

HISTORICAL DOCUMENT - The concepts and procedures are valid, check
current code for updated values (~~FBC 5th Edition~~ Chapter 7, Sections 722.2, 722.3, 722.4)
FBC 7th Edition

Calculated Fire Resistance

for

Concrete

and

Concrete Masonry



FLORIDA CODE APPROVED PROCEDURES

The Standard Building Code and the South Florida Building Code allow fire resistance ratings of concrete and concrete masonry members and assemblies to be determined by calculation methods. This publication summarizes these approved calculation procedures. Requirements for walls, floor and roof slabs, and columns are tabulated and calculation procedures are demonstrated by example.

At the time of this printing all the procedures herein have been approved by the Standard Building Code and are contained in Chapter 31 of that code. In the South Florida Building Code, these procedures have been incorporated with minor variations into Chapter 37 ... for both the Dade and Broward editions.

Analytical Methods of Determining Fire Endurance of Concrete and Masonry Members—Model Code Approved Procedures

Fire endurance: *A measure of the elapsed time during which a material or assembly continues to exhibit fire resistance under specified conditions of test and performance. As applied to elements of buildings, fire endurance shall be measured by the methods and to the criteria defined by ASTM Methods E 119, "Standard Methods of Fire Tests of Building Construction and Materials." (Fire endurance is a technical term.)*

Fire resistance: *The property of a material or assembly to withstand fire or give protection from it. As applied to elements of buildings, fire resistance is characterized by the ability to confine a fire or to continue to perform a given structural function, or both. (Fire resistance is a descriptive term.)*

Fire rating: *A time required, usually expressed in hours, for an element in a building to maintain its particular fire-resistant properties. Model codes establish the required fire ratings for various building elements. (Fire rating or fire-resistance rating is a legal term.)*

PART I INTRODUCTION AND STANDARD FIRE TEST

Fire endurance periods for building components are normally determined by physical tests conducted according to ASTM E 119, "Standard Methods of Fire Tests of Building Construction and Materials." Provisions of the ASTM E 119 test require that specimens be subjected to a fire which follows the standard time-temperature curve shown in Fig. 1.

Under the E 119 standard, the fire endurance of a member or assembly is determined by the time required to reach the first of any of the following three end points:

1. Ignition of cotton waste due to passage of flame through cracks or fissures.

2. A temperature rise of 325°F (single point) or 250°F (average) on the unexposed surface of the member or assembly. This is known as the heat transmission end point.
3. Inability to carry the applied design load, that is, structural collapse.

Additional rating criteria for the fire endurance of a member or assembly include

1. Concrete structural members: in some cases the average temperature of the tension steel at any section must not exceed 800° F for cold-drawn prestressing steel or 1100°F for reinforcing bars. Tests show that the respective steels retain approximately 50% of their original yield strength at these temperatures.
2. For wall sections: the ability to resist the impact, erosion, and cooling effects of a specific size hose stream.

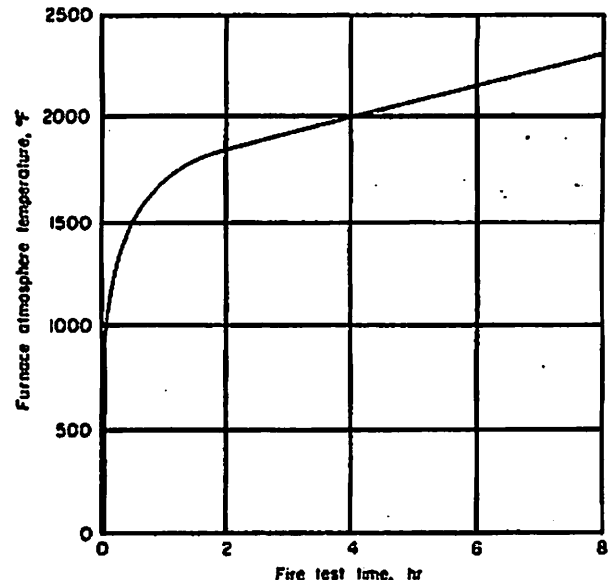


Fig. 1. ASTM Standard E 119 time-temperature curve.

Much of the following information through page 13 is excerpted from "Fire Protection Planning Report No. 13; Analytical Methods of Determining Fire Endurance of Concrete and Masonry Members - Model Code Approved Procedures," SR 267.01B, Concrete and Masonry Industry Firesafety Committee, 5420 Old Orchard Road, Skokie, Illinois 60077-4321.

Table 1 presents a listing of ASTM E119 end-point criteria and test conditions and outlines applicable end points of various concrete and masonry members and assemblies.

ASTM E 119 classifies beams, floors, and roofs as either restrained or unrestrained. A restrained member is one in which the thermal expansion is restricted. Reinforced concrete assemblies are generally classified as restrained if they have continuity at interior supports or are restricted from lateral movement at exterior supports. Table 2 should be referenced when determining the presence of thermal restraint.

The three model codes in the United States are the BOCA National Building Code (B/NBC), ICBO Uniform Building Code (UBC), and SBCCI Standard Building Code (SBC). All require firetesting in accordance with ASTM E 119 or analytical calculation based on ASTM E119 test data to satisfy all fire-resistance ratings required by the codes. These recently approved analytical methods present significant cost savings when compared to actual ASTM E 119 firetesting.

ANALYTICAL METHODS

Over many years the results of ASTM E 119 standard fire tests have been analyzed. Along with standard fire tests there has been research and development of data on strength of steel and concrete at elevated temperatures, temperature distribution within concrete, verification and modification of theory, and the effects of restraining thermal expansion during heating. This testing and research forms the basis for the analytical, or the calculation methods of determining fire endurance.

Calculation of fire endurance can be classified into two categories: rational design and empirical design.

Rational Design

Rational design utilizes ASTM E119 fire-test results, data on steel and concrete strength at elevated temperatures, temperature distribution within heated concrete, and the effects of support conditions and restraint of thermal expansion to perform structural engineering calculations. With the information listed, the engineer can then estimate by calculation the strength of members exposed to standard fire tests for various lengths of exposure time. Many fire tests have been performed to further develop and verify that rational design calculations correctly estimate strengths of members exposed to the standard fire test.

In a rational design calculation the fire endurance would be the length of time required for the load capacity of the member to be reduced to equal that of the applied loading.

Empirical Design

Empirical design utilizes tabulated results of ASTM E119 fire tests and design aids, such as data on strength of heated concrete and steel, and temperature distributions in concrete and masonry to calculate factors such as

critical concrete thicknesses and cover. Application of empirical design is simpler than rational design in that no structural engineering calculations are required.

END-POINT CRITERIA AND ANALYTICAL METHODS

To analytically calculate the fire endurance of a given member it is useful to understand which end-point criteria will govern design of that member. As previously discussed, the first end point reached during the E119 fire test establishes the fire endurance *period* of the member. To further aid in understanding applicability of various end-point criteria, Table 1 should be referenced.

Walls

Concrete and masonry walls nearly always fail the heat transmission end point before allowing passage of flame or failing structurally. By examining heat transmission through various thicknesses of concrete, made with various types of aggregates, from E 119 fire tests it is possible to determine a given thickness or equivalent thickness of concrete, masonry, or brick to limit the temperature rise to below 250°F (average) or to 325°F (single point) as specified in ASTM E 119.

Beams

Prestressed and normally reinforced concrete beams cannot be so easily categorized. The ability of a beam to carry a design load is the primary end point and is dependent on several factors which are accounted for in rational design methods. The rational design of a beam would consider the applied load, amount of concrete cover, beam spacing, span length and beam dimension, concrete and steel strengths, aggregate type in the concrete, type of support, and restraint of thermal expansion. Considering the above factors, the structural designer would calculate the load-carrying capacity of the beam at a specific length of exposure time, that being the code-required-fire endurance period for the member being examined.

Empirical design of beams in accordance with, for example, Chapter 31 of the SBC and Chapter 37 of SFBC replaces rational design and considers the above factors for specifying concrete cover requirements for beams of different aggregate type concrete of varying width in both restrained and unrestrained conditions as shown in Table 7. Tests show that with all other factors equal the primary factors in beam fire endurance are the amount of concrete cover over prestressing strands or reinforcing steel bars and the method of support.

