1/2, 2 or 3	3	LW	5/8 / 5/8
3	1-1/2, 2 or 3	2	LW	13/16 / 1/2
3	1-1/2, 2 or 3	3	NW	13/16 / 13/16
3	1-1/2, 2 or 3	2	NW	7/8 / 5/8
4	2, 3 or 4	3	LW or NW	1-7/16 / 13/16
4	2, 3 or 4	2	LW or NW	1-1/2 / 1-1/8

Fig. VII.6 UL D858 Steel Floor Unit SFRM Thickness Requirements[5]

SFRM Thickness Applied to the Beams: Figure VII.7 shows a summary of the SFRM thickness amounts required for a minimum beam size of W10x25 coated with Isolatek Type D-C/F material. Therefore, for a 2-hour restrained assembly rating, a W10x25 with a ½ in. (12.7 mm) SFRM thickness will be used in the adjustment equation. The *W/D* value for the discontinued W10x25 section is 0.69.

In order to use the SFRM adjustment formula, the beam member must be compact. Both the W14x22 and W18x55 are considered compact sections.

W14x22, $W/D = 0.53$

The W14x22 has a *W/D* less than that of the tested W10x25 beam (W/D = 0.69), therefore the SFRM thickness adjustment equation must be used.

$$T_1 = \left(\frac{0.69+0.6}{0.53+0.6}\right) * 0.50 = 0.57$$

use ⅝ in. (15.9mm)

W18x55, $W/D = 0.96$

The W18x55 has a *W/D* greater than that of the tested W10x25 beam, therefore the ½ in. (12.7 mm) thickness of fire protection material required for the W10x25 beam may be directly used on the W18x55 beam. However, the thickness adjustment equation may provide a lesser amount of fire protection, so it should be checked.

$$T_1 = \left(\frac{0.69+0.6}{0.96+0.6}\right) * 0.50 = 0.41$$

use 7⁄16 in. (11.1mm)

Restrained Assembly Rating (Hr)	Unrestrained Beam Rating (Hr)	Thickness (in.) for W10x25 min. size
1	1	1/2
1-1/2	1	1/2
2	1	1/2
3	1-1/2	7/8
4	2	1-1/8
--	3	1-1/2
--	4	1-3/4

Fig. VII.7 UL D858 Steel Beam SFRM Thickness Requirements[5]

In summary, the following SFRM thicknesses are required:

Steel Deck – ⅜ in. (9.5 mm) of Isolatek Type D-C/F applied to crests and valleys

W14x22 – ⅝ in. (15.9 mm) of Isolatek Type D-C/F

W18x55 – 7⁄16 in. (11.1 mm) of Isolatek Type D-C/F

VII.11 BEAM SUBSTITUTION

Standardized beam-only tests provide fire test results of beams with various fire protection methods without the necessity of reconstructing the entire floor assembly each time a test is run. However, because only representative sections of roof or floor constructions are used in the beam-only test, they must be incorporated into compatible complete assembly tests before they may be used to meet the requirements of building code fire ratings. The UL Directory lists beam-only tests in the N and S design series.

Beam-only tests are commonly used in instances where the authority having jurisdiction requires a higher rating for beams acting as the structural frame than for the rest of the floor or ceiling assembly. In these cases, fire protection for the structural frame may be accomplished by substituting an N or S series beam-only design meeting the frame rating requirements into a complete roof or floor assembly test of a lesser rating. Other instances where a beam-only test can be used are when the complete assembly test does not specify a steel beam, or when the profile or type of beam desired is different than that listed in the assembly[8]. For instance, the fire resistance of a castellated beam section protected with SFRM has been determined as a part of a beam-only test (UL N831). In order to use this type of member in a roof or floor assembly, it must replace a different type of beam section (i.e. W-shape) specified in the complete assembly test.

Not every beam-only test may be substituted into a complete assembly test. Rather, the UL provides specific requirements as to when this substitution may take place. These requirements are:

1. Non-composite or composite beams may be substituted into assemblies with composite beams. Only non-composite beams may be incorporated into assemblies with non-composite tests.

2. Beam-only designs may only be used in complete roof or floor assembly tests that have a “similar or greater capacity for heat dissipation from the beam” than the beam-only test. For concrete floors, greater density range and volume per unit floor area provide a greater heat dissipation capacity.
3. Beam-only designs shall have an equal or greater unrestrained beam rating than the complete roof or floor assembly unrestrained beam rating.
4. Beam-only designs requiring roof or floor deck fire protection (N400-N800 design series) may be incorporated into assemblies with unprotected decks as long as the beam fire protection material is oversprayed for 12 in. (305 mm) on either side of the beam. The thickness of the oversprayed material shall be the same as required for the beam. Beam-only designs with unprotected decks (N900 design series) may be incorporated directly into complete assembly tests with unprotected decks with no overspraying required.

VII.11.1 EXAMPLE VII-3

Determine the thickness of SFRM required to meet IBC Construction Type IA requirements for the floor section shown in Example VII-1. An unprotected deck design is to be used.

Table VII.3 shows that for Construction Type IA, the IBC requires a 2-hour rating for the floor construction, but requires a 3-hour rating for the structural frame. The IBC designates components “having direct connections to the columns” as members of the structural frame. Therefore the W18x55 girders, as well as the W14x22 members along column lines 1 and 2 require a 3-hour rating.

All steel structures are classified as restrained; therefore a UL beam-only design supporting a 3-hour restrained beam-only rating must be found and incorporated into a 2-hour floor assembly. As in the previous examples, the selected assembly must support the use of composite beams, lightweight concrete and fluted deck. The selected beam-only design must support the use of composite beams. In this example, the unprotected deck assembly UL D925 (Figure VII.8) and beam-only design UL N782 (Figure VII.10) will be evaluated.

Slab Design: UL D925 supports the use of both normal weight and lightweight concrete. It requires a 3¼ in. (82.6 mm) lightweight concrete deck with a unit weight of 107-116 pcf (1,710-1,860 kg/m^3) over a 2 in. deck for a 2-hour restrained assembly rating. The compressive strength of the concrete shall be 3,000 psi (20.7 MPa).

Deck Design: The assembly allows both composite and non-composite fluted decks. Fluted units may be galvanized, uncoated, or phosphatized/painted. The assembly requires the deck to have a minimum thickness of gauge 22 MSG.

SFRM Thickness: Figure VII.9 shows a summary of the SFRM thickness amounts required by UL D925 for a W8x28 beam coated with W. R. Grace Type MK-6 material. Similar to UL D902, UL D925 lists several unrestrained beam ratings for each restrained assembly rating. A 2-hour restrained assembly rating with a 1-hour unrestrained beam rating is an acceptable solution for this example and requires the least amount of fireproofing material. Therefore, a 7⁄16 in. (11.1 mm) thickness applied to the W8x28 test beam supporting all fluted floor units with lightweight concrete will be chosen.

In order to use the SFRM adjustment formula, the beam members must be compact. Both the W14x22 and W18x55 are classified as compact sections.

W14x22, $W/D = 0.53$

The W14x22 floor member has a W/D less than that of the tested W8x28 beam ($W/D = 0.82$), therefore the SFRM thickness adjustment equation must be used.

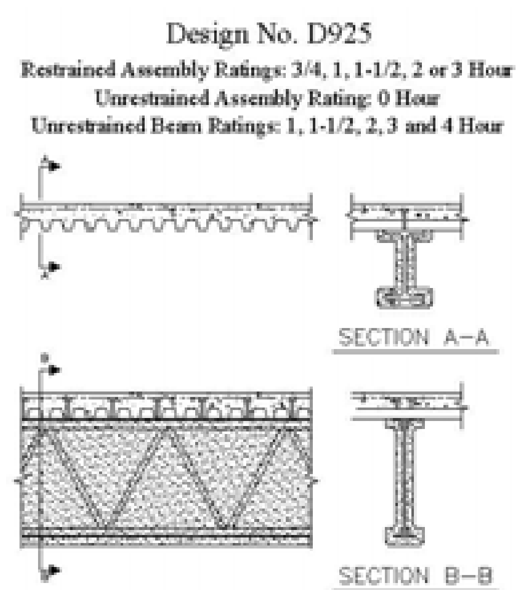

Fig. VII.8 UL Design D925[5]

$$T_1 = \left(\frac{0.82 + 0.6}{0.53 + 0.6}\right) * 0.4375 = 0.55$$

use 9/16 in. (14.3mm)

Protection for the structural frame members will now be determined using UL N782 (Figure VII.10). However, before UL N782 may be incorporated into the floor assembly, it should be checked to ensure it has a concrete slab with lower capacity for dissipating heat away from the beam than the floor assembly.

Slab Design: UL N782 supports the use of both normal weight and lightweight concrete. For lightweight concrete, it specifies a unit weight of 110 pcf (1,760 kg/m^3). When no unit weight range is given, the commentary in the UL Directory allows a tolerance of plus or minus 3 pcf (48.1 kg/m^3). Therefore, the concrete unit weight of 107-113 pcf (1,710 kg/m^3-1,810 kg/m^3) is within the range of UL D925. The 2½ in. concrete thickness for UL N782 is less than the thickness specified in UL D925; therefore it meets the requirement of having a lower heat dissipation capacity than the floor system.

Restrained Assembly Rating (Hr)	Unrestrained Assembly Rating (Hr)	Unrestrained Beam Rating (Hr)	Thickness (in.) for W8x28, All Fluted LW Concrete Deck
1	1	1	7/16
1-1/2	1	1	7/16
1-1/2	1-1/2	1-1/2	3/4
2	1	1	7/16
2	2	2	1
3	1-1/2	1-1/2	3/4
3	3	3	1-5/16
3	3	4	1-5/8

Fig. VII.9 UL D925 Steel Beam SFRM Thickness Requirements[5]

Design No. N782

Restrained Beam Ratings: 1, 1-1/2, 2, 3 and 4 Hour

Unrestrained Beam Ratings: 1, 1-1/2, 2, 3 and 4 Hour

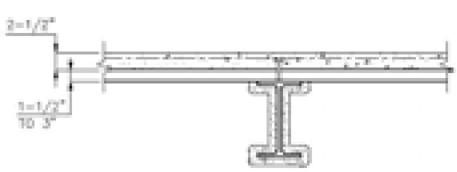

Fig. VII.10 UL Design N782[5]

SFRM Thickness: Figure VII.11 shows a summary of the SFRM thickness amounts required by UL N782 for a W8x28 beam coated with W. R. Grace Type MK-6 material. A 3-hour restrained fire-rating is required. Therefore, a 1 3/16 in. (30.2 mm) thickness applied to the W8x28 test beam (*W/D* = 0.82) supporting all fluted floor units with lightweight concrete will be chosen.

W14x22, *W/D* = 0.53

$$T_1 = \left(\frac{0.82 + 0.6}{0.53 + 0.6}\right) * 1.19 = 1.49$$

use 1½ in. (38.1mm)

W18x55, *W/D* = 0.96

$$T_1 = \left(\frac{0.82 + 0.6}{0.96 + 0.6}\right) * 1.19 = 1.08$$

use 1⅛ in. (28.6mm)

The W18x55 has a *W/D* greater than that of the tested W8x28 beam, therefore the 1 3/16 in. (30.2 mm) thickness of fire protection material required for the W8x28 beam may be directly used on the W18x55 beam. However, the thickness adjustment equation may provide a lesser amount of fire protection, so it will be checked.

In summary, the following SFRM thicknesses are required:

Steel Deck – No Protection Required

W14x22, Typ. Floor – 9/16 in. (14.3 mm) of W. R. Grace Type MK-6

W14x22, at Gridlines 1 & 2 – 1½ in. (38.1 mm) of W. R. Grace Type MK-6

W18x55 – 1⅛ in. (28.6 mm) of W. R. Grace Type MK-6

Rating (Hr)	Thickness (in.) Restrained Beam	Thickness (in.) Unrestrained Beam
1	7/16	7/16
1-1/2	7/16	3/4
2	11/16	1
3	1-3/16	1-5/16
4	1-5/8	1-5/8

Fig. VII.11 UL N782 Steel Beam SFRM Thickness Requirements[5]

VII.12 STEEL JOIST ASSEMBLIES

As for steel beams, steel joist assemblies should be chosen to closely match the desired construction while providing the necessary fire resistance requirements. Joists can be protected either through fire-rated ceiling systems or by individual protection. All details and requirements of the listed assembly should be closely followed as many factors can affect the fire endurance rating. In addition to the items listed above, details for fire-rated joist assemblies may include:

- Providing the minimum distance from the bottom chord of the joist to the ceiling membrane.
- Restricting the maximum joist spacing.
- Providing the specified size and area of bridging bars or angles. For SFRM assemblies, bridging shall be protected with the required joist coating thickness for a minimum distance of 12 in. adjacent to the joist.
- Using a fire resistant material to fill the void between the top chord of the joist and the steel deck.

Joists may also typically be painted. The spray-applied fire protection adhesion/adherence issues commonly associated with a steel deck are limited when using joists as the protection material fully encapsulates the chord and web members[9].

VII.13 JOIST SUBSTITUTION

Beam-only tests incorporating joists may also be properly substituted into roof or floor assemblies. These tests are subject to the same requirements as those listed in Section VII.11. However, in addition to having an equal or greater unrestrained beam rating than the complete roof or floor assembly unrestrained beam rating, joist and truss beam-only designs shall have a restrained beam rating equal to or greater than the restrained assembly rating.

The specified joist listed in the floor- or roof-ceiling design is a minimum size. Joists of the same series (K, S, J, or H) which meet both the minimum depth and minimum weight per foot of the listed joist may be substituted. In addition, the UL Directory allows K-Series Joists to be substituted for other series joists providing they meet the following requirements.

1. In floor-ceiling assemblies, K-Series Joists of equal or greater depth and weight per foot as the minimum size joist may be directly substituted in as long as the assembly includes a structural concrete floor and suspended ceiling membrane.
2. In roof-ceiling assemblies, K-Series Joists of equal or greater depth and weight per foot as the minimum size joist may be substituted in for other series joists providing they meet the following:
   A. Minimum nominal depth of 10 in.
   B. Maximum tensile stress of 26,000 psi or any other stress limitation specified in a design containing an S-, J- or H-Series Joist.

It should be noted that when a K-Series Joist is being directly substituted for another K-Series Joist listed in an assembly, there is no stress limitation imposed unless specifically required by the assembly.

Stress limitations may be met by factoring the design load applied to the joist[9,10]. For example, a K-Series Joist with a 30,000 psi tensile stress may be substituted for a listed H-Series Joist with a 26,000 psi tensile stress so long as the K-Series Joist is selected to support its design load multiplied by 30,000/26,000.

REFERENCES

[1] European Convention for Constructional Steelwork (ECCS) – Technical Committee 3 (2001), *Model Code on Fire Engineering, First Edition,* Brussels, Belgium.

[2] American Society for Testing and Materials (ASTM) (2000), *Standard Test Methods for Fire Tests of Building Construction and Materials*, Specification No. E119-00, West Conshohocken, PA.

[3] Underwriters Laboratories Inc. (UL) (2003), *Fire Tests of Building Construction and Materials,* Thirteenth Edition, Standard No. UL 263, Northbrook, IL.

[4] Gewain, R.G., Troup, E.W.J. (2001), "Restrained Fire Resistance Ratings in Structural Steel Buildings," *Engineering Journal*, AISC, Vol. 38, No. 2, Chicago, IL.

[5] Underwriters Laboratories Inc. (UL) (2003), *Fire Resistance Directory, 2003*, Vol. 1, Northbrook, IL.

[6] International Code Council, Inc. (ICC) (2000), *International Building Code, 2000,* Falls Church, VA.

[7] American Institute of Steel Construction (AISC) (2001), *Manual of Steel Construction, Load and Resistance Factor Design,* Third Edition, Chicago, IL.

[8] American Iron and Steel Institute (AISI) (1984), *Designing Fire Protection for Steel Beams*, Washington, D.C.

[9] Schultz, Walter (2003), "Design of Fire-Resistive Assemblies with Steel Joists," *Modern Steel Construction*, August.

[10] Steel Joist Institute (2003), *Design of Fire-Resistive Assemblies with Steel Joists*, SJI Technical Digest 10, July, Myrtle Beach, SC.

Section VIII
FIRE PROTECTION FOR STEEL TRUSSES

VIII.1 GENERAL INFORMATION

Structural systems utilizing trusses are common for long span conditions where column-free spaces are required. They also provide an economical means for supporting heavy loads. However, due to their inherently unique nature, trusses are often not redundant systems. Therefore, special attention to the fire protection of such systems is essential.

Building codes require structural systems to provide up to 4-hour fire resistance ratings. Construction requirements that satisfy these ratings are based on standardized fire tests. Standards for these tests are produced by the American Society for Testing Materials (ASTM E119)[1], Underwriters Laboratories (ANSI/UL 263)[2], and the National Fire Prevention Association (NFPA 251)[3]. Various testing facilities, including UL, have conducted and documented hundreds of fire tests on beam and column systems using the requirements listed in these standards. The number of these tests stands in stark contrast to the very few tests performed on complete truss assemblies. The inherently large nature of truss assemblies create difficulties for standard fire test furnaces, while a myriad of different member sizes, sections, and geometries make listing standard truss assemblies often impractical. Therefore, a rational approach based on the existing fire test data must be used for providing adequate fire resistance to steel trusses. The procedures described in this guide are logical approaches that have been either incorporated in the building codes or accepted by building officials in numerous projects. However, because some of these rationalized methods are used in lieu of large-scale test data, it is essential that the designer consult with the authority having jurisdiction (AHJ) early in the design process to ensure the chosen approach will be accepted.

VIII.2 BUILDING CODES

There are several different model building codes that regulate construction throughout the United States. In the past, these codes have included the Basic Building Code (BOCA)[4], the Standard Building Code (SBC)[5], and the Uniform Building Code (UBC)[6]. In January of 2003, these building code organizations ceased to exist individually and were consolidated into the International Code Council (ICC). The ICC is responsible for publishing a national code, designated as the International Building Code (IBC)[7]. The National Fire Protection Association (NFPA) has also published a separate national building code, the NFPA 5000[8], which has been approved by the American National Standards Institute (ANSI).

The fire protection designs provided in this guide will be based on the consolidated provisions of the 2000 IBC. It is important for the designer to note that, depending on the building code used, certain specific fire-rating requirements may vary from those used in this document. However, the methodology presented remains essentially the same.

VIII.2.1 Level of Protection. Each building code regulates the required fire resistance the structural truss is to have based on the occupancy, size, and construction type classification of the building. The occupancy is determined by the intended use and number of occupants in the building. The construction type is determined by the combustibility and fire resistance of building elements (including trusses). Some codes further define the truss according to its function. For instance, the SBC and BOCA codes require a different level of protection depending on the number of floors the truss is to carry. The UBC and IBC make no such distinction when determining the level of fire protection required. Instead, the UBC and IBC recognize that many structural truss types, including staggered trusses and transfer trusses, have direct connections to the column elements of the building. They define elements such as these as being part of the structural frame. Fire resistance rating requirements for all members are listed in IBC Table 601. Values for structural frame elements from this table are summarized in Table VIII.1.

When defining the level of protection, it is important to note that some buildings incorporating structural steel trusses are multi-storied structures requiring fire suppression systems. For buildings with an automatic sprinkler system, IBC sections 504 and 506 provide for increases in allowable building heights and areas, respectively, for most occupancy groups. In lieu of height and area increases, construction types in sprinklered high rise buildings having occupied floors located higher than 75 ft (22.9 m) above the lowest level of fire department access are permitted a reduction in the fire resistance requirement as follows:

Table VIII.1 IBC Fire Resistance Requirements for Building Structural Frame		
Construction		Rating (hours)
Type I	A	3
	B	2
Type II	A	1
	B	0
Type III	A	1
	B	0
Type V	A	1
	B	0

IBC Section 403.3.1 Type of construction. The following reductions in the minimum construction type allowed in Table 601 shall be allowed as provided in Section 403.3:

1. *Type IA construction shall be allowed to be reduced to Type IB.*

2. *In other than Groups F-1, M and S-1, Type IB construction shall be allowed to be reduced to Type IIA.*

These allowable height and area increases, or construction type adjustments often represent a significant reduction in fireproofing materials and labor costs.

VIII.2.2 Protection Methods. Full-scale steel truss assemblies impose logistical difficulties on testing facilities, resulting in a very limited number of assembly tests. To compensate for the lack of testing on complete assemblies, the IBC provides the following provision allowing test data for components of the assembly to be used:

IBC Section 713.2.3 Truss protection. The required thickness and construction of fire resistance rated assemblies enclosing trusses shall be based on the results of full-scale tests or combinations of tests on truss components or on approved calculations based on such tests that satisfactorily demonstrate that the assembly has the required fire resistance.

In most instances, this requirement results in truss protection by one of three following methods, or a combination thereof[9].

1. Individual element protection for each truss component. This method is usually performed with spray-applied fire resistive materials (SFRM), intumescent coatings or by providing gypsum board (or other approved) encasement to each individual element.

2. Wall membrane enclosure of the entire truss for its full height and length with fire resistive materials.

3. Fire resistant floor/ceiling assemblies constructed with SFRM or ceiling membrane protection.

IBC Section 713.2.1 requires that truss elements must be individually protected on all sides of each truss element or by enclosure of the entire truss for its full height and width if it supports the following:

1. More than two floors.

2. More than one floor and one roof.

3. A load-bearing wall of any height.

4. A nonload-bearing wall more than two stories high.

Ceiling membrane protection may not be used for these specific cases.

Trusses supporting construction different than that listed may be protected by any approved method, including ceiling protection.

VIII.2.2.1 Individual Element Protection. A common method of truss fire protection is to individually preserve the integrity of each truss element. This may be accomplished by either spraying each element with a fire resistive material or by encasement in gypsum board. Spraying the elements is often the most cost-effective solution, while encasing the elements in insulating materials can be used for aesthetic reasons.

The thickness of individual truss element SFRM protection is determined according to the function of the element. IBC Section 720.5.2.3 requires that SFRM thickness for elements simultaneously exposed to fire on all sides (vertical, diagonal, and sometimes bottom chord elements) shall be determined on the same basis as columns, using the column equation in Section 720.5.1.3 (as discussed in Section VI.8.8 of this guide). SFRM thickness for elements that directly support floor or roof construction (top chord, and sometimes, bottom chord elements, as in staggered trusses) shall be determined with the same equation, but using the *W/D* ratio for three-sided exposure as for beams and girders.

IBC Table 719.1(1) contains prescriptive designs for individual truss element encasement protection by regular or “Type X” gypsum board, concrete, plaster on metal lath, and other materials.

VIII.2.2.2 Wall Envelope Protection. Some structural truss systems utilize “in wall” trusses. These trusses are enclosed in walls that often provide a minimum 1-hour fire rating between compartments separated by the wall, regardless if they are encapsulating the truss or not. Therefore, it is cost-effective to utilize this fire resistance provided by the wall as part of the fire protection for the truss.

Most testing facilities provide fire-rated designs for non-loadbearing wall assemblies; however, these wall assemblies are tested for their fire separation ability only, without testing the temperature rise in any loadbearing members that could be encapsulated in the wall. A notable exception to that is UL Design U436 that incorporates steel truss members inside the wall cavity. In the fire resistance tests that led to the development of this design, the temperatures of the steel truss members remained below the critical temperatures for ASTM E119 unloaded column tests (1000 ºF (538 °C) average at any section, or 1200 ºF (649 °C) at any single point) for the rating periods. Therefore, this UL design satisfies the provisions of IBC Section 713.2.3 for truss protection, as discussed in Section VIII.2.2.

A logical analogy can also be made comparing the load-bearing steel truss assembly to a load-bearing light-gage stud wall assembly. A load-bearing wall assembly must not only pass fire compartment-alization requirements as per a non-load-bearing wall, but must also successfully support the load during the rated time. Therefore, a bearing wall fire resistance rating indicates that the wall structure can sustain load for the duration of the rated time. The larger, heavier members of the truss have a much greater heat capacity than the light-gage steel studs. Therefore, given the same protection, the truss assembly will support load for a time period equal to or greater than the rated time of the stud wall assembly. The same fire protection (gypsum board type, size, and attachment) specified in the light-gage stud assembly must be provided in the steel truss assembly for the analogy to remain valid.

VIII.2.2.3 Wall Envelope Combined with Individual Protection. For trusses enclosed within walls, it is possible to combine the individual protection of SFRM with the protection afforded by the wall. It is rational that, using the same logic as described for wall membrane protection, the truss elements sprayed with fireproofing materials will receive the additional benefit of the wall enclosure. However, an explicit procedure of combining the two methods has not been officially documented.

VIII.2.2.4 Fire Resistive Floor/Ceiling Systems. Where structural trusses are used to create long-span floors or roofs, two basic methods of fire protection may be used. The first is to apply SFRM to each truss. The thickness of the SFRM may be determined by referencing floor or roof assembly framed with trusses or joists (UL groups D, G, and P), or by referencing an individual truss or joist for substitution into a floor or roof assembly (UL groups N, and S). A second option is to utilize the protective shield created by the ceiling membrane. For fire resistive purposes, the trusses behind this shield may also be modeled as large joists in tested floor/ceiling or roof/ceiling assemblies. However, all other design details of the system must be in strict accordance with the listed assembly. These may include requiring hold down clips for ceiling tiles, enclosing recessed light fixtures in acoustical material, providing specific suspension system details, ceiling penetration restrictions, etc. It should be noted that ceiling membrane protection cannot be used where individual truss protection is required as described in Section VIII.2.2.

The justification for modeling in-ceiling trusses as joists is based on two parameters. The first of these is provided by the testing facilities calling for a minimum size of joist in each assembly[10]. These joists have relatively small chord and web members compared to the substantial member sizes of a structural truss. Accordingly, these larger members provide a greater heat capacity because heavier members take longer to reach a certain critical temperature[9]. The second parameter stems from the fact that larger trusses create a deeper interstitial space between the floor and the ceiling than that provided in tested joist assemblies. The increase in volume allows for greater heat dispersion resulting in a slower rate of thermal transfer[9]. The benefits of an increase in interstitial depth are corroborated in the Underwriters Laboratories (UL) Directory[10]. The Directory makes allowances for both lowering the ceiling provided the minimum dimension from the bottom chord to the ceiling is met and allowing intermediate supports to be used to create a ceiling stiffness equal to that of the listed assembly. The Directory also allows the minimum listed spacing between joists to be increased up to 4 ft, however many economical truss systems exceed this spacing. For these instances, an assembly with an unlimited joist spacing such as D216 or D502 should be chosen.

Because the premise for substituting trusses for joist is temperature based, only unrestrained assemblies should be used in the design[9]. Unrestrained beams are rated entirely on the time it takes to reach a critical temperature. Restrained assemblies are based on the time to structural failure.

VIII.3 STRUCTURAL STEEL TRUSS SYSTEMS

Structural steel truss systems can be generally be categorized in one of three basic assemblies.

1. Typical Truss Systems
2. Staggered Truss Systems
3. Transfer Truss Systems

VIII.3.1 Typical Truss Systems. Typical truss systems are an economical way to provide large, open areas within buildings. The trusses are generally evenly spaced elements supporting floor or roof construction. These secondary trusses can be supported by other trusses, steel girders, columns, and walls. Fire protection for the truss system can be provided using a floor/ceiling assembly or direct applied protection.

The space within the depth of the truss can be used for circulation of building utilities and, in some cases, structure may be provided between the bottom chords (catwalks and platforms) to create an interstitial space for building equipment. The interstitial truss system is well suited for occupancies where significant amounts of electrical and mechanical circulation are common such as hospitals.

Because interstitial trusses support loads from only one floor, most building codes allow protection by any accepted fire protection construction method, including individual member protection with SFRM, or using the protection afforded by a fire resistive ceiling. When using a fire resistive ceiling system for truss protection, it is important that all other ceiling design details be in strict accordance with the listed assembly. Due to the possibility of a fire within the interstitial space, no storage should be permitted within. All piping, ductwork, and catwalks should be made of noncombustible materials, and all electrical wiring should be installed within steel conduit or have Teflon coating[9].

VIII.3.1.1 EXAMPLE VIII-1

Determine the thickness of SFRM to be applied to a floor truss to provide a 2-hour fire resistance rating. A composite deck with lightweight concrete will be used. The floor trusses are constructed with WT9x20 top and bottom chords and LL3x3x¼ diagonal members. The trusses are 3 ft (0.91 m) deep and are spaced at 7 ft (2.13 m) center-to-center.

UL D925

For a 2-hour beam rating, the minimum specified size of top and bottom chords constructed of tee-shaped sections are 1.10 in.^{2} (710 mm^2) and 0.84 in.^{2} (739 mm^2), respectively. These areas are much smaller than the 5.88 in.^{2} (3,790 mm^2) steel area provided by the WT section. The minimum specified end web member area is 0.44 in.^{2} (287 mm^2), which is much smaller than the 2.88 in.^{2} (1860 mm^2) provided by the double angle.

Because the rationale for exchanging joists for trusses is based solely on temperature effects, only unrestrained ratings should be used for the design. Therefore, for a 2-hour unrestrained beam rating the required thickness of material applied to the truss is the same as that for a 12K3 or 16K2 joist and can be read directly from the listing:

h = 2 1⁄16 in. (52.4 mm) of MK-6
Concrete thickness = 3¼ in. (82.6 mm)

VIII.3.1.2 EXAMPLE VIII-2

Design the fire protection for the composite deck and truss as in Example VIII-1 with a suspended ceiling membrane in lieu of applying SFRM.

UL D216

As in the previous example, the cross sectional steel area of the truss greatly exceeds the minimum joist values listed in the assembly. Therefore, the structural truss may be substituted for the joist in the assembly. For reasons mentioned before, only an unrestrained beam rating should be used for the truss. UL D216 lists multiple combinations of ceiling panel sizes, materials, and concrete topping thickness that meet the requirements for a 2-hour unrestrained beam rating. All of the specific ceiling details required by the listing must be followed.

VIII.3.2 Staggered Truss Systems. The staggered truss system was first developed by the Architecture and Civil Engineering departments at the Massachusetts Institute of Technology in the late 1960's. It is primarily used in residential high rise buildings allowing low floor-to-floor heights while still providing column-free interior spaces. Many modern hotels and apartment buildings have been constructed with this system, including the Embassy Suites Hotel in New York City, The Aladdin Hotel & Casino in Las

Vegas, and the Clayton Park Apartments in White Plains, NY. An isometric view of a schematic staggered truss system is shown in Figure VIII.1.

Construction of a staggered truss system generally consists of story-high trusses spanning the entire building width and supported by columns at each truss end at the exterior wall. The trusses alternate position from story to story in a running bond type of pattern as shown in Figure VIII.2. The floor at each level is alternately supported at each truss by either the top or bottom chord. The trusses are usually enclosed within the walls separating the building units.

Staggered truss projects are most cost-effective for tall buildings. For many occupancy groups, including residential, this frequently results in a 1-hour or 2-hour structural frame requirement. In these types of construction, it is often cost-effective to use the wall membrane for the fire protection of the trusses. For other occupancy groups, including institutional, a 3-hour structural frame fire resistance rating may be required. The additional fire resistance that must be added to the wall to meet the truss requirements will likely be greater than what the wall fire requirements would be otherwise. In these instances, SFRM protection is often a more cost-efficient solution.

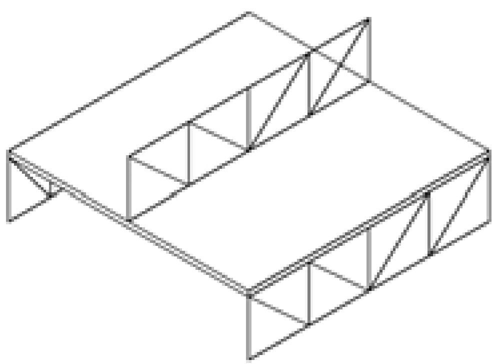

Fig. VIII.1 Staggered Truss System

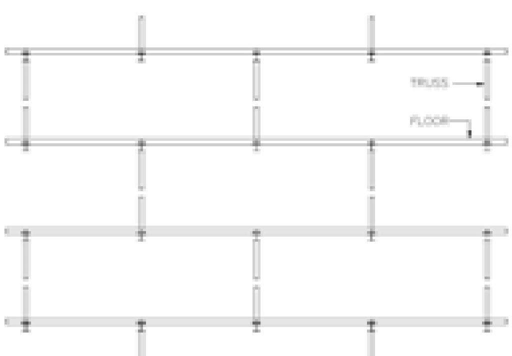

Fig. VIII.2 Typical Staggered Truss Pattern

VIII.3.2.1 EXAMPLE VIII-3

Design a gypsum board wall membrane system encapsulating a staggered truss profile shown in Figure VIII.3 to provide a 1-hour truss and a 1-hour wall fire resistance rating. The deck consists of hollow-core, precast normal weight concrete units with a 3,000 psi (20.7 MPa) concrete topping. Truss members are as follows:

Top chord:	W10x49
Bottom chord:	W10x60
Vertical Members:	HSS6x6x5⁄16
Diagonal Members:	HSS6x6x5⁄16

UL U425 – Truss and Wall Ratings

The truss fire rating can be extrapolated from the UL U425 listing for a 1-hour light-gage load-bearing wall. As mentioned in Section VII.2.2.2, the larger, heavier truss members have a much greater heat capacity than the light-gage steel studs. Therefore, it is conservative to conclude that the truss assembly will support load for a time period greater than or equal to the rated time of the light-gage wall assembly.

The major parameters for 1-hour rating may then be read directly from UL U425:

1 layer, ⅝ in. (16 mm) thick wallboard
1 in. (25 mm) long self-tapping screws type S-12
Screw spacing = 12 in. (305 mm) c/c
Stud spacing = 24 in. (610 mm) c/c

Other details of protective wall envelope should be developed to the satisfaction of AHJ.

UL U436 – Truss and Wall Rating

UL U436 (Figure VIII.4) provides complete detailing for truss protections. As required in the tested design listing, all truss elements in this example exceed the minimum weight of 3.75 lb/ft.

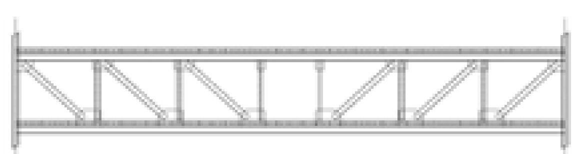

Fig. VIII.3 Staggered Truss Profile

Similar to UL U425, the construction parameters for a 1-hour rated assembly meeting UL U436 are:

1 layer, ⅝ in. (16 mm) thick wallboard
1 in. (25 mm) long self-tapping screws type S
Screw spacing = 12 in. c/c (305 mm)(field)
= 8 in. c/c (203 mm)(edges)
Stud spacing = 24 in. (610 mm) c/c

The listing should be further consulted for other details specific to the assembly, such as wall bracing requirements not mentioned herein.

VIII.3.2.2 EXAMPLE VIII-4

Design the fire protection for the staggered truss as in Example VIII-3 with SFRM applied to each individual member in lieu of wall membrane protection.

UL X772 – Truss Rating, Top & Bottom Chords

Section 720.5.2.3 of the IBC requires the fire protection of truss elements that directly support floor or roof construction to be determined on the same basis as columns. This procedure is executed using the column equation in 720.5.1.3, shown below as Equation VIII-1, but using a *W/D (or A/P)* ratio for beams and girders (i.e. three-sided exposure). For this purpose, a UL X-series design may be used for the material-dependent constants, C_1 and C_2. Requirements for using a X-series test are listed in Chapter VI Fire Protection for Steel Columns in this design guide. For this example, a UL assembly incorporating the use of wide-flange column members is required. UL X772 will accomplish this purpose.

$$R = \left[C_1 \left(\frac{W}{D} \right) + C_2 \right] h \qquad \textbf{(VIII-1)}$$

where
h = SFRM Thickness (in.)
R = Fire Resistance Rating (hours)
W = Column weight (lbs per ft)
D = Perimeter of the column at the interface of the SFRM (in.)
C_1 & C_2 = Material dependent constants

C_1 & C_2 can be identified directly from the UL listing or from Table VI.4 as:

C_1 = 1.05
C_2 = 0.61

The *W/D* ratios for each beam is as follows:

W/D for W10x49 (top chord) = 1.01
W/D for W10x60 (bottom chord) = 1.22

For a 1-hour assembly, the required thickness of SFRM is as follows:

W10x49:
h = 1 / [(1.05 * 1.01) + 0.61]
h = 0.60 in., use ⅝ in. (15.9mm) of MK-6

W10x60:
h = 1 / [(1.05 * 1.22) + 0.61]
h = 0.53 in., use 9⁄16 in. (14.3mm) of MK-6

UL X771 – Truss Rating, Web Members

Section 720.5.2.3 of the IBC requires the fire protection of truss elements that can be simultaneously exposed to fire on all sides shall be determined on the same basis as columns, using *W/D* (or *A/P*) ratios for column elements (i.e. four-sided exposure). For this example, a UL assembly incorporating the use of HSS members is required. UL X771 will accomplish this purpose.

According to UL X771, the thickness of SFRM applied to the column is a function of the column cross sectional area (A) divided by the column perimeter (P). The *A/P* of a rectangular or square tube is determined by:

$$\frac{A}{P} = \frac{[t*(a+b-2*t)]}{a+b} \qquad \textbf{(VIII-2)}$$

where
t = Wall thickness of tube
a = Outer width of tube
b = Outer length of tube

For an HSS 6x6x5⁄16
A/P = [0.31*(6+6-2*.31)]/(6+6)
A/P = 0.30

The listing allows the thickness of SFRM applied to the column to be determined according to the following equation:

$$h = \frac{R-0.20}{4.43(A/P)} \qquad \textbf{(VIII-3)}$$

where
h = Thickness of SFRM in inches
R = Rating in hours

$h = (1\text{-}0.20)/(4.43*0.30)$
$h = 0.60$ in., use ⅝ in. (15.9mm) of MK-6

VIII.3.3 Transfer Truss Systems. The primary function of transfer truss systems is to provide clear areas to the floors below. They are often substantial structural members that accomplish this purpose by supporting columns and walls above, or tension elements below, the truss.

Because of the substantial number of floors these members support, the IBC limits the permissible truss fire protection methods, as described in Section VIII.2.2. Therefore, fire resistance ratings for these systems are commonly provided by individual truss element protection or by protective wall envelopes.

VIII.4 SUMMARY

Structural steel trusses continue to provide effective solutions to many diverse building demands. Although large trusses are not usually tested for fire resistance, extrapolation from existing fire test data on columns and smaller trusses and joists, combined with logical reasoning based on heat transfer fundamentals and accumulated fire-incident experience, provide practical and conservative approaches for determining the appropriate protection of structural steel trusses.

REFERENCES

[1] American Society for Testing and Materials (ASTM) (2000), *Standard Test Methods for Fire Tests of Building Construction and Materials*, Specification No. E119-00, West Conshohocken, PA.

[2] Underwriters Laboratories Inc. (UL) (2003), *Fire Tests of Building Construction and Materials,* Thirteenth Edition, Standard No. UL 263, Northbrook, IL.

[3] National Fire Protection Association (NFPA) (1999), *NFPA 251 Standard Methods of Tests of Fire Endurance of Building Construction and Materials*, 1999 Edition, Quincy, MA.

[4] Building Officials and Code Administrators International, Inc. (BOCAI) (1999), *BOCA National Building Code 1999, #307-99*, Fourteenth Edition, Country Club Hills, IL.

[5] Southern Building Code Congress International (SBCCI) (1997), *1997 Standard Building Code*, Birmingham, AL.

[6] International Conference of Building Officials (ICBO) (1997), *1997 Uniform Building Code*, Vol. 1, Whittier, CA.

[7] International Code Council, Inc. (ICC) (2000), *International Building Code, 2000,* Falls Church, VA.

[8] National Fire Protection Association (NFPA) (2003), *NFPA 5000: Building Construction and Safety Code,* 2003 Edition, Quincy, MA.

[9] American Iron and Steel Institute (AISI) (1981), *Designing Fire Protection for Steel Trusses*, Second Edition, Washington, D.C.

[10] Underwriters Laboratories Inc. (UL) (2003), *Fire Resistance Directory, 2003*, Vol. 1, Northbrook, IL.

Section IX SPRAY-APPLIED FIRE RESISTIVE MATERIAL TESTING & INSPECTION

IX.1 GENERAL INFORMATION

The need for a consistent practice for field testing of Spray-Applied Fire Resistive Materials (SFRM) was first addressed by the Association of the Wall and Ceiling Industries-International (AWCI) in 1975 with its publication *Inspection Procedure for Field Applied Sprayed Fire Protection Materials*[1]. Since this date, several other standards have been published. The most referenced of these have been developed by the American Society for Testing and Materials (ASTM). ASTM E605[2] provides guidelines for determining thickness and density, and ASTM E736[3] provides test methods for the cohesion / adhesion of SFRM. Additional standards have been published by both The Underwriters Laboratories Inc. in the United States (UL)[4] and Canada (ULC). Some building codes, including the Standard Building Code (SBC)[5], Uniform Building Code (UBC)[6], and International Building Code (IBC)[7], have also published their own guidelines or have made amendments to the ASTM standards.

