Masonry[1]

Mankind's longest used building construction materials is masonry and even by today's standards is the most affordable material for many types of structure, even under seismic, hurricane or aggressive environments.

In the majority of ways in which masonry is used, masonry is more so a type of construction comprising masonry units, mortar and concrete filler (called grout). These form the constituents of many types of structural systems: walls; columns; arches; beams, and floors. However individual units also have extensive application as: wall; floor and roofing tiles; veneer (or backing); pavers; tunnel, drain and refractory linings, and sewer pipe.

Masonry units are typically made in relatively small sizes to be sufficiently light that it can be handled by an individual. There are several types of masonry unit in terms of form and basic material. With respect to the former there are solid and voided units where the voids can be vertical or horizontal. In terms of basic materials, the main types are:

1. Burned or unburned clay
2. Stone
3. Adobe
4. Shale
5. Concrete
6. Glass

Modern code-based requirements for regions subjected to significant seismic or wind loads, such as obtains in most of the Caribbean islands, stipulate that the masonry used for building construction, particularly the walls, must be adequately reinforced.

As such, the information presented herein is based primarily on burned clay masonry units, and concrete masonry units, as these are the principal types used for reinforced masonry wall construction.

Reinforced Masonry Wall Construction

The main types of masonry walls are: single-leaf (wythe) hollow unit; single-leaf (wythe) solid unit; double-leaf (wythe) hollow unit; double-leaf (wythe) solid unit; cavity; composite, and veneer.

The single-wythe hollow or solid unit walls can be fully or partially grouted. The double leaf is essentially two single-leaf walls placed side-by-side without a space between and connected together using either horizontal metal ties, or by bonding blocks at right angles to the run of the wall. Cavity walls are like double leaf walls except that there is a space between the wythes that is filled with concrete. Composite walls are the same as double-wythe or cavity walls except that the wythes are made of

[1] This document is based on excerpts from *Reinforced Masonry Design* by Schneider and Dickey

different types of masonry unit or a different material. Veneer walls are double wythe walls where one of the wythes is unreinfored. This unreinfored layer is mainly used for aesthetic reasons.

The following sketches illustrate the various types of wall and how they are reinforced and tied..

