CHAPTER 1 - Concrete Masonry as a Building Material

1.1 INTRODUCTION

The beginning of the twenty-first century has heralded an explosion of technological advancement in all fields of human endeavor. The rapid gains in information technology, computer science, and engineering have led to similar advances in the design and construction of buildings. The size and sophistication of testing equipment has improved significantly, enabling us to better understand the behavior of structural components under various kinds of loads. New building materials and structural systems continue to emerge and challenge existing views of how buildings can be constructed.

Things are no different with the design of concrete masonry structures. Structural analysis and design techniques continue to improve as engineers take advantage of increased computer capabilities and better understanding of masonry's response to external and internal loads. There is also a renewed emphasis on sustainable building design and other approaches that maximize the use of scarce building resources.

It is important that the new ideas and materials are introduced to students and practicing engineers. Professors of structural engineering have the opportunity to introduce these new concepts and ideas in the classroom. Professional structural engineers have the opportunity to learn from published literature, and seminars or company in-house learning programs. This document has been developed to provide structural engineers, students, and professors with a basic introduction to reinforced concrete masonry design in earthquake country. It is hoped that it will specifically help meet the needs of professors and professionals seeking to teach or learn reinforced concrete masonry design. The material has been arranged for:

- Participants in a one day Reinforced Masonry Design Seminar of the type sponsored by the Concrete Masonry Association of California and Nevada.
- Professors who wish to present an introduction to the design of reinforced concrete masonry structures in approximately 15 lecture hours.
- Professional engineers who wish to present an in-house professional seminar in approximately 8 or 9 lecture hours.

The material could also be expanded for use in a 40-hour course such as exists at many colleges and universities.

1.2 MASONRY, TMS 402, ASCE 7 AND THE IBC

Masonry has been used as a construction material for centuries. However, the catastrophic damage that still sometimes occurs to masonry structures during severe earthquakes around the world illustrates the unfortunate results of constructing masonry buildings without a solid technical understanding of the material. Even in the western United States, which has a history of large and damaging earthquakes, the danger posed by unreinforced masonry buildings still exists. Fortunately, building officials, structural engineers and owners are actively working to mitigate the hazard that these buildings pose.

After the 1933 Long Beach Earthquake, a new era began for masonry buildings in California. For the first time, buildings constructed with masonry were required to satisfy new seismic design criteria that required the use of reinforcing steel. With the development of these criteria, structural engineers started down a successful path of developing masonry design standards that have been continuously updated. Because of these efforts, a technical basis for design of masonry now exists and reinforced concrete masonry is a safe and economical building material.

For several years, the Uniform Building Code (UBC)[1.1] was the design standard that formed the basis for structural design of masonry in the western United States. The requirements for masonry design, which were influenced heavily by the SEAOC Blue Book,[1.2] are contained in Chapter 21 of the last edition of the UBC, which was published in 1997. In 2000, attempts to unify building design criteria across the United States culminated in the first edition of the International Building Code (IBC).[1.3] As with the UBC, the IBC is updated on a three-year cycle and the latest edition was published in 2012. The IBC is now generally accepted as the consensus design document across the nation and has been adopted widely.

The 2012 IBC utilizes nationally approved design standards as the bedrock of the design criteria. It references ASCE 7-10, "Minimum Design Loads for Buildings and other Structures,"[1.4] which is published by the American Society of Civil Engineers (ASCE), for determining structural design loads. For masonry design, the IBC references the standard developed by the Masonry Standards Joint Committee (MSJC). The MSJC is a joint committee comprised of members of The Masonry Society (TMS), the American Concrete Institute (ACI) and the Structural Engineering Institute (SEI) of the ASCE. The three organizations, with TMS as the lead agency, cooperate to maintain a standard that can only be changed through a professional consensus approval process. In this process, structural engineers, researchers and manufacturers may propose code changes to the committee, who then reject or accept the proposed code change based on the technical merit of each proposal. This allows all segments of the masonry industry to be active participants in the development of the masonry design criteria. There are two parts (with companion commentaries) to the MSJC standard:

- Building Code Requirements for Masonry Structures (TMS 402-11/ACI 530-11/ASCE 5-11)[1.5]
- Specification for Masonry Structures (TMS 602-11/ACI 530.1-11/ASCE 6-11) [1.6]

It should be noted that while the IBC refers to the ASCE 7 and MSJC standards extensively, it does not adopt the standards in their entirety. The IBC generally adopts national design standards with a few amendments where necessary to maintain the philosophy and format of the main code. In addition, building departments may make further modifications to address local building practices or loading conditions. It is important that structural engineers investigate the specific requirements of the jurisdiction for each building being designed. Since the IBC is the basis of the building codes used by most engineers, this book is based primarily on the IBC, which in turn references ASCE 7 and MSJC standards. Commonly adopted modifications and amendments to the standards will be discussed where appropriate.

The MSJC standards TMS 402 and TMS 602 are typically published every three years. Each new edition provides updated design, construction, and quality control criteria that are based on available analytical and experimental studies. Strength design criteria for masonry were introduced for the first time in the 2002 edition of TMS 402. The requirements were grounded on the strength design provisions that were first introduced in the 1985 edition of the Uniform Building Code, as a result of efforts spearheaded by CMACN since 1979. It represented the culmination of considerable effort by the Structural Engineers Association of California (SEAOC) Seismology Committee, General Design Committees and their associated subcommittees, the Structural Engineers Association of Washington (SEAW) and the Masonry Industry Code Committee (MICC). The work also depended heavily on the research funded by the National Science Foundation (NSF) and the masonry industry through the Technical Coordinating Committee for Masonry Research (TCCMAR) program[1.7].

The 2011 edition of TMS 402 presents the designer with the choice of designing masonry buildings using either allowable stress design or strength design. Either choice should be viewed within the professionally acceptable bounds of engineering decision making. The code contains eight chapters and one appendix as outlined in Table 1.2.1. In the 2008 edition of the standard, provisions for the design of Autoclaved Aerated Concrete (AAC) masonry were included in Appendix A. In TMS 402-11 provisions for AAC masonry have been moved to Chapter 8 and Appendix A has been left blank in order to redirect users to Chapter 8 for AAC Masonry provisions.

This document will concentrate on the first three chapters of TMS 402-11, which address the type of concrete masonry construction most commonly used in the western United States.

Table 1.2.1
Contents of TMS 402

Chapter 1	General Design Requirements for Masonry
Chapter 2	Allowable Stress Design of Masonry
Chapter 3	Strength Design of Masonry
Chapter 4	Prestressed Masonry
Chapter 5	Empirical Design of Masonry
Chapter 6	Veneer
Chapter 7	Glass Unit Masonry
Chapter 8	Strength Design of Autoclaved Aerated Concrete (AAC) Masonry
Appendix B	Design of Masonry Infill

1.3 THE MASONRY BUILDING

While concrete masonry is often used to construct mid-rise buildings, its most widespread use is in the construction of one to three-story structures. In California, a walk down the major streets of most cities will indicate that many retail stores, markets and low-rise office buildings are constructed with reinforced masonry or contain masonry structural elements or systems. The use of masonry for such buildings typically manifests itself in one of two forms. Either the building is structurally simple with walls that have a few large regular openings (for example, a department or grocery store) or it contains several regular openings that create piers and short-span beams.

Figures 1.3.1 to 1.3.3 show plan and elevation views of three common types of masonry buildings. In the first type of masonry building shown in Figure 1.3.1, the vertical roof load is supported by interior steel columns, and thus the walls support relatively low axial loads. These walls typically have few openings and a length that exceeds their height. Consequently, shear deformations dominate response and the walls have limited ductility. However, since the walls are long, they typically have sufficient capacity to resist lateral loads and the earthquake or wind induced stresses are low. Thus, the ductility demands are low and the walls will perform adequately. On the other hand, the heights of the walls in the mid-rise concrete masonry building shown in Figure 1.3.2 are large compared to their lengths. Such walls respond to lateral loads primarily in a flexural manner and possess excellent ductility if they are detailed correctly. Figure 1.3.3 shows a typical concrete masonry office or laboratory building. The walls in this type of building have several openings that break them into piers. Structural designs of various masonry components of the three types of buildings described above are presented in Appendix A of this document.

Figure 1.3.4 shows an isometric view of the various building components for a masonry building. The figure shows how the concrete masonry units are constructed to form beams, lintels, pilasters and walls. The next section will discuss the various materials that make up the masonry system – masonry units, mortar, grout and reinforcing steel.

