BASIC COMPONENTS OF MASONRY

In the architectural history of masonry, we have seen that masonry can be used in a wide variety of architectural applications, including:

- walls (bearing, shear, structural, decorative, bas-relief, mosaic)
- arches, domes and vaults
- beams, columns

Masonry, while often simple and elegant in form, can be complex in behavior. Also, unlike concrete, it cannot be ordered by the cubic yard. To understand its behavior, and to be able to specify masonry correctly, we must examine each of its basic components.

Basic Components of Masonry:

- units,
- mortar,
- grout,
- accessory materials

Units

Masonry units, as noted below, can be classified as:

- adobe (unfired clay)
- roofing tile
- drain tile
- refractory brick
- wall tile
- glazed facing tile (terra cotta, ceramic veneer)
- structural clay products
    - structural tile
        - facing tile
        - glazed
        - textured
    - floor tile
- brick (solid, frogged, cored, hollow)
    - facing and building brick
    - glazed brick
    - floor and paving brick
        - industrial
        - paving
        - patio
    - chemical resistant brick
    - sewer brick
    - chimney lining brick

- concrete block (solid, hollow)
- glass
- stone (artificial shape)
- rock (natural shape)

In this course, we shall emphasize the behavior and use of structural masonry units, of fired clay or of concrete.

Mortar

In the US, three basic cementitious systems are used for mortar: portland cement-lime mortar; masonry cement mortar; and mortar cement mortar. The first two are widely used; the third has been recently introduced.

- *Portland Cement-Lime Mortar* (different proportions of portland cement, lime and masonry sand). This can be batched by hand on site using material from bags, or batched automatically on site using material from silos.

- *Masonry-Cement Mortar* (different proportions of masonry cement and sand; may also contain additional portland cement). Masonry cement formulations and manufacturing processes are manufacturer-specific. Ingredients are not required to be identified, and usually are not. Masonry cement generally consists of portland cement, pozzolan cement or slag cement, plasticizing additives, air-entraining additives, water-retention additives, and finely ground limestone (added primarily as a filler, but with some plasticizing and cementitious effect).

- *Mortar-Cement Mortar* (different proportions of mortar cement and sand; may also contain additional portland cement). Mortar cement formulations and manufacturing processes are manufacturer-specific. Ingredients are not required to be identified, and usually are not. Mortar cement generally consists of portland cement, pozzolan cement or slag cement, plasticizing additives, air-entraining additives, water retention additives, and finely ground limestone (added primarily as a filler, but with some plasticizing and cementitious effect). It differs from masonry cement in that it is formulated specifically for tensile bond strength comparable to that of portland cement-lime mortar.

Grout

Grout is fluid concrete with pea-gravel aggregate. It can be used to fill some or all cells in hollow units, or between wythes.

Accessory Materials

- Reinforcement
- Connectors (galvanized or stainless steel)
- ties connect a masonry wall to another wall
- anchors connect a masonry wall to a frame
- fasteners connect something else to a masonry wall
- Sealants
- expansion joints (brick masonry)

- control joints (concrete masonry)
- construction joints
- Flashing
- Coatings
- paints
- water-repellent coatings
- Vapor Barriers

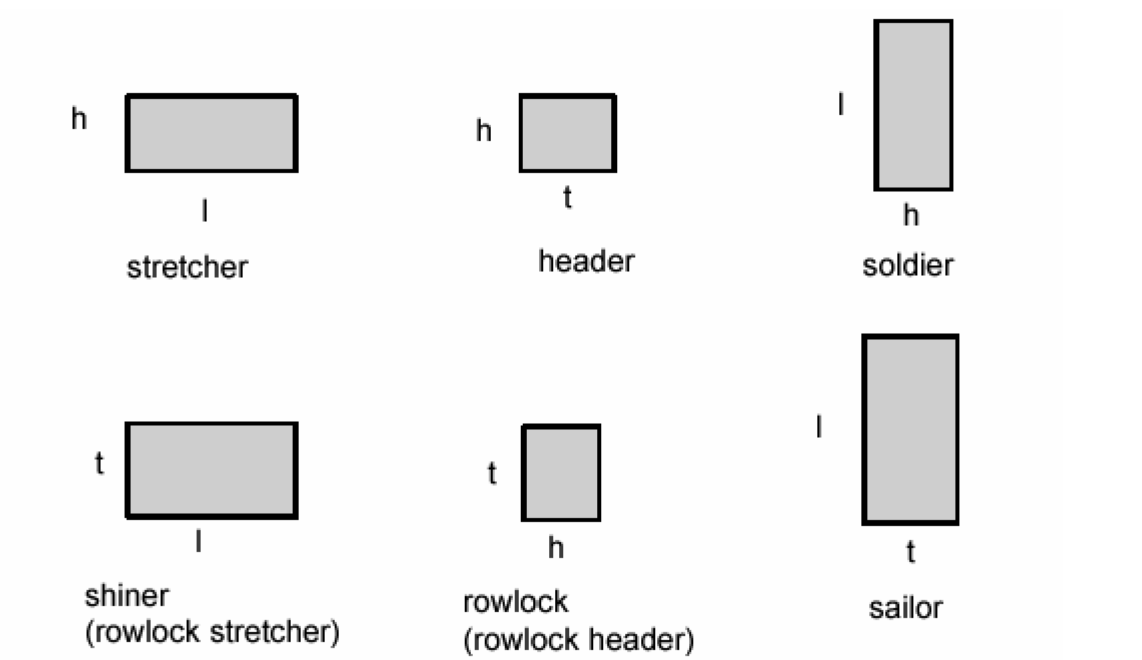
Units Placed to Form Architectural and/or Structural Components
Dimensions:

Masonry unit dimensions are typically described in terms of (thickness x height x length). Typically, the length is the largest dimension; the thickness is next; and the height is the smallest dimension. For example, a typical brick has dimensions of 4 x 2.67 x 8 inches. These are **nominal dimensions**; that is, the distances occupied by the unit plus one-half a joint width on each side. Joints are normally 3/8 in. thick. The **specified dimensions** of the brick themselves are smaller; in this case, 3-5/8 x 2-1/4 x 7-5/8 in. The **actual dimensions** are the specified dimensions plus or minus the allowable manufacturing tolerance.

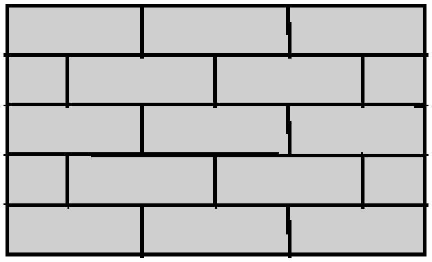
The sides of a masonry unit are often designated in literature by special names:

- *bed*: side formed by thickness x length
- *face*: side formed by height x length
- *head*: side formed by thickness x height (end)

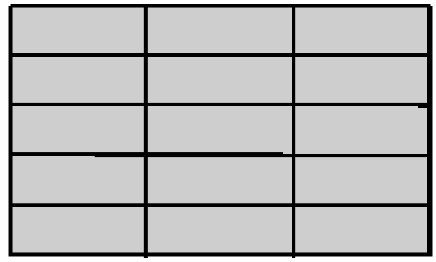
Orientation of Masonry Units in a Wall: all figures below are viewed perpendicular to the plane of the wall:



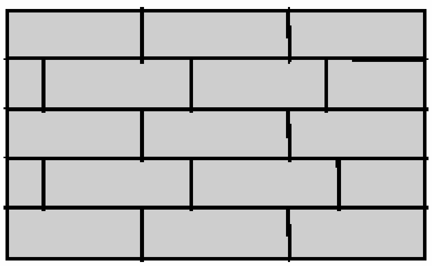
Bond Patterns:



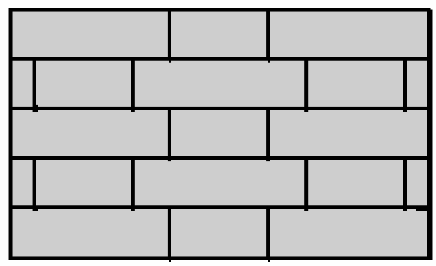
Running Bond



Stack Bond



1/3 Running Bond



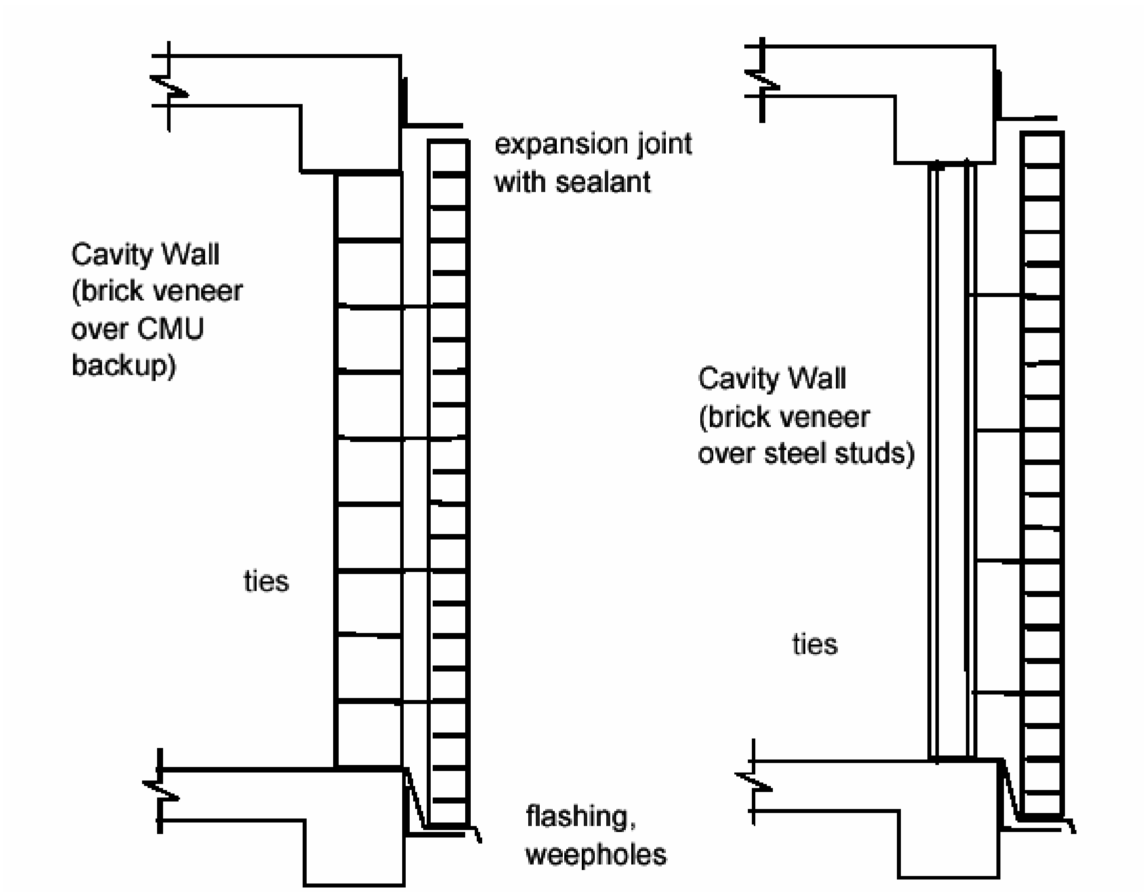
Flemish Bond

Types of Walls:

- single wythe: barrier wall
- multiple wythe: composite wall (brick-block)
- filled collar joint
- bonded headers

- cavity wall (cavity ≧ 2 inches wide)

- brick veneer over concrete block backup
- brick veneer over steel stud



Modern Masonry Mortar

Modern masonry mortar is composed of cementitious agent (portland cement or other hydraulic cements and hydrated lime, or masonry cement, or mortar cement), sand, and water. Each of these can be referred to as a masonry system. These masonry systems are defined by ASTM C 270. That specification defines, for all masonry systems, different masonry types. In general, these are distinguished by the amount of portland cement that they use.

Types of Masonry Mortar:

Types of masonry mortar are designated as shown below. The letters M, N, S, and O represent every second letter of the phrase, "mason work:"

M, S, N, O (M A S O N W O R K)

This designation was selected intentionally (rather than, for example, "A, B, C, D"), to avoid the implication that a "Type A" mortar would always be the best.

Characteristics of Different Types of Masonry Mortar

- Type M: high compressive strength and tensile bond strength
- Type S: moderate compressive and tensile bond strength
- Type N: low compressive strength and tensile bond strength
- Type O: very low compressive and tensile bond strength
- Type K: no longer used

Proportions of Portland Cement Lime Mortar

Mortar Type	Mortar Proportions by Volume		
	Portland Cement	Hydrated Lime	Mason's Sand (2-1/4 to 3 times volume of cementitious materials)
M	1	≤ 1/4	3
S	1	1/2	4-1/2
N	1	1	6
O	1	2	9

Portland Cement-lime Mortar Specifications

PCL Mortar Type	Property Requirements for PCL Mortar		
	Compressive Strength, psi	Water Retention	Maximum Air Content
M	2500	75%	12%
S	1800	75%	12%
N	750	75%	14% (12% if reinforced)
O	350	75%	14% (12% if reinforced)

Proportions Masonry Cement Type Mortar

Mortar Type	Mortar Proportions by Volume				
	Portland Cement	Masonry Cement Type			mason's sand (2-1/4 to 3 times volume of cementitious materials)
		M	S	N	
M		1			3
S			1		3
N				1	3
O				1	3
M	1			1	6
S	1/2			1	4-1/2

The first four are the more common specifications for this type of mortar.

Property Specifications of Masonry Cement Mortar

MC Mortar Type	Property Requirements for MC Mortar		
	Compressive Strength, psi	Water Retention	Maximum Air Content
M	2500	75%	18%
S	1800	75%	18%
N	750	75%	20% (18% if reinforced)
O	350	75%	20% (18% if reinforced)

Mortar Cement Mortar Proportion Specifications

Mortar Type	Mortar Proportions by Volume				
	Portland Cement	Mortar Cement Type			mason's sand (2-1/4 to 3 times volume of cementitious materials)
		M	S	N	
M		1			3
S			1		3
N				1	3
O				1	3
M	1			1	6
S	1/2			1	4-1/2

Property Specifications of Mortar Cement Mortar

Mortar Cement Mortar Type	Property Requirements for Mortar Cement Mortar		
	Compressive Strength, psi	Water Retention	Maximum Air Content
M	2500	75%	12%
S	1800	75%	12%
N	750	75%	14% (12% if reinforced)
O	350	75%	14% (12% if reinforced)

Characteristics of Fresh Mortar:

Workability (ease of being spread under a trowel) is described in terms of **flow**: a standard-shaped, circular sample of mortar 4 inches in diameter is placed on a flow table, which is then dropped 25 times. The flow is defined as the increase in diameter, divided by the original diameter and multiplied by 100. Thus, if the final diameter is 8 inches, the flow is (8 - 4) / 4, or 100. Laboratory-mixed mortars have a flow of about 110 $\pm$ 5; field mortars, about 130 to 150. Field mortars **should** be re-tempered (water added) as necessary to maintain workability, but should not be used beyond 2-1/2 hours after mixing. Workability can also be measured with a cone penetrometer.