Floors and Roofs

Calculation of fire endurance of reinforced and prestressed concrete roof and floor slabs is based on both analysis of heat transmission and of load-carrying capacity at elevated temperatures. The heat transmission end point can be analyzed similarly to walls. As with

Table 1
Applicable End-Point Criteria and Test Conditions for Concrete and Masonry Members and Assemblies (Based on ASTM E 119 Standard Fire Tests)

End point		250° F average temperature rise or 325° point temp. rise on unexposed surface	Flame impingement through cracks or fissures sufficient to ignite cotton waste	Carry applied load	Steel temperature end point	Restrained during testing	Hose stream test
Member							
Walls	Bearing	Yes	Yes	Yes	Not considered	No ¹	Yes ²
	Nonbearing	Yes	Yes	No Load applied			
Floors and roofs	Restrained	Yes	Yes	Yes	No ³	Yes	No
	Unrestrained	Yes	Yes	Yes			
Columns		No	No	Yes	No	Restraint not imposed; test specifies simulation of end connection	No
Individual beams-restrained: prestressed or reinforced		No	No	Yes	Yes ⁴	Yes	No
Individual beams - Unrestrained: prestressed or reinforced		No	No	Yes	No	No	No

¹ Non-load-bearing walls are restrained but not loaded during tests. Bearing walls are loaded but not restrained

² Hose stream tests apply only to those walls required to have a one-hour rating or greater

³ Restrained floor and roof slabs utilizing concrete beams spaced greater than 4' center-to-center must not exceed steel temperature limits of 1100°F (reinforcing steel) and 800°F (prestressing steel) for one-half the rating period or 1 hour whichever is greater

⁴ Reinforcing steel in concrete beams or joists spaced greater than 4' center-to-center and cast monolithically with floors and columns must be maintained below 800°F (prestressing) and 1100°F (reinforcing) for 1 hour or one-half the desired rating period, whichever is greater.

Table 2.
Construction Classification, Restrained and Unrestrained

UNRESTRAINED	
Wall Bearing:	Single span and simply supported end spans of multiple bays such as concrete slabs or precast units ¹
RESTRAINED	
Wall Bearing:	Interior spans of multiple bays: (1) Cast-in-place concrete slab systems (2) Precast concrete where the potential thermal expansion is resisted by adjacent construction ² Concrete framing: (1) Beams securely fastened to the framing members. (2) All types of cast-in-place floor or roof systems (such as beam-and-slabs, flat slabs, pan joist and waffle slabs) where the floor or roof system is cast with the framing members. (3) Interior and exterior spans of precast systems with cast-in-place joints resulting in restraint equivalent to that which would exist in condition 1, concrete framing. (4) All types of prefabricated floor or roof systems where the structural members are secured to such systems and the potential thermal expansion of the floor or roof systems is resisted by the framing system or the adjoining floor or roof construction.

1. Floor and roof systems can be considered restrained when they are tied into walls with or without tie beams, the walls being designed and detailed to resist thermal thrust from the floor or roof system. 2. For example, resistance to potential thermal expansion is considered to be achieved when:

1. Continuous structural concrete topping is used.
2. The space between the ends of precast units or between the ends of units and the vertical face of supports is filled with concrete or mortar, and
3. The space between the ends of precast units and the vertical faces of supports, or between the ends of solid or hollow-core slab units does not exceed 0.25 % of the length for normal weight concrete members or 0.1 % of the length for structural lightweight concrete members.

beams, the ability of roofs and floors to carry load is influenced by several factors in design. Tabulated values for concrete cover, similar to those for beams, exist for roof and floor slabs and are shown in Table 8.

Columns

The structural fire endurance of concrete columns is influenced primarily by the column size and the concrete aggregate type. The basis at present for column fire endurance design are tabulated minimum cover and column size requirements based on past ASTM E 119 tests which were run to the structural failure end point and a just completed 10 year column testing program at the laboratories of the National Research Council of Canada and the Portland Cement Association. Results have been incorporated into the current model building codes and are included in this booklet update of '92.

FACTORS INFLUENCING ENDURANCE OF CONCRETE AND MASONRY EXPOSED TO FIRE

Three principal factors influence the fire endurance of concrete and masonry. These factors, thickness and aggregate type, thermal restraint conditions, and temperature distribution through members are included in the code-approved methods for calculating fire resistance and need to be understood before attempting to carry out the calculations.

Effect of Thickness and Aggregate Type

The factors which determine the fire endurance of concrete and masonry members or assemblies subject to the heat transmission end point criteria (walls, floors, roofs) are the thickness and the aggregate type of concrete used.

This can be seen clearly in Table 3, which shows that for a given aggregate type the length of time to reach a 250°F temperature rise on the unexposed surface increases as the thickness of the concrete increases. Examination of Table 3 also shows that lightweight aggregate concrete transmits heat more slowly than

normal-weight concrete, resulting in longer fire endurances. As unit weight, determined by aggregate type, is reduced, resistance to heat transmission increases.

Structural lightweight concretes use aggregate such as expanded shale, clay, and slate and have unit weights ranging from 100 lbs per cu ft to about 120 lbs per cu ft. Normal-weight concretes have unit weights ranging from 135 to 150 lbs per cu ft. Normal-weight concretes utilize siliceous aggregates obtained from natural sand and gravel or carbonate aggregates such as limestone. Lightweight insulating concretes with unit weights of as low as 30 lbs per cu ft are also available.

Effect of Restraint of Members During Fire Loading

Most cast-in-place reinforced concrete members are considered restrained. Precast or prestressed concrete members are more difficult to classify, and conditions which affect thermal restraint should be carefully examined in every case involving a beam, floor, or roof assembly. The tabular methods contained within the model codes consider either fully restrained or fully unrestrained members subjected to ASTM E 119 fire tests. In most cases the presence of restraint will enhance fire endurance.

Table 2, which is adapted from Appendix X3 of ASTM E 119 (also contained within the UL Fire Resistance Directory), provides some criteria for identifying whether a given member or assembly is restrained or unrestrained.

Temperature Distribution Within Concrete and Masonry Members and Assemblies

In concrete and masonry, several factors influence temperature distribution through a member; primary are the shape or thickness of the member and the concrete aggregate type. Temperature distribution through or within the member during ASTM E 119 fire testing is important in determining heat transmission rates in walls and floors and roofs and in determining steel and concrete temperatures in beams, floors and roofs, and columns.

Table 3.
Fire Endurances of Naturally Dried Specimens¹

Slab Thickness in.	Fire endurance, hr:min.		
	Siliceous aggregate	Carbonate aggregate	Sanded expanded shale aggregate ²
1 1/2	0:18	0:18	0:24
2 1/2	0:35	0:41	0:54
4	1:18	1:27	2:18
5	2:01	2:17	3:00
6	2:50	3:16	4:55
7	3:57	4:31	-

¹ Times shown are times required to reach 250°F average temperature on unexposed surface.

² With sand from Elgin, Illinois, replacing 60% (by absolute volume) of the fines.

PART II

CODE-APPROVED METHODS OF CALCULATION

NOTE:

For calculating the fire rating of concrete and concrete masonry materials two factors must be known.

They are:

- 1) Equivalent Thickness, and**
- 2) Type of aggregate**

AGGREGATE TYPE USED IN FLORIDA

Limestone aggregate is most commonly used for both concrete and concrete masonry throughout Florida with the possible exception of the Panhandle. In the case of concrete, limestone falls into the carbonate category (Fig. 2/ Table 4,6,7,8,9 and 10). However, for concrete masonry (Table 5 and Table 10), the classification of aggregates is broken down even further with limestone placed in a separate category along with cinders and expanded slag. Granites and "crushed river run" fall into the category of siliceous for both concrete and concrete masonry. If aggregate type is in doubt, the information can generally be obtained from the concrete or masonry supplier. Aggregate type is important because the different aggregate type concretes transmit heat at different rates as can be seen in the following tables.

PART II
CODE-APPROVED METHODS OF CALCULATION

HEAT TRANSMISSION END POINT

Solid Concrete Walls, Floors, and Roofs of Constant Thickness

When considering flat, single-wythe concrete or masonry walls, floors, or roofs, heat transmission endurance periods are based on the actual or equivalent thickness of the assembly in accordance with Fig. 2 (concrete) or Fig. 3 (masonry). These are summarized in Table 4 for Concrete and Table 5 for Masonry which illustrate the general form the information appears in the model codes.

EQUIVALENT THICKNESS CONCEPT:

When the building component in question is ribbed, tapered, undulating, or has hollow cores, an equivalent *solid thickness* must be determined. *Equivalent thickness* is the thickness obtained by considering the *gross cross-sectional area of a wall minus the area of voids or undulations in hollow or ribbed sections, all divided by the width of the member*. Calculation of equivalent thickness is outlined for several common concrete and masonry building components in Figs. 4, 5, and 6 and elsewhere within the text.

Table 4.
Minimum Equivalent Thickness, in., of
Cast-in-Place or Precast Concrete Walls,
Loadbearing or Non-Loadbearing^{1,2}

Concrete

Concrete aggregate type	Minimum slab thickness (inches) for fire-resistance rating				
	1 hr	1-1/2 hr	2 hr	3 hr	4 hr
Siliceous	3.5	4.3	5.0	6.2	7.0
Carbonate	3.2	4.0	4.6	5.7	6.6
Sand-lightweight	2.7	3.3	3.8	4.6	5.4
Lightweight	2.5	3.1	3.6	4.4	5.1

Table 5.
Minimum Equivalent Thickness in Inches
of Load-Bearing Concrete Masonry Unit Walls
for Fire-Resistance Ratings^{1,2}

Concrete
Masonry

Aggregate Type	1 hr	2 hr	3 hr	4 hr
Expanded slag or pumice aggregates	2.1	3.2	4.0	4.1
Expanded shale, clay, or slate agg.	2.6	3.6	4.4	5.1
Limestone, cinders, or unexpanded slag aggregates	2.7	4.0	5.0	5.9
Calcareous gravel aggregates	2.8	4.2	5.3	6.2
Siliceous gravel aggregates	3.0	4.5	5.7	6.7

¹Fire ratings for thicknesses between tabulated values may be obtained by direct interpolation

²Where all of the core spaces of hollow-core wall panels or masonry units are filled with loose-fill material such as expanded shale, clay or slag, vermiculite or perlite, or solid grouted, the fire-resistance rating of the wall is the same as that of a solid wall of the same aggregate type and of the same overall thickness

Tapered Flanges

Equivalent thickness for a concrete T-beam with tapered flanges is taken as the actual thickness of the flange measured at a distance of twice the minimum thickness or 6" from the end of the flange (whichever is less). This is shown in Fig. 4.