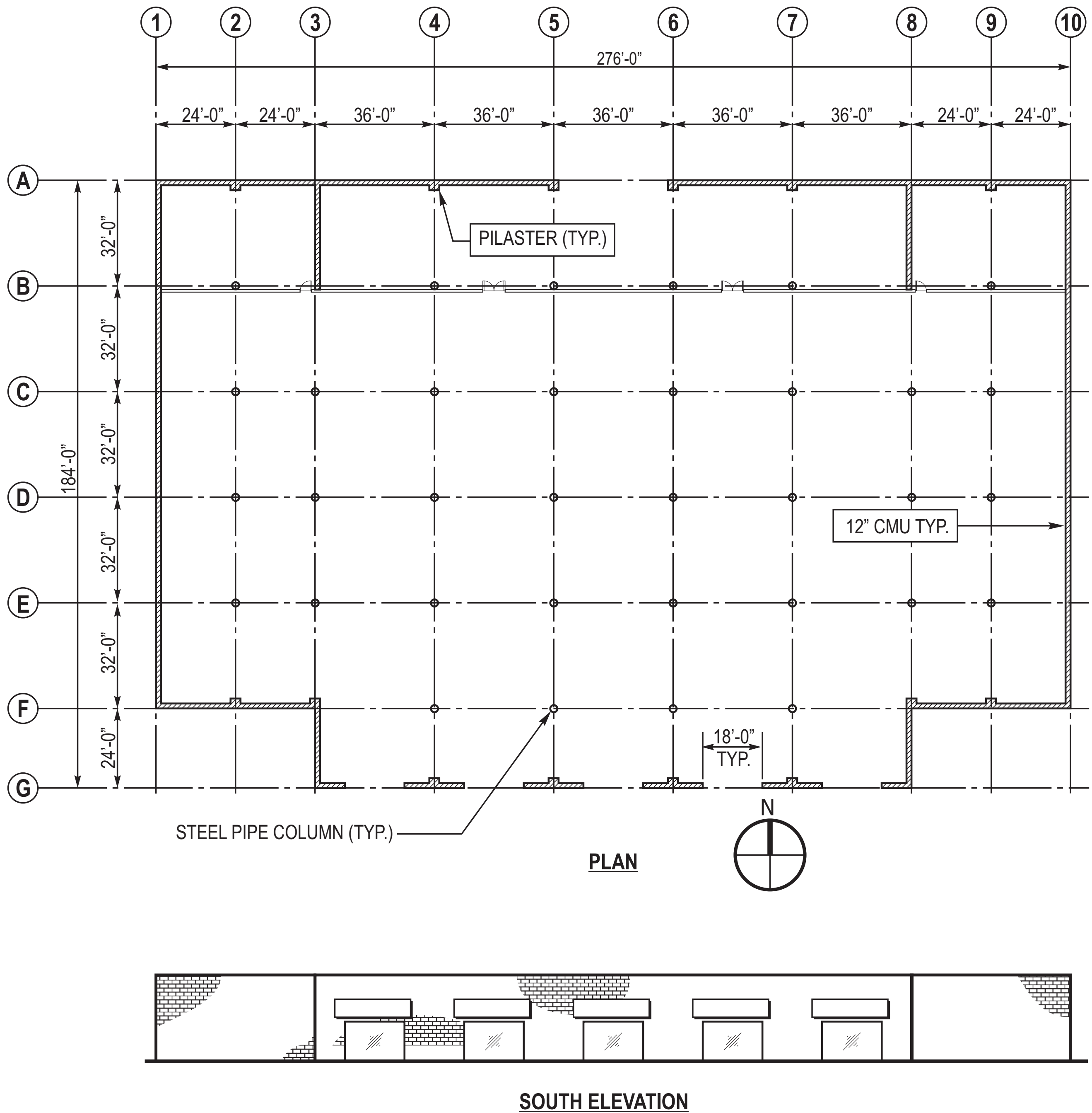
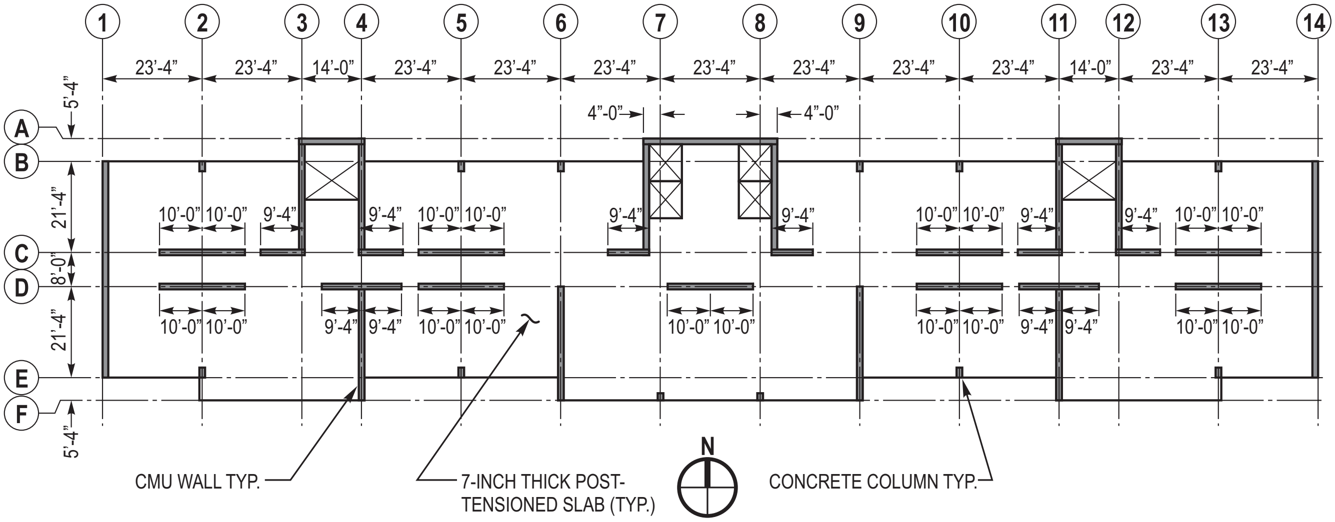
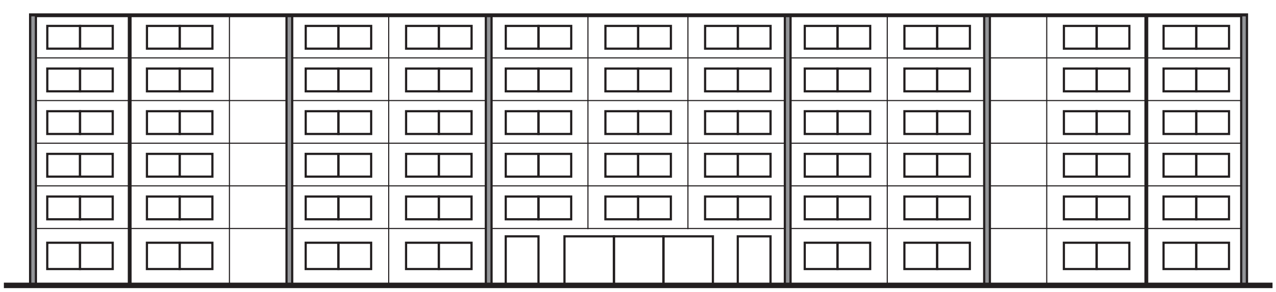