The purpose of this section is to provide the designer with a summary of SFRM testing and inspection procedures based on the 2000 edition of the IBC and referencing ASTM. Due to the many different referenced standards, the authority having jurisdiction (AHU) should be consulted for specific testing criteria pertinent to a particular building.

IX.2 THICKNESS DETERMINATION ASTM E605

Procedure: This procedure is valid for both sprayed fiber and cementitious types of SFRM. The thickness of the material is determined by inserting the penetrating pin of a thickness gauge (Figure IX.1) perpendicularly through the fire protection to the substrate. The sliding disk should then be moved to the SFRM surface with enough pressure to register the average surface plane. After the pin is withdrawn, a reading may then be determined by observing the position of the sliding clip gauge. Readings should be made in increments of 1⁄16 in. (1.6 mm). For reporting and averaging purposes, any individual measured thickness exceeding the specified thickness by ¼ in. (6.4 mm) or more shall be recorded as the specified thickness plus ¼ in. (6.4 mm)

Testing frequency: The IBC requires the number of tests for members as follows:

> *1704.11.3.1 Floor, roof and wall assemblies. The thickness of the sprayed fire-resistant material applied to floor, roof and wall assemblies shall be determined in accordance with ASTM E 605, taking the average of not less than four measurements for each 1,000 square feet (93 m²) of the sprayed area on each floor or part thereof.*
>
> *1704.11.3.2 Structural framing members. The thickness of the sprayed fire-resistant material applied to structural members shall be determined in accordance with ASTM E 605. Thickness testing shall be performed on not less than 25 percent of the structural members on each floor.*

Member tests: Member tests for various structural elements are as follows:

1. Flat decks – Four random symmetrical measurements should be taken within a 12 in. (305 mm) square and reported as an average.
2. Fluted decks – Four random symmetrical measurements should be taken within a 12 in. (305 mm) square and reported as an average. One measurement should be taken in each of the following: valley, crest, and sides.
3. Beams – Nine thickness measurements should be made at each end of a 12 in. (305 mm) length in a pattern as shown in Figure IX.2.

Fig. IX.1 Thickness Gauge[1]

4. Joists and Trusses – Seven thickness measurements should be made at each end of a 12 in. (305 mm) length in a pattern as shown in Figure IX.3.
5. Columns – Twelve thickness measurements should be made at each end of a 12 in. (305 mm) length in a pattern as shown in Figure IX.4.

Minimum Allowable Thickness: The average calculated thickness of the SFRM is to be greater than or equal to the design thickness. Section 1704.11.3 of the IBC requires individual measurements for the design thickness of 1 in. (25.4 mm) or greater to be no less than the design thickness minus ¼ in. (6.4 mm). For the design thickness of less than 1 in. (25.4 mm), the IBC limits the individual measurement to be no less than the design thickness minus 25 percent.

Procedure in case of deficiency: ASTM E605 requires deficient items to be corrected and retested along with another item of the same type selected at random. When an item does not meet the prescribed requirements, only that specific element is deemed deficient. All other items in the bay, as well as similar elements in other areas of the building, are not to be considered deficient based solely on the failure of the tested item.

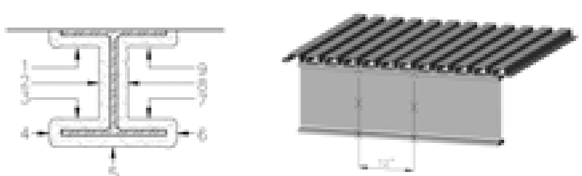

Fig. IX.2 SFRM Thickness Measurement Locations at Beams

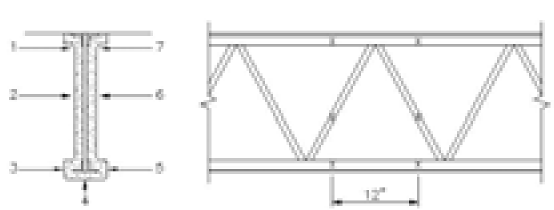

Fig. IX.3 SFRM Thickness Measurement Locations at Joists

SFRM thickness deficiencies on an element may be corrected by simply applying additional material. As an alternative to this method, certain fire resistance rating criteria and some SFRM manufacturers publish thickness to density correction formulas. These formulas may allow an item found lacking in thickness, but exceeding the requirements for density, or vice versa (i.e. the overall weight in pounds per square foot is equivalent), to be considered passing. The testing agency that published the fire assembly should be consulted when using this procedure.

IX.3 DENSITY DETERMINATION ASTM E605

Procedure: This procedure is valid for both sprayed fiber and cementitious types of SFRM. The density of the sample is determined by first scoring the specimen around the perimeter of a rectangular template. A minimum of 12 thickness measurements should be taken symmetrically within the scored region and averaged. The specimen should then be cut away from the substrate along the perimeter of the template and removed.

The density of the specimen is then calculated as follows:

$$D = \frac{W}{l * w * t} \qquad \textbf{(IX-1)}$$

where

D = density, lb/ft^3 (kg/m^3)
W = constant weight of dried material, lb (kg)
l = length of specimen, ft (m)
w = width of specimen, ft (m)
t = average thickness of the field measurements of the specimen, ft (m)

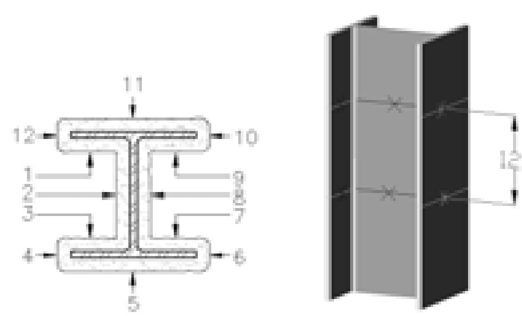

Fig. IX.4 SFRM Thickness Measurement Locations at Columns

ASTM E605 also lists an alternate, displacement-type method for determining the SFRM density applied to irregular surfaces or for specimens that are difficult to remove from the substrate.

Testing frequency: Tests should be taken at every floor or per every 10,000 ft^2 (929 m^2), whichever provides the greater number of tests.

Member tests: ASTM E605 requires density tests to be taken at random for each of the following elements: the flat portion of the deck; a beam, either the bottom of the beam lower flange or the beam web; and a column, either the column web or the outside of one of the column flanges.

Minimum Allowable Density: The average and individual SFRM density measurements are to meet the manufacturer's minimum specifications for the designated mix.

Procedure in case of deficiency: If an item is found to be deficient, the same procedure as described in Section IX.2 Thickness Determination should be followed.

IX.4 COHESION/ADHESION DETERMINATION ASTM E736

Procedure: This procedure is valid for both sprayed fiber and cementitious types of SFRM. A metal or rigid plastic bottle screw cap with attached hook, as shown in Figure IX.5, is filled with urethane resin adhesive and immediately placed against the surface of the SFRM. All excess adhesive around the edges of the cap should be removed. A spring-type weighing scale is then attached to the hook. A force of 11 lb (5 kg) per minute, applied either at a minimum uniform or incremental rate, is engaged to the scale, perpendicular to the SFRM surface. The force shall be applied until either a predetermined value is achieved or failure occurs. As an alternate, a non-destructive field test may be performed by supporting a fixed weight for 1 minute.

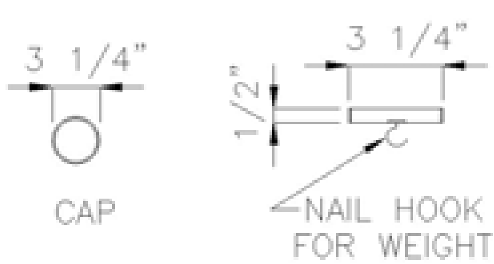

Fig IX.5 Test Cap[1]

The cohesive/adhesive force is then calculated as follows:

$$CA = \frac{F}{A} \qquad \textbf{(IX–2)}$$

where
CA = cohesive/adhesive force, lb/ft^2 (N/m^2)
F = recorded force, lb (N)
A = area of the cap, ft^2 (m^2)

Testing frequency: The IBC requires the number of tests for members as follows:

> *1704.11.5.1 Floor, roof and wall assemblies. The test samples for determining the cohesive/adhesive bond strength of the sprayed fire-resistant materials shall be selected from each floor, roof and wall assembly at the rate of not less than one sample for every 10,000 square feet (929 m^2) or part thereof of the sprayed area in each story.*

> *1704.11.5.2 Structural framing members. The test samples for determining the cohesive/adhesive bond strength of the sprayed fire-resistant materials shall be selected from beams, girders, joists, trusses and columns at the rate of not less than one sample for each type of structural framing member for each 10,000 (929 m^2) square feet of floor area or part thereof in each story.*

Member tests: All tests should be performed on a minimum 12 in. by 12 in. (305 mm by 305 mm) area on the element. On members where this area is unavailable, such as beams and fluted decks, an area the size of the width of the beam or the flute by 12 in. (305 mm) is to be used. The minimum area shall not be less than 4 in. by 12 in. (102 mm by 305 mm).

Minimum Allowable Bond Strength: The IBC requires the minimum cohesive/adhesive bond strength of the cured specimen to not be less than 150 lb/ft^2 (7.2 kPa).

Procedure in case of deficiency: Certain fire resistance rating criteria and some SFRM manufacturers allow bonding agents or mechanical attachments to be used where bond strength test results are found to be less than the minimum accepted values. The SFRM manufacturer should be consulted.

REFERENCES

[1] The Association of the Wall and Ceiling Industries, International (AWCI) (1997), *Technical Manual 12 A, Standard Practice for the Testing and Inspection of Field Applied Sprayed Fire-Resistive Materials; an Annotated Guide*, Third Edition, Falls Church, VA.

[2] American Society for Testing and Materials (ASTM) (2000), *Standard Test Methods for Thickness and Density of Sprayed Fire-Resistive Material (SFRM) Applied to Structural Members*, Specification No. E605-93, West Conshohocken, PA.

[3] American Society for Testing and Materials (ASTM) (2000), *Standard Test Method for Cohesion/Adhesion of Sprayed Fire-Resistive Materials Applied to Structural Members*, Specification No. E736-00, West Conshohocken, PA.

[4] Underwriters Laboratories Inc. (UL) (2003), *Fire Resistance Directory, 2003*, Vol. 1, Northbrook, IL.

[5] Southern Building Code Congress International (SBCCI) (1997), *1997 Standard Building Code*, Birmingham, AL.

[6] International Conference of Building Officials (ICBO) (1997), *1997 Uniform Building Code*, Volume 1, Whittier, CA.

[7] International Code Council, Inc. (ICC) (2000), *International Building Code, 2000,* Falls Church, VA.

Section X ENGINEERED FIRE PROTECTION

X.1 GENERAL INFORMATION

The primary objective of a fire protection system is to allow the structure to function (i.e. sustain load and limit spread of the fire) for a sufficient time to permit occupant egress from the facility, fire suppression operations and search and rescue operations. Analytical tools are available to simulate the heat generated by combustion of the building contents. The heat determined by analysis can be used as input to a generalized equation for temperature rise in a protected or unprotected steel section. Thus, the temperature gradient of a steel member caused by the heat input can be predicted at a specific time. All materials degrade with increases in temperature. The relationship between specific steel properties and temperature are well documented. It is possible to predict the effective yield strength at an elevated temperature and, using the appropriate value, the capacity of the steel section at the elevated temperature can be determined.

X.2 BUILDING CODES

The most frequently employed building code provisions relating to fire protection are prescriptive. For the case of roof and/or floor construction, the required level of fire resistance is determined from the building code. Then an assembly that has been tested for fire endurance is referenced and adjustments to the thickness of fire protection materials are determined so that the actual beam performance will approximate the tested beam performance.

The building code does permit the use of an alternate approach. Alternative approaches may be done on a case by cases basis, or the entire building may be designed using a performance based design approach.

NFPA 5000, *Building Construction and Safety Code*[1], establishes an equivalency approach in Section 1.5. Numerous criteria exist for approval of an equivalent design method and all such designs must be acceptable to the authority having jurisdiction. The charging language for equivalency states:

> *1.5.1 General. Nothing in this Code shall be intended to prevent the use of systems, fire resistance, effectiveness, durability, and safety over those prescribed by this Code. Technical documentation shall be submitted to the authority having jurisdiction to demonstrate equivalency. The system, method, or device shall be approved for the intended purpose by the authority having jurisdiction (AHJ).*

Conversely, NFPA 5000, Section 4.3, permits the use of performance based design approaches that comply with Chapter 5 of the Code to be applied to the entire design process.

> *4.3.1 Options. Building design meeting the goals and objectives of Section 4.1 shall be provided in accordance with either of the following:*
>
> *(1) The prescriptive-based provisions of 4.3.2*
> *(2) The performance-based provisions of 4.3.3*

Regardless of whether the design is done using the purely prescriptive approach, an equivalency approach for parts of the design, or if it is done using the performance based design approach, the specified goals and objectives contained within Chapter 4 of NFPA 5000 must still be adhered to.

Among these goals is the statement in Section 4.4.8 that requires an appropriate level of protection for the structural system. That goal is noted under the heading dealing with multiple and appropriate safeguards. It states:

> *4.4.8 Structural Integrity. The building's structural members and assemblies shall be provided with the appropriate degree of fire resistance to limit structural damage to an acceptable level and to limit damage to the building and its contents and to adjacent buildings and property.*

The International Building Code (IBC)[2] permits the use of alternate approaches to the prescriptive procedures in paragraph 104.11.

> *104.11 Alternative materials, design and methods of construction and equipment. The provisions of this code are not intended to prevent the installation of any material or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design or method of construction shall be approved where the building official finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, at least the equivalent of*

that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety.

According to both codes, subject to the approval of the authority having jurisdiction (AHU), where calculations and/or other documentation confirm the ability of the structural system to remain functional for the intended time period under an expected fire exposure, an equivalent level of protection can be verified.

X.3 LOAD COMBINATIONS

A fire is recognized as a low-probability event in paragraph 2.5 of ASCE 7[3]. The load combinations to be used in checking the capacity of a structure or structural element to withstand the effects of an extraordinary event are presented in the ASCE 7 commentary paragraph C2.5. There are two load combinations to be considered as follows:

$$1.2D + A_k + (0.5\,L \text{ or } 0.2S) \qquad \textbf{(X – 1)}$$

$$(0.9 \text{ or } 1.2)D + A_k + 0.2W \qquad \textbf{(X – 2)}$$

where

A_k = load effect from the extraordinary event
D = dead load
L = live load
S = snow load
W = wind load

The load effect of the fire extraordinary event has a load factor of 1.0 and the companion actions of 0.5L, 0.2S and 0.2W reflect the small probability of joint occurrence of all loads.

X.4 HEAT TRANSFER

An all inclusive heat transfer evaluation involves a complex three-dimensional analysis including the influence of radiation and convection. In addition to the typical conductive heat transfer, the mechanism involves convection and radiation between the surface of the protection and the fire, as depicted in Figure X.1. Furthermore, most protective materials have some moisture content, and the heat required to vaporize the moisture affects the rate of temperature increase in the steel. However, a simplification using a one-dimensional heat transfer equation can generally be used to predict steel temperature increases with reasonable accuracy.

A generalized equation[4] for the temperature rise in a protected steel section considering the thermal capacity of the insulation is:

$$\Delta T_s = \frac{k_p}{d_p}\left[\frac{T_f - T_s}{c_s \dfrac{W}{D} + \dfrac{c_p\,\rho_p\,d_p}{2}}\right]\Delta t \qquad \textbf{(X – 3)}$$

where

ΔT_s = change in steel temperature in time step Δt (°C)
Δt = time step (sec.)
T_s = steel temperature (°C)
T_f = fire (furnace) temperature (°C)
D = heated perimeter (m)
W = weight per unit length (kg/m)
c_s = specific heat of steel (J/kg °C)
c_p = specific heat of insulation (J/kg °C)
ρ_p = density of insulation (kg/m^3)
d_p = thickness of insulation (m)

Note: The *W/D* ratio in Equation X-3 has units of kg/m^2. The *W/D* ratios listed by AISC and reproduced in Appendix A have units of lb/ft-in. To convert the *W/D* ratios listed in Appendix A to SI units multiply by 58.6.

Thus, Equation X-3 defines the increase in temperature of an insulated steel section as a function of the thermal properties of the steel and insulation assuming a one-dimensional heat transfer equation.

The specific heat values for steel and spray-applied fire resistive materials (SFRM) vary with temperature. However, using a constant value for these parameters results in a reasonably accurate correlation between calculations and test results. The specific heat of steel may be evaluated at 572 °F (300 °C) and the specific heat of SFRM may be considered at 932 °F (500 °C).

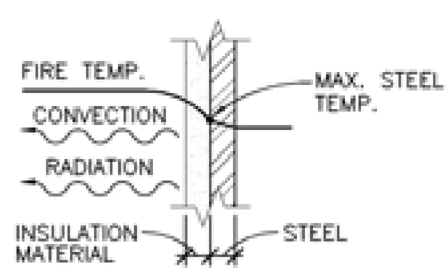

Fig. X.1 Heat Transfer Mechanism within an Insulated Steel Member

A representative value for the specific heat of steel is:

$c_s \approx 560$ J/kg°C (0.13 Btu/lb °F)

The thermal properties of SFRM vary between manufacturers. Representative values for lightweight SFRM are:

ρ_i = 293kg/m^3 (18.30 pcf)

C_i = 754 J/kg°C (0.18 Btu/lb °F)

k_i = 0.135 W/m°C (0.0013 Btu/hr ft °F)

The standard time temperature curve defined in ASTM E 119[5] represents the heat input for the tested assemblies listed in the Underwriters Laboratory (UL) Directory[6]. Thus, the time-temperature relationship required by ASTM E119 can be used as input to Equation X-3 and the calculated temperature compared to the measured temperature to confirm the accuracy of Equation X-3.

A spreadsheet can be created to use time step increments and predict the temperature increase in the protected steel beam. The representative thermal values of insulation have been used with the heat input from a standard fire to generate time temperature curves. A time step increment of one second was used in these numerical predictions. The calculated results were found to closely match measured bottom flange temperatures.

A representative comparison is presented graphically in Figure X.6. At 120 minutes, the calculated temperature of the bottom flange of the tested W8x28 with 1 in. (25.4 mm) of SRFM is 1,240 °F (671 °C) and the measured temperature was 1,200 °F (649 °C).

X.5 TEMPERATURE GRADIENT

A fire beneath a structural floor initially affects the bottom flange, and a temperature gradient develops over the depth of the beam member. A concrete slab over the top flange acts as a heat sink, dissipating heat away from the steel. This heat dissipation can result in a substantial difference in temperature between the bottom and top flange.

Review of numerous test results conducted by UL confirmed that it is reasonable to assume a 25 percent reduction in the top flange temperature from that of the bottom flange. The temperature gradient is not linear between the top flange and the bottom flange; the mid-depth temperature is generally higher than the average temperature between the flanges. Thus, it is conservative to assume a mid-depth temperature equal to the bottom flange temperature and a linear decrease in temperature from mid-depth to the top of the top flange. This gradient is depicted in Figure X.2.

X.6 STEEL PROPERTIES AT ELEVATED TEMPERATURES

Steel properties, like those of other conventional construction materials, degrade with increases in temperature. The influence of elevated temperatures on the modulus of elasticity (E_m) and the yield strength (F_{ym}) of steel is presented in Table X.1 as a ratio of the value at the elevated temperature to the value at 68 °F (20 °C)[7].

X.7 COMPOSITE STEEL BEAM CAPACITY AT ELEVATED TEMPERATURES

As mentioned previously, steel properties diminish when subjected to elevated temperatures. However, as fire conditions are considered to represent an ultimate state for the element, and serviceability is not an issue, the designer may fully utilize the plastic capacity and moment redistribution effects within typical composite sections. Additionally, reduced load factors, as mentioned above, may also be applied to the beam due to the extraordinary nature of a building fire and the unlikely probability of the full design load occurring during the event.

Under fire conditions, the rotational restraint provided by the continuous floor slab allows the moment diagram to shift, considering negative moment demands at the beam ends. Capacity for this demand at the ends of the beam is provided by the slab reinforcing steel running parallel with the beam coupled with the steel section[8]. Therefore, the decrease in the positive capacity of the beam section during the event is compensated as the moment demand shifts into the negative bending reserve provided at the beam ends. The beam section retains

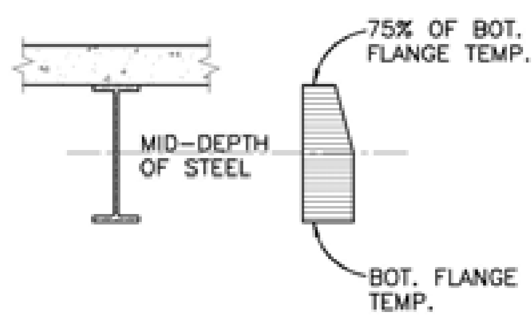

Fig X.2 Illustration of Design Temperature Gradient

Table X.1 Steel Modulus of Elasticity and Yield Strength Reduction at Elevated Temperatures		
Steel Temperature °F [°C]	E_m/E	F_{ym}/F_y
68 [20]	1.00	1.00
200 [93]	1.00	1.00
400 [204]	0.90	1.00
600 [316]	0.78	1.00
750 [399]	0.70	1.00
800 [427]	0.67	0.94
1,000 [538]	0.49	0.66
1,200 [649]	0.22	0.35
1,400 [760]	0.11	0.16
1,600 [871]	0.07	0.07
1,800 [982]	0.05	0.04
2,000 [1,090]	0.02	0.02
2,200 [1,200]	0.00	0.00

the ability to successfully support its load as long as the moment demand falls within this envelope of positive and negative moment capacities, as shown in Figure X.3.

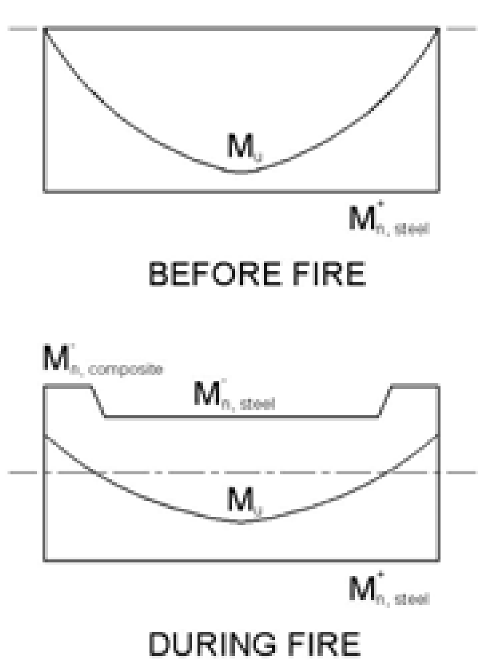

Fig X.3 Moment Envelops Before and During Fire Event[8]

X.7.1 Positive Nominal Flexural Strength. Once the temperature gradient is known across the beam section (Figure X.2), and its corresponding effects upon the physical properties of the beam are known (Table X.1), the positive nominal flexural strength at mid-span can be determined.

It is often convenient to begin with the assumption that the neutral axis lies within the concrete slab. Under this assumption, the concrete slab is in the compression zone, and the entire steel section provides the tensile component. The concrete is modeled to achieve its full plastic capacity at a strain of 0.003, and the steel is assumed to be fully yielded. The assumption of designing the concrete to its full plastic capacity is generally valid as the temperature of the top surface of the slab does not increase dramatically. This is a reasonable assumption, given the limit on temperature rise for the unexposed side of 250 °F (121 °C) in standard fire resistance tests.

With these assumptions, and the reduced steel yield strengths along the section of the beam, the tensile component of the flexural capacity, F_T, may be determined.

$$F_T = F_{tf} + F_w + F_{bf} \qquad \textbf{(X - 4)}$$

where
F_{tf} = yield capacity of the top flange at its elevated temperature (ksi or MPa)
F_w = yield capacity of the web at its elevated temperature (ksi or MPa)
F_{bf} = yield capacity of the bottom flange at its elevated temperature (ksi or MPa)

The depth of the equivalent rectangular compression block, a, may then be computed.

$$a = \frac{F_T}{0.85 * f'_c * b_f} \qquad \textbf{(X – 5)}$$

where
f'_c = compressive strength of concrete (ksi or MPa)
b_f = effective concrete slab width (in. or mm)

If the equivalent compression block is less than the slab depth, then the assumption that the neutral axis lies within the slab is valid. If not, then the compression in the steel can be accounted for as illustrated in the AISC Manual procedures for this case.

The nominal moment capacity, M_n, may then be determined by summing the moments of concrete and steel components about the neutral axis of the member. If the neutral axis lies within the slab, each element of the tensile resistance (F_{tf}, F_w, F_{bf}) forms a couple with a portion of the concrete compressive force (F_c). Therefore, the nominal moment capacity may be determined by multiplying each of these elements with its respective lever arm to the compressive force. A diagram of these forces is shown in Figure X.4.

X.7.2 Negative Nominal Flexural Strength. The negative nominal flexural strength at the ends of the beam is provided by the concrete slab reinforcement running parallel with the beam, possibly in combination with the top flange, acting in tension and forming a couple with the remaining portion of the steel beam acting in compression.

When computing the negative flexural strength, it is convenient to start with the assumption that the neutral axis is located within the beam web. It is also assumed that the steel is fully yielded in tension and compression, thus achieving its full plastic capacity. Again, a building fire represents an ultimate state, and serviceability requirements need not be satisfied.

With these assumptions, and the reduced steel yield strength values along the section of the beam, the initial iteration for the tensile component of the flexural capacity, F_T, may be found.

$$F_T = F_{RB} + F_{tf} \qquad \textbf{(X - 6)}$$

where

F_{RB} = tensile yield force of the reinforcing steel (ksi or MPa)

F_{tf} = yield capacity of the top flange at its elevated temperature (ksi or MPa)

The initial iteration for the compressive component of the flexural capacity, F_C, may then be run.

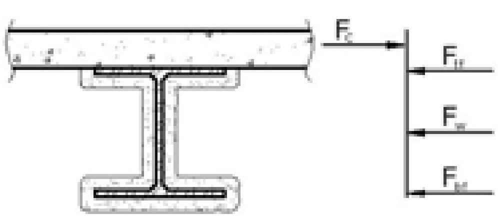

Fig X.4 Typical Positive Moment Force Resultants[8]

$$F_C = F_w + F_{bf} \qquad \textbf{(X - 7)}$$

where

F_w = yield capacity of the web at its elevated temperature (ksi or MPa)

F_{bf} = yield capacity of the bottom flange at its elevated temperature (ksi or MPa)

The above steps are then repeated until a state of equilibrium exists where

$$F_T = F_C \qquad \textbf{(X - 8)}$$

A diagram of these forces is shown in Figure X.5.

X.8 ANALYTICAL SFRM THICKNESS CALCULATION SUMMARY

Due to the iterative nature of the analytical approach to determining required amount of fire protection, the use of a spreadsheet is recommended. A summary for the approach is described below.

1. Using the Extraordinary Loading Condition (e.g. fire) of ASCE 7 (Equations X-1 and X-2), calculate the moment capacity required.

2. Choose a trial thickness of SFRM to be applied to the beam (minimum of ⅜ in. or 9.5 mm). It is often convenient to start with a thickness recommended by a UL assembly representative of the actual construction (e.g. UL D925, UL D902, etc.).

3. Using the heat transfer equation of thermal dynamics and heat input predicted by the standard fire test (ASTM E119) for the fire endurance required, calculate the steel temperature of the bottom flange at the required time rating, as shown in Equation X-3.

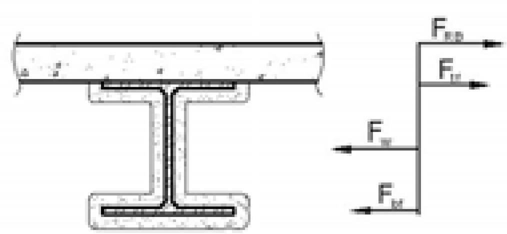

Fig X.5 Typical Negative Moment Force Resultants[8]

4. Calculate the steel temperature gradient across the remainder of the section, with the temperature staying constant from the bottom flange to the midpoint of the web, then linearly decreasing by 25 percent at the top flange, as depicted in Figure X.2.

5. Calculate the steel stress capacities available at the elevated temperatures for the beam bottom flange, web, and top flange using the values shown in Table X.1.

6. Determine the location of the plastic neutral axis and moment capacity at mid span using the bottom flange, web, and top flange forces available at elevated temperatures in conjunction with the compressive force in the concrete slab (composite action) as described in Section X.7.1, Positive Nominal Flexural Strength.

7. Determine the location of the plastic neutral axis and moment capacity at the supports using the bottom flange, web, and top flange forces available at elevated temperatures in conjunction with the tensile force in the reinforcing steel over the support as described in Section X.7.2, Negative Nominal Flexural Strength.

8. Confirm that the moment capacity envelope determined in 6 and 7 satisfy the capacity requirements as determined in 1. If the capacity is less than required, consider one of the following options:

   1. Increase the thickness of fireproofing.
   2. Increase the area of the reinforcing steel running parallel to the beam.
   3. Increase the steel beam size

X.9 ADVANCED METHODS OF ANALYSIS

Computer assisted numerical modeling has provided an exciting resource for investigating the performance of steel-framed structures subjected to fire.

To generate an accurate prediction of structural action in a fire, both the thermal input and the mechanical response must be considered. A realistic model for the thermal input is dependent upon the size of the fire compartment, the ventilation available throughout combustion and the type and quantity of combustibles involved. These parameters can be determined as a function of architectural layout (compartment size, ventilation openings) and occupancy (amount of combustibles). Thus, the thermal input can be rationally established as input to the established heat transfer and structural analysis models.

Structural response under fire conditions has been the focus of numerous investigations[4,9,10]. Computer models have been created that reflect the complex mechanisms of membrane action, thermally induced thrust, heat induced yielding, etc. The future of Fire Engineering will evolve from these pursuits. The result is certain to be the construction of more rational fire resistant steel structures and greater confidence in the fire safety of those built environments.

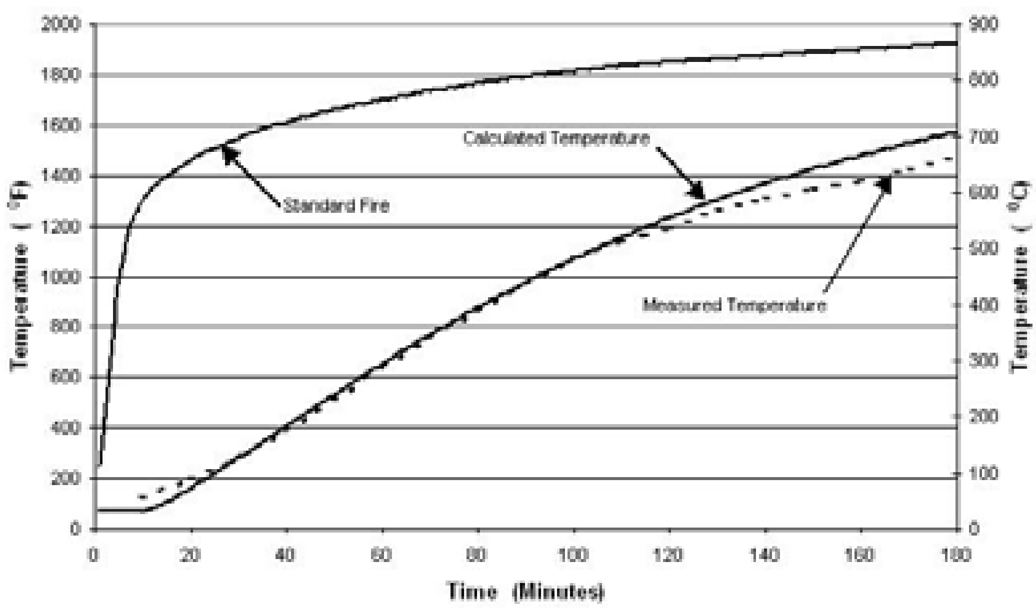

Fig X.6 Bottom Flange Temperature of W8x28 with 1in. SFRM Insulation

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Appendix A
W/D TABLES

(Reprinted from the 3rd Edition, *LRFD Manual of Steel Construction*)

**Table 1-36.
W-Shapes
Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas**

Shape	Case A			Case B			Case C			Case D		
	Peri-meter	W/D Ratio	Surf. Area	Peri-meter	W/D Ratio	Surf. Area	Peri-meter	W/D Ratio	Surf. Area	Peri-meter	W/D Ratio	Surf. Area
	in.		ft²/ft	in.		ft²/ft	in.		ft²/ft	in.		ft²/ft
W44×335	133	2.52	11.1	149	2.25	12.4	104	3.22	8.67	120	2.79	10.0
×290	132	2.20	11.0	147	1.97	12.3	103	2.82	8.58	119	2.44	9.92
×262	131	2.00	10.9	147	1.78	12.3	102	2.57	8.50	118	2.22	9.83
×230	130	1.77	10.8	146	1.58	12.2	102	2.25	8.50	117	1.97	9.75
W40×593	130	4.56	10.8	147	4.03	12.3	103	5.76	8.58	119	4.98	9.92
×503	128	3.93	10.7	144	3.49	12.0	101	4.98	8.42	117	4.30	9.75
×431	126	3.42	10.5	143	3.01	11.9	98.8	4.36	8.23	115	3.75	9.58
×397	126	3.15	10.5	142	2.80	11.8	98.1	4.05	8.18	114	3.48	9.50
×372	125	2.98	10.4	141	2.64	11.8	97.3	3.82	8.11	113	3.29	9.42
×362	125	2.90	10.4	141	2.57	11.8	97.2	3.72	8.10	113	3.20	9.42
×324	124	2.61	10.3	140	2.31	11.7	96.3	3.36	8.03	112	2.89	9.33
×297	123	2.41	10.3	139	2.14	11.6	95.4	3.11	7.95	111	2.68	9.25
×277	123	2.25	10.3	139	1.99	11.6	95.2	2.91	7.93	111	2.50	9.25
×249	123	2.02	10.3	139	1.79	11.6	94.6	2.63	7.88	110	2.26	9.17
×215	122	1.76	10.2	138	1.56	11.5	93.8	2.29	7.82	110	1.95	9.17
×199	121	1.64	10.1	137	1.45	11.4	93.2	2.14	7.77	109	1.83	9.08
W40×392	116	3.38	9.67	128	3.06	10.7	95.6	4.10	7.97	108	3.63	9.00
×331	114	2.90	9.50	126	2.63	10.5	93.8	3.53	7.82	106	3.12	8.83
×327	113	2.89	9.42	125	2.62	10.4	93.7	3.49	7.81	106	3.08	8.83
×278	112	2.48	9.33	124	2.24	10.3	92.4	3.01	7.70	104	2.67	8.67
×264	112	2.36	9.33	124	2.13	10.3	91.9	2.87	7.66	104	2.54	8.67
×235	112	2.10	9.33	124	1.90	10.3	91.3	2.57	7.61	103	2.28	8.58
×211	111	1.90	9.25	123	1.72	10.3	90.6	2.33	7.55	102	2.07	8.50
×183	110	1.66	9.17	122	1.50	10.2	89.8	2.04	7.48	102	1.79	8.50
×167	109	1.53	9.08	121	1.38	10.1	89.0	1.88	7.42	101	1.65	8.42
×149	109	1.37	9.08	121	1.23	10.1	88.2	1.69	7.35	100	1.49	8.33
W36×798	131	6.09	10.9	149	5.36	12.4	102	7.82	8.50	120	6.65	10.0
×650	128	5.08	10.7	146	4.45	12.2	98.6	6.59	8.22	116	5.60	9.67
×527	125	4.22	10.4	142	3.71	11.8	95.6	5.51	7.97	113	4.66	9.42
×439	123	3.57	10.3	140	3.14	11.7	93.6	4.69	7.80	111	3.95	9.25
×393	121	3.25	10.1	138	2.85	11.5	92.4	4.25	7.70	109	3.61	9.08
×359	121	2.97	10.1	137	2.62	11.4	91.5	3.92	7.63	108	3.32	9.00
×328	120	2.73	10.0	137	2.39	11.4	90.8	3.61	7.57	107	3.07	8.92
×300	120	2.50	10.0	136	2.21	11.3	90.1	3.33	7.51	107	2.80	8.92
×280	119	2.35	9.92	136	2.06	11.3	89.6	3.13	7.47	106	2.64	8.83
×260	119	2.18	9.92	135	1.93	11.3	89.2	2.91	7.43	106	2.45	8.83
×245	118	2.08	9.83	135	1.81	11.3	88.7	2.76	7.39	105	2.33	8.75
×230	118	1.95	9.83	134	1.72	11.2	88.3	2.60	7.36	105	2.19	8.75
W36×256	108	2.37	9.00	120	2.13	10.0	87.0	2.94	7.25	99.2	2.58	8.27
×232	108	2.15	9.00	120	1.93	10.0	86.3	2.69	7.19	98.4	2.36	8.20
×210	107	1.96	8.92	119	1.76	9.92	85.6	2.45	7.13	97.8	2.15	8.15
×194	107	1.81	8.92	119	1.63	9.92	85.1	2.28	7.09	97.2	2.00	8.10
×182	106	1.72	8.83	119	1.53	9.92	84.7	2.15	7.06	96.8	1.88	8.07
×170	106	1.60	8.83	118	1.44	9.83	84.4	2.01	7.03	96.4	1.76	8.03
×160	106	1.51	8.83	118	1.36	9.83	84.0	1.90	7.00	96.0	1.67	8.00
×150	105	1.43	8.75	117	1.28	9.75	83.8	1.79	6.98	95.8	1.57	7.98
×135	105	1.29	8.75	117	1.15	9.75	83.2	1.62	6.93	95.2	1.42	7.93
W33×387	117	3.31	9.75	133	2.91	11.1	88.2	4.39	7.35	104	3.72	8.67
×354	116	3.05	9.67	132	2.68	11.0	87.3	4.05	7.28	103	3.44	8.58
×318	115	2.77	9.58	131	2.43	10.9	86.4	3.68	7.20	102	3.12	8.50
×291	114	2.55	9.50	130	2.24	10.8	85.5	3.40	7.13	101	2.88	8.42
×263	113	2.33	9.42	129	2.04	10.8	84.8	3.10	7.07	101	2.60	8.42
×241	113	2.13	9.42	129	1.87	10.8	84.3	2.86	7.03	100	2.41	8.33
×221	112	1.97	9.33	128	1.73	10.7	83.6	2.64	6.97	99.4	2.22	8.28
×201	112	1.79	9.33	127	1.58	10.6	83.1	2.42	6.93	98.8	2.03	8.23

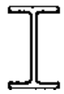
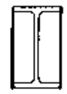
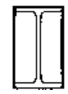
Case A: Shape perimeter, minus one flange surface.
Case B: Shape perimeter.
Case C: Box perimeter, minus one flange surface.
Case D: Box perimeter.

