

National Concrete Masonry Association  
an information series from the national authority on concrete masonry technology

## DENSITY-RELATED PROPERTIES OF CONCRETE MASONRY ASSEMBLIES

**TEK 2-6**  
Unit Properties (2008)

**Keywords:** acoustics, aesthetics, compressive strength, concrete density, energy efficiency, fire resistance rating, movement control, productivity, water penetration resistance

### INTRODUCTION

The versatility of concrete masonry as a construction assembly is well established through the variety of applications and structures it is used to create. Concrete masonry offers almost limitless combinations of color, shape, size, strength, texture, and density. This TEK illustrates the various physical and design properties influenced by the density of concrete masonry units, and provides references to guide the user towards a fuller discussion and more detailed information. Although most of the following discussions use lightweight and normal weight concrete masonry as examples, the properties of medium weight masonry can typically be expected to fall between the two.

Note that while some of these density-related properties, such as sound transmission loss, may be directly referenced in building codes such as the *International Building Code* (ref. 1), other properties or characteristics, such as aesthetics and construction productivity fall outside the scope of the building code.

### BASICS OF CONCRETE MASONRY UNIT DENSITY

The density of a concrete masonry unit is expressed as the oven-dry density of concrete in pounds per cubic foot ( $\text{lb}/\text{ft}^3$  [ $\text{kg}/\text{m}^3$ ]) as determined in accordance with ASTM C 140, *Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units* (ref. 2). In production, the density of a given concrete masonry unit is controlled in part by the methods used to manufacture the unit, but largely by the type of aggregate used in production. Through the use of lightweight aggregates, normal weight aggregates, or blends of lightweight and normal weight aggregates, the resulting density of concrete masonry units can be varied by the producer to achieve one or more desired physical properties.

ASTM C 90, *Standard Specification for Loadbearing*

*Concrete Masonry Units* (ref. 3) defines three density classes for concrete masonry units:

- Lightweight – units having an average density less than  $105 \text{ lb}/\text{ft}^3$  ( $1,680 \text{ kg}/\text{m}^3$ ).
- Medium Weight – units having an average density of  $105 \text{ lb}/\text{ft}^3$  ( $1,680 \text{ kg}/\text{m}^3$ ) or more, but less than  $125 \text{ lb}/\text{ft}^3$  ( $2,000 \text{ kg}/\text{m}^3$ ).
- Normal Weight – units having an average density of  $125 \text{ lb}/\text{ft}^3$  ( $2,000 \text{ kg}/\text{m}^3$ ) or more.

When a specific density classification or density range is desired for a project, it should be specified in the project documents along with the other physical properties of the concrete masonry units such as size, strength, color, and texture. Before specifying a specific density range, designers are encouraged to first consult with manufacturers local to the project for availability. As with all physical properties of concrete masonry, minor variation in density from unit to unit and from batch to batch should be expected.

In accordance with ASTM C 90, aggregates used to manufacture concrete masonry units must conform to either ASTM C 33, *Standard Specification for Concrete Aggregates* (ref. 4), or ASTM C 331, *Standard Specification for Lightweight Aggregates for Concrete Masonry Units* (ref. 5). Whereas normal weight aggregates are typically mined or quarried, lightweight aggregates may be manufactured, mined or quarried from a natural source, or a by-product of another process. Although not all aggregate types are produced in all areas of the country, non-local aggregates may be available. If a concrete masonry unit of a specific aggregate type is desired, potential suppliers should be consulted for availability prior to specifying them.

### FIRE RESISTANCE

Fire resistance ratings of one to four hours can be achieved with concrete masonry of various widths (or thicknesses), configurations and densities. As outlined in TEK 7-1A, *Fire Resistance Rating of Concrete Masonry Assemblies* (ref. 6), the fire resistance rating of a concrete masonry assembly can be determined by physical testing, through a listing service, or by a standardized calculation procedure. Whether through direct measurement or by cal-

culation, the fire resistance rating of a given concrete masonry assembly varies directly with the aggregate type and with the volume of concrete in the unit, expressed as the equivalent thickness. Through extensive testing and analysis, empirical relationships have been established between the fire resistance rating of a concrete masonry assembly and the corresponding type of aggregate and equivalent thickness of the unit used to construct the assembly. These relationships are summarized in Figure 1.