FIGURE 1.3.1 Typical One-Story Concrete Masonry Warehouse Building

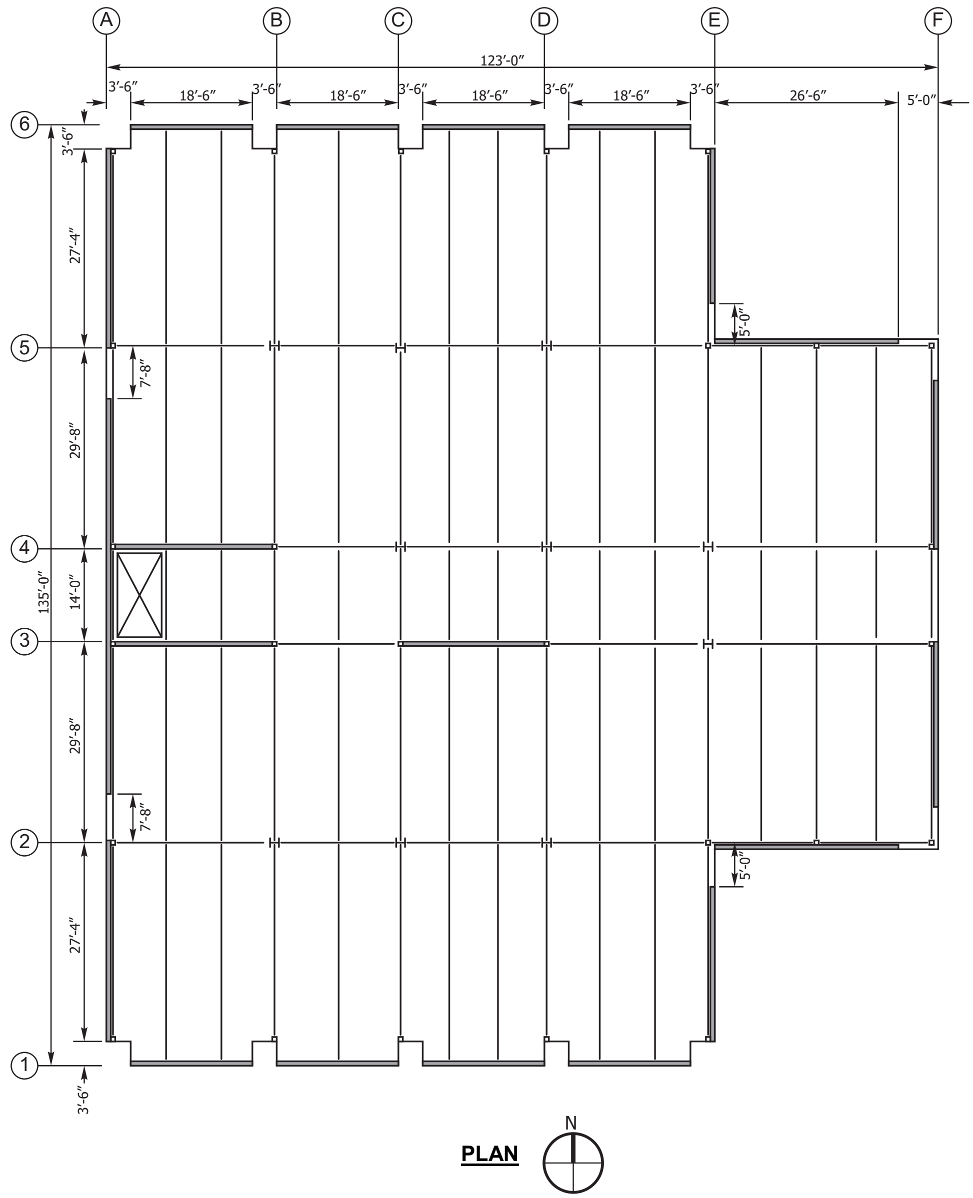


PLAN

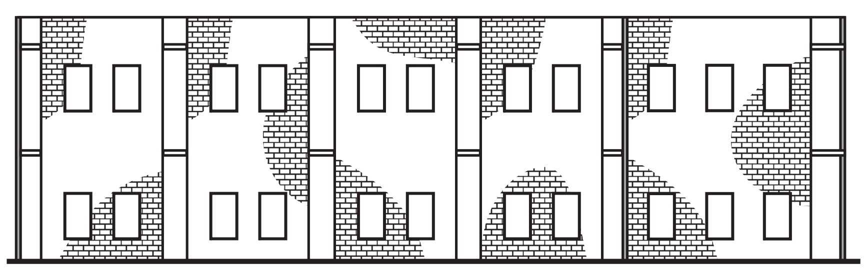


SOUTH ELEVATION

FIGURE 1.3.2 Typical Concrete Masonry Mid-Rise Building



PLAN



SOUTH ELEVATION

FIGURE 1.3.3 Typical Concrete Masonry Office/Laboratory Building

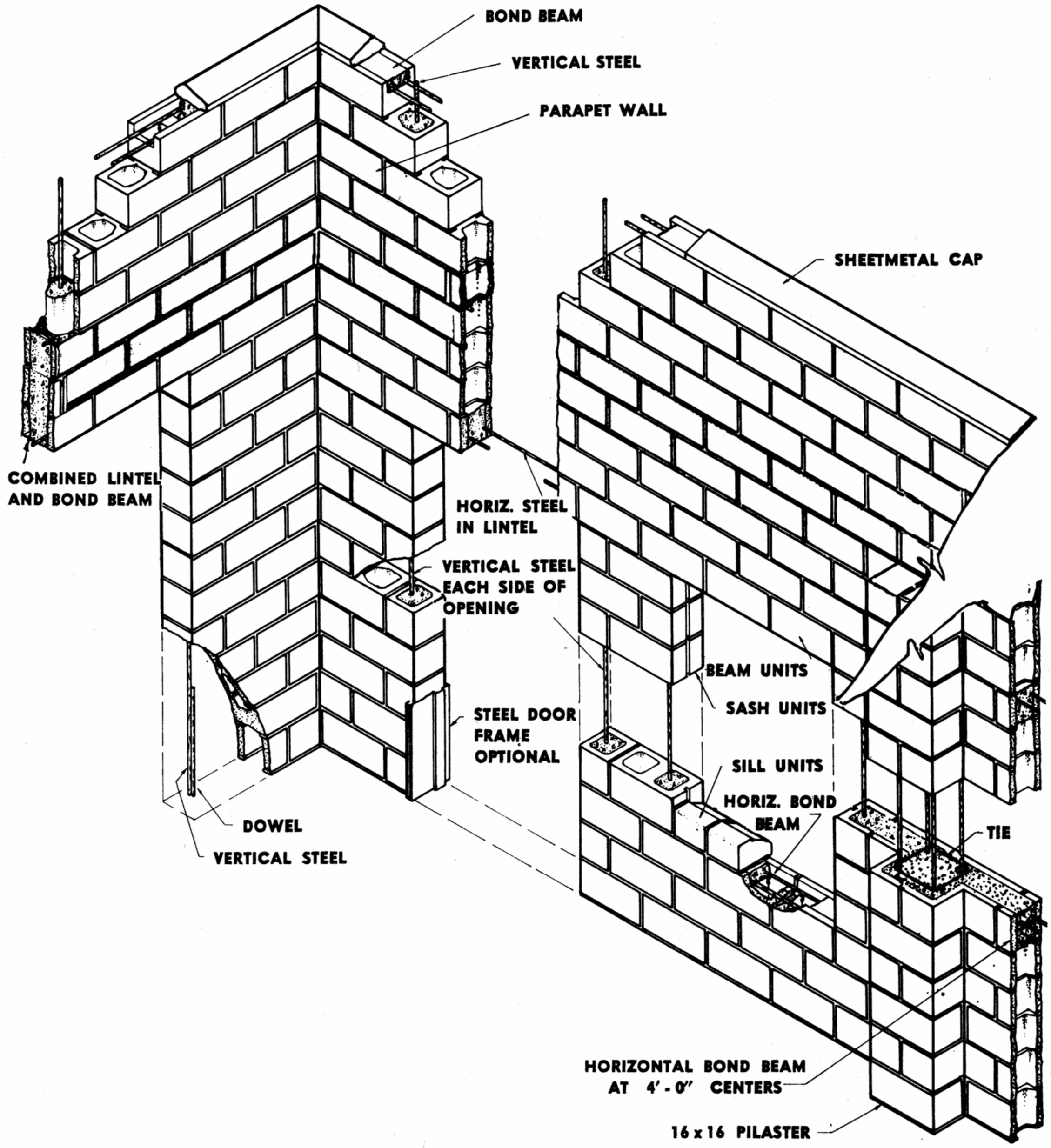


FIGURE 1.3.4 Masonry Building Components

1.4 MATERIALS

1.4.1 Concrete Masonry Units

Concrete masonry units may be either solid concrete bricks or ***hollow masonry units***. Hollow masonry units are defined as units with a net cross-sectional area in every plane parallel to the bearing surface that is less than 75 percent of the gross cross-sectional area in the same plane. Most of the latest reinforced concrete masonry research has been conducted on hollow unit masonry.

As with many other materials, the American Society of Testing and Materials (ASTM) provides specifications that govern the manufacture of masonry units. The primary ASTM document for concrete masonry units is ASTM C90, "Standard Specification for Load Bearing Concrete Masonry Units"[1.8]. The document provides requirements for materials, dimensions, finish and appearance of masonry units.

The modular nature of masonry construction requires that concrete masonry units are produced with standardized dimensions. The industry standard is to specify dimensions with the unit's width (or thickness) first, the unit's height next and unit's length last. For example, an 8×8×16 concrete masonry unit is 8 inches wide, 8 inches high and 16 inches long. These are called the ***nominal dimensions*** of the unit. The actual dimension of masonry units are typically $^3/_8$ inch smaller than the nominal dimensions to allow for mortar joints. This means that an 8×8×16 unit is actually $7^5/_8$ inches wide, $7^5/_8$ inches high and $15^5/_8$ inches long. These are called the ***specified standard dimensions.*** Figure 1.4.1 shows typical dimensions of 8-inch units. As can be seen from the figure, various kinds of units can be used depending where the unit is placed in the structure. Table 1.4.1 provides the minimum thickness of face shells and webs of concrete masonry units with different nominal widths. The dimensions of a wide range of units are provided in Appendix C.

As shown in Figure 1.4.1, concrete masonry units are produced with different shapes within the modular dimension to serve various purposes in a structure. ***Bond beam units*** are hollow units with portions depressed 1¼ inches or more to permit the forming of a continuous channel for reinforcing steel and grout. ***Open end units,*** or A-blocks, are hollow units with one end closed and the opposite end open, forming two cells when laid in the wall. ***Double open end units*** are hollow units with both ends open. They are often called H-blocks. Double open end units are typically used in solid-grouted walls since they permit the grout to flow freely between units. ***Lintel units***, or U-blocks, are masonry units with a solid bottom surface and no webs. They are usually placed to form a continuous beam over openings. ***Sill units*** are solid concrete masonry units used for sills or openings. Other commonly used units include ***pilaster units***, which are used in the construction of reinforced concrete masonry pilasters and columns, ***return units*** or L-blocks that are used in the construction of corners for various wall thicknesses, and ***sash units*** which have an end slot for use in openings to receive metal window frames and pre-molded expansion joint material.

ASTM C90 classifies concrete masonry units into lightweight, medium weight and normal weight units based on the oven-dry density of the concrete used. In order to achieve satisfactory performance in the structure, the water absorption is limited for each of these types of units, as shown in Table 1.4.2. In addition, the linear shrinkage of units at the time of delivery to the purchaser should not be greater than 0.065%.