Table 1-36 (cont.). W-Shapes
Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A Perimeter in.	Case A W/D Ratio	Case A Surf. Area ft²/ft	Case B Perimeter in.	Case B W/D Ratio	Case B Surf. Area ft²/ft	Case C Perimeter in.	Case C W/D Ratio	Case C Surf. Area ft²/ft	Case D Perimeter in.	Case D W/D Ratio	Case D Surf. Area ft²/ft
W33×169	99.6	1.70	8.30	111	1.52	9.25	79.1	2.14	6.59	90.6	1.87	7.55
×152	99.3	1.53	8.28	111	1.37	9.25	78.6	1.93	6.55	90.2	1.69	7.52
×141	98.4	1.43	8.20	110	1.28	9.17	78.1	1.81	6.51	89.6	1.57	7.47
×130	98.3	1.32	8.19	110	1.18	9.17	77.7	1.67	6.48	89.2	1.46	7.43
×118	97.8	1.21	8.15	109	1.08	9.08	77.3	1.53	6.44	88.8	1.33	7.40
W30×391	109	3.59	9.08	125	3.13	10.4	82.0	4.77	6.83	97.6	4.01	8.13
×357	108	3.31	9.00	124	2.88	10.3	81.1	4.40	6.76	96.6	3.70	8.05
×326	107	3.05	8.92	123	2.65	10.3	80.2	4.06	6.68	95.6	3.41	7.97
×292	107	2.73	8.92	122	2.39	10.2	79.3	3.68	6.61	94.6	3.09	7.88
×261	106	2.46	8.83	121	2.16	10.1	78.4	3.33	6.53	93.6	2.79	7.80
×235	105	2.24	8.75	120	1.96	10.00	77.7	3.02	6.48	92.8	2.53	7.73
×211	105	2.01	8.75	120	1.76	10.00	76.9	2.74	6.41	92.0	2.29	7.67
×191	103	1.85	8.58	118	1.62	9.83	76.4	2.50	6.37	91.4	2.09	7.62
×173	104	1.66	8.67	119	1.45	9.92	75.8	2.28	6.32	90.8	1.91	7.57
W30×148	90.3	1.64	7.53	101	1.47	8.42	71.9	2.06	5.99	82.4	1.80	6.87
×132	89.5	1.47	7.46	100	1.32	8.33	71.1	1.86	5.93	81.6	1.62	6.80
×124	89.3	1.39	7.44	99.8	1.24	8.32	70.9	1.75	5.91	81.4	1.52	6.78
×116	89.1	1.30	7.43	99.6	1.16	8.30	70.5	1.65	5.88	81.0	1.43	6.75
×108	88.9	1.21	7.41	99.4	1.09	8.28	70.1	1.54	5.84	80.6	1.34	6.72
×99	88.5	1.12	7.38	99.0	1.00	8.25	69.9	1.42	5.83	80.4	1.23	6.70
×90	88.0	1.02	7.33	98.4	0.915	8.20	69.4	1.30	5.78	79.8	1.13	6.65
W27×539	106	5.08	8.83	121	4.45	10.1	80.3	6.71	6.69	95.6	5.64	7.97
×368	101	3.64	8.42	116	3.17	9.67	75.5	4.87	6.29	90.2	4.08	7.52
×336	100	3.36	8.33	115	2.92	9.58	74.6	4.50	6.22	89.2	3.77	7.43
×307	98.8	3.11	8.23	113	2.72	9.42	73.6	4.17	6.13	88.0	3.49	7.33
×281	98.2	2.86	8.18	113	2.49	9.42	73.0	3.85	6.08	87.4	3.22	7.28
×258	97.7	2.64	8.14	112	2.30	9.33	72.3	3.57	6.03	86.6	2.98	7.22
×235	96.6	2.43	8.05	111	2.12	9.25	71.6	3.28	5.97	85.8	2.74	7.15
×217	96.0	2.26	8.00	110	1.97	9.17	70.9	3.06	5.91	85.0	2.55	7.08
×194	95.6	2.03	7.97	110	1.76	9.17	70.2	2.76	5.85	84.2	2.30	7.02
×178	95.0	1.87	7.92	109	1.63	9.08	69.7	2.55	5.81	83.8	2.12	6.98
×161	94.6	1.70	7.88	109	1.48	9.08	69.2	2.33	5.77	83.2	1.94	6.93
×146	94.3	1.55	7.86	108	1.35	9.00	68.8	2.12	5.73	82.8	1.76	6.90
W27×129	82.8	1.56	6.90	92.8	1.39	7.73	65.2	1.98	5.43	75.2	1.72	6.27
×114	82.3	1.39	6.86	92.4	1.23	7.70	64.7	1.76	5.39	74.8	1.52	6.23
×102	82.1	1.24	6.84	92.1	1.11	7.68	64.2	1.59	5.35	74.2	1.37	6.18
×94	81.5	1.15	6.79	91.5	1.03	7.63	63.8	1.47	5.32	73.8	1.27	6.15
×84	81.2	1.03	6.77	91.2	0.921	7.60	63.4	1.32	5.28	73.3	1.15	6.11
W24×370	92.9	3.98	7.74	107	3.46	8.92	69.7	5.31	5.81	83.4	4.44	6.95
×335	91.5	3.66	7.63	105	3.19	8.75	68.5	4.89	5.71	82.0	4.09	6.83
×306	90.8	3.37	7.57	104	2.94	8.67	67.6	4.53	5.63	81.0	3.78	6.75
×279	89.7	3.11	7.48	103	2.71	8.58	66.7	4.18	5.56	80.0	3.49	6.67
×250	89.0	2.81	7.42	102	2.45	8.50	65.8	3.80	5.48	79.0	3.16	6.58
×229	88.1	2.60	7.34	101	2.27	8.42	65.1	3.52	5.43	78.2	2.93	6.52
×207	87.6	2.36	7.30	101	2.05	8.42	64.4	3.21	5.37	77.4	2.67	6.45
×192	87.1	2.20	7.26	100	1.92	8.33	64.0	3.00	5.33	77.0	2.49	6.42
×176	86.5	2.03	7.21	99.4	1.77	8.28	63.3	2.78	5.28	76.2	2.31	6.35
×162	86.3	1.88	7.19	99.3	1.63	8.28	63.0	2.57	5.25	76.0	2.13	6.33
×146	85.8	1.70	7.15	98.7	1.48	8.23	62.3	2.34	5.19	75.2	1.94	6.27
×131	85.3	1.54	7.11	98.2	1.33	8.18	61.9	2.12	5.16	74.8	1.75	6.23
×117	84.5	1.38	7.04	97.3	1.20	8.11	61.4	1.91	5.12	74.2	1.58	6.18
×104	84.1	1.24	7.01	96.9	1.07	8.08	61.0	1.70	5.08	73.8	1.41	6.15
W24×103	73.5	1.40	6.13	82.5	1.25	6.88	58.0	1.78	4.83	67.0	1.54	5.58
×94	73.5	1.28	6.13	82.5	1.14	6.88	57.7	1.63	4.81	66.7	1.41	5.56
×84	73.2	1.15	6.10	82.2	1.02	6.85	57.2	1.47	4.77	66.2	1.27	5.52
×76	72.5	1.05	6.04	81.5	0.933	6.79	56.8	1.34	4.73	65.8	1.16	5.48
×68	72.2	0.942	6.02	81.2	0.837	6.77	56.4	1.21	4.70	65.3	1.04	5.44

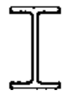
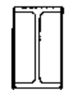
Case A: Shape perimeter, minus one flange surface.
Case B: Shape perimeter.
Case C: Box perimeter, minus one flange surface.
Case D: Box perimeter.

Table 1-36 (cont.).
W-Shapes
Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A 			Case B 			Case C 			Case D 		
	Peri-meter	*W/D* Ratio	Surf. Area	Peri-meter	*W/D* Ratio	Surf. Area	Peri-meter	*W/D* Ratio	Surf. Area	Peri-meter	*W/D* Ratio	Surf. Area
	in.		ft^2/ft	in.		ft^2/ft	in.		ft^2/ft	in.		ft^2/ft
W24×62	66.4	0.934	5.53	73.5	0.844	6.13	54.4	1.14	4.53	61.5	1.01	5.13
×55	66.4	0.828	5.53	73.4	0.749	6.12	54.2	1.01	4.52	61.2	0.899	5.10
W21×201	80.5	2.50	6.71	93.1	2.16	7.76	58.6	3.43	4.88	71.2	2.82	5.93
×182	80.0	2.28	6.67	92.5	1.97	7.71	57.9	3.14	4.83	70.4	2.59	5.87
×166	79.5	2.09	6.63	91.9	1.81	7.66	57.4	2.89	4.78	69.8	2.38	5.82
×147	78.7	1.87	6.56	91.2	1.61	7.60	56.7	2.59	4.73	69.2	2.12	5.77
×132	78.5	1.68	6.54	90.9	1.45	7.58	56.0	2.36	4.67	68.4	1.93	5.70
×122	77.9	1.57	6.49	90.3	1.35	7.53	55.8	2.19	4.65	68.2	1.79	5.68
×111	77.4	1.43	6.45	89.7	1.24	7.48	55.3	2.01	4.61	67.6	1.64	5.63
×101	77.4	1.30	6.45	89.7	1.13	7.48	55.1	1.83	4.59	67.4	1.50	5.62
W21×93	66.3	1.40	5.53	74.8	1.24	6.23	51.6	1.80	4.30	60.0	1.55	5.00
×83	65.8	1.26	5.48	74.2	1.12	6.18	51.2	1.62	4.27	59.5	1.39	4.96
×73	65.5	1.11	5.46	73.8	0.989	6.15	50.7	1.44	4.23	59.0	1.24	4.92
×68	65.1	1.04	5.43	73.4	0.926	6.12	50.5	1.35	4.21	58.7	1.16	4.89
×62	65.1	0.952	5.43	73.3	0.846	6.11	50.2	1.24	4.18	58.5	1.06	4.88
×55	64.4	0.854	5.37	72.6	0.758	6.05	49.8	1.10	4.15	58.0	0.948	4.83
×48	64.0	0.750	5.33	72.1	0.666	6.01	49.3	0.974	4.11	57.5	0.835	4.79
W21×57	59.9	0.952	4.99	66.5	0.857	5.54	48.8	1.17	4.07	55.3	1.03	4.61
×50	59.7	0.838	4.98	66.3	0.754	5.53	48.1	1.04	4.01	54.7	0.914	4.56
×44	59.0	0.746	4.92	65.5	0.672	5.46	47.9	0.919	3.99	54.4	0.809	4.53
W18×175	71.1	2.46	5.93	82.5	2.12	6.88	51.4	3.40	4.28	62.8	2.79	5.23
×158	70.5	2.24	5.88	81.8	1.93	6.82	50.7	3.12	4.23	62.0	2.55	5.17
×143	69.8	2.05	5.82	81.0	1.77	6.75	50.2	2.85	4.18	61.4	2.33	5.12
×130	69.3	1.88	5.78	80.5	1.61	6.71	49.8	2.61	4.15	61.0	2.13	5.08
×119	69.2	1.72	5.77	80.5	1.48	6.71	49.3	2.41	4.11	60.6	1.96	5.05
×106	68.6	1.55	5.72	79.8	1.33	6.65	48.6	2.18	4.05	59.8	1.77	4.98
×97	68.1	1.42	5.68	79.2	1.22	6.60	48.3	2.01	4.03	59.4	1.63	4.95
×86	67.8	1.27	5.65	78.9	1.09	6.58	47.9	1.80	3.99	59.0	1.46	4.92
×76	67.3	1.13	5.61	78.3	0.971	6.53	47.4	1.60	3.95	58.4	1.30	4.87
W18×71	58.0	1.22	4.83	65.6	1.08	5.47	44.6	1.59	3.72	52.3	1.36	4.36
×65	57.6	1.13	4.80	65.2	0.997	5.43	44.4	1.46	3.70	52.0	1.25	4.33
×60	57.5	1.04	4.79	65.0	0.923	5.42	44.0	1.36	3.67	51.5	1.17	4.29
×55	57.1	0.963	4.76	64.7	0.850	5.39	43.7	1.26	3.64	51.3	1.07	4.28
×50	56.8	0.880	4.73	64.3	0.778	5.36	43.5	1.15	3.63	51.0	0.980	4.25
W18×46	52.4	0.878	4.37	58.5	0.786	4.88	42.3	1.09	3.53	48.3	0.952	4.03
×40	52.1	0.768	4.34	58.1	0.688	4.84	41.8	0.957	3.48	47.8	0.837	3.98
×35	52.1	0.672	4.34	58.1	0.602	4.84	41.4	0.845	3.45	47.4	0.738	3.95
W16×100	62.7	1.59	5.23	73.1	1.37	6.09	44.4	2.25	3.70	54.8	1.82	4.57
×89	62.4	1.43	5.20	72.8	1.22	6.07	44.0	2.02	3.67	54.4	1.64	4.53
×77	61.6	1.25	5.13	71.9	1.07	5.99	43.3	1.78	3.61	53.6	1.44	4.47
×67	61.4	1.09	5.12	71.6	0.936	5.97	42.8	1.57	3.57	53.0	1.26	4.42
W16×57	52.1	1.09	4.34	59.2	0.963	4.93	39.9	1.43	3.33	47.0	1.21	3.92
×50	52.0	0.962	4.33	59.1	0.846	4.93	39.7	1.26	3.31	46.7	1.07	3.89
×45	51.7	0.870	4.31	58.7	0.767	4.89	39.2	1.15	3.27	46.3	0.972	3.86
×40	51.3	0.780	4.28	58.3	0.686	4.86	39.0	1.03	3.25	46.0	0.870	3.83
×36	51.3	0.702	4.28	58.3	0.617	4.86	38.8	0.928	3.23	45.8	0.786	3.82
W16×31	46.9	0.661	3.91	52.4	0.592	4.37	37.3	0.831	3.11	42.9	0.723	3.58
×26	46.6	0.558	3.88	52.1	0.499	4.34	36.9	0.705	3.08	42.4	0.613	3.53

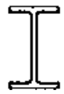
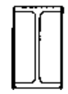
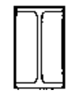
Case A: Shape perimeter, minus one flange surface.
Case B: Shape perimeter.
Case C: Box perimeter, minus one flange surface.
Case D: Box perimeter.

Table 1-36 (cont.). W-Shapes
Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A 			Case B 			Case C 			Case D 		
	Peri-meter	*W/D* Ratio	Surf. Area	Peri-meter	*W/D* Ratio	Surf. Area	Peri-meter	*W/D* Ratio	Surf. Area	Peri-meter	*W/D* Ratio	Surf. Area
	in.		ft²/ft	in.		ft²/ft	in.		ft²/ft	in.		ft²/ft
W14×808	92.3	8.75	7.69	111	7.28	9.25	64.2	12.6	5.35	82.8	9.76	6.90
×730	90.4	8.08	7.53	108	6.76	9.00	62.7	11.6	5.23	80.6	9.06	6.72
×665	88.8	7.49	7.40	107	6.21	8.92	60.9	10.9	5.08	78.6	8.46	6.55
×605	86.9	6.96	7.24	104	5.82	8.67	59.2	10.2	4.93	76.6	7.90	6.38
×550	85.6	6.43	7.13	103	5.34	8.58	57.6	9.55	4.80	74.8	7.35	6.23
×500	84.0	5.95	7.00	101	4.95	8.42	56.2	8.90	4.68	73.2	6.83	6.10
×455	82.3	5.53	6.86	99.1	4.59	8.26	54.8	8.30	4.57	71.6	6.35	5.97
×426	81.8	5.21	6.82	98.5	4.32	8.21	54.1	7.87	4.51	70.8	6.02	5.90
×398	80.7	4.93	6.73	97.3	4.09	8.11	53.2	7.48	4.43	69.8	5.70	5.82
×370	79.9	4.63	6.66	96.4	3.84	8.03	52.3	7.07	4.36	68.8	5.38	5.73
×342	79.1	4.32	6.59	95.5	3.58	7.96	51.4	6.65	4.28	67.8	5.04	5.65
×311	78.1	3.98	6.51	94.3	3.30	7.86	50.4	6.17	4.20	66.6	4.67	5.55
×283	77.3	3.66	6.44	93.4	3.03	7.78	49.5	5.72	4.13	65.6	4.31	5.47
×257	76.5	3.36	6.38	92.5	2.78	7.71	48.8	5.27	4.07	64.8	3.97	5.40
×233	75.6	3.08	6.30	91.5	2.55	7.63	47.9	4.86	3.99	63.8	3.65	5.32
×211	75.2	2.81	6.27	91.0	2.32	7.58	47.2	4.47	3.93	63.0	3.35	5.25
×193	74.3	2.60	6.19	90.0	2.14	7.50	46.7	4.13	3.89	62.4	3.09	5.20
×176	74.1	2.38	6.18	89.8	1.96	7.48	46.1	3.82	3.84	61.8	2.85	5.15
×159	73.5	2.16	6.13	89.1	1.78	7.43	45.6	3.49	3.80	61.2	2.60	5.10
×145	72.7	1.99	6.06	88.2	1.64	7.35	45.1	3.22	3.76	60.6	2.39	5.05
W14×132	70.0	1.89	5.83	84.7	1.56	7.06	44.1	2.99	3.68	58.8	2.24	4.90
×120	70.1	1.71	5.84	84.8	1.42	7.07	43.7	2.75	3.64	58.4	2.05	4.87
×109	69.6	1.57	5.80	84.2	1.29	7.02	43.2	2.52	3.60	57.8	1.89	4.82
×99	69.2	1.43	5.77	83.8	1.18	6.98	43.0	2.30	3.58	57.6	1.72	4.80
×90	68.7	1.31	5.73	83.2	1.08	6.93	42.5	2.12	3.54	57.0	1.58	4.75
W14×82	56.5	1.45	4.71	66.6	1.23	5.55	38.7	2.12	3.23	48.8	1.68	4.07
×74	56.2	1.32	4.68	66.3	1.12	5.53	38.5	1.92	3.21	48.6	1.52	4.05
×68	55.7	1.22	4.64	65.7	1.04	5.48	38.0	1.79	3.17	48.0	1.42	4.00
×61	55.7	1.10	4.64	65.7	0.928	5.48	37.8	1.61	3.15	47.8	1.28	3.98
W14×53	49.8	1.06	4.15	57.9	0.915	4.83	35.9	1.48	2.99	43.9	1.21	3.66
×48	49.5	0.970	4.13	57.5	0.835	4.79	35.6	1.35	2.97	43.7	1.10	3.64
×43	49.2	0.874	4.10	57.2	0.752	4.77	35.4	1.21	2.95	43.4	0.991	3.62
W14×38	47.0	0.809	3.92	53.8	0.706	4.48	35.0	1.09	2.92	41.7	0.911	3.48
×34	46.9	0.725	3.91	53.7	0.633	4.48	34.8	0.977	2.90	41.5	0.819	3.46
×30	46.6	0.644	3.88	53.4	0.562	4.45	34.3	0.875	2.86	41.1	0.730	3.43
W14×26	41.4	0.628	3.45	46.5	0.559	3.88	32.8	0.793	2.73	37.9	0.686	3.16
×22	41.2	0.534	3.43	46.2	0.476	3.85	32.4	0.679	2.70	37.4	0.588	3.12
W12×336	69.3	4.85	5.78	82.7	4.06	6.89	47.0	7.15	3.92	60.4	5.56	5.03
×305	67.9	4.49	5.66	81.1	3.76	6.76	45.8	6.66	3.82	59.0	5.17	4.92
×279	66.6	4.19	5.55	79.7	3.50	6.64	44.9	6.21	3.74	58.0	4.81	4.83
×252	65.7	3.84	5.48	78.7	3.20	6.56	43.8	5.75	3.65	56.8	4.44	4.73
×230	64.7	3.55	5.39	77.6	2.96	6.47	43.1	5.34	3.59	56.0	4.11	4.67
×210	64.2	3.27	5.35	77.0	2.73	6.42	42.2	4.98	3.52	55.0	3.82	4.58
×190	63.4	3.00	5.28	76.1	2.50	6.34	41.5	4.58	3.46	54.2	3.51	4.52
×170	62.6	2.72	5.22	75.2	2.26	6.27	40.6	4.19	3.38	53.2	3.20	4.43
×152	62.1	2.45	5.18	74.6	2.04	6.22	39.9	3.81	3.33	52.4	2.90	4.37
×136	60.9	2.23	5.08	73.3	1.86	6.11	39.2	3.47	3.27	51.6	2.64	4.30
×120	60.4	1.99	5.03	72.7	1.65	6.06	38.5	3.12	3.21	50.8	2.36	4.23
×106	59.9	1.77	4.99	72.1	1.47	6.01	38.0	2.79	3.17	50.2	2.11	4.18
×96	59.7	1.61	4.98	71.9	1.34	5.99	37.6	2.55	3.13	49.8	1.93	4.15
×87	59.1	1.47	4.93	71.2	1.22	5.93	37.1	2.35	3.09	49.2	1.77	4.10
×79	58.8	1.34	4.90	70.9	1.11	5.91	36.9	2.14	3.08	49.0	1.61	4.08
×72	58.3	1.23	4.86	70.3	1.02	5.86	36.6	1.97	3.05	48.6	1.48	4.05
×65	58.3	1.11	4.86	70.3	0.925	5.86	36.2	1.80	3.02	48.2	1.35	4.02
W12×58	52.7	1.10	4.39	62.7	0.925	5.23	34.4	1.69	2.87	44.4	1.31	3.70
×53	52.0	1.02	4.33	62.0	0.855	5.17	34.2	1.55	2.85	44.2	1.20	3.68

Case A: Shape perimeter, minus one flange surface.
Case B: Shape perimeter.
Case C: Box perimeter, minus one flange surface.
Case D: Box perimeter.

Table 1-36 (cont.).
W-Shapes
Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A 			Case B 			Case C 			Case D 		
	Peri-meter	W/D Ratio	Surf. Area	Peri-meter	W/D Ratio	Surf. Area	Peri-meter	W/D Ratio	Surf. Area	Peri-meter	W/D Ratio	Surf. Area
	in.		ft²/ft	in.		ft²/ft	in.		ft²/ft	in.		ft²/ft
W12×50	47.0	1.06	3.92	55.0	0.909	4.58	32.5	1.54	2.71	40.6	1.23	3.38
×45	46.2	0.974	3.85	54.3	0.829	4.53	32.3	1.39	2.69	40.3	1.12	3.36
×40	46.5	0.860	3.88	54.5	0.734	4.54	31.8	1.26	2.65	39.8	1.01	3.32
W12×35	43.2	0.810	3.60	49.8	0.703	4.15	31.6	1.11	2.63	38.1	0.919	3.18
×30	42.9	0.699	3.58	49.4	0.607	4.12	31.1	0.965	2.59	37.6	0.798	3.13
×26	42.5	0.612	3.54	49.0	0.531	4.08	30.9	0.841	2.58	37.4	0.695	3.12
W12×22	35.3	0.623	2.94	39.3	0.560	3.28	28.6	0.769	2.38	32.7	0.673	2.73
×19	35.2	0.540	2.93	39.2	0.485	3.27	28.4	0.669	2.37	32.4	0.586	2.70
×16	35.0	0.457	2.92	39.0	0.410	3.25	28.0	0.571	2.33	32.0	0.500	2.67
×14	34.6	0.405	2.88	38.6	0.363	3.22	27.8	0.504	2.32	31.7	0.442	2.64
W10×112	51.5	2.17	4.29	61.9	1.81	5.16	33.2	3.37	2.77	43.6	2.57	3.63
×100	50.7	1.97	4.23	61.0	1.64	5.08	32.5	3.08	2.71	42.8	2.34	3.57
×88	50.5	1.74	4.21	60.8	1.45	5.07	31.9	2.76	2.66	42.2	2.09	3.52
×77	49.9	1.54	4.16	60.1	1.28	5.01	31.4	2.45	2.62	41.6	1.85	3.47
×68	49.1	1.38	4.09	59.2	1.15	4.93	30.9	2.20	2.58	41.0	1.66	3.42
×60	49.1	1.22	4.09	59.2	1.01	4.93	30.5	1.97	2.54	40.6	1.48	3.38
×54	48.6	1.11	4.05	58.6	0.922	4.88	30.2	1.79	2.52	40.2	1.34	3.35
×49	48.3	1.01	4.03	58.3	0.840	4.86	30.0	1.63	2.50	40.0	1.23	3.33
W10×45	42.6	1.06	3.55	50.7	0.888	4.23	28.2	1.60	2.35	36.2	1.24	3.02
×39	42.0	0.929	3.50	50.0	0.780	4.17	27.8	1.40	2.32	35.8	1.09	2.98
×33	42.0	0.786	3.50	49.9	0.661	4.16	27.4	1.20	2.28	35.4	0.932	2.95
W10×30	37.1	0.809	3.09	42.9	0.699	3.58	26.8	1.12	2.23	32.6	0.920	2.72
×26	36.7	0.708	3.06	42.5	0.612	3.54	26.4	0.985	2.20	32.1	0.810	2.68
×22	36.3	0.606	3.03	42.1	0.523	3.51	26.2	0.840	2.18	31.9	0.690	2.66
W10×19	31.3	0.607	2.61	35.3	0.538	2.94	24.4	0.779	2.03	28.4	0.669	2.37
×17	31.3	0.543	2.61	35.3	0.482	2.94	24.2	0.702	2.02	28.2	0.603	2.35
×15	31.0	0.484	2.58	35.0	0.429	2.92	24.0	0.625	2.00	28.0	0.536	2.33
×12	30.6	0.392	2.55	34.6	0.347	2.88	23.7	0.506	1.98	27.7	0.433	2.31
W8×67	40.7	1.65	3.39	48.9	1.37	4.08	26.3	2.55	2.19	34.6	1.94	2.88
×58	40.2	1.44	3.35	48.5	1.20	4.04	25.7	2.26	2.14	33.9	1.71	2.83
×48	39.7	1.21	3.31	47.8	1.00	3.98	25.1	1.91	2.09	33.2	1.45	2.77
×40	39.0	1.03	3.25	47.1	0.849	3.93	24.6	1.63	2.05	32.6	1.23	2.72
×35	38.6	0.907	3.22	46.7	0.749	3.89	24.3	1.44	2.03	32.3	1.08	2.69
×31	38.6	0.803	3.22	46.6	0.665	3.88	24.0	1.29	2.00	32.0	0.969	2.67
W8×28	34.2	0.819	2.85	40.7	0.688	3.39	22.7	1.23	1.89	29.2	0.959	2.43
×24	34.1	0.704	2.84	40.6	0.591	3.38	22.4	1.07	1.87	28.9	0.830	2.41
W8×21	31.1	0.675	2.59	36.4	0.577	3.03	21.8	0.963	1.82	27.1	0.775	2.26
×18	30.9	0.583	2.58	36.1	0.499	3.01	21.5	0.837	1.79	26.8	0.672	2.23
W8×15	27.2	0.551	2.27	31.2	0.481	2.60	20.2	0.743	1.68	24.2	0.620	2.02
×13	26.9	0.483	2.24	30.9	0.421	2.58	20.0	0.650	1.67	24.0	0.542	2.00
×10	26.7	0.375	2.23	30.6	0.327	2.55	19.7	0.508	1.64	23.7	0.422	1.98
W6×25	29.8	0.839	2.48	35.9	0.696	2.99	18.8	1.33	1.57	24.9	1.00	2.08
×20	29.5	0.678	2.46	35.5	0.563	2.96	18.4	1.09	1.53	24.4	0.820	2.03
×15	28.8	0.521	2.40	34.8	0.431	2.90	18.0	0.833	1.50	24.0	0.625	2.00
W6×16	23.4	0.684	1.95	27.4	0.584	2.28	16.6	0.964	1.38	20.6	0.777	1.72
×12	22.8	0.526	1.90	26.8	0.448	2.23	16.1	0.745	1.34	20.1	0.597	1.68
×9	22.6	0.398	1.88	26.6	0.338	2.22	15.7	0.573	1.31	19.7	0.457	1.64
×8.5	22.7	0.374	1.89	26.6	0.320	2.22	15.6	0.545	1.30	19.5	0.436	1.63
W5×19	24.5	0.776	2.04	29.5	0.644	2.46	15.3	1.24	1.28	20.4	0.931	1.70
×16	24.1	0.664	2.01	29.1	0.550	2.43	15.0	1.07	1.25	20.0	0.800	1.67
W4×13	19.4	0.670	1.62	23.4	0.556	1.95	12.4	1.05	1.03	16.4	0.793	1.37

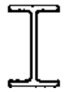
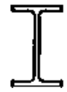
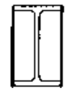
Case A: Shape perimeter, minus one flange surface.
Case B: Shape perimeter.
Case C: Box perimeter, minus one flange surface.
Case D: Box perimeter.

Table 1-37.
M-Shapes
Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B			Case C			Case D		
	Perimeter	*W/D* Ratio	Surf. Area	Perimeter	*W/D* Ratio	Surf. Area	Perimeter	*W/D* Ratio	Surf. Area	Perimeter	*W/D* Ratio	Surf. Area
	in.		ft²/ft	in.		ft²/ft	in.		ft²/ft	in.		ft²/ft
M12×11.8	32.5	0.363	2.71	35.6	0.331	2.97	27.1	0.435	2.26	30.1	0.392	2.51
×10.8	32.5	0.332	2.71	35.6	0.303	2.97	27.1	0.399	2.26	30.1	0.359	2.51
×10	33.0	0.303	2.75	36.2	0.276	3.02	27.3	0.366	2.28	30.5	0.328	2.54
M10×9	27.4	0.328	2.28	30.1	0.299	2.51	22.7	0.396	1.89	25.4	0.354	2.12
×8	27.4	0.292	2.28	30.1	0.266	2.51	22.6	0.354	1.88	25.3	0.316	2.11
×7.5	27.4	0.274	2.28	30.1	0.249	2.51	22.7	0.330	1.89	25.4	0.295	2.12
M8×6.5	22.2	0.293	1.85	24.5	0.265	2.04	18.3	0.355	1.53	20.6	0.316	1.72
×6.2	22.4	0.277	1.87	24.7	0.251	2.06	18.3	0.339	1.53	20.6	0.301	1.72
M6×4.4	17.0	0.259	1.42	18.8	0.234	1.57	13.8	0.319	1.15	15.7	0.280	1.31
×3.7	17.2	0.215	1.43	19.2	0.193	1.60	13.8	0.268	1.15	15.8	0.234	1.32
M5×18.9	23.9	0.791	1.99	28.9	0.654	2.41	15.0	1.26	1.25	20.0	0.945	1.67
M4×6	18.2	0.330	1.52	22.0	0.273	1.83	11.4	0.526	0.950	15.2	0.395	1.27

Case A: Shape perimeter, minus one flange surface.
Case B: Shape perimeter.
Case C: Box perimeter, minus one flange surface.
Case D: Box perimeter.

Table 1-38.
S-Shapes
Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A 			Case B 			Case C 			Case D 		
	Peri-meter	*W/D* Ratio	Surf. Area	Peri-meter	*W/D* Ratio	Surf. Area	Peri-meter	*W/D* Ratio	Surf. Area	Peri-meter	*W/D* Ratio	Surf. Area
	in.		ft^2/ft	in.		ft^2/ft	in.		ft^2/ft	in.		ft^2/ft
S24×121	68.6	1.76	5.72	76.6	1.58	6.38	57.1	2.12	4.76	65.1	1.86	5.43
×106	68.4	1.55	5.70	76.3	1.39	6.36	56.9	1.86	4.74	64.7	1.64	5.39
S24×100	65.5	1.53	5.46	72.8	1.37	6.07	55.3	1.81	4.61	62.5	1.60	5.21
×90	65.4	1.38	5.45	72.5	1.24	6.04	55.1	1.63	4.59	62.3	1.44	5.19
×80	65.2	1.23	5.43	72.2	1.11	6.02	55.0	1.45	4.58	62.0	1.29	5.17
S20×96	57.9	1.66	4.83	65.1	1.47	5.43	47.8	2.01	3.98	55.0	1.75	4.58
×86	57.8	1.49	4.82	64.9	1.33	5.41	47.7	1.80	3.98	54.7	1.57	4.56
S20×75	55.4	1.35	4.62	61.8	1.21	5.15	46.4	1.62	3.87	52.8	1.42	4.40
×66	55.3	1.19	4.61	61.5	1.07	5.13	46.3	1.43	3.86	52.5	1.26	4.38
S18×70	50.9	1.38	4.24	57.2	1.22	4.77	42.3	1.65	3.53	48.5	1.44	4.04
×54.7	50.7	1.08	4.23	56.7	0.965	4.73	42.0	1.30	3.50	48.0	1.14	4.00
S15×50	43.6	1.15	3.63	49.2	1.02	4.10	35.6	1.40	2.97	41.3	1.21	3.44
×42.9	43.4	0.988	3.62	48.9	0.877	4.08	35.5	1.21	2.96	41.0	1.05	3.42
S12×50	36.9	1.36	3.08	42.4	1.18	3.53	29.5	1.69	2.46	35.0	1.43	2.92
×40.8	36.6	1.11	3.05	41.9	0.974	3.49	29.3	1.39	2.44	34.5	1.18	2.88
S12×35	36.4	0.962	3.03	41.5	0.843	3.46	29.1	1.20	2.43	34.2	1.02	2.85
×31.8	36.3	0.876	3.03	41.3	0.770	3.44	29.0	1.10	2.42	34.0	0.935	2.83
S10×35	31.7	1.10	2.64	36.7	0.954	3.06	24.9	1.41	2.08	29.9	1.17	2.49
×25.4	31.5	0.806	2.63	36.1	0.704	3.01	24.7	1.03	2.06	29.3	0.867	2.44
S8×23	26.0	0.885	2.17	30.1	0.764	2.51	20.2	1.14	1.68	24.3	0.947	2.03
×18.4	25.8	0.713	2.15	29.8	0.617	2.48	20.0	0.920	1.67	24.0	0.767	2.00
S6×17.25	20.4	0.846	1.70	24.0	0.719	2.00	15.6	1.11	1.30	19.1	0.903	1.59
×12.5	20.2	0.619	1.68	23.5	0.532	1.96	15.3	0.817	1.28	18.7	0.668	1.56
S5×10	17.3	0.578	1.44	20.3	0.493	1.69	13.0	0.769	1.08	16.0	0.625	1.33
S4×9.5	14.5	0.655	1.21	17.3	0.549	1.44	10.8	0.880	0.900	13.6	0.699	1.13
×7.7	14.4	0.535	1.20	17.1	0.450	1.43	10.7	0.720	0.892	13.3	0.579	1.11
S3×7.5	11.8	0.636	0.983	14.3	0.524	1.19	8.51	0.881	0.709	11.0	0.682	0.917
×5.7	11.6	0.491	0.967	14.0	0.407	1.17	8.33	0.684	0.694	10.7	0.533	0.892

Case A: Shape perimeter, minus one flange surface.
Case B: Shape perimeter.
Case C: Box perimeter, minus one flange surface.
Case D: Box perimeter.

Table 1-39.
HP-Shapes
Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B			Case C			Case D		
	Perimeter	*W/D* Ratio	Surf. Area	Perimeter	*W/D* Ratio	Surf. Area	Perimeter	*W/D* Ratio	Surf. Area	Perimeter	*W/D* Ratio	Surf. Area
	in.		ft^2/ft	in.		ft^2/ft	in.		ft^2/ft	in.		ft^2/ft
HP14×117	70.5	1.66	5.88	85.4	1.37	7.12	43.3	2.70	3.61	58.2	2.01	4.85
×102	69.9	1.46	5.83	84.7	1.20	7.06	42.8	2.38	3.57	57.6	1.77	4.80
×89	69.7	1.28	5.81	84.4	1.05	7.03	42.3	2.10	3.53	57.0	1.56	4.75
×73	69.1	1.06	5.76	83.7	0.872	6.98	41.8	1.75	3.48	56.4	1.29	4.70
HP12×84	59.0	1.42	4.92	71.3	1.18	5.94	36.9	2.28	3.08	49.2	1.71	4.10
×74	58.7	1.26	4.89	70.9	1.04	5.91	36.4	2.03	3.03	48.6	1.52	4.05
×63	58.5	1.08	4.88	70.6	0.892	5.88	35.9	1.75	2.99	48.0	1.31	4.00
×53	57.6	0.920	4.80	69.6	0.761	5.80	35.6	1.49	2.97	47.6	1.11	3.97
HP10×57	48.4	1.18	4.03	58.6	0.973	4.88	30.2	1.89	2.52	40.4	1.41	3.37
×42	48.2	0.871	4.02	58.3	0.720	4.86	29.5	1.42	2.46	39.6	1.06	3.30
HP8×36	38.5	0.935	3.21	46.7	0.771	3.89	24.2	1.49	2.02	32.3	1.11	2.69

Case A: Shape perimeter, minus one flange surface.
Case B: Shape perimeter.
Case C: Box perimeter, minus one flange surface.
Case D: Box perimeter.

Table 1-40.
C-Shapes (American Standard Channels)
Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B			Case C			Case D		
	Peri-meter	*W*/*D* Ratio	Surf. Area	Peri-meter	*W*/*D* Ratio	Surf. Area	Peri-meter	*W*/*D* Ratio	Surf. Area	Peri-meter	*W*/*D* Ratio	Surf. Area
	in.		ft^2/ft	in.		ft^2/ft	in.		ft^2/ft	in.		ft^2/ft
C15×50	39.7	1.26	3.31	43.4	1.15	3.62	33.7	1.48	2.81	37.4	1.34	3.12
×40	39.2	1.02	3.27	42.7	0.937	3.56	33.5	1.19	2.79	37.0	1.08	3.08
×33.9	38.8	0.874	3.23	42.2	0.803	3.52	33.4	1.01	2.78	36.8	0.921	3.07
C12×30	32.3	0.929	2.69	35.5	0.845	2.96	27.2	1.10	2.27	30.3	0.990	2.53
×25	32.0	0.781	2.67	35.0	0.714	2.92	27.1	0.923	2.26	30.1	0.831	2.51
×20.7	31.7	0.653	2.64	34.6	0.598	2.88	26.9	0.770	2.24	29.9	0.692	2.49
C10×30	28.0	1.07	2.33	31.0	0.968	2.58	23.0	1.30	1.92	26.1	1.15	2.18
×25	27.6	0.906	2.30	30.5	0.820	2.54	22.9	1.09	1.91	25.8	0.969	2.15
×20	27.2	0.735	2.27	29.9	0.669	2.49	22.7	0.881	1.89	25.5	0.784	2.13
×15.3	26.8	0.571	2.23	29.4	0.520	2.45	22.6	0.677	1.88	25.2	0.607	2.10
C9×20	24.9	0.803	2.08	27.6	0.725	2.30	20.7	0.966	1.73	23.3	0.858	1.94
×15	24.5	0.612	2.04	27.0	0.556	2.25	20.5	0.732	1.71	23.0	0.652	1.92
×13.4	24.3	0.551	2.03	26.7	0.502	2.23	20.4	0.657	1.70	22.9	0.585	1.91
C8×18.75	22.6	0.830	1.88	25.1	0.747	2.09	18.5	1.01	1.54	21.1	0.889	1.76
×13.75	22.1	0.622	1.84	24.4	0.564	2.03	18.3	0.751	1.53	20.7	0.664	1.73
×11.5	21.9	0.525	1.83	24.1	0.477	2.01	18.3	0.628	1.53	20.5	0.561	1.71
C7×14.75	20.0	0.738	1.67	22.3	0.661	1.86	16.3	0.905	1.36	18.6	0.793	1.55
×12.25	19.7	0.622	1.64	21.9	0.559	1.83	16.2	0.756	1.35	18.4	0.666	1.53
×9.8	19.4	0.505	1.62	21.5	0.456	1.79	16.1	0.609	1.34	18.2	0.538	1.52
C6×13	17.6	0.739	1.47	19.8	0.657	1.65	14.2	0.915	1.18	16.3	0.798	1.36
×10.5	17.3	0.607	1.44	19.3	0.544	1.61	14.0	0.750	1.17	16.1	0.652	1.34
×8.2	17.0	0.482	1.42	18.9	0.434	1.58	13.9	0.590	1.16	15.8	0.519	1.32
C5×9	14.9	0.604	1.24	16.8	0.536	1.40	11.9	0.756	0.992	13.8	0.652	1.15
×6.7	14.5	0.462	1.21	16.3	0.411	1.36	11.8	0.568	0.983	13.5	0.496	1.13
C4×7.25	12.4	0.585	1.03	14.2	0.511	1.18	9.72	0.746	0.810	11.4	0.636	0.950
×5.4	12.1	0.446	1.01	13.6	0.397	1.13	9.58	0.564	0.798	11.2	0.482	0.933
×4.5	12.1	0.372	1.01	13.6	0.331	1.13	9.58	0.470	0.798	11.2	0.402	0.933
C3×6	10.1	0.594	0.842	11.7	0.513	0.975	7.60	0.789	0.633	9.20	0.652	0.767
×5	9.86	0.507	0.822	11.4	0.439	0.950	7.50	0.667	0.625	9.00	0.556	0.750
×4.1	9.61	0.427	0.801	11.0	0.373	0.917	7.41	0.553	0.618	8.82	0.465	0.735
×3.5	9.50	0.368	0.792	10.9	0.321	0.908	7.37	0.475	0.614	8.74	0.400	0.728

Case A: Shape perimeter, minus one flange surface.
Case B: Shape perimeter.
Case C: Box perimeter, minus one flange surface.
Case D: Box perimeter.

