THICKNESS DETERMINATION FOR SPRAY-APPLIED FIRE RESISTIVE MATERIALS

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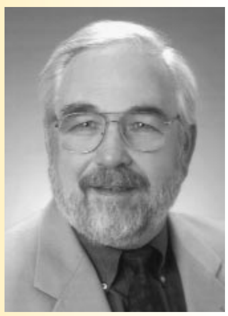

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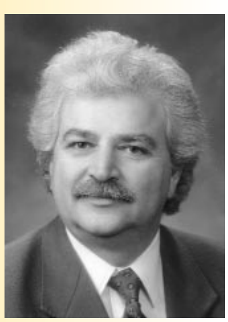

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Following The World Trade Center disaster, a review of current design practices has commenced with hope that out of the tragedy something may be gleaned that could influence more effective new building designs. Fireproofing is a legitimate area of focus. There is little debate that a more rational approach to fire protection is possible than our current reliance on the prescriptive method using tested assemblies. Efforts are being expended to formulate a rational approach for evaluating the performance of steel structures in a fire environment and a more rational performance based approach to fire protection is certainly on the horizon. Nonetheless, the design team is faced with providing fire-safe buildings under current guidelines. This paper addresses the method for determining the thickness of spray-applied fire resistive material based on the current prescriptive code approach.

BACKGROUND

Among the material properties, the yield strength and elastic modulus of construction materials (steel and concrete), the properties that influence strength and deformation, are reduced at elevated temperatures. Therefore, insulation is applied to extend the time that steel structures can sustain load at elevated temperatures. The time the structural system is required to endure a fire is influenced by building area, height, use and occupancy and is directed by the applicable building code. The amount and type of insulation is determined through testing, or more commonly by referencing existing test data for assemblies similar to those intended in the building.

Insulation can be provided in many forms including masonry or concrete encasement, gypsum board wrappings, insulation board enclosures, intumescent coatings and spray-applied fire resistive materials. The most common form of insulation for a structural steel assembly is a spray-applied fire resistive material. Spray-applied fire resistive materials use a binder, generally gypsum or Portland cement, that is mixed with insulating materials to form a slurry or mixed at a nozzle and spray-applied. "Cafco 300", manufactured by Isolatek and "Monocote MK-6", manufactured by W. R. Grace, are examples of slurry based insulating materials. "Blaze Shield", manufactured by Isolatek, is an example of a nozzle mixed spray-applied insulation.

The thickness of spray-applied fire resistive material needed to produce the building code dictated duration of fire endurance is determined by testing. Beams supporting slab construction representing the construction intended in the actual building are coated with a specific thickness of spray-applied fire resistive material and tested over a furnace. Since it would be impractical to test all the steel sections to be used in the actual building along with a full range of spray-applied fire resistive material thicknesses, procedures have been developed that facilitate adjusting the spray-applied fire resistive material thickness used on the tested beam to determine the thickness required in the real structure. The purpose here is to clarify the correct application of the equation for adjustment of spray-applied fire protection material thickness.

STANDARD FIRE TEST

Fire tests are performed in accordance with ASTM E-119 [1]. A slab system, the same as anticipated in the building, is constructed over supporting beams above a furnace. The beams are instrumented with thermal couples, protected with spray-applied fire resistive material and shimmed tight to a perimeter frame and the assembly placed over the furnace. All assemblies are tested fully loaded and restrained against the test frame. However, a single test is used to determine two conditions of thermal restraint of the structural system, restrained and unrestrained. Thermal restraint is defined as the condition when the surrounding or supporting structure is capable of resisting substantial thermal expansion throughout the range of anticipated elevated temperatures. The supports of a thermally unrestrained condition are free to rotate and expand. Except in unusual conditions, steel framed structures are thermally restrained [2].