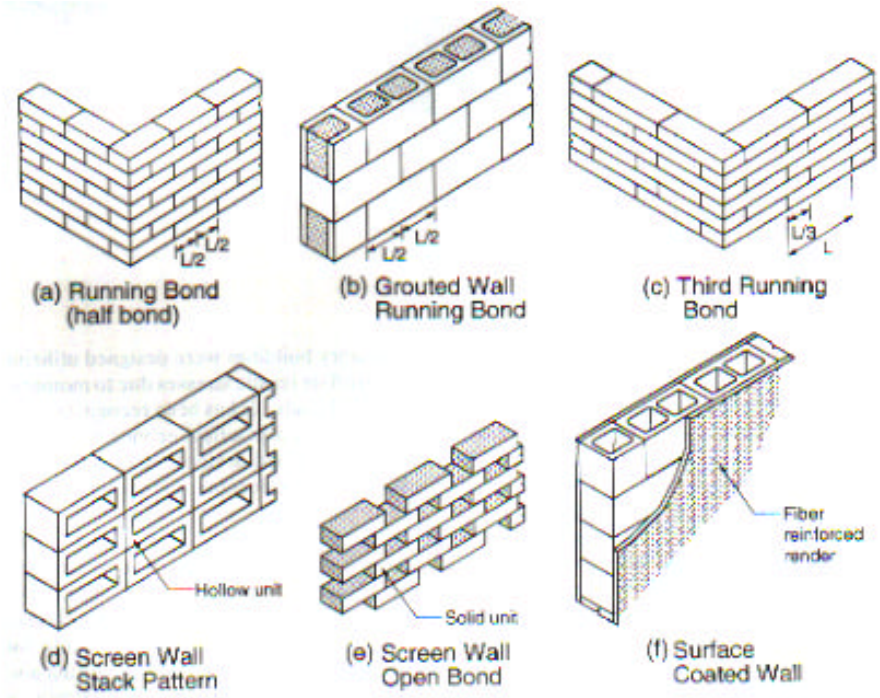
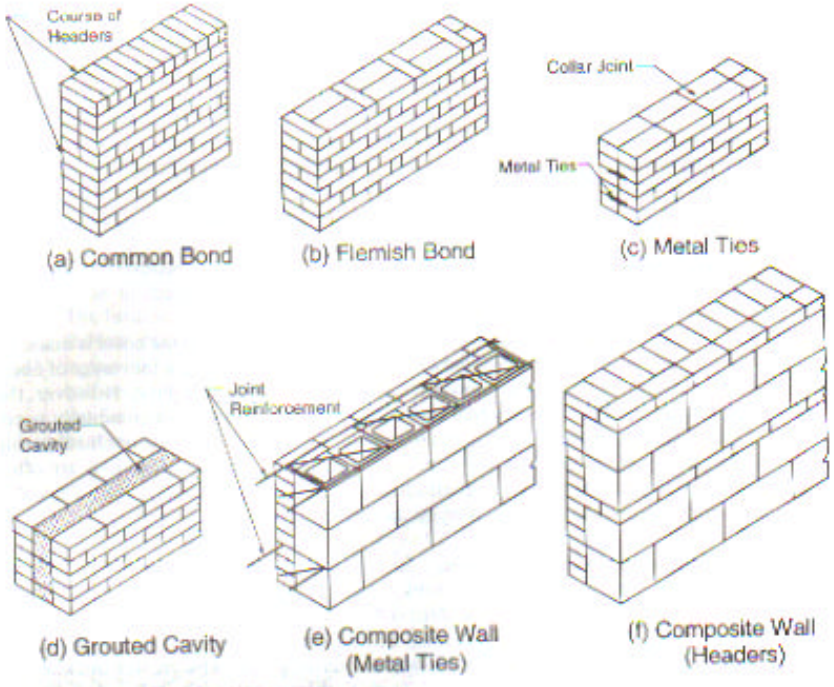


Figure 2.1 Single-wythe walls



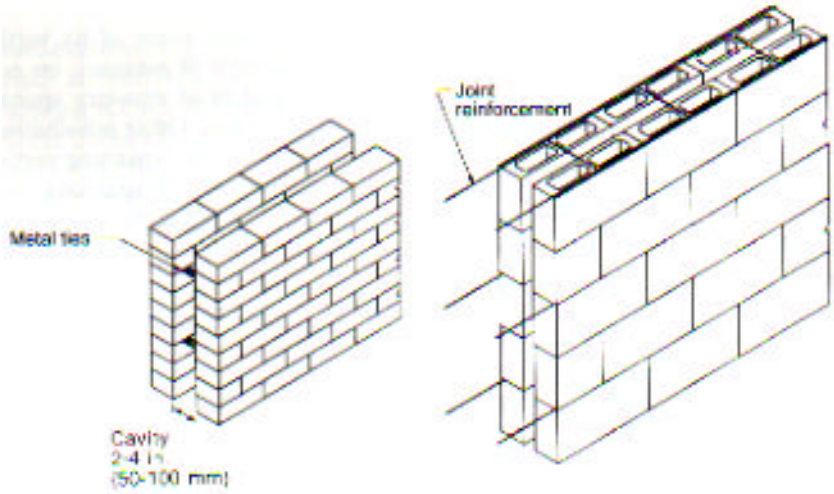


Figure 2.5 Cavity walls.

