



# TECHNICAL NOTES on Brick Construction

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## Technical Notes 3 - Overview of Building Code Requirements for Masonry Structures (ACI 530-02/ASCE 5-02/TMS 402-02) and Specification for Masonry Structures (ACI 530.1-02/ASCE 6-02/TMS 602-02)

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**Abstract:** This *Technical Notes* provides a review of the national masonry design standard, ACI 530/ASCE 5/TMS 402, and its accompanying masonry specification, ACI 530.1/ASCE 6/TMS 602. New provisions and revisions of existing standards for masonry design are emphasized. Subjects discussed pertaining to the design standard are: allowable stress and strength design of unreinforced and reinforced masonry, prestressed masonry, empirical design, glass block masonry, masonry veneer, quality assurance, and seismic provisions. Items addressed for the masonry specification are: requirements checklist and submittals, masonry quality assurance and inspection requirements, reinforcement and metal accessories, erection tolerances, construction procedures and grouting requirements.

**Key Words:** adhered veneer, allowable stress design, anchored veneer, building code, design standard, empirical design, inspection, prestressed masonry, specification, strength design.

### INTRODUCTION

The American Concrete Institute (ACI), American Society of Civil Engineers (ASCE), and The Masonry Society (TMS) promulgate a national consensus standard for the structural design of masonry elements and a standard specification for masonry construction. These standards are titled the *Building Code Requirements for Masonry Structures* (ACI 530/ASCE 5/TMS 402) and the *Specification for Masonry Structures* (ACI 530.1/ASCE 6/TMS 602). They were developed to consolidate and advance existing standards for the design and construction of masonry.

This *Technical Notes*, the first in a series, discusses various sections of the *Building Code Requirements for Masonry Structures* and the *Specification for Masonry Structures* in brief detail. Emphasis is placed on the new requirements in the 2002 edition of the standards. Changes from prior masonry standards dealing with the design of brick masonry structures are also presented. Other *Technical Notes* in this series provide material and section properties of brick masonry members and more extensive discussion of the requirements of these standards. For more information about the requirements of these standards and examples of their application, the reader is referred to the *Masonry Designer's Guide* (MDG). The MDG is published by The Masonry Society and contains an extensive number of design examples that illustrate the proper application of the MSJC Code and Specification requirements.

In this *Technical Notes*, the *Building Code Requirements for Masonry Structures* and the *Specification for Masonry Structures* are referred to as the Masonry Standards Joint Committee (MSJC) Code and Specification, respectively. The pertinent section and article numbers from the MSJC Code and Specification, are stated in parentheses following the discussion of particular topics for quick reference.

### HISTORY AND DEVELOPMENT

The development of this single masonry standard for the design and construction industry began in 1977. At that time, there were several design standards for masonry. These standards did not have consistent requirements. It was difficult for engineers and architects to select the appropriate design criteria for

masonry elements. Concerned individuals representing masonry materials and the design profession saw the need for a single, national consensus standard for the design and construction of all types of masonry.

In 1977, ACI and ASCE agreed to jointly develop a consensus standard for masonry design with the support of the masonry industry. The MSJC was formed with a balanced membership of building officials, contractors, university professors, consultants, material producers and designers who are members of ACI or ASCE. The Masonry Society joined as a sponsoring organization in 1991. Currently, the MSJC is comprised of over eighty regular (voting) and forty associate members. The MSJC Code and Specification are available from each of the sponsoring organizations or from the Brick Industry Association.

Changes to the MSJC Code and Specification are written, balloted and approved within the MSJC. A review by the sponsoring organizations' technical activity committees follows. In order to obtain a national consensus, the approved draft undergoes a public review. Approval by the MSJC of the first edition of the MSJC Code and Specification occurred in June 1986. Public review began in 1988 with the final approval of the 1988 MSJC Code and Specification in August 1989.

Commentaries for the MSJC Code and Specification were also developed. These documents provide background information on the design and specification provisions. Considerations of the MSJC members in determining requirements and references to research papers and articles are included in the commentaries for further information.

The MSJC Code, Specification and Commentaries are revised on a three- or four-year cycle. The first revision was issued in 1992. Most of the changes were editorial in nature or clarified intent or omissions. In 1995 new chapters on glass unit masonry and anchored masonry veneers were added, and the MSJC Specification was reformatted. Metric conversions were added throughout the standards in accordance with the metrication policy of ASCE in addition to an index of key words. The 1999 edition includes a number of significant changes. The MSJC Code and its Commentary were reformatted. A chapter on prestressed masonry, a section on adhered veneer and a quality assurance program were added. Other changes in the MSJC Code and Specification include new design values for elastic moduli and masonry compressive strength and the inclusion of mortar cement. In the 2002 edition there were significant changes to the seismic design provisions, with prescriptive requirements for specific shear wall types. A chapter on strength design was added. Other minor changes are documented in this *Technical Notes*.

## **Building Code Acceptance**

The MSJC Code is to be adopted by a model building code and, subsequently, by a local jurisdiction. State and local building code committees are encouraged to adopt the model building codes which include the MSJC Code for the design of masonry. With adoption of the MSJC Code, the Specification is automatically adopted because the MSJC Code requires that materials and construction comply with the MSJC Specification. The local jurisdiction has the responsibility for enforcement and compliance of masonry construction to the MSJC Specification once it is adopted.