Table 1-41.
MC-Shapes (Miscellaneous Channels)
Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B			Case C			Case D		
	Perimeter	W/D Ratio	Surf. Area	Perimeter	W/D Ratio	Surf. Area	Perimeter	W/D Ratio	Surf. Area	Perimeter	W/D Ratio	Surf. Area
	in.		ft²/ft	in.		ft²/ft	in.		ft²/ft	in.		ft²/ft
MC18×58	47.0	1.23	3.92	51.2	1.13	4.27	40.2	1.44	3.35	44.4	1.31	3.70
×51.9	46.7	1.11	3.89	50.8	1.02	4.23	40.1	1.29	3.34	44.2	1.17	3.68
×45.8	46.5	0.985	3.88	50.5	0.907	4.21	40.0	1.15	3.33	44.0	1.04	3.67
×42.7	46.3	0.922	3.86	50.3	0.849	4.19	40.0	1.07	3.33	43.9	0.973	3.66
MC13×50	37.6	1.33	3.13	42.0	1.19	3.50	30.4	1.64	2.53	34.8	1.44	2.90
×40	37.0	1.08	3.08	41.1	0.973	3.43	30.2	1.32	2.52	34.4	1.16	2.87
×35	36.7	0.954	3.06	40.7	0.860	3.39	30.1	1.16	2.51	34.1	1.03	2.84
×31.8	36.5	0.871	3.04	40.5	0.785	3.38	30.0	1.06	2.50	34.0	0.935	2.83
MC12×50	35.0	1.43	2.92	39.1	1.28	3.26	28.1	1.78	2.34	32.3	1.55	2.69
×45	34.6	1.30	2.88	38.6	1.17	3.22	28.0	1.61	2.33	32.0	1.41	2.67
×40	34.3	1.17	2.86	38.2	1.05	3.18	27.9	1.43	2.33	31.8	1.26	2.65
×35	34.0	1.03	2.83	37.7	0.928	3.14	27.8	1.26	2.32	31.5	1.11	2.63
×31	33.7	0.920	2.81	37.4	0.829	3.12	27.7	1.12	2.31	31.3	0.990	2.61
MC12×10.6	27.8	0.381	2.32	29.3	0.362	2.44	25.5	0.416	2.13	27.0	0.393	2.25
MC10×41.1	31.4	1.31	2.62	35.7	1.15	2.98	24.3	1.69	2.03	28.6	1.44	2.38
×33.6	30.8	1.09	2.57	34.9	0.963	2.91	24.1	1.39	2.01	28.2	1.19	2.35
×28.5	30.4	0.938	2.53	34.3	0.831	2.86	24.0	1.19	2.00	27.9	1.02	2.33
MC10×25	28.9	0.865	2.41	32.3	0.774	2.69	23.4	1.07	1.95	26.8	0.933	2.23
×22	28.7	0.767	2.39	32.0	0.688	2.67	23.3	0.944	1.94	26.6	0.827	2.22
MC10×8.4	23.8	0.353	1.98	25.3	0.332	2.11	21.5	0.391	1.79	23.0	0.365	1.92
MC9×25.4	27.2	0.934	2.27	30.7	0.827	2.56	21.5	1.18	1.79	25.0	1.02	2.08
×23.9	27.0	0.885	2.25	30.5	0.784	2.54	21.5	1.11	1.79	24.9	0.960	2.08
MC8×22.8	25.2	0.905	2.10	28.7	0.794	2.39	19.5	1.17	1.63	23.0	0.991	1.92
×21.4	25.1	0.853	2.09	28.5	0.751	2.38	19.5	1.10	1.63	22.9	0.934	1.91
MC8×20	23.9	0.837	1.99	27.0	0.741	2.25	19.0	1.05	1.58	22.1	0.905	1.84
×18.7	23.8	0.786	1.98	26.8	0.698	2.23	19.0	0.984	1.58	22.0	0.850	1.83
MC8×8.5	20.8	0.409	1.73	22.7	0.374	1.89	17.9	0.475	1.49	19.7	0.431	1.64
MC7×22.7	23.5	0.966	1.96	27.1	0.838	2.26	17.6	1.29	1.47	21.2	1.07	1.77
×19.1	23.1	0.827	1.93	26.5	0.721	2.21	17.5	1.09	1.46	20.9	0.914	1.74
MC6×18	21.2	0.849	1.77	24.7	0.729	2.06	15.5	1.16	1.29	19.0	0.947	1.58
×15.3	21.3	0.718	1.78	24.8	0.617	2.07	15.5	0.987	1.29	19.0	0.805	1.58
MC6×16.3	19.9	0.819	1.66	22.9	0.712	1.91	15.0	1.09	1.25	18.0	0.906	1.50
×15.1	19.7	0.766	1.64	22.6	0.668	1.88	14.9	1.01	1.24	17.9	0.844	1.49
MC6×12	18.6	0.645	1.55	21.1	0.569	1.76	14.5	0.828	1.21	17.0	0.706	1.42

Case A: Shape perimeter, minus one flange surface.
Case B: Shape perimeter.
Case C: Box perimeter, minus one flange surface.
Case D: Box perimeter.

Table 1-42. Angles
Surface Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A-1			Case A-2			Case B		
	Perimeter in.	*W/D* Ratio	Surf. Area ft^2/ft	Perimeter in.	*W/D* Ratio	Surf. Area ft^2/ft	Perimeter in.	*W/D* Ratio	Surf. Area ft^2/ft
L8×8×1 1/8	23.7	2.41	1.98	23.7	2.41	1.98	31.7	1.80	2.64
×1	23.7	2.16	1.98	23.7	2.16	1.98	31.7	1.62	2.64
×7/8	23.7	1.91	1.98	23.7	1.91	1.98	31.7	1.43	2.64
×3/4	23.7	1.65	1.98	23.7	1.65	1.98	31.7	1.24	2.64
×5/8	23.7	1.39	1.98	23.7	1.39	1.98	31.7	1.04	2.64
×9/16	23.7	1.26	1.98	23.7	1.26	1.98	31.7	0.94	2.64
×1/2	23.7	1.13	1.98	23.7	1.13	1.98	31.7	0.842	2.64
L8×6×1	21.8	2.04	1.82	19.8	2.24	1.65	27.8	1.60	2.32
×7/8	21.8	1.80	1.82	19.8	1.98	1.65	27.8	1.41	2.32
×3/4	21.8	1.56	1.82	19.8	1.72	1.65	27.8	1.22	2.32
×5/8	21.8	1.31	1.82	19.8	1.44	1.65	27.8	1.03	2.32
×9/16	21.8	1.19	1.82	19.8	1.31	1.65	27.8	0.932	2.32
×1/2	21.8	1.06	1.82	19.8	1.17	1.65	27.8	0.835	2.32
×7/16	21.8	0.936	1.82	19.8	1.03	1.65	27.8	0.734	2.32
L8×4×1	19.8	1.90	1.65	15.8	2.38	1.32	23.8	1.58	1.98
×7/8	19.8	1.68	1.65	15.8	2.11	1.32	23.8	1.40	1.98
×3/4	19.8	1.46	1.65	15.8	1.83	1.32	23.8	1.21	1.98
×5/8	19.8	1.23	1.65	15.8	1.54	1.32	23.8	1.03	1.98
×9/16	19.8	1.12	1.65	15.8	1.40	1.32	23.8	0.929	1.98
×1/2	19.8	0.995	1.65	15.8	1.25	1.32	23.8	0.828	1.98
×7/16	19.8	0.879	1.65	15.8	1.10	1.32	23.8	0.731	1.98
L7×4×3/4	17.8	1.47	1.48	14.8	1.77	1.23	21.8	1.20	1.82
×5/8	17.8	1.24	1.48	14.8	1.49	1.23	21.8	1.01	1.82
×1/2	17.8	1.01	1.48	14.8	1.21	1.23	21.8	0.821	1.82
×7/16	17.8	0.888	1.48	14.8	1.07	1.23	21.8	0.725	1.82
×3/8	17.8	0.764	1.48	14.8	0.919	1.23	21.8	0.624	1.82
L6×6×1	17.8	2.11	1.48	17.8	2.11	1.48	23.8	1.58	1.98
×7/8	17.8	1.87	1.48	17.8	1.87	1.48	23.8	1.39	1.98
×3/4	17.8	1.62	1.48	17.8	1.62	1.48	23.8	1.21	1.98
×5/8	17.8	1.37	1.48	17.8	1.37	1.48	23.8	1.02	1.98
×9/16	17.8	1.24	1.48	17.8	1.24	1.48	23.8	0.924	1.98
×1/2	17.8	1.10	1.48	17.8	1.10	1.48	23.8	0.824	1.98
×7/16	17.8	0.972	1.48	17.8	0.972	1.48	23.8	0.727	1.98
×3/8	17.8	0.837	1.48	17.8	0.837	1.48	23.8	0.626	1.98
×5/16	17.8	0.702	1.48	17.8	0.702	1.48	23.8	0.525	1.98
L6×4×7/8	15.8	1.72	1.32	13.8	1.96	1.15	19.8	1.37	1.65
×3/4	15.8	1.49	1.32	13.8	1.70	1.15	19.8	1.19	1.65
×5/8	15.8	1.25	1.32	13.8	1.43	1.15	19.8	1.00	1.65
×9/16	15.8	1.13	1.32	13.8	1.30	1.15	19.8	0.904	1.65
×1/2	15.8	1.01	1.32	13.8	1.16	1.15	19.8	0.808	1.65
×7/16	15.8	0.892	1.32	13.8	1.02	1.15	19.8	0.712	1.65
×3/8	15.8	0.772	1.32	13.8	0.884	1.15	19.8	0.616	1.65
×5/16	15.8	0.646	1.32	13.8	0.739	1.15	19.8	0.515	1.65
L6×3 1/2×1/2	15.3	1.00	1.28	12.8	1.20	1.07	18.8	0.814	1.57
×3/8	15.3	0.758	1.28	12.8	0.906	1.07	18.8	0.617	1.57
×5/16	15.3	0.635	1.28	12.8	0.759	1.07	18.8	0.517	1.57
L5×5×7/8	14.8	1.84	1.23	14.8	1.84	1.23	19.8	1.38	1.65
×3/4	14.8	1.60	1.23	14.8	1.60	1.23	19.8	1.20	1.65
×5/8	14.8	1.36	1.23	14.8	1.36	1.23	19.8	1.02	1.65
×1/2	14.8	1.10	1.23	14.8	1.10	1.23	19.8	0.823	1.65
×7/16	14.8	0.973	1.23	14.8	0.973	1.23	19.8	0.727	1.65
×3/8	14.8	0.838	1.23	14.8	0.838	1.23	19.8	0.626	1.65
×5/16	14.8	0.703	1.23	14.8	0.703	1.23	19.8	0.525	1.65

Case A-1: Shape perimeter, minus short leg surface.
Case A-2: Shape perimeter, minus long leg surface.
Case B: Shape perimeter.

Table 1-42 (cont.). Angles
Surface Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A-1			Case A-2			Case B		
	Perimeter	*W/D* Ratio	Surf. Area	Perimeter	*W/D* Ratio	Surf. Area	Perimeter	*W/D* Ratio	Surf. Area
	in.		ft^2/ft	in.		ft^2/ft	in.		ft^2/ft
L5×3$^1/_2$×$^3/_4$	13.3	1.49	1.11	11.8	1.68	0.98	16.8	1.18	1.400
×$^5/_8$	13.3	1.26	1.11	11.8	1.42	0.98	16.8	1.00	1.400
×$^1/_2$	13.3	1.02	1.11	11.8	1.15	0.98	16.8	0.810	1.400
×$^3/_8$	13.3	0.782	1.11	11.8	0.881	0.98	16.8	0.619	1.400
×$^5/_{16}$	13.3	0.656	1.11	11.8	0.739	0.98	16.8	0.519	1.400
×$^1/_4$	13.3	0.529	1.11	11.8	0.596	0.98	16.8	0.418	1.400
L5×3×$^1/_2$	12.8	1.00	1.07	10.8	1.19	0.90	15.8	0.810	1.320
×$^7/_{16}$	12.8	0.883	1.07	10.8	1.05	0.90	15.8	0.715	1.320
×$^3/_8$	12.8	0.761	1.07	10.8	0.902	0.90	15.8	0.616	1.320
×$^5/_{16}$	12.8	0.640	1.07	10.8	0.758	0.90	15.8	0.518	1.320
×$^1/_4$	12.8	0.516	1.07	10.8	0.611	0.90	15.8	0.418	1.320
L4×4×$^3/_4$	11.8	1.57	0.98	11.8	1.57	0.983	15.8	1.17	1.320
×$^5/_8$	11.8	1.33	0.98	11.8	1.33	0.983	15.8	0.994	1.320
×$^1/_2$	11.8	1.08	0.98	11.8	1.08	0.983	15.8	0.804	1.320
×$^7/_{16}$	11.8	0.949	0.98	11.8	0.949	0.983	15.8	0.709	1.320
×$^3/_8$	11.8	0.824	0.98	11.8	0.824	0.983	15.8	0.615	1.320
×$^5/_{16}$	11.8	0.692	0.98	11.8	0.692	0.983	15.8	0.516	1.320
×$^1/_4$	11.8	0.558	0.98	11.8	0.558	0.983	15.8	0.416	1.320
L4×3$^1/_2$×$^1/_2$	11.5	1.03	0.96	11.0	1.08	0.917	15.0	0.793	1.250
×$^3/_8$	11.5	0.791	0.96	11.0	0.827	0.917	15.0	0.607	1.250
×$^5/_{16}$	11.5	0.665	0.96	11.0	0.695	0.917	15.0	0.510	1.250
×$^1/_4$	11.5	0.537	0.96	11.0	0.562	0.917	15.0	0.412	1.250
L4×3×$^5/_8$	11.0	1.24	0.92	10.0	1.36	0.833	14.0	0.971	1.170
×$^1/_2$	11.0	1.01	0.92	10.0	1.11	0.833	14.0	0.793	1.170
×$^3/_8$	11.0	0.770	0.92	10.0	0.847	0.833	14.0	0.605	1.170
×$^5/_{16}$	11.0	0.647	0.92	10.0	0.712	0.833	14.0	0.509	1.170
×$^1/_4$	11.0	0.523	0.92	10.0	0.575	0.833	14.0	0.411	1.170
L3$^1/_2$×3$^1/_2$×$^1/_2$	10.3	1.08	0.86	10.3	1.08	0.858	13.8	0.80	1.150
×$^7/_{16}$	10.3	0.953	0.86	10.3	0.953	0.858	13.8	0.712	1.150
×$^3/_8$	10.3	0.826	0.86	10.3	0.826	0.858	13.8	0.617	1.150
×$^5/_{16}$	10.3	0.695	0.86	10.3	0.695	0.858	13.8	0.519	1.150
×$^1/_4$	10.3	0.562	0.86	10.3	0.562	0.858	13.8	0.420	1.150
L3$^1/_2$×3×$^1/_2$	9.84	1.05	0.82	9.34	1.10	0.778	12.8	0.805	1.070
×$^7/_{16}$	9.84	0.924	0.82	9.34	0.973	0.778	12.8	0.710	1.070
×$^3/_8$	9.84	0.801	0.82	9.34	0.844	0.778	12.8	0.616	1.070
×$^5/_{16}$	9.84	0.676	0.82	9.34	0.712	0.778	12.8	0.520	1.070
×$^1/_4$	9.84	0.547	0.82	9.34	0.576	0.778	12.8	0.420	1.070
L3$^1/_2$×2$^1/_2$×$^1/_2$	9.34	1.01	0.778	8.34	1.13	0.695	11.8	0.80	0.983
×$^3/_8$	9.34	0.774	0.778	8.34	0.867	0.695	11.8	0.613	0.983
×$^5/_{16}$	9.34	0.653	0.778	8.34	0.731	0.695	11.8	0.517	0.983
×$^1/_4$	9.34	0.529	0.778	8.34	0.592	0.695	11.8	0.419	0.983
L3×3×$^1/_2$	8.84	1.06	0.737	8.84	1.06	0.737	11.8	0.79	0.983
×$^7/_{16}$	8.84	0.937	0.737	8.84	0.937	0.737	11.8	0.702	0.983
×$^3/_8$	8.84	0.811	0.737	8.84	0.811	0.737	11.8	0.608	0.983
×$^5/_{16}$	8.84	0.683	0.737	8.84	0.683	0.737	11.8	0.512	0.983
×$^1/_4$	8.84	0.553	0.737	8.84	0.553	0.737	11.8	0.414	0.983
×$^3/_{16}$	8.84	0.419	0.737	8.84	0.419	0.737	11.8	0.314	0.983
L3×2$^1/_2$×$^1/_2$	8.34	1.02	0.695	7.84	1.09	0.653	10.8	0.79	0.900
×$^7/_{16}$	8.34	0.906	0.695	7.84	0.964	0.653	10.8	0.700	0.900
×$^3/_8$	8.34	0.787	0.695	7.84	0.837	0.653	10.8	0.607	0.900
×$^5/_{16}$	8.34	0.664	0.695	7.84	0.707	0.653	10.8	0.513	0.900
×$^1/_4$	8.34	0.538	0.695	7.84	0.573	0.653	10.8	0.416	0.900
×$^3/_{16}$	8.34	0.409	0.695	7.84	0.435	0.653	10.8	0.316	0.900

Case A-1: Shape perimeter, minus short leg surface.
Case A-2: Shape perimeter, minus long leg surface.
Case B: Shape perimeter.

Table 1-42 (cont.).
Angles
Surface Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A-1			Case A-2			Case B		
	Perimeter in.	*W/D* Ratio	Surf. Area ft²/ft	Perimeter in.	*W/D* Ratio	Surf. Area ft²/ft	Perimeter in.	*W/D* Ratio	Surf. Area ft²/ft
L3×2×1/2	7.87	0.978	0.656	6.87	1.12	0.573	9.87	0.78	0.823
×3/8	7.87	0.756	0.656	6.87	0.866	0.573	9.87	0.603	0.823
×5/16	7.87	0.639	0.656	6.87	0.732	0.573	9.87	0.510	0.823
×1/4	7.87	0.520	0.656	6.87	0.595	0.573	9.87	0.414	0.823
×3/16	7.87	0.396	0.656	6.87	0.454	0.573	9.87	0.316	0.823
L2 1/2×2 1/2×1/2	7.39	1.04	0.616	7.39	1.04	0.616	9.89	0.77	0.824
×3/8	7.39	0.798	0.616	7.39	0.798	0.616	9.89	0.597	0.824
×5/16	7.39	0.674	0.616	7.39	0.674	0.616	9.89	0.504	0.824
×1/4	7.39	0.547	0.616	7.39	0.547	0.616	9.89	0.408	0.824
×3/16	7.39	0.414	0.616	7.39	0.414	0.616	9.89	0.309	0.824
L2 1/2×2×3/8	6.89	0.769	0.574	6.39	0.829	0.533	8.89	0.596	0.741
×5/16	6.89	0.652	0.574	6.39	0.703	0.533	8.89	0.505	0.741
×1/4	6.89	0.530	0.574	6.39	0.571	0.533	8.89	0.411	0.741
×3/16	6.89	0.403	0.574	6.39	0.435	0.533	8.89	0.313	0.741
L2×2×3/8	5.89	0.789	0.491	5.89	0.789	0.491	7.89	0.589	0.658
×5/16	5.89	0.669	0.491	5.89	0.669	0.491	7.89	0.499	0.658
×1/4	5.89	0.545	0.491	5.89	0.545	0.491	7.89	0.407	0.658
×3/16	5.89	0.418	0.491	5.89	0.418	0.491	7.89	0.312	0.658
×1/8	5.89	0.284	0.491	5.89	0.284	0.491	7.89	0.212	0.658

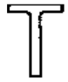
Case A-1: Shape perimeter, minus short leg surface.
Case A-2: Shape perimeter, minus long leg surface.
Case B: Shape perimeter.

Table 1-43.
WT-Shapes
Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B			Case C			Case D		
	Perimeter, in.	W/D Ratio	Surf. Area, ft^2/ft	Perimeter, in.	W/D Ratio	Surf. Area, ft^2/ft	Perimeter, in.	W/D Ratio	Surf. Area, ft^2/ft	Perimeter, in.	W/D Ratio	Surf. Area, ft^2/ft
WT22×167.5	59.3	2.82	4.94	75.3	2.22	6.28	60.0	2.79	5.00	76.0	2.20	6.33
×145	58.7	2.47	4.89	74.5	1.95	6.21	59.4	2.44	4.95	75.2	1.93	6.27
×131	58.5	2.24	4.88	74.3	1.76	6.19	59.2	2.21	4.93	75.0	1.75	6.25
×115	58.1	1.98	4.84	73.9	1.56	6.16	58.8	1.96	4.90	74.6	1.54	6.22
WT20×296.5	58.6	5.06	4.88	75.3	3.94	6.28	59.7	4.97	4.98	76.4	3.88	6.37
×251.5	57.3	4.39	4.78	73.7	3.41	6.14	58.4	4.31	4.87	74.8	3.36	6.23
×215.5	56.3	3.83	4.69	72.5	2.97	6.04	57.4	3.75	4.78	73.6	2.93	6.13
×198.5	56.0	3.54	4.67	72.1	2.75	6.01	57.1	3.48	4.76	73.2	2.71	6.10
×186	55.6	3.35	4.63	71.7	2.59	5.98	56.7	3.28	4.73	72.8	2.55	6.07
×181	55.5	3.26	4.63	71.5	2.53	5.96	56.6	3.20	4.72	72.6	2.49	6.05
×162	55.0	2.95	4.58	70.9	2.28	5.91	56.1	2.89	4.68	72.0	2.25	6.00
×148.5	54.5	2.72	4.54	70.3	2.11	5.86	55.6	2.67	4.63	71.4	2.08	5.95
×138.5	54.3	2.55	4.53	70.1	1.98	5.84	55.4	2.50	4.62	71.2	1.95	5.93
×124.5	54.1	2.30	4.51	69.9	1.78	5.83	55.2	2.26	4.60	71.0	1.75	5.92
×107.5	53.7	2.00	4.48	69.5	1.55	5.79	54.8	1.96	4.57	70.6	1.52	5.88
×99.5	53.3	1.87	4.44	69.1	1.44	5.76	54.4	1.83	4.53	70.2	1.42	5.85
WT20×196	52.9	3.71	4.41	65.3	3.00	5.44	54.0	3.63	4.50	66.4	2.95	5.53
×165.5	51.9	3.19	4.33	64.1	2.58	5.34	53.0	3.12	4.42	65.2	2.54	5.43
×163.5	51.8	3.16	4.32	63.9	2.56	5.33	52.9	3.09	4.41	65.0	2.52	5.42
×139	51.1	2.72	4.26	63.1	2.20	5.26	52.2	2.66	4.35	64.2	2.17	5.35
×132	50.8	2.60	4.23	62.7	2.11	5.23	51.9	2.54	4.33	63.8	2.07	5.32
×117.5	50.4	2.33	4.20	62.3	1.89	5.19	51.5	2.28	4.29	63.4	1.85	5.28
×105.5	50.1	2.11	4.18	61.9	1.70	5.16	51.2	2.06	4.27	63.0	1.67	5.25
×91.5	49.7	1.84	4.14	61.5	1.49	5.13	50.8	1.80	4.23	62.6	1.46	5.22
×83.5	49.3	1.69	4.11	61.1	1.37	5.09	50.4	1.66	4.20	62.2	1.34	5.18
×74.5	48.9	1.52	4.08	60.7	1.23	5.06	50.0	1.49	4.17	61.8	1.21	5.15
WT18×399	58.9	6.77	4.91	76.9	5.19	6.41	60.0	6.65	5.00	78.0	5.12	6.50
×325	56.9	5.71	4.74	74.5	4.36	6.21	58.0	5.60	4.83	75.6	4.30	6.30
×263.5	55.3	4.76	4.61	72.5	3.63	6.04	56.4	4.67	4.70	73.6	3.58	6.13
×219.5	54.1	4.06	4.51	71.1	3.09	5.93	55.2	3.98	4.60	72.2	3.04	6.02
×196.5	53.5	3.67	4.46	70.3	2.80	5.86	54.6	3.60	4.55	71.4	2.75	5.95
×179.5	53.0	3.39	4.42	69.7	2.58	5.81	54.1	3.32	4.51	70.8	2.54	5.90
×164	52.5	3.12	4.38	69.1	2.37	5.76	53.6	3.06	4.47	70.2	2.34	5.85
×150	52.4	2.86	4.37	69.1	2.17	5.76	53.5	2.80	4.46	70.2	2.14	5.85
×140	52.1	2.69	4.34	68.7	2.04	5.73	53.2	2.63	4.43	69.8	2.01	5.82
×130	51.7	2.51	4.31	68.3	1.90	5.69	52.8	2.46	4.40	69.4	1.87	5.78
×122.5	51.4	2.38	4.28	67.9	1.80	5.66	52.5	2.33	4.38	69.0	1.78	5.75
×115	51.4	2.24	4.28	67.9	1.69	5.66	52.5	2.19	4.38	69.0	1.67	5.75
WT18×128	48.8	2.62	4.07	61.0	2.10	5.08	49.6	2.58	4.13	61.8	2.07	5.15
×116	48.6	2.39	4.05	60.7	1.91	5.06	49.3	2.35	4.11	61.4	1.89	5.12
×105	48.0	2.19	4.00	60.2	1.74	5.02	48.8	2.15	4.07	61.0	1.72	5.08
×97	47.7	2.03	3.98	59.8	1.62	4.98	48.5	2.00	4.04	60.6	1.60	5.05
×91	47.7	1.91	3.98	59.8	1.52	4.98	48.5	1.88	4.04	60.6	1.50	5.05
×85	47.4	1.79	3.95	59.4	1.43	4.95	48.2	1.76	4.02	60.2	1.41	5.02
×80	47.2	1.69	3.93	59.2	1.35	4.93	48.0	1.67	4.00	60.0	1.33	5.00
×75	47.0	1.60	3.92	59.0	1.27	4.92	47.8	1.57	3.98	59.8	1.25	4.98
×67.5	46.8	1.44	3.90	58.8	1.15	4.90	47.6	1.42	3.97	59.6	1.13	4.97
WT16.5×193.5	51.4	3.76	4.28	67.6	2.86	5.63	52.2	3.71	4.35	68.4	2.83	5.70
×177	51.0	3.47	4.25	67.1	2.64	5.59	51.7	3.42	4.31	67.8	2.61	5.65
×159	50.5	3.15	4.21	66.5	2.39	5.54	51.2	3.11	4.27	67.2	2.37	5.60
×145.5	49.9	2.92	4.16	65.8	2.21	5.48	50.7	2.87	4.23	66.6	2.18	5.55
×131.5	49.7	2.65	4.14	65.5	2.01	5.46	50.4	2.61	4.20	66.2	1.99	5.52
×120.5	49.4	2.44	4.12	65.3	1.85	5.44	50.1	2.41	4.18	66.0	1.83	5.50
×110.5	49.1	2.25	4.09	64.9	1.70	5.41	49.8	2.22	4.15	65.6	1.68	5.47
×100.5	48.6	2.07	4.05	64.3	1.56	5.36	49.3	2.04	4.11	65.0	1.55	5.42

Case A: Shape perimeter, minus one flange surface.
Case B: Shape perimeter.
Case C: Box perimeter, minus one flange surface.
Case D: Box perimeter.

Table 1-43 (cont.). WT-Shapes Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A 			Case B 			Case C 			Case D 		
	Perimeter	W/D Ratio	Surf. Area	Perimeter	W/D Ratio	Surf. Area	Perimeter	W/D Ratio	Surf. Area	Perimeter	W/D Ratio	Surf. Area
	in.		ft²/ft	in.		ft²/ft	in.		ft²/ft	in.		ft²/ft
WT16.5×84.5	44.5	1.90	3.71	56.0	1.51	4.67	45.3	1.87	3.78	56.8	1.49	4.73
×76	44.2	1.72	3.68	55.8	1.36	4.65	45.0	1.69	3.75	56.6	1.34	4.72
×70.5	44.2	1.60	3.68	55.7	1.27	4.64	44.9	1.57	3.74	56.4	1.25	4.70
×65	43.7	1.49	3.64	55.2	1.18	4.60	44.5	1.46	3.71	56.0	1.16	4.67
×59	43.5	1.36	3.63	55.0	1.07	4.58	44.3	1.33	3.69	55.8	1.06	4.65
WT15×195.5	48.0	4.07	4.00	63.6	3.07	5.30	48.8	4.01	4.07	64.4	3.04	5.37
×178.5	47.5	3.76	3.96	63.0	2.83	5.25	48.3	3.70	4.03	63.8	2.80	5.32
×163	47.0	3.47	3.92	62.4	2.61	5.20	47.8	3.41	3.98	63.2	2.58	5.27
×146	46.5	3.14	3.88	61.8	2.36	5.15	47.3	3.09	3.94	62.6	2.33	5.22
×130.5	46.0	2.84	3.83	61.2	2.13	5.10	46.8	2.79	3.90	62.0	2.10	5.17
×117.5	45.7	2.57	3.81	60.8	1.93	5.07	46.5	2.53	3.88	61.6	1.91	5.13
×105.5	45.3	2.33	3.78	60.4	1.75	5.03	46.1	2.29	3.84	61.2	1.72	5.10
×95.5	44.9	2.13	3.74	59.9	1.59	4.99	45.6	2.09	3.80	60.6	1.58	5.05
×86.5	44.6	1.94	3.72	59.6	1.45	4.97	45.4	1.91	3.78	60.4	1.43	5.03
WT15×74	40.3	1.84	3.36	50.8	1.46	4.23	41.1	1.80	3.43	51.6	1.43	4.30
×66	40.1	1.65	3.34	50.6	1.30	4.22	40.9	1.61	3.41	51.4	1.28	4.28
×62	39.9	1.55	3.33	50.4	1.23	4.20	40.7	1.52	3.39	51.2	1.21	4.27
×58	39.7	1.46	3.31	50.2	1.16	4.18	40.5	1.43	3.38	51.0	1.14	4.25
×54	39.5	1.37	3.29	50.0	1.08	4.17	40.3	1.34	3.36	50.8	1.06	4.23
×49.5	39.3	1.26	3.28	49.8	0.994	4.15	40.1	1.23	3.34	50.6	0.978	4.22
×45	39.2	1.15	3.27	49.6	0.907	4.13	40.0	1.13	3.33	50.4	0.893	4.20
WT13.5×269.5	47.1	5.72	3.93	62.4	4.32	5.20	47.9	5.63	3.99	63.2	4.26	5.27
×184	44.3	4.15	3.69	59.0	3.12	4.92	45.1	4.08	3.76	59.8	3.08	4.98
×168	43.8	3.84	3.65	58.4	2.88	4.87	44.6	3.77	3.72	59.2	2.84	4.93
×153.5	43.2	3.55	3.60	57.6	2.66	4.80	44.0	3.49	3.67	58.4	2.63	4.87
×140.5	42.8	3.28	3.57	57.2	2.46	4.77	43.6	3.22	3.63	58.0	2.42	4.83
×129	42.5	3.04	3.54	56.8	2.27	4.73	43.3	2.98	3.61	57.6	2.24	4.80
×117.5	42.0	2.80	3.50	56.2	2.09	4.68	42.8	2.75	3.57	57.0	2.06	4.75
×108.5	41.7	2.60	3.48	55.8	1.94	4.65	42.5	2.55	3.54	56.6	1.92	4.72
×97	41.4	2.34	3.45	55.4	1.75	4.62	42.2	2.30	3.52	56.2	1.73	4.68
×89	41.2	2.16	3.43	55.3	1.61	4.61	41.9	2.12	3.49	56.0	1.59	4.67
×80.5	40.8	1.97	3.40	54.8	1.47	4.57	41.6	1.94	3.47	55.6	1.45	4.63
×73	40.6	1.80	3.38	54.6	1.34	4.55	41.4	1.76	3.45	55.4	1.32	4.62
WT13.5×64.5	36.8	1.75	3.07	46.8	1.38	3.90	37.6	1.72	3.13	47.6	1.36	3.97
×57	36.5	1.56	3.04	46.6	1.22	3.88	37.3	1.53	3.11	47.4	1.20	3.95
×51	36.2	1.41	3.02	46.2	1.10	3.85	37.0	1.38	3.08	47.0	1.09	3.92
×47	36.2	1.30	3.02	46.2	1.02	3.85	37.0	1.27	3.08	47.0	1.00	3.92
×42	36.0	1.17	3.00	45.9	0.915	3.83	36.8	1.14	3.07	46.7	0.899	3.89
WT12×185	40.9	4.52	3.41	54.6	3.39	4.55	41.7	4.44	3.48	55.4	3.34	4.62
×167.5	40.3	4.16	3.36	53.8	3.11	4.48	41.1	4.08	3.43	54.6	3.07	4.55
×153	39.8	3.84	3.32	53.2	2.88	4.43	40.6	3.77	3.38	54.0	2.83	4.50
×139.5	39.3	3.55	3.28	52.6	2.65	4.38	40.1	3.48	3.34	53.4	2.61	4.45
×125	38.8	3.22	3.23	52.0	2.40	4.33	39.6	3.16	3.30	52.8	2.37	4.40
×114.5	38.3	2.99	3.19	51.4	2.23	4.28	39.1	2.93	3.26	52.2	2.19	4.35
×103.5	38.0	2.72	3.17	51.0	2.03	4.25	38.8	2.67	3.23	51.8	2.00	4.32
×96	37.6	2.55	3.13	50.6	1.90	4.22	38.4	2.50	3.20	51.4	1.87	4.28
×88	37.3	2.36	3.11	50.2	1.75	4.18	38.1	2.31	3.18	51.0	1.73	4.25
×81	37.2	2.18	3.10	50.2	1.61	4.18	38.0	2.13	3.17	51.0	1.59	4.25
×73	36.9	1.98	3.08	49.8	1.47	4.15	37.7	1.94	3.14	50.6	1.44	4.22
×65.5	36.5	1.79	3.04	49.4	1.33	4.12	37.3	1.76	3.11	50.2	1.30	4.18
×58.5	36.2	1.62	3.02	49.0	1.19	4.08	37.0	1.58	3.08	49.8	1.17	4.15
×52	36.0	1.44	3.00	48.8	1.07	4.07	36.8	1.41	3.07	49.6	1.05	4.13

Case A: Shape perimeter, minus one flange surface.
Case B: Shape perimeter.
Case C: Box perimeter, minus one flange surface.
Case D: Box perimeter.

Table 1-43 (cont.). WT-Shapes
Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B			Case C			Case D		
	Perimeter	W/D Ratio	Surf. Area	Perimeter	W/D Ratio	Surf. Area	Perimeter	W/D Ratio	Surf. Area	Perimeter	W/D Ratio	Surf. Area
	in.		ft²/ft	in.		ft²/ft	in.		ft²/ft	in.		ft²/ft
WT12×51.5	32.8	1.57	2.73	41.8	1.23	3.48	33.6	1.53	2.80	42.6	1.21	3.55
×47	32.7	1.44	2.73	41.8	1.12	3.48	33.5	1.40	2.79	42.5	1.11	3.54
×42	32.4	1.30	2.70	41.5	1.01	3.46	33.2	1.27	2.77	42.2	0.995	3.52
×38	32.2	1.18	2.68	41.2	0.922	3.43	33.0	1.15	2.75	42.0	0.905	3.50
×34	32.0	1.06	2.67	41.0	0.829	3.42	32.8	1.04	2.73	41.7	0.815	3.48
WT12×31	30.1	1.03	2.51	37.1	0.836	3.09	30.8	1.01	2.57	37.9	0.818	3.16
×27.5	29.8	0.923	2.48	36.8	0.747	3.07	30.6	0.899	2.55	37.6	0.731	3.13
WT10.5×100.5	34.9	2.88	2.91	47.5	2.12	3.96	35.6	2.82	2.97	48.2	2.09	4.02
×91	34.5	2.64	2.88	47.0	1.94	3.92	35.3	2.58	2.94	47.8	1.90	3.98
×83	34.0	2.44	2.83	46.4	1.79	3.87	34.8	2.39	2.90	47.2	1.76	3.93
×73.5	33.8	2.17	2.82	46.3	1.59	3.86	34.5	2.13	2.88	47.0	1.56	3.92
×66	33.4	1.98	2.78	45.8	1.44	3.82	34.2	1.93	2.85	46.6	1.42	3.88
×61	33.3	1.83	2.78	45.7	1.33	3.81	34.0	1.79	2.83	46.4	1.31	3.87
×55.5	33.1	1.68	2.76	45.4	1.22	3.78	33.9	1.64	2.83	46.2	1.20	3.85
×50.5	32.9	1.53	2.74	45.2	1.12	3.77	33.7	1.50	2.81	46.0	1.10	3.83
WT10.5×46.5	29.4	1.58	2.45	37.8	1.23	3.15	30.0	1.55	2.50	38.4	1.21	3.20
×41.5	29.2	1.42	2.43	37.5	1.11	3.13	29.8	1.39	2.48	38.1	1.09	3.18
×36.5	28.9	1.26	2.41	37.2	0.981	3.10	29.5	1.24	2.46	37.8	0.966	3.15
×34	28.9	1.18	2.41	37.1	0.916	3.09	29.5	1.15	2.46	37.7	0.902	3.14
×31	28.6	1.08	2.38	36.9	0.840	3.08	29.2	1.06	2.43	37.5	0.827	3.13
×27.5	28.4	0.968	2.37	36.7	0.749	3.06	29.0	0.948	2.42	37.2	0.739	3.10
×24	28.1	0.854	2.34	36.3	0.661	3.03	28.7	0.836	2.39	36.9	0.650	3.08
WT10.5×28.5	27.0	1.06	2.25	33.6	0.848	2.80	27.6	1.03	2.30	34.1	0.836	2.84
×25	26.7	0.936	2.23	33.2	0.753	2.77	27.3	0.916	2.28	33.9	0.737	2.83
×22	26.5	0.830	2.21	33.0	0.667	2.75	27.1	0.812	2.26	33.6	0.655	2.80
WT9×87.5	30.7	2.85	2.56	42.1	2.08	3.51	31.4	2.79	2.62	42.8	2.04	3.57
×79	30.2	2.62	2.52	41.5	1.90	3.46	31.0	2.55	2.58	42.3	1.87	3.53
×71.5	29.9	2.39	2.49	41.1	1.74	3.43	30.7	2.33	2.56	41.9	1.71	3.49
×65	29.7	2.19	2.48	40.9	1.59	3.41	30.5	2.13	2.54	41.7	1.56	3.48
×59.5	29.5	2.02	2.46	40.8	1.46	3.40	30.3	1.96	2.53	41.6	1.43	3.47
×53	29.2	1.82	2.43	40.4	1.31	3.37	29.9	1.77	2.49	41.1	1.29	3.43
×48.5	28.9	1.68	2.41	40.0	1.21	3.33	29.7	1.63	2.48	40.8	1.19	3.40
×43	28.8	1.49	2.40	39.9	1.08	3.33	29.5	1.46	2.46	40.6	1.06	3.38
×38	28.5	1.33	2.38	39.5	0.962	3.29	29.2	1.30	2.43	40.2	0.945	3.35
WT9×35.5	25.5	1.39	2.13	33.1	1.07	2.76	26.1	1.36	2.18	33.7	1.05	2.81
×32.5	25.4	1.28	2.12	32.9	0.988	2.74	26.0	1.25	2.17	33.5	0.970	2.79
×30	25.2	1.19	2.10	32.8	0.915	2.73	25.8	1.16	2.15	33.4	0.898	2.78
×27.5	25.1	1.10	2.09	32.6	0.844	2.72	25.7	1.07	2.14	33.2	0.828	2.77
×25	24.9	1.000	2.08	32.4	0.772	2.70	25.5	0.980	2.13	33.0	0.758	2.75
WT9×23	23.6	0.975	1.97	29.6	0.777	2.47	24.1	0.954	2.01	30.2	0.762	2.52
×20	23.4	0.855	1.95	29.4	0.680	2.45	23.9	0.837	1.99	29.9	0.669	2.49
×17.5	23.1	0.758	1.93	29.1	0.601	2.43	23.7	0.738	1.98	29.7	0.589	2.48
WT8×50	26.6	1.88	2.22	37.0	1.35	3.08	27.4	1.82	2.28	37.8	1.32	3.15
×44.5	26.4	1.69	2.20	36.8	1.21	3.07	27.2	1.64	2.27	37.6	1.18	3.13
×38.5	26.1	1.48	2.18	36.4	1.06	3.03	26.8	1.44	2.23	37.1	1.04	3.09
×33.5	25.7	1.30	2.14	35.9	0.933	2.99	26.5	1.26	2.21	36.7	0.913	3.06
WT8×28.5	23.0	1.24	1.92	30.1	0.947	2.51	23.6	1.21	1.97	30.7	0.928	2.56
×25	22.7	1.10	1.89	29.8	0.839	2.48	23.3	1.07	1.94	30.4	0.822	2.53
×22.5	22.6	0.996	1.88	29.6	0.760	2.47	23.2	0.970	1.93	30.2	0.745	2.52
×20	22.4	0.893	1.87	29.4	0.680	2.45	23.0	0.870	1.92	30.0	0.667	2.50
×18	22.3	0.807	1.86	29.2	0.616	2.43	22.9	0.786	1.91	29.8	0.604	2.48
WT8×15.5	20.8	0.745	1.73	26.4	0.587	2.20	21.4	0.724	1.78	26.9	0.576	2.24
×13	20.6	0.631	1.72	26.1	0.498	2.18	21.2	0.613	1.77	26.7	0.487	2.23

Case A: Shape perimeter, minus one flange surface.
Case B: Shape perimeter.
Case C: Box perimeter, minus one flange surface.
Case D: Box perimeter.