A fire is ignited within the furnace and controlled to follow a standard time temperature relationship (standard fire). The fire is continued and the thermal couple readings are recorded. The time when either the average steel temperature reaches 1100°F or any one location reaches 1300°F is recorded. This time establishes the unrestrained assembly and unrestrained beam rating as long as the temperature on the non-fired side has not been raised more than 250°F or cotton balls on the non-fire side have not ignited. The standard fire is continued and a second time recorded when any one of the following conditions occurs; the load can no longer be supported, the temperature on the non-fired side has raised more than 250°F or cotton balls on the non-fire side have ignited. If this second time exceeds twice the unrestrained time then twice the unrestrained time is recorded as the restrained assembly rating otherwise the second time is recorded as the restrained assembly rating. A provision in establishing the restrained rating of an assembly is that the temperature limits (1100°F and 1300°F) not be exceeded at one-half the restrained rating time or one hour whichever is greater. Therefore, for the case of a one-hour fire resistance rating, the spray-applied fire resistive material thickness is independent of a restrained or unrestrained rating.

The plot of temperature versus time depicted in Figure 1 is a simplified graphic of the application of ASTM E119 in determining the fire resistance rating for restrained and unrestrained assemblies.

BEAM SUBSTITUTION

The beams used in the fire test will seldom match the steel sections used in the actual building. However, the thickness of spray-applied fire resistive material applied to the test beam can be used as a basis for calculating the thickness to be used on the substitute beam. If the rate of temperature increase in a substitute beam can be confirmed to be equal to or less than the rate of temperature change in the test beam, the performance of the assembly, with a substitute beam, will be as good as or better than the tested assembly.

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 a steel member's fire resistance is *W/D* where: *W* = the weight per unit length of the member and *D* = the perimeter of the member exposed to the temperature differential. The larger the value of *W/D*, the slower the rate of temperature change. Thus, if the steel section to be substituted for the tested section has a larger *W/D* than the *W/D* of the tested beam a reduced thickness of spray-applied fire resistive material can be used and the substituted beam will gain heat at a rate less than or equal to that of the test beam.

If the *W/D* ratio of the substitute beam is less than the *W/D* of the tested beam, an increase in the fire protection thickness can be determined to assure that the thermal performance of the substitute beam is equal to that of the tested beam.

The equation for adjustment of the tested beam protection material thickness is:

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

where

W_1 = Substitute Beam weight (lbs/ft)

D_1 = Substitute Beam perimeter exposed to fire (in.)

W_2 = Test Beam weight (lbs/ft)

D_2 = Test Beam perimeter exposed to fire (in.)

T_1 = Required thickness of spray-applied fire resistive material (in.)

T_2 = Tested thickness of spray-applied fire resistive material (in.)

A minimum thickness of $^3/8$ in. must be maintained and since the basis for beam substitution is thermal performance, the substitution equation is only applicable to the unrestrained beam rating which is established based on temperature rise.

Assemblies tested by Underwriters Laboratories Inc. are reported in the UL Fire Resistance Directory [4]. Floor-ceiling assemblies with spray-applied fire resistive material protection are designated D700-999. The referenced assembly must represent the

