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SEISMIC DESIGN AND DETAILING REQUIREMENTS FOR MASONRY STRUCTURES

INTRODUCTION

Historically, degree of seismic risk and the resulting design loads have been linked to seismic zones, with higher seismic zones associated with higher anticipated ground motion. More recently, design codes and standards (refs. 1, 2, 3) have replaced the use of seismic zones with Seismic Design Categories (SDCs). While seismic zones and design categories share similar concepts, there are also specific considerations that make each unique. The information that follows outlines the procedure for defining a project's SDC, the permissible design methods that can be used with each SDC, and the prescriptive reinforcement associated with each SDC level.

This TEK is based on the requirements of the 2006 and 2009 editions of the *International Building Code* (IBC) (refs. 3a, 3b). While the applicable seismic provisions covered have not changed significantly over the last several code cycles, designers and contractors should be aware of several key revisions that have been introduced in recent years.

SEISMIC DESIGN CATEGORIES

SDCs range from SDC A (lowest seismic risk) through SDC F (highest seismic risk). Several factors contribute to defining the seismic design category for a particular project, including:

- Maximum earthquake ground motion. Ground acceleration values are obtained from maps published in the IBC (ref. 3) or the ASCE 7 *Minimum Design Loads for Buildings and Other Structures* (ref. 2).
- Local soil profile. Soil profiles are classified as Site Class A (hard rock) through Site Class F (organic or liquefiable soils). When the soil properties are not known in sufficient detail to determine the site class, Site Class D (moderately stiff soil) is assumed.
- Use or occupancy hazard of the structure. Each structure is assigned to one of four unique Occupancy Categories corresponding to its use or hazard to life safety. Structures assigned to Occupancy Category I include those with a very low hazard to human life in the event of failure

(including many agricultural buildings and minor storage facilities). Structures assigned to Occupancy Category III include those that would present a substantial public hazard including schools, jails, and structures with an occupancy load greater than 5,000. Structures assigned to Occupancy Category IV are designated essential facilities (such as hospitals and fire stations) and structures that contain substantial quantities of hazardous materials. Structures assigned to Occupancy Category II are those not included in any of the other three categories.

Figures 1 and 2 define the SDC for 0.2 and 1 second spectral response acceleration, respectively. Each figure is based on Site Class D (the default class when the soil profile is not known) and is applicable to structures assigned to Occupancy Categories I, II, and III (buildings other than high hazard exposure structures). Note that if the soil profile is known and is lower than D, a correspondingly lower SDC may be realized.

Structures are assigned to the highest SDC obtained from either Figure 1 or Figure 2. Alternatively, Section 1613.5.6.1 of the 2006 or 2009 IBC (refs. 3a, 3b) permits the SDC to be determined based solely on Figure 1 (0.2 second spectral response acceleration) for relatively short, squat structures (common for masonry buildings) meeting the requirements of that section. Table 1 may be used to apply Figures 1 and 2 to structures assigned to Occupancy Category IV.

DESIGN LIMITATIONS

Based on the assigned SDC, limitations are placed on the design methodology that is permitted to be used for the design of the seismic force-resisting system (i.e., the masonry shear walls).

Designers have the option of using several design methods for masonry structures: empirical design (ref. 4); allowable stress design (ref. 5); strength design (ref. 6); or prestressed masonry design (ref. 7), each of which is based on the provisions contained in the Masonry Standards Joint Committee *Building Code Requirements for Masonry Structures* (MSJC) (ref. 1).