According to ASTM C270, mortar can be specified by proportion (the default) or by property. If mortar is specified by proportion, the following characteristics of fresh mortar are controlled indirectly as a result of complying with the required proportions. If mortar is specified by property, they are controlled directly:

1) retentivity: this is the ratio of the flow after suction to the initial flow. Flow after suction is measured using mortar from which some of the water has been removed using a standard vacuum apparatus. In one other specification, the mortar is spread on a masonry unit and allowed to sit for 1 minute. According to ASTM C270, mortar is required to have a retentivity of at least 75%.

2) air content: percent air by volume (C 91). Portland cement-lime mortar and mortar cement mortar usually have a maximum permissible air content of 12%. Masonry cement mortar usually has a maximum air content of 18% if used in reinforced masonry.

Characteristics of Hardened Mortar:

These include compressive strength and tensile bond strength. Only the first is controlled by ASTM C270. If mortar is specified by the property specification of ASTM C 270, compressive strength is controlled directly. It is measured using 2-inch mortar cubes, made with laboratory flow mortar, cured for 28 days under standard conditions of 100% relative humidity and 70 F. It typically ranges from 500 to 3000 psi. It does not significantly affect the compressive strength of masonry assemblages (see below). ASTM C 270 requires minimum compressive strengths of 2500 psi, 1800 psi, 750 psi, and 350 psi for Type M, S, N, and O mortar, respectively.

If mortar is specified by the proportion specification of ASTM C 270, compressive strength is controlled indirectly. Masonry cement mortar meeting the proportion specification usually has a compressive strength slightly greater than the minimum value specified in the property specification. Portland cement lime mortar meeting the proportion specification usually has a compressive strength considerably greater than the minimum value specified in the property specification.

Note on Portland Cement-Lime versus Masonry Cement Mortars

At times in the past, and to some extent even to this day, controversy has existed within the masonry technical community over the comparative performance of portland cement-lime mortar and masonry cement mortar. Each class of mortar has advantages and disadvantages.

The advantages of ***portland cement-lime mortar*** are its high tensile bond strength, and the generally higher water-penetration resistance of masonry laid using it. Its disadvantages are the additional complexity of mixing three ingredients, and some lack of workability (stickiness) if not re-tempered. The first disadvantage can be overcome by single-bag or silo mixes. The second can sometimes be overcome by re-tempering.

The advantages of ***masonry cement mortar*** are its relative simplicity of batching and its good workability. It has a “fluffy” consistency (because of its entrained air), which leads to good productivity. Its lower tensile bond strength is accounted for by lower allowable stresses in design codes. In part because of these lower bond strengths, and in part because of other reasons, masonry cement is prohibited in zones of high seismic risk in the US. Lower water-penetration resistance of walls made with masonry cement mortar is not addressed. From the viewpoint of cement producers, masonry cement is a profitable “niche” product. A 70-lb bag of masonry cement typically contains about 28 lb or less of portland cement, about 40 lb of ground limestone, air-entraining additives, and possibly additives for water-retention and plasticity. This bag commonly sells for the same price as 94 lb of portland cement.

Mortar cement was introduced in the 1990’s to preserve the construction advantages and potential profitability of masonry cement, while at the same time increasing the tensile bond strength of the resulting mortar to values comparable to those of portland cement-lime mortar. Mortar cement is regarded by building codes as the equivalent of portland cement-lime mortar, and is permitted even in the most seismic zones of the US.

MASONRY GROUT

Masonry grout is essentially fluid concrete. It is used to fill spaces in masonry, and to surround reinforcement and anchors.

Applicable ASTM Specification:
C476: Grout for Masonry

Grout for masonry is composed of portland cement, sand, and pea gravel. It is permitted to contain a small amount of hydrated masons' lime, but usually does not. It is permitted to be specified by proportion or by property.

Proportion specifications for grout for masonry:

Grout Type	Grout Proportions by Volume			
	Portland Cement	Hydrated Lime	Mason’s Sand	Pea Gravel
Fine	1	$\leq 1/10$	2-1/4 to 3	-
Coarse	1	$\leq 1/10$	2-1/4 to 3	1 to 2

Properties of Fresh Grout:

Masonry grout is placed with a slump of at least 8 inches, so that it will flow freely into the cells of the masonry. Because of its high water-cement ratio at time of grouting, masonry grout undergoes considerable plastic shrinkage as the excess water is absorbed by the surrounding units. To prevent the formation of voids due to this process, the grout is consolidated during placement, and re-consolidated after initial plastic shrinkage. Grouting admixture such as Sika's "Grout-Aid," which contain plasticizers and water-retention agents, are also useful in the grouting process.