Table 1-43 (cont.). WT-Shapes
Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B			Case C			Case D		
	Peri-meter	W/D Ratio	Surf. Area	Peri-meter	W/D Ratio	Surf. Area	Peri-meter	W/D Ratio	Surf. Area	Peri-meter	W/D Ratio	Surf. Area
	in.		ft^2/ft	in.		ft^2/ft	in.		ft^2/ft	in.		ft^2/ft
WT7×404	40.3	10.00	3.36	58.9	6.86	4.91	41.4	9.76	3.45	60.0	6.73	5.00
×365	39.2	9.31	3.27	57.1	6.39	4.76	40.3	9.06	3.36	58.2	6.27	4.85
×332.5	38.2	8.70	3.18	55.9	5.95	4.66	39.3	8.46	3.28	57.0	5.83	4.75
×302.5	37.3	8.11	3.11	54.7	5.53	4.56	38.4	7.88	3.20	55.8	5.42	4.65
×275	36.3	7.58	3.03	53.5	5.14	4.46	37.4	7.35	3.12	54.6	5.04	4.55
×250	35.5	7.04	2.96	52.5	4.76	4.38	36.6	6.83	3.05	53.6	4.66	4.47
×227.5	34.7	6.56	2.89	51.5	4.42	4.29	35.8	6.35	2.98	52.6	4.33	4.38
×213	34.3	6.21	2.86	51.0	4.18	4.25	35.4	6.02	2.95	52.1	4.09	4.34
×199	33.8	5.89	2.82	50.4	3.95	4.20	34.9	5.70	2.91	51.5	3.86	4.29
×185	33.3	5.56	2.78	49.8	3.71	4.15	34.4	5.38	2.87	50.9	3.63	4.24
×171	32.8	5.21	2.73	49.2	3.48	4.10	33.9	5.04	2.83	50.3	3.40	4.19
×155.5	32.2	4.83	2.68	48.4	3.21	4.03	33.3	4.67	2.78	49.5	3.14	4.13
×141.5	31.7	4.46	2.64	47.8	2.96	3.98	32.8	4.31	2.73	48.9	2.89	4.08
×128.5	31.3	4.11	2.61	47.3	2.72	3.94	32.4	3.97	2.70	48.4	2.65	4.03
×116.5	30.8	3.78	2.57	46.7	2.49	3.89	31.9	3.65	2.66	47.8	2.44	3.98
×105.5	30.4	3.47	2.53	46.2	2.28	3.85	31.5	3.35	2.63	47.3	2.23	3.94
×96.5	30.1	3.21	2.51	45.8	2.11	3.82	31.2	3.09	2.60	46.9	2.06	3.91
×88	29.8	2.95	2.48	45.5	1.93	3.79	30.9	2.85	2.58	46.6	1.89	3.88
×79.5	29.5	2.69	2.46	45.1	1.76	3.76	30.6	2.60	2.55	46.2	1.72	3.85
×72.5	29.2	2.48	2.43	44.7	1.62	3.73	30.3	2.39	2.53	45.8	1.58	3.82
WT7×66	28.3	2.33	2.36	43.0	1.53	3.58	29.4	2.24	2.45	44.1	1.50	3.68
×60	28.1	2.14	2.34	42.8	1.40	3.57	29.2	2.05	2.43	43.9	1.37	3.66
×54.5	27.8	1.96	2.32	42.4	1.29	3.53	28.9	1.89	2.41	43.5	1.25	3.63
×49.5	27.7	1.79	2.31	42.3	1.17	3.53	28.8	1.72	2.40	43.4	1.14	3.62
×45	27.4	1.64	2.28	41.9	1.07	3.49	28.5	1.58	2.38	43.0	1.05	3.58
WT7×41	23.7	1.73	1.98	33.8	1.21	2.82	24.4	1.68	2.03	34.5	1.19	2.88
×37	23.6	1.57	1.97	33.7	1.10	2.81	24.3	1.52	2.03	34.4	1.08	2.87
×34	23.3	1.46	1.94	33.3	1.02	2.78	24.0	1.42	2.00	34.0	1.00	2.83
×30.5	23.2	1.31	1.93	33.1	0.921	2.76	23.9	1.28	1.99	33.9	0.900	2.83
WT7×26.5	21.3	1.24	1.78	29.3	0.904	2.44	22.0	1.20	1.83	30.0	0.883	2.50
×24	21.1	1.14	1.76	29.1	0.825	2.43	21.8	1.10	1.82	29.9	0.803	2.49
×21.5	20.9	1.03	1.74	28.9	0.744	2.41	21.7	0.991	1.81	29.7	0.724	2.48
WT7×19	20.2	0.941	1.68	27.0	0.704	2.25	20.9	0.909	1.74	27.6	0.688	2.30
×17	20.1	0.846	1.68	26.9	0.632	2.24	20.7	0.821	1.73	27.5	0.618	2.29
×15	19.9	0.754	1.66	26.7	0.562	2.23	20.6	0.728	1.72	27.3	0.549	2.28
WT7×13	18.3	0.710	1.53	23.4	0.556	1.95	19.0	0.684	1.58	24.0	0.542	2.00
×11	18.1	0.608	1.51	23.1	0.476	1.93	18.7	0.588	1.56	23.7	0.464	1.98
WT6×168	29.4	5.71	2.45	42.8	3.93	3.57	30.2	5.56	2.52	43.6	3.85	3.63
×152.5	28.7	5.31	2.39	41.9	3.64	3.49	29.5	5.17	2.46	42.7	3.57	3.56
×139.5	28.2	4.95	2.35	41.3	3.38	3.44	29.0	4.81	2.42	42.1	3.31	3.51
×126	27.7	4.55	2.31	40.7	3.10	3.39	28.4	4.44	2.37	41.4	3.04	3.45
×115	27.2	4.23	2.27	40.1	2.87	3.34	28.0	4.11	2.33	40.9	2.81	3.41
×105	26.7	3.93	2.23	39.5	2.66	3.29	27.5	3.82	2.29	40.3	2.61	3.36
×95	26.3	3.61	2.19	39.0	2.44	3.25	27.1	3.51	2.26	39.8	2.39	3.32
×85	25.9	3.28	2.16	38.5	2.21	3.21	26.6	3.20	2.22	39.2	2.17	3.27
×76	25.4	2.99	2.12	37.9	2.01	3.16	26.2	2.90	2.18	38.7	1.96	3.23
×68	25.1	2.71	2.09	37.5	1.81	3.13	25.8	2.64	2.15	38.2	1.78	3.18
×60	24.7	2.43	2.06	37.0	1.62	3.08	25.4	2.36	2.12	37.7	1.59	3.14
×53	24.3	2.18	2.03	36.5	1.45	3.04	25.1	2.11	2.09	37.3	1.42	3.11
×48	24.1	1.99	2.01	36.3	1.32	3.03	24.9	1.93	2.08	37.1	1.29	3.09
×43.5	23.9	1.82	1.99	36.0	1.21	3.00	24.6	1.77	2.05	36.7	1.19	3.06
×39.5	23.7	1.67	1.98	35.8	1.10	2.98	24.5	1.61	2.04	36.6	1.08	3.05
×36	23.5	1.53	1.96	35.5	1.01	2.96	24.3	1.48	2.03	36.3	0.992	3.03
×32.5	23.4	1.39	1.95	35.4	0.918	2.95	24.1	1.35	2.01	36.1	0.900	3.01
WT6×29	21.5	1.35	1.79	31.5	0.921	2.63	22.2	1.31	1.85	32.2	0.901	2.68
×26.5	21.4	1.24	1.78	31.4	0.844	2.62	22.1	1.20	1.84	32.0	0.828	2.67

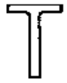
Case A: Shape perimeter, minus one flange surface.
Case B: Shape perimeter.
Case C: Box perimeter, minus one flange surface.
Case D: Box perimeter.

Table 1-43 (cont.). WT-Shapes Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B			Case C			Case D		
	Perimeter, in.	*W/D* Ratio	Surf. Area, ft^2/ft	Perimeter, in.	*W/D* Ratio	Surf. Area, ft^2/ft	Perimeter, in.	*W/D* Ratio	Surf. Area, ft^2/ft	Perimeter, in.	*W/D* Ratio	Surf. Area, ft^2/ft
WT6×25	19.5	1.28	1.63	27.6	0.906	2.30	20.3	1.23	1.69	28.4	0.880	2.37
×22.5	19.4	1.16	1.62	27.5	0.818	2.29	20.1	1.12	1.68	28.2	0.798	2.35
×20	19.2	1.04	1.60	27.2	0.735	2.27	20.0	1.00	1.67	28.0	0.714	2.33
WT6×17.5	18.5	0.946	1.54	25.0	0.700	2.08	19.1	0.916	1.59	25.6	0.684	2.13
×15	18.3	0.820	1.53	24.8	0.605	2.07	18.9	0.794	1.58	25.4	0.591	2.12
×13	18.1	0.718	1.51	24.6	0.528	2.05	18.7	0.695	1.56	25.2	0.516	2.10
WT6×11	15.9	0.692	1.33	19.9	0.553	1.66	16.4	0.671	1.37	20.4	0.539	1.70
×9.5	15.7	0.605	1.31	19.7	0.482	1.64	16.2	0.586	1.35	20.2	0.470	1.68
×8	15.5	0.516	1.29	19.5	0.410	1.63	16.0	0.500	1.33	20.0	0.400	1.67
×7	15.4	0.455	1.28	19.4	0.361	1.62	15.9	0.440	1.33	19.9	0.352	1.66
WT5×56	21.2	2.64	1.77	31.6	1.77	2.63	21.8	2.57	1.82	32.2	1.74	2.68
×50	20.8	2.40	1.73	31.1	1.61	2.59	21.4	2.34	1.78	31.7	1.58	2.64
×44	20.5	2.15	1.71	30.8	1.43	2.57	21.1	2.09	1.76	31.4	1.40	2.62
×38.5	20.2	1.91	1.68	30.4	1.27	2.53	20.8	1.85	1.73	31.0	1.24	2.58
×34	19.9	1.71	1.66	30.0	1.13	2.50	20.5	1.66	1.71	30.6	1.11	2.55
×30	19.7	1.52	1.64	29.8	1.01	2.48	20.3	1.48	1.69	30.4	0.987	2.53
×27	19.5	1.38	1.63	29.5	0.915	2.46	20.1	1.34	1.68	30.1	0.897	2.51
×24.5	19.4	1.26	1.62	29.4	0.833	2.45	20.0	1.23	1.67	30.0	0.817	2.50
WT5×22.5	17.5	1.29	1.46	25.5	0.882	2.13	18.1	1.24	1.51	26.1	0.862	2.18
×19.5	17.3	1.13	1.44	25.3	0.771	2.11	17.9	1.09	1.49	25.9	0.753	2.16
×16.5	17.1	0.965	1.43	25.1	0.657	2.09	17.7	0.932	1.48	25.7	0.642	2.14
WT5×15	15.8	0.949	1.32	21.6	0.694	1.80	16.3	0.920	1.36	22.1	0.679	1.84
×13	15.6	0.833	1.30	21.3	0.610	1.78	16.1	0.807	1.34	21.9	0.594	1.83
×11	15.4	0.714	1.28	21.2	0.519	1.77	15.9	0.692	1.33	21.7	0.507	1.81
WT5×9.5	13.8	0.688	1.15	17.8	0.534	1.48	14.3	0.664	1.19	18.3	0.519	1.53
×8.5	13.6	0.625	1.13	17.7	0.480	1.48	14.1	0.603	1.18	18.1	0.470	1.51
×7.5	13.5	0.556	1.13	17.5	0.429	1.46	14.0	0.536	1.17	18.0	0.417	1.50
×6	13.4	0.448	1.12	17.3	0.347	1.44	13.8	0.435	1.15	17.8	0.337	1.48
WT4×33.5	16.7	2.01	1.39	25.0	1.34	2.08	17.3	1.94	1.44	25.6	1.31	2.13
×29	16.4	1.77	1.37	24.6	1.18	2.05	17.0	1.71	1.42	25.2	1.15	2.10
×24	16.0	1.50	1.33	24.1	0.996	2.01	16.6	1.45	1.38	24.7	0.972	2.06
×20	15.7	1.27	1.31	23.8	0.840	1.98	16.3	1.23	1.36	24.4	0.820	2.03
×17.5	15.5	1.13	1.29	23.6	0.742	1.97	16.1	1.09	1.34	24.2	0.723	2.02
×15.5	15.4	1.01	1.28	23.4	0.662	1.95	16.0	0.969	1.33	24.0	0.646	2.00
WT4×14	14.2	0.986	1.18	20.7	0.676	1.73	14.6	0.959	1.22	21.1	0.664	1.76
×12	14.0	0.857	1.17	20.5	0.585	1.71	14.4	0.833	1.20	20.9	0.574	1.74
WT4×10.5	13.1	0.802	1.09	18.4	0.571	1.53	13.6	0.772	1.13	18.8	0.559	1.57
×9	13.0	0.692	1.08	18.2	0.495	1.52	13.4	0.672	1.12	18.6	0.484	1.55
WT4×7.5	11.7	0.641	0.975	15.7	0.478	1.31	12.1	0.620	1.01	16.1	0.466	1.34
×6.5	11.6	0.560	0.967	15.6	0.417	1.30	12.0	0.542	1.00	16.0	0.406	1.33
×5	11.4	0.439	0.950	15.4	0.325	1.28	11.8	0.424	0.983	15.8	0.316	1.32
WT3×12.5	12.0	1.04	1.00	18.1	0.691	1.51	12.5	1.00	1.04	18.5	0.676	1.54
×10	11.8	0.847	0.98	17.8	0.562	1.48	12.2	0.820	1.02	18.2	0.549	1.52
×7.5	11.6	0.647	0.967	17.6	0.426	1.47	12.0	0.625	1.00	18.0	0.417	1.50
WT3×8	9.9	0.807	0.826	13.9	0.576	1.16	10.3	0.777	0.858	14.3	0.559	1.19
×6	9.64	0.622	0.803	13.6	0.441	1.13	10.00	0.600	0.833	14.0	0.429	1.17
×4.5	9.43	0.477	0.786	13.4	0.336	1.12	9.84	0.457	0.820	13.8	0.326	1.15
×4.25	9.36	0.454	0.780	13.3	0.320	1.11	9.78	0.435	0.815	13.7	0.310	1.14
WT2.5×9.5	9.86	0.963	0.822	14.9	0.638	1.24	10.2	0.931	0.850	15.2	0.625	1.27
×8	9.69	0.826	0.808	14.7	0.544	1.23	10.00	0.800	0.833	15.0	0.533	1.25
WT2×6.5	7.87	0.826	0.656	11.9	0.546	0.99	8.22	0.791	0.685	12.3	0.528	1.03

Case A: Shape perimeter, minus one flange surface.
Case B: Shape perimeter.
Case C: Box perimeter, minus one flange surface.
Case D: Box perimeter.

Table 1-44.
MT-Shapes
Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A 			Case B 			Case C 			Case D 		
	Perimeter in.	*W/D* Ratio	Surf. Area ft²/ft	Perimeter in.	*W/D* Ratio	Surf. Area ft²/ft	Perimeter in.	*W/D* Ratio	Surf. Area ft²/ft	Perimeter in.	*W/D* Ratio	Surf. Area ft²/ft
MT6×5.9	14.8	0.399	1.23	17.9	0.330	1.49	15.1	0.391	1.26	18.1	0.326	1.51
×5.4	14.7	0.367	1.23	17.8	0.303	1.48	15.1	0.358	1.26	18.1	0.298	1.51
×5	15.0	0.333	1.25	18.2	0.275	1.52	15.2	0.329	1.27	18.5	0.270	1.54
MT5×4.5	12.4	0.363	1.03	15.1	0.298	1.26	12.7	0.354	1.06	15.4	0.292	1.28
×4	12.3	0.325	1.03	15.0	0.267	1.25	12.6	0.317	1.05	15.3	0.261	1.28
×3.75	12.5	0.300	1.04	15.2	0.247	1.27	12.7	0.295	1.06	15.4	0.244	1.28
MT4×3.25	9.96	0.326	0.830	12.2	0.266	1.02	10.3	0.316	0.858	12.6	0.258	1.05
×3.1	10.1	0.307	0.842	12.3	0.252	1.03	10.3	0.301	0.858	12.6	0.246	1.05
MT3×2.2	7.66	0.287	0.638	9.50	0.232	0.792	7.84	0.281	0.653	9.68	0.227	0.807
×1.85	7.76	0.238	0.647	9.76	0.190	0.813	7.92	0.234	0.660	9.92	0.186	0.827
MT2.5×9.45	9.66	0.978	0.805	14.7	0.643	1.23	10.00	0.945	0.833	15.0	0.630	1.25
MT2×3	7.31	0.410	0.609	11.1	0.270	0.925	7.60	0.395	0.633	11.4	0.263	0.950

Case A: Shape perimeter, minus one flange surface.
Case B: Shape perimeter.
Case C: Box perimeter, minus one flange surface.
Case D: Box perimeter.

Table 1-45.
ST-Shapes
Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A Perimeter, in.	Case A *W/D* Ratio	Case A Surf. Area, ft²/ft	Case B Perimeter, in.	Case B *W/D* Ratio	Case B Surf. Area, ft²/ft	Case C Perimeter, in.	Case C *W/D* Ratio	Case C Surf. Area, ft²/ft	Case D Perimeter, in.	Case D *W/D* Ratio	Case D Surf. Area, ft²/ft
ST12×60.5	31.2	1.94	2.60	39.2	1.54	3.27	32.7	1.85	2.73	40.7	1.49	3.39
×53	31.0	1.71	2.58	38.8	1.37	3.23	32.5	1.63	2.71	40.3	1.32	3.36
ST12×50	29.9	1.67	2.49	37.1	1.35	3.09	31.3	1.60	2.61	38.5	1.30	3.21
×45	29.8	1.51	2.48	36.9	1.22	3.08	31.1	1.45	2.59	38.3	1.17	3.19
×40	29.6	1.35	2.47	36.6	1.09	3.05	31.0	1.29	2.58	38.0	1.05	3.17
ST10×48	26.3	1.83	2.19	33.5	1.43	2.79	27.6	1.74	2.30	34.8	1.38	2.90
×43	26.1	1.65	2.18	33.2	1.30	2.77	27.5	1.56	2.29	34.5	1.25	2.88
ST10×37.5	25.1	1.49	2.09	31.5	1.19	2.63	26.4	1.42	2.20	32.8	1.14	2.73
×33	25.0	1.32	2.08	31.3	1.05	2.61	26.3	1.25	2.19	32.5	1.02	2.71
ST9×35	23.0	1.52	1.92	29.3	1.19	2.44	24.3	1.44	2.03	30.5	1.15	2.54
×27.35	22.8	1.20	1.90	28.8	0.950	2.40	24.0	1.14	2.00	30.0	0.912	2.50
ST7.5×25	19.5	1.28	1.63	25.2	0.992	2.10	20.6	1.21	1.72	26.3	0.951	2.19
×21.45	19.4	1.11	1.62	24.9	0.861	2.08	20.5	1.05	1.71	26.0	0.825	2.17
ST6×25	16.4	1.52	1.37	21.9	1.14	1.83	17.5	1.43	1.46	23.0	1.09	1.92
×20.4	16.2	1.26	1.35	21.4	0.953	1.78	17.3	1.18	1.44	22.5	0.907	1.88
ST6×17.5	16.1	1.09	1.34	21.2	0.825	1.77	17.1	1.02	1.43	22.2	0.788	1.85
×15.9	16.0	0.994	1.33	21.0	0.757	1.75	17.0	0.935	1.42	22.0	0.723	1.83
ST5×17.5	14.0	1.25	1.17	18.9	0.926	1.58	14.9	1.17	1.24	19.9	0.879	1.66
×12.7	13.7	0.927	1.14	18.4	0.690	1.53	14.7	0.864	1.23	19.3	0.658	1.61
ST4×11.5	11.3	1.02	0.942	15.5	0.742	1.29	12.2	0.943	1.02	16.3	0.706	1.36
×9.2	11.2	0.821	0.933	15.2	0.605	1.27	12.0	0.767	1.00	16.0	0.575	1.33
ST3×8.625	8.89	0.970	0.741	12.5	0.690	1.04	9.57	0.901	0.798	13.1	0.658	1.09
×6.25	8.65	0.723	0.721	12.0	0.521	1.00	9.33	0.670	0.778	12.7	0.492	1.06
ST2.5×5	7.38	0.678	0.615	10.4	0.481	0.867	8.00	0.625	0.667	11.0	0.455	0.917
ST2×4.75	6.20	0.766	0.517	9.00	0.528	0.750	6.80	0.699	0.567	9.60	0.495	0.800
×3.85	6.06	0.635	0.505	8.72	0.442	0.727	6.66	0.578	0.555	9.32	0.413	0.777
ST1.5×3.75	5.01	0.749	0.418	7.52	0.499	0.627	5.51	0.681	0.459	8.02	0.468	0.668
×2.85	4.83	0.590	0.403	7.16	0.398	0.597	5.33	0.535	0.444	7.66	0.372	0.638

Case A: Shape perimeter, minus one flange surface.
Case B: Shape perimeter.
Case C: Box perimeter, minus one flange surface.
Case D: Box perimeter.

Table 1-46.
Rectangular (and Square) HSS
Surface and Box Perimeters, Area-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B			Case C		
	Perimeter	A/P Ratio	Surf. Area	Perimeter	A/P Ratio	Surf. Area	Perimeter	A/P Ratio	Surf. Area
	in.		ft^2/ft	in.		ft^2/ft	in.		ft^2/ft
HSS20×12×5/8	52.3	0.668	4.36	44.3	0.789	3.69	62.0	0.564	5.17
×1/2	52.3	0.542	4.36	44.3	0.640	3.69	62.4	0.454	5.20
×3/8	52.2	0.413	4.35	44.2	0.487	3.68	62.8	0.343	5.23
×5/16	52.2	0.346	4.35	44.2	0.409	3.68	63.0	0.287	5.25
HSS20×8×5/8	48.3	0.627	4.03	36.3	0.834	3.03	54.0	0.561	4.50
×1/2	48.3	0.510	4.03	36.3	0.679	3.03	54.4	0.453	4.53
×3/8	48.2	0.389	4.02	36.2	0.518	3.02	54.8	0.342	4.57
×5/16	48.2	0.327	4.02	36.2	0.435	3.02	55.0	0.286	4.58
HSS20×4×1/2	44.3	0.472	3.69	28.3	0.739	2.36	46.4	0.450	3.87
×3/8	44.2	0.361	3.68	28.2	0.566	2.35	46.8	0.341	3.90
×5/16	44.2	0.304	3.68	28.2	0.476	2.35	47.0	0.285	3.92
HSS18×12×5/8	48.3	0.675	4.03	42.3	0.771	3.53	58.0	0.563	4.83
×1/2	48.3	0.549	4.03	42.3	0.627	3.53	58.4	0.453	4.87
×3/8	48.2	0.418	4.02	42.2	0.477	3.52	58.8	0.342	4.90
HSS18×6×5/8	42.3	0.606	3.53	30.3	0.846	2.53	46.0	0.558	3.83
×1/2	42.3	0.494	3.53	30.3	0.691	2.53	46.4	0.450	3.87
×3/8	42.2	0.378	3.52	30.2	0.528	2.52	46.8	0.341	3.90
×5/16	42.2	0.318	3.52	30.2	0.445	2.52	47.0	0.285	3.92
×1/4	42.1	0.257	3.51	30.1	0.359	2.51	47.2	0.229	3.93
HSS16×16×5/8	48.3	0.723	4.03	48.3	0.723	4.03	62.0	0.564	5.17
×1/2	48.3	0.587	4.03	48.3	0.587	4.03	62.4	0.454	5.20
×3/8	48.2	0.447	4.02	48.2	0.447	4.02	62.8	0.343	5.23
×5/16	48.2	0.375	4.02	48.2	0.375	4.02	63.0	0.287	5.25
HSS16×12×5/8	44.3	0.684	3.69	40.3	0.752	3.36	54.0	0.561	4.50
×1/2	44.3	0.556	3.69	40.3	0.611	3.36	54.4	0.453	4.53
×3/8	44.2	0.424	3.68	40.2	0.466	3.35	54.8	0.342	4.57
×5/16	44.2	0.356	3.68	40.2	0.392	3.35	55.0	0.286	4.58
HSS16×8×5/8	40.3	0.636	3.36	32.3	0.794	2.69	46.0	0.558	3.83
×1/2	40.3	0.519	3.36	32.3	0.648	2.69	46.4	0.450	3.87
×3/8	40.2	0.397	3.35	32.2	0.495	2.68	46.8	0.341	3.90
×5/16	40.2	0.334	3.35	32.2	0.417	2.68	47.0	0.285	3.92
HSS16×4×1/2	36.3	0.474	3.03	24.3	0.708	2.03	38.4	0.447	3.20
×3/8	36.2	0.364	3.02	24.2	0.544	2.02	38.8	0.339	3.23
×5/16	36.2	0.306	3.02	24.2	0.459	2.02	39.0	0.284	3.25
HSS14×14×5/8	42.3	0.716	3.53	42.3	0.716	3.53	54.0	0.561	4.50
×1/2	42.3	0.582	3.53	42.3	0.582	3.53	54.4	0.453	4.53
×3/8	42.2	0.444	3.52	42.2	0.444	3.52	54.8	0.342	4.57
×5/16	42.2	0.373	3.52	42.2	0.373	3.52	55.0	0.286	4.58
HSS14×12×1/2	40.3	0.565	3.36	38.3	0.595	3.19	50.4	0.452	4.20
×3/8	40.2	0.432	3.35	38.2	0.454	3.18	50.8	0.341	4.23
HSS14×10×5/8	38.3	0.670	3.19	34.3	0.748	2.86	46.0	0.558	3.83
×1/2	38.3	0.546	3.19	34.3	0.610	2.86	46.4	0.450	3.87
×3/8	38.2	0.418	3.18	34.2	0.466	2.85	46.8	0.341	3.90
×5/16	38.2	0.351	3.18	34.2	0.393	2.85	47.0	0.285	3.92
×1/4	38.1	0.284	3.18	34.1	0.317	2.84	47.2	0.229	3.93
HSS14×6×5/8	34.3	0.612	2.86	26.3	0.798	2.19	38.0	0.553	3.17
×1/2	34.3	0.501	2.86	26.3	0.654	2.19	38.4	0.447	3.20
×3/8	34.2	0.385	2.85	26.2	0.502	2.18	38.8	0.339	3.23
×5/16	34.2	0.324	2.85	26.2	0.424	2.18	39.0	0.284	3.25
×1/4	34.1	0.263	2.84	26.1	0.343	2.18	39.2	0.229	3.27
×3/16	34.1	0.198	2.84	26.1	0.259	2.18	39.4	0.172	3.28

Case A: Shape perimeter, minus one short surface.
Case B: Shape perimeter, minus one long surface.
Case C: Shape perimeter.

Table 1-46 (cont.). Rectangular (and Square) HSS Surface and Box Perimeters, Area-to-Perimeter Ratios, and Surface Areas

Shape	Case A 			Case B 			Case C 		
	Perimeter	A/P Ratio	Surf. Area	Perimeter	A/P Ratio	Surf. Area	Perimeter	A/P Ratio	Surf. Area
	in.		ft²/ft	in.		ft²/ft	in.		ft²/ft
HSS14×4×5/8	32.3	0.578	2.69	22.3	0.837	1.86	34.0	0.550	2.83
×1/2	32.3	0.475	2.69	22.3	0.688	1.86	34.4	0.445	2.87
×3/8	32.2	0.365	2.68	22.2	0.530	1.85	34.8	0.338	2.90
×5/16	32.2	0.308	2.68	22.2	0.448	1.85	35.0	0.283	2.92
×1/4	32.1	0.250	2.68	22.1	0.363	1.84	35.2	0.228	2.93
×3/16	32.1	0.189	2.68	22.1	0.274	1.84	35.4	0.171	2.95
HSS12×12×5/8	36.3	0.707	3.03	36.3	0.707	3.03	46.0	0.558	3.83
×1/2	36.3	0.576	3.03	36.3	0.576	3.03	46.4	0.450	3.87
×3/8	36.2	0.441	3.02	36.2	0.441	3.02	46.8	0.341	3.90
×5/16	36.2	0.371	3.02	36.2	0.371	3.02	47.0	0.285	3.92
×1/4	36.1	0.300	3.01	36.1	0.300	3.01	47.2	0.229	3.93
HSS12×10×1/2	34.3	0.556	2.86	32.3	0.590	2.69	42.4	0.449	3.53
×3/8	34.2	0.426	2.85	32.2	0.452	2.68	42.8	0.340	3.57
×5/16	34.2	0.358	2.85	32.2	0.381	2.68	43.0	0.285	3.58
×1/4	34.1	0.290	2.84	32.1	0.308	2.68	43.2	0.229	3.60
HSS12×8×5/8	32.3	0.650	2.69	28.3	0.742	2.36	38.0	0.553	3.17
×1/2	32.3	0.532	2.69	28.3	0.608	2.36	38.4	0.447	3.20
×3/8	32.2	0.409	2.68	28.2	0.467	2.35	38.8	0.339	3.23
×5/16	32.2	0.345	2.68	28.2	0.394	2.35	39.0	0.284	3.25
×1/4	32.1	0.279	2.68	28.1	0.319	2.34	39.2	0.229	3.27
×3/16	32.1	0.211	2.68	28.1	0.241	2.34	39.4	0.172	3.28
HSS12×6×5/8	30.3	0.616	2.53	24.3	0.768	2.03	34.0	0.550	2.83
×1/2	30.3	0.506	2.53	24.3	0.631	2.03	34.4	0.445	2.87
×3/8	30.2	0.390	2.52	24.2	0.486	2.02	34.8	0.338	2.90
×5/16	30.2	0.329	2.52	24.2	0.410	2.02	35.0	0.283	2.92
×1/4	30.1	0.267	2.51	24.1	0.333	2.01	35.2	0.228	2.93
×3/16	30.1	0.202	2.51	24.1	0.252	2.01	35.4	0.171	2.95
HSS12×4×5/8	28.3	0.578	2.36	20.3	0.805	1.69	30.0	0.546	2.50
×1/2	28.3	0.476	2.36	20.3	0.664	1.69	30.4	0.443	2.53
×3/8	28.2	0.368	2.35	20.2	0.513	1.68	30.8	0.337	2.57
×5/16	28.2	0.311	2.35	20.2	0.434	1.68	31.0	0.282	2.58
×1/4	28.1	0.252	2.34	20.1	0.353	1.68	31.2	0.228	2.60
×3/16	28.1	0.191	2.34	20.1	0.267	1.68	31.4	0.171	2.62
HSS12×3½×3/8	27.7	0.362	2.31	19.2	0.522	1.60	29.8	0.336	2.48
×5/16	27.7	0.306	2.31	19.2	0.442	1.60	30.0	0.282	2.50
HSS12×3×5/16	27.2	0.301	2.27	18.2	0.450	1.52	29.0	0.282	2.42
×1/4	27.1	0.244	2.26	18.1	0.366	1.51	29.2	0.227	2.43
×3/16	27.1	0.185	2.26	18.1	0.277	1.51	29.4	0.171	2.45
HSS12×2×1/4	26.1	0.236	2.18	16.1	0.382	1.34	27.2	0.227	2.27
×3/16	26.1	0.179	2.18	16.1	0.290	1.34	27.4	0.171	2.28
HSS10×10×5/8	30.3	0.693	2.53	30.3	0.693	2.53	38.0	0.553	3.17
×1/2	30.3	0.568	2.53	30.3	0.568	2.53	38.4	0.447	3.20
×3/8	30.2	0.436	2.52	30.2	0.436	2.52	38.8	0.339	3.23
×5/16	30.2	0.367	2.52	30.2	0.367	2.52	39.0	0.284	3.25
×1/4	30.1	0.297	2.51	30.1	0.297	2.51	39.2	0.229	3.27
×3/16	30.1	0.225	2.51	30.1	0.225	2.51	39.4	0.172	3.28
HSS10×8×1/2	28.3	0.542	2.36	26.3	0.583	2.19	34.4	0.445	2.87
×3/8	28.2	0.417	2.35	26.2	0.449	2.18	34.8	0.338	2.90
×5/16	28.2	0.352	2.35	26.2	0.379	2.18	35.0	0.283	2.92
×1/4	28.1	0.285	2.34	26.1	0.307	2.18	35.2	0.228	2.93
×3/16	28.1	0.216	2.34	26.1	0.232	2.18	35.4	0.171	2.95

Case A: Shape perimeter, minus one short surface.
Case B: Shape perimeter, minus one long surface.
Case C: Shape perimeter.

Table 1-46 (cont.). Rectangular (and Square) HSS Surface and Box Perimeters, Area-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B			Case C		
	Perimeter	A/P Ratio	Surf. Area	Perimeter	A/P Ratio	Surf. Area	Perimeter	A/P Ratio	Surf. Area
	in.		ft^2/ft	in.		ft^2/ft	in.		ft^2/ft
HSS10×6×5/8	26.3	0.622	2.19	22.3	0.733	1.86	30.0	0.546	2.50
×1/2	26.3	0.512	2.19	22.3	0.605	1.86	30.4	0.443	2.53
×3/8	26.2	0.396	2.18	22.2	0.467	1.85	30.8	0.337	2.57
×5/16	26.2	0.335	2.18	22.2	0.395	1.85	31.0	0.282	2.58
×1/4	26.1	0.272	2.18	22.1	0.321	1.84	31.2	0.228	2.60
×3/16	26.1	0.206	2.18	22.1	0.243	1.84	31.4	0.171	2.62
HSS10×5×3/8	25.2	0.384	2.10	20.2	0.479	1.68	28.8	0.336	2.40
×5/16	25.2	0.325	2.10	20.2	0.405	1.68	29.0	0.282	2.42
×1/4	25.1	0.264	2.09	20.1	0.329	1.68	29.2	0.227	2.43
×3/16	25.1	0.200	2.09	20.1	0.250	1.68	29.4	0.171	2.45
HSS10×4×5/8	24.3	0.577	2.03	18.3	0.766	1.53	26.0	0.540	2.17
×1/2	24.3	0.478	2.03	18.3	0.635	1.53	26.4	0.439	2.20
×3/8	24.2	0.371	2.02	18.2	0.493	1.52	26.8	0.335	2.23
×5/16	24.2	0.314	2.02	18.2	0.418	1.52	27.0	0.281	2.25
×1/4	24.1	0.256	2.01	18.1	0.340	1.51	27.2	0.227	2.27
×3/16	24.1	0.194	2.01	18.1	0.258	1.51	27.4	0.171	2.28
HSS10×3 1/2×3/16	23.6	0.191	1.97	17.1	0.263	1.43	26.4	0.170	2.20
HSS10×3×3/8	23.2	0.357	1.93	16.2	0.511	1.35	24.8	0.334	2.07
×5/16	23.2	0.303	1.93	16.2	0.434	1.35	25.0	0.280	2.08
×1/4	23.1	0.246	1.93	16.1	0.353	1.34	25.2	0.226	2.10
×3/16	23.1	0.187	1.93	16.1	0.269	1.34	25.4	0.170	2.12
×1/8	23.1	0.127	1.93	16.1	0.182	1.34	25.6	0.114	2.13
HSS10×2×3/8	22.2	0.341	1.85	14.2	0.534	1.18	22.8	0.332	1.90
×5/16	22.2	0.290	1.85	14.2	0.454	1.18	23.0	0.279	1.92
×1/4	22.1	0.237	1.84	14.1	0.370	1.18	23.2	0.226	1.93
×3/16	22.1	0.180	1.84	14.1	0.282	1.18	23.4	0.170	1.95
HSS9×7×5/8	25.3	0.646	2.11	23.3	0.702	1.94	30.0	0.546	2.50
×1/2	25.3	0.533	2.11	23.3	0.579	1.94	30.4	0.443	2.53
×3/8	25.2	0.411	2.10	23.2	0.447	1.93	30.8	0.337	2.57
×5/16	25.2	0.348	2.10	23.2	0.378	1.93	31.0	0.282	2.58
×1/4	25.1	0.282	2.09	23.1	0.307	1.93	31.2	0.228	2.60
×3/16	25.1	0.214	2.09	23.1	0.232	1.93	31.4	0.171	2.62
HSS9×5×5/8	23.3	0.602	1.94	19.3	0.727	1.61	26.0	0.540	2.17
×1/2	23.3	0.499	1.94	19.3	0.602	1.61	26.4	0.439	2.20
×3/8	23.2	0.387	1.93	19.2	0.467	1.60	26.8	0.335	2.23
×5/16	23.2	0.328	1.93	19.2	0.396	1.60	27.0	0.281	2.25
×1/4	23.1	0.267	1.93	19.1	0.322	1.59	27.2	0.227	2.27
×3/16	23.1	0.202	1.93	19.1	0.245	1.59	27.4	0.171	2.28
HSS9×3×1/2	21.3	0.458	1.78	15.3	0.638	1.28	22.4	0.435	1.87
×3/8	21.2	0.357	1.77	15.2	0.498	1.27	22.8	0.332	1.90
×5/16	21.2	0.304	1.77	15.2	0.424	1.27	23.0	0.279	1.92
×1/4	21.1	0.248	1.76	15.1	0.346	1.26	23.2	0.226	1.93
×3/16	21.1	0.188	1.76	15.1	0.263	1.26	23.4	0.170	1.95
HSS8×8×5/8	24.3	0.673	2.03	24.3	0.673	2.03	30.0	0.546	2.50
×1/2	24.3	0.555	2.03	24.3	0.555	2.03	30.4	0.443	2.53
×3/8	24.2	0.428	2.02	24.2	0.428	2.02	30.8	0.337	2.57
×5/16	24.2	0.362	2.02	24.2	0.362	2.02	31.0	0.282	2.58
×1/4	24.1	0.294	2.01	24.1	0.294	2.01	31.2	0.228	2.60
×3/16	24.1	0.223	2.01	24.1	0.223	2.01	31.4	0.171	2.62
HSS8×6×5/8	22.3	0.629	1.86	20.3	0.691	1.69	26.0	0.540	2.17
×1/2	22.3	0.521	1.86	20.3	0.572	1.69	26.4	0.439	2.20
×3/8	22.2	0.404	1.85	20.2	0.444	1.68	26.8	0.335	2.23
×5/16	22.2	0.342	1.85	20.2	0.376	1.68	27.0	0.281	2.25
×1/4	22.1	0.279	1.84	20.1	0.306	1.68	27.2	0.227	2.27
×3/16	22.1	0.211	1.84	20.1	0.233	1.68	27.4	0.171	2.28

Case A: Shape perimeter, minus one short surface.
Case B: Shape perimeter, minus one long surface.
Case C: Shape perimeter.

Table 1-46 (cont.). Rectangular (and Square) HSS Surface and Box Perimeters, Area-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B			Case C		
	Perimeter	A/P Ratio	Surf. Area	Perimeter	A/P Ratio	Surf. Area	Perimeter	A/P Ratio	Surf. Area
	in.		ft²/ft	in.		ft²/ft	in.		ft²/ft
HSS8×4×5/8	20.3	0.577	1.69	16.3	0.718	1.36	22.0	0.533	1.83
×1/2	20.3	0.481	1.69	16.3	0.599	1.36	22.4	0.435	1.87
×3/8	20.2	0.375	1.68	16.2	0.468	1.35	22.8	0.332	1.90
×5/16	20.2	0.319	1.68	16.2	0.398	1.35	23.0	0.279	1.92
×1/4	20.1	0.260	1.68	16.1	0.325	1.34	23.2	0.226	1.93
×3/16	20.1	0.198	1.68	16.1	0.247	1.34	23.4	0.170	1.95
×1/8	20.1	0.134	1.68	16.1	0.168	1.34	23.6	0.114	1.97
HSS8×3×1/2	19.3	0.457	1.61	14.3	0.618	1.19	20.4	0.432	1.70
×3/8	19.2	0.358	1.60	14.2	0.484	1.18	20.8	0.331	1.73
×5/16	19.2	0.305	1.60	14.2	0.413	1.18	21.0	0.278	1.75
×1/4	19.1	0.249	1.59	14.1	0.337	1.18	21.2	0.225	1.77
×3/16	19.1	0.190	1.59	14.1	0.257	1.18	21.4	0.170	1.78
×1/8	19.1	0.129	1.59	14.1	0.175	1.18	21.6	0.114	1.80
HSS8×2×3/8	18.2	0.340	1.52	12.2	0.507	1.02	18.8	0.329	1.57
×5/16	18.2	0.290	1.52	12.2	0.433	1.02	19.0	0.277	1.58
×1/4	18.1	0.237	1.51	12.1	0.355	1.01	19.2	0.224	1.60
×3/16	18.1	0.181	1.51	12.1	0.271	1.01	19.4	0.169	1.62
×1/8	18.1	0.124	1.51	12.1	0.185	1.01	19.6	0.114	1.63
HSS7×7×5/8	21.3	0.659	1.78	21.3	0.659	1.78	26.0	0.540	2.17
×1/2	21.3	0.545	1.78	21.3	0.545	1.78	26.4	0.439	2.20
×3/8	21.2	0.423	1.77	21.2	0.423	1.77	26.8	0.335	2.23
×5/16	21.2	0.359	1.77	21.2	0.359	1.77	27.0	0.281	2.25
×1/4	21.1	0.292	1.76	21.1	0.292	1.76	27.2	0.227	2.27
×3/16	21.1	0.221	1.76	21.1	0.221	1.76	27.4	0.171	2.28
HSS7×5×5/8	19.3	0.607	1.61	17.3	0.677	1.44	22.0	0.533	1.83
×1/2	19.3	0.506	1.61	17.3	0.564	1.44	22.4	0.435	1.87
×3/8	19.2	0.395	1.60	17.2	0.440	1.43	22.8	0.332	1.90
×5/16	19.2	0.335	1.60	17.2	0.374	1.43	23.0	0.279	1.92
×1/4	19.1	0.274	1.59	17.1	0.306	1.43	23.2	0.226	1.93
×3/16	19.1	0.208	1.59	17.1	0.233	1.43	23.4	0.170	1.95
×1/8	19.1	0.141	1.59	17.1	0.158	1.43	23.6	0.114	1.97
HSS7×4×1/2	18.3	0.482	1.53	15.3	0.577	1.28	20.4	0.432	1.70
×3/8	18.2	0.378	1.52	15.2	0.453	1.27	20.8	0.331	1.73
×5/16	18.2	0.322	1.52	15.2	0.385	1.27	21.0	0.278	1.75
×1/4	18.1	0.263	1.51	15.1	0.315	1.26	21.2	0.225	1.77
×3/16	18.1	0.201	1.51	15.1	0.240	1.26	21.4	0.170	1.78
×1/8	18.1	0.136	1.51	15.1	0.164	1.26	21.6	0.114	1.80
HSS7×3×1/2	17.3	0.456	1.44	13.3	0.594	1.11	18.4	0.428	1.53
×3/8	17.2	0.359	1.43	13.2	0.468	1.10	18.8	0.329	1.57
×5/16	17.2	0.307	1.43	13.2	0.400	1.10	19.0	0.277	1.58
×1/4	17.1	0.251	1.43	13.1	0.328	1.09	19.2	0.224	1.60
×3/16	17.1	0.192	1.43	13.1	0.250	1.09	19.4	0.169	1.62
×1/8	17.1	0.131	1.43	13.1	0.171	1.09	19.6	0.114	1.63
HSS6×6×5/8	18.3	0.640	1.53	18.3	0.640	1.53	22.0	0.533	1.83
×1/2	18.3	0.533	1.53	18.3	0.533	1.53	22.4	0.435	1.87
×3/8	18.2	0.416	1.52	18.2	0.416	1.52	22.8	0.332	1.90
×5/16	18.2	0.354	1.52	18.2	0.354	1.52	23.0	0.279	1.92
×1/4	18.1	0.289	1.51	18.1	0.289	1.51	23.2	0.226	1.93
×3/16	18.1	0.220	1.51	18.1	0.220	1.51	23.4	0.170	1.95
×1/8	18.1	0.149	1.51	18.1	0.149	1.51	23.6	0.114	1.97
HSS6×5×3/8	17.2	0.400	1.43	16.2	0.425	1.35	20.8	0.331	1.73
×5/16	17.2	0.341	1.43	16.2	0.362	1.35	21.0	0.278	1.75
×1/4	17.1	0.278	1.43	16.1	0.296	1.34	21.2	0.225	1.77
×3/16	17.1	0.212	1.43	16.1	0.225	1.34	21.4	0.170	1.78

Case A: Shape perimeter, minus one short surface.
Case B: Shape perimeter, minus one long surface.
Case C: Shape perimeter.