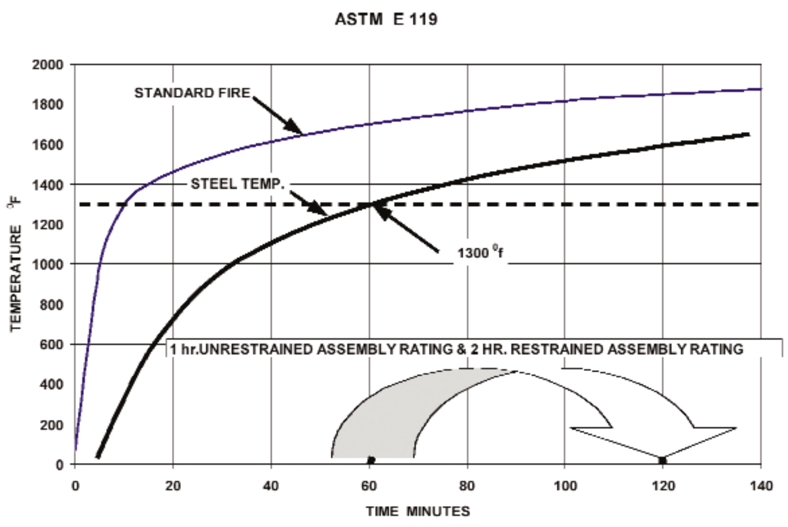


Figure 1

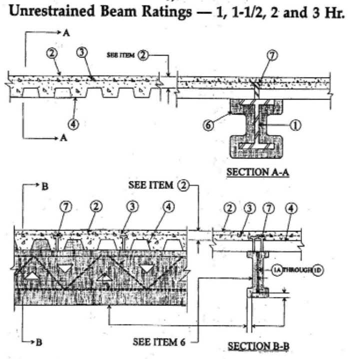
FIRE RESISTANCE DIRECTORY LISTINGS

	SPRAY ON			CONCRETE				DECKS													
				NW	LW																
	Applied on Deck	Wet Slurry	Nozzle applied Fiber	147-153 psf	107-113 pcf	107-120 pcf	114-120 pcf	9/16" Form Deck	1 5/16" Form Deck	1 1/2" Comp Deck	1 5/8" Comp Deck	2" Comp Deck	3" Comp Deck	4 1/2" Comp Deck	Fluted Deck	Cellular Deck	Steel joist option	Roof applications	4 hr Rating Available	Composite Beams	Tested beam sizes
D-739	✔	✔		✔	✔	✔	✔			✔		✔	✔		✔	✔			✔	✔	W8x28 W6x12
D-743	✔	✔		✔	✔							✔	✔		✔	✔					W8x20 W8x28
D-744	✔	✔		✔						✔					✔	✔			✔	✔	W6x15.5
D-759	✔	✔		✔	✔					✔		✔	✔		✔	✔	✔	✔			W8x28
D-779	✔	✔		✔	✔	✔	✔			✔		✔	✓		✔		✔		✔	✔	W8x28 W12x16
D-780	✔	✔		✔	✔			✔	✔						✔		✔			✔	W8x28
D-782	✔	✔					✔			✔		✔	✔		✔		✔		✔		W8x28
D-832	✔		✔	✔			✔			✔		✔	✔		✔	✔		✔			W8x24 W8x28
D-858	✔		✔	✔	✔					✔		✔	✔		✔	✔			✔	✔	W10x25
D-859	✔		✔	✔	✔							✔	✔		✔	✔				✔	W8x20
D-860	✔	✔	✔				✔			✔		✔	✔		✔	✔			✔	✔	W8x20 W8x28
D-902		✔	✔	✔	✔	✔	✔			✔	✔	✔	✔	✔	✔	✔	✔	✔		✔	W8x28 W12x14
D-925		✔		✔		✔	✔			✔	✔	✔	✔	✔	✔	✔	✔	✔		✔	W8x28 W12x16

Figure 2

intended construction and the details of the slab construction are important, not only to model the slab's resistance to heat transfer, but also to appropriately model the dissipation of heat away from the beam. Several UL tested assemblies are indicated in Figure 2. Each of these designations can be referenced to provide 1, 1½, 2, and 3 hour fire resistance ratings depending on the slab construction and the thickness and type of fire protection. If composite beams are used in the test, either composite or non-composite beams may be used in the actual structure. However, if non-composite beams are used in the test, composite beams cannot be used in the structure. The UL designations tabulated in Figure 2 represent systems that do not rely on the ceiling for fire resistance and among these the UL designations D902 and D925 are commonly referenced. These designations are for assemblies that do not require spray-applied fire resistive material on the deck. Excerpts from the Fire Resistance Directory for D902 are indicated in Figures 3, Figure 5 and Figure 6 and will be used to illustrate the determination of the spray-applied fire resistive material.

Design No. D902
Restrained Assembly Ratings — 1, 1-1/2, 2 and 3 Hr.
Unrestrained Assembly Ratings — 0, 1, 1-1/2, 2 or 3 Hr. (See Items 4 & 6)
Unrestrained Beam Ratings — 1, 1-1/2, 2 and 3 Hr.



1. Beam — W12X14 or W8X28, min size, see Items 6A through 6D.

Figure 3

EXAMPLE 1

Consider a building structured using 30'-0" × 30'-0" bays having a floor plate of 180' × 120'. Floor beams are W16×26 spaced 7'-6" on center and designed to act compositely with the floor slab. The interior girders are W21×44 composite beams. Lateral stability is achieved using perimeter moment frames and the spandrel members are W24×55 with moment connections to the perimeter columns. The slab is constructed using a 3¼ in. of lightweight concrete (107-116 pcf) over 2 in. deep composite deck. The construction is type 1B as defined by the International Building Code IBC [3] and the floor system is required to have a 2-hour fire resistance rating.