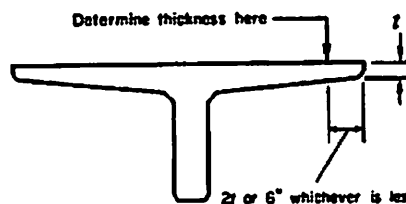


Fig. 4 Equivalent thickness of a tapered member.

Fig. 2
CONCRETE

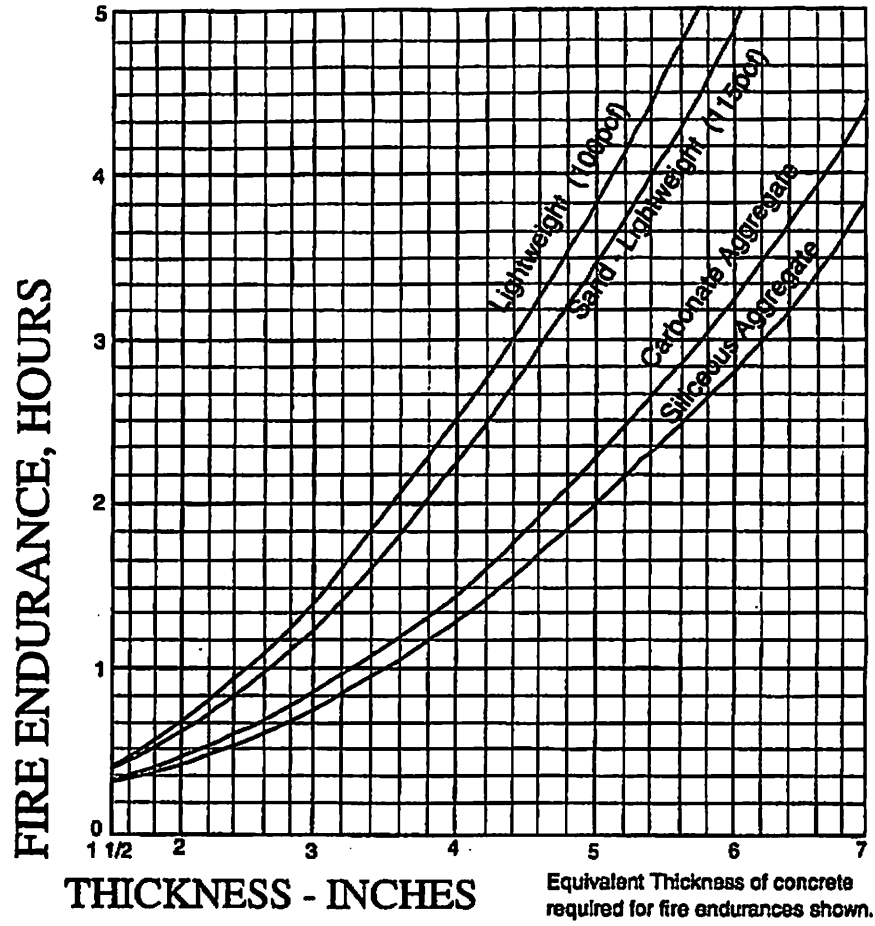
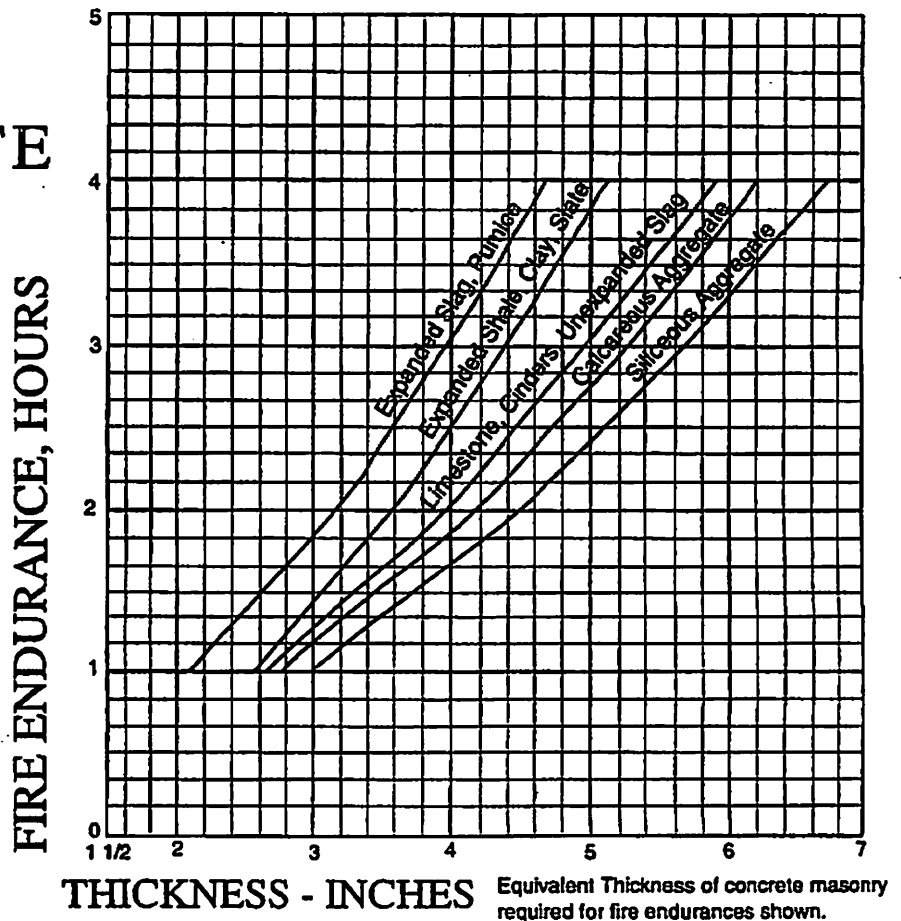


Fig. 3
CONCRETE MASONRY



Ribbed Concrete Members

For ribbed or undulating surfaces, calculation of equivalent thickness is based on the spacing of the stem components and minimum thickness of the flange. Calculation of the equivalent thickness is determined based on the provisions shown in Fig. 4.

For $s \geq 4t$, the thickness to be used shall be t
 For $s \leq 2t$, the thickness to be used shall be t_o

For $4t > s > 2t$ the thickness shall be $t + (4t/s - 1)(t_o - t)$

s = spacing of ribs or undulations t = minimum thickness
 t_o = equivalent thickness of the panel calculated as the net cross-sectional area of the panel divided by the width; not to exceed $2t$

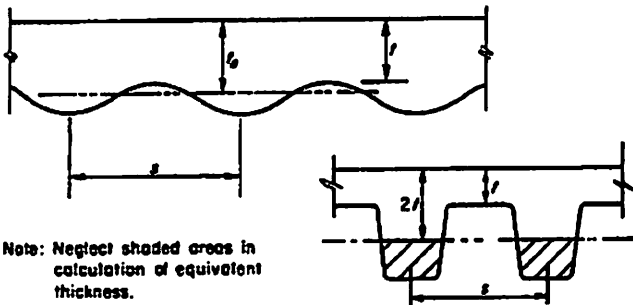


Fig. 5. Equivalent thickness of a ribbed or undulating section.

Hollow-Core Concrete Planks

The equivalent thickness (t_{eq}) of hollow-core planks is obtained by the equation

$$t_{eq} = A_{net} / \text{width}$$

where A_{net} is the gross cross section (thickness X width) minus the area of cores. This is shown in Fig. 5.

A_{net} = area of gross cross section - area of cores

$$A_{net} = 8 \text{ in.} \times 72 \text{ in.} - 5 \left(\frac{\pi (4)^2}{4} \right)$$

$$= 576 \text{ sq in.} - 62.8 \text{ sq in.} = 513.2 \text{ sq in.}$$

$$t_{eq} = \frac{513.2 \text{ sq in.}}{72 \text{ in.}} = 7.1 \text{ in.}$$

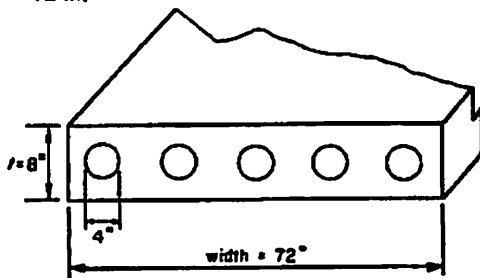


Fig. 6. Typical hollow-core concrete plank.