These relationships between aggregate type/equivalent thickness and the corresponding fire resistance rating are shown graphically in Figure 2. Note that equivalent thicknesses used in Figure 2 are for illustration only, and represent typical equivalent thicknesses for standard hollow concrete masonry units. Actual units may have higher or lower equivalent thicknesses than those shown, with corresponding higher or lower fire resistance ratings. In general, 8-in. (203-mm) and wider concrete masonry units can be supplied with fire resistance ratings up to four hours. For example, a typical hollow 8 in. (203 mm) concrete masonry unit with an equivalent (solid) thickness of 4.0 in. (102 mm), can have a calculated fire resistance rating from 1.8 hours to 3 hours, depending on the type of aggregate used to produce the unit.

## SOUND CONTROL

The control of sound between adjacent dwelling units or between dwelling units and public areas is an important design consideration for user comfort. Sound Transmission Class (STC), expressed in decibels (dB), is a single number rating that provides a measure of the sound insulating properties of walls. The higher the STC rating, the better the assembly can block or reduce the transmission of sound across it. For concrete masonry construction, STC

can be calculated using the installed weight of the assembly, which is a function of the unit density, unit size and configuration, presence of surface finishes, and presence of grout or other cell-fill materials such as sand. See *Sound Transmission Class Ratings for Concrete Masonry Walls*, TEK 13-1B (ref. 7) for a full discussion. In accordance with *Standard Method for Determining the Sound Transmission Class Rating for Masonry Walls* (ref. 8), the STC rating for single wythe concrete masonry assemblies without additional surface treatments is determined by the following equation:

$$STC = 19.6W^{0.230} \quad \text{Eqn. 1.}$$

$$SI \quad STC = 13.6W^{0.230}$$

Where  $W$  = the average wall weight based on the weight of: the masonry units; the weight of mortar, grout and loose fill material in the voids within the wall; and the weight of surface treatments (excluding drywall) and other wall components, lb/ft<sup>2</sup> (kg/m<sup>2</sup>).

All other design variables being equal, the STC value of masonry construction increases with increasing unit density. Note that STC values determined by the calculation tend to be conservative. Generally, higher STC values are obtained by referring to actual tests than by the calculation.

In addition to the STC rating, the value of the Noise Reduction Coefficient (NRC) can also be influenced to some extent by concrete unit density. NRC measures the ability of a surface to absorb sound (based on a scale of 0 to 1), which can be an important characteristic in some applications, such as concert halls and assembly areas. A higher NRC value indicates that more sound is absorbed by an assembly. NRC values for concrete masonry walls are tabulated according to: the application of any coatings to the wall, the surface texture (coarse, medium or fine) and the density classification (lightweight or normal weight).