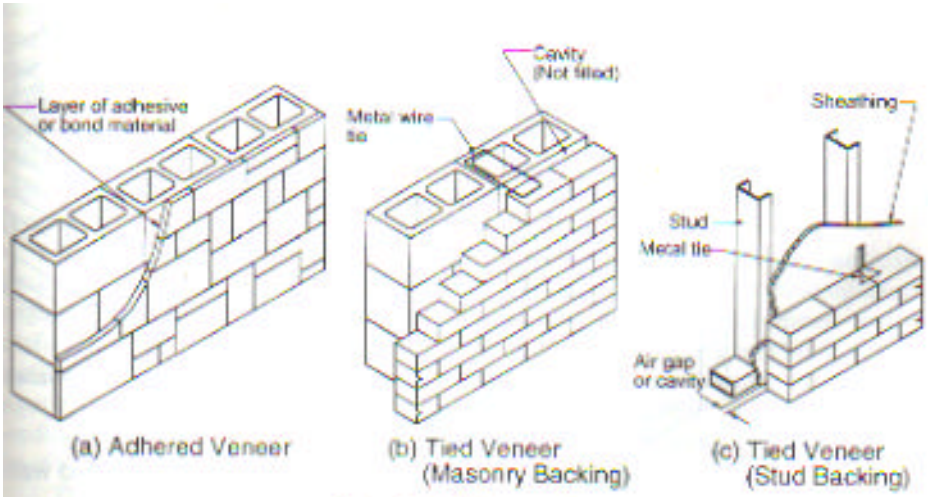


Figure 2.6 Veneer walls.

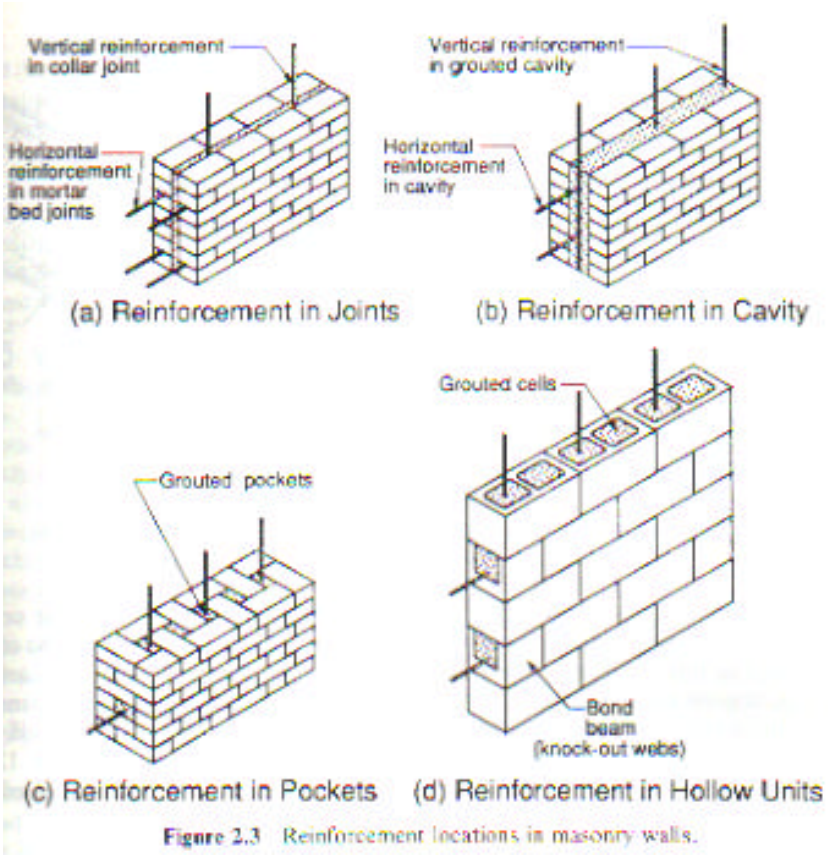


Figure 2.3 Reinforcement locations in masonry walls.