Concrete Masonry - (Block)

Hollow or solid concrete masonry units are available in nominal thicknesses of 2, 4, 6, 8, 10, and 12 in. with varying percentages of solid area. The equivalent thickness for hollow block can be calculated using a procedure similar to that for hollow-core slabs. Equivalent thickness for concrete masonry can be determined from the following equation:

$$t_{eq} = \% \text{ solid} \times \text{thickness}$$

The percent solid in any given masonry unit can be obtained from the manufacturer. Once equivalent thickness is known, the fire-resistance rating of masonry walls can be determined from Table 4. See notes to Table 4 for each model code's provision regarding fire endurance of filled block. If 100% solid flat-sided concrete masonry units are used, the equivalent thickness is the actual thickness.

Multi-Wythe Walls

A multi-wythe wall (that is, a wall with more than one layer of material) has a greater fire-endurance period than a simple summation of fire-endurance periods of the various layers. An equation for determining estimated fire endurance of multi-wythe walls based on the heat transmission end point is:

$$R = (R_1^{0.59} + R_2^{0.59} \dots + R_n^{0.59})^{1.7} \quad \text{Eq. 1}$$

where

R = total fire-endurance rating in minutes

R_1 , etc. = fire endurance in minutes of each individual wythe (or component lamina)

The equation is not applicable in all cases and must be used keeping the following conditions in mind.

1. The fire endurances (determined in accordance with ASTM E 119) of each wythe must be known.
2. The equation does not account for orientation of layering. It is known that if the more fire-resistant material is on the fire-exposed surface, a higher total rating would be obtained during actual testing than if the wythes were reversed.
3. The exponent 1.7 and its reciprocal 0.59 are average values which vary from material to material.

Graphical Method

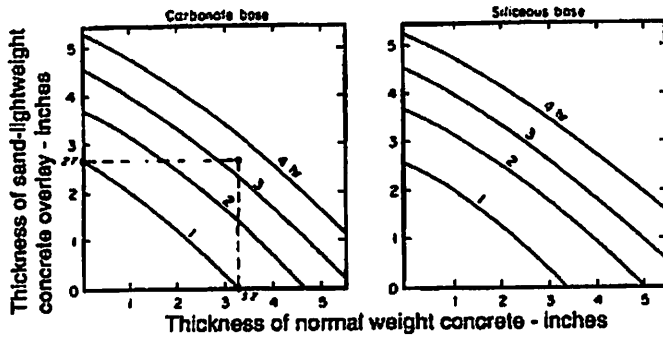


Fig. 7 Fire endurance of multi-wythe walls—graphical method (based on fire exposure on normal weight concrete side of assembly).

GRAPHIC vs CALCULATION METHOD:

Graphic Method:

Fig. 7 shows a graphical method for determining the fire resistance rating of a two wythe wall. Each wythe has an individual fire endurance rating of one hour, but, when used together the result is a 3 hr-17 min. rating.

Calculation Method:

3.20" carbonate aggregate concrete from Fig. 2, $R = 1.0$ hr
 2.70" sand-lightweight concrete from Fig. 2, $R = 1.0$ hr
 $R_{Total} = ((60)^{0.59} + (60)^{0.59})^{1.7} = 197$ minutes (3hr, 17 minutes)

The equation is generally accurate within ten percent. Graphical means of calculating multi-wythe fire resistance, as shown in Fig. 7, should be used when greater accuracy is required.

Table 6 shows values for $R^{0.59}$ to be used in the multi-wythe equation. Note that concrete masonry and brick are not included. $R^{0.59}$ values may be obtained for any wall tested per ASTM E 119 by simply raising the resistance, in minutes, to the 0.59 power. For example, from Fig. 2 it can be seen that 3.5 inches of siliceous aggregate concrete will provide one hour fire endurance, and $(60)^{0.59} = 11.3$. Referring to Table 6 we can read $R^{0.59}$ directly which for 3.5 inches of siliceous aggregate concrete is 11.3.

Sandwich Panel Wall Section

Precast concrete panels consisting of a layer of foamed insulation between two layers (wythes) of concrete have become a popular method of providing energy-efficient walls. Foam insulation can be considered to have a fire-resistance rating (R) of 5 minutes if one inch or thicker ($R^{0.59} = 2.5$ minutes). For thicknesses less than one inch, the effect of the foam insulation should not be considered in calculating the panel fire endurance.

Multicourse Concrete Floors and Roofs

Calculations of heat transmission fire endurance of multicourse floors and roofs are similar to analysis of multiwythe walls. Fig. 7 shows the required thickness of a siliceous or carbonate aggregate concrete base course and an overlay of sand-lightweight concrete required to achieve fire endurances from one to four hours. Ratings shown are based on the heat transmission end point. Graphs such as Fig. 7 have been approved for analytical calculation of multicourse floor, roof, and wall fire endurance by all model codes. Reference 1 is an excellent source of this graphical data.

STRUCTURAL END POINT

Reinforced and Prestressed Concrete Beams

Reinforced and prestressed concrete beam fire endurance is governed by the ability of the beam to carry structural loads. In addition, steel temperatures must in some cases be maintained below the ASTM E 119 limits of 800°F for prestressing steel and 1100°F for reinforcing steel. Under the ASTM E 119 standard, beams can be tested for either restrained or unrestrained conditions. A summary of ASTM E 119 conditions of acceptance and steel temperature criteria for beams follows:

1. Beams—tested restrained and used restrained.

For individual restrained beams spaced more than 4 feet on center, the steel temperatures must be limited to below 800°F (prestressing) or 1100°F (reinforcing) for one hour or one-half the desired rating period, whichever is greater.

Table 6.

$R_n^{0.59}$ Values for Various Thicknesses of Concrete Floors, Roofs, and Walls; Various Aggregate Types¹

Type of material	Values of $R_n^{0.59}$ for use in Eq. 1											
	1 1/2 in.	2 in.	2 1/2 in.	3 in.	3 1/2 in.	4 in.	4 1/2 in.	5 in.	5 1/2 in.	6 in.	6 1/2 in.	7 in.
Siliceous aggregate concrete	5.3	6.5	8.1	9.5	11.3	13.0	14.9	16.9	18.8	20.7	22.8	25.1
Carbonate aggregate concrete	5.5	7.1	8.9	10.4	12.0	14.0	16.2	18.1	20.3	21.9	24.7	27.2 ⁽⁴⁾
Sand-lightweight concrete	6.5	8.2	10.5	12.8	15.5	18.1	20.7	23.3	26.0	(⁽⁴⁾)	(⁽⁴⁾)	(⁽⁴⁾)
Lightweight concrete	6.6	8.8	1.2	13.7	16.5	19.1	21.9	24.7	27.8			
Insulating concrete ⁽²⁾	9.3	13.3	16.6	18.3	23.1	26.5	(⁽⁴⁾)	(⁽⁴⁾)	(⁽⁴⁾)	(⁽⁴⁾)	(⁽⁴⁾)	(⁽⁴⁾)
Air Space ⁽³⁾	-	-	-	-	-	-	-	-	-	-	-	-

(1) All model codes recognize the use of the listed $R_n^{0.59}$ values for concrete and masonry. To be used when calculating total resistance in minutes.
 (2) Dry unit weight 35 pct or less and consisting of cellular perlite or vermiculite concrete.
 (3) The $R_n^{0.59}$ value for one 1/2- to 3 1/2-inch air space is 3.3. The $R_n^{0.59}$ value for two 1/2- to 3 1/2-inch air spaces is 6.7
 (4) The fire-resistance rating for this thickness exceeds 4 hours.

2. Beams—tested in an unrestrained condition and used unrestrained. Steel temperature limits are waived, the beam is rated on its ability to carry the applied load.

3. Beams—tested in a restrained condition but used unrestrained.

Steel temperatures in concrete beams must be maintained below the limits of 800°F for prestressing and 1100°F for reinforcing bars for the entire endurance period.

The several different classifications for beams graphically illustrated the several conditions which influence beam fire endurance. Factors such as beam width and spacing, restraint conditions, and concrete cover are considered in Table 7. The tabulated cover requirements in Table 7 will maintain steel temperatures below the ASTM E 119 limits for the listed exposure times for the shown restraint conditions, beam widths, and concrete aggregate type (if prestressed).