Table 1-46 (cont.). Rectangular (and Square) HSS Surface and Box Perimeters, Area-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B			Case C		
	Perimeter, in.	*A*/*P* Ratio	Surf. Area, ft^2/ft	Perimeter, in.	*A*/*P* Ratio	Surf. Area, ft^2/ft	Perimeter, in.	*A*/*P* Ratio	Surf. Area, ft^2/ft
HSS6×4×1/2	16.3	0.484	1.36	14.3	0.552	1.19	18.4	0.428	1.53
×3/8	16.2	0.381	1.35	14.2	0.435	1.18	18.8	0.329	1.57
×5/16	16.2	0.326	1.35	14.2	0.372	1.18	19.0	0.277	1.58
×1/4	16.1	0.267	1.34	14.1	0.304	1.18	19.2	0.224	1.60
×3/16	16.1	0.204	1.34	14.1	0.233	1.18	19.4	0.169	1.62
×1/8	16.1	0.139	1.34	14.1	0.159	1.18	19.6	0.114	1.63
HSS6×3×1/2	15.3	0.455	1.28	12.3	0.567	1.03	16.4	0.424	1.37
×3/8	15.2	0.361	1.27	12.2	0.449	1.02	16.8	0.326	1.40
×5/16	15.2	0.309	1.27	12.2	0.385	1.02	17.0	0.275	1.42
×1/4	15.1	0.254	1.26	12.1	0.316	1.01	17.2	0.223	1.43
×3/16	15.1	0.194	1.26	12.1	0.242	1.01	17.4	0.169	1.45
×1/8	15.1	0.133	1.26	12.1	0.166	1.01	17.6	0.114	1.47
HSS6×2×3/8	14.2	0.337	1.18	10.2	0.469	0.850	14.8	0.323	1.23
×5/16	14.2	0.289	1.18	10.2	0.403	0.850	15.0	0.273	1.25
×1/4	14.1	0.239	1.18	10.1	0.333	0.842	15.2	0.222	1.27
×3/16	14.1	0.183	1.18	10.1	0.256	0.842	15.4	0.168	1.28
×1/8	14.1	0.126	1.18	10.1	0.176	0.842	15.6	0.113	1.30
HSS5 1/2×5 1/2×3/8	16.7	0.412	1.39	16.7	0.412	1.39	20.8	0.331	1.73
×5/16	16.7	0.351	1.39	16.7	0.351	1.39	21.0	0.278	1.75
×1/4	16.6	0.287	1.38	16.6	0.287	1.38	21.2	0.225	1.77
×3/16	16.6	0.219	1.38	16.6	0.219	1.38	21.4	0.170	1.78
×1/8	16.6	0.149	1.38	16.6	0.149	1.38	21.6	0.114	1.80
HSS5×5×1/2	15.3	0.516	1.28	15.3	0.516	1.28	18.4	0.428	1.53
×3/8	15.2	0.407	1.27	15.2	0.407	1.27	18.8	0.329	1.57
×5/16	15.2	0.347	1.27	15.2	0.347	1.27	19.0	0.277	1.58
×1/4	15.1	0.284	1.26	15.1	0.284	1.26	19.2	0.224	1.60
×3/16	15.1	0.217	1.26	15.1	0.217	1.26	19.4	0.169	1.62
×1/8	15.1	0.148	1.26	15.1	0.148	1.26	19.6	0.114	1.63
HSS5×4×1/2	14.3	0.487	1.19	13.3	0.524	1.11	16.4	0.424	1.37
×3/8	14.2	0.386	1.18	13.2	0.415	1.10	16.8	0.326	1.40
×5/16	14.2	0.330	1.18	13.2	0.356	1.10	17.0	0.275	1.42
×1/4	14.1	0.272	1.18	13.1	0.292	1.09	17.2	0.223	1.43
×3/16	14.1	0.208	1.18	13.1	0.224	1.09	17.4	0.169	1.45
HSS5×3×1/2	13.3	0.454	1.11	11.3	0.534	0.942	14.4	0.418	1.20
×3/8	13.2	0.362	1.10	11.2	0.427	0.933	14.8	0.323	1.23
×5/16	13.2	0.311	1.10	11.2	0.367	0.933	15.0	0.273	1.25
×1/4	13.1	0.257	1.09	11.1	0.303	0.925	15.2	0.222	1.27
×3/16	13.1	0.197	1.09	11.1	0.233	0.925	15.4	0.168	1.28
×1/8	13.1	0.135	1.09	11.1	0.160	0.925	15.6	0.113	1.30
HSS5×2 1/2×1/4	12.6	0.248	1.05	10.1	0.310	0.842	14.2	0.221	1.18
×3/16	12.6	0.191	1.05	10.1	0.239	0.842	14.4	0.167	1.20
×1/8	12.6	0.131	1.05	10.1	0.164	0.842	14.6	0.113	1.22
HSS5×2×3/8	12.2	0.335	1.02	9.20	0.444	0.767	12.8	0.319	1.07
×5/16	12.2	0.289	1.02	9.16	0.384	0.763	13.0	0.271	1.08
×1/4	12.1	0.239	1.01	9.13	0.318	0.761	13.2	0.220	1.10
×3/16	12.1	0.185	1.01	9.10	0.246	0.758	13.4	0.167	1.12
×1/8	12.1	0.127	1.01	9.07	0.169	0.756	13.6	0.113	1.13
HSS4 1/2×4 1/2×1/2	13.8	0.505	1.15	13.8	0.505	1.15	16.4	0.424	1.37
×3/8	13.7	0.400	1.14	13.7	0.400	1.14	16.8	0.326	1.40
×5/16	13.7	0.343	1.14	13.7	0.343	1.14	17.0	0.275	1.42
×1/4	13.6	0.281	1.13	13.6	0.281	1.13	17.2	0.223	1.43
×3/16	13.6	0.216	1.13	13.6	0.216	1.13	17.4	0.169	1.45
×1/8	13.6	0.147	1.13	13.6	0.147	1.13	17.6	0.114	1.47

Case A: Shape perimeter, minus one short surface.
Case B: Shape perimeter, minus one long surface.
Case C: Shape perimeter.

Table 1-46 (cont.). Rectangular (and Square) HSS Surface and Box Perimeters, Area-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B			Case C		
	Perimeter in.	A/P Ratio	Surf. Area ft^2/ft	Perimeter in.	A/P Ratio	Surf. Area ft^2/ft	Perimeter in.	A/P Ratio	Surf. Area ft^2/ft
HSS4×4×1/2	12.3	0.491	1.03	12.3	0.491	1.03	14.4	0.418	1.20
×3/8	12.2	0.392	1.02	12.2	0.392	1.02	14.8	0.323	1.23
×5/16	12.2	0.337	1.02	12.2	0.337	1.02	15.0	0.273	1.25
×1/4	12.1	0.278	1.01	12.1	0.278	1.01	15.2	0.222	1.27
×3/16	12.1	0.214	1.01	12.1	0.214	1.01	15.4	0.168	1.28
×1/8	12.1	0.146	1.01	12.1	0.146	1.01	15.6	0.113	1.30
HSS4×3×3/8	11.2	0.365	0.933	10.2	0.401	0.850	12.8	0.319	1.07
×5/16	11.2	0.315	0.933	10.2	0.346	0.850	13.0	0.271	1.08
×1/4	11.1	0.261	0.925	10.1	0.287	0.842	13.2	0.220	1.10
×3/16	11.1	0.202	0.925	10.1	0.222	0.842	13.4	0.167	1.12
×1/8	11.1	0.139	0.925	10.1	0.153	0.842	13.6	0.113	1.13
HSS4×2 1/2×5/16	10.7	0.303	0.892	9.16	0.352	0.763	12.0	0.269	1.00
×1/4	10.6	0.251	0.883	9.13	0.293	0.761	12.2	0.219	1.02
×3/16	10.6	0.195	0.883	9.10	0.227	0.758	12.4	0.166	1.03
HSS4×2×3/8	10.2	0.332	0.850	8.20	0.413	0.683	10.8	0.314	0.900
×5/16	10.2	0.289	0.850	8.16	0.359	0.680	11.0	0.267	0.917
×1/4	10.1	0.241	0.842	8.13	0.300	0.678	11.2	0.218	0.933
×3/16	10.1	0.187	0.842	8.10	0.233	0.675	11.4	0.166	0.950
×1/8	10.1	0.130	0.842	8.07	0.162	0.673	11.6	0.112	0.967
HSS3 1/2×3 1/2×3/8	10.7	0.382	0.892	10.7	0.382	0.892	12.8	0.319	1.07
×5/16	10.7	0.330	0.892	10.7	0.330	0.892	13.0	0.271	1.08
×1/4	10.6	0.273	0.883	10.6	0.273	0.883	13.2	0.220	1.10
×3/16	10.6	0.211	0.883	10.6	0.211	0.883	13.4	0.167	1.12
×1/8	10.6	0.145	0.883	10.6	0.145	0.883	13.6	0.113	1.13
HSS3 1/2×2 1/2×3/8	9.70	0.349	0.808	8.70	0.389	0.725	10.8	0.314	0.900
×5/16	9.66	0.304	0.805	8.66	0.339	0.722	11.0	0.267	0.917
×1/4	9.63	0.253	0.803	8.63	0.283	0.719	11.2	0.218	0.933
×3/16	9.60	0.197	0.800	8.60	0.220	0.717	11.4	0.166	0.950
×1/8	9.57	0.136	0.798	8.57	0.152	0.714	11.6	0.112	0.967
HSS3×3×3/8	9.20	0.368	0.767	9.20	0.368	0.767	10.8	0.314	0.900
×5/16	9.16	0.320	0.763	9.16	0.320	0.763	11.0	0.267	0.917
×1/4	9.13	0.267	0.761	9.13	0.267	0.761	11.2	0.218	0.933
×3/16	9.10	0.208	0.758	9.10	0.208	0.758	11.4	0.166	0.950
×1/8	9.07	0.144	0.756	9.07	0.144	0.756	11.6	0.112	0.967
HSS3×2 1/2×5/16	8.66	0.305	0.722	8.16	0.324	0.680	10.0	0.264	0.833
×1/4	8.63	0.256	0.719	8.13	0.271	0.678	10.2	0.216	0.850
×3/16	8.60	0.199	0.717	8.10	0.212	0.675	10.4	0.165	0.867
×1/8	8.57	0.139	0.714	8.07	0.147	0.673	10.6	0.112	0.883
HSS3×2×5/16	8.16	0.288	0.680	7.16	0.328	0.597	9.00	0.261	0.750
×1/4	8.13	0.243	0.678	7.13	0.277	0.594	9.20	0.214	0.767
×3/16	8.10	0.190	0.675	7.10	0.217	0.592	9.40	0.164	0.783
×1/8	8.07	0.133	0.673	7.07	0.152	0.589	9.60	0.112	0.800
HSS3×1 1/2×1/4	7.63	0.228	0.636	6.13	0.284	0.511	8.20	0.212	0.683
×3/16	7.60	0.180	0.633	6.10	0.224	0.508	8.40	0.163	0.700
×1/8	7.57	0.126	0.631	6.07	0.158	0.506	8.60	0.111	0.717
HSS3×1×1/8	7.07	0.119	0.589	5.07	0.166	0.423	7.60	0.110	0.633
HSS2 1/2×2 1/2×5/16	7.66	0.31	0.638	7.66	0.307	0.638	9.00	0.261	0.750
×1/4	7.63	0.259	0.636	7.63	0.259	0.636	9.20	0.214	0.767
×3/16	7.60	0.203	0.633	7.60	0.203	0.633	9.40	0.164	0.783
×1/8	7.57	0.142	0.631	7.57	0.142	0.631	9.60	0.112	0.800
HSS2 1/2×1 1/2×1/4	6.63	0.227	0.553	5.63	0.268	0.469	7.20	0.209	0.600
×3/16	6.60	0.181	0.550	5.60	0.213	0.467	7.40	0.161	0.617
×1/8	6.57	0.128	0.548	5.57	0.151	0.464	7.60	0.110	0.633

Case A: Shape perimeter, minus one short surface.
Case B: Shape perimeter, minus one long surface.
Case C: Shape perimeter.

Table 1-46 (cont.). Rectangular (and Square) HSS Surface and Box Perimeters, Area-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B			Case C		
	Perimeter	A/P Ratio	Surf. Area	Perimeter	A/P Ratio	Surf. Area	Perimeter	A/P Ratio	Surf. Area
	in.		ft^2/ft	in.		ft^2/ft	in.		ft^2/ft
HSS2 1/4×2 1/4×1/4	6.13	0.253	0.511	6.13	0.253	0.511	7.20	0.212	0.600
×3/16	6.85	0.200	0.571	6.85	0.200	0.571	8.40	0.163	0.700
×1/8	6.82	0.140	0.568	6.82	0.140	0.568	8.60	0.111	0.717
HSS2×2×1/4	6.13	0.246	0.511	6.13	0.246	0.511	7.20	0.209	0.600
×3/16	6.10	0.196	0.508	6.10	0.196	0.508	7.40	0.161	0.617
×1/8	6.07	0.138	0.506	6.07	0.138	0.506	7.60	0.110	0.633
HSS2×1 1/2×3/16	5.60	0.182	0.467	5.10	0.200	0.425	6.40	0.159	0.533
HSS2×1×3/16	5.10	0.166	0.425	4.10	0.206	0.342	5.40	0.156	0.450
×1/8	5.07	0.120	0.423	4.07	0.149	0.339	5.60	0.108	0.467
HSS1 3/4×1 3/4×3/16	5.35	0.191	0.446	5.35	0.191	0.446	6.40	0.159	0.533
HSS1 5/8×1 5/8×3/16	4.97	0.187	0.414	4.97	0.187	0.414	5.90	0.158	0.492
×1/8	4.94	0.135	0.412	4.94	0.135	0.412	6.10	0.109	0.508
HSS1 1/2×1 1/2×3/16	4.60	0.184	0.383	4.60	0.184	0.383	5.40	0.156	0.450
×1/8	4.57	0.133	0.381	4.57	0.133	0.381	5.60	0.108	0.467
HSS1 1/4×1 1/4×3/16	3.85	0.174	0.321	3.85	0.174	0.321	4.40	0.152	0.367
×1/8	3.82	0.129	0.318	3.82	0.129	0.318	4.60	0.107	0.383

Case A: Shape perimeter, minus one short surface.
Case B: Shape perimeter, minus one long surface.
Case C: Shape perimeter.

Table 1-47.
Round HSS
Surface and Box Perimeters, Area-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B		
	Perimeter	*A*/*P* Ratio	Surf. Area	Perimeter	*A*/*P* Ratio	Surf. Area
	in.		ft²/ft	in.		ft²/ft
HSS20.000×0.500	62.8	0.454	5.23	80.0	0.357	6.67
×0.375	62.8	0.343	5.23	80.0	0.269	6.67
HSS18.000×0.500	56.5	0.453	4.71	72.0	0.356	6.00
×0.375	56.5	0.342	4.71	72.0	0.269	6.00
HSS16.000×0.500	50.3	0.451	4.19	64.0	0.355	5.33
×0.438	50.3	0.397	4.19	64.0	0.312	5.33
×0.375	50.3	0.341	4.19	64.0	0.268	5.33
×0.312	50.3	0.286	4.19	64.0	0.224	5.33
HSS14.000×0.500	44.0	0.450	3.67	56.0	0.353	4.67
×0.375	44.0	0.340	3.67	56.0	0.267	4.67
×0.312	44.0	0.285	3.67	56.0	0.224	4.67
HSS12.750×0.500	40.1	0.448	3.34	51.0	0.352	4.25
×0.375	40.1	0.339	3.34	51.0	0.267	4.25
×0.250	40.1	0.229	3.34	51.0	0.180	4.25
HSS12.500×0.625	39.3	0.554	3.28	50.0	0.435	4.17
×0.500	39.3	0.448	3.28	50.0	0.352	4.17
×0.375	39.3	0.339	3.28	50.0	0.266	4.17
×0.312	39.3	0.284	3.28	50.0	0.223	4.17
×0.250	39.3	0.229	3.28	50.0	0.180	4.17
×0.188	39.3	0.172	3.28	50.0	0.135	4.17
HSS11.250×0.625	35.3	0.551	2.94	45.0	0.433	3.75
×0.500	35.3	0.446	2.94	45.0	0.350	3.75
×0.375	35.3	0.338	2.94	45.0	0.266	3.75
×0.312	35.3	0.283	2.94	45.0	0.223	3.75
×0.250	35.3	0.228	2.94	45.0	0.179	3.75
×0.188	35.3	0.171	2.94	45.0	0.135	3.75
HSS10.750×0.500	33.8	0.445	2.82	43.0	0.349	3.58
×0.250	33.8	0.228	2.82	43.0	0.179	3.58
HSS10.000×0.625	31.4	0.547	2.62	40.0	0.430	3.33
×0.500	31.4	0.443	2.62	40.0	0.348	3.33
×0.375	31.4	0.337	2.62	40.0	0.265	3.33
×0.312	31.4	0.283	2.62	40.0	0.222	3.33
×0.250	31.4	0.228	2.62	40.0	0.179	3.33
×0.188	31.4	0.171	2.62	40.0	0.134	3.33
HSS9.625×0.500	30.2	0.443	2.52	38.5	0.348	3.21
×0.375	30.2	0.336	2.52	38.5	0.264	3.21
×0.312	30.2	0.282	2.52	38.5	0.222	3.21
×0.250	30.2	0.227	2.52	38.5	0.179	3.21
×0.188	30.2	0.171	2.52	38.5	0.134	3.21
HSS8.750×0.500	27.5	0.440	2.29	35.0	0.346	2.92
×0.375	27.5	0.335	2.29	35.0	0.263	2.92
×0.312	27.5	0.281	2.29	35.0	0.221	2.92
×0.250	27.5	0.227	2.29	35.0	0.178	2.92
×0.188	27.5	0.171	2.29	35.0	0.134	2.92
HSS8.625×0.500	27.1	0.440	2.26	34.5	0.346	2.88
×0.375	27.1	0.335	2.26	34.5	0.263	2.88
×0.322	27.1	0.290	2.26	34.5	0.227	2.88
×0.250	27.1	0.227	2.26	34.5	0.178	2.88
×0.188	27.1	0.170	2.26	34.5	0.134	2.88
HSS7.625×0.125	24.0	0.114	2.00	30.5	0.090	2.54
HSS7.500×0.500	23.6	0.436	1.97	30.0	0.343	2.50
×0.375	23.6	0.333	1.97	30.0	0.261	2.50
×0.312	23.6	0.280	1.97	30.0	0.220	2.50
×0.250	23.6	0.226	1.97	30.0	0.177	2.50
×0.188	23.6	0.170	1.97	30.0	0.133	2.50

Case A: Shape perimeter. Case B: Box perimeter, equal to four times the depth.

Table 1-47 (cont.).
Round HSS
Surface and Box Perimeters, Area-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B		
	Perimeter	*A*/*P* Ratio	Surf. Area	Perimeter	*A*/*P* Ratio	Surf. Area
	in.		ft^2/ft	in.		ft^2/ft
HSS7.000×0.500	22.0	0.434	1.83	28.0	0.341	2.33
×0.375	22.0	0.332	1.83	28.0	0.260	2.33
×0.312	22.0	0.279	1.83	28.0	0.219	2.33
×0.250	22.0	0.225	1.83	28.0	0.177	2.33
×0.188	22.0	0.170	1.83	28.0	0.133	2.33
×0.125	22.0	0.114	1.83	28.0	0.090	2.33
HSS6.875×0.500	21.6	0.434	1.80	27.5	0.341	2.29
×0.375	21.6	0.331	1.80	27.5	0.260	2.29
×0.312	21.6	0.279	1.80	27.5	0.219	2.29
×0.250	21.6	0.225	1.80	27.5	0.177	2.29
×0.188	21.6	0.170	1.80	27.5	0.133	2.29
HSS6.625×0.500	20.8	0.432	1.73	26.5	0.340	2.21
×0.432	20.8	0.378	1.73	26.5	0.297	2.21
×0.375	20.8	0.331	1.73	26.5	0.260	2.21
×0.312	20.8	0.278	1.73	26.5	0.219	2.21
×0.280	20.8	0.251	1.73	26.5	0.197	2.21
×0.250	20.8	0.225	1.73	26.5	0.177	2.21
×0.188	20.8	0.169	1.73	26.5	0.133	2.21
×0.125	20.8	0.114	1.73	26.5	0.0895	2.21
HSS6.125×0.500	19.2	0.430	1.60	24.5	0.337	2.04
×0.375	19.2	0.329	1.60	24.5	0.258	2.04
×0.312	19.2	0.277	1.60	24.5	0.218	2.04
×0.250	19.2	0.224	1.60	24.5	0.176	2.04
×0.188	19.2	0.169	1.60	24.5	0.133	2.04
HSS6.000×0.500	18.8	0.429	1.57	24.0	0.337	2.00
×0.375	18.8	0.329	1.57	24.0	0.258	2.00
×0.312	18.8	0.277	1.57	24.0	0.217	2.00
×0.280	18.8	0.250	1.57	24.0	0.196	2.00
×0.250	18.8	0.224	1.57	24.0	0.176	2.00
×0.188	18.8	0.169	1.57	24.0	0.133	2.00
×0.125	18.8	0.114	1.57	24.0	0.0893	2.00
HSS5.563×0.375	17.5	0.327	1.46	22.3	0.257	1.86
×0.258	17.5	0.231	1.46	22.3	0.181	1.86
×0.188	17.5	0.169	1.46	22.3	0.132	1.86
×0.134	17.5	0.122	1.46	22.3	0.0960	1.86
HSS5.500×0.500	17.3	0.426	1.44	22.0	0.334	1.83
×0.375	17.3	0.327	1.44	22.0	0.257	1.83
×0.258	17.3	0.230	1.44	22.0	0.181	1.83
HSS5.000×0.500	15.7	0.422	1.31	20.0	0.331	1.67
×0.375	15.7	0.325	1.31	20.0	0.255	1.67
×0.312	15.7	0.274	1.31	20.0	0.215	1.67
×0.258	15.7	0.229	1.31	20.0	0.180	1.67
×0.250	15.7	0.222	1.31	20.0	0.174	1.67
×0.188	15.7	0.168	1.31	20.0	0.132	1.67
×0.125	15.7	0.113	1.31	20.0	0.0890	1.67
HSS4.500×0.337	14.1	0.293	1.18	18.0	0.230	1.50
×0.237	14.1	0.210	1.18	18.0	0.165	1.50
×0.188	14.1	0.167	1.18	18.0	0.131	1.50
×0.125	14.1	0.113	1.18	18.0	0.0888	1.50
HSS4.000×0.337	12.6	0.290	1.05	16.0	0.228	1.33
×0.313	12.6	0.270	1.05	16.0	0.212	1.33
×0.250	12.6	0.219	1.05	16.0	0.172	1.33
×0.237	12.6	0.209	1.05	16.0	0.164	1.33
×0.226	12.6	0.200	1.05	16.0	0.157	1.33
×0.220	12.6	0.194	1.05	16.0	0.153	1.33
×0.188	12.6	0.166	1.05	16.0	0.131	1.33
×0.125	12.6	0.113	1.05	16.0	0.0885	1.33

Case A: Shape perimeter. Case B: Box perimeter, equal to four times the depth.

Table 1-47 (cont.). Round HSS
Surface and Box Perimeters, Area-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B		
	Perimeter	A/P Ratio	Surf. Area	Perimeter	A/P Ratio	Surf. Area
	in.		ft^2/ft	in.		ft^2/ft
HSS3.500×0.313	11.0	0.267	0.917	14.0	0.210	1.17
×0.300	11.0	0.258	0.917	14.0	0.202	1.17
×0.250	11.0	0.217	0.917	14.0	0.171	1.17
×0.216	11.0	0.189	0.917	14.0	0.149	1.17
×0.203	11.0	0.179	0.917	14.0	0.140	1.17
×0.188	11.0	0.165	0.917	14.0	0.130	1.17
×0.125	11.0	0.112	0.917	14.0	0.0881	1.17
HSS3.000×0.300	9.42	0.254	0.785	12.0	0.199	1.00
×0.250	9.42	0.215	0.785	12.0	0.169	1.00
×0.216	9.42	0.188	0.785	12.0	0.147	1.00
×0.203	9.42	0.177	0.785	12.0	0.139	1.00
×0.188	9.42	0.164	0.785	12.0	0.129	1.00
×0.152	9.42	0.135	0.785	12.0	0.106	1.00
×0.134	9.42	0.120	0.785	12.0	0.0941	1.00
×0.120	9.42	0.108	0.785	12.0	0.0847	1.00
HSS2.875×0.250	9.03	0.214	0.753	11.5	0.168	0.958
×0.203	9.03	0.177	0.753	11.5	0.139	0.958
×0.188	9.03	0.163	0.753	11.5	0.128	0.958
×0.125	9.03	0.111	0.753	11.5	0.0874	0.958
HSS2.500×0.250	7.85	0.211	0.654	10.0	0.166	0.833
×0.188	7.85	0.162	0.654	10.0	0.127	0.833
×0.125	7.85	0.111	0.654	10.0	0.0869	0.833
HSS2.375×0.250	7.46	0.210	0.622	9.50	0.165	0.792
×0.218	7.46	0.186	0.622	9.50	0.146	0.792
×0.188	7.46	0.161	0.622	9.50	0.127	0.792
×0.154	7.46	0.134	0.622	9.50	0.106	0.792
×0.125	7.46	0.110	0.622	9.50	0.0867	0.792
HSS1.900×0.145	5.97	0.125	0.498	7.60	0.0985	0.633
HSS1.660×0.140	5.22	0.120	0.435	6.64	0.0941	0.553

Case A: Shape perimeter. Case B: Box perimeter, equal to four times the depth.

Table 1-48. Steel Pipe Surface and Box Perimeters, Area-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B		
	Perimeter	*A*/*P* Ratio	Surf. Area	Perimeter	*A*/*P* Ratio	Surf. Area
	in.		ft^2/ft	in.		ft^2/ft
Standard Weight						
12	40.1	0.364	3.34	51.0	0.286	4.25
10	33.8	0.353	2.81	43.0	0.277	3.58
8	27.1	0.310	2.26	34.5	0.243	2.88
6	20.8	0.268	1.73	26.5	0.211	2.21
5	17.5	0.246	1.46	22.3	0.193	1.85
4	14.1	0.225	1.18	18.0	0.176	1.50
3 1/2	12.6	0.213	1.05	16.0	0.167	1.33
3	11.0	0.203	0.916	14.0	0.159	1.17
2 1/2	9.03	0.189	0.753	11.5	0.148	0.958
2	7.46	0.144	0.622	9.50	0.113	0.792
1 1/2	5.97	0.134	0.497	7.60	0.105	0.633
1 1/4	5.22	0.128	0.435	6.64	0.101	0.553
1	4.13	0.120	0.344	5.26	0.0939	0.438
3/4	3.30	0.101	0.275	4.20	0.0792	0.350
1/2	2.64	0.0949	0.220	3.36	0.0745	0.280
Extra Strong						
12	40.1	0.480	3.34	51.0	0.377	4.25
10	33.8	0.477	2.81	43.0	0.374	3.58
8	27.1	0.471	2.26	34.5	0.370	2.88
6	20.8	0.404	1.73	26.5	0.317	2.21
5	17.5	0.350	1.46	22.3	0.275	1.85
4	14.1	0.312	1.18	18.0	0.245	1.50
3 1/2	12.6	0.293	1.05	16.0	0.230	1.33
3	11.0	0.274	0.916	14.0	0.215	1.17
2 1/2	9.03	0.250	0.753	11.5	0.196	0.958
2	7.46	0.198	0.622	9.50	0.156	0.792
1 1/2	5.97	0.179	0.497	7.60	0.141	0.633
1 1/4	5.22	0.169	0.435	6.64	0.133	0.553
1	4.13	0.155	0.344	5.26	0.121	0.438
3/4	3.30	0.131	0.275	4.20	0.103	0.350
1/2	2.64	0.121	0.220	3.36	0.0952	0.280
Double-Extra Strong						
8	27.1	0.786	2.26	34.5	0.618	2.88
6	20.8	0.751	1.73	26.5	0.590	2.21
5	17.5	0.649	1.46	22.3	0.510	1.85
4	14.1	0.573	1.18	18.0	0.450	1.50
3	11.0	0.497	0.916	14.0	0.390	1.17
2 1/2	9.03	0.446	0.753	11.5	0.350	0.958
2	7.46	0.356	0.622	9.50	0.280	0.792

Case A: Shape perimeter. Case B: Box perimeter, equal to four times the depth.

Table 1-49.
Equal-Leg Double Angles
Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B			Case C			Case D		
	Perimeter	*W/D* Ratio	Surf. Area	Perimeter	*W/D* Ratio	Surf. Area	Perimeter	*W/D* Ratio	Surf. Area	Perimeter	*W/D* Ratio	Surf. Area
	in.		ft²/ft	in.		ft²/ft	in.		ft²/ft	in.		ft²/ft
2L8×8×1 1/8	32.2	3.55	2.68	49.0	3.55	4.08	32.8	3.49	2.73	49.5	2.31	4.13
×1	32.2	3.19	2.68	49.0	2.09	4.08	32.8	3.13	2.73	49.5	2.07	4.13
×7/8	32.2	2.81	2.68	49.0	1.85	4.08	32.8	2.76	2.73	49.5	1.83	4.13
×3/4	32.2	2.43	2.68	49.0	1.60	4.08	32.8	2.39	2.73	49.5	1.58	4.13
×5/8	32.2	2.05	2.68	49.0	1.35	4.08	32.8	2.01	2.73	49.5	1.33	4.13
×9/16	32.2	1.85	2.68	49.0	1.22	4.08	32.8	1.82	2.73	49.5	1.20	4.13
×1/2	32.2	1.66	2.68	49.0	1.09	4.08	32.8	1.63	2.73	49.5	1.08	4.13
2L6×6×1	24.3	3.09	2.03	37.1	2.02	3.09	24.8	3.02	2.07	37.5	2.00	3.13
×7/8	24.3	2.73	2.03	37.1	1.79	3.09	24.8	2.68	2.07	37.5	1.77	3.13
×3/4	24.3	2.37	2.03	37.1	1.55	3.09	24.8	2.32	2.07	37.5	1.54	3.13
×5/8	24.3	2.00	2.03	37.1	1.31	3.09	24.8	1.96	2.07	37.5	1.30	3.13
×9/16	24.3	1.81	2.03	37.1	1.19	3.09	24.8	1.77	2.07	37.5	1.17	3.13
×1/2	24.3	1.61	2.03	37.1	1.06	3.09	24.8	1.58	2.07	37.5	1.05	3.13
×7/16	24.3	1.42	2.03	37.1	0.933	3.09	24.8	1.40	2.07	37.5	0.923	3.13
×3/8	24.3	1.23	2.03	37.1	0.803	3.09	24.8	1.20	2.07	37.5	0.795	3.13
×5/16	24.3	1.03	2.03	37.1	0.674	3.09	24.8	1.01	2.07	37.5	0.667	3.13
2L5×5×7/8	20.3	2.69	1.69	31.1	1.76	2.59	20.8	2.63	1.73	31.5	1.73	2.63
×3/4	20.3	2.33	1.69	31.1	1.52	2.59	20.8	2.28	1.73	31.5	1.50	2.63
×5/8	20.3	1.98	1.69	31.1	1.29	2.59	20.8	1.93	1.73	31.5	1.28	2.63
×1/2	20.3	1.61	1.69	31.1	1.05	2.59	20.8	1.57	1.73	31.5	1.03	2.63
×7/16	20.3	1.42	1.69	31.1	0.926	2.59	20.8	1.38	1.73	31.5	0.914	2.63
×3/8	20.3	1.22	1.69	31.1	0.797	2.59	20.8	1.19	1.73	31.5	0.787	2.63
×5/16	20.3	1.02	1.69	31.1	0.669	2.59	20.8	1.00	1.73	31.5	0.660	2.63
2L4×4×3/4	16.4	2.26	1.37	25.2	1.47	2.10	16.8	2.20	1.40	25.5	1.45	2.13
×5/8	16.4	1.91	1.37	25.2	1.25	2.10	16.8	1.87	1.40	25.5	1.23	2.13
×1/2	16.4	1.55	1.37	25.2	1.01	2.10	16.8	1.51	1.40	25.5	0.996	2.13
×7/16	16.4	1.37	1.37	25.2	0.889	2.10	16.8	1.33	1.40	25.5	0.878	2.13
×3/8	16.4	1.19	1.37	25.2	0.771	2.10	16.8	1.16	1.40	25.5	0.762	2.13
×5/16	16.4	0.995	1.37	25.2	0.648	2.10	16.8	0.971	1.40	25.5	0.640	2.13
×1/4	16.4	0.802	1.37	25.2	0.522	2.10	16.8	0.783	1.40	25.5	0.516	2.13
2L3 1/2×3 1/2×1/2	14.4	1.54	1.20	22.2	1.00	1.85	14.8	1.50	1.23	22.5	0.987	1.88
×7/16	14.4	1.36	1.20	22.2	0.885	1.85	14.8	1.33	1.23	22.5	0.873	1.88
×3/8	14.4	1.18	1.20	22.2	0.767	1.85	14.8	1.15	1.23	22.5	0.756	1.88
×5/16	14.4	0.994	1.20	22.2	0.645	1.85	14.8	0.968	1.23	22.5	0.636	1.88
×1/4	14.4	0.804	1.20	22.2	0.522	1.85	14.8	0.782	1.23	22.5	0.515	1.88
2L3×3×1/2	12.4	1.51	1.03	19.2	0.97	1.60	12.8	1.460	1.07	19.5	0.959	1.63
×7/16	12.4	1.34	1.03	19.2	0.86	1.60	12.8	1.290	1.07	19.5	0.849	1.63
×3/8	12.4	1.16	1.03	19.2	0.75	1.60	12.8	1.120	1.07	19.5	0.735	1.63
×5/16	12.4	0.974	1.03	19.2	0.629	1.60	12.8	0.944	1.07	19.5	0.619	1.63
×1/4	12.4	0.789	1.03	19.2	0.509	1.60	12.8	0.764	1.07	19.5	0.502	1.63
×3/16	12.4	0.597	1.03	19.2	0.385	1.60	12.8	0.578	1.07	19.5	0.379	1.63
2L2 1/2×2 1/2×1/2	10.5	1.46	0.875	16.3	0.94	1.360	10.8	1.420	0.90	16.5	0.927	1.38
×3/8	10.5	1.12	0.875	16.3	0.72	1.360	10.8	1.090	0.90	16.5	0.715	1.38
×5/16	10.5	0.949	0.875	16.3	0.611	1.360	10.8	0.922	0.90	16.5	0.604	1.38
×1/4	10.5	0.770	0.875	16.3	0.496	1.360	10.8	0.748	0.90	16.5	0.490	1.38
×3/16	10.5	0.583	0.875	16.3	0.375	1.360	10.8	0.567	0.90	16.5	0.371	1.38
2L2×2×3/8	8.54	1.09	0.712	13.3	0.70	1.110	8.8	1.060	0.73	13.5	0.689	1.13
×5/16	8.54	0.923	0.712	13.3	0.592	1.110	8.8	0.901	0.73	13.5	0.584	1.13
×1/4	8.54	0.752	0.712	13.3	0.483	1.110	8.8	0.734	0.73	13.5	0.476	1.13
×3/16	8.54	0.576	0.712	13.3	0.370	1.110	8.8	0.562	0.73	13.5	0.364	1.13
×1/8	8.54	0.391	0.712	13.3	0.251	1.110	8.8	0.382	0.73	13.5	0.247	1.13

Case A: Combined shape perimeter, minus two vertical leg widths, minus two horizontal leg widths, and plus a space (space = 3/4-in.).
Case B: Combined shape perimeter, minus two vertical leg widths and plus a space (space = 3/4-in.).
Case C: Combined box perimeter, equal to two horizontal leg widths plus a space (space = 3/4-in.) plus twice the depth.
Case D: Combined box perimeter, equal to four horizontal leg widths plus two spaces (space = 3/4-in.) plus twice the depth.