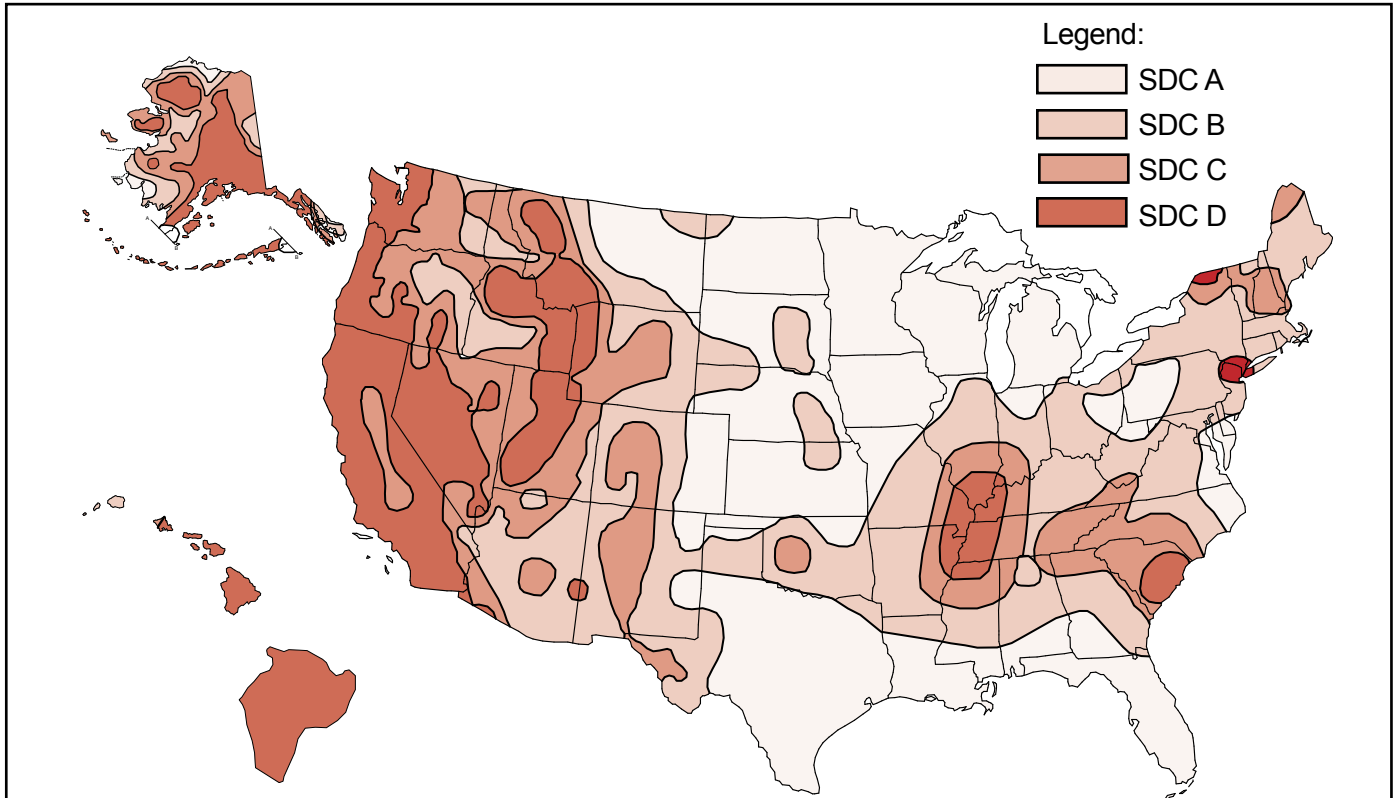


Figure 1—Seismic Design Categories for Site Class D, Seismic Use Group I and II, for a 0.2-Second Spectral Response Acceleration