Table 7.
Minimum Cover in Inches for Reinforced and Prestressed Concrete Beams*

Table 7 A. Minimum Cover to Main Reinforcing Bars for Reinforced Concrete Beams (Applicable to All Types of Structural Concrete)⁽¹⁾

Restrained or Unrestrained ⁽²⁾	Beam Width ⁽³⁾ (inches)	Cover thickness (inches) for fire-resistance rating				
		1 hr	1 1/2 hr	2 hr	3 hr	4 hr
Restrained	5	3/4	3/4	3/4	1 ⁽¹⁾	1 1/4 ⁽¹⁾
Restrained	7	3/4	3/4	3/4	3/4	3/4
Restrained	≥10	3/4	3/4	3/4	3/4	3/4
Unrestrained	5	3/4	1	1 1/4	-	-
Unrestrained	7	3/4	3/4	3/4	1 3/4	3
Unrestrained	≥10	3/4	3/4	3/4	1	1 3/4

⁽¹⁾The cover for an individual reinforcing bar is the minimum thickness of concrete between the surface of the bar and the fire-exposed surface of the beam. For beams in which several bars are used, the cover is assumed to be the average of the minimum cover of the individual bars, where the minimum cover for corner bars used in the calculation shall be reduced to 1/2 of the actual value. The cover for an individual bar must be not less than 1/2 of the value given in Table 7A nor less than 3/4 inch.

⁽²⁾See Table 2 for guidance on restrained and unrestrained assemblies. Tabulated values for restrained assemblies apply to beams spaced more than 4 feet on center; for restrained beams spaced 4 feet or less on center, minimum cover of 3/4 inch is adequate for ratings of 4 hours or less.

⁽³⁾For beam widths between the tabulated values, the minimum cover thickness can be determined by direct interpolation.

Table 7 B. Minimum Cover for Prestressed Concrete Beams⁽¹⁾

Restrained or Unrestrained ⁽²⁾	Concrete aggregate type	Beam width ⁽³⁾ (inches)	Cover thickness ⁽⁴⁾ (inches) for fire-resistance rating				
			1 hr	1 1/2 hr	2 hr	3 hr	4 hr
Restrained	Carbonate or siliceous	8	1 1/2	1 1/2	1 1/2	1 3/4 ⁽¹⁾	2 1/2 ⁽¹⁾
Restrained	Carbonate or siliceous	≥12	1 1/2	1 1/2	1 1/2	1 1/2	1 7/8 ⁽¹⁾
Restrained	Sand-lightweight	8	1 1/2	1 1/2	1 1/2	1 1/2	2 ⁽¹⁾
Restrained	Sand-lightweight	≥12	1 1/2	1 1/2	1 1/2	1 1/2	1 5/8 ⁽¹⁾
Unrestrained	Carbonate or siliceous	8	1 1/2	1 3/4	2 1/2	5 ⁽²⁾	-
Unrestrained	Carbonate or siliceous	≥12	1 1/2	1 1/2	1 7/8	2 1/2	3
Unrestrained	Sand-lightweight	8	1 1/2	1 1/2	2	3 1/4	-
Unrestrained	Sand-lightweight	≥12	1 1/2	1 1/2	1 5/8	2	2 1/2

⁽¹⁾ Minimum cover to nonprestressed reinforcing in prestressed concrete beams shall be determined by values shown in Table 7A.

⁽²⁾ See Table 2 for guidance on restrained and unrestrained assemblies. Tabulated values for restrained assemblies apply to beams more than 4 feet on center. For restrained beams spaced 4 ft. or less on centers, minimum cover of 3/4 in. is adequate for 4 hour rating or less.

⁽³⁾ For beam width between 8 and 12 inches, minimum cover thickness can be determined by direct interpolation.

⁽⁴⁾ The cover for an individual tendon is the minimum thickness of concrete between the surface of the tendon and the fire-exposed surface of the beam, except that for ungrouted ducts the assumed cover thickness is the minimum thickness of concrete between the surface of the duct and the surface of the beam. For beams in which several tendons are used, the cover is assumed to be the average of the minimum cover of individual tendons, where the minimum cover for corner tendons used in the calculation shall be reduced to one-half the actual value. The cover for any individual tendon must be not less than one-half the value given in Table 7B nor less than 1 inch.

⁽⁵⁾Not practical for 8-inch-wide beam, but shown for purposes of interpolation.

Reinforced or Prestressed Concrete Floor and Roof Slabs

As previously discussed, the fire endurance of floor and roof slabs is based on either the heat transmission or structural failure end point. It is for this reason that code approved empirical methods require both a minimum slab thickness to limit heat transmission and a minimum amount of concrete cover to limit steel temperatures. As discussed earlier, the fire endurance of reinforced or prestressed concrete slabs is dependent upon several factors, such as type of aggregate in the concrete, concrete cover, and restraint of thermal expansion.

The values for slabs shown in Table 8 represent minimum required slab thickness and concrete cover requirements for reinforced or prestressed slabs for various aggregate type concretes in restrained or unrestrained conditions. The tabular fire durances listed in Table 8 are based on examination of past

ASTME 119 test results of slabs with similar cover, restraint conditions, and concrete aggregate type. The specified cover for unrestrained assemblies will maintain steel temperatures below the specified limits of 800°F for prestressing and 1100°F for reinforcing steel. Again, Table 2 should be referenced when determining whether a floor or roof is restrained or unrestrained.

Table 8
Minimum Slab and Concrete Cover Thickness in Inches for Listed Fire Resistance of Reinforced Concrete Floors and Roofs

Table 8A. Minimum Slab Thickness for Concrete Floors or Roofs¹

Concrete aggregate type	Minimum slab thickness (inches) for fire-resistance rating				
	1 hr	1 1/2hr	2hr	3hr	4hr
Siliceous	3.5	4.3	5.0	6.2	7.0
Carbonate	3.2	4.0	4.6	5.7	6.6
Sand-lightweight	2.7	3.3	3.8	4.6	5.4
Lightweight	2.5	3.1	3.6	4.4	5.1

*Note:
Notes to Table 4 apply to Table 8 as well, Figure 2 may be used in lieu of this table

Table 8B. Cover Thickness for Reinforced Concrete Floor and Roof Slabs¹

Concrete aggregate type	Thickness of cover (inches) for fire-resistance rating									
	Restrained ²					Unrestrained ²				
	1 hr	1 1/2hr	2hr	3hr	4hr	1 hr	1 1/2hr	2hr	3hr	4hr
Siliceous	3/4	3/4	3/4	3/4	3/4	3/4	3/4	1	1 1/4	1 5/8
Carbonate	3/4	3/4	3/4	3/4	3/4	3/4	3/4	3/4	1 1/4	1 5/8
Sand-lightweight	3/4	3/4	3/4	3/4	3/4	3/4	3/4	3/4	1 1/4	1 1/4
Lightweight	3/4	3/4	3/4	3/4	3/4	3/4	3/4	3/4	1 1/4	1 1/4

Table 8 C. Cover Thickness for Prestressed Concrete Floor or Roof Slabs¹

Concrete aggregate type	Thickness of cover (inches) for fire-resistance rating									
	Restrained ²					Unrestrained ²				
	1 hr	1 1/2hr	2hr	3hr	4hr	1 hr	1 1/2hr	2hr	3hr	4hr
Siliceous	3/4	3/4	3/4	3/4	3/4	1 1/8	1 1/2	1 3/4	2 3/8	2 3/4
Carbonate	3/4	3/4	3/4	3/4	3/4	1	1 3/8	1 5/8	2 1/8	2 1/4
Sand-lightweight	3/4	3/4	3/4	3/4	3/4	1	1 3/8	1 1/2	2	2 1/4
Lightweight	3/4	3/4	3/4	3/4	3/4	1	1 3/8	1 1/2	2	2 1/4

¹ The minimum thickness of concrete cover to the positive moment reinforcement is given in Table 8B for reinforced concrete and Table 8C for prestressed concrete.

Table 8 is applicable for solid or hollow-core one way or two way slabs with flat undersurfaces. Slabs may be cast-in-place or precast. For precast prestressed concrete not covered elsewhere, the procedures contained in PCI *Design for Fire Resistance of Precast Prestressed Concrete* shall be acceptable.

² See Table 2 for guidance on restrained and unrestrained assemblies.

Concrete Columns

Fire endurance of concrete columns is governed under ASTM E 119 by their ability to carry the applied load under firetesting. The endurance is affected primarily by the size of the column and aggregate type. A summary of the tabular code-approved minimum column dimensions and concrete cover requirements is shown in Table 9A and 9B.

Table 9A. Minimum Concrete Column Size and Concrete Cover¹

Concrete aggregate type	Minimum column dimension (inches) for fire-resistance rating				
	1 hr	1 1/2hr	2 hr	3 hr	4 hr
Siliceous	8	8	10	12	14
Carbonate	8	8	10	11	12
Sand-lightweight	8	8	9	10.5	12

Table 9B. Minimum Sizes of Concrete Columns with Fire Exposure Conditions on Two Parallel Sides^{1,2}

Concrete aggregate type	Minimum column dimension (inches) for fire-resistance rating				
	1 hr	1 1/2hr	2hr	3hr	4hr
Siliceous	8	8	8	8	10
Carbonate	8	8	8	8	10
Sand-lightweight	8	8	8	8	10

¹ Minimum Cover for Reinforced Concrete Columns. The minimum cover to the main reinforcement in columns for fire-resistance ratings of one hour, one and one-half hours, two hours, and three hours shall be 1 1/2 inches for four-hour rating, the minimum cover to the main reinforcement shall be 2 inches for siliceous aggregate concrete and 1 1/2 inches for carbonate aggregate concrete or sand-lightweight concrete.