Table 1-50. LLBB Double Angles Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B			Case C			Case D		
	Perimeter	*W/D* Ratio	Surf. Area	Perimeter	*W/D* Ratio	Surf. Area	Perimeter	*W/D* Ratio	Surf. Area	Perimeter	*W/D* Ratio	Surf. Area
	in.		ft²/ft	in.		ft²/ft	in.		ft²/ft	in.		ft²/ft
2L8×6×1	28.3	3.14	2.36	41.1	2.16	3.43	28.8	3.08	2.40	41.5	2.14	3.46
×7/8	28.3	2.78	2.36	41.1	1.91	3.43	28.8	2.73	2.40	41.5	1.89	3.46
×3/4	28.3	2.40	2.36	41.1	1.65	3.43	28.8	2.36	2.40	41.5	1.64	3.46
×5/8	28.3	2.02	2.36	41.1	1.39	3.43	28.8	1.99	2.40	41.5	1.38	3.46
×9/16	28.3	1.83	2.36	41.1	1.26	3.43	28.8	1.80	2.40	41.5	1.25	3.46
×1/2	28.3	1.64	2.36	41.1	1.13	3.43	28.8	1.61	2.40	41.5	1.12	3.46
×7/16	28.3	1.44	2.36	41.1	0.993	3.43	28.8	1.42	2.40	41.5	0.983	3.46
2L8×4×1	24.3	3.09	2.03	33.1	2.27	2.76	24.8	3.03	2.07	33.5	2.24	2.79
×7/8	24.3	2.74	2.03	33.1	2.01	2.76	24.8	2.69	2.07	33.5	1.99	2.79
×3/4	24.3	2.38	2.03	33.1	1.75	2.76	24.8	2.33	2.07	33.5	1.73	2.79
×5/8	24.3	2.01	2.03	33.1	1.47	2.76	24.8	1.97	2.07	33.5	1.46	2.79
×9/16	24.3	1.82	2.03	33.1	1.34	2.76	24.8	1.78	2.07	33.5	1.32	2.79
×1/2	24.3	1.62	2.03	33.1	1.19	2.76	24.8	1.59	2.07	33.5	1.18	2.79
×7/16	24.3	1.43	2.03	33.1	1.05	2.76	24.8	1.40	2.07	33.5	1.04	2.79
2L7×4×3/4	22.3	2.35	1.86	31.1	1.68	2.59	22.8	2.30	1.90	31.5	1.66	2.63
×5/8	22.3	1.98	1.86	31.1	1.42	2.59	22.8	1.94	1.90	31.5	1.40	2.63
×1/2	22.3	1.61	1.86	31.1	1.15	2.59	22.8	1.57	1.90	31.5	1.14	2.63
×7/16	22.3	1.42	1.86	31.1	1.02	2.59	22.8	1.39	1.90	31.5	1.00	2.63
×3/8	22.3	1.22	1.86	31.1	0.875	2.59	22.8	1.19	1.90	31.5	0.863	2.63
2L6×4×7/8	20.3	2.67	1.69	29.1	1.86	2.43	20.8	2.61	1.73	29.5	1.84	2.46
×3/4	20.3	2.32	1.69	29.1	1.62	2.43	20.8	2.26	1.73	29.5	1.59	2.46
×5/8	20.3	1.95	1.69	29.1	1.36	2.43	20.8	1.90	1.73	29.5	1.34	2.46
×9/16	20.3	1.76	1.69	29.1	1.23	2.43	20.8	1.72	1.73	29.5	1.21	2.46
×1/2	20.3	1.58	1.69	29.1	1.10	2.43	20.8	1.54	1.73	29.5	1.08	2.46
×7/16	20.3	1.39	1.69	29.1	0.969	2.43	20.8	1.36	1.73	29.5	0.956	2.46
×3/8	20.3	1.20	1.69	29.1	0.838	2.43	20.8	1.17	1.73	29.5	0.827	2.46
×5/16	20.3	1.00	1.69	29.1	0.701	2.43	20.8	0.981	1.73	29.5	0.692	2.46
2L6×3 1/2×1/2	19.3	1.59	1.61	27.1	1.13	2.26	19.8	1.55	1.65	27.5	1.11	2.29
×3/8	19.3	1.20	1.61	27.1	0.856	2.26	19.8	1.17	1.65	27.5	0.844	2.29
×5/16	19.3	1.01	1.61	27.1	0.717	2.26	19.8	0.982	1.65	27.5	0.707	2.29
2L5×3 1/2×3/4	17.4	2.28	1.45	25.1	1.58	2.09	17.8	2.22	1.48	25.5	1.55	2.13
×5/8	17.4	1.93	1.45	25.1	1.34	2.09	17.8	1.89	1.48	25.5	1.32	2.13
×1/2	17.4	1.56	1.45	25.1	1.08	2.09	17.8	1.53	1.48	25.5	1.07	2.13
×3/8	17.4	1.20	1.45	25.1	0.829	2.09	17.8	1.17	1.48	25.5	0.816	2.13
×5/16	17.4	1.00	1.45	25.1	0.695	2.09	17.8	0.980	1.48	25.5	0.684	2.13
×1/4	17.4	0.808	1.45	25.1	0.560	2.09	17.8	0.790	1.48	25.5	0.551	2.13
2L5×3×1/2	16.4	1.56	1.37	23.1	1.11	1.93	16.8	1.52	1.40	23.5	1.09	1.96
×7/16	16.4	1.38	1.37	23.1	0.978	1.93	16.8	1.35	1.40	23.5	0.962	1.96
×3/8	16.4	1.19	1.37	23.1	0.843	1.93	16.8	1.16	1.40	23.5	0.829	1.96
×5/16	16.4	0.999	1.37	23.1	0.709	1.93	16.8	0.975	1.40	23.5	0.697	1.96
×1/4	16.4	0.805	1.37	23.1	0.571	1.93	16.8	0.786	1.40	23.5	0.562	1.96
2L4×3 1/2×1/2	15.8	1.51	1.32	23.5	1.01	1.96	15.8	1.51	1.32	23.5	1.01	1.96
×3/8	15.8	1.15	1.32	23.5	0.774	1.96	15.8	1.15	1.32	23.5	0.774	1.96
×5/16	15.8	0.968	1.32	23.5	0.651	1.96	15.8	0.968	1.32	23.5	0.651	1.96
×1/4	15.8	0.782	1.32	23.5	0.526	1.96	15.8	0.782	1.32	23.5	0.526	1.96
2L4×3×5/8	14.8	1.84	1.23	21.5	1.27	1.79	14.8	1.84	1.23	21.5	1.27	1.79
×1/2	14.8	1.50	1.23	21.5	1.03	1.79	14.8	1.50	1.23	21.5	1.03	1.79
×3/8	14.8	1.14	1.23	21.5	0.788	1.79	14.8	1.14	1.23	21.5	0.788	1.79
×5/16	14.8	0.962	1.23	21.5	0.662	1.79	14.8	0.962	1.23	21.5	0.662	1.79
×1/4	14.8	0.777	1.23	21.5	0.535	1.79	14.8	0.777	1.23	21.5	0.535	1.79

Case A: Combined shape perimeter, minus two vertical leg widths, minus two horizontal leg widths, and plus a space (space = 3/4-in.).
Case B: Combined shape perimeter, minus two vertical leg widths and plus a space (space = 3/4-in.).
Case C: Combined box perimeter, equal to two horizontal leg widths plus a space (space = 3/4-in.) plus twice the depth.
Case D: Combined box perimeter, equal to four horizontal leg widths plus two spaces (space = 3/4-in.) plus twice the depth.

Table 1-50 (cont.).
LLBB Double Angles
Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B			Case C			Case D		
	Perimeter	*W/D* Ratio	Surf. Area	Perimeter	*W/D* Ratio	Surf. Area	Perimeter	*W/D* Ratio	Surf. Area	Perimeter	*W/D* Ratio	Surf. Area
	in.		ft^2/ft	in.		ft^2/ft	in.		ft^2/ft	in.		ft^2/ft
2L3$^1/_2$×3×$^1/_2$	13.4	1.54	1.12	20.2	1.02	1.68	13.8	1.49	1.15	20.5	1.00	1.71
×$^7/_{16}$	13.4	1.36	1.12	20.2	0.900	1.68	13.8	1.32	1.15	20.5	0.887	1.71
×$^3/_8$	13.4	1.18	1.12	20.2	0.780	1.68	13.8	1.14	1.15	20.5	0.769	1.71
×$^5/_{16}$	13.4	0.993	1.12	20.2	0.658	1.68	13.8	0.964	1.15	20.5	0.649	1.71
×$^1/_4$	13.4	0.803	1.12	20.2	0.533	1.68	13.8	0.780	1.15	20.5	0.525	1.71
2L3$^1/_2$×2$^1/_2$×$^1/_2$	12.4	1.52	1.03	18.2	1.03	1.52	12.8	1.47	1.07	18.5	1.02	1.54
×$^3/_8$	12.4	1.17	1.03	18.2	0.795	1.52	12.8	1.13	1.07	18.5	0.782	1.54
×$^5/_{16}$	12.4	0.984	1.03	18.2	0.670	1.52	12.8	0.953	1.07	18.5	0.659	1.54
×$^1/_4$	12.4	0.797	1.03	18.2	0.543	1.52	12.8	0.772	1.07	18.5	0.534	1.54
2L3×2$^1/_2$×$^1/_2$	11.4	1.50	0.950	17.2	0.992	1.43	11.8	1.45	0.983	17.5	0.975	1.46
×$^7/_{16}$	11.4	1.33	0.950	17.2	0.879	1.43	11.8	1.28	0.983	17.5	0.864	1.46
×$^3/_8$	11.4	1.15	0.950	17.2	0.763	1.43	11.8	1.11	0.983	17.5	0.750	1.46
×$^5/_{16}$	11.4	0.972	0.950	17.2	0.644	1.43	11.8	0.939	0.983	17.5	0.633	1.46
×$^1/_4$	11.4	0.788	0.950	17.2	0.522	1.43	11.8	0.761	0.983	17.5	0.513	1.46
×$^3/_{16}$	11.4	0.598	0.950	17.2	0.397	1.43	11.8	0.578	0.983	17.5	0.390	1.46
2L3×2×$^1/_2$	10.5	1.47	0.875	15.2	1.01	1.27	10.8	1.43	0.900	15.5	0.994	1.29
×$^3/_8$	10.5	1.13	0.875	15.2	0.783	1.27	10.8	1.10	0.900	15.5	0.768	1.29
×$^5/_{16}$	10.5	0.958	0.875	15.2	0.662	1.27	10.8	0.931	0.900	15.5	0.649	1.29
×$^1/_4$	10.5	0.779	0.875	15.2	0.538	1.27	10.8	0.757	0.900	15.5	0.528	1.29
×$^3/_{16}$	10.5	0.594	0.875	15.2	0.411	1.27	10.8	0.578	0.900	15.5	0.403	1.29
2L2$^1/_2$×2×$^3/_8$	9.54	1.11	0.800	14.3	0.741	1.19	9.75	1.09	0.813	14.5	0.731	1.21
×$^5/_{16}$	9.54	0.941	0.800	14.3	0.628	1.19	9.75	0.921	0.813	14.5	0.619	1.21
×$^1/_4$	9.54	0.765	0.800	14.3	0.510	1.19	9.75	0.749	0.813	14.5	0.503	1.21
×$^3/_{16}$	9.54	0.583	0.800	14.3	0.389	1.19	9.75	0.570	0.813	14.5	0.383	1.21

Case A: Combined shape perimeter, minus two vertical leg widths, minus two horizontal leg widths, and plus a space (space = $^3/_4$-in.).
Case B: Combined shape perimeter, minus two vertical leg widths and plus a space (space = $^3/_4$-in.).
Case C: Combined box perimeter, equal to two horizontal leg widths plus a space (space = $^3/_4$-in.) plus twice the depth.
Case D: Combined box perimeter, equal to four horizontal leg widths plus two spaces (space = $^3/_4$-in.) plus twice the depth.

Table 1-51.
SLBB Double Angles
Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B			Case C			Case D		
	Perimeter	*W/D* Ratio	Surf. Area	Perimeter	*W/D* Ratio	Surf. Area	Perimeter	*W/D* Ratio	Surf. Area	Perimeter	*W/D* Ratio	Surf. Area
	in.		ft^2/ft	in.		ft^2/ft	in.		ft^2/ft	in.		ft^2/ft
2L8×6×1	28.3	3.14	2.36	45.1	1.97	3.76	28.8	3.08	2.40	45.5	1.95	3.79
×7/8	28.3	2.78	2.36	45.1	1.74	3.76	28.8	2.73	2.40	45.5	1.73	3.79
×3/4	28.3	2.40	2.36	45.1	1.51	3.76	28.8	2.36	2.40	45.5	1.49	3.79
×5/8	28.3	2.02	2.36	45.1	1.27	3.76	28.8	1.99	2.40	45.5	1.26	3.79
×9/16	28.3	1.83	2.36	45.1	1.15	3.76	28.8	1.80	2.40	45.5	1.14	3.79
×1/2	28.3	1.64	2.36	45.1	1.03	3.76	28.8	1.61	2.40	45.5	1.02	3.79
×7/16	28.3	1.44	2.36	45.1	0.905	3.76	28.8	1.42	2.40	45.5	0.897	3.79
2L8×4×1	24.3	3.09	2.03	41.1	1.83	3.43	24.8	3.03	2.07	41.5	1.81	3.46
×7/8	24.3	2.74	2.03	41.1	1.62	3.43	24.8	2.69	2.07	41.5	1.60	3.46
×3/4	24.3	2.38	2.03	41.1	1.41	3.43	24.8	2.33	2.07	41.5	1.39	3.46
×5/8	24.3	2.01	2.03	41.1	1.19	3.43	24.8	1.97	2.07	41.5	1.18	3.46
×9/16	24.3	1.82	2.03	41.1	1.08	3.43	24.8	1.78	2.07	41.5	1.07	3.46
×1/2	24.3	1.62	2.03	41.1	0.959	3.43	24.8	1.59	2.07	41.5	0.949	3.46
×7/16	24.3	1.43	2.03	41.1	0.847	3.43	24.8	1.40	2.07	41.5	0.839	3.46
2L7×4×3/4	22.3	2.35	1.86	37.1	1.41	3.09	22.8	2.30	1.90	37.5	1.40	3.13
×5/8	22.3	1.98	1.86	37.1	1.19	3.09	22.8	1.94	1.90	37.5	1.18	3.13
×1/2	22.3	1.61	1.86	37.1	0.965	3.09	22.8	1.57	1.90	37.5	0.96	3.13
×7/16	22.3	1.42	1.86	37.1	0.852	3.09	22.8	1.39	1.90	37.5	0.84	3.13
×3/8	22.3	1.22	1.86	37.1	0.733	3.09	22.8	1.19	1.90	37.5	0.73	3.13
2L6×4×7/8	20.3	2.67	1.69	33.1	1.64	2.76	20.8	2.61	1.73	33.5	1.62	2.79
×3/4	20.3	2.32	1.69	33.1	1.42	2.76	20.8	2.26	1.73	33.5	1.40	2.79
×5/8	20.3	1.95	1.69	33.1	1.20	2.76	20.8	1.90	1.73	33.5	1.18	2.79
×9/16	20.3	1.76	1.69	33.1	1.08	2.76	20.8	1.72	1.73	33.5	1.07	2.79
×1/2	20.3	1.58	1.69	33.1	0.967	2.76	20.8	1.54	1.73	33.5	0.955	2.79
×7/16	20.3	1.39	1.69	33.1	0.852	2.76	20.8	1.36	1.73	33.5	0.842	2.79
×3/8	20.3	1.20	1.69	33.1	0.737	2.76	20.8	1.17	1.73	33.5	0.728	2.79
×5/16	20.3	1.00	1.69	33.1	0.616	2.76	20.8	0.981	1.73	33.5	0.609	2.79
2L6×3 1/2×1/2	19.3	1.59	1.61	32.1	0.953	2.68	19.8	1.55	1.65	32.5	0.942	2.71
×3/8	19.3	1.20	1.61	32.1	0.723	2.68	19.8	1.17	1.65	32.5	0.714	2.71
×5/16	19.3	1.01	1.61	32.1	0.606	2.68	19.8	0.982	1.65	32.5	0.598	2.71
2L5×3 1/2×3/4	17.4	2.28	1.45	28.1	1.41	2.34	17.8	2.22	1.48	28.5	1.39	2.38
×5/8	17.4	1.93	1.45	28.1	1.20	2.34	17.8	1.89	1.48	28.5	1.18	2.38
×1/2	17.4	1.56	1.45	28.1	0.968	2.34	17.8	1.53	1.48	28.5	0.954	2.38
×3/8	17.4	1.20	1.45	28.1	0.740	2.34	17.8	1.17	1.48	28.5	0.730	2.38
×5/16	17.4	1.00	1.45	28.1	0.621	2.34	17.8	0.980	1.48	28.5	0.612	2.38
×1/4	17.4	0.808	1.45	28.1	0.500	2.34	17.8	0.790	1.48	28.5	0.493	2.38
2L5×3×1/2	16.4	1.56	1.37	27.1	0.945	2.26	16.8	1.52	1.40	27.5	0.931	2.29
×7/16	16.4	1.38	1.37	27.1	0.834	2.26	16.8	1.35	1.40	27.5	0.822	2.29
×3/8	16.4	1.19	1.37	27.1	0.719	2.26	16.8	1.16	1.40	27.5	0.708	2.29
×5/16	16.4	0.999	1.37	27.1	0.604	2.26	16.8	0.975	1.40	27.5	0.596	2.29
×1/4	16.4	0.805	1.37	27.1	0.487	2.26	16.8	0.786	1.40	27.5	0.480	2.29
2L4×3 1/2×1/2	15.8	1.510	1.32	24.5	0.971	2.04	15.8	1.51	1.32	24.5	0.971	2.04
×3/8	15.8	1.150	1.32	24.5	0.743	2.04	15.8	1.15	1.32	24.5	0.743	2.04
×5/16	15.8	0.968	1.32	24.5	0.624	2.04	15.8	0.968	1.32	24.5	0.624	2.04
×1/4	15.8	0.782	1.32	24.5	0.504	2.04	15.8	0.782	1.32	24.5	0.504	2.04
2L4×3×5/8	14.8	1.84	1.23	23.5	1.16	1.96	14.8	1.84	1.23	23.5	1.16	1.96
×1/2	14.8	1.50	1.23	23.5	0.945	1.96	14.8	1.50	1.23	23.5	0.945	1.96
×3/8	14.8	1.14	1.23	23.5	0.721	1.96	14.8	1.14	1.23	23.5	0.721	1.96
×5/16	14.8	0.962	1.23	23.5	0.606	1.96	14.8	0.962	1.23	23.5	0.606	1.96
×1/4	14.8	0.777	1.23	23.5	0.489	1.96	14.8	0.777	1.23	23.5	0.489	1.96

Case A: Combined shape perimeter, minus two vertical leg widths, minus two horizontal leg widths, and plus a space (space = 3/4-in.).
Case B: Combined shape perimeter, minus two vertical leg widths and plus a space (space = 3/4-in.).
Case C: Combined box perimeter, equal to two horizontal leg widths plus a space (space = 3/4-in.) plus twice the depth.
Case D: Combined box perimeter, equal to four horizontal leg widths plus two spaces (space = 3/4-in.) plus twice the depth.

Table 1-51 (cont.). SLBB Double Angles
Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A 			Case B 			Case C 			Case D 		
	Peri-meter	*W/D* Ratio	Surf. Area	Peri-meter	*W/D* Ratio	Surf. Area	Peri-meter	*W/D* Ratio	Surf. Area	Peri-meter	*W/D* Ratio	Surf. Area
	in.		ft^2/ft	in.		ft^2/ft	in.		ft^2/ft	in.		ft^2/ft
2L3 $^1/_2$×3×$^1/_2$	13.4	1.54	1.12	21.2	0.972	1.77	13.8	1.49	1.15	21.5	0.958	1.79
×$^7/_{16}$	13.4	1.36	1.12	21.2	0.858	1.77	13.8	1.32	1.15	21.5	0.846	1.79
×$^3/_8$	13.4	1.18	1.12	21.2	0.743	1.77	13.8	1.14	1.15	21.5	0.733	1.79
×$^5/_{16}$	13.4	0.993	1.12	21.2	0.627	1.77	13.8	0.964	1.15	21.5	0.619	1.79
×$^1/_4$	13.4	0.803	1.12	21.2	0.508	1.77	13.8	0.780	1.15	21.5	0.500	1.79
2L3 $^1/_2$×2 $^1/_2$×$^1/_2$	12.4	1.52	1.03	20.2	0.932	1.68	12.8	1.47	1.07	20.5	0.918	1.71
×$^3/_8$	12.4	1.17	1.03	20.2	0.716	1.68	12.8	1.13	1.07	20.5	0.705	1.71
×$^5/_{16}$	12.4	0.984	1.03	20.2	0.604	1.68	12.8	0.953	1.07	20.5	0.595	1.71
×$^1/_4$	12.4	0.797	1.03	20.2	0.489	1.68	12.8	0.772	1.07	20.5	0.482	1.71
2L3×2 $^1/_2$×$^1/_2$	11.4	1.50	0.950	18.2	0.937	1.52	11.8	1.45	0.983	18.5	0.92	1.54
×$^7/_{16}$	11.4	1.33	0.950	18.2	0.831	1.52	11.8	1.28	0.983	18.5	0.82	1.54
×$^3/_8$	11.4	1.15	0.950	18.2	0.721	1.52	11.8	1.11	0.983	18.5	0.71	1.54
×$^5/_{16}$	11.4	0.972	0.950	18.2	0.609	1.52	11.8	0.939	0.983	18.5	0.599	1.54
×$^1/_4$	11.4	0.788	0.950	18.2	0.493	1.52	11.8	0.761	0.983	18.5	0.485	1.54
×$^3/_{16}$	11.4	0.598	0.950	18.2	0.375	1.52	11.8	0.578	0.983	18.5	0.369	1.54
2L3×2×$^1/_2$	10.5	1.47	0.88	17.2	0.895	1.43	10.8	1.43	0.900	17.5	0.88	1.46
×$^3/_8$	10.5	1.13	0.88	17.2	0.692	1.43	10.8	1.10	0.900	17.5	0.68	1.46
×$^5/_{16}$	10.5	0.958	0.88	17.2	0.585	1.43	10.8	0.931	0.900	17.5	0.575	1.46
×$^1/_4$	10.5	0.779	0.88	17.2	0.476	1.43	10.8	0.757	0.900	17.5	0.467	1.46
×$^3/_{16}$	10.5	0.594	0.88	17.2	0.363	1.43	10.8	0.578	0.900	17.5	0.357	1.46
2L2 $^1/_2$×2×$^3/_8$	9.5	1.11	0.80	15.3	0.693	1.28	9.75	1.090	0.813	15.5	0.684	1.29
×$^5/_{16}$	9.5	0.941	0.80	15.3	0.587	1.28	9.75	0.921	0.813	15.5	0.579	1.29
×$^1/_4$	9.5	0.765	0.80	15.3	0.477	1.28	9.75	0.749	0.813	15.5	0.471	1.29
×$^3/_{16}$	9.5	0.583	0.80	15.3	0.363	1.28	9.75	0.570	0.813	15.5	0.359	1.29

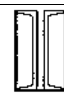
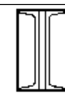
Case A: Combined shape perimeter, minus two vertical leg widths, minus two horizontal leg widths, and plus a space (space = $^3/_4$-in.).
Case B: Combined shape perimeter, minus two vertical leg widths and plus a space (space = $^3/_4$-in.).
Case C: Combined box perimeter, equal to two horizontal leg widths plus a space (space = $^3/_4$-in.) plus twice the depth.
Case D: Combined box perimeter, equal to four horizontal leg widths plus two spaces (space = $^3/_4$-in.) plus twice the depth.

Table 1-52. 2C-Shapes (Double American Standard Channels) Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A			Case B			Case C			Case D		
	Perimeter in.	W/D Ratio	Surf. Area ft^2/ft	Perimeter in.	W/D Ratio	Surf. Area ft^2/ft	Perimeter in.	W/D Ratio	Surf. Area ft^2/ft	Perimeter in.	W/D Ratio	Surf. Area ft^2/ft
2C15×50	50.2	1.99	4.18	58.4	1.71	4.87	38.2	2.62	3.18	46.4	2.16	3.87
×40	49.1	1.63	4.09	56.9	1.41	4.74	37.8	2.12	3.15	45.6	1.75	3.80
×33.9	48.4	1.40	4.03	56.0	1.21	4.67	37.6	1.80	3.13	45.1	1.50	3.76
2C12×30	41.4	1.45	3.45	48.5	1.24	4.04	31.1	1.93	2.59	38.2	1.57	3.18
×25	40.7	1.23	3.39	47.6	1.05	3.97	30.9	1.62	2.58	37.7	1.33	3.14
×20.7	40.1	1.03	3.34	46.7	0.887	3.89	30.6	1.35	2.55	37.3	1.11	3.11
2C10×30	36.7	1.63	3.06	43.5	1.38	3.63	26.8	2.24	2.23	33.6	1.79	2.80
×25	35.9	1.39	2.99	42.4	1.18	3.53	26.5	1.89	2.21	33.1	1.51	2.76
×20	35.1	1.14	2.93	41.3	0.969	3.44	26.2	1.53	2.18	32.5	1.23	2.71
×15.3	34.3	0.892	2.86	40.3	0.759	3.36	26.0	1.18	2.17	31.9	0.959	2.66
2C9×20	32.6	1.23	2.72	38.6	1.04	3.22	24.1	1.66	2.01	30.1	1.33	2.51
×15	31.7	0.946	2.64	37.4	0.802	3.12	23.7	1.27	1.98	29.5	1.02	2.46
×13.4	31.4	0.854	2.62	37.0	0.724	3.08	23.6	1.14	1.97	29.2	0.918	2.43
2C8×18.75	30.0	1.25	2.50	35.8	1.05	2.98	21.8	1.72	1.82	27.6	1.36	2.30
×13.75	28.9	0.952	2.41	34.3	0.802	2.86	21.4	1.29	1.78	26.9	1.02	2.24
×11.5	28.5	0.807	2.38	33.7	0.682	2.81	21.3	1.08	1.78	26.5	0.868	2.21
2C7×14.75	26.7	1.10	2.23	32.1	0.919	2.68	19.4	1.52	1.62	24.7	1.19	2.06
×12.25	26.1	0.939	2.18	31.3	0.783	2.61	19.1	1.28	1.59	24.3	1.01	2.03
×9.8	25.6	0.766	2.13	30.5	0.643	2.54	18.9	1.04	1.58	23.9	0.820	1.99
2C6×13	24.0	1.08	2.00	29.1	0.893	2.43	17.1	1.52	1.43	22.1	1.18	1.84
×10.5	23.3	0.901	1.94	28.1	0.747	2.34	16.8	1.25	1.40	21.6	0.972	1.80
×8.2	22.7	0.722	1.89	27.3	0.601	2.28	16.6	0.988	1.38	21.2	0.774	1.77
2C5×9	20.6	0.874	1.72	25.1	0.717	2.09	14.5	1.24	1.21	19.1	0.942	1.59
×6.7	19.8	0.677	1.65	24.1	0.556	2.01	14.3	0.937	1.19	18.5	0.724	1.54
2C4×7.25	17.6	0.824	1.47	21.8	0.665	1.82	12.2	1.19	1.02	16.4	0.884	1.37
×5.4	16.9	0.639	1.41	20.8	0.519	1.73	11.9	0.908	0.992	15.8	0.684	1.32
×4.5	16.9	0.533	1.41	20.8	0.433	1.73	11.9	0.756	0.992	15.8	0.570	1.32
2C3×6	15.0	0.800	1.25	19.0	0.632	1.58	9.95	1.21	0.829	13.9	0.863	1.16
×5	14.5	0.690	1.21	18.2	0.549	1.52	9.75	1.03	0.813	13.5	0.741	1.13
×4.1	14.0	0.586	1.17	17.5	0.469	1.46	9.57	0.857	0.798	13.1	0.626	1.09
×3.5	13.8	0.507	1.15	17.2	0.407	1.43	9.49	0.738	0.791	13.0	0.538	1.08

Case A: Combined shape perimeter, minus top flange surfaces, minus twice the depth and plus a space (space = 3/4-in.).
Case B: Combined shape perimeter, minus twice the depth plus two spaces (space = 3/4-in.).
Case C: Combined box perimeter, equal to two flange surfaces plus a space (space = 3/4-in.) plus twice the depth.
Case D: Box perimeter, equal to four flange surfaces plus two spaces (space = 3/4-in.) plus twice the depth.

Table 1-53.
2MC-Shapes (Double Miscellaneous Channels)
Surface and Box Perimeters, Weight-to-Perimeter Ratios, and Surface Areas

Shape	Case A 			Case B 			Case C 			Case D 		
	Peri-meter	*W/D* Ratio	Surf. Area	Peri-meter	*W/D* Ratio	Surf. Area	Peri-meter	*W/D* Ratio	Surf. Area	Peri-meter	*W/D* Ratio	Surf. Area
	in.		ft²/ft	in.		ft²/ft	in.		ft²/ft	in.		ft²/ft
2MC18×58	58.8	1.97	4.90	67.9	1.71	5.66	45.2	2.57	3.77	54.3	2.14	4.53
×51.9	58.2	1.78	4.85	67.2	1.54	5.60	45.0	2.31	3.75	53.9	1.93	4.49
×45.8	57.7	1.59	4.81	66.5	1.38	5.54	44.8	2.04	3.73	53.5	1.71	4.46
×42.7	57.4	1.49	4.78	66.1	1.29	5.51	44.7	1.91	3.73	53.3	1.60	4.44
2MC13×50	49.9	2.00	4.16	59.5	1.68	4.96	35.6	2.81	2.97	45.1	2.22	3.76
×40	48.7	1.64	4.06	57.8	1.38	4.82	35.1	2.28	2.93	44.2	1.81	3.68
×35	48.1	1.46	4.01	57.0	1.23	4.75	34.9	2.01	2.91	43.8	1.60	3.65
×31.8	47.7	1.33	3.98	56.4	1.13	4.70	34.8	1.83	2.90	43.5	1.46	3.63
2MC12×50	46.7	2.14	3.89	55.8	1.79	4.65	33.0	3.03	2.75	42.1	2.38	3.51
×45	46.0	1.96	3.83	54.8	1.64	4.57	32.8	2.74	2.73	41.5	2.17	3.46
×40	45.3	1.77	3.78	53.9	1.48	4.49	32.5	2.46	2.71	41.1	1.95	3.43
×35	44.7	1.57	3.73	53.0	1.32	4.42	32.3	2.17	2.69	40.6	1.72	3.38
×31	44.1	1.41	3.68	52.2	1.19	4.35	32.1	1.93	2.68	40.2	1.54	3.35
2MC12×10.6	32.4	0.654	2.70	36.2	0.586	3.02	27.8	0.763	2.32	31.5	0.673	2.63
2MC10×41.1	43.6	1.89	3.63	52.9	1.55	4.41	29.4	2.80	2.45	38.8	2.12	3.23
×33.6	42.3	1.59	3.53	51.3	1.31	4.28	29.0	2.32	2.42	37.9	1.77	3.16
×28.5	41.5	1.37	3.46	50.2	1.14	4.18	28.7	1.99	2.39	37.3	1.53	3.11
2MC10×25	38.6	1.30	3.22	46.1	1.08	3.84	27.6	1.81	2.30	35.1	1.42	2.93
×22	38.1	1.15	3.18	45.4	0.969	3.78	27.4	1.61	2.28	34.8	1.26	2.90
2MC10×8.4	28.4	0.592	2.37	32.1	0.523	2.68	23.8	0.706	1.98	27.5	0.611	2.29
2MC9×25.4	37.1	1.37	3.09	44.8	1.13	3.73	25.8	1.97	2.15	33.5	1.52	2.79
×23.9	36.8	1.30	3.07	44.5	1.07	3.71	25.7	1.86	2.14	33.3	1.44	2.78
2MC8×22.8	35.1	1.30	2.93	42.9	1.06	3.58	23.8	1.92	1.98	31.5	1.45	2.63
×21.4	34.9	1.23	2.91	42.5	1.01	3.54	23.7	1.81	1.98	31.3	1.37	2.61
2MC8×20	32.6	1.23	2.72	39.4	1.02	3.28	22.8	1.75	1.90	29.6	1.35	2.47
×18.7	32.3	1.16	2.69	39.0	0.959	3.25	22.7	1.65	1.89	29.4	1.27	2.45
2MC8×8.5	26.4	0.644	2.20	30.9	0.550	2.58	20.5	0.829	1.71	25.0	0.680	2.08
2MC7×22.7	33.7	1.35	2.81	41.7	1.09	3.48	22.0	2.06	1.83	29.9	1.52	2.49
×19.1	32.9	1.16	2.74	40.6	0.941	3.38	21.7	1.76	1.81	29.3	1.30	2.44
2MC6×18	31.2	1.15	2.60	39.0	0.923	3.25	19.8	1.82	1.65	27.5	1.31	2.29
×15.3	31.4	0.975	2.62	39.1	0.783	3.26	19.8	1.55	1.65	27.5	1.11	2.29
2MC6×16.3	28.5	1.14	2.38	35.2	0.926	2.93	18.8	1.73	1.57	25.5	1.28	2.13
×15.1	28.2	1.07	2.35	34.8	0.868	2.90	18.6	1.62	1.55	25.3	1.19	2.11
2MC6×12	25.9	0.927	2.16	31.6	0.759	2.63	17.8	1.35	1.48	23.5	1.02	1.96

Case A: Combined shape perimeter, minus top flange surfaces, minus twice the depth and plus a space (space = 3/4-in.).
Case B: Combined shape perimeter, minus twice the depth plus two spaces (space = 3/4-in.).
Case C: Combined box perimeter, equal to two flange surfaces plus a space (space = 3/4-in.) plus twice the depth.
Case D: Box perimeter, equal to four flange surfaces plus two spaces (space = 3/4-in.) plus twice the depth.

Appendix B-1
D-902 SFRM THICKNESS

W8x28 Test Beam		D-902 FIBER				
		1, 1 1/2 & 2 Hours		3 Hour		
		Fluted Deck	Cellular Deck	Fluted Deck	Fluted Deck	Cellular Deck
Section	W/D	NW or LW Concrete	NW or LW Concrete	NW Concrete	LW Concrete	NW or LW Concrete
W4X13	0.65	7/16	9/16	9/16	13/16	1
W5X16	0.65	7/16	9/16	9/16	13/16	1
W5X19	0.76	7/16	9/16	9/16	3/4	15/16
W6X9	0.39	9/16	3/4	3/4	1	1 1/4
W6X12	0.51	1/2	11/16	11/16	7/8	1 1/8
W6X15	0.51	1/2	11/16	11/16	7/8	1 1/8
W6X16	0.66	7/16	9/16	9/16	13/16	1
W6X20	0.67	7/16	9/16	9/16	13/16	1
W6X25	0.82	3/8	1/2	1/2	11/16	7/8
W8X10	0.37	9/16	3/4	3/4	1	1 5/16
W8X13	0.47	1/2	11/16	11/16	15/16	1 3/16
W8X15	0.54	1/2	5/8	5/8	7/8	1 1/8
W8X17	0.54	1/2	5/8	5/8	7/8	1 1/8
W8X18	0.57	1/2	5/8	5/8	7/8	1 1/16
W8X20	0.57	1/2	5/8	5/8	7/8	1 1/16
W8X21	0.66	7/16	9/16	9/16	13/16	1
W8X24	0.69	7/16	9/16	9/16	3/4	1
W8X28	0.80	3/8	1/2	1/2	11/16	7/8
W8X31	0.79	7/16	9/16	9/16	3/4	15/16
W8X35	0.88	3/8	1/2	1/2	11/16	7/8
W8X40	1.00	3/8	7/16	7/16	5/8	13/16
W8X48	1.18	3/8	7/16	7/16	9/16	3/4
W8X58	1.41	3/8	3/8	3/8	1/2	5/8
W8X67	1.61	3/8	3/8	3/8	7/16	9/16
W10X12	0.38	9/16	3/4	3/4	1	1 1/4
W10X15	0.48	1/2	11/16	11/16	15/16	1 3/16
W10X17	0.54	1/2	5/8	5/8	7/8	1 1/8
W10X19	0.59	1/2	5/8	5/8	13/16	1 1/16
W10X22	0.59	1/2	5/8	5/8	13/16	1 1/16
W10X26	0.69	7/16	9/16	9/16	3/4	1
W10X30	0.79	7/16	9/16	9/16	3/4	15/16
W10X33	0.77	7/16	9/16	9/16	3/4	15/16
W10X39	0.90	3/8	1/2	1/2	11/16	7/8
W10X45	1.03	3/8	7/16	7/16	5/8	13/16
W10X49	0.99	3/8	1/2	1/2	5/8	13/16
W10X54	1.09	3/8	7/16	7/16	5/8	3/4

W8x28 Test Beam		D-902 FIBER				
		1, 1 1/2 & 2 Hours		3 Hour		
		Fluted Deck	Cellular Deck	Fluted Deck	Fluted Deck	Cellular Deck
Section	W/D	NW or LW Concrete	NW or LW Concrete	NW Concrete	LW Concrete	NW or LW Concrete
W10X60	1.20	3/8	7/16	7/16	9/16	11/16
W10X68	1.35	3/8	3/8	3/8	1/2	11/16
W10X77	1.52	3/8	3/8	3/8	1/2	5/8
W10X88	1.72	3/8	3/8	3/8	7/16	9/16
W10X100	1.93	3/8	3/8	3/8	7/16	1/2
W10X112	2.14	3/8	3/8	3/8	3/8	1/2
W12X14	0.40	9/16	3/4	3/4	1	1 1/4
W12X16	0.45	1/2	11/16	11/16	15/16	1 3/16
W12X19	0.53	1/2	5/8	5/8	7/8	1 1/8
W12X22	0.61	7/16	5/8	5/8	13/16	1 1/16
W12X26	0.60	7/16	5/8	5/8	13/16	1 1/16
W12X30	0.69	7/16	9/16	9/16	3/4	1
W12X35	0.79	7/16	9/16	9/16	3/4	15/16
W12X40	0.85	3/8	1/2	1/2	11/16	7/8
W12X45	0.95	3/8	1/2	1/2	5/8	13/16
W12X50	1.04	3/8	7/16	7/16	5/8	3/4
W12X53	0.99	3/8	1/2	1/2	5/8	13/16
W12X58	1.08	3/8	7/16	7/16	5/8	3/4
W12X65	1.09	3/8	7/16	7/16	5/8	3/4
W12X72	1.20	3/8	7/16	7/16	9/16	11/16
W12X79	1.32	3/8	3/8	3/8	9/16	11/16
W12X87	1.44	3/8	3/8	3/8	1/2	5/8
W12X96	1.58	3/8	3/8	3/8	1/2	9/16
W12X106	1.73	3/8	3/8	3/8	7/16	9/16
W12X120	1.94	3/8	3/8	3/8	7/16	1/2
W12X136	2.18	3/8	3/8	3/8	3/8	1/2
W12X152	2.41	3/8	3/8	3/8	3/8	7/16
W12X170	2.66	3/8	3/8	3/8	3/8	7/16
W12X190	2.94	3/8	3/8	3/8	3/8	3/8
W14X22	0.52	1/2	5/8	5/8	7/8	1 1/8
W14X26	0.61	7/16	5/8	5/8	13/16	1 1/16
W14X30	0.63	7/16	5/8	5/8	13/16	1
W14X34	0.71	7/16	9/16	9/16	3/4	15/16
W14X38	0.79	7/16	9/16	9/16	3/4	15/16
W14X43	0.85	3/8	1/2	1/2	11/16	7/8
W14X48	0.94	3/8	1/2	1/2	5/8	13/16
W14X53	1.03	3/8	7/16	7/16	5/8	13/16
W14X61	1.07	3/8	7/16	7/16	5/8	3/4
W14X68	1.19	3/8	7/16	7/16	9/16	11/16
W14X74	1.28	3/8	3/8	3/8	9/16	11/16
W14X82	1.41	3/8	3/8	3/8	1/2	5/8
W14X90	1.27	3/8	3/8	3/8	9/16	11/16
W14X99	1.39	3/8	3/8	3/8	1/2	5/8

W8x28 Test Beam		D-902 FIBER				
		1, 1 1/2 & 2 Hours		3 Hour		
		Fluted Deck	Cellular Deck	Fluted Deck	Fluted Deck	Cellular Deck
Section	W/D	NW or LW Concrete	NW or LW Concrete	NW Concrete	LW Concrete	NW or LW Concrete
W14X109	1.53	3/8	3/8	3/8	1/2	5/8
W14X120	1.67	3/8	3/8	3/8	7/16	9/16
W14X132	1.83	3/8	3/8	3/8	7/16	9/16
W14X145	1.94	3/8	3/8	3/8	7/16	1/2
W14X159	2.12	3/8	3/8	3/8	3/8	1/2
W14X176	2.32	3/8	3/8	3/8	3/8	7/16
W14X193	2.53	3/8	3/8	3/8	3/8	7/16
W14X211	2.74	3/8	3/8	3/8	3/8	3/8
W16X26	0.55	1/2	5/8	5/8	7/8	1 1/8
W16X31	0.65	7/16	9/16	9/16	13/16	1
W16X36	0.69	7/16	9/16	9/16	3/4	1
W16X40	0.76	7/16	9/16	9/16	3/4	15/16
W16X45	0.85	3/8	1/2	1/2	11/16	7/8
W16X50	0.94	3/8	1/2	1/2	5/8	13/16
W16X57	1.07	3/8	7/16	7/16	5/8	3/4
W16X67	1.07	3/8	7/16	7/16	5/8	3/4
W16X77	1.22	3/8	7/16	7/16	9/16	11/16
W16X89	1.40	3/8	3/8	3/8	1/2	5/8
W16X100	1.56	3/8	3/8	3/8	1/2	5/8
W18X35	0.66	7/16	9/16	9/16	13/16	1
W18X40	0.75	7/16	9/16	9/16	3/4	15/16
W18X46	0.86	3/8	1/2	1/2	11/16	7/8
W18X50	0.87	3/8	1/2	1/2	11/16	7/8
W18X55	0.95	3/8	1/2	1/2	5/8	13/16
W18X60	1.03	3/8	7/16	7/16	5/8	13/16
W18X65	1.11	3/8	7/16	7/16	5/8	3/4
W18X71	1.21	3/8	7/16	7/16	9/16	11/16
W18X76	1.11	3/8	7/16	7/16	5/8	3/4
W18X86	1.24	3/8	7/16	7/16	9/16	11/16
W18X97	1.39	3/8	3/8	3/8	1/2	5/8
W18X106	1.52	3/8	3/8	3/8	1/2	5/8
W18X119	1.69	3/8	3/8	3/8	7/16	9/16
W18X130	1.84	3/8	3/8	3/8	7/16	9/16
W18X143	2.01	3/8	3/8	3/8	3/8	1/2
W18X158	2.20	3/8	3/8	3/8	3/8	7/16
W18X175	2.42	3/8	3/8	3/8	3/8	7/16
W18X192	2.62	3/8	3/8	3/8	3/8	7/16
W21X44	0.73	7/16	9/16	9/16	3/4	15/16
W21X50	0.83	3/8	1/2	1/2	11/16	7/8
W21X57	0.93	3/8	1/2	1/2	11/16	13/16
W21X62	0.94	3/8	1/2	1/2	5/8	13/16
W21X68	1.03	3/8	7/16	7/16	5/8	13/16