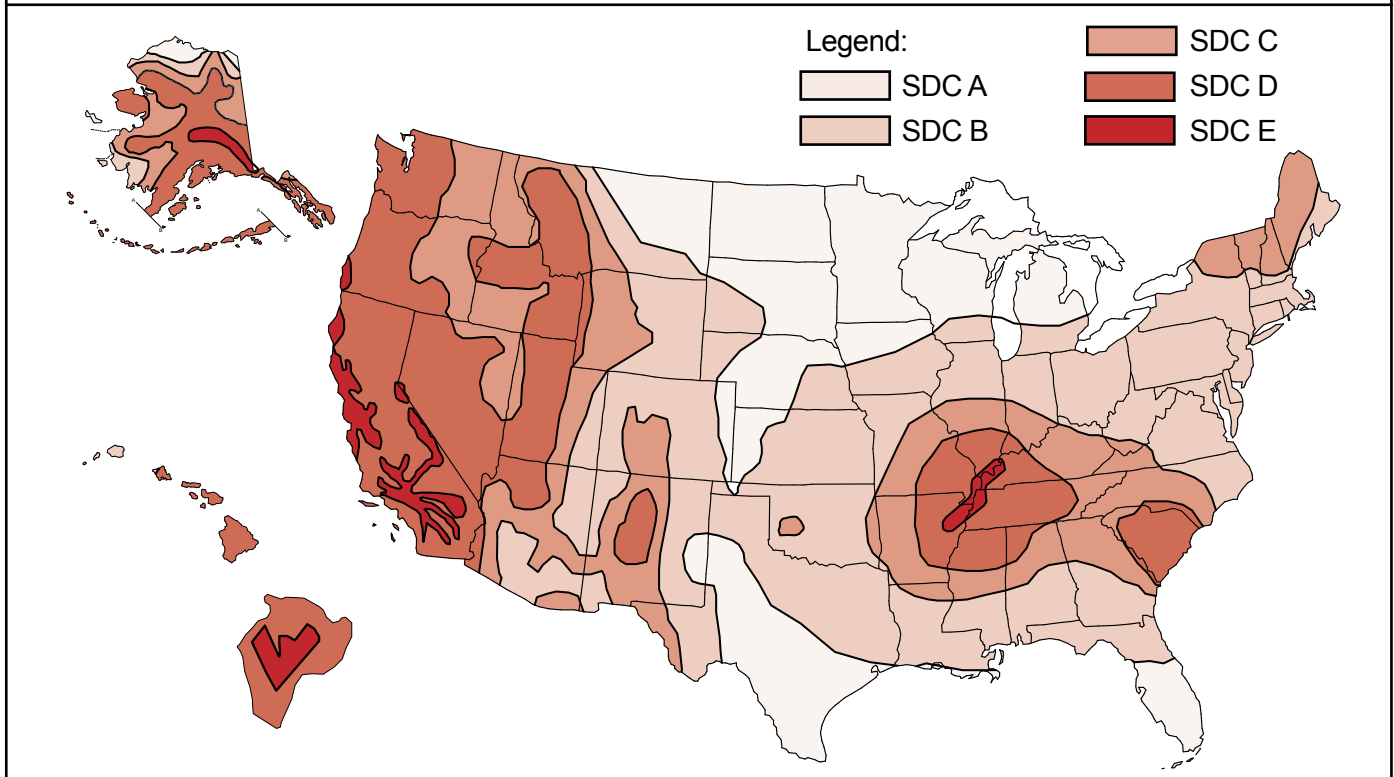


Figure 2—Seismic Design Categories for Site Class D, Seismic Use Group I and II, for a 1-Second Spectral Response Acceleration

There are, however, restrictions placed on the use of both empirical design and unreinforced masonry, neither of which considers reinforcement, if present, as contributing to the structure’s strength or ductility. Table 2 summarizes the design procedures that may be used for each SDC.

Similarly, as the seismic risk/hazard increases, codes require more reinforcement to be incorporated into the structure. This reinforcement is prescriptively required as a minimum and is not a function of any level of determined loading on the structure. That is, design loads may require a specific reinforcement schedule to safely resist applied loads, which cannot be less than the minimum prescriptive seismic reinforcement triggered by the assigned SDC. For convenience, each level of prescriptive seismic reinforcement is given a unique name as summarized in Table 3.

The following discussion reviews in detail the seismic design requirements for loadbearing and nonloadbearing concrete masonry assemblies as required under the 2006 and 2009 IBC, which in turn reference the 2005 and 2008 MSJC, respectively. While many of the seismic design and detailing requirements between these two code editions are similar, there are unique differences that need to be considered when using one set of provisions over the other. The information presented covers the seismic design and detailing requirements for all concrete masonry construction with the exception of concrete masonry veneers, which is addressed in TEK 03-06C, *Concrete Masonry Veneers* (ref. 8).

The requirements listed below for each SDC and shear wall type are cumulative. That is, masonry assemblies in structures assigned to SDC B must meet the requirements for SDC A as well as those for SDC B. Buildings assigned to SDC C must meet the requirements for Categories A, B and C, and so on.