² The minimum dimensions are acceptable for rectangular columns with a fire exposure condition on 3 or 4 sides provided each of two parallel sides of the column are at least 36

WALLS WITH GYPSUM WALLBOARD OR PLASTER FINISHES

In many cases drywall, plaster or stucco finishes are added to concrete or concrete masonry walls. While finishes are normally applied for architectural consideration, they also provide additional fire resistance value. The Codes make provision for calculating the additional fire resistance provided by finishes applied to concrete and concrete masonry walls.

It should be noted that when finishes are used to achieve the required fire resistance rating, the concrete component of the wall system must provide at least 1/2 of the total required rating. This is to assure structural integrity during a fire.

Since certain finishes deteriorate more rapidly when exposed directly to fire than when on the non-fire side of the wall, two separate tables are required. Table 10 applies to finishes on the non-fire exposed-side of the wall and Table 11 to finishes on the fire-exposed side. Table 10 converts the thickness of the finish to equivalent thickness of the base wall.

This is then added to the base wall equivalent thickness and the fire resistance rating is determined by interpolation of Table 5 for concrete masonry, or Fig.2 or Table 4 for concrete as appropriate. The values in Table 11 are essentially the length of time the various finishes will remain intact when exposed to fire, thus affording that amount of additional fire protection.

Table 10. Multiplying Factor For Finishes On Non-Fire Exposed Side Of Wall

Type of Finish Applied to Wall	Type of Aggregate Used in Concrete or Concrete Masonry			
	Concrete: Siliceous or Carbonate	Concrete: Sand-Light-Weight	Concrete: Lightweight	Concrete Masonry: Pumice, or Expanded Slag
Portland Cement - Sand Plaster	1.00	0.75 ¹	0.75 ¹	0.50 ¹
Gypsum-Sand Plaster or Gypsum Wallboard	1.25	1.00	1.00	1.00
Gypsum Vermiculite or Perlite Plaster	1.75	1.50	1.25	1.25

1. For Portland cement-sand plaster 5/8" or less in thickness and applied directly to the concrete masonry on the non-fire side of the wall, the multiplying factor shall be 1.00.

**Table 11. Time Assigned To Finish Materials
On Fire - Exposed Side Of Wall**

Finish description	Time, Min.
Gypsum Wallboard	
3/8"	10
1/2"	15
5/8"	30
2 layers of 3/8"	25
1 layer 3/8", 1 layer 1/2"	35
2 layers 1/2"	40
Type X Gypsum Wallboard	
1/2"	25
5/8"	40
Portland Cement-sand plaster applied directly to concrete masonry	See Note 1
Portland cement-sand plaster on metal lath	
3/4"	20
7/8"	25
1"	30
Gypsum sand plaster on 3/8" gypsum lath	
1/2"	35
5/8"	40
3/4"	50
Gypsum sand plaster on metal lath	
3/4"	50
7/8"	60
1"	80

1 The actual thickness of Portland cement and plaster provided it is 5/8" or less in thickness, may be included in determining the equivalent thickness of the masonry for use in Table 4.

JOINTS BETWEEN CONCRETE WALL PANELS

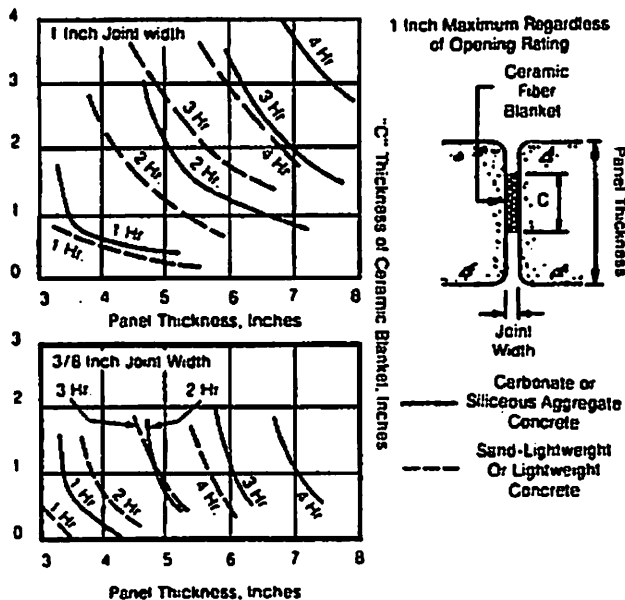


Fig. 8. Minimum thickness of ceramic fiber blanket required between precast concrete wall panels to provide fire resistance ratings of 1 hr. to 4 hrs. (For joint widths between 3/8" and 1", the thickness of ceramic fiber blanket may be determined by interpolation.)

A common misconception regarding fire-rated tilt-up and precast walls is that they need to be cast solidly to retain fire resistance integrity. This is not true. Joints between panels which are not protected are to be considered as openings and included in the percentages permitted such as Table 600 in the Standard Building Code. However, if protected joints are required, provision is made for this in joints up to 1-inch wide by inserting ceramic fiber blanket material in the joint space. The chart used to determine the amount of material to be used is shown in Fig. 8.

CONCLUSION

Calculation of fire endurance of concrete and masonry members has progressed from pure research to practical structural design applications. Further refinements of analytical methods are going on now, aided in great part by computer simulations of concrete and masonry performance under fire-test conditions.

The information contained in this report scratches the surface on the topic of analytical and empirical design. The practicing structural engineer will find references 1, 2, and 3 excellent sources of additional information on the rational methods for calculating fire resistance. The engineer, architect, or building official will find this a handy and usable guide in assessing concrete and masonry requirements with regard to fire endurance. Calculation procedures provide a viable timesaving and cost saving means of determining a member's fire endurance without running full scale ASTM E119 fire tests. Along with savings of time and money, the building official, architect, or engineer will have a much clearer concept of how certain variables affect fire endurance if analytical procedures are utilized.

REFERENCES

1. *Reinforced Concrete Fire Resistance*, Concrete Reinforcing Steel Institute, Schaumburg, Illinois, 1980.
2. Gustafarro, A. H. and Martin, L. D., *Design for Fire Resistance of Precast Prestressed Concrete*, Pre stressed Concrete Institute, Chicago, Illinois, 1977.
3. *Guide for Determining the Fire Endurance of Concrete Elements*, 21 6R-81, American Concrete Institute, Detroit, Michigan, 1981.
4. *Fire Safety with Concrete Masonry*, NCMA-TEK 35-B, National Concrete Masonry Association, Herndon, Virginia.
5. *Fire Protection Planning Report No. 13; Analytical Methods of Determining Fire Endurance of Concrete and Masonry Members - Model Code Approved Procedures - SR 267.01B*, Concrete and Masonry Industry Firesafety Committee, 5420 Old Orchard Road, Skokie, Illinois 60077-4321.

- APPENDIX - EXAMPLE CALCULATIONS

BEAM-SLAB EXAMPLE

The cast-in-place limestone aggregate reinforced concrete beam and slab shown in Fig. 9 form a floor system in a multistory occupancy of Type I construction (SBC). Assume this assembly is required by code to have 3 hours of fire resistance. Can it attain this? If not, how can the fire resistance be increased to 3 hours?

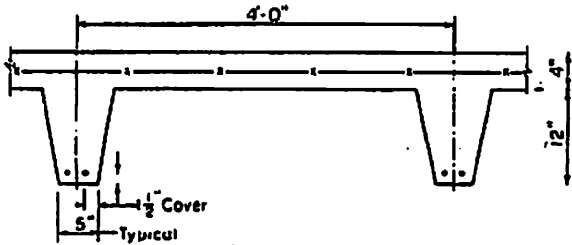


Fig. 9 Carbonate (limestone) aggregate cast-in-place - restrained.

Solution

Beam-slab systems must satisfy *both* heat transmission and structural failure end points. The member shown in Fig. 9 is considered restrained due to its being cast-in-place with framing members.

HEAT TRANSMISSION END POINT

Referring to Fig. 5, the equivalent thickness is determined using the three equations comparing s (stem spacing) and t (slab thickness). Replacing 4'-0" for s , and 4" for t , $t_e \geq 4t$. Therefore $t_{eq} = t = 4"$.

The required slab thickness from Table 8A (or Fig. 2) for a three hour fire-resistance rating is 5.7 inches; the 4 inches will provide between one-and-a-half and two hours resistance to heat transmission to the unexposed surface, not three hours as required.

STRUCTURAL END POINT

Slab. For many cast-in-place concrete slabs, the structural cover exceeds cover required to achieve fire resistance. This is clearly the case with this example where 2 1/4 inches cover is provided versus 3/4 inches required by Table 8B for three hours fire resistance.

Beam. Table 7A, for reinforced concrete beams, specifies 1 inch of concrete cover in 5-inch-wide restrained beams to attain three hours fire resistance. Note that the example beams are spaced 4 feet center to center. Footnote one states that for restrained beams spaced 4 feet or less on centers, the cover can be reduced to a minimum of 3/4 inches for four-hour ratings or less. The 1 1/2-inch cover provided clearly satisfies the code requirements for 3 hours fire resistance.