Properties of Hardened Grout:

The most important property of hardened grout is its compressive strength. If grout is specified by property, it must have a compressive strength of at least 2000 psi. If it is specified by proportion, its compressive strength is controlled indirectly to at least that value, by the ingredients used. Because of its high water-cement ratio at the time of grouting, masonry grout cast into impermeable molds has a very low compressive strength, which is not representative of its strength under field conditions, when the surrounding units absorb water from it. For this reason, ASTM C 1019 (Compressive Strength of Grout) requires that the compression specimen be cast using a permeable mold. The most common way of preparing such a mold is to arrange masonry units so that they enclose a block whose base is 2 inches square, and whose height is equal to the height of the units. The block is surrounded by paper towels or filter paper, so that the compressive specimen's water-cement ratio is similar to that of grout in the actual wall.

CLAY MASONRY UNITS

Geology:

Bricks are formed of clay, a sedimentary mineral. Clay is found in the form of surface clay, shale (naturally compressed and hardened clay), or fire clay (deeper clays). In the United States, clay is found primarily in central Texas and the east coast, although small amounts are found in sedimentary deposits throughout the country.

Chemistry:

Clays and shales are about 65% silicon oxide and 20% aluminum oxide. They may also contain varying amounts of other metallic oxides (manganese, phosphorus, calcium, magnesium, sodium, potassium and vanadium). These metallic oxides give a brick a distinctive color, decrease the brick's vitrification temperature, and also affect its appearance and durability. For example, small amounts of chromite, added to light-colored (buff) clay, will give it a gray color; small amounts of manganese, added to buff clay, will give it a brown color.

Manufacturing:

Three processes are in use today:

1) soft mud process: clay containing 20% - 30% water by weight is molded.

2) stiff mud process: clay containing 12% - 15% water by weight is mixed, forced through a die, and cut with wire. This is the most common process in the United States.

3) dry press process: mix clay containing 7% - 10% water by weight, form in hydraulic press. This process is rare.

After forming, various surface textures can be imparted to the brick: wire-cut; rug (heavy scratches); matte (light scratches); or sand finished. The brick are then placed on specially insulated railway cars, and subjected to the firing process. This involves 6 basic steps:

1) <u>Pre-heating</u>: The green brick are dried at about 350 F, in drying ovens heated by exhaust gases from the kiln. During this process, the brick shrink. The brick then move into a tunnel kiln, which is kept relatively cool at the entrance, hot in the middle, and cooler again at the exit. The heat comes from burning fuel within the kiln itself. Over a period of 12 hours to as long as 3 days, the brick pass from the entrance to the hottest section, and then to the cooler exit. Temperatures in the different sections are regulated to produce different results. The brick pass through the following steps:

2) <u>Dehydration</u>: The brick continue to dry at temperatures from 300 F to about 800 F.

3) <u>Oxidation</u>: At temperatures from about 800 F to 1800 F, organic material burns.

4) <u>Vitrification (or incipient vitrification)</u>: At temperatures of 1600 F to 2400 F, the clay begins to vitrify. Silicates in the clay begin to fuse, binding the unvitrified clay particles together. This point is termed “incipient fusion.” The temperature used depends on the type of clay. Most clays will undergo incipient fusion at about 2000 F. The purest clays, which are used for refractory brick, are fired at temperatures up to 2400 F.

5) Control of Oxygen: The color of metallic oxides can be changed by feeding additional air into the kiln at this point, or by intentionally withholding air. The latter is termed “flashing.”

6) Cooling: The brick are then slowly cooled.

Visual and Serviceability Characteristics:

The following characteristics are covered by ASTM C62 (Standard Specification for Building Brick) or by ASTM C216 (Standard Specification for Facing Brick):

- dimensional tolerances
- durability: Moderate Weathering (MW), Normal Weathering (NW), and Severe Weathering (SW)
- freeze-thaw resistance
- appearance

Mechanical Characteristics:

Compressive strength varies from 1,200 to 30,000 psi. It is typically 8,000 to 15,000 psi. Building brick (ASTM C62) must have a minimum compressive strength (average of 5 units, tested flatwise) of 1500 psi for Grade NW (normal weathering), 2500 psi for Grade MW (moderate weathering), and 3000 psi for Grade SW (severe weathering). Building brick (ASTM

C216) must have corresponding compressive strengths of 2500 psi for Grade MW, and 3000 psi for Grade SW. Grade NW does not exist under ASTM C216.

Specification of Clay Masonry Units

Clay masonry units are specified in accordance with the required appearance and durability.

- The required appearance determines whether the brick need to conform to C62 or to C216. Under C216, the required dimensional tolerances determine the class (FBS or FBX).

- The required durability and freeze-thaw resistance determine whether the brick need to conform to Grade NW, MW or SW. The required durability and freeze-thaw resistance depend on the "weathering index" (product of the average annual number of freezing cycle days and the average annual winter rainfall in inches), defined in detail in ASTM C62 and depicted in a map in that specification. "Negligible" weathering regions have weathering indices of less than 50; "moderate" weathering regions have weathering indices between 50 and 500; and "severe" weathering regions have weathering indices in excess of 500. Under ASTM C62 (Building Brick), Grade NW brick are recommended for interior use only. Grade MW brick are permitted for use in "severe" weathering regions. Grade SW brick are recommended for use in "severe" weathering regions, and whenever brick are in contact with the ground, or laid in horizontal surfaces, or likely to be permeated with water. Under ASTM C216 (Facing Brick), there are no Grade NW brick. Grade MW brick are permitted for use in “severe” weathering regions. Grade SW brick are required for use whenever the weathering index is greater than or equal to 500, and whenever brick in other than vertical surfaces are in contact with soil.