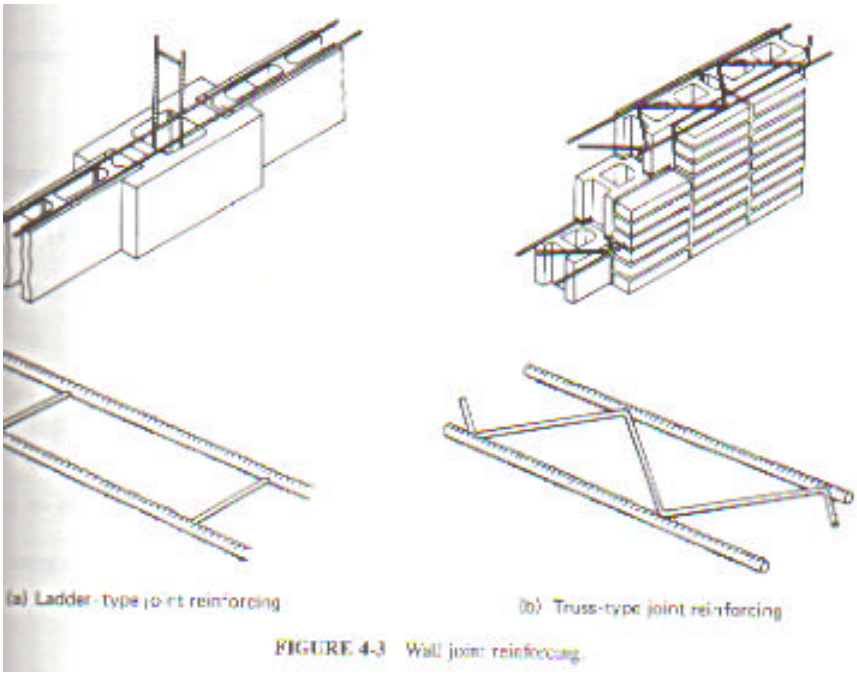


FIGURE 4-3 Wall joint reinforcing.

In the Caribbean practice, the main type of reinforced masonry wall used is the 150 and 200mm single-wythe hollow unit wall that is partially or fully grouted. These walls are typically of concrete vertically-celled hollow units though there is the recent availability in Trinidad and Tobago of a fired clay vertically-celled hollow unit block.

The main type of single-storey residential construction in Trinidad and Tobago is based on a 100mm fired clay hollow unit where the cells are horizontal and therefore unreinforced. An unreinforced 100mm concrete block is also extensively in mass housing projects used but the cells are vertical and too small to reliably accept reinforcement. Recent research has indicated that masonry wall construction based on these types of units are unsafe for the seismic conditions of Trinidad and Tobago and a new Residential Building Code is in progress that will disallow its use for any load-bearing functions.

The design of masonry walls in the Caribbean is based on U.S codes of practice and therefore the terminology of this document is based on the ASTM standards. As such, the vertically-celled concrete hollow unit is called a block, the aforementioned vertically-celled hollow clay unit is called a brick, and horizontally-celled hollow clay units are called structural tiles. A unit is considered to be solid if its net solid area is more than 75 percent of its gross area. In local parlance, probable based on U.K terminology, all hollow units are called blocks and only units without voids are called bricks.

Clay Hollow Brick (Vertical Cell) Units

Hollow bricks are hollow units similar in size and shape to hollow concrete block, except that they are made of fired clay or shale. This relatively new product represents the major development in effective and economically competitive reinforced brickwork and, as such, warrants clarification. The Trinidad and Tobago Bureau of Standards is currently in the process of developing a local standard for this type of unit.

They evolved primarily in the western region of the United States. One shape, made in the 1940s, contained two cells, providing a volume with about 25% voids. Hence, it was accepted by the UBC under the "cored solid brick" classification. It provided a single-wythe reinforceable unit. Later, another unit was manufactured and accepted on the basis of a special ICBO approval as a "load-bearing" tile, but with face shells not less than 1 1/4 in. thick. This product was 16 in. long and 8 in. high, so its size resulted in a rapid lay up of wall areas.