Conclusion

In order to attain three hours fire resistance, the slab must be made more resistant to heat transmission. The steel cover requirements for three hours structural fire resistance in both the slab and the beam stem are satisfied.

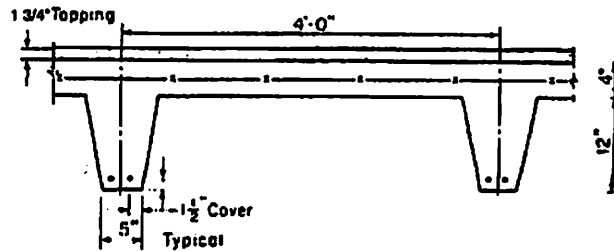


Fig. 10 Carbonate (limestone) aggregate cast-in-place - restrained with 1 3/4" lightweight topping.

In discussing multi-wythe (multilayer) walls and floors earlier in the report, it was shown that significant resistance to heat transmission could be attained by considering the effect of layering of materials. This can be done using Eq. 1 or graphical methods.

In this example problem, referring to Fig. 10, a 4 inch base slab of carbonate aggregate with approximately 1 3/4 inches of sand-lightweight concrete topping will provide the additional required resistance to heat transmission to attain three hours fire resistance.

Checking Fig. 11 against Eq. 1, the 4" of carbonate aggregate concrete base slab has 1 hour, 30 minutes fire resistance (Fig. 2 or Table 8A). Fig. 2 shows that 1 3/4 inches of sand-lightweight topping will provide approximately 30 minutes resistance to heat transmission:

Using Eq. 1,

$$R = (R_1^{0.59} + R_2^{0.59})^{1.7}$$

$$R = (90)^{0.59} + (30)^{0.59})^{1.7} = 186 \text{ minutes}$$

(3 hours, 6 minutes)

Therefore the slab system shown in Fig. 10 will provide three hours fire resistance if a 1 3/4 inch topping of sand-lightweight concrete is applied.

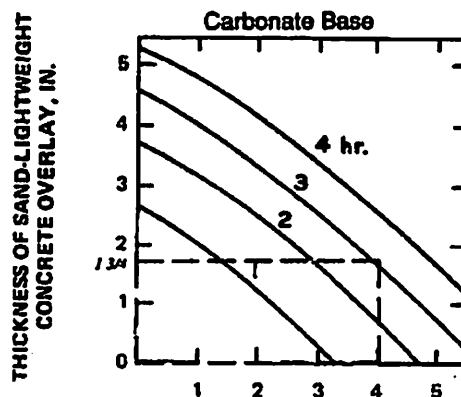


Fig. 11 Graphical solution of multi-wythe fire endurance

AGGREGATE TYPE USED IN FLORIDA

Limestone aggregate is most commonly used for both concrete and concrete masonry throughout Florida with the possible exception of the Panhandle. In the case of concrete, limestone falls into the carbonate category (Fig. 2/ Table 4,6,7,8,9 and 10). However, for concrete masonry (Fig. 3/Table 5 and Table 10), the classification of aggregates is broken down even further with limestone placed in a separate category along with cinders and expanded slag. Granites and "crushed river run" fall into the category of siliceous for both concrete and concrete masonry. If aggregate type is in doubt, the information can generally be obtained from the concrete or masonry supplier. Aggregate type is important because the different aggregate type concretes transmit heat at different rates as can be seen in the above referenced tables.

MASONRY WALL EXAMPLE

Consider 8" concrete masonry to be used in wall situations requiring (A) two-hour fire resistance rating and (B) four-hour fire resistance rating. Using the code approved calculation provisions of this publication, determine whether standard 8" block will attain either of these required ratings. If not, how can the fire resistance rating be increased to achieve the requirements specified?

Solution

Checking with the local block suppliers, we find that the standard block available is 8" normal weight, limestone aggregate, 50% solid units. Using the formula on page 6 for determining equivalent thickness:

$$\begin{aligned} t_{eq} &= \% \text{ solid} \times \text{thickness} \\ &= 50\% \times 7 \frac{5}{8}" \\ &= 3.8" \end{aligned}$$

Interpolating Table 5 or reading directly from Fig. 3 for 3.8" t_{eq} limestone aggregate we find the total fire resistance rating:

$$R = 1.82 \text{ hours} < \text{both } 2.0 \text{ hrs. and } 4.0 \text{ hrs. required}$$

Steps must be taken to increase the fire resistance rating of the wall.

A. Two-Hour Fire Resistance Rating

Many different options are available to increase the fire resistance rating of the wall depending upon its location within the building, its use and the finish applied. Often no special finish other than painting is desired or needed. In those situations Options 1, 2 & 3 are appropriate:

Option 1:

Most block manufacturers have a variety of mold boxes available for concrete masonry, making it feasible to specify block with greater equivalent thickness. From Fig. 3/Table 5 we find that 4.0" t_{eq} of limestone aggregate block will meet two-hour rating. This is a viable option as two-hour fire rated normal weight block is readily available across the state. Require 4.0" t_{eq} or 53% solid (4.0" + 7 5/8") (See Fig. 12).

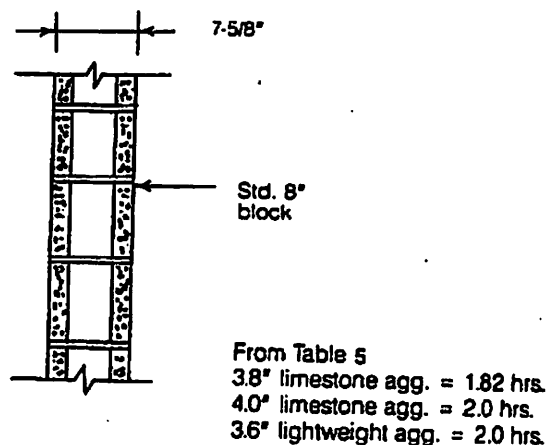


Fig. 12. Base wall section.

Option 2:

Specify lightweight aggregate block. Again from Table 5, 3.6" t_{eq} of expanded shale, clay or slate will meet two-hour. Therefore the same 3.8" t_{eq} block would satisfy the two hour requirement if made with lightweight aggregate rather than limestone aggregate. (See Fig. 12)

Option 3:

Fill the cores with approved loose fill material such as expanded shale, clay, slate, or slag, or vermiculite or perlite as shown in Fig. 13. In this case, the wall can be considered solid for fire resistance rating purposes (see footnote 2, Table 5) resulting in an equivalent thickness of 7-5/8". This significantly exceeds the requirements for a two-hour wall. In fact, it would suffice for four-hour as well (5.9" t_{eq} required for four-hours per Fig. 3/Table 5). Grouting the cores solid effects the same result.

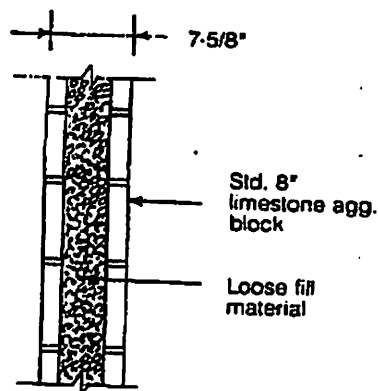


Fig. 13. Filling cells with approved loose fill material or grout results in fire resistance rating of over four hours.

B. Four-Hour Fire Resistance Rating

Four-hour fire rated assemblies, the procedures are identical to those above. According to Table 4, 5.9" t_{eq} of limestone aggregate block or 5.1" lightweight aggregate block is required for four-hour (Options one and two respectively). Lightweight four-hour rated block is approximately 67% solid; normal weight is somewhat higher. Here again, both lightweight and normal weight four-hour block are readily available in most areas of the state.

Option 3, filling the cores with approved loose fill material or grout to meet four-hour has already been discussed in the example for two-hour in the previous section.

A fourth option available, adding finishes to increase fire resistance rating, as discussed under the section entitled "Walls with Gypsum Wallboard or Plaster Finishes."

OPTION 4 - MASONRY WALLS WITH FINISHES EXAMPLE

The following example deals with the various finishes commonly applied in Florida to the basic 8" concrete masonry wall and code approved procedures to determine their contribution toward the overall fire resistance rating.

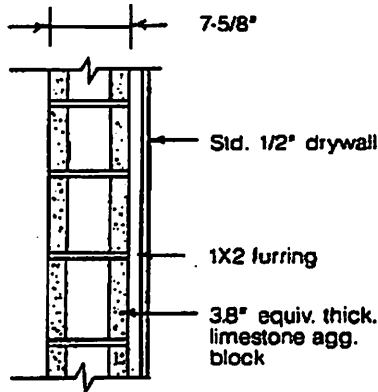


Fig. 14. Standard 1/2-inch drywall on just one side increases fire resistance rating by 15 min. (2.07 hrs. total).

Option 4a - Standard 1/2" drywall on one side of the wall-a common exterior wall section shown in Fig. 14. If different types of finishes are used on each side of the wall, then the calculation must be performed twice considering fire on either side. The lower value obtained is used as the rating.