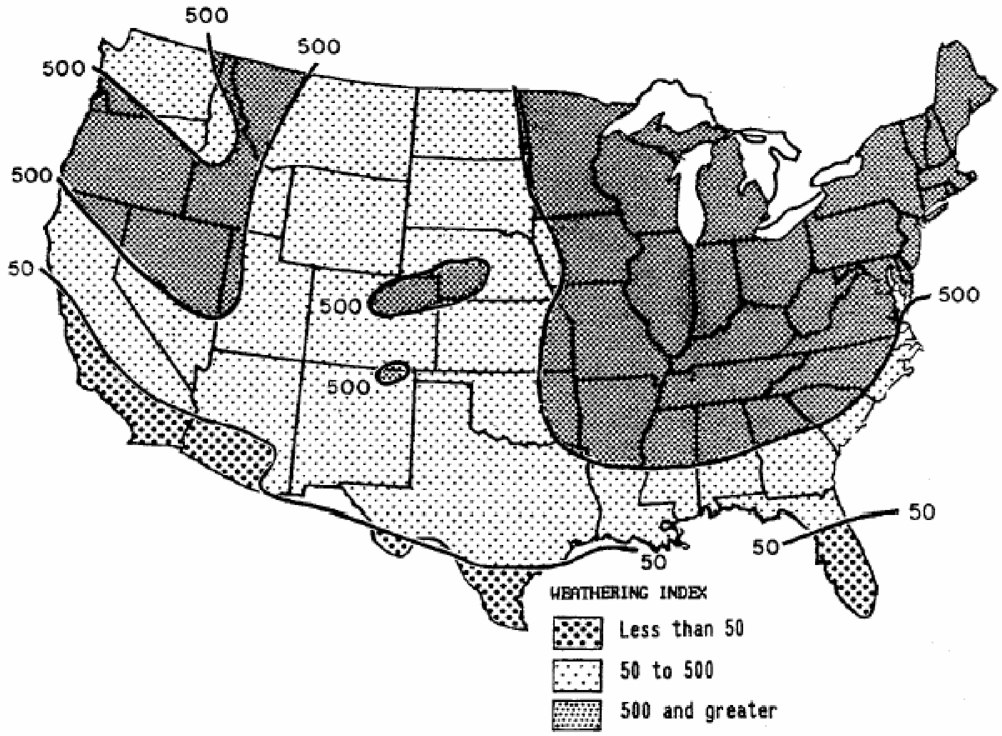


FIG. 1 Weathering Indices in the United States (see Table 2)

(The weathering index is the product of the average annual number of freezing cycle days and the average annual winter rainfall in inches. See ASTM C62.)

CONCRETE MASONRY UNITS

Materials and Manufacturing:

Concrete masonry units are formed from zero-slump portland cement concrete, usually using lightweight aggregate. The mix is vibrated under pressure in multiple-block molds. After stripping the molds, the units are cured under atmospheric conditions, atmospheric steam, or high-pressure steam (autoclaving). Concrete units normally have a much higher void ratio than clay units, making determination of (c/b) ratios unnecessary.

Visual and Serviceability Characteristics:

The following visual and serviceability characteristics are addressed by ASTM C90 (Standard Specification for Hollow Load-Bearing Concrete Masonry Units):

1) dimensional tolerances: ASTM C90 prescribes maximum dimensional tolerances of ± 1/8 inch. Thicknesses of face shells and webs are specified.

2) chippage: according to ASTM C90, up to 5% of a shipment may contain units with chips up to 1 inch in size.

Other visual and serviceability characteristics, such as color, are not addressed by ASTM C90. Color is gray or white, unless metallic oxide pigments are used.

Mechanical Characteristics:

The following mechanical characteristics are covered by ASTM C90, ASTM C140, and ASTM C426:

1) compressive strength is typically 1500 to 3000 psi on the net area (actual area of concrete). ASTM C90 requires a minimum compressive strength (average of 3 units) of 1900 psi, measured on the net area.

2) Absorption is evaluated in the following manner. The unit is immersed in cold water for 24 hours. It is weighed immersed (weight, F), and weighed in air while still wet (weight, E). It is then dried for at least 24 hours at a temperature of 212 ^{o}F to 239 ^{o}F, and again weighed (weight, C).The absorption in lbs/ft^3 is calculated as [(E - C) / (E - F)] x 62.4. Maximum permissible absorption is 18 lbs/ft^3 for lightweight units (less than 105 lb/ft^3 oven-dried weight), 15 lbs/ft^3 for medium-weight units (105 - 125 lb/ft^3), and 13 lbs/ft^3 for normal-weight units (more than 125 lb/ft^3).