TABLE 1.4.1
Minimum Thickness of Face Shells and Webs

Nominal Width of Units (in)	Face Shell Thickness, t_{fs} (in)	Web Thickness, t_w (in)
3	¾	¾
6	1	1
8	$1^1/_4$	1
10	$1^3/_8$	$1^1/_8$
12 or greater	$1^1/_2$	$1^1/_8$

TABLE 1.4.2
Absorption Requirements for Masonry Units

Weight Classification (pcf)	Water Absorption, Max, lb/ft (Average of 3 Units)
Lightweight, Less than 105	18
Medium Weight, 105 to less than 125	15
Normal Weight, 125 or more	13

Concrete masonry units can also be classified based on appearance. ***Precision units***, which are the most commonly used concrete masonry units, have a relatively smooth surface. No overall dimension in a precision unit should differ from the specified standard dimensions by more than $^1/_8$ inch. ***Split face units*** are also quite popular for the rough textured surface that is obtained by splitting a large unit crosswise or lengthwise to obtain two units. ***Slumped units*** or ***slumpstone*** units are obtained by applying compression to units before they are completely cured to obtain the distinctive convex shape.

Hollow concrete masonry units are manufactured in highly automated concrete block plants. At the completion of the manufacturing process, units are selected at random and tested to ensure that the strength and other characteristics of the units are consistent with the design requirements. ASTM standard C140[1.9] provides requirements for the sampling and testing of units. A more detailed description on these sampling and testing methods is provided in Section 2.3.

The strength of hollow concrete masonry units varies primarily with the cement content and aggregate content that are used. Typically, most units used in California and Nevada for building construction have a minimum compressive strength of 1900 psi when measured on the net area of the unit. However, with certain mix designs, it is possible to produce units with strengths greater than 4000 psi in controlled conditions. Students and professionals are generally welcome to visit these plants. If such a visit is desired, arrangements can be made through CMACN.

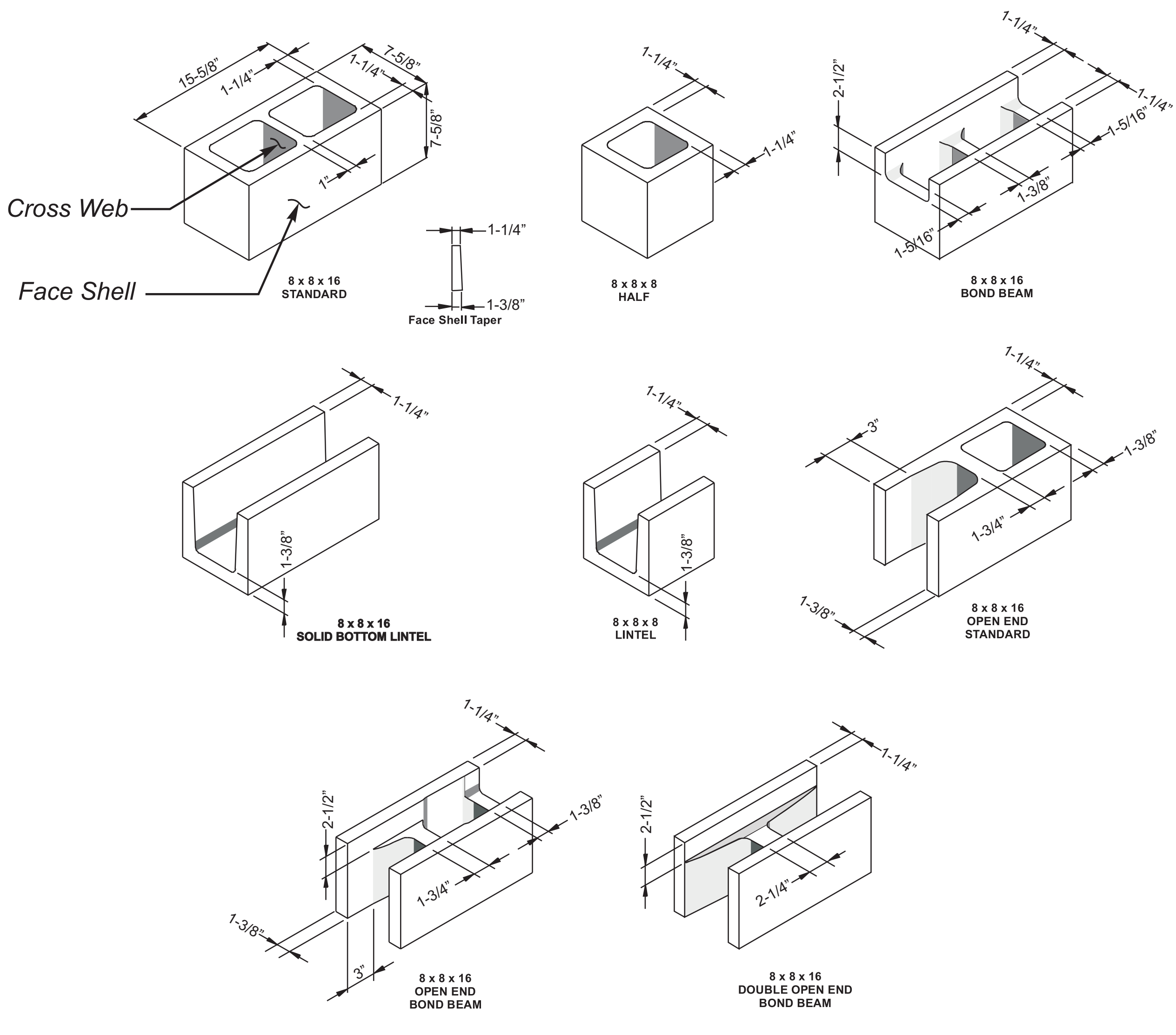


FIGURE 1.4.1 Typical Concrete Masonry Units

1.4.2 Mortar

Mortar consists of cementitious materials and fine aggregates (sand) that are mixed with water to form a workable paste. The mortar is placed between the joints of the masonry units to bond the individual masonry units into a single composite element. Mortar also serves as a seating material that enables the masonry units to be aligned precisely by accommodating the variances in the units and correcting minor inaccuracies in placement.

The cementitious materials used in mortar may be either Portland cement, masonry cement or mortar cement. Hydrated lime or lime putty is also used (only with Portland cement) to improve the workability of the mortar. In the western United States, Portland cement and lime are the most commonly used cementitious materials in mortar. Mortar cement is not commonly used and masonry cement, which is a proprietary blend of Portland cement and plasticizers, is not typically permitted for structural masonry.

ASTM C270[1.10] provides specifications for mortar used in masonry construction. The standard categorizes mortar in two ways:

1. The mortar can be specified by the volumetric proportions of the constituent materials.
2. The mortar can be specified by its properties, which are obtained by testing under laboratory conditions.

Tables 1.4.3 and 1.4.4 show the requirements for specifying mortar by property and proportion, respectively. Mortar is classified as Type M, S, N or O depending on the proportion of materials or its performance. The most commonly used mortar for the western United States is Type S mortar, which has proportions by volume of 1:¼ - ½:3 for Portland cement, lime, and sand, respectively. This will provide a workable mix, which has sufficient strength to achieve typically required masonry strengths, and will exhibit good bond characteristics when mixed and placed by experienced masons.

Each of the principal components of mortar makes a definite contribution to its performance. Portland cement contributes to the mortar's strength, durability and bond strength. Lime, which sets only on contact with air, improves workability by helping the mortar retain water and elasticity. Sand acts as a filler and also contributes to the strength of the mix. Sand also greatly decreases the setting time and drying shrinkage of mortar and thereby reduces cracking. Sand also enables the unset mortar to retain its shape and thickness under several courses of concrete masonry units. Water is the mixing agent that gives workability and hydrates the cement.

Workability is the property of mortar characterized by a smooth, plastic consistency that makes it easy to spread. Workable mortar holds the weight of concrete blocks when placed and helps with alignment. Mortar adheres to vertical masonry surfaces and readily squeezes out of mortar joints. Water affects the workability of a mix by influencing the consistency. A well-graded, smooth aggregate improves workability.

Admixtures may be used to improve certain mortar characteristics. Air entrainment admixtures add to workability through the action of miniature air bubbles, which function like ball bearings in the mixture. In very hot, dry weather an admixture may be added to retard the setting time to allow a little more time before the mortar must be retempered. On the other hand, admixtures may be added to mortar in cold climates to accelerate the hydration of the cement in the mortar.