2006 IBC SEISMIC DESIGN AND DETAILING REQUIREMENTS

The seismic design and detailing provisions for masonry are invoked through Section 2106 of the IBC (ref. 3a), which in turn references the 2005 MSJC (ref. 1a). The IBC provisions detail a series of modifications and additions to the seismic requirements contained in the MSJC, which include:

- IBC Section 2106.1 requires all masonry walls, regardless of SDC, not designed as part of the seismic force-resisting system (partition and nonloadbearing walls, eg.) to be structurally isolated, so that in-plane loads are not inadvertently imparted to them. The MSJC, conversely, requires isolation of such elements only for SDC C and higher.
- IBC Section 2106.1.1 outlines minimum prescriptive detailing requirements for three prestressed masonry shear wall types: ordinary plain, intermediate, and special prestressed masonry shear walls. While the MSJC contains general design requirements for prestressed masonry systems, it does not contain prescriptive seismic requirements applicable to this design approach.
- Anchorage requirements are addressed by Section 2106.2 of the IBC. Although analogous requirements are included in MSJC Section 1.14.3.3, the MSJC requirements are based on antiquated design loads that are no longer compatible with those of the IBC.
- For structures assigned to SDC C and higher that include columns, pilasters and beams, and that are part of the seismic force-resisting system and support discontinuous masonry walls, IBC Section 2106.4.1 requires these elements to have a minimum transverse reinforcement ratio of 0.0015, with a maximum transverse reinforcement spacing of one-fourth the least nominal dimension for columns and pilasters and one-half the nominal depth for beams.
- For structures assigned to SDC D and higher, IBC Section 2106.5 includes modifications that are an indirect means of attempting to increase the flexural ductility of elements that are part of the seismic force-resisting system. For elements designed by allowable stress design provisions (MSJC Chapter 2), in-plane shear and diagonal tension stresses are required to be increased by 50 percent. For elements

Table 1—SDC for Structures Assigned to Occupancy Category IV

SDC based on Figures 1 and 2	Revised SDC for Occupancy Category IV
A	A
B	C
C	D
D	D
E	F

Table 2—Permitted Design Procedures for Elements Participating in the Lateral Force-Resisting System

SDC	Empirical design	Allowable stress design		Strength design		Prestressed
		Unreinforced	Reinforced	Unreinforced	Reinforced	
A	X	X	X	X	X	X
B		X	X	X	X	X
C			X		X	X
D			X		X	X
E			X		X	X
F			X		X	X

designed by strength design provisions (MSJC Chapter 3) that are controlled by flexural limit states, the nominal shear strength at the base of a masonry shear wall is limited to the strength provided by the horizontal shear reinforcement in accordance with Eqn. 1.

$$V_n = A_n \rho_n f_y \quad \text{Eqn. 1}$$

Due to a shear capacity check in MSJC Section 3.1.3 that requires the nominal shear strength of a shear wall to equal or exceed the shear corresponding to the development of approximately 156% of the nominal flexural strength, Equation 1 controls except in cases where the nominal shear strength equals or exceeds 250% of the required shear strength. For such cases, the nominal shear strength is determined as a combination of the shear strength provided by the masonry and the shear reinforcement.

2005 MSJC SEISMIC DESIGN AND DETAILING REQUIREMENTS

The majority of the prescriptive seismic design and detailing requirements for masonry assemblies are invoked by reference to Section 1.14 of the 2005 MSJC. The following summarizes these requirements as they apply to concrete masonry construction.

Masonry Shear Wall Types

In addition to the prestressed masonry shear walls outlined by the IBC, the MSJC includes detailing requirements for six different shear wall options. A summary of these shear wall types follows. Table 3 summarizes the SDCs where each shear wall type may be used.

Empirically Designed Masonry Shear Walls—Masonry shear walls designed by the empirical design method (MSJC Chapter 5). Empirically designed masonry shear walls do not account for the contribution of reinforcement (if present) in determining the strength of the system.

Ordinary Plain (Unreinforced) Masonry Shear Walls—Ordinary plain masonry shear walls are designed as unreinforced elements, and as such rely entirely on the masonry to carry and distribute the anticipated loads. These shear walls do not require any prescriptive reinforcement. As such, they are limited to SDCs A and B.