Two of the previous model building code organizations, the Standard Building Code Congress International (SBCCI) and the Building Officials and Code Administrators (BOCA), chose to include the MSJC Code in their documents. This adoption by reference began in 1988 and 1989, respectively. The International Council of Building Officials (ICBO) chose to maintain masonry design criteria within the *Uniform Building Code* itself, rather than adopting the MSJC standards by reference. However, many of the masonry design and construction requirements of the *Uniform Building Code* have been changed over the last several years to be consistent with the requirements of the MSJC Code and Specification.

The International Code Council (ICC) was formed by the three existing code organizations (SBCCI), (BOCA) and (ICBO) with the charge to produce a single set of codes, referred to as the I-codes. Two I-codes that are important to the brick industry are the International Building Code (IBC) and International Residential Code (IRC). The National Fire Protection Association (NFPA) is also developing another building code called NFPA 5000. The I-codes and NFPA 5000 reference the 2002 MSJC Code.

## Benefits

The MSJC Code and Specification have had positive results; the design and construction community has become more confident with their use. Designers have one national standard that covers nearly all types of masonry construction. Architects are able to prepare and submit complete, concise specifications more easily. Contractors have more consistent and better quality specifications for projects. Owners obtain more uniform quality of masonry. Other benefits presented by the MSJC Code and Specification are:

1. Nearly all forms of masonry are covered, including unreinforced, reinforced and prestressed masonry, glass unit masonry, and adhered and anchored veneer masonry.
2. Requirements for all masonry materials are covered, including clay and shale brick, concrete block, stone, glass unit, mortar, grout and metal accessories.
3. Differences in material properties are recognized and quantified.
4. The same rational design procedures are utilized for clay and concrete masonry.
5. Responsibilities and duties of the owner, designer, testing agency, and contractor are clearly established.
6. Quality assurance and inspection requirements are included.
7. Design, materials and testing are the decision of the architect or engineer.
8. Contract administration is easier.

Since the introduction of the MSJC standards in 1988, there has been a shift in the masonry design and construction communities. Designers and contractors use the MSJC Code and Specification with more frequency. Indicative of this growth, the MSJC Code is now a required reference for the Professional Engineer's Principles and Practice examination. The MSJC Specification has placed greater demands on the masonry contractor with the use of masonry as a structural material. Many requirements are performance related, which may require more site inspection for verification of compliance. These demands are advantageous and vital to the development of confidence that the masonry strengths assumed by the designer are met by the constructed masonry.

## THE MSJC CODE (ACI 530/ASCE 5/TMS 402)

The MSJC Code is the basis for masonry design by the architect or engineer. The provisions of the MSJC Code will dictate the size and shape of masonry walls, beams, pilasters and columns. Further, it influences the masonry materials the designer will require in the project specification. It consists of seven chapters, which are listed below.

Chapter 1 - General Design Requirements for Masonry

Chapter 2 - Allowable Stress Design

Chapter 3 - Strength Design of Masonry (New Chapter)

Chapter 4 - Prestressed Masonry

Chapter 5 - Empirical Design of Masonry

Chapter 6 - Veneer

Chapter 7 - Glass Unit Masonry

Some relevant sections of the codes are discussed in this *Technical Notes* and are indicated in parentheses for each of the chapters.

## Chapter 1 - General Design Requirements for Masonry

Chapter 1 contains the scope of the minimum requirements for the design of any masonry element. In this chapter, it states that the MSJC Code supplements the model building code enforced in a jurisdiction. When the MSJC Code conflicts with the local building code, the local building code governs. (1.1)

Project drawings and specifications must identify the individual responsible for their preparation. Items required by the MSJC Code must be clearly marked such as: loads used in design, specified compressive strength of masonry, reinforcement, anchors and ties with size and spacing, size and location of all structural elements, provisions for differential movement, and size and location of conduit, pipes and sleeves. Contract documents must include a quality assurance program. (1.2)

The MSJC Code permits alternative design methods from those stated in the MSJC Code. This is to recognize new applications of masonry and different structural analysis techniques. (1.3)

Chapter 1 also includes the notation and definitions contained within the MSJC Code. Capital letters are used for permitted stresses and lower case letters are used for calculated or applied stresses. (1.5) For example,  $F_a$  is the notation for the allowable compressive stress due to axial load, while  $f_a$  denotes the calculated compressive stress due to axial load. The definitions are specifically related to their meaning as used in the MSJC Code. Definitions in the MSJC Code are coordinated with those in the MSJC Specification. Definitions of terms relating to strength design of masonry and for prestressed masonry have been added. (1.6)

The following are brief summaries, highlights, of several sections within Chapter 1.