W8x28 Test Beam		D-902 FIBER				
		1, 1 1/2 & 2 Hours		3 Hour		
		Fluted Deck	Cellular Deck	Fluted Deck	Fluted Deck	Cellular Deck
Section	W/D	NW or LW Concrete	NW or LW Concrete	NW Concrete	LW Concrete	NW or LW Concrete
W21X73	1.10	3/8	7/16	7/16	5/8	3/4
W21X83	1.24	3/8	7/16	7/16	9/16	11/16
W21X93	1.38	3/8	3/8	3/8	1/2	5/8
W21X101	1.29	3/8	3/8	3/8	9/16	11/16
W21X111	1.41	3/8	3/8	3/8	1/2	5/8
W21X122	1.54	3/8	3/8	3/8	1/2	5/8
W21X132	1.66	3/8	3/8	3/8	7/16	9/16
W21X147	1.83	3/8	3/8	3/8	7/16	9/16
W21X166	2.06	3/8	3/8	3/8	3/8	1/2
W21X182	2.24	3/8	3/8	3/8	3/8	7/16
W21X201	2.45	3/8	3/8	3/8	3/8	7/16
W24X55	0.82	3/8	1/2	1/2	11/16	7/8
W24X62	0.92	3/8	1/2	1/2	11/16	13/16
W24X68	0.92	3/8	1/2	1/2	11/16	13/16
W24X76	1.03	3/8	7/16	7/16	5/8	13/16
W24X84	1.13	3/8	7/16	7/16	9/16	3/4
W24X94	1.26	3/8	7/16	7/16	9/16	11/16
W24X103	1.37	3/8	3/8	3/8	1/2	5/8
W24X104	1.22	3/8	7/16	7/16	9/16	11/16
W24X117	1.36	3/8	3/8	3/8	1/2	5/8
W24X131	1.52	3/8	3/8	3/8	1/2	5/8
W24X146	1.68	3/8	3/8	3/8	7/16	9/16
W24X162	1.85	3/8	3/8	3/8	7/16	1/2
W24X176	2.01	3/8	3/8	3/8	3/8	1/2
W24X192	2.18	3/8	3/8	3/8	3/8	1/2
W24X207	2.33	3/8	3/8	3/8	3/8	7/16
W24X229	2.56	3/8	3/8	3/8	3/8	7/16
W27X84	1.02	3/8	7/16	7/16	5/8	13/16
W27X94	1.13	3/8	7/16	7/16	9/16	3/4
W27X102	1.23	3/8	7/16	7/16	9/16	11/16
W27X114	1.36	3/8	3/8	3/8	1/2	5/8
W27X129	1.53	3/8	3/8	3/8	1/2	5/8
W27X146	1.53	3/8	3/8	3/8	1/2	5/8
W27X161	1.68	3/8	3/8	3/8	7/16	9/16
W27X178	1.85	3/8	3/8	3/8	7/16	1/2
W27X194	2.00	3/8	3/8	3/8	3/8	1/2
W27X217	2.22	3/8	3/8	3/8	3/8	7/16
W27X235	2.40	3/8	3/8	3/8	3/8	7/16
W27X258	2.61	3/8	3/8	3/8	3/8	7/16
W30X108	1.20	3/8	7/16	7/16	9/16	11/16
W30X116	1.28	3/8	3/8	3/8	9/16	11/16
W30X124	1.37	3/8	3/8	3/8	1/2	5/8

W8x28 Test Beam		D-902 FIBER				
		1, 1 1/2 & 2 Hours		3 Hour		
		Fluted Deck	Cellular Deck	Fluted Deck	Fluted Deck	Cellular Deck
Section	W/D	NW or LW Concrete	NW or LW Concrete	NW Concrete	LW Concrete	NW or LW Concrete
W30X132	1.45	3/8	3/8	3/8	1/2	5/8
W30X148	1.62	3/8	3/8	3/8	7/16	9/16
W30X173	1.66	3/8	3/8	3/8	7/16	9/16
W30X191	1.82	3/8	3/8	3/8	7/16	9/16
W30X211	2.00	3/8	3/8	3/8	3/8	1/2
W30X235	2.21	3/8	3/8	3/8	3/8	7/16
W30X261	2.44	3/8	3/8	3/8	3/8	7/16
W30X90	1.01	3/8	7/16	7/16	5/8	13/16
W30X99	1.10	3/8	7/16	7/16	5/8	3/4
W33X118	1.19	3/8	7/16	7/16	9/16	11/16
W33X130	1.31	3/8	3/8	3/8	9/16	11/16
W33X141	1.41	3/8	3/8	3/8	1/2	5/8
W33X152	1.51	3/8	3/8	3/8	1/2	5/8
W33X169	1.68	3/8	3/8	3/8	7/16	9/16
W33X201	1.78	3/8	3/8	3/8	7/16	9/16
W33X221	1.94	3/8	3/8	3/8	7/16	1/2
W33X241	2.11	3/8	3/8	3/8	3/8	1/2
W36X135	1.28	3/8	3/8	3/8	9/16	11/16
W36X150	1.41	3/8	3/8	3/8	1/2	5/8
W36X160	1.50	3/8	3/8	3/8	1/2	5/8
W36X170	1.59	3/8	3/8	3/8	1/2	9/16
W36X182	1.69	3/8	3/8	3/8	7/16	9/16
W36X194	1.80	3/8	3/8	3/8	7/16	9/16
W36X210	1.94	3/8	3/8	3/8	7/16	1/2
W36X230	1.92	3/8	3/8	3/8	7/16	1/2
W36X232	2.13	3/8	3/8	3/8	3/8	1/2
W36X245	2.04	3/8	3/8	3/8	3/8	1/2
W36X256	2.34	3/8	3/8	3/8	3/8	7/16
W36X260	2.16	3/8	3/8	3/8	3/8	1/2
W36X280	2.31	3/8	3/8	3/8	3/8	7/16
W36X300	2.47	3/8	3/8	3/8	3/8	7/16
W40X149	1.35	3/8	3/8	3/8	1/2	11/16
W40X167	1.50	3/8	3/8	3/8	1/2	5/8
W40X174	1.42	3/8	3/8	3/8	1/2	5/8
W40X183	1.63	3/8	3/8	3/8	7/16	9/16
W40X199	1.61	3/8	3/8	3/8	7/16	9/16
W40X211	1.87	3/8	3/8	3/8	7/16	1/2
W40X215	1.74	3/8	3/8	3/8	7/16	9/16
W40X235	2.07	3/8	3/8	3/8	3/8	1/2
W40X249	2.00	3/8	3/8	3/8	3/8	1/2
W40X264	2.32	3/8	3/8	3/8	3/8	7/16
W40X277	2.21	3/8	3/8	3/8	3/8	7/16

W8x28 Test Beam		D-902 FIBER				
		1, 1 1/2 & 2 Hours		**3 Hour**		
		Fluted Deck	Cellular Deck	Fluted Deck	Fluted Deck	Cellular Deck
Section	W/D	NW or LW Concrete	NW or LW Concrete	NW Concrete	LW Concrete	NW or LW Concrete
W40X278	2.43	3/8	3/8	3/8	3/8	7/16
W40X297	2.37	3/8	3/8	3/8	3/8	7/16
W40X321	2.55	3/8	3/8	3/8	3/8	7/16
W40X331	2.86	3/8	3/8	3/8	3/8	3/8
W40X372	2.93	3/8	3/8	3/8	3/8	3/8
W40X431	3.35	3/8	3/8	3/8	3/8	3/8
W44X230	1.75	3/8	3/8	3/8	7/16	9/16
W44X262	1.98	3/8	3/8	3/8	3/8	1/2
W44X290	2.18	3/8	3/8	3/8	3/8	1/2
W44X335	2.50	3/8	3/8	3/8	3/8	7/16

W8x28 Test Beam		D-902 CEMENTITIOUS			
		1, 1 1/2 & 2 Hours		3 Hour	
		Fluted Deck	Cellular Deck	Fluted Deck	Cellular Deck
Section	W/D	NW or LW Concrete	NW or LW Concrete	NW or LW Concrete	NW or LW Concrete
W4X13	0.65	3/8	3/8	9/16	11/16
W5X16	0.65	3/8	3/8	9/16	11/16
W5X19	0.76	3/8	3/8	9/16	5/8
W6X9	0.39	1/2	1/2	3/4	13/16
W6X12	0.51	7/16	7/16	11/16	3/4
W6X15	0.51	7/16	7/16	11/16	3/4
W6X16	0.66	3/8	3/8	9/16	5/8
W6X20	0.67	3/8	3/8	9/16	5/8
W6X25	0.82	3/8	3/8	1/2	9/16
W8X10	0.37	1/2	1/2	3/4	13/16
W8X13	0.47	7/16	7/16	11/16	3/4
W8X15	0.54	7/16	7/16	5/8	3/4
W8X17	0.54	7/16	7/16	5/8	3/4
W8X18	0.57	3/8	3/8	5/8	11/16
W8X20	0.57	3/8	3/8	5/8	11/16
W8X21	0.66	3/8	3/8	9/16	5/8
W8X24	0.69	3/8	3/8	9/16	5/8
W8X28	0.80	3/8	3/8	1/2	9/16
W8X31	0.79	3/8	3/8	9/16	5/8
W8X35	0.88	3/8	3/8	1/2	9/16
W8X40	1.00	3/8	3/8	7/16	1/2
W8X48	1.18	3/8	3/8	7/16	1/2
W8X58	1.41	3/8	3/8	3/8	7/16
W8X67	1.61	3/8	3/8	3/8	3/8
W10X12	0.38	1/2	1/2	3/4	13/16
W10X15	0.48	7/16	7/16	11/16	3/4
W10X17	0.54	7/16	7/16	5/8	3/4
W10X19	0.59	3/8	3/8	5/8	11/16
W10X22	0.59	3/8	3/8	5/8	11/16
W10X26	0.69	3/8	3/8	9/16	5/8
W10X30	0.79	3/8	3/8	9/16	5/8
W10X33	0.77	3/8	3/8	9/16	5/8
W10X39	0.90	3/8	3/8	1/2	9/16
W10X45	1.03	3/8	3/8	7/16	1/2
W10X49	0.99	3/8	3/8	1/2	1/2
W10X54	1.09	3/8	3/8	7/16	1/2
W10X60	1.20	3/8	3/8	7/16	7/16
W10X68	1.35	3/8	3/8	3/8	7/16
W10X77	1.52	3/8	3/8	3/8	3/8
W10X88	1.72	3/8	3/8	3/8	3/8
W10X100	1.93	3/8	3/8	3/8	3/8

W8x28 Test Beam		D-902 CEMENTITIOUS			
		1, 1 1/2 & 2 Hours		3 Hour	
		Fluted Deck	Cellular Deck	Fluted Deck	Cellular Deck
Section	W/D	NW or LW Concrete	NW or LW Concrete	NW or LW Concrete	NW or LW Concrete
W10X112	2.14	3/8	3/8	3/8	3/8
W12X14	0.40	7/16	7/16	3/4	13/16
W12X16	0.45	7/16	7/16	11/16	3/4
W12X19	0.53	7/16	7/16	5/8	3/4
W12X22	0.61	3/8	3/8	5/8	11/16
W12X26	0.60	3/8	3/8	5/8	11/16
W12X30	0.69	3/8	3/8	9/16	5/8
W12X35	0.79	3/8	3/8	9/16	5/8
W12X40	0.85	3/8	3/8	1/2	9/16
W12X45	0.95	3/8	3/8	1/2	9/16
W12X50	1.04	3/8	3/8	7/16	1/2
W12X53	0.99	3/8	3/8	1/2	1/2
W12X58	1.08	3/8	3/8	7/16	1/2
W12X65	1.09	3/8	3/8	7/16	1/2
W12X72	1.20	3/8	3/8	7/16	7/16
W12X79	1.32	3/8	3/8	3/8	7/16
W12X87	1.44	3/8	3/8	3/8	7/16
W12X96	1.58	3/8	3/8	3/8	3/8
W12X106	1.73	3/8	3/8	3/8	3/8
W12X120	1.94	3/8	3/8	3/8	3/8
W12X136	2.18	3/8	3/8	3/8	3/8
W12X152	2.41	3/8	3/8	3/8	3/8
W12X170	2.66	3/8	3/8	3/8	3/8
W12X190	2.94	3/8	3/8	3/8	3/8
W14X22	0.52	7/16	7/16	5/8	3/4
W14X26	0.61	3/8	3/8	5/8	11/16
W14X30	0.63	3/8	3/8	5/8	11/16
W14X34	0.71	3/8	3/8	9/16	5/8
W14X38	0.79	3/8	3/8	9/16	5/8
W14X43	0.85	3/8	3/8	1/2	9/16
W14X48	0.94	3/8	3/8	1/2	9/16
W14X53	1.03	3/8	3/8	7/16	1/2
W14X61	1.07	3/8	3/8	7/16	1/2
W14X68	1.19	3/8	3/8	7/16	1/2
W14X74	1.28	3/8	3/8	3/8	7/16
W14X82	1.41	3/8	3/8	3/8	7/16
W14X90	1.27	3/8	3/8	3/8	7/16
W14X99	1.39	3/8	3/8	3/8	7/16
W14X109	1.53	3/8	3/8	3/8	3/8
W14X120	1.67	3/8	3/8	3/8	3/8
W14X132	1.83	3/8	3/8	3/8	3/8
W14X145	1.94	3/8	3/8	3/8	3/8
W14X159	2.12	3/8	3/8	3/8	3/8

W8x28 Test Beam		D-902 CEMENTITIOUS			
		1, 1 1/2 & 2 Hours		3 Hour	
		Fluted Deck	Cellular Deck	Fluted Deck	Cellular Deck
Section	W/D	NW or LW Concrete	NW or LW Concrete	NW or LW Concrete	NW or LW Concrete
W14X176	2.32	3/8	3/8	3/8	3/8
W14X193	2.53	3/8	3/8	3/8	3/8
W14X211	2.74	3/8	3/8	3/8	3/8
W16X26	0.55	7/16	7/16	5/8	11/16
W16X31	0.65	3/8	3/8	9/16	11/16
W16X36	0.69	3/8	3/8	9/16	5/8
W16X40	0.76	3/8	3/8	9/16	5/8
W16X45	0.85	3/8	3/8	1/2	9/16
W16X50	0.94	3/8	3/8	1/2	9/16
W16X57	1.07	3/8	3/8	7/16	1/2
W16X67	1.07	3/8	3/8	7/16	1/2
W16X77	1.22	3/8	3/8	7/16	7/16
W16X89	1.40	3/8	3/8	3/8	7/16
W16X100	1.56	3/8	3/8	3/8	3/8
W18X35	0.66	3/8	3/8	9/16	5/8
W18X40	0.75	3/8	3/8	9/16	5/8
W18X46	0.86	3/8	3/8	1/2	9/16
W18X50	0.87	3/8	3/8	1/2	9/16
W18X55	0.95	3/8	3/8	1/2	9/16
W18X60	1.03	3/8	3/8	7/16	1/2
W18X65	1.11	3/8	3/8	7/16	1/2
W18X71	1.21	3/8	3/8	7/16	7/16
W18X76	1.11	3/8	3/8	7/16	1/2
W18X86	1.24	3/8	3/8	7/16	7/16
W18X97	1.39	3/8	3/8	3/8	7/16
W18X106	1.52	3/8	3/8	3/8	3/8
W18X119	1.69	3/8	3/8	3/8	3/8
W18X130	1.84	3/8	3/8	3/8	3/8
W18X143	2.01	3/8	3/8	3/8	3/8
W18X158	2.20	3/8	3/8	3/8	3/8
W18X175	2.42	3/8	3/8	3/8	3/8
W18X192	2.62	3/8	3/8	3/8	3/8
W21X44	0.73	3/8	3/8	9/16	5/8
W21X50	0.83	3/8	3/8	1/2	9/16
W21X57	0.93	3/8	3/8	1/2	9/16
W21X62	0.94	3/8	3/8	1/2	9/16
W21X68	1.03	3/8	3/8	7/16	1/2
W21X73	1.10	3/8	3/8	7/16	1/2
W21X83	1.24	3/8	3/8	7/16	7/16
W21X93	1.38	3/8	3/8	3/8	7/16
W21X101	1.29	3/8	3/8	3/8	7/16
W21X111	1.41	3/8	3/8	3/8	7/16

W8x28 Test Beam		D-902 CEMENTITIOUS			
		1, 1 1/2 & 2 Hours		3 Hour	
		Fluted Deck	Cellular Deck	Fluted Deck	Cellular Deck
Section	W/D	NW or LW Concrete	NW or LW Concrete	NW or LW Concrete	NW or LW Concrete
W21X122	1.54	3/8	3/8	3/8	3/8
W21X132	1.66	3/8	3/8	3/8	3/8
W21X147	1.83	3/8	3/8	3/8	3/8
W21X166	2.06	3/8	3/8	3/8	3/8
W21X182	2.24	3/8	3/8	3/8	3/8
W21X201	2.45	3/8	3/8	3/8	3/8
W24X55	0.82	3/8	3/8	1/2	9/16
W24X62	0.92	3/8	3/8	1/2	9/16
W24X68	0.92	3/8	3/8	1/2	9/16
W24X76	1.03	3/8	3/8	7/16	1/2
W24X84	1.13	3/8	3/8	7/16	1/2
W24X94	1.26	3/8	3/8	7/16	7/16
W24X103	1.37	3/8	3/8	3/8	7/16
W24X104	1.22	3/8	3/8	7/16	7/16
W24X117	1.36	3/8	3/8	3/8	7/16
W24X131	1.52	3/8	3/8	3/8	3/8
W24X146	1.68	3/8	3/8	3/8	3/8
W24X162	1.85	3/8	3/8	3/8	3/8
W24X176	2.01	3/8	3/8	3/8	3/8
W24X192	2.18	3/8	3/8	3/8	3/8
W24X207	2.33	3/8	3/8	3/8	3/8
W24X229	2.56	3/8	3/8	3/8	3/8
W27X84	1.02	3/8	3/8	7/16	1/2
W27X94	1.13	3/8	3/8	7/16	1/2
W27X102	1.23	3/8	3/8	7/16	7/16
W27X114	1.36	3/8	3/8	3/8	7/16
W27X129	1.53	3/8	3/8	3/8	3/8
W27X146	1.53	3/8	3/8	3/8	3/8
W27X161	1.68	3/8	3/8	3/8	3/8
W27X178	1.85	3/8	3/8	3/8	3/8
W27X194	2.00	3/8	3/8	3/8	3/8
W27X217	2.22	3/8	3/8	3/8	3/8
W27X235	2.40	3/8	3/8	3/8	3/8
W27X258	2.61	3/8	3/8	3/8	3/8
W30X108	1.20	3/8	3/8	7/16	7/16
W30X116	1.28	3/8	3/8	3/8	7/16
W30X124	1.37	3/8	3/8	3/8	7/16
W30X132	1.45	3/8	3/8	3/8	7/16
W30X148	1.62	3/8	3/8	3/8	3/8
W30X173	1.66	3/8	3/8	3/8	3/8
W30X191	1.82	3/8	3/8	3/8	3/8
W30X211	2.00	3/8	3/8	3/8	3/8

W8x28 Test Beam		D-902 CEMENTITIOUS			
		1, 1 1/2 & 2 Hours		3 Hour	
		Fluted Deck	Cellular Deck	Fluted Deck	Cellular Deck
Section	W/D	NW or LW Concrete	NW or LW Concrete	NW or LW Concrete	NW or LW Concrete
W30X235	2.21	3/8	3/8	3/8	3/8
W30X261	2.44	3/8	3/8	3/8	3/8
W30X90	1.01	3/8	3/8	7/16	1/2
W30X99	1.10	3/8	3/8	7/16	1/2
W33X118	1.19	3/8	3/8	7/16	1/2
W33X130	1.31	3/8	3/8	3/8	7/16
W33X141	1.41	3/8	3/8	3/8	7/16
W33X152	1.51	3/8	3/8	3/8	3/8
W33X169	1.68	3/8	3/8	3/8	3/8
W33X201	1.78	3/8	3/8	3/8	3/8
W33X221	1.94	3/8	3/8	3/8	3/8
W33X241	2.11	3/8	3/8	3/8	3/8
W36X135	1.28	3/8	3/8	3/8	7/16
W36X150	1.41	3/8	3/8	3/8	7/16
W36X160	1.50	3/8	3/8	3/8	3/8
W36X170	1.59	3/8	3/8	3/8	3/8
W36X182	1.69	3/8	3/8	3/8	3/8
W36X194	1.80	3/8	3/8	3/8	3/8
W36X210	1.94	3/8	3/8	3/8	3/8
W36X230	1.92	3/8	3/8	3/8	3/8
W36X232	2.13	3/8	3/8	3/8	3/8
W36X245	2.04	3/8	3/8	3/8	3/8
W36X256	2.34	3/8	3/8	3/8	3/8
W36X260	2.16	3/8	3/8	3/8	3/8
W36X280	2.31	3/8	3/8	3/8	3/8
W36X300	2.47	3/8	3/8	3/8	3/8
W40X149	1.35	3/8	3/8	3/8	7/16
W40X167	1.50	3/8	3/8	3/8	3/8
W40X174	1.42	3/8	3/8	3/8	7/16
W40X183	1.63	3/8	3/8	3/8	3/8
W40X199	1.61	3/8	3/8	3/8	3/8
W40X211	1.87	3/8	3/8	3/8	3/8
W40X215	1.74	3/8	3/8	3/8	3/8
W40X235	2.07	3/8	3/8	3/8	3/8
W40X249	2.00	3/8	3/8	3/8	3/8
W40X264	2.32	3/8	3/8	3/8	3/8
W40X277	2.21	3/8	3/8	3/8	3/8
W40X278	2.43	3/8	3/8	3/8	3/8
W40X297	2.37	3/8	3/8	3/8	3/8
W40X321	2.55	3/8	3/8	3/8	3/8
W40X331	2.86	3/8	3/8	3/8	3/8
W40X372	2.93	3/8	3/8	3/8	3/8

W8x28 Test Beam		D-902 CEMENTITIOUS			
		1, 1 1/2 & 2 Hours		**3 Hour**	
		Fluted Deck	Cellular Deck	Fluted Deck	Cellular Deck
Section	W/D	NW or LW Concrete	NW or LW Concrete	NW or LW Concrete	NW or LW Concrete
W40X431	3.35	3/8	3/8	3/8	3/8
W44X230	1.75	3/8	3/8	3/8	3/8
W44X262	1.98	3/8	3/8	3/8	3/8
W44X290	2.18	3/8	3/8	3/8	3/8
W44X335	2.50	3/8	3/8	3/8	3/8

Appendix B-2
D-925 SFRM THICKNESS

W8x28 Test Beam		D-925					
		1, 1 1/2 & 2 Hours			3 Hour		
		Fluted Deck	Fluted Deck	Cellular Deck	Fluted Deck	Fluted Deck	Cellular Deck
Section	W/D	LW Concrete	NW Concrete	NW or LW Concrete	LW Concrete	NW Concrete	NW or LW Concrete
W4X13	0.65	1/2	9/16	9/16	7/8	15/16	15/16
W5X16	0.65	1/2	9/16	9/16	7/8	15/16	15/16
W5X19	0.76	1/2	9/16	9/16	13/16	7/8	7/8
W6X9	0.39	5/8	3/4	3/4	1 1/16	1 3/16	1 3/16
W6X12	0.51	9/16	11/16	11/16	1	1 1/16	1 1/16
W6X15	0.51	9/16	11/16	11/16	1	1 1/16	1 1/16
W6X16	0.66	1/2	9/16	9/16	7/8	15/16	15/16
W6X20	0.67	1/2	9/16	9/16	7/8	15/16	15/16
W6X25	0.82	7/16	1/2	1/2	3/4	13/16	13/16
W8X10	0.37	11/16	3/4	3/4	1 1/8	1 3/16	1 3/16
W8X13	0.47	5/8	11/16	11/16	1	1 1/8	1 1/8
W8X15	0.54	9/16	5/8	5/8	15/16	1	1
W8X17	0.54	9/16	5/8	5/8	15/16	1	1
W8X18	0.57	9/16	5/8	5/8	15/16	1	1
W8X20	0.57	9/16	5/8	5/8	15/16	1	1
W8X21	0.66	1/2	9/16	9/16	7/8	15/16	15/16
W8X24	0.69	1/2	9/16	9/16	7/8	15/16	15/16
W8X28	0.80	7/16	1/2	1/2	3/4	13/16	13/16
W8X31	0.79	1/2	9/16	9/16	13/16	7/8	7/8
W8X35	0.88	7/16	1/2	1/2	3/4	13/16	13/16
W8X40	1.00	7/16	7/16	7/16	11/16	3/4	3/4
W8X48	1.18	3/8	7/16	7/16	5/8	11/16	11/16
W8X58	1.41	3/8	3/8	3/8	9/16	5/8	5/8
W8X67	1.61	3/8	3/8	3/8	1/2	9/16	9/16
W10X12	0.38	5/8	3/4	3/4	1 1/8	1 3/16	1 3/16
W10X15	0.48	5/8	11/16	11/16	1	1 1/16	1 1/16
W10X17	0.54	9/16	5/8	5/8	15/16	1	1
W10X19	0.59	9/16	5/8	5/8	15/16	1	1
W10X22	0.59	9/16	5/8	5/8	15/16	1	1
W10X26	0.69	1/2	9/16	9/16	7/8	15/16	15/16
W10X30	0.79	1/2	9/16	9/16	13/16	7/8	7/8
W10X33	0.77	1/2	9/16	9/16	13/16	7/8	7/8
W10X39	0.90	7/16	1/2	1/2	3/4	13/16	13/16
W10X45	1.03	7/16	7/16	7/16	11/16	3/4	3/4
W10X49	0.99	7/16	1/2	1/2	11/16	3/4	3/4
W10X54	1.09	3/8	7/16	7/16	5/8	11/16	11/16

W8x28 Test Beam		D-925					
		1, 1 1/2 & 2 Hours			3 Hour		
		Fluted Deck	Fluted Deck	Cellular Deck	Fluted Deck	Fluted Deck	Cellular Deck
Section	W/D	LW Concrete	NW Concrete	NW or LW Concrete	LW Concrete	NW Concrete	NW or LW Concrete
W10X60	1.20	3/8	7/16	7/16	5/8	11/16	11/16
W10X68	1.35	3/8	3/8	3/8	9/16	5/8	5/8
W10X77	1.52	3/8	3/8	3/8	1/2	9/16	9/16
W10X88	1.72	3/8	3/8	3/8	1/2	1/2	1/2
W10X100	1.93	3/8	3/8	3/8	7/16	1/2	1/2
W10X112	2.14	3/8	3/8	3/8	7/16	7/16	7/16
W12X14	0.40	5/8	3/4	3/4	1 1/16	1 3/16	1 3/16
W12X16	0.45	5/8	11/16	11/16	1	1 1/8	1 1/8
W12X19	0.53	9/16	5/8	5/8	15/16	1 1/16	1 1/16
W12X22	0.61	9/16	5/8	5/8	7/8	1	1
W12X26	0.60	9/16	5/8	5/8	7/8	1	1
W12X30	0.69	1/2	9/16	9/16	7/8	15/16	15/16
W12X35	0.79	1/2	9/16	9/16	13/16	7/8	7/8
W12X40	0.85	7/16	1/2	1/2	3/4	13/16	13/16
W12X45	0.95	7/16	1/2	1/2	11/16	3/4	3/4
W12X50	1.04	3/8	7/16	7/16	11/16	3/4	3/4
W12X53	0.99	7/16	1/2	1/2	11/16	3/4	3/4
W12X58	1.08	3/8	7/16	7/16	5/8	11/16	11/16
W12X65	1.09	3/8	7/16	7/16	5/8	11/16	11/16
W12X72	1.20	3/8	7/16	7/16	5/8	11/16	11/16
W12X79	1.32	3/8	3/8	3/8	9/16	5/8	5/8
W12X87	1.44	3/8	3/8	3/8	9/16	9/16	9/16
W12X96	1.58	3/8	3/8	3/8	1/2	9/16	9/16
W12X106	1.73	3/8	3/8	3/8	1/2	1/2	1/2
W12X120	1.94	3/8	3/8	3/8	7/16	1/2	1/2
W12X136	2.18	3/8	3/8	3/8	7/16	7/16	7/16
W12X152	2.41	3/8	3/8	3/8	3/8	7/16	7/16
W12X170	2.66	3/8	3/8	3/8	3/8	3/8	3/8
W12X190	2.94	3/8	3/8	3/8	3/8	3/8	3/8
W14X22	0.52	9/16	5/8	5/8	15/16	1 1/16	1 1/16
W14X26	0.61	9/16	5/8	5/8	7/8	1	1
W14X30	0.63	1/2	5/8	5/8	7/8	15/16	15/16
W14X34	0.71	1/2	9/16	9/16	13/16	7/8	7/8
W14X38	0.79	1/2	9/16	9/16	13/16	7/8	7/8
W14X43	0.85	7/16	1/2	1/2	3/4	13/16	13/16
W14X48	0.94	7/16	1/2	1/2	11/16	3/4	3/4
W14X53	1.03	7/16	7/16	7/16	11/16	3/4	3/4
W14X61	1.07	3/8	7/16	7/16	11/16	11/16	11/16
W14X68	1.19	3/8	7/16	7/16	5/8	11/16	11/16
W14X74	1.28	3/8	3/8	3/8	9/16	5/8	5/8
W14X82	1.41	3/8	3/8	3/8	9/16	5/8	5/8
W14X90	1.27	3/8	3/8	3/8	9/16	5/8	5/8
W14X99	1.39	3/8	3/8	3/8	9/16	5/8	5/8

W8x28 Test Beam		D-925					
		1, 1 1/2 & 2 Hours			3 Hour		
		Fluted Deck	Fluted Deck	Cellular Deck	Fluted Deck	Fluted Deck	Cellular Deck
Section	W/D	LW Concrete	NW Concrete	NW or LW Concrete	LW Concrete	NW Concrete	NW or LW Concrete
W14X109	1.53	3/8	3/8	3/8	1/2	9/16	9/16
W14X120	1.67	3/8	3/8	3/8	1/2	9/16	9/16
W14X132	1.83	3/8	3/8	3/8	7/16	1/2	1/2
W14X145	1.94	3/8	3/8	3/8	7/16	1/2	1/2
W14X159	2.12	3/8	3/8	3/8	7/16	7/16	7/16
W14X176	2.32	3/8	3/8	3/8	3/8	7/16	7/16
W14X193	2.53	3/8	3/8	3/8	3/8	3/8	3/8
W14X211	2.74	3/8	3/8	3/8	3/8	3/8	3/8
W16X26	0.55	9/16	5/8	5/8	15/16	1	1
W16X31	0.65	1/2	9/16	9/16	7/8	15/16	15/16
W16X36	0.69	1/2	9/16	9/16	7/8	15/16	15/16
W16X40	0.76	1/2	9/16	9/16	13/16	7/8	7/8
W16X45	0.85	7/16	1/2	1/2	3/4	13/16	13/16
W16X50	0.94	7/16	1/2	1/2	11/16	3/4	3/4
W16X57	1.07	3/8	7/16	7/16	11/16	11/16	11/16
W16X67	1.07	3/8	7/16	7/16	11/16	11/16	11/16
W16X77	1.22	3/8	7/16	7/16	5/8	5/8	5/8
W16X89	1.40	3/8	3/8	3/8	9/16	5/8	5/8
W16X100	1.56	3/8	3/8	3/8	1/2	9/16	9/16
W18X35	0.66	1/2	9/16	9/16	7/8	15/16	15/16
W18X40	0.75	1/2	9/16	9/16	13/16	7/8	7/8
W18X46	0.86	7/16	1/2	1/2	3/4	13/16	13/16
W18X50	0.87	7/16	1/2	1/2	3/4	13/16	13/16
W18X55	0.95	7/16	1/2	1/2	11/16	3/4	3/4
W18X60	1.03	7/16	7/16	7/16	11/16	3/4	3/4
W18X65	1.11	3/8	7/16	7/16	5/8	11/16	11/16
W18X71	1.21	3/8	7/16	7/16	5/8	11/16	11/16
W18X76	1.11	3/8	7/16	7/16	5/8	11/16	11/16
W18X86	1.24	3/8	7/16	7/16	5/8	5/8	5/8
W18X97	1.39	3/8	3/8	3/8	9/16	5/8	5/8
W18X106	1.52	3/8	3/8	3/8	1/2	9/16	9/16
W18X119	1.69	3/8	3/8	3/8	1/2	1/2	1/2
W18X130	1.84	3/8	3/8	3/8	7/16	1/2	1/2
W18X143	2.01	3/8	3/8	3/8	7/16	7/16	7/16
W18X158	2.20	3/8	3/8	3/8	3/8	7/16	7/16
W18X175	2.42	3/8	3/8	3/8	3/8	7/16	7/16
W18X192	2.62	3/8	3/8	3/8	3/8	3/8	3/8
W21X44	0.73	1/2	9/16	9/16	13/16	7/8	7/8
W21X50	0.83	7/16	1/2	1/2	3/4	13/16	13/16
W21X57	0.93	7/16	1/2	1/2	11/16	3/4	3/4
W21X62	0.94	7/16	1/2	1/2	11/16	3/4	3/4
W21X68	1.03	7/16	7/16	7/16	11/16	3/4	3/4

W8x28 Test Beam		D-925					
		1, 1 1/2 & 2 Hours			3 Hour		
		Fluted Deck	Fluted Deck	Cellular Deck	Fluted Deck	Fluted Deck	Cellular Deck
Section	W/D	LW Concrete	NW Concrete	NW or LW Concrete	LW Concrete	NW Concrete	NW or LW Concrete
W21X73	1.10	3/8	7/16	7/16	5/8	11/16	11/16
W21X83	1.24	3/8	7/16	7/16	5/8	5/8	5/8
W21X93	1.38	3/8	3/8	3/8	9/16	5/8	5/8
W21X101	1.29	3/8	3/8	3/8	9/16	5/8	5/8
W21X111	1.41	3/8	3/8	3/8	9/16	5/8	5/8
W21X122	1.54	3/8	3/8	3/8	1/2	9/16	9/16
W21X132	1.66	3/8	3/8	3/8	1/2	9/16	9/16
W21X147	1.83	3/8	3/8	3/8	7/16	1/2	1/2
W21X166	2.06	3/8	3/8	3/8	7/16	7/16	7/16
W21X182	2.24	3/8	3/8	3/8	3/8	7/16	7/16
W21X201	2.45	3/8	3/8	3/8	3/8	3/8	3/8
W24X55	0.82	7/16	1/2	1/2	3/4	13/16	13/16
W24X62	0.92	7/16	1/2	1/2	3/4	3/4	3/4
W24X68	0.92	7/16	1/2	1/2	3/4	3/4	3/4
W24X76	1.03	7/16	7/16	7/16	11/16	3/4	3/4
W24X84	1.13	3/8	7/16	7/16	5/8	11/16	11/16
W24X94	1.26	3/8	7/16	7/16	5/8	5/8	5/8
W24X103	1.37	3/8	3/8	3/8	9/16	5/8	5/8
W24X104	1.22	3/8	7/16	7/16	5/8	5/8	5/8
W24X117	1.36	3/8	3/8	3/8	9/16	5/8	5/8
W24X131	1.52	3/8	3/8	3/8	1/2	9/16	9/16
W24X146	1.68	3/8	3/8	3/8	1/2	1/2	1/2
W24X162	1.85	3/8	3/8	3/8	7/16	1/2	1/2
W24X176	2.01	3/8	3/8	3/8	7/16	7/16	7/16
W24X192	2.18	3/8	3/8	3/8	7/16	7/16	7/16
W24X207	2.33	3/8	3/8	3/8	3/8	7/16	7/16
W24X229	2.56	3/8	3/8	3/8	3/8	3/8	3/8
W27X84	1.02	7/16	7/16	7/16	11/16	3/4	3/4
W27X94	1.13	3/8	7/16	7/16	5/8	11/16	11/16
W27X102	1.23	3/8	7/16	7/16	5/8	5/8	5/8
W27X114	1.36	3/8	3/8	3/8	9/16	5/8	5/8
W27X129	1.53	3/8	3/8	3/8	1/2	9/16	9/16
W27X146	1.53	3/8	3/8	3/8	1/2	9/16	9/16
W27X161	1.68	3/8	3/8	3/8	1/2	1/2	1/2
W27X178	1.85	3/8	3/8	3/8	7/16	1/2	1/2
W27X194	2.00	3/8	3/8	3/8	7/16	7/16	7/16
W27X217	2.22	3/8	3/8	3/8	3/8	7/16	7/16
W27X235	2.40	3/8	3/8	3/8	3/8	7/16	7/16
W27X258	2.61	3/8	3/8	3/8	3/8	3/8	3/8
W30X108	1.20	3/8	7/16	7/16	5/8	11/16	11/16
W30X116	1.28	3/8	3/8	3/8	9/16	5/8	5/8
W30X124	1.37	3/8	3/8	3/8	9/16	5/8	5/8

W8x28 Test Beam		D-925					
		1, 1 1/2 & 2 Hours			3 Hour		
		Fluted Deck	Fluted Deck	Cellular Deck	Fluted Deck	Fluted Deck	Cellular Deck
Section	W/D	LW Concrete	NW Concrete	NW or LW Concrete	LW Concrete	NW Concrete	NW or LW Concrete
W30X132	1.45	3/8	3/8	3/8	9/16	9/16	9/16
W30X148	1.62	3/8	3/8	3/8	1/2	9/16	9/16
W30X173	1.66	3/8	3/8	3/8	1/2	9/16	9/16
W30X191	1.82	3/8	3/8	3/8	7/16	1/2	1/2
W30X211	2.00	3/8	3/8	3/8	7/16	7/16	7/16
W30X235	2.21	3/8	3/8	3/8	3/8	7/16	7/16
W30X261	2.44	3/8	3/8	3/8	3/8	3/8	3/8
W30X90	1.01	7/16	7/16	7/16	11/16	3/4	3/4
W30X99	1.10	3/8	7/16	7/16	5/8	11/16	11/16
W33X118	1.19	3/8	7/16	7/16	5/8	11/16	11/16
W33X130	1.31	3/8	3/8	3/8	9/16	5/8	5/8
W33X141	1.41	3/8	3/8	3/8	9/16	5/8	5/8
W33X152	1.51	3/8	3/8	3/8	1/2	9/16	9/16
W33X169	1.68	3/8	3/8	3/8	1/2	1/2	1/2
W33X201	1.78	3/8	3/8	3/8	1/2	1/2	1/2
W33X221	1.94	3/8	3/8	3/8	7/16	1/2	1/2
W33X241	2.11	3/8	3/8	3/8	7/16	7/16	7/16
W36X135	1.28	3/8	3/8	3/8	9/16	5/8	5/8
W36X150	1.41	3/8	3/8	3/8	9/16	5/8	5/8
W36X160	1.50	3/8	3/8	3/8	1/2	9/16	9/16
W36X170	1.59	3/8	3/8	3/8	1/2	9/16	9/16
W36X182	1.69	3/8	3/8	3/8	1/2	1/2	1/2
W36X194	1.80	3/8	3/8	3/8	7/16	1/2	1/2
W36X210	1.94	3/8	3/8	3/8	7/16	1/2	1/2
W36X230	1.92	3/8	3/8	3/8	7/16	1/2	1/2
W36X232	2.13	3/8	3/8	3/8	7/16	7/16	7/16
W36X245	2.04	3/8	3/8	3/8	7/16	7/16	7/16
W36X256	2.34	3/8	3/8	3/8	3/8	7/16	7/16
W36X260	2.16	3/8	3/8	3/8	7/16	7/16	7/16
W36X280	2.31	3/8	3/8	3/8	3/8	7/16	7/16
W36X300	2.47	3/8	3/8	3/8	3/8	3/8	3/8
W40X149	1.35	3/8	3/8	3/8	9/16	5/8	5/8
W40X167	1.50	3/8	3/8	3/8	1/2	9/16	9/16
W40X174	1.42	3/8	3/8	3/8	9/16	5/8	5/8
W40X183	1.63	3/8	3/8	3/8	1/2	9/16	9/16
W40X199	1.61	3/8	3/8	3/8	1/2	9/16	9/16
W40X211	1.87	3/8	3/8	3/8	7/16	1/2	1/2
W40X215	1.74	3/8	3/8	3/8	1/2	1/2	1/2
W40X235	2.07	3/8	3/8	3/8	7/16	7/16	7/16
W40X249	2.00	3/8	3/8	3/8	7/16	7/16	7/16
W40X264	2.32	3/8	3/8	3/8	3/8	7/16	7/16
W40X277	2.21	3/8	3/8	3/8	3/8	7/16	7/16

W8x28 Test Beam		D-925					
		1, 1 1/2 & 2 Hours			3 Hour		
		Fluted Deck	Fluted Deck	Cellular Deck	Fluted Deck	Fluted Deck	Cellular Deck
Section	W/D	LW Concrete	NW Concrete	NW or LW Concrete	LW Concrete	NW Concrete	NW or LW Concrete
W40X278	2.43	3/8	3/8	3/8	3/8	7/16	7/16
W40X297	2.37	3/8	3/8	3/8	3/8	7/16	7/16
W40X321	2.55	3/8	3/8	3/8	3/8	3/8	3/8
W40X331	2.86	3/8	3/8	3/8	3/8	3/8	3/8
W40X372	2.93	3/8	3/8	3/8	3/8	3/8	3/8
W40X431	3.35	3/8	3/8	3/8	3/8	3/8	3/8
W44X230	1.75	3/8	3/8	3/8	1/2	1/2	1/2
W44X262	1.98	3/8	3/8	3/8	7/16	1/2	1/2
W44X290	2.18	3/8	3/8	3/8	7/16	7/16	7/16
W44X335	2.50	3/8	3/8	3/8	3/8	3/8	3/8