TABLE 1.4.3 Mortar Property Specification Requirements

Mortar	Type	Average Compressive Strength at 28 Days (psi)	Minimum Water Retention (%)	Maximum Air Content (%)	Aggregate ratio (measured in damp loose condition)
Cement-lime	M	2500	75	12	Not less than 2¼ and not more than 3½ times the sum of the separate volumes of cementitious materials
	S	1800	75	12	
	N	750	75	14	
	O	350	75	14	
Mortar cement	M	2500	75	12	
	S	1800	75	12	
	N	750	75	14	
	O	350	75	14	
Masonry cement	M	2500	75	18	
	S	1800	75	18	
	N	750	75	20	
	O	350	75	20	

TABLE 1.4.4 Mortar Proportion Specification Requirements

Mortar	Type	Proportions by Volume (Cementitious materials)								Aggregate Measured in a Damp, Loose Condition
		Portland Cement or Blended Cement	Mortar Cement			Masonry Cement			Hydrated Lime or Lime Putty	
			M	S	N	M	S	N		
Cement-lime	M	1	-	-	-	-	-	-	¼	Not less than 2¼ and not more than 3 times the sum of the separate volumes of cementitious materials
	S	1	-	-	-	-	-	-	over ¼ to ½	
	N	1	-	-	-	-	-	-	over ½ to 1¼	
	O	1	-	-	-	-	-	-	over 1¼ to 2½	
Mortar Cement	M	1	-	-	1	-	-	-	-	
	M	-	1	-	-	-	-	-	-	
	S	½	-	-	1	-	-	-	-	
	S	-	-	1	-	-	-	-	-	
	N	-	-	-	1	-	-	-	-	
	O	-		-	1	-	-	-		
Masonry Cement	M	1	-	-	-	-	-	1	-	
	M	-	-	-	-	1	-	-	-	
	S	½	-	-	-	-	-	1	-	
	S	-	-	-	-	-	1	-	-	
	N	-	-	-	-	-	-	1	-	
	O	-	-	-	-	-	-	1	-	

1.4.3 Grout

Grout is a mixture of cementitious material, aggregate, and enough water to cause the mixture to flow readily, without segregation, into cells or cavities in the concrete masonry units. In reinforced concrete masonry wall construction, grout is always placed in wall spaces containing steel reinforcement. The grout bonds to the masonry units and steel so that they act together to resist imposed loads. In some reinforced load-bearing masonry walls, all cells, including those without reinforcement, are grouted to further increase the strength of the wall.

ASTM C476[1.11] provides requirements for grout in masonry construction. The specification identifies two types of grout – ***fine grout*** and ***coarse grout***, depending on the size of aggregate used. Fine grout is typically used where the grout space is small, and consists primarily of 1 part Portland cement and $2^{1}/_{4}$ to 3 parts of sand by volume. Course aggregate contains the same materials as fine aggregate but also includes 1 to 2 parts of pea gravel. Both types of grout are required to contain enough water to have slump of 8 to 11 inches.

Admixtures can also be used to improve the properties of grout. Various admixtures can be used to decrease the shrinkage of the grout as it hardens, improve the slump without additional water, reduce the amount of cement required, or to improve grout performance in cold or hot climates. However, admixtures must be used with care since they can sometimes diminish certain grout characteristics while improving others. For this reason, admixtures are not typically accepted unless specifically approved by the building official.

Typically, grout is required to have a minimum compressive strength of 2000 psi. Higher values can be used to obtain a larger overall masonry compressive strength. Lower values are permitted if the required masonry strength is achieved by prism testing. Standard methods for sampling and testing of grout are given in ASTM C1019[1.12]. The grout must be tested under conditions that are representative of the conditions in the structure.

1.4.4 Reinforcement

Reinforcing steel used in concrete masonry construction consists of deformed bars and joint reinforcement. Deformed bars typically comply with either ASTM A615[1.13] or ASTM A706[1.14]. ASTM A615 provides standard specifications for plain carbon-steel reinforcing bars that are most commonly used. ASTM A706 covers low alloy steel bars, which are used when more restrictive mechanical properties and chemical composition are required to enhance weldability and provide closer control of tensile properties. Deformed bars used in concrete masonry range from a minimum size of #3 to a maximum size of #9 for strength design and #11 for allowable stress design. The bars are usually Grade 60 with a minimum yield strength of 60,000 psi although Grade 40 bars with a minimum yield strength of 40,000 psi are sometimes used for #3 and #4 bars.

Identification marks are rolled into the surface of bars using either the line system or number system, as shown in

Figures 1.4.2 and 1.4.3. Marks are used to denote the producer's mill designation, bar size, and type of steel. For Grade 60 bars, additional marks indicate yield strength. (Grade 40 bars show only three marks with no grade mark). Grade mark lines are smaller and between the two main longitudinal ribs which are on opposite sides of all bars manufactured in the United States.

Joint reinforcement, which is placed horizontally in the mortar joints between the units, is of the ladder type or truss type as shown in Figure 1.4.4. The use of ladder type joint reinforcement is preferred in several jurisdictions because truss type reinforcement can interfere with the placement of vertical reinforcing steel and the flow of grout in cells.

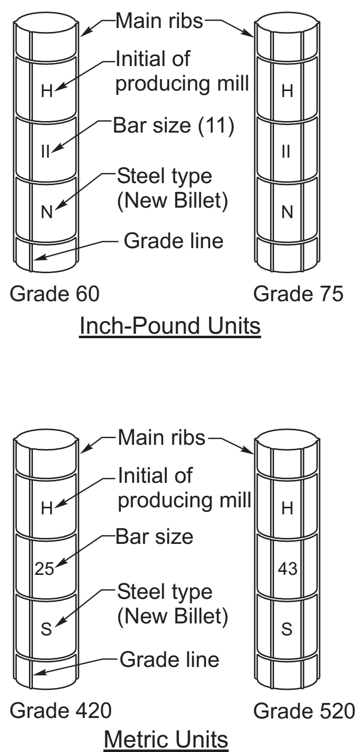


FIGURE 1.4.2 Reinforcing Bar Identification Using the Line System

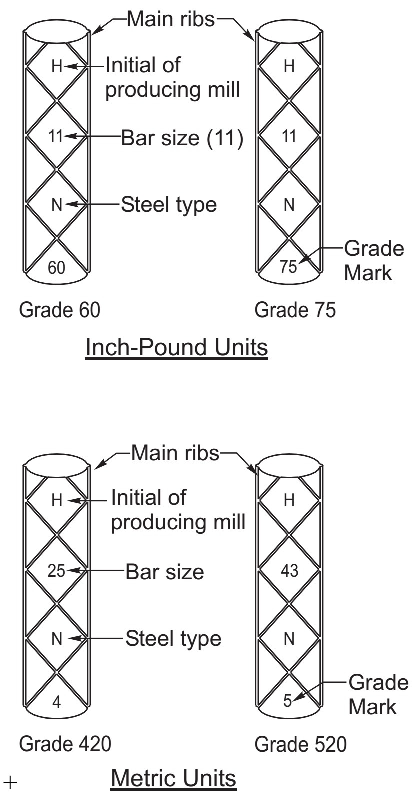
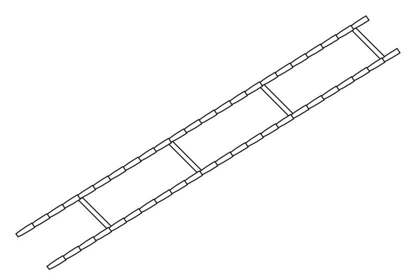
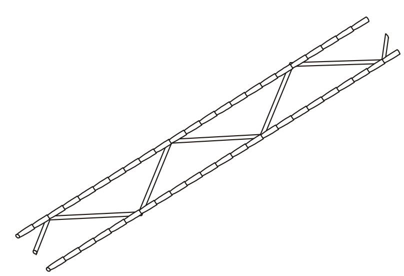


FIGURE 1.4.3 Reinforcing Bar Identification Using the Number System



(a) Ladder Type Joint Reinforcing



(b) Truss Type Joint Reinforcing

FIGURE 1.4.4 Joint Reinforcement

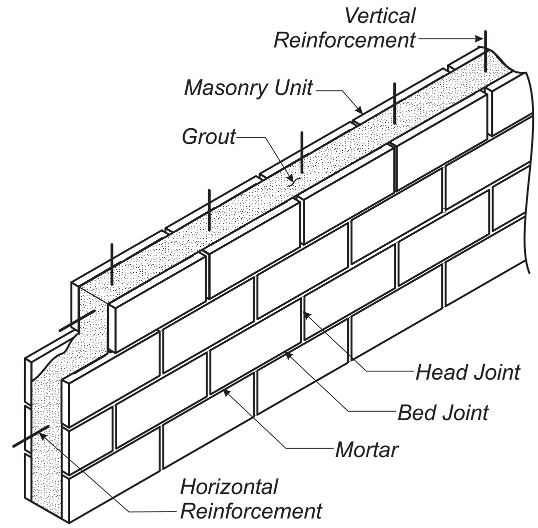
1.5 THE CONCRETE MASONRY SYSTEM

The four components of reinforced concrete masonry (units, mortar, grout and reinforcement) are combined to form the complete concrete masonry system, as shown in Figure 1.5.1. The fundamental element is the concrete masonry unit. Mortar is typically placed horizontally above and below the face shells in the bed joints and vertically in the head joints. Sometimes, head joint mortar is eliminated by the use of interlocking head joints. Figure 1.5.2 shows different ways of applying mortar. The correct type of mortar joint must be used for masonry that is exposed to weather to ensure adequate moisture penetration and durability.

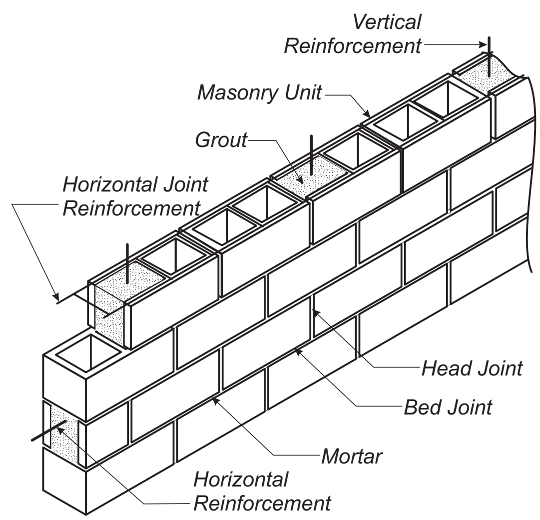
When concrete masonry units are placed, they are often laid in ***running bond***. TMS 402 code defines running bond as the placement of masonry units such that head joints in successive courses are horizontally offset by at least one-quarter of the unit length. Units that are placed with no overlap at all have been traditionally defined as being laid in ***stack bond***. TMS 402 does not make this distinction and classifies masonry as being placed in running bond or not in running bond. When units are not laid in running bond, additional requirements need to be satisfied. Figures 1.5.3 and 1.5.4 show examples of units laid in running bond and stack bond, respectively.