**Section 1.7 - Loading.** Service loads are used as the basis of design and are governed by the building code that adopts the MSJC Code. If a building code is not enforced in the area under consideration, then the MSJC Code requires that the load provisions of the 1993 edition of *ASCE 7 Design Loads for Buildings and Other Structures* apply to masonry structures. Allowable stresses given in the MSJC Code are based on failure stresses with a factor of safety in the range of 2 to 5. The structural system must resist wind and earthquake loads and accommodate the resulting deformations. (1.7.3) The effects of restraint of movement due to prestressing, vibrations, impact, shrinkage, expansion, temperature changes, creep, unequal settlement of supports and differential movement must also be considered in design. (1.7.4)

**Section 1.8 - Material Properties.** Material properties are included for both clay and concrete masonry. The MSJC Code and Specification was the first national masonry standard to state design coefficients for thermal expansion, moisture expansion, shrinkage and creep. For design computations, the amount of shrinkage of brick masonry is taken as zero. The moduli of elasticity,  $E_m$ , of clay and concrete masonry is no longer based on the net area compressive strength of the brick and the type of mortar used in construction.  $E_m$  is now directly related to the specified compressive strength of masonry,  $f'_m$ . For clay masonry,  $E_m$  is equal to 700 times  $f'_m$ . Alternately,  $E_m$  may be determined by the chord modulus of elasticity taken between 0.05 and 0.33 of the maximum compressive strength of each prism determined by test in accordance with Article 1.4 B.3 of the MSJC Specification. Refer to *Technical Notes 18 Series* for an extensive discussion of differential movement of brick masonry elements. (1.8.2.2)

**Section 1.9 - Section Properties.** Section properties are used to determine stress computations. Computations for stiffness, radius of gyration and flange design for intersecting walls are based on the minimum net area of the section. This is normally the mortar-bedded area. When different materials are combined in a single element, the transformed area must be used to account for differences in elastic moduli of the dissimilar materials. Radius of gyration of the section, rather than the minimum thickness, is used to determine the slenderness reduction for members in compression. (1.9)

**Section 1.10 - Deflection.** Deflection limits are imposed for beams and lintels that support unreinforced masonry. The deflection should not exceed the span length divided by 600 or 0.3 in. (7.6 mm). Deflection of the masonry member should be calculated based upon uncracked section properties. (1.10, 1.9.2)

**Section 1.11 - Stack Bond Masonry.** The MSJC Code requires that stack bond masonry be reinforced with a prescriptive amount of horizontal reinforcement. This may be placed as joint reinforcement or in bond beams spaced not more than 48 in. (1.2 m) on center vertically. (1.11)

**Section 1.12 - Details of Reinforcement.** The reinforcement detailing requirements given in this chapter are similar to those for reinforced concrete under ACI 318, Building Code Requirements for Reinforced Concrete. The maximum size of reinforcing bar permitted in masonry members, designed by the allowable stress or empirical design methods, is a No. 11 (M #36) bar. Horizontal joint reinforcement is permitted as structural reinforcement for the same design methods. Placement limits for reinforcement include minimum grout spaces between the bars and masonry units of 1/4 in. (6.4 mm) and 1/2 in. (12.7 mm) for fine and coarse grout, respectively. (1.12.2 - 1.12.3)

This section contains protection requirements for reinforcing steel. A minimum amount of masonry cover is required, depending upon the exposure conditions. Corrosion protection is required for joint reinforcement, wall ties, anchors and inserts in exterior walls. (1.12.4)

Minimum development lengths are stated for reinforcement. A 50 percent increase is recommended for epoxy coated bars. (2.1.10.2) Standard hooks, minimum bend diameters, and splice requirements are consistent with those for reinforced concrete members. (1.12.5, 1.12.6) Chapter 3 contains variations in some of these requirements when strength design is used.

**Section 1.13 - Seismic Design Requirements.** These requirements apply to the design and construction of all masonry, except glass unit masonry and masonry veneers, for all Seismic Design Categories (SDC) as defined in ASCE 7-98. Early editions of the MSJC included seismic design information as optional information in the Appendix and based the requirements on Seismic Zones. Since 1995, the seismic requirements are mandatory parts of the Code. Seismic provisions for masonry veneers are found in Chapter 6, Veneers.

Special seismic requirements in Section 1.13 are invoked by SDC. The requirements are additive for each higher SDC. For example, buildings in category D must meet all the requirements for buildings in categories A, B and C, plus the additional requirements stated in Section 1.13 for buildings in category D.

Five types of shear walls that serve as the lateral force-resisting system are described. Each has a required design method and prescriptive reinforcement requirements, see Table 1. Their use is permitted by the seismic design category applicable to the structure under design.

**TABLE 1**

**Requirement for Masonry Shear Walls Based on Shear Wall Designation**

Shear Wall Designation	Reinforcement Requirements	Permitted SDC
Empirically Designed	None	SDC A
Ordinary Plain (unreinforced)	None	SDC A and B
Detailed Plain (unreinforced)	Section 1.13.2.2.2.1 and 1.13.2.2.2.2	SDC A and B
Ordinary Reinforced	Section 1.13.2.2.2.1 and 1.13.2.2.2.2	SDC A, B, and C
Intermediate Reinforced	Section 1.13.2.2.4	SDC A, B, and C
Special Reinforced	Section 1.13.2.2.5	SDC A, B, C, D, E and F

In category A, the provisions of Chapters 2, 3, 4, or 5 of the MSJC Code apply. There is a calculated story drift limit of 0.007 times the story height. Anchorage of masonry walls must meet a minimum design force of 1000 times the effective peak velocity-related acceleration. (1.13.3)

For buildings in category B, the lateral force-resisting system must comply with the requirements of Chapter 2, 3, or 4 of the MSJC Code. It cannot be designed in accordance with the empirical requirements of Chapter 5. The lateral force-resisting system includes structural masonry members such as columns,

beams and shear walls. It does not include non-loadbearing elements, such as partition walls. (1.13.4)

Masonry buildings in category C must meet more stringent requirements. Members that are not part of the main lateral force-resisting system must be isolated so that they do not adversely affect the response of the lateral force-resisting system. Connections are strengthened and minimum amounts of reinforcement are required for shear walls and non-loadbearing masonry members in order to provide more ductility to the structure. (1.13.5) Partition walls, screen walls and other elements that are not designed to resist vertical or lateral loads other than their own weight must be isolated from receiving these loads and designed to accommodate drift.