3) Shrinkage of concrete masonry units due to drying and carbonation is 300 - 600 µå. In general, shrinkage is controlled by controlling the concrete mix used to make the units, and by limiting the moisture content of the units between the time of production and when they are placed in the wall. The concrete masonry industry formerly produced Type I (moisture-controlled) units, which due to a combination of inherent characteristics and packaging were designed to shrink less, and Type II units (non moisture-controlled). This distinction was not as useful as successful as originally hoped, because it was difficult to control the condition of Type I units in the field. As a result, ASTM C90 now does not refer to Type I and Type II units. All C 90 units must meet the shrinkage requirements that formerly applied to Type II units.

Other Characteristics:

The following characteristic are not covered by ASTM specifications:

1) surface texture can be smooth, slump block, split-face block, ribbed block, various patterns, polished face
2) tensile strength is about 10% of compressive strength.
3) Tensile bond strength (strength between mortar and block) is typically about 40 to 75 psi when portland cement-lime mortar is used and about 35 psi or less when masonry cement mortar is used. In contrast to clay units, the tensile bond strength of concrete masonry units is not sensitive to initial rate of absorption. For this reason, specifications for concrete masonry units do not require determination of IRA.
4) Initial rate of absorption (IRA) is typically 40 - 160 grams per minute / 30 square inches of bed area. Because the tensile bond strength of concrete masonry units is not sensitive to initial rate of absorption, specifications for concrete masonry units do not require determination of IRA.
5) modulus of elasticity is typically 1 - 3 x 10$_6$ psi.

6) coefficient of thermal expansion is typically : 4 - 5 µå/F.

MASONRY SUBASSEMBLAGES

Properties of Masonry Assemblages:

The following characteristics of masonry subassemblages are covered by ASTM Specifications E72, C1388, C1389, C1390, C1391, C1072, C1357, and C1314.

1) compressive strength: this is often denoted by f_m. Using ASTM C1314, it is measured using stack-bonded prisms whose maximum (h/d) ratio (height divided by least lateral dimension thickness) is between 1.3 and 5. For example:

a) hollow concrete masonry units measuring 8 x 8 x 16 inches, tested as a 2-high prism, would have a height of 16 inches and a minimum lateral dimension of 8 inches, for a maximum (h/d) ratio of 2.

b) modular brick measuring 4 x 2-2/3 x 8 inches, tested as a 6-high prism, would have a height of 16 inches and a minimum base dimension of 4 inches, for a maximum (h/d) ratio of 4.

The compressive strength of a clay masonry prism is less than that of the mortar or the unit tested alone. This is because clay masonry prisms typically fail due to transverse splitting. The mortar is usually more flexible than the units. Under compression perpendicular to the bed joints, it expands laterally, placing the units in transverse biaxial tension. The prism cracks perpendicular to the bed joints (parallel to the direction of the applied load).

Because concrete masonry prisms typically have mortar and units of similar strengths and elasticity, these tend to fail like a concrete prism.

2) Tensile bond strength can be measured by tests on wall specimens (E72), by modulus of rupture tests on masonry beams (E518), by bond wrench tests (C1072), or by crossed-brick couplet tests. Results from these tests are not equal. Strict protocols for bond-wrench testing are specified in C1357.

3) Shear strength can be measured by diagonal compression tests (E519).

4) Water permeability is measured in terms the amount of water passing through a wall under a standard pressure gradient, simulating the effects of wind-driven rain (E514).

MASONRY ACCESSORY MATERIALS

Masonry accessory materials consist of the following:

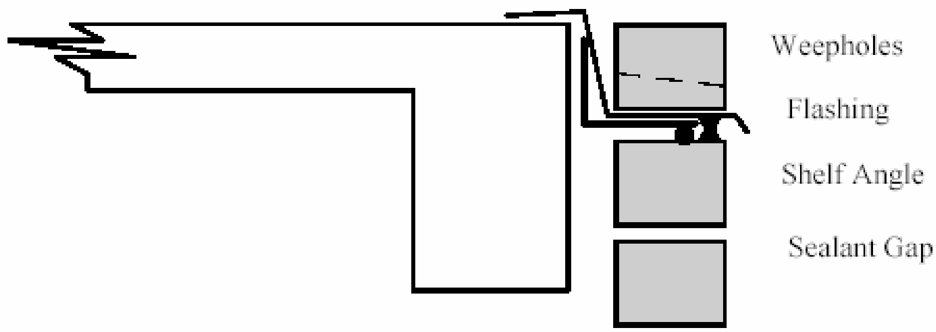
- Reinforcement
- Connectors (galvanized or stainless steel)

- ties connect a masonry wall to another wall
- anchors connect a masonry wall to a frame
- fasteners connect something else to a masonry wall
- Sealants
- expansion joints (brick masonry)
- control joints (concrete masonry)
- construction joints
- Flashing
- Coatings
- paints
- water-repellent coatings
- Vapor Barriers

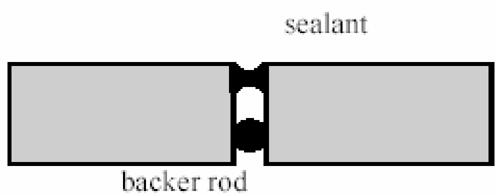
Movement Joints

Three basic kinds of movement joints are used in masonry construction: expansion joints, control joints, and construction joints.