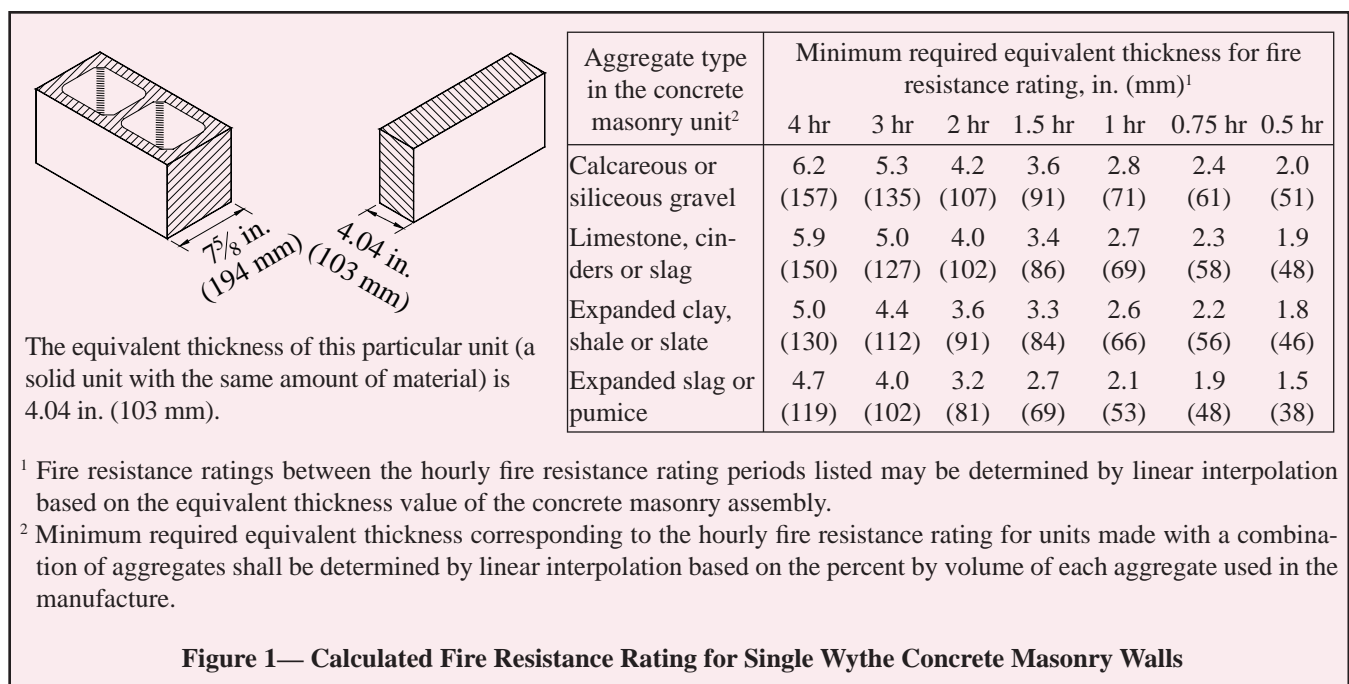
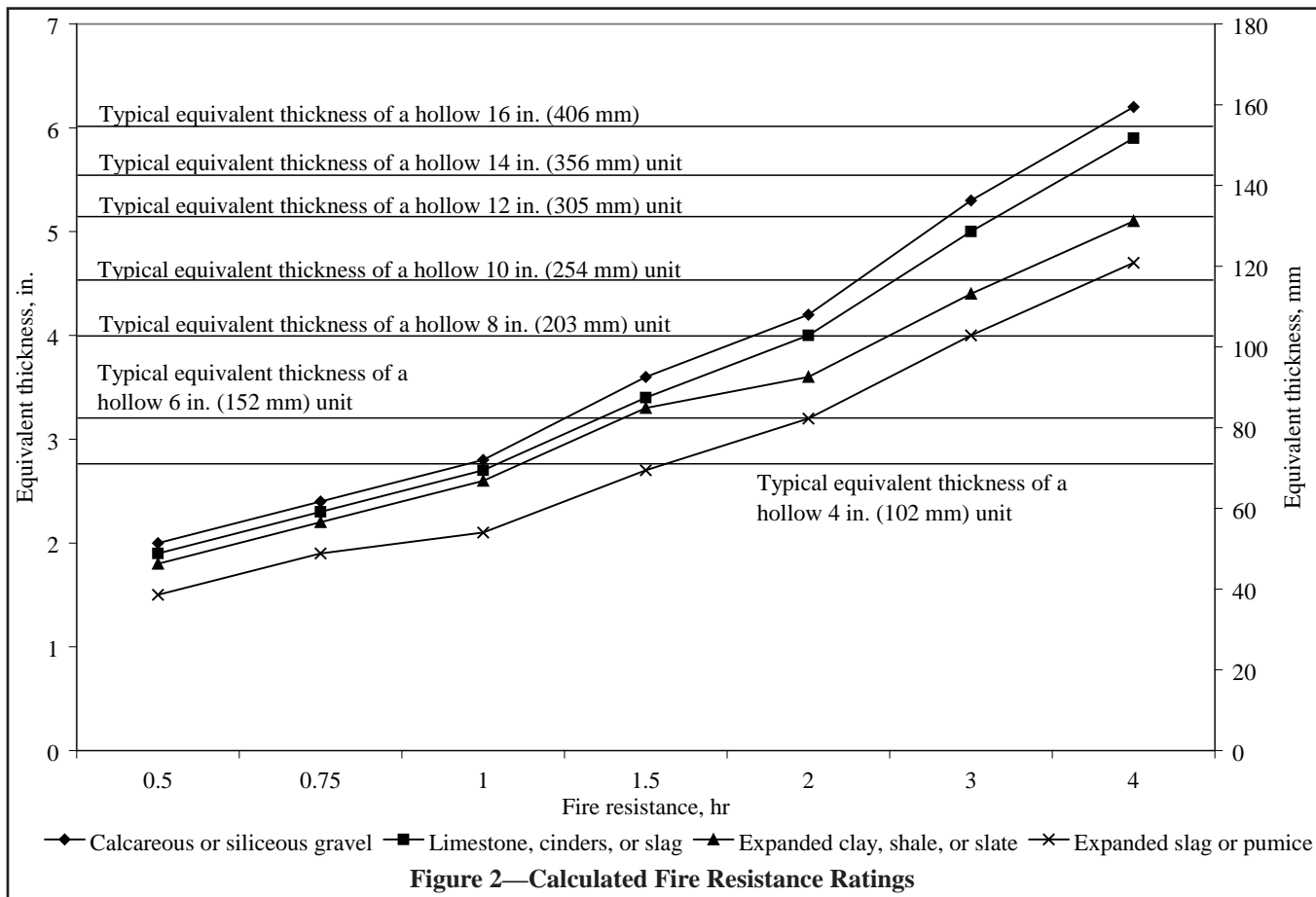