The special seismic provisions for categories D and E are still more restrictive. Minimum reinforcement requirements are increased for all members. Type N mortar and masonry cement mortars are not permitted for the lateral force-resisting system. (1.13.6, 1.13.7)

**Section 1.14 - Quality Assurance.** This section defines a quality assurance program with different requirements based on the type of facility and method of design. Minimum tests, submittals and inspection requirements are defined for three levels of quality assurance. (1.14.1)

The quality assurance program must include procedures for reporting, review and resolution of noncompliances. (1.14.5) Qualifications for testing laboratories and for inspection agencies must also be defined. (1.14.6)

The quality assurance program requires that each wythe of masonry and the grout, if present, must meet or exceed the specified compressive strength of masonry,  $f_m$ . Compressive strength of masonry must be verified in accordance with the provisions of the MSJC Specification. (1.14.2)

**Section 1.15 - Construction.** Construction of masonry must comply with the MSJC Specification. Requirements for grouting are introduced in Section 1.15. The type of grout, either fine or coarse, determines the minimum grout space dimensions and maximum grout pour height permitted. New in the 2002 edition is the inclusion of a grout demonstration panel. The limits can be exceeded if the panel indicates that the spaces are filled and adequately consolidated. Grout must attain a minimum compressive strength of 2000 psi (13.8 MPa) at 28 days. (Table 1.15.1)

In addition, Section 1.15 contains provisions for pipes and conduits embedded in masonry elements. The effect on structural performance of the opening caused by the embedded item must be considered. Limitations on location, size, relative area and materials contained within pipes and conduit are included. (1.15.2)

## **Chapter 2 - Allowable Stress Design**

Allowable stress design (ASD) methodology has been used in masonry design for many years. The ASD provisions of the MSJC Code are the most advanced to date for masonry members and are reflective of the extensive amount of research and experience gained over the last century.

Chapter 2 of the MSJC Code states general provisions and establishes the scope of the rational design requirements. The rational design provisions are based upon a few assumptions inherent in the ASD approach, which are as follows:

1. Masonry materials are linearly elastic under service loads (materials rebound to original position when unloaded, rather than deforming permanently).
2. Stress is directly proportional to strain (applied load is directly proportional to displacement).
3. Masonry materials behave homogeneously (brick, mortar and grout behave as one element rather than separately).
4. Sections plane before bending remain plane after bending (flexural members do not warp).

Service loads are used as the basis of allowable stress design. Allowable stresses given in the MSJC Code are based on failure stresses with a factor of safety in the range of 2 to 5. Section 2.1.2 contains the loading combinations to be used for allowable stress design. For moment strength design under Section 4.5.3.3.2, factored loads shall be combined as required by the general building code. When the general

building code does not provide load combinations, structures or members shall use the most restrictive combinations of loads. (2.1.2)

The specified compressive strength of masonry,  $f'm$ , must be determined by the designer and clearly stated in the contract documents. The specified compressive strength must be verified by the contractor as required by the methods stipulated in the MSJC Specification. (2.1.3)

Anchor bolts consist of plate, headed and bent bar assemblies. Allowable loads for tension, shear and combined tension and shear are given. Provisions for minimum embedment length are provided to ensure proper transfer of load between the masonry and the anchor bolt. (2.1.4) Refer to *Technical Notes 44* for further discussion of the design of anchor bolts.

The MSJC Code requirements differentiate between multiwythe walls with respect to composite or non-composite action. Composite action requires a rigid transfer of stress between wythes so that the wythes act as a single element in resisting loads. The wythes must be bonded with a filled collar joint and metal ties or with masonry headers. Prescriptive size and spacing limitations for metal wall ties are taken from previous masonry standards. For multiwythe, composite walls, criteria for allowable shear stresses at the interface between a wythe and a collar joint have been introduced that were not included in previous masonry standards. These allowable shear stresses are: a) 5 psi (34.5 kPa) for mortared collar joints, b) 10 psi (69.0 kPa) for grouted collar joints, and c) the square root of the unit compressive strength of the header. (2.1.5.2.2)

When non-composite action occurs, each wythe is designed to individually resist the effects of imposed loads. Loads are apportioned to wythes based upon their relative stiffnesses. As with composite walls, prescriptive requirements for metal wall ties are based on past experience. (2.1.5.3) Wall ties with drips are now prohibited.