Vertical reinforcing steel bars are placed in the cells of the masonry units. Thus, masonry laid in running bond must be arranged so that the cells are aligned vertically to permit the vertical bars to continue through the wall without being obstructed. Vertical reinforcement can be placed as one layer of reinforcement in the center of the wall, as shown in the Figure 1.5.1(a) or as two layers of reinforcement in the cells of 12-inch, 10-inch and, sometimes, 8-inch thick masonry. Horizontal reinforcement is placed either as deformed bars in bond beam units or as joint reinforcement embedded in mortar in the bed joints with a cover of at least $^{1}/_{2}$-inch, or $^{5}/_{8}$-inch when the masonry is exposed to weather or earth. The diameter of longitudinal reinforcement should not be greater than one half the least clear dimension of the cell or bond beam in which the bar is placed. In addition, the vertical reinforcement should not exceed 4 percent of the area of the grout space. When there are lap splices, the maximum area of vertical reinforcement should not exceed 8 percent of the cell area.

To allow for adequate encasement of reinforcing steel by grout, the reinforcement must be placed with a clear distance from any surface of masonry units of not less than $^{1}/_{4}$-inch for fine grout and $^{1}/_{2}$-inch for coarse grout. Tolerances for placement of reinforcing steel in shear walls and flexural elements are shown in Table 1.5.1. Vertical bars must be placed within 2 inches of the required location along the length of a wall. These tolerances should be taken into account when performing calculations to determine the capacity of masonry elements.



(a) Fully Grouted Wall



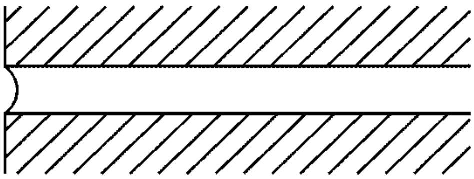
(b) Partially Grouted Wall

FIGURE 1.5.1 Typical Concrete Masonry Walls

TABLE 1.5.1
Tolerances for Placement of Steel in Walls and Flexural Elements

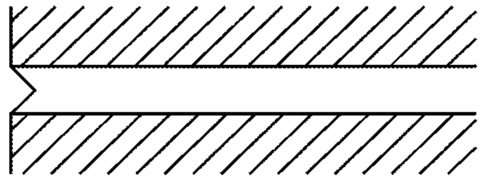
Effective Depth, *d* (in)	Tolerance (in)
$d \le 8$ in	± $^{1}/_{2}$ in
8 in < d ≤ 24 in	± 1 in
d > 24 in	± $1^{1}/_{4}$ in

RECOMMENDED JOINTS
Best Weather Protection



Concave Joint

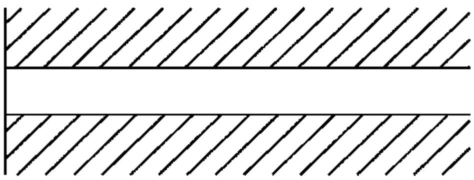
Most common joint used. Tooling works the mortar tight into the joint to produce a good weather joint. Pattern is emphasized and small irregularities in laying are concealed.



V Joint

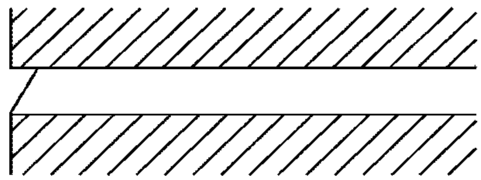
Tooling works the mortar tight and provides a good weather joint. Used to emphasize joints and conceal small irregularities in laying.

ACCEPTABLE JOINTS
Weather Joint Possible with Proper Tooling



Flush Joint

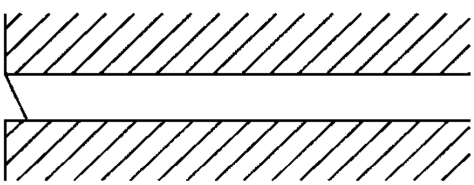
Use where wall is to be plastered or where it is desired to hide joints under paint. Special care is required to make joint weatherproof. Mortar joints must be compressed to assure intimate contact with the block.



Weathered Joint

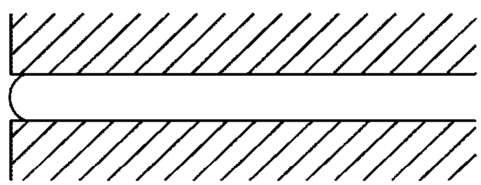
Use to emphasize horizontal joints. Acceptable weather joint with proper tooling. Care must be taken to properly paint the overhang ledge of the unit at each mortar joint.

NON-WEATHER JOINTS
For Special Effects Only



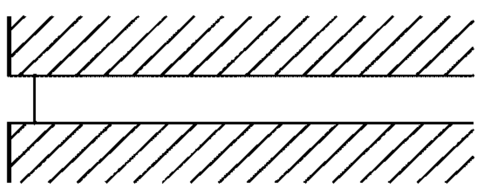
Struck Joint

Use to emphasize horizontal joints, poor weather joint - not recommended.



Beaded Joint

Special effect, poor exterior weather joint because of exposed ledge - not recommended.



Raked Joint

Strongly emphasized joints. Poor weather joint - not recommended.