A 2-hour restrained assembly rating can be achieved with a 3¼ in. lightweight concrete thickness over 2 in. composite deck as confirmed by the table in Figure 5 that is taken from UL designation D902. Also, steel form units from 1½ in. to 4½ in.deep are included in this tested assembly. Therefore, the 2 in. deep composite deck is covered by this UL designation. The deck can be phosphatized steel/painted since the configuration is all fluted. The deck must be a minimum of 22 gage. The heat dissipation provided by the slab is influenced by its mass. Thus changes in unit weight of the concrete have an influence on the rating. The fire resistance can be met with concrete having a unit weight of between 107 and 116 pcf.

The table in Figure 6 is from the UL Directory designation D902 listing is for a fiber-based spray-applied fire resistive material which is applied by introducing fiber and water at the spray nozzle during application.

There are several unrestrained beam ratings for each restrained assembly rating. A 3¼ in. LW concrete fill over composite deck will provide a 2 hour fire resistance rating for a restrained assembly with 3/8 in. of spray-applied fire resistive material on the W8×28 test beam. The unrestrained beam rating with 3/8 in. of spray-applied fire resistive material provides a 1-hour unrestrained beam rating. A 2-hour unrestrained beam rating can be achieved with 1 in. of spray-applied material on the test beam and a 3-hour unrestrained beam rating can be achieved with 1$^{9}/_{16}$ in. spray-applied material on the test beam. The restrained assembly rating remains at 2 hours in spite of the increase in beam protection from $^{3}/_{8}$ in. to 1$^{9}/_{16}$ in. for the all fluted deck condition. However, a 1 hour unrestrained beam rating is an acceptable component of a 2-hour restrained assembly rating with $^{3}/_{8}$ in. of spray-applied fire resistive material on the W8×28 test beam.

A 2-hour fire resistance assembly rating with lightweight concrete has an associated 1-hour unrestrained beam rating with a $^{3}/_{8}$ in. thickness of spray-applied fire-resistive material applied to the W8×28 test beam. The *W/D* ratio for the W8×28 is 0.80. The required material thickness for the W16×26, W21×44 and W24×55 are calculated as follows:

W16×26 *W/D* = 0.55

$$T_1 = \left(\frac{0.80 + 0.6}{0.55 + 0.6}\right) 0.375$$
$$= 0.457 \quad use \ \tfrac{1}{2}"$$

W21×44 W / D = 0.73

$$T_1 = \left(\frac{0.80 + 0.6}{0.73 + 0.6}\right) 0.375$$
$$= 0.395 \quad use \ \tfrac{7}{16}"$$

W24×55 W / D = 0.82

$$T_1 = \left(\frac{0.80 + 0.6}{0.82 + 0.6}\right) 0.375$$
$$= 0.356 \quad use \ \tfrac{3}{8}" \ (minimum)$$

The approximate quantity of spray-applied fire resistive material required for the horizontal steel framing can be calculated considering a 30’ length (1 bay) by 120’ width (4 bays) of the building. In that 3,600 ft^2 section there are sixteen W16×26 beams, three W21×44 girders and two W24×55 spandrels.

EXAMPLE 1 SUMMARY

Sprayed Material Quantity

W16×26 $^{1}/_{2}$”
0.50” × 3.89 sf / ft × 30 ft × 16
= 933.60 board ft

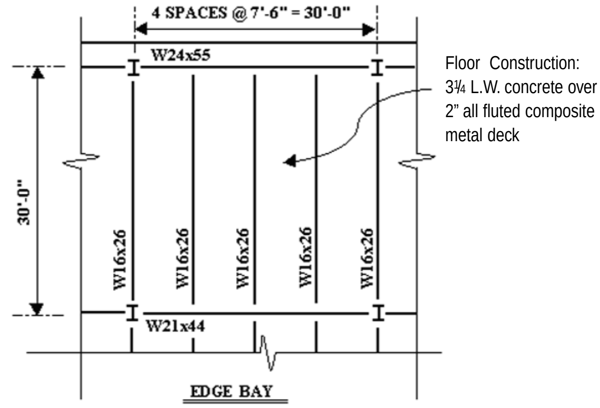


Figure 4

FIRE RESISTANCE DIRECTORY (BXRH)