Columns are isolated vertical members whose horizontal dimension at right angles to the thickness does not exceed 3 times its thickness. Also, the member's height must be at least 3 times its thickness. The minimum dimension of a column is 8 in. (203 mm) and the maximum ratio of effective height to least nominal dimension (slenderness ratio) of a column is 25. Columns must contain a minimum of four vertical reinforcing bars and a minimum amount of lateral ties. (2.1.6)

Pilasters are thickened elements of a wall which provide resistance to lateral loads or a combination of axial and lateral loads. Design procedures consider the pilaster and wall to act integrally, provided the two are properly bonded. Vertical reinforcement that is intended to resist axial loads must be laterally tied in the same manner that is required for columns. (2.1.7)

Concentrated loads must be distributed over a prescribed length of wall. Requirements depend on bond pattern, presence of bond beams and the width of the wall. The allowable bearing stress is one-fourth of the specified compressive strength of masonry, but may be increased for smaller bearing areas. (2.1.9)

Provisions for development of reinforcement are included. (2.1.10) Bars, hooks, welded wire fabric, and splices are covered.

Section 2.2 - Unreinforced Masonry. Section 2.2 covers requirements for the design of masonry structures in which tensile stresses in masonry are taken into consideration. This is known as unreinforced (plain) masonry. Such members may, in fact, contain reinforcement for shrinkage or other reasons, but this reinforcement is neglected in the structural design process.

The allowable axial compressive stress equation uses a different slenderness reduction factor from that used in earlier masonry standards. The factor is a function of the radius of gyration of the member's cross section, rather than its thickness. Additionally, the factor of safety changed from 5 in previous masonry standards to 4 in the MSJC Code. Unlike previous masonry design standards, the MSJC Code does not place an arbitrary limit on the slenderness ratio of walls. Rather, the slenderness reduction factor becomes very small for more slender walls. An equation limiting the applied axial load to one-quarter of a modified Euler buckling load is included. The classic Euler buckling load has been modified to reflect a member with negligible tensile strength. The unity equation has been used to limit the combination of bending and axial load in masonry design for many years. (2.2.3, 2.3.3)

Variables affecting flexural tension of masonry include the plane on which the stress acts, mortar materials, unit cross-section, and presence of grout. The allowable flexural tension stresses for grouted masonry normal to bed joints were modified in the 2002 edition. (2.2.3.2)

Allowable shear stresses are based upon a parabolic shear stress distribution rather than an average shear stress distribution, as used in previous masonry standards. Consequently, allowable shear stresses are approximately 1.5 times those in previous masonry standards. Four allowable shear stresses for in-plane shear must be evaluated. No allowable shear stress values are given for out-of-plane shear, but typically these same values for in-place shear are applied. (2.2.5)

Section 2.3 - Reinforced Masonry. Section 2.3 contains requirements for the allowable stress design of masonry elements neglecting the tensile strength of masonry. This is commonly termed reinforced masonry. In this procedure, steel reinforcement is used to resist all tensile forces. Reinforcement may also be required to resist shear forces. The MSJC Code does not prescribe a minimum amount of reinforcement, except for masonry columns and for buildings in Seismic Design Categories as given in Chapter 1. The size and placement of compressive, flexural and shear reinforcement is determined by design requirements. (2.3.1) Allowable steel stresses are taken from previous masonry standards. Reinforcement used to resist compressive stresses must be laterally tied. (2.3.2.2)

When the applied shear stress exceeds the given allowable shear stress for reinforced masonry without shear reinforcement, shear reinforcement is required. For reinforced masonry containing shear reinforcement, allowable shear stresses are increased by a factor of 3.0 for flexural members and 1.5 for shear walls. To use the increased allowable shear stresses, shear reinforcement must be provided to resist 100 percent of the shear force. (2.3.5)

### **Chapter 3 - Strength Design of Masonry**

This chapter is new in the 2002 edition of the MSJC Code. This chapter was developed from research funded by the National Science Foundation and the masonry industry.

Strength design identifies the possible failure modes that the masonry element can exhibit. By performing this type of analysis the engineer can preclude an undesirable failure. Strength design provides for design of inelastic performance of masonry. The loads and stresses considered are similar to those used in allowable stress design, but service level loads are replaced with strength design loads and allowable stresses are replaced with nominal values based on research. The required strength of the masonry must be greater than its nominal strength multiplied by a strength reduction factor,  $\phi$ . The strength reduction factors selected are similar to those used in concrete.

Strength design of masonry shall comply with the minimum requirements of this chapter. In addition, the requirements of Chapter 1, Section 3.1, and either Section 3.2 or 3.3 also apply. (3.1.1) The strength requirements are in accordance with the legally adopted building code. When this information is not defined in the building code then the requirements of ASCE 7-98 govern. (3.1.2) Notations and definitions used in strength design are found in Sections 1.5 and 1.6, respectively.

The remainder of Chapter 3 covers design strength (3.1.3), strength reduction factors (3.1.4), deformation requirements (3.1.5), headed and bent-bar anchor bolts (3.1.6), material properties (3.1.7), reinforced masonry (3.2), and unreinforced (plain) masonry (3.3). Design equations are similar to those for allowable stress design when possible. Perhaps the most significant difference is in the development length. The strength design formula includes cover, bar size, and masonry specified compressive strength as variables. This formula also applies to splices.

This chapter includes maximum reinforcement ratios chosen to prevent brittle failure of shear walls. These are applied with specific limits on strain in the masonry and steel. There are also dimensional limits for beams, piers, and columns.

It must be pointed out that Strength Design of Masonry may not be practical in many situations and may in fact not provide the results a designer may seek.