Figure 1— Calculated Fire Resistance Rating for Single Wythe Concrete Masonry Walls



Assuming a similar surface texture and coating, a concrete masonry wall constructed with lightweight units will have a higher NRC than a companion wall constructed with normal weight units, due to the larger pore structure often associated with lower density units. Painting or coating the surface of the concrete masonry assembly reduces the NRC for both lightweight and normal weight concrete masonry. See *Noise Control with Concrete Masonry*, TEK 13-2A (ref. 9) for a full discussion.

### COMPRESSIVE STRENGTH

Regardless of unit density, all loadbearing concrete masonry units meeting the physical properties of ASTM C 90 (ref. 3) must have a minimum average compressive strength of 1,900 psi (13.1 MPa). It is possible to produce concrete masonry units that meet or exceed the ASTM C 90 minimum strength in any density classification, although not all combinations of physical properties may be commonly available in all regions. Therefore, local producers should always be consulted for product availability before specifying. In general, for a given concrete masonry unit mix design, higher compressive strengths can be achieved by increasing the unit density through adjustments to the manufacturing methods. (ref. 16).

Table 1—Absorption Requirements for Concrete Masonry Units

Density classification	Maximum water absorption, lb/ft <sup>3</sup> (kg/m <sup>3</sup> )	
	Average of 3 units	Individual unit
Lightweight	18 (288)	20 (320)
Medium weight	15 (240)	17 (272)
Normal weight	13 (208)	15 (240)

### WATER PENETRATION AND ABSORPTION

Concrete masonry unit specifications typically establish upper limits on the amount of water permitted to be absorbed. Expressed in pounds of water per cubic foot of concrete (kilograms of water per cubic meter of concrete), these limits vary with the density classification of the unit, as shown in Table 1.

While the absorption values are not directly related to unit physical properties such as compressive strength and resistance to mechanisms of deterioration such as freeze-thaw, they do provide a measurement of the void structure within the concrete matrix of the unit. Several production variables can affect the void structure, including degree of compaction, water content of the plastic mix, and aggregate gradation. Due to the vesicular structure of lower density units, there is a potential for higher measured absorption than is typical for most higher density units. Consequently,

ASTM C 90 permits lower density units to have a higher maximum absorption value.