Fire Resistance Ratings - ANSI / UL 263 (BXUV)–*Continued*

Restrained Assembly Rating Hr	Concrete (Type)	Concrete Unit Weight pcf	Concrete Thkns In.
1-1/2	Normal Weight	147-153	4
2	Normal Weight	147-153	4-1/2
3	Normal Weight	147-153	5-1/4
1	Lightweight	107-113	2-1/2
1	Lightweight	107-120	2-5/8
1-1/2	Lightweight	107-113	3
2	Lightweight	107-113	3-1/4
2	Lightweight	107-116	3-1/4*
2	Lightweight	114-120	3-1/2
3	Lightweight	107-113	4-3/16
3	Lightweight	114-120	4-7/16

*With 2 and 3 in. deep steel floor units only.

3. **Welded Wire Fabric** — 6x6 10/10 SWG.

4. **Steel Floor and Form Units*** — Composite 1-1/2, 1-5/8, 2 or 3 in. deep galv units or 4-1/2 in. deep non-composite galv units. Fluted units may be phos/ptd. Min gauges are 22 MSG for fluted and 20/20 for cellular and partial cellular units. The following combinations of units may be used:
(1) All 24, 26, 28 or 36 in. wide cellular or partial cellular.
(2) All fluted.
(3) One or two 3 in. deep, 12 in. wide, 18/18 MSG min cellular alternating with 3 in. deep fluted or other cellular.
(4)Any blend of fluted and 24, 26, 28 or 36 in. wide cellular or partial cellular.

Figure 5

W21×44 $^{7}/_{16}$”
0.438”× 4.94 sf / ft × 30 ft × 3
= 194.51 board ft

W24×55 $^{3}/_{8}$”
0.375”× 5.54 sf / ft × 30 ft × 2
= 124.65 board ft

Total = 1,252.76 board ft

1,252.76 / 3,600 = 0.35 board ft / ft^2

BEAM ONLY TESTS

In addition to assembly tests, beams alone can be tested under ASTM E119. Test results from the beam only test cannot be used independently but are valuable when used with an assembly test. The beam only tests are conducted over a furnace with a slab so that the beam will be subjected to heat input that is at least as severe as the heat input felt by a beam in an assembly test. To meet that objective, the floor construction of the beam only design must have a lower capacity for heat dissipation than the heat dissipation of the slab in the assembly. If the slab used in the beam only test had a higher capacity for heat dissipation, this substitute beam would have less thermal input than the assembly test. A lower capacity for heat dissipation will result if the slab over the beam only test has a lower unit weight and/or a reduced volume per unit area. The beam only tests are generally tested with reduced slab thickness and lightweight concrete to satisfy this lower capacity for heat dissipation requirement.

The beam only test is valuable when beam elements in an assembly are required to have a greater rating than the assembly. The UL Directory designate the beam only tests as Series

N for floor conditions and Series S for roof conditions. In order to use the beam only test with an assembly test, restrictions are imposed:

1. The floor or roof construction of the beam-only design must have a lower capacity for heat dissipation than the floor or roof construction of the assembly.
2. The spray-applied material of the beam-only test must be the same as the spray-applied material of the assembly test.

The UL listing N823 beam-only test meeting this criteria for substitution in the UL D902 assembly test is indicated in Figure 7.

EXAMPLE 2

Again consider the construction depicted in Figure 4 but requiring a Type 1A construction classification as defined by IBC. Under Type 1A construction, the structural assembly is required to provide a 2-hour fire resistance rating and the structural frame is required to provide a 3-hour fire resistance rating. The structural frame is defined as the columns and girders, beams, trusses and spandrels having direct connection to the columns.

The $2^{1}/_{2}$ in. concrete slab with a density of 102 pcf satisfies the lower capacity for heat dissipation criteria considering the $3^{1}/_{4}$ in. lightweight slab that is part of the D902 assembly. The spray-applied material in the beam-only test is the same as the spray-applied material in the assembly test. Therefore, this beam-only test can be used to determine the protection required to make the structural frame comply with a 3-hour rating in an assembly having a 2-hour rating.