Detailed Plain (Unreinforced) Masonry Shear Walls—Detailed

plain masonry shear walls are also designed as unreinforced elements, however some prescriptive reinforcement is mandated by the MSJC to help ensure a minimum level of inelastic deformation capacity and energy dissipation in the event of an earthquake. As the anticipated seismic risk increases (which corresponds to higher SDCs), the amount of prescriptive reinforcement also increases. The minimum prescriptive reinforcement for detailed plain masonry shear walls is shown in Figure 3.

Ordinary Reinforced Masonry Shear Walls—Ordinary reinforced masonry shear walls, which are designed using reinforced masonry procedures, rely on the reinforcement to carry and distribute anticipated tensile stresses, and on the masonry to carry compressive stresses. Although such walls contain some reinforcement, the MSJC also mandates prescriptive reinforcement to ensure a minimum level of performance during a design level earthquake. The reinforcement required by design may also serve as the prescriptive reinforcement. The minimum prescriptive vertical and horizontal reinforcement requirements are identical to those for detailed plain masonry shear walls (see Figure 3).

Intermediate Reinforced Masonry Shear Walls—Intermediate reinforced masonry shear walls are designed using reinforced masonry design procedures. Intermediate reinforced shear wall reinforcement requirements differ from those for ordinary reinforced in that the maximum spacing of vertical reinforcement is reduced from 120 in. (3,048 mm) to 48 in. (1,219 mm) (see Figure 4).

Special Reinforced Masonry Shear Walls—Prescriptive reinforcement for special reinforced masonry shear walls must comply with the requirements for intermediate reinforced masonry shear walls and the following (see also Figure 5):

- The sum of the cross-sectional area of horizontal and vertical reinforcement must be at least 0.002 times the gross cross-sectional wall area.
- The cross-sectional reinforcement area in each direction must be at least 0.0007 times the gross cross-sectional wall area.
- The vertical and horizontal reinforcement must be uniformly distributed.
- The minimum cross-sectional area of vertical reinforcement

Table 3—Permitted Shear Wall Types for Seismic Design Categories

SDC	Empirical	Ordinary unreinforced ^A	Detailed unreinforced	Ordinary reinforced	Intermediate reinforced ^A	Special reinforced ^A
A	X	X	X	X	X	X
B		X	X	X	X	X
C				X	X	X
D						X
E						X
F						X

^A Includes prestressed masonry assemblies meeting the same prescriptive reinforcement requirements as conventional masonry construction.

must be one-third of the required horizontal reinforcement.

- All horizontal reinforcement must be anchored around the vertical reinforcement with a standard hook.

The following additional requirements pertain to stack bond masonry shear walls assigned to SDC D, E or F. These walls must be constructed using fully grouted open-end units, fully grouted hollow units laid with full head joints, or solid units. The maximum reinforcement spacing for stack bond masonry shear walls assigned to SDC D is 24 in. (610 mm). For those assigned to SDC E or F, the cross-sectional area of horizontal reinforcement must be at least 0.0025 times the gross cross-sectional area of the masonry, and it must be spaced at 16 in. (406 mm) o.c., maximum.

Prescriptive Seismic Detailing for Nonloadbearing Elements

When incorporated into structures assigned to SDC C, D, E or F, masonry partition walls and other nonloadbearing masonry elements (i.e., those not designed to resist loads other than those induced by their own mass) must be isolated from the lateral force-resisting system. This helps ensure that forces are not inadvertently transferred from the structural to the nonstructural system. Nonstructural elements, such as partition walls, assigned to SDC C and above must be reinforced in either the horizontal or vertical direction (see Figure 6).

2009 IBC SEISMIC DESIGN AND DETAILING REQUIREMENTS

Unlike the 2006 IBC, the 2009 edition, which references the 2008 MSJC, contains no modifications to the seismic design and detailing provisions of the referenced standard. A summary of the substantive differences between the seismic design and detailing provisions of the 2005 and 2008 editions of the MSJC follows.

2008 MSJC SEISMIC DESIGN AND DETAILING REQUIREMENTS

The 2008 MSJC includes a comprehensive reorganization of the seismic design and detailing requirements intended to clarify the scope and intent of these provisions. In addition to the reorganization, several substantive changes applicable to concrete masonry construction have been incorporated, and these are detailed below. The prescriptive seismic detailing requirements for masonry shear walls remains substantially the same as under the 2005 MSJC and 2006 IBC.