The higher absorption limits permitted by ASTM C 90 for lower density units do not necessarily correlate to reduced water penetration resistance. One reason is that water penetration resistance is known to be highly affected by workmanship and dependent on detailing for water management. It is generally recognized that these two factors more heavily influence the wall's water penetration resistance than do other factors, such as unit density.

## AESTHETIC CONSIDERATIONS

One of the most significant architectural benefits of designing with concrete masonry is the versatility afforded by the layout and appearance of the finished assembly, which can be varied with the unit size and shape, color of the units and mortar, bond pattern, and surface finish of the units. The term "architectural concrete masonry unit" (ref. 10) is often used to generically describe units exhibiting any number of surface finishes or colors. Loadbearing single wythe masonry walls constructed with these units uniquely offer the designer structural function, envelope enclosure and the aesthetics of a finished wall surface without the need for additional materials, components or assemblies.

In general, the many options available for architectural concrete masonry units can be offered in any of the three unit density classifications. However, with respect to unit appearance, any change in aggregates (whether a change in source or a change in aggregate type) used to manufacture a concrete masonry unit may change its color or texture, particularly for units with mechanically altered features such as split or ground-face surfaces. As a result, when aesthetics are an important consideration, sample units submitted for conceptual design should incorporate the specific aggregate intended to be used in the actual production of the units. Note that various degrees of surface "smoothness" (tight, fine, medium, coarse) can be obtained using the same aggregate by varying the mix design (proportions and moisture), aggregate gradation, aggregate shape, and degree of compaction during manufacture.

In addition to production variables, the appearance of the finished masonry is also affected by workmanship, and the mortar color and jointing. Where color, texture and finish are of particular concern, the designer should specify a special sample panel for review and approval during the submittal process (ref. 1, 17).

## ENERGY EFFICIENCY

When selecting masonry for its energy efficiency, two material thermal properties should be considered:

- R-value—a material's ability to resist the transfer of heat under steady-state conditions; and
- Thermal mass (heat capacity)—a material's ability to store and release heat (ref. 11).

These physical properties, in combination with a building's design, layout, location, climate, exposure, use,

or occupancy as required by building codes, influence the energy efficiency and thermal characteristics of the building envelope and of the building.

Increasing the unit density, unit thickness, unit solid content, and amount/extent of grout, increases the installed weight of the masonry assembly, which is directly related to its heat capacity. (ref. 11). Conversely, increasing the density or amount of grout used in a concrete masonry assembly decreases its R-value (ref. 12). Because of the multitude of variables that determine the overall energy efficiency of a structure, some projects benefit more by increasing the thermal mass of an assembly while others see more energy efficiency by increasing the R-value. As such, the unique requirements of each project should be considered individually for maximum benefit.

## STRUCTURAL DESIGN INFLUENCES

The structural design of masonry is based on the specified compressive strength of masonry,  $f'_m$ , which is a function of the compressive strength of the unit and the type of mortar used in construction. It is possible to produce a wide range of compressive strengths within each of the density classes. Therefore, for a given unit compressive strength and mortar type, the strength of the masonry assembly is unaffected by the unit density. As such, the design flexural, shear, and bearing strengths of masonry, some deformational properties such as elastic modulus, and the structural behavior of the masonry assembly determined by contemporary codes and standards are independent of the density of the concrete masonry unit.

Unit density, however, can influence other structural design considerations, aside from compressive strength. Reducing the density of a concrete masonry unit can reduce the overall weight of a structure, and potentially reduce the required size of the supporting foundation, slab, or beam. Reducing the weight of a structure or element also reduces the seismic load a structure or element must be designed to resist, because the magnitude of seismic loading is a direct function of dead load.