The test beam in both conditions is a W8×28 and $1^{1}/_{4}$ in. of spray-applied material will produce a 3-hour restrained beam rating. The *W/D* of the test beam is 0.80. The spray-applied fire resistive material thickness requirements for members that have *W/D* ratios varying that of the test beam can be determined using the beam substitution equation.

The substitution equation is limited to adjustments to unrestrained beam ratings only. Unlike the assembly tests that confirm a beam with a lower unrestrained rating is adequate to maintain the higher assembly rating, no analogous data is reported in the beam only test. A conservative approach is to simply use the thickness of the unrestrained beam. The unrestrained spray-applied fire resistive material thickness is used in this example for comparison purposes. An alternate approach is demonstrated in Example 3.

The spray-applied fire resistance material thickness applied to the W8×28 test beam for a 3-hour unrestrained beam rating under UL N823 is $1^{5}/_{8}$ in. Therefore, the following adjustments for the structural frame members apply:

W16×26 $W/D = 0.55$

$$T_1 = \left(\frac{0.80 + 0.6}{0.55 + 0.6}\right) 1.625$$
$$= 1.98 \quad use\ 2"$$

W21×44 $W/D = 0.73$

$$T_1 = \left(\frac{0.80 + 0.6}{0.73 + 0.6}\right) 1.625$$
$$= 1.71 \quad use\ 1\tfrac{3}{4}"$$

W24×55 $W/D = 0.82$

$$T_1 = \left(\frac{0.80 + 0.6}{0.82 + 0.6}\right) 1.625$$
$$= 1.60 \quad use\ 1\tfrac{5}{8}"$$

The approximate quantity of spray-applied fire resistive material required for the horizontal steel framing for IBC Type 1A construction is summarized below.

Restrained Assembly Rating Hr	Unrestrained Beam Rating Hr	Concrete Type	Protection Mtl Thkns on Structural Member In. W8x28 When Deck Is All Fluted	W8x28 When Deck Is Blend or All Cellular	W12x14 When Deck Is All Fluted	Joist Item 1A When Deck Is Fluted Cellular or Blend	Joist Item 1B When Deck Is Fluted Cellular or Blend
1	1	NW	3/8,5/8**	1/2+,11/16**	9/16,15/16**	1	—
1-1/2	1	NW	3/8,5/8**	1/2+,11/16**	9/16,15/16**	1-9/16	—
2	1	NW	3/8,5/8**	1/2+,11/16**	9/16,15/16**	2-1/16	—
2	2	NW	3/4	1-3/8+	1-1/16	2-1/16	—
2	3	NW	1-3/16	2-1/8+	1-11/16	—	3-1/4
3	1-1/2	NW	1/2	7/8*	3/4	—	3-1/4
3	2	NW	3/4	1-3/8+	1-1/16	—	3-1/4
3	3	NW	1-3/16	2-1/8+	1-11/16	—	3-1/4
1	1	LW	3/8,5/8**	1/2+,11/16**	9/16,15/16**	1-1/8	—
1-1/2	1	LW	3/8,5/8**	1/2+,11/16**	9/16,15/16**	1-3/4	—
2	1	LW	3/8,5/8**	1/2+,11/16**	9/16,15/16**	2-1/4	—
2	2	LW	1	1-3/8+	1-7/16	2-1/4	—
2	3	LW	1-9/16+	2-1/8+	2-1/4	—	3-1/4
3	1-1/2	LW	11/16	7/8*	1	—	3-1/4
3	2	LW	1+	1-3/8+	1-7/16	—	3-1/4

**This thickness applies when optional Item 12 or 13 are used over 3-1/4 in. lightweight concrete topping.
*May be reduced to 3/4 in. for the 1-1/2 hr Unrestrained Beam Rating when the material is sprayed 2 in. beyond the beams's top flange and no reduction in thickness is made at the tips of the bottom flange.
+Thickness of Spray-Applied Fire Resistive Materials may be reduced to one half of this thickness on the lower flange tips of the steel beam.