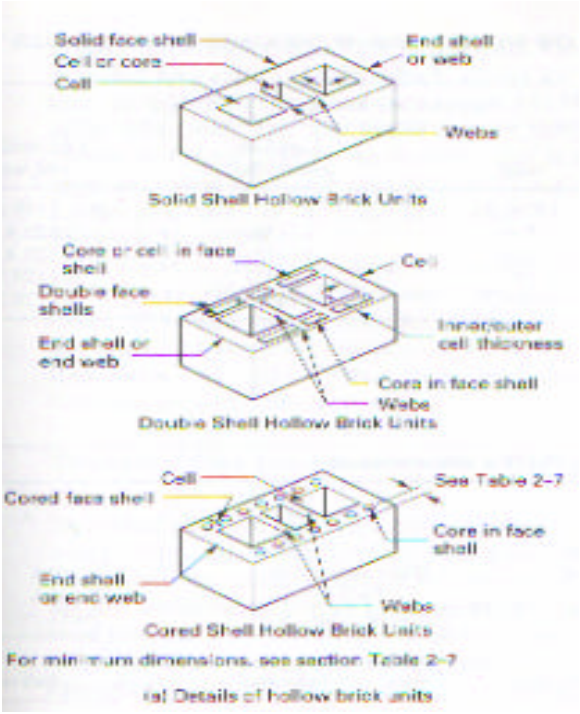
Subsequently, WSCPA developed a Hollow Brick Standard, since no ASTM specification existed at that time, and obtained an approval for its use under the UBC (ICBO Evaluation Report #2730). It included a description of the masonry unit, the compressive strength of both the unit and its assemblage (f'_m), a method of laying, and fire ratings both with and withour plaster. This Standard was used extensively and still provides an excellent guide to the use of hollow brick. However, the Evaluation Report has since been withdrawn, yielding to the subsequently drafted ASTM C-652 Specification (and also the revised UBC Standard 24-1). In this way, the hollow brick grew into a national product from a regional one. Although ASTM C-652 is not as direct as the former WSCPA standard, it adequately serves the purpose, and it is parallel in form, wording, content, and limits to the other clay standards, such as C-62 and C-216.

Although similar in shape to hollow concrete units, hollow brick demonstrates much higher masonry compressive strengths, making it an ideal material for use in mid-rise masonry buildings. For example, the 5-in. unit (t = 4.5 in.) develops a net compressive strength of 10,000 lb/in., compared to the 2000 to

3000 lb/in. attained by concrete block. This 5-in. thickness seems to offer the optimum in structural utility, coupled with the lowest possible weight and use of floor space, that is, an f 'm of 6000 lb/in. for inspected work with a nominal wall weight of 45 lb/ft'. These hollow bricks are also available in nominal thickness of 4, 6, and 8 in. as needed for load, height, and fire resistance.

Other significant features of this product include:

1. Very high compressive strengths can be developed.
2. Face shell thickness is, as with concrete block, sufficient to provide stability and sound mortar beds.
3. Cross-web requirements are similar to concrete block.
4. The cell sizes and areas are adequate for placement of the grouted reinforcement and the insulating fill.
5. It provides for valid fire ratings, either hollow or filled with grout or insulation, and with or without plaster coats.



The following table describes the main properties of clay hollow block (vertical core) units.