### **Chapter 4 - Prestressed Masonry**



Prestressed masonry is used to eliminate tensile stresses in masonry due to externally applied loads. A controlled amount of precompression is applied to the masonry to offset the tensile forces created under service loads. The use of prestressing is well documented in concrete design and construction; however its use in masonry construction in the United States is limited. The United Kingdom has a history of successful prestressed masonry construction for over two decades.

The equipment for prestressed masonry is similar to that used in concrete construction. Some proprietary systems have been developed specifically for use in prestressed masonry. Types of structures that have utilized prestressed masonry in the United States include freestanding walls, such as fences, bearing walls and masonry veneers designed to span between columns, rather than span floor-to-floor.

Prestressing tendons placed in openings in the masonry may be grouted or ungrouted. The tendons may be pre-tensioned or post-tensioned. Pre-tensioned tendons are stressed against external abutments prior to placing the masonry. Post-tensioned tendons are stressed against the masonry after it has been placed. Most construction applications to date have been post-tensioned, ungrouted masonry because of the ease of construction and overall economy. As a result, the MSJC Code focuses primarily on post-tensioned masonry.

Chapter 4 provides minimum requirements for the design of structures that are prestressed with bonded or unbonded prestressing tendons. The general design requirements found in Chapter 1, including seismic provisions, apply to prestressed masonry with a few modifications. (4.1) Prestressed members are designed using elastic analysis and allowable stress design. A new term,  $f'_{mi}$  is defined as the specified compressive strength of masonry at the time of transfer of the prestress force. (4.2)

The remainder of Chapter 4 covers permissible stresses in the prestressing tendons, effective prestress, axial compression and flexure, axial tension, shear, deflection, prestressing tendon anchorages, couplers, end blocks, protection of prestressing tendons and accessories, and development of bonded tendons.

## **Chapter 5 - Empirical Design of Masonry**

Chapter 5 presents empirical requirements for masonry structures. These requirements are based on past proven performance. Configuration of masonry structures for compliance with empirical limits is a technique that predates rational design methods. The empirical provisions of previous masonry standards have been modified and advanced in Chapter 5 to reflect contemporary construction materials and methods. The requirements are essentially unchanged from the 1999 edition.

The empirical requirements in Chapter 5 may be applied to the following masonry elements:

1. The lateral force-resisting system for buildings in Seismic Design Categories (SDC) A, and for other building elements in SDC A through C, as defined in ASCE 7-98. (5.1.2)
2. Buildings subject to basic wind speed of 110 mph (145 km/hr) or less as defined by the ASCE 7-98 standard. (5.1.2.2)
3. Buildings not exceeding 35 ft (10.67 m) when the masonry walls are part of the main lateral force-resisting system. (5.2)

The empirical requirements may not be applied to structures resisting horizontal loads other than those due to wind or seismic events, except that foundation walls may be as permitted in Section 5.6.3. The empirical requirements for foundation walls include limits on the height of backfill. There are a number of restrictions on the backfill soil and the configuration of cross walls. (5.6.3.1) The 2002 Code also requires foundation piers to be a minimum of 8 in. (203 mm) in thickness. (5.6.4) The empirical requirements of the MSJC Code are discussed in *Technical Notes 42 Revised*.

## **Chapter 6 - Veneers.**

The requirements of Chapter 6 apply to masonry veneers. In the 2002 MSJC Code, provisions address anchored masonry veneer and adhered masonry veneer. The requirements of this chapter are especially important to the brick industry as the majority of brick produced in the United States is used as veneer.

Section 6.2 - Anchored veneer. The majority of this chapter contains prescriptive requirements for masonry

veneer, but alternative design methods are permitted. (6.2.1) The prescriptive requirements cannot be used in areas where the wind speed exceeds 110 mph (145 km/hr) as given in ASCE 7-98. (6.2.2.1) Many of the requirements are based upon those found in *Technical Notes 28 Series* on brick veneer walls and *Technical Notes 44B* on wall ties. (6.2.2.3-6.2.2.9) Seismic requirements are included for buildings in SDC C, D, and E. (6.2.2.10)

Section 6.3 - Adhered veneer. Adhered veneer can be designed by the prescriptive requirements contained in this section or by alternative design methods. (6.3.1) Prescriptive requirements found in the 2002 MSJC Code are based on similar requirements that have been used in the Uniform Building Code for over 30 years. These requirements limit unit size to no more than 2 5/8 in. (66.7 mm) in specified thickness, 36 in. (914 mm) in any face dimension and 5 ft<sup>2</sup> (0.46 m<sup>2</sup>) in total face area. The weight of adhered veneer units is limited to 15 lbs/ft<sup>2</sup> (718 Pa). (6.3.2)

Adhesion between the veneer units and the backing must have a shear strength of 50 psi (345 kPa) or greater based on gross unit surface area when tested in accordance with ASTM C 482. Alternatively, adhered units may be applied using the procedure found in MSJC Specification Article 3.3C. (6.3.2.4)

## **Chapter 7 - Glass Unit Masonry**

Chapter 7 applies to glass unit masonry. The 2002 edition contains few changes from the 1999 version. The provisions are largely based upon those in the three previous model building codes. Requirements are primarily prescriptive and empirical.