Figure 6

EXAMPLE 2 SUMMARY

Sprayed Material Quantity

W16×26 (Filler Beam) $^{1}/_{2}$"
$0.50" \times 3.89\ ft^2/ft \times 30\ ft \times 12$
= 700.20 board ft

W16×26 (Structural Frame) 2"
$2.00" \times 3.89\ ft^2/ft \times 30\ ft \times 4$
= 933.60 board ft

W21×44 (Structural Frame) $1^{3}/_{4}$"
$1.75" \times 4.94\ ft^2/ft \times 30\ ft \times 3$
= 778.05 board ft

W24×55 (Structural Frame) $1^{5}/_{8}$"
$1.625" \times 5.54\ ft^2/ft \times 30\ ft \times 2$
= 540.15 board ft

Total = 2,952.00 board ft

$2{,}952.00/3{,}600 = 0.82\ board\ ft/ft^2$

The beam substitution equation is restricted to determining the fireproofing thickness for substitution beams based on the unrestrained beam thickness since the equation is temperature related and the unrestrained beam rating is based on temperature. When applying the equation to determining fireproofing thickness in a restrained assembly, the procedure is rational. The spray-applied material thickness for unrestrained beam rating (e.g. 1-hour) associated with the restrained assembly rating (e.g. 2-hours) is the T_2 parameter in Equation (1). The application is not as straightforward when applying the beam only design. Example 2 applies the beam only design but the spray-applied material thickness associated with a 3-hour unrestrained beam was used. The spray-applied material thickness is that associated with an unrestrained beam in spite of the restrained beam condition.

EXAMPLE 3

An argument can be made that the more appropriate approach in this case of a restrained beam having a higher hourly rating than the assembly would be to use the thickness associated with the restrained beam. Example 3 takes this approach. This example is a reevaluation of the thickness determined in Example 2 but using the spray-applied material thickness associated with a restrained beam. The W24×55 member has a *W/D* greater than the test beam and the 1¼ in. spray-applied fire resistive material thickness applies. Calculation of the spray-applied material thickness for the other members follows:

W16×26 $W/D = 0.55$

$$T_1 = \left(\frac{0.80 + 0.6}{0.55 + 0.6}\right) 1.25$$

$$= 1.52 \quad use \ 1\tfrac{9}{16}"$$

W21×44 $W/D = 0.73$

$$T_1 = \left(\frac{0.80 + 0.6}{0.73 + 0.6}\right) 1.25$$

$$= 1.32 \quad use \ 1\tfrac{3}{8}"$$

W24×55 $W/D = 0.82$

$$T_1 = \left(\frac{0.80 + 0.6}{0.82 + 0.6}\right) 1.25$$

$$= 1.23 \quad use \ 1\tfrac{1}{4}"$$

EXAMPLE 3 SUMMARY

<u>Sprayed Material Quantity</u>

W16×26 (Filler Beam) ½”
$0.50” \times 3.89\ ft^2/ft \times 30\ ft \times 12$
= 700.20 board feet

W16×26 (Structural Frame) 1¹/₁₆”
$1.56” \times 3.89\ ft^2/ft \times 30\ ft \times 4$
= 728.21 board feet

W21×44 (Structural Frame) 1¾”
$1.25” \times 4.94\ ft^2/ft \times 30\ ft \times 3$
= 555.75 board feet

W24×55 (Structural Frame) 1¼”
$1.375” \times 5.54\ ft^2/ft \times 30\ ft \times 2$
= 457.05 board feet

Total = 2441.21 board ft

$2{,}441.21 / 3{,}600 = 0.68$ board ft/ft^2

CONCLUSION

The procedure demonstrated in Example 1 is the correct process for determining the spray-applied fire resistive material thickness when a higher rating on the beams in the assembly is not required. The procedure demonstrated in Example 3 is appropriate when substituting beams with a higher rating in an assembly with a lesser rating.

Using data from existing UL tests to determine the correct thickness of spray-applied fire resistive material requires the correct assessment of thermal restraint (RESTRAINED) and a basic understanding of ASTM E119 test procedures. The data reported in a single UL test may include variations in slab thickness, differing deck depths, lightweight and normal weight concrete, fluted and / or cellular deck, etc. Then, thickness data is provided for multiple fire durations and differing conditions of restraint for both the assembly and the test beam. The sheer volume of information available makes the calculation of the correct thickness of spray-applied fire resistive material complex. A frequent response to dealing with the complexity is to take a conservative approach and assume the assembly to be thermally unrestrained and to use the spray-applied fire resistive material thickness associated with an unrestrained beam. If this excessive approach were used in Example 1 above, a two hour rated assembly with two-hour beams, the spray-applied fire resistive material would increase from 0.35 board ft/ft^2 to 0.70 board ft/ft^2. The fiber spray-applied fire resistive material represented by UL D902 has an in-place cost in the range of \$0.57 to \$0.85 per board foot. Thus, an unnecessary cost of between \$0.20 and \$0.30 per ft^2 of building area is incurred by the taking the conservative approach.