PROPERTIES OF HOLLOW CLAY BLOCK VERTICAL CELL UNITS

PROPERTY	DESIGNATED BY	**PURPOSE**	**NOTES**
Grade	SW; MW (i.e severe or moderate weathering).	Long term service life; based on durability.	For blocks, durability is mainly resistance to frost/thaw action; based on U.S weathering index (i.e. average number of freezing cycle days times average annual winter rainfall in inches). C/B ratio along with compressive strength and total absorption now recognised as more reliable indicators of durability.
Block Type	HBS (Hollow Brick Standard); HBX (Extra); HBA (Architectural Variation); HBB	HBS is the typical; HBX is for greater dimensional precision; HBA is for architectural effects; HBB is for when large variations in size, colour, or texture is allowed.	In the existing TTBS standard, Block Type is Grade.
Block Class	H40V (25% to 40% area is void); H60V (40% to 60% area is void)	To distinguish between hollow, solid and tile units; to ensure adequate web and face shell thicknesses.	If the void area is less than 25%, the unit is considered a solid unit rather than a hollow unit; if the void area is greater than 60% it is considered a tile. Solid units and tiles have separate standards.
Total Absorption	Water absorbed after 24hr submersion in cold water, expressed as % of total dry weight of the unit	Measures the ability to form a good bond with the mortar. This occurs because the unit floats thus increasing the w/c ratio at the interface.	Partial indicator of durability.
Saturation Coefficient	C/B Ratio (cold to boiling); ratio of percent of water absorbed (the boiling water immersion period is 5 hr).	Represents the portion of the total pore space that is readily filled with water.	Caters for differences in raw material or manufacturing process on durability. If no differences, then either compressive strength or total absorption correlates well with freeze/thaw resistance.
Initial Rate of Absorption	Weight of water absorbed per unit area in 1 minute.	Measures the unit's suction ability via capillary action; also measures water-tightness. If too high, less	Suction has little bearing on the transmission of water through the unit leading to leakage. This is mostly via spaces between the unit and mortar interface and under a pressure differential between the inside and outside wall surfaces. If greater than

		water is available for the hydration of the mortar in the cement; hence it measures the tendency for reduced mortar tensile bond strength.	40g/min, the unit should be prewetted 24hr before laying.
Compressive Strength	Maximum load (in kN or lbs) per unit gross area that the unit can sustain in compression.	All load-resisting and stiffness properties of the unit, as well as durability, correlates directly with the compressive strength.	Strength of the unit is not the same as strength of the masonry which is unit + mortar + grout (if any). Masonry compressive strength is determined by prism testing and measured in terms of net area.
Modulus of Elasticity	Compressive force required for unit axial deformation.	Measures the deformability of the unit.	Important for serviceability requirements of structural design. Directly correlates with compressive strength.
Flexural Strength	Strength under transverse bending; also called the modulus or rupture.	Enables calculation of the load required to initiate cracking in a structural element.	Important for serviceability requirements of structural design.

The following are typical property values.

CLASS H60V: HOLLOW BRICKS MINIMUM THICKNESS OF FACE SHELLS AND WEBS, IN. (MM)

Nominal width of units	Face shell thicknesses: Solid	Cored or double shell	End shells or end webs
3 and 4 (76 and 101)	3/4(19.05)	...	3/4 (19.05)
6 (152)	1 (25.4)	1 1/2 (38)	1 (25.4)
8 (203)	1 1/4 (32)	1 1/2 (38)	1 (25.4)
10 (254)	1 3/8 (35)	1 3/8 (41)	1 1/8 (29.5)
12 (306)	1 1/2 (38)	2 (50)	1 1/8 (29.5)

Physical Requirements

Designation	Compressive strength (hollow brick in bearing position) gross area, min. psi (MPa): Average of 5 brick	Individual	Water absorption by 5-h boiling, max. %: Average of 5 brick	Individual	Saturation coefficient, max: Average of 5 brick	Individual
Grade SW	3000 (20.7)	2500 (17.2)	17.0	20.0	0.78	0.80
Grade MW	2500 (17.2)	2200 (15.2)	22.0	25.0	0.88	0.90

Structural Clay Load-bearing Wall Tile

Structural clay tile was developed to satisfy a need for lightweight masonry, especially when used in filler panels and spandrel walls. Also, it can be utilized when the finished surface is a plaster or some other type of finish. The result is a building material that has, in varying degrees, the desirable characteristics of brick-strength and durability-while reducing such undesirable qualities as weight. Although certain types of tile do not have high strength values, others possess very high strengths and make excellent structural units.