Participating versus Nonparticipating Members—Elements of a masonry structure must now be explicitly classified either as participating in the seismic force-resisting system (for example, shear walls) or as nonparticipating members (for example, nonloadbearing partition walls). Elements designated as shear walls must satisfy the requirements for one of the designated shear wall types. Nonparticipating members must be appropriately isolated to prevent their inadvertent structural participation. This provision is similar in intent to the 2006 IBC requirement to isolate partition walls in SDC A and higher.

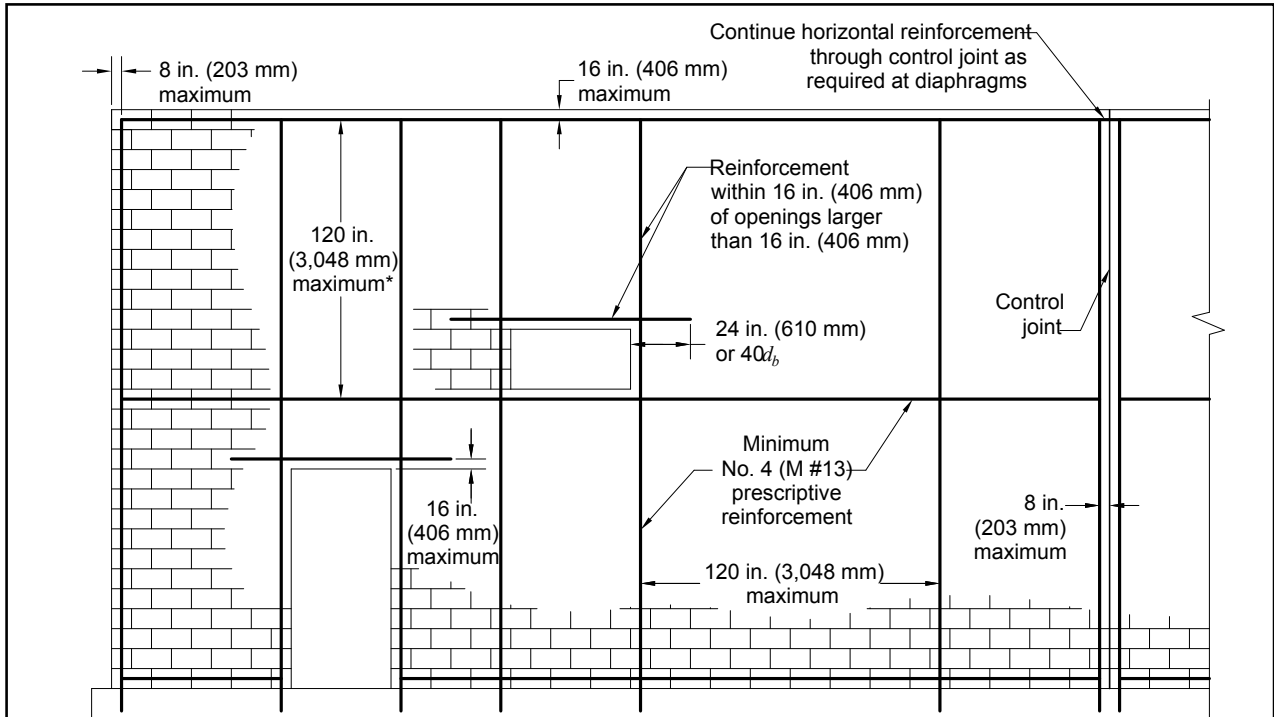
Connections—In previous editions of the MSJC, a minimum unfactored (service level) connection design force of 200 lb/ft (2,919 N/m) was prescribed for all masonry shear wall assemblies except ordinary plain (unreinforced) masonry shear walls. In the 2008 MSJC, this minimum design load has been removed and replaced with a reference to the minimum loads prescribed by the adopted model building code. When the adopted model building code does not prescribe such loads, the requirements of ASCE 7 are to be used, which require a factored design force (strength level) of 280 lb/ft (4,087 N/m).

Story Drift—Due to the inherent stiffness of masonry structures, designers are no longer required to check the displacement of one story relative to adjacent stories for most masonry systems, simplifying the design process. Shear wall systems that are not exempted from checks for story drift include prestressed masonry shear walls and special reinforced masonry shear walls.