As with thermal mass and sound control, there may be circumstances where increasing the unit density is structurally beneficial. For example, the structural stability against overturning and uplift is increased with increasing structural weight. Hence, while increased structural dead load increases seismic design forces, it also concurrently helps to resist wind loads. Therefore, there may be some structural advantage to using lightweight units in areas of high seismic risk; and normal weight units in areas prone to high winds, hurricanes and/or tornadoes. Structural design considerations, however, are often relatively minor compared to other factors that may influence the choice of unit density.

## PRODUCTIVITY

For a given unit configuration, and with all other factors affecting production being equal, lower unit weights

typically enable a mason to lay more units within a given timeframe (ref. 13). Other factors influencing the daily productivity of a mason may include environmental conditions, unit size and shape, building size and configuration, masonry bond pattern, and reinforcement and other detailing (ref. 13).

## MOVEMENT CONTROL

Regardless of the density of a concrete masonry unit, the established movement control recommendations for concrete masonry construction are applicable. See *Crack Control in Concrete Masonry Walls*, TEK 10-1A, and *Control Joints for Concrete Masonry Walls – Empirical Method*, TEK 10-2B (refs. 14, 15) for more detailed guidance.

ASTM C 90 requires that linear drying shrinkage of all concrete masonry units, regardless of unit density, not exceed 0.065% at the time of delivery to the jobsite. However, despite the fact that not all concrete masonry units exhibit the same linear drying shrinkage within this limit, established movement control recommendations (refs. 14, 15) are independent of the concrete masonry unit density.

## SUMMARY

Issues of masonry design and construction can be influenced and addressed to varying extents through the choice of concrete masonry unit density, but generally the resulting effects of varying unit density on masonry behavior and performance are quite limited. Notwithstanding these effects, the designer can be assured that concrete masonry constructed of any unit density offers sufficient flexibility and alternatives in the choice of materials, design, and construction detailing to satisfy the structural and architectural requirements of the project.

## REFERENCES

1. *International Building Code*. International Code Council, 2003 and 2006.
2. *Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units*, ASTM C 140-06,

ASTM International, 2006.

3. *Standard Specification for Loadbearing Concrete Masonry Units*, ASTM C 90-06a, ASTM International, 2006.
4. *Standard Specification for Concrete Aggregates*, ASTM C 33-03, ASTM International, 2006.
5. *Standard Specification for Lightweight Aggregates for Concrete Masonry Units*, ASTM C 331-05, ASTM International, 2006.
6. *Fire Resistance Rating of Concrete Masonry Assemblies*, TEK 7-1A, National Concrete Masonry Association, 2006.
7. *Sound Transmission Class Ratings for Concrete Masonry Walls*, TEK 13-1B, National Concrete Masonry Association, 2007.
8. *Standard Method for Determining the Sound Transmission Class Rating for Masonry Walls*, TMS 0302-07, The Masonry Society, 2007.
9. *Noise Control with Concrete Masonry*, TEK 13-2A, National Concrete Masonry Association, 2007.
10. *Architectural Concrete Masonry Units*, TEK 2-3A, National Concrete Masonry Association, 2001.
11. *Heat Capacity (HC) Values for Concrete Masonry Walls*, TEK 6-16, National Concrete Masonry Association, 1989.
12. *R-Values for Single Wythe Concrete Masonry Walls*, TEK 6-2A, National Concrete Masonry Association, 2005.
13. *Productivity and Modular Coordination in Concrete Masonry Construction*, TEK 4-1A, National Concrete Masonry Association, 2002.
14. *Crack Control in Concrete Masonry Walls*, TEK 10-1A, National Concrete Masonry Association, 2005.
15. *Control Joints for Concrete Masonry Walls – Empirical Method*, TEK 10-2B. National Concrete Masonry Association, 2005.
16. Holm, T. A. *Engineered Masonry With High Strength Lightweight Concrete Masonry Units*. Concrete Facts, Vol. 17, No. 2, 1972.
17. *Specification for Masonry Structures*, ACI 530.1/ASCE 6/TMS 602. Reported by the Masonry Standards Joint Committee, 2002 and 2005.

NCMA and the companies disseminating this technical information disclaim any and all responsibility and liability for the accuracy and the application of the information contained in this publication.