This tile unit is covered by ASTM designation C34, which defines two grades of structural clay tile: LBX and LB. Also, UBC Standard 24-8 covers these products. Grade LBX tile is suitable for general use in load-bearing walls and adaptable for use in severe weather conditions, provided that it is burned to the normal maturity of the clay. It is also suitable for the direct application of stucco. Grade LB tile must be used only when the wall is not exposed to severe weathering action or for exposed masonry protected with a facing of 3 in. or more of other masonry. Tile of Grade LBX can be accepted under all

conditions in lieu of grade LB. The units range in thickness from 4 to 12 in in the following nominal dimensions: 12x12, 8x12, 6x12, 8x8, and 5 1/3 x 12.

The following table lists the absorption and compressive strength requirements of structural clay tile,

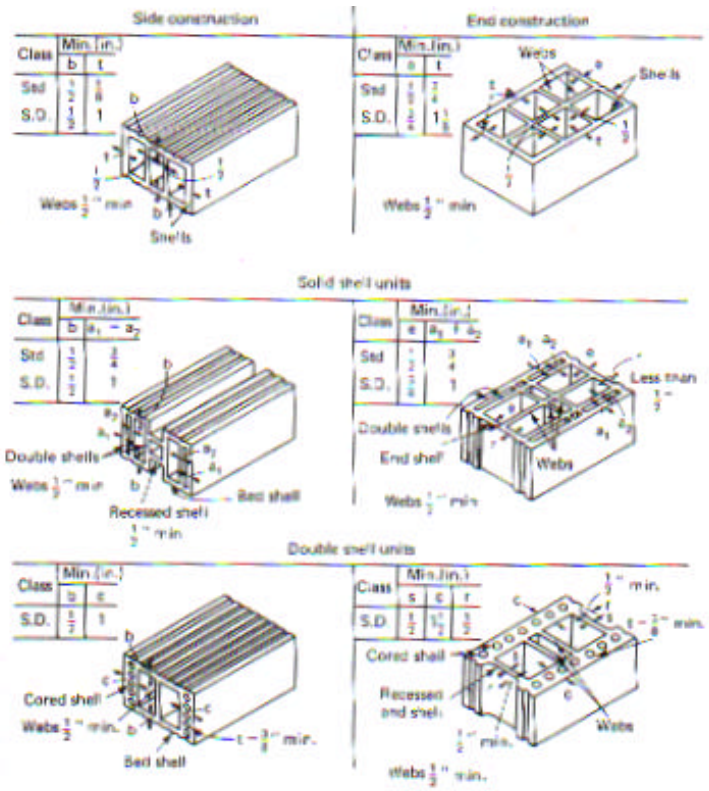


FIGURE 2-9 Structural clay tile units (8 in.).

both load-bearing (C34) and nonload-bearing (C56), as well as for facing tile (C212). Glazed units (CI26) are also listed.

The non load-bearing units (C56) may be used for nonstructural partitions. They are excluded from use in earthquake zones 2, 3, and 4, because all masonry there must be reinforced, which requires a structural masonry unit. Since they are nonstructural in function, no strength requirement is listed in the table.

PHYSICAL REQUIREMENTS FOR CLAY TILE

	Absorption %, 1-hr boiling		Minimum compression strength' (lb/in^2) End constr. tile		Side constr. tile	
Type and grzde	Average of five tests	Indiv.	Min. average of five tests	Indiv. Min.	Min. average of five tests	Indiv. min.
Load-bearing (C34)						
LBX	16	19	1400	1000	700	500
LB	25	28	1000	700	700	500
Nonload-bearing (C56)						
NB	-	28				
Facing tile (C212)						
Types						
FTX	9	11				
FTS	16	19				
Classes						
Standard			1400	1000	700	500
Special duty			2500	2000	1200	1000
Glazed units (C 1 26)			3000	2500	2000	1500

'Compression strength based on gross area (obtained as a product of horizontal face dimension as placed in the wall times its thickness).

Hollow Concrete Block

Solid concrete units are commonly called concrete bricks, whereas hollow units are known as concrete blocks, hollow blocks, or cinder blocks. Hollow units have net cross-sectional area in every plane parallel to the bearing surface with less than 75% of the cross-sectional area in the same plane. If this ratio is 75% or more, the unit is categorized as solid (Portland Cement Association 1991).