Stack Bond Prescriptive Detailing—Special reinforced masonry shear walls constructed of masonry laid in stack bond must now have a minimum area of horizontal reinforcement of 0.0015 times the gross cross-sectional wall area. This is an increase from the 0.0007 required in such walls in structures assigned to SDC D, and is a decrease from the 0.0025 required in such walls in structures assigned to SDC E and F by earlier editions of the MSJC.

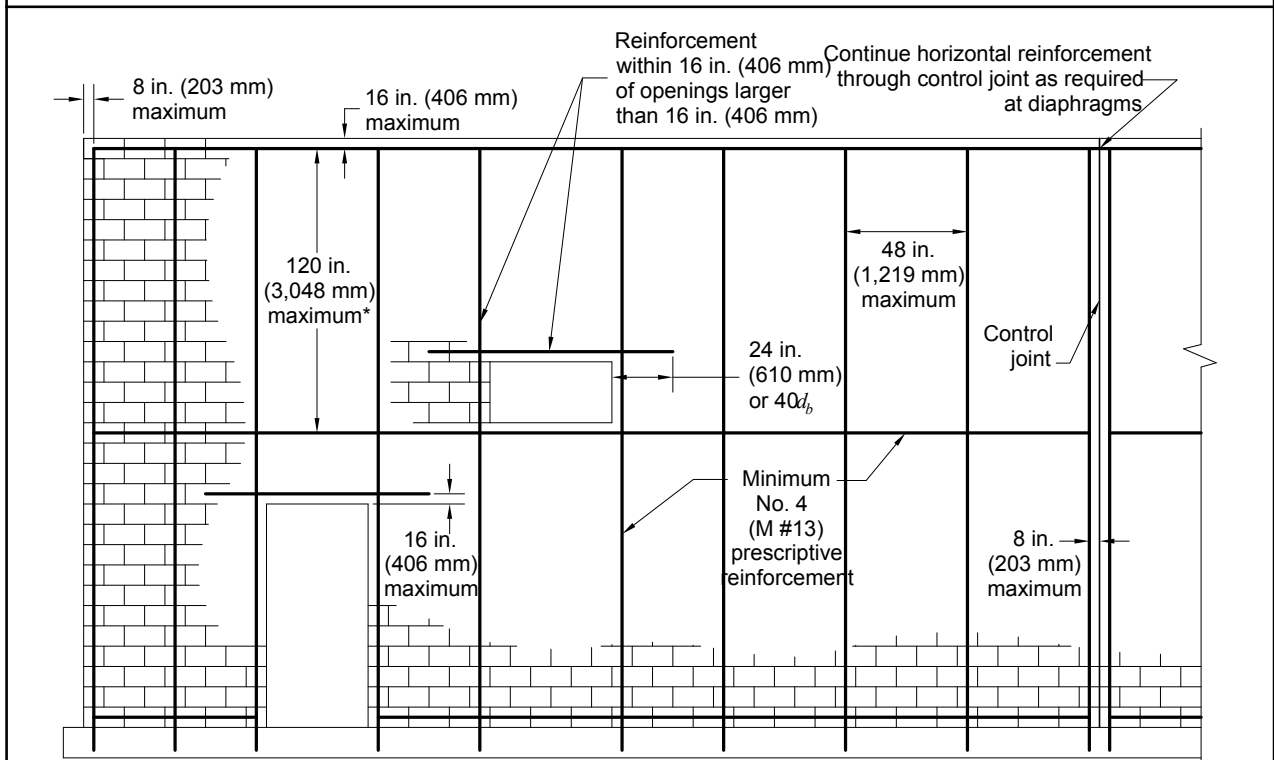
Shear Capacity Check—In the 2005 MSJC, all masonry elements (both reinforced and unreinforced) designed by the strength design method were required to have a design shear strength exceeding the shear corresponding to the development of 125 percent of the nominal flexural strength, but need not be greater than 2.5 times the required shear strength. Because this provision is related primarily to the seismic performance of masonry structures, the 2008 MSJC requires it only for special reinforced masonry shear walls. Similarly, when designing special reinforced masonry shear walls by the allowable stress design method, the shear and diagonal tension stresses resulting from in-plane seismic forces are required