Maximum wall areas are imposed by a design wind pressure graph for standard units, 3 7/8 in. (98.4 mm) thick. When 3 in. (76.2 mm) thick units are used, a maximum wind pressure of 20 psf (958 Pa) is imposed and the maximum wall area is reduced. The size of interior wall panels is limited to 250 ft<sup>2</sup> (23.22 m<sup>2</sup>) and 150 ft<sup>2</sup> (13.94 m<sup>2</sup>) for standard and thin units, respectively. (7.1, 7.2) Provisions regarding lateral support for panels limited to one unit wide or one unit high are included. (7.3)

The MSJC Code also imposes requirements for expansion joints. (7.4)

Base surface treatment requires the surface on which glass unit masonry panels are placed to be coated with an elastic waterproofing material. (7.5)

Glass unit masonry shall be built with Type S or N mortar. (7.6)

Glass unit masonry panels must contain a minimum amount of horizontal joint reinforcement. The MSJC Code requires a minimum of two parallel W1.7 (MW11) wires spaced at 16 in. (406 mm) o.c. vertically. Joint reinforcement is very important because the limitations on wall panel size are based upon the failure of the reinforced section, rather than the first cracking strength of panels. (7.7)

## **THE MSJC SPECIFICATION (ACI 530.1/ASCE 6/TMS 602)**

The MSJC Specification is a reference standard that an architect or engineer may cite in the contract documents for any project. The MSJC Specification contains requirements for the contractor regarding materials, construction and quality assurance. The MSJC Code requires compliance of construction of the masonry with the MSJC Specification, so it is an integral part of the MSJC Code. The language is in imperative voice for ease of interpretation and enforcement. The MSJC Specification should be referenced in the contract documents and may be modified as required for the particular project.

The 2002 edition of the MSJC Specification consists of three components: a) Part 1 - General, b) Part 2 - Products and c) Part 3 - Execution. The format was changed to the present one in 1995 to be more consistent with the Construction Specifications Institute's MASTERFORMAT.

Major changes in the 2002 edition relate to quality assurance and ease of use. Quality assurance is established in conjunction with the MSJC Code and the MSJC Specification contains specific instructions for the parties involved. The phrase "When required" was eliminated. Inclusion of this phrase in earlier

editions made it necessary for the user to extensively edit the MSJC Specification for application to a particular project.

## **Requirements Checklists and Submittals**

The requirements checklists help the designer to choose and specify the necessary products and procedures found in the contract documents. Building codes set minimum requirements to protect property and life safety. However, written contract documents may have more restrictive requirements than provided in the building code. Adjustments for the particular project should be made by the designer by reviewing the requirements checklists.

There are two checklists, mandatory and optional, that alert the designer to issues that must be addressed. The mandatory list requires a choice on inspection, testing, material selection and items not provided on the drawings or details of the project. The most significant change from the 1999 MSJC Specification in the mandatory checklist is exclusion of determining specified compressive strength compliance. In addition, the 1999 MSJC Specification required that the level of quality assurance be specified.

### **Part 1 - General**

In Part 1 it is stated that the MSJC Specification covers requirements for materials and construction of masonry elements. The provisions govern any project unless other requirements are specifically stated in the contract documents. (1.1)

Definitions are provided and are coordinated with those found in the MSJC Code. (1.2) All standards referenced in the MSJC Specification are listed. These standards include material specifications, sampling procedures, test methods, detailing requirements, construction procedures and classifications. The references are updated to the most current edition at the time of the MSJC Code and Specification approval. (1.3)

The compressive strength of each wythe of masonry must equal or exceed that specified by the engineer or architect. The compressive strength must be verified by the contractor by one of two methods: *unit strength* or *prism test*. The unit strength method is a means to evaluate the strength of masonry based upon the tested compressive strength of individual units and the mortar type specified. The prism test method requires the sampling and testing of masonry prisms built with the same types of materials that are used in the masonry construction. The MSJC Specification specifies prism testing to be done in accordance with ASTM C 1314, Standard Test Method for Compressive Strength of Masonry Prisms. (1.4B) Adhesion of adhered veneer units to their backing is to be determined in accordance with ASTM C 482, Test Method for Bond Strength of Ceramic Tile to Portland Cement. (1.4C)

Part 1 provides a list of items to be included in project submittals. Submittals should include mortar and grout mix designs and test results, masonry unit samples and certificates, samples of metal items such as reinforcement and wall ties. This also includes construction procedures for cold- and hot-weather construction. (1.5)

Quality assurance is required by the MSJC Specification. The duties and services of the testing agency, inspection agency and contractor are specified and are dependent upon the level of quality assurance required. Article 1.6A outlines the responsibilities of the testing agencies. Article 1.6B specifies the responsibilities of the inspection agency. Article 1.6C contains the contractor's services and duties. The contractor must employ an independent testing laboratory to perform required tests, to document submittals, certify product compliance, establish mortar and grout mix designs, provide supporting data for changes requested by the contractor, or appeal rejection of material found to be defective. The contractor must include in the submittals the results of all testing performed to qualify the materials and to establish mix designs. Quality assurances are actions taken by the owner or the owner's representative. They provide assurance that actions of the contractor and supplier are in accordance with applicable standards of good practice. Quality assurances are administrative policies and responsibilities related to quality control measures that meet the owner's quality objectives. Quality control is the action taken by the producer or contractor. This is simply systematic performance of construction, testing and inspection to verify that proper materials and methods are used.

Quality assurance involves inspection and testing, preparation and erection of the masonry structure.