Concrete masonry units are manufactured using a relatively dry (zero-slump) concrete mixture consisting of portland cement, aggregates, water, and admixtures. Type 1 cement is usually used to manufacture concrete masonry units; however, Type III is sometimes used to reduce the curing time. Air-entrained concrete is sometimes used to increase the resistance of the masonry structure to freeze and thaw effects and to improve workability, compaction, and molding characteristics of the units during manufacturing. The units are molded under pressure, then cured, usually using low-pressure steam curing. After manufacturing, the units are stored under controlled conditions so that the concrete continues curing.

Concrete masonry units can be classified as load-bearing (ASTM C90) and nonload-bearing (ASTM C129). Load-bearing units must satisfy a higher minimum compressive strength requirement than non-load-bearing units.

Load-bearing concrete masonry units are manufactured in two types: Type 1, moisture-controlled units, and Type II, non-moisture-controlled units. Type I units are required to comply with certain moisture content provisions specified by ASTM C90, whereas Type 11 does not have to comply with these requirements.

The moisture content is controlled in Type I units to limit the amount of shrinking due to moisture loss after construction. Type I units are used in and areas and must have low moisture content when delivered to the job site. In addition, they must be protected from rain, and other moisture before being used. If moisture content is not reduced in the units before using them, drying shrinkage will occur, which might cause cracking when climatic balance is achieved.

In humid areas, moisture control of the concrete blocks is not required. Type II units are permitted in such cases, but they should not be very moist during construction in order to avoid excessive drying shrinkage, which might cause cracking. They should be stored long enough to achieve climatic balance depending on the material used, moisture content in the units, and humidity conditions. Type II units are more commonly used in construction than Type I.

Mortar, Grout and Plaster

Mortar is a mixture of portland cement, lime, sand, and water. Adding a small percentage of lime to the cement mortar makes the mortar "fat" or "rich," which increases its workability. Mortar can be classified as lime mortar or cement mortar. Lime mortar is made of lime, sand, and water, whereas cement (or cement-lime) mortar is made of lime mortar mixed with portland cement (Portland Cement Association 1987).

Mortar is used for the following functions:

- bonding masonry units together
- serving as a seating material for the units
- leveling and seating the units
- providing aesthetic quality of the structure

Lime mortar gains strength slowly with a typical compressive strength of 0.7 MPa to 2.8 MPa (100 psi to 400 psi). Cement mortar is manufactured in four types: M, S, N, and O. Type M has the lowest amount of hydrated lime, whereas type O has the highest amount. The compressive strength of mortar is tested using 50-mm cubes according to ASTM C109. The minimum average compressive strengths of types M, S, N, and O at 28 days are 17.2 MPa, 12.4 MPa, 5.2 MPa, and 2.4 MPa (2500 psi, 1800 psi, 750 psi, and 350 psi) (ASTM C270).

Mortar starts to bind masonry units when it sets. During construction, bricks and blocks should be rubbed and pressed down in order to force the mortar into the pores of the masonry units to produce maximum adhesion. It should be noted, however, that mortar is the weakest part of the masonry wall. Therefore, thin mortar layers generally produce stronger walls than do thick layers.

Grout is a high-slump concrete consisting of portland cement, lime, sand, fine gravel, and water. Grout is used to fill the cores or voids in hollow masonry units for the purpose of: 1) bonding the masonry

units, 2) bonding the reinforcing steel to the masonry, 3) increasing the bearing area, 4) increasing fire resistance, and 5) improving the overturning resistance by increasing the weight.

Plaster is a fluid mixture of portland cement, lime, sand, and water, which is used for finishing either masonry walls or framed (wood) walls. Plaster is used for either exterior or interior walls. Stucco is plaster used to cover exterior walls. The average compressive strength of plaster is about 13.8 MPa (2000 psi) at 28 days.