1) Expansion joints are used in clay masonry to accommodate expansion.

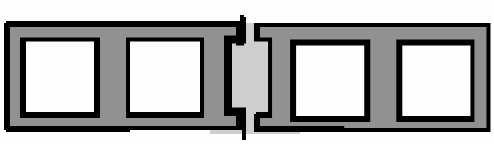


Horizontally Oriented Expansion Joint under Shelf Angle



Vertically Oriented Expansion Joint

2) Control joints are used in concrete masonry to conceal cracking due to shrinkage.



Shrinkage Control Joint

3) Construction joints are placed between different sections of a structure.

FIRE RESISTANCE OF MASONRY

2003 *International Building Code*, Chapters 3, 5-9

Objectives of Design for Fire Resistance

The objective of design for fire resistance is to limit loss of life to occupants, fire-fighters, owners, neighbors, and the public, and to limit loss of property to the building in question, and to adjacent buildings. These objectives are usually but not always consistent. For example, about one-third of all deaths in fires occur as a result of inhaling toxic fumes from combustible finishes. Control of such toxic fumes is important for limiting loss of life, but irrelevant for limiting loss of property.

In the United States: 8,000 deaths per year are due to building fires (4 per 100,000 population) 80,000 injuries per year due to building fires (40 per 100,000 population). In general, fire resistance depends on non-combustibility of materials, and also on compartmentation (dividing the building into closed sub-volumes so that fire can be enclosed).

STEPS IN DESIGN FOR FIRE RESISTANCE

In the US, design for fire resistance involves computing, directly and indirectly, the fire loading in the building under consideration and the possible consequences of fire in that building. Based on that combination of loading and consequences of fire, the required resistance to the effects of fire (measured in terms of hours of fire resistance) is specified, and the building components are prescribed accordingly. For purposes of this course, fire resistance is carried out according to the provisions of the 2003 *International Building Code* (2003 IBC).

1) Classify Building according to Occupancy and Use:
2) Classify Building according to Type of Construction:
3) Establish Building's Allowable Height and Area, Based on the Use and Occupancy Classification and the Type of Construction
4) Establish Each Building Component's Required Fire Resistance in Hours, Based on the Occupancy and Material Classification
5) Establish Fire-Rating Requirements for Exterior Walls based on Fire Separation Distance
6) Establish Maximum Area of Exterior Wall Openings
7) Verify that Each Building Components Fire Resistance in Hours Equals or Exceeds the Required Fire Resistance in Hours

DURABILITY OF MASONRY

Masonry's durability can be described in terms of its resistance to the following failure sequence: cracking; leaking; staining; spalling; and collapse. Durability of masonry depends on the following factors:

1.0 Destructive agents
- 1.1 Climatological
- 1.1.1 Water
- 1.1.2 Heat
- 1.1.3 Air

1.2 Geological
1.3 Biological
- 1.3.1 Bacteria
- 1.3.2 Plants
- 1.3.3 Animals

1.4 Chemical
- 1.4.1 Constituents
- 1.4.2 Contaminants
- 1.4.3 Pollutants

2.0 Mechanics of Destruction
- 2.1 Crystallization
  - 2.1.1 Water
  - 2.1.2 Salts
  - 2.2 Hydration
- 2.3 Oxidation (iron oxide occupies twice as much volume as the original steel)
- 2.4 Osmosis
- 2.5 Deformation
  - 2.5.1 Thermal
  - 2.5.2 Moisture
  - 2.5.3 Wet-dry
  - 2.5.4 Freezing
  - 2.5.5 Elastic
  - 2.5.6 Creep
  - 2.5.7 Shrinkage
  - 2.5.8 Differential Movement

3.0 Materials: Manufacturers and Distributors
- 3.1 Physical Properties of Materials
  - 3.1.1 Porosity
  - 3.1.2 Strength
  - 3.1.3 Test Methods
  - 3.1.4 Specifications
- 3.2 Product Quality Control

4.0 Design: Architects and Engineers
- 4.1 Exposure Severity
  - 4.1.1 Climate and Environment
  - 4.1.2 Position of Structure
  - 4.1.3 Position in Structure
- 4.2 Control of Water Penetration Resistance
- 4.3 Control of Cracking

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Components of Masonry, Bonding Patterns and Fire Resistance and Durability

5.0 Construction: Contractors and Inspectors
- 5.1 Construction Quality Control
  - 5.1.1 Water Penetration Resistance
  - 5.1.2 Expansion and Control Joints
  - 5.1.3 Wall Anchorage

6.0 Maintenance: Owner
- 6.1 Periodic Inspection
  - 6.1.1 Sealant Joints
  - 6.1.2 Cracks
  - 6.1.3 Leaks
  - 6.1.4 Stains
- 6.2 Maintenance Techniques
  - 6.2.1 Control of Water Penetration
  - 6.2.2 Control of Cracking