FIGURE 1.5.2 Types of Mortar Joints

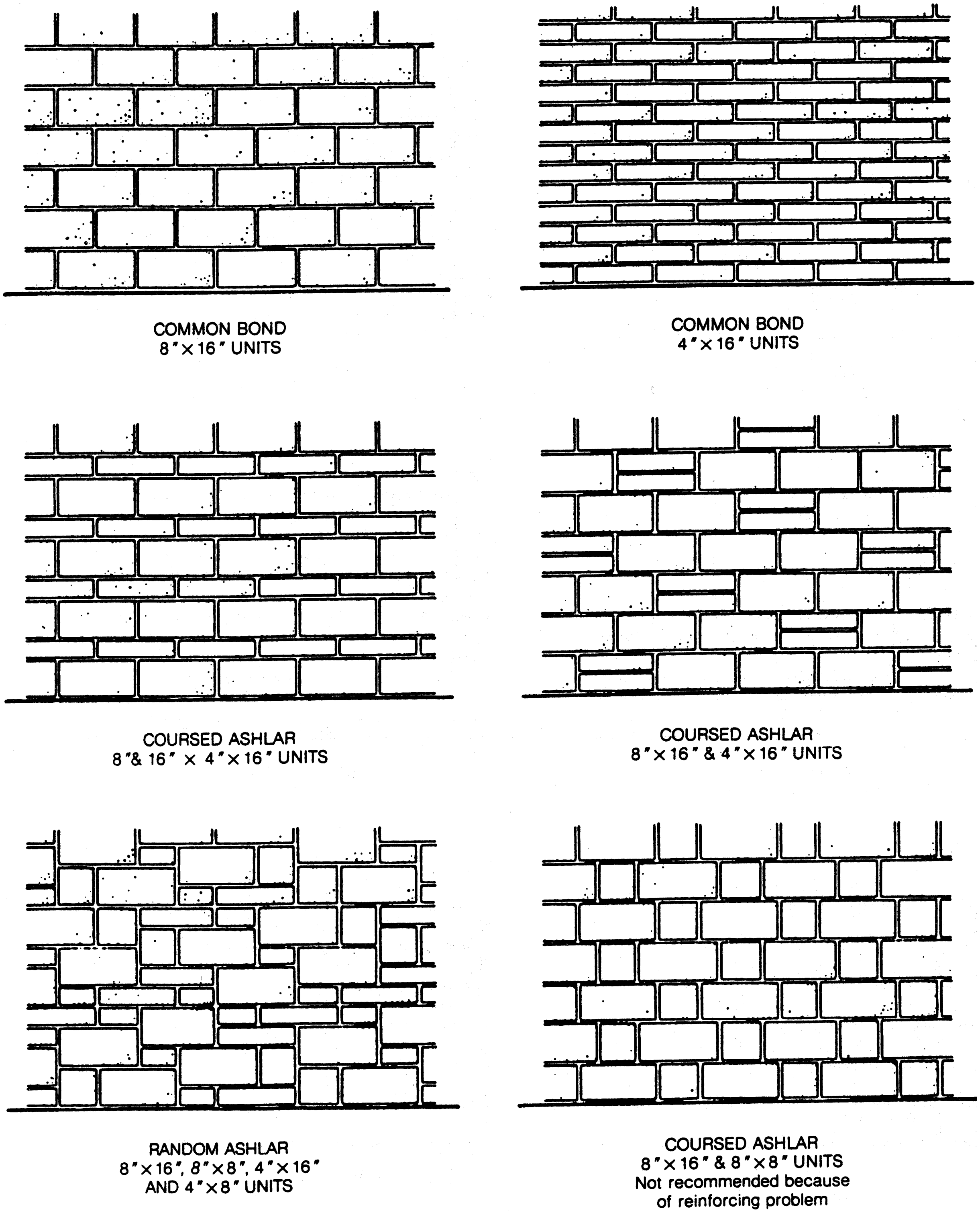


FIGURE 1.5.3 Examples of Running Bond Construction

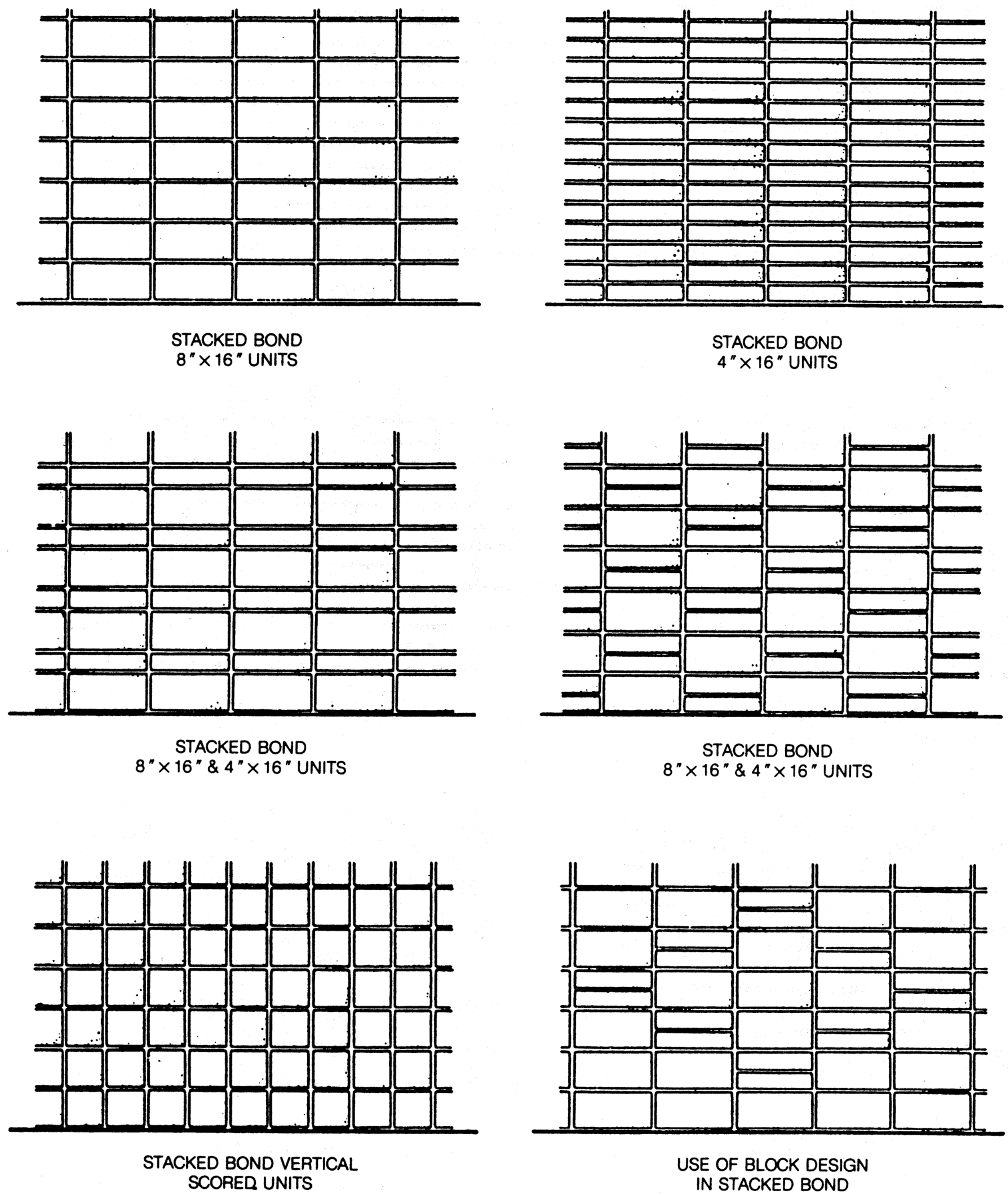


FIGURE 1.5.3 Examples of Stack Bond Construction (Other than Running Bond)

Grouting of the cells is the final operation in the construction of a masonry wall segment. The grout binds the masonry units together and when there is steel in the cell, creates a bond to the steel so that the reinforced masonry acts as a composite unit.

Vibration, or consolidation, of the grout is a very important part of quality concrete masonry construction. Some of the water in the grout, which allows the grout to flow easily, is quickly absorbed by the concrete masonry units. The removal of the moisture causes the grout to shrink and pull away from the reinforcing bars. Consolidation brings the grout back into contact with the steel and assures a good bond between the grout, the unit, and the reinforcing steel. Voids that are formed during grouting can also be removed by proper vibration.

For grout pours of 12 inches or less, consolidation may be achieved by puddling with a puddle stick. However when the grout pour height exceeds 12 inches, a mechanical vibrator must be used and consolidation must be repeated (reconsolidation) after initial water loss and settlement has occurred. Strict control is necessary to prevent excess vibration of the grout, which can cause the material to segregate.

A type of grout that may soon be in common use if the current research continues to be successful is ***self-consolidating grout***, which can be placed without consolidation. Self-consolidating grout contains new superplasticizing admixtures that prevent stickiness between particles without leading to aggregate segregation. The superplasticizers also keep the water within the grout mix longer and prevent the stiffening that occurs when concrete masonry units absorb most of the water before the grout fills the voids. Self-consolidating grout has the potential to significantly reduce the time and cost of labor required to construct concrete masonry without affecting quality of the final product. However, it is important that the grout fills tight spaces completely and that there is no loss in strength or serviceability because the grout is not consolidated. The current research[1.15] is focused on developing procedures to ensure that self-consolidating grout can be used efficiently without compromising the performance of concrete masonry structures.

In ***partially grouted*** masonry, grout is poured only in selected cells, typically those with reinforcement. In ***fully grouted*** masonry, grout is poured in all masonry cells to form a solid element with no voids. Most masonry construction in California and Nevada is fully grouted. This is because earthquake load demands often require that masonry contains closely spaced vertical reinforcement and deformed bars as horizontal reinforcement. Since it is impractical to partially grout cells that are so closely spaced and create the block-outs needed to selectively grout cells horizontally, fully grouted masonry is usually more cost effective. However, in some instances when the loads are relatively low, such as fence walls, horizontal joint reinforcement may be used in lieu of deformed bars and only cells with vertical reinforcement need to be grouted.

A ***grout pour*** is the total height of masonry that is grouted prior to the erection of additional masonry. A ***grout lift*** is the height of grout that is placed in a single, continuous operation before consolidation. Thus, a grout pour consists of one or more grout lifts. Section 3.5 of TMS 602 (Specification for Masonry Structures) limits the grout lift to a height of 5 feet 4 inches unless the masonry has cured for 4 hours, the grout slump is maintained between 10 and 11 inches and no intermediate reinforced bond beams are placed between the top and bottom of the pour height. If all the above conditions are met, grout may be placed in lifts of up to 12 feet 8 inches. If the first two conditions are satisfied but there is a an intermediate bond beam between the top and the bottom of the pour height, the grout lift height is limited to the bottom of the lowest bond beam that is more than 5 feet 4 inches above the bottom of the lift, but should not exceed 12 feet 8 inches.

There are two grout placement procedures in general use:

1. ***Low-lift grouting***, where additional courses of masonry are only constructed after each lift of about 5 feet 4 inches is cured.
2. ***High-lift grouting***, where masonry units are constructed up to a story height (or higher) and grout is placed in lifts of about 5 feet 4 inches in height.

Low-lift grouting is the simplest method of grouting concrete masonry and is common on smaller projects. Low-lift grouting requires no special concrete block shapes or equipment. The wall is built to scaffold height, or to a bond-beam course and steel reinforcing bars are then placed in the designated vertical cells and in horizontal bond beam units. The cells are then grouted, with the level of the grout being stopped at least 1½ inches from the top of the masonry. The steel reinforcing should project above the top course a minimum of the code-specified lap splice length to ensure a proper lap splice with the steel added for the next grout lift.

In high-lift grouting, the grouting operation is postponed until the concrete masonry wall is laid up to a full story height or higher. This method of construction can be quite effective and economical since the mason can lay blocks continuously without stopping for the grout to be poured. The term high lift grouting is a misnomer since it is the *pour* that exceeds 5 feet 4 inches and not the lift.

A major concern in high-lift grouting is the prevention of blowouts, which may occur when the hydrostatic pressure of the wet grout causes the wall to move or even collapse laterally. Blowouts can be prevented by adequately bracing the walls or by grouting in small lifts. Grout can also be placed in 2 to 4 feet lifts with 15 to 60 minute waiting periods between lifts. This waiting period allows some of the excess moisture to be absorbed into the concrete block units and reduces the hydrostatic pressure.