Inspection is assumed for every masonry project under the MSJC Code, a change from previous masonry standards. The level of inspection and the amount of testing depend upon the level of quality assurance specified. The level of quality assurance is determined according to facility function, as defined by the general building code, and the method of design. The MSJC Specification contains the same Quality Assurance tables that are found in the MSJC Code. (1.6)

Sample panels for masonry walls are required for Level 2 or 3 quality assurance. The construction of a grout demonstration panel, used to depart from the requirements of Articles 3.5 C-E is also a part of quality assurance. (1.6D)

Requirements for delivery, storage and handling of masonry materials are stated in order to avoid contamination that might reduce the quality of the constructed masonry. (1.7) Project-specific conditions such as support of construction loads by the masonry and shoring and weather exposure during construction must be addressed. Cold- and hot-weather construction requirements are included and are mandatory when they apply. The provisions for cold-weather construction have been revised in the 2002 MSJC Specification. Provisions for both cold-and hot-weather construction are separated into preparation, and construction protection. In most cases the methods to achieve the requirements are left to the discretion of the contractor. (1.8)

## **Part 2 - Products**

This section lists the available American Society for Testing and Materials (ASTM) standards for masonry materials, including masonry units, mortar, grout, reinforcement and metal accessories. Specific requirements are given if an appropriate ASTM standard does not exist. Referenced ASTM standards for brick and tile are C 34, C 56, C 62, C 126, C 212, C 216, C 652, and C 1088. There are provisions for spacing of cross wires in joint reinforcement that are not included in standard for this material. Minimum corrosion protection requirements for metal items are stated including galvanized and epoxy coatings. Requirements for corrosion protection of bonded and unbonded prestressing tendons are also included. Criteria are specified for prestressing anchorages, couplers and end blocks. An accessories section provides requirements on contraction joint material, expansion joint material, asphalt emulsions, masonry cleaners and joint fillers. (2.1-2.5)

The MSJC Specification contains requirements for the mixing of mortar and grout. Time of mixing and additives to mortar are limited. The grout must meet ASTM C 476 and be furnished and placed with a slump between 8 in. (200 mm) and 11 in. (275 mm). (2.6)

Standard fabrication limits are stated for reinforcement and for prefabricated masonry panels. These include bend and hook requirements for reinforcing bars. Prefabricated masonry panels must conform to the provisions of ASTM C 901. (2.7)

## **Part 3 - Execution**

The execution of the work includes initial inspection; preparation; masonry erection; reinforcement, tie and anchor installation; grout placement; prestressing tendon installation and stressing procedure; field quality control; and cleaning. Dimensional tolerances for foundations on which masonry is placed are provided and should be measured prior to the start of masonry work. (3.1) As part of the preparation requirements, clay or shale masonry units having initial absorption rates in excess of one gram per minute per in<sup>2</sup>, as measured with ASTM C 67 must be pre-wetted, so the initial rate of absorption will not exceed one gram per minute per in<sup>2</sup> when the units are used. Cleanouts are required at the base of masonry to be grouted whenever pour heights exceed 5 ft (1.5 m). (3.2)

Standard requirements for good workmanship are required by the MSJC Specification. These include the requirement for completely filled mortar joints and grouted spaces. Proper support of masonry and bracing during construction is required but is not prescribed. Dimensional tolerances for the masonry are listed to ensure structural performance. The tolerances should not be used to establish appearance criteria, unless specifically noted as such by the project specifications. (3.3)

Inspection of reinforcement and metal accessories is required to ensure that they have been properly placed and are free of materials that hinder bond. Tolerances for locating and placing reinforcing steel, wall ties, and veneer anchors are prescribed. Criteria for adjustable wall ties, which are repeated from the

MSJC Code, are included. Placement requirements for veneer anchors have been added (3.4)

Prior to grout placement, debris must be removed from grout spaces. The grouting requirements found in the MSJC Code are repeated in the MSJC Specification. Maximum grout pour heights are determined by the type of grout used and the dimensions of the grout space. Consolidation of grout is required to fill voids created by the loss of water from grout by absorption into the masonry. Alternate grout placement requirements, established through the use of a grout demonstration panel, are permitted. (3.5)

Prestressing tendon installation and stressing requirements include: tolerances; application and measurement of the prestressing force; grouting bonded tendons; and burning and welding operations. (3.6)

As part of field quality control, the specified compressive of masonry  $f'_m$  is verified in accordance with Article 1.6, Quality Assurance; grout is sampled and tested in accordance with Articles 1.4B and 1.6. Provisions for cleaning exposed masonry surfaces complete the MSJC Specification. (3.8)

## **SUMMARY**

This *Technical Notes* provides an overview to the criteria contained in the MSJC Code and Specification. The discussion centers on the design requirements to be followed by architects and engineers and the masonry specifications to be implemented by the contractor during construction. Changes to the Code and Specification in the 2002 editions are emphasized. The MSJC Code and Specification provide the designer with coordination between the design and construction phases of all masonry buildings.

The information and suggestions contained in this *Technical Notes* are based on the available data and the experience of the engineering staff of the Brick Industry Association. The information contained herein must be used in conjunction with good technical judgment and a basic understanding of the properties of brick masonry. Final decisions on the use of the information contained in this *Technical Notes* are not within the purview of the Brick Industry Association and must rest with the project architect, engineer and owner.