REFERENCES

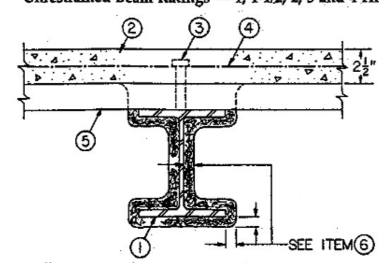
[1] American Society for Testing and Materials (ASTM) (2000), “*Standard Test Methods for Fire Testing of Building Construction and Materials*”, Specification No. E 119-00, West Conshohocken, Pennsylvania.

[2] Gewain, R.G., Troup, E.W.J., “Restrained Fire Resistance Ratings in Structural Steel Buildings”, *Engineering Journal*, Vol. 38, No.2, American Institute of Steel Construction, Chicago, IL, 2001.

[3] International Code Council, Inc. (IBC) (2000), “*International Building Code, 2000*”, Falls Chu rch, Virginia.

[4] Underwriters Laboratories Inc. (UL) (2000), “*Fire Resistance Directory, Volume 1, 2000*”, Northbrook, Illinois.

Design No. N823
Restrained Beam Ratings — 1, 1-1/2, 2, 3 and 4 Hr.
Unrestrained Beam Ratings — 1, 1-1/2, 2, 3 and 4 Hr.



1. **Steel Beam** — W8x28 min size.
2. **Normal Weight or Lightweight Concrete** — Compressive strength 2800 psi. For normal weight concrete either carbonate or siliceous aggregate may be used. Unit weight 150 pcf (2403 kg/cu meter). For lightweight concrete, unit weight 102 pcf (1634 kg/cu meter).
3. **Shear Connector (Optional)** — Studs, 3/4 in. (19 mm) diameter headed type or equivalent per AISC specifications. Welded to top flange of beam through the steel floor units.
4. **Welded Wire Fabric** — 6x6, W1.4xW1.4.
5. **Steel Floor and Form Units** — 1-1/2, 2 or 3 in. deep fluted units, welded to beam.
6. **Spray-Applied Fire Resistive Materials*** — Spray applied in one or more coats to a final thickness as shown in the table below, to steel surfaces which must be clean and free of dirt, loose scale and oil. When fluted units are used, the crest areas above the beam shall be filled with this material. Min avg density of 13 pcf and min ind density of 11 pcf for Types II or DC/F. Min avg and min ind densities of 22 and 19 pcf, respectively, for Type HP. For method of density determination, refer to Design Information Section.

The following table is for lightweight concrete.

Rating Hr	Thkns In. (mm)	
	Unrestrained Beam Rating Hr	Restrained Beam Rating Hr
1	3/8(9.5)	3/8(9.5)
1-1/2	11/16(17.5)	7/16(11.1)
2	1(25.4)	3/4(19.0)
3	1-5/8(41.3)	1-1/4(31.7)

The following table is for normal weight concrete.

Rating Hr	Thkns In. (mm)	
	Unrestrained Beam Rating Hr	Restrained Beam Rating Hr
1	3/8(9.5)	3/8(9.5)
1-1/2	1/2(12.7)	3/8(9.5)
2	3/4(19.0)	1/2(12.7)
3	1-3/16(30.2)	1(25.4)
4	1-9/16(39.7)	1-7/16(36.6)

CIL GROUP LTD —Type D-C/F or Type II. Investigated for exterior use. Type EBS or Type X adhesive/sealer.
ISOLATEK INTERNATIONAL —Type D-C/F, HP or Type II. Investigated for exterior use. Type EBS or Type X adhesive/surface sealer optional.
*Bearing the UL Classification Marking

Figure 7