1). Check Drywall on non-fire-exposed side (NFS) only.

$$t_{eq} \text{ of block (given)} = 3.8"$$

$$\text{Contribution of } 1/2" \text{ drywall on NFS (Table 10-pg.12)} = 1.00 \times 0.5" = 0.5"$$

$$\text{Total } t_{eq} \text{ of block and drywall on NFS} = 4.3"$$

$$\text{Fire resistance rating of } 4.3" \text{ limestone agg. block (interpolate Table 5)} = 2.3 \text{ hrs.}$$

2). Check drywall on fire-exposed side (FS).

$$\text{Block contribution Fig. 3 or (interpolate Table 5)} = 1.82 \text{ hrs.}$$

$$\text{Drywall contribution on FS (Table 11)} = 15 \text{ min.} = 0.25 \text{ hrs}$$

$$\text{Fire resistance rating} = 2.07 \text{ hrs}$$

2.07 < 2.3. Therefore 2.07 controls. However, 2.07 hrs. exceeds the 2.0 hrs. required, so standard 1/2" drywall on just one side of the block wall will meet two-hour.

Option 4b - We already know that drywall on just one side of the given block wall will provide the required two-hour fire resistance rating. Drywall on both sides will provide even more protection, so there is no need to check it. However, since drywall on both sides of a block wall is a common interior wall section, the calculation procedure is presented for illustrative purposes. Try 1/2" standard drywall on both sides of the block wall (Fig. 15).

$$t_{eq} \text{ of block (given)} = 3.8"$$

$$\text{Contribution of drywall on NFS (Table 10, pg. 12)} = 1.00 \times 0.5" = 0.5"$$

$$t_{eq} \text{ of block and NFS drywall} = 4.3"$$

$$\text{Fire resistance rating of } 4.3" \text{ limestone agg. block (interpolate Table 5)} = 2.3 \text{ hrs.}$$

$$\text{Contribution of } 1/2" \text{ drywall on FS (Table 11)} = 15 \text{ min.} = 0.25 \text{ hrs}$$

$$\text{Total fire resistance rating of assembly} = 2.5 \text{ hrs.}$$

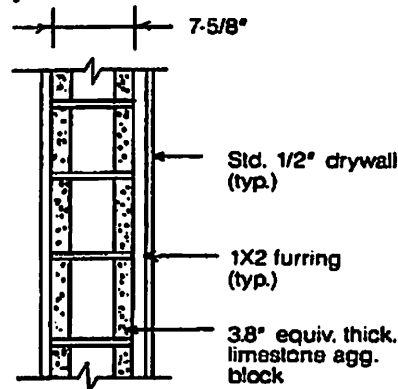


Fig. 15. Standard 1/2-inch drywall on both sides increases fire resistance rating by nearly 3/4 hour. Total calculated fire resistance rating is 2-1/2 hours.

4c. Another common wall section is stucco on the exterior and 1/2" standard drywall on the interior (Fig. 16). Here again, since finishes on each side of the wall are different, the calculation procedure is performed twice, assuming fire on either side with the lowest value obtained governing.

1). Assume fire on drywall (interior) side.

$$t_{eq} \text{ of block (given)} = 3.8"$$

$$t_{eq} \text{ of stucco on NFS (Footnote 1, Table 10, pg. 12)} = 1.00 \times 5/8" = 0.62"$$

$$t_{eq} \text{ of block and stucco on NFS} = 4.42"$$

$$\text{Fire resistance rating of } 4.42" \text{ limestone agg. block (Fig. 3 or interpolate Table 5)} = 2.42 \text{ hrs}$$

$$\text{Contribution of } 1/2" \text{ drywall on FS (Table 11)} = 15 \text{ min.} = 0.25 \text{ hrs}$$

$$\text{Rating with fire on drywall side} = 2.67 \text{ hrs}$$

2). Assume fire on stucco side.

$$t_{eq} \text{ of block (given)} = 3.8"$$

$$t_{eq} \text{ of drywall on NFS (Table 10, pg. 12)} = 1.00 \times .50" = 0.50"$$

$$t_{eq} \text{ stucco on FS (Table 11)} = 5/8" = 0.62"$$

$$\text{Total } t_{eq} = 4.92"$$

Rating with fire on stucco side
 (Fig. 3 or interpolate Table 5 with 4.92" limestone agg.) = 2.9 hrs.
 2.67 < 2.9 hrs. Therefore fire on drywall side governs with 2.67 hrs.
 Total fire resistance rating of assembly = 2.67 hrs

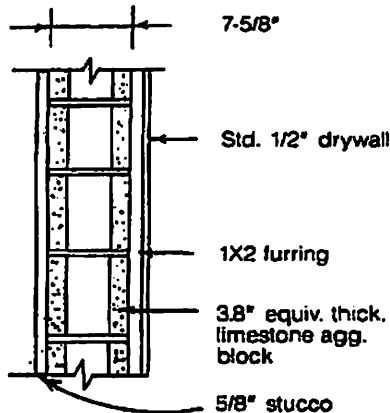


Fig. 16 Standard 1/2-inch drywall on one side and 5/8" stucco on the other side of 3.8" limestone aggregate block increases the fire resistance rating by 0.85 hrs. Total calculated fire resistance rating is 2-2/3 hours.

These examples demonstrate the effectiveness of finishes in contributing to the overall fire resistance of a concrete masonry wall. As can be seen, standard 1/2" drywall on both sides adds nearly 3/4 hour additional fire resistance in this case. Stucco exterior and 1/2" drywall interior effect even better results.

Calculations for utilizing finishes for four-hour rating are accomplished in exactly the same manner as for two-hour in Option 4 above. However, remember the requirement that the concrete component of the wall system must provide at least 1/2 of the total required rating when using finishes to achieve the fire resistance rating. Therefore, the block itself will have to be rated at least two hours unless the walls are solid grouted.

CONCRETE WALLS WITHOUT AND WITH FINISHES

Procedures for calculating the fire resistance rating of concrete walls (cast-in-place, tilt-up, or precast) are identical to those shown above for concrete masonry. The only difference is that Fig. 2 or Table 4 is used instead of Table 5. Determining the fire resistance rating of concrete walls is generally easier than for masonry because concrete wall sections tend to be solid. This means that the equivalent thickness is the same as the actual thickness. However, if a form liner or other means is used to provide a ribbed or undulating surface, the equivalent thickness is determined as shown in Fig. 5. Equivalent thickness of hollow-core walls is determined as shown in Fig. 6.

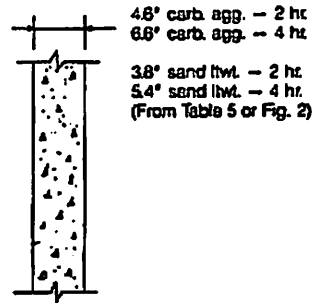


Fig. 17. Calculation of fire resistance ratings for concrete walls is generally easier than for masonry since concrete walls are usually solid.

For concrete walls with finishes, calculations are performed identically to those for concrete masonry with finishes as discussed above, using the appropriate sections of Tables 10 and 11. As mentioned previously, the most commonly used aggregate for concrete in Florida is limestone which falls into the carbonate category. Crushed river run and granites used mainly in the Panhandle fall into the siliceous category.

Joints between precast or tilt-up wall panels in fire rated walls may need to be treated with ceramic fiber blanket as indicated in Part II section entitled "Joints Between Concrete Wall Panels". See Fig. 8, pg. 13

SUMMARY ON CONCRETE FINISHES

Required fire resistance ratings apply to the entire wall or floor/ceiling assemblies. Most block and concrete walls and floors receive some kind of finish, such as drywall, stucco, plaster, etc., which adds to the fire resistance rating of the base walls or floors.

Sometimes a concrete product does not meet the fire resistance rating required, as in the case of many standard 8" blocks that calculate to just under a two-hour rating. Often a one-half inch drywall or stucco finish on just one side will provide the additional amount needed to comply. Finishes on both sides will produce even higher ratings. The following table gives the rule-of-thumb for finishes..

Table 12 Rule of Thumb Increases for Finishes

FINISH	BASE WALL RATING →	APPROXIMATE INCREASE IN FIRE RESISTANCE RATING (MINUTES) ^{1,2}		
		1 hr.	2 hr.	3 hr.
1/2" Standard Drywall one side		15	15	15
5/8" Standard Drywall one side		30	30	30
1/2" Drywall both sides		40	45	50
5/8" Drywall both sides		60	70	75
1/2" Stucco one side		20	30	35
5/8" Stucco one side		25	35	40
1/2" Stucco both sides		40	55	65
5/8" Stucco both sides		50	70	70+
1/2" Drywall one side 1/2" stucco other side		35	45	50
5/8" Drywall one side, 5/8" stucco other side		55	65	70

1. Values listed are for normal weight block, lightweight block, limestone or siliceous aggregate concrete or sand-lightweight concrete.
 2. Values are approximate only and in many cases are quite conservative.

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For further information on fire resistance of concrete and concrete masonry and determining fire resistance ratings by code approved calculation methods contact:



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