In addition to ensuring that blowouts do not occur, care must be taken when high lift grouting is used to ensure that no debris such as mortar droppings or loose aggregate is wedged in the grout space. Section 3.2 of TMS 602 requires that cleanouts be provided at the bottom course of masonry when the grout pour exceeds 5 feet 4 inches. The cleanouts must be openings of sufficient size to permit removal of debris and must have a minimum size of 3-inches. For fully grouted masonry, the cleanouts should be spaced no more than 32 inches apart. For partially grouted masonry, it is recommended that the cleanouts are spaced at every cell containing vertical reinforcement but no more than 48 inches apart. After cleaning and removal of debris, the cleanouts must be closed and braced to ensure that grout does not leak during the grouting process.

The maximum height of the grout pour that can be used depends on whether fine or coarse grout is used and on the size of the space into which the grout is being poured. Table 1.5.2 provides the TMS 402 grout space requirements for various pour heights. If the minimum dimensions of the grout space exceed 5 to 6 inches, the cavities can be filled with conventional concrete with a maximum aggregate size of 1 inch.

TABLE 1.5.2[1.5]
Grout Space Requirements

Grout Type	Maximum Grout Pour Height	Minimum Width of Grout Space (in)	Minimum Grout Space Dimensions for Grouting Cells of Hollow Units (in × in)
Fine	1’-0”	$^3/_4$	$1^1/_2 \times 2$
Fine	5’-4”	2	2 × 3
Fine	12’-8”	$2^1/_2$	$2^1/_2 \times 3$
Fine	24’-0”	3	3 × 3
Coarse	1’-0”	$1^1/_2$	$1^1/_2 \times 3$
Coarse	5’-4”	2	$2^1/_2 \times 3$
Coarse	12’-8”	$2^1/_2$	3 × 3
Coarse	24’-0”	3	3 × 4

1.6 PROPERTIES OF CONCRETE MASONRY

Various physical characteristics are used in the design of concrete masonry. These properties must be calculated to determine how the masonry will perform when subjected to various loading and weather conditions. TMS 402 provides values for several concrete masonry properties, which are to be used unless different values are determined by testing. These criteria provide coefficients that define the strength and stiffness of the concrete masonry system as well as the effects of temperature, moisture and creep.

1.6.1 Specified Compressive Strength

The specified compressive strength, f'_m, is probably the most important property of concrete masonry used by structural engineers. It is the minimum compressive strength, expressed as a force per unit of net cross-sectional area that is required by construction documents. The compressive strength is based on the properties of the composite masonry assemblage and is determined by the combined characteristics of the masonry units, mortar and grout. There are two methods of determining the compressive strength of masonry:

1. ***Unit strength method*** in which the masonry compressive strength is calculated from the separate strengths of the concrete masonry units and grout, and the type of mortar used.
2. ***Prism test method*** in which the masonry compressive strength is determined from a test of a representative sample (prisms) of the masonry.

Engineers should specify that either the unit strength method or the prism test method may to be used to verify the masonry compressive strength. This gives the masonry contractor the flexibility to achieve the required masonry strength using the most efficient method with the available materials.

When the unit strength method is used, the masonry compressive strength is determined based on the strength of the units and the type of mortar as shown in Table 1.6.1. The compressive strength of the grout must be at least equal to f'_m but not less than 2000 psi.

TABLE 1.6.1
Compressive Strength of Masonry Using the Unit Strength Method

Net Area Compressive Strength of Concrete Masonry Units (psi)		Net Area Compressive Strength of Masonry (psi)
Type M or S Mortar	Type N Mortar	
1250	1300	1000
1900	2150	1500
2800	3050	2000
3750	4050	2500
4800	5250	3000

Prism tests to determine the compressive strength of masonry are performed as specified in ASTM C1314.[1.16] Section 2.3 of the next chapter provides more detail on how prism tests are conducted.

1.6.2 Modulus of Elasticity

The modulus of elasticity in compression, E_m determines the stiffness of the masonry that is used for calculating deflections due to flexural or compressive effects. TMS 402 provides the following equation for calculating the modulus of elasticity of concrete masonry:

$$E_m = 900 f'_m \qquad (1.6.1)$$

As an alternative, the modulus of elasticity may be determined based on the chord modulus of elasticity taken between 0.05 and 0.33 of the masonry compressive strength obtained from prism tests. Figure 1.6.1 illustrates how the chord modulus is obtained. Measurements below 0.05 f'_m are ignored because of the initial stiffening that occurs due to imperfect bearing of the test set-up, and because most instruments are inaccurate at extremely low strains. The modulus of rigidity, or shear modulus is used to calculate the shear deformation of concrete masonry elements and is given by:

$$E_v = 0.4E_m \qquad (1.6.2)$$

For steel reinforcement, the modulus of elasticity is given by:

$$E_s = 29,000,000\,\text{psi} \qquad (1.6.3)$$

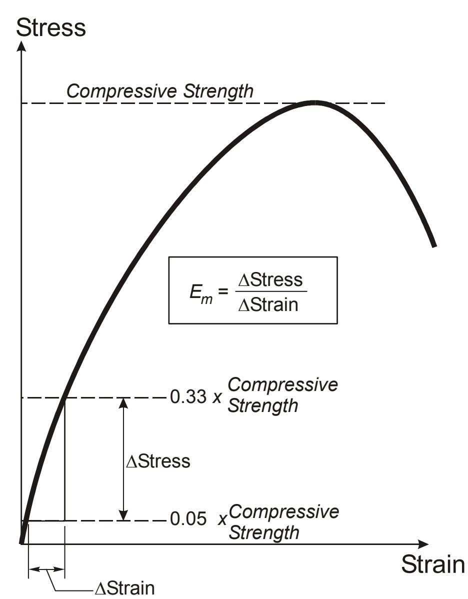


FIGURE 1.6.1 Determination of Masonry Elastic Modulus in Compression

1.6.3 Modulus of Rupture

The modulus of rupture, f_r is the stress at which load-induced cracking occurs when masonry is subjected to flexural loads. The modulus of rupture depends primarily on the quality of the mortar and the amount of grout used. Table 1.6.2 provides values of f_r for masonry elements. Linear interpolation between fully grouted and ungrouted masonry based on percentage of grouting may be used to determine values for partially grouted masonry with tensile stresses normal to bed joints.

For grouted masonry not in running bond, tension parallel to the bed joints should be assumed to be resisted by only the horizontal grout section. This is because masonry not in running bond is assumed to have no flexural bond across mortared head joints. The modulus of rupture of grout is assumed to be 250 psi.

The values shown in Table 1.6.2 are for use with strength design. Values for determining the cracking stress of masonry when using allowable stress design procedures are provided in TMS 402.

TABLE 1.6.2[1.5]
Modulus of Rupture for Out-of-Plane Bending

Direction of Flexural Tensile Stress	Masonry Type	Mortar Types			
		Portland Cement/Lime or Mortar Cement		Masonry Cement or Air-Entrained Portland Cement/Lime	
		M or S	N	M or S	N
Normal to Bed Joints in Running Bond or Not in Running Bond	Solid Units	100	75	60	38
	Ungrouted Hollow Units	63	48	38	23
	Fully Grouted Hollow Units	163	158	153	145
Parallel to Bed Joints in Running Bond	Solid Units	200	150	120	75
	Ungrouted and Partially Grouted Hollow Units	125	95	75	48
	Fully Grouted Hollow Units	200	150	120	75
Parallel to Bed Joints Not in Running Bond	Continuous Grout Section Parallel to Bed Joints	250	250	250	250
	Other	0	0	0	0

1.6.4 Reinforcement Strength

The reinforcement strength used in design shall be equal to the specified yield strength of the reinforcement, f_y. The value of f_y shall not exceed 60 ksi and the actual yield strength should not exceed 1.3 times f_y. Note that ASTM A706 specifies an upper limit on the yield strength of reinforcing bars. Therefore, bars satisfying ASTM A706 will meet the requirement of a maximum strength of $1.3f_y$. If ASTM A615 or ASTM A996 bars are used however, the project specifications should include requirements for submittal of tests demonstrating that the yield stress does not exceed 1.3 times f_y.

1.6.5 Thermal Expansion Coefficient

The thermal expansion coefficient, k_t determines the changes in concrete masonry volume with variations in temperature. TMS 402 provides the following equation for the thermal expansion modulus:

$$k_t = 4\times10^{-6}\ \text{in/in/}^\circ\text{F} \qquad (1.6.4)$$

1.6.6 Shrinkage Coefficient

The shrinkage of concrete masonry due to moisture loss after construction depends on the materials used. Earlier editions of TMS 402 provided a shrinkage coefficient for moisture controlled masonry units, which were assumed to shrink less because less moisture was lost over time. However, the current edition of ASTM C90 has eliminated the designation of Type I and Type II units, which represented moisture controlled and non-moisture controlled units, respectively. This is because of the uncertainty associated with utilizing moisture content alone to determine masonry shrinkage. In addition, it was not always possible to store moisture controlled units at the construction site in a manner that maintains the required moisture content. TMS 402-11 therefore provides one shrinkage coefficient, which is identical to the prior value for non moisture-controlled units:

$$k_m = 0.5s_l \qquad (1.6.5)$$

1.6.7 Creep Coefficient

The creep coefficient determines the long-term deformation of masonry under sustained loads. In TMS 402, the creep coefficient for concrete masonry is given by:

$$k_c = 2.5\times10^{-7}\ \text{, per psi} \qquad (1.6.6)$$

1.7 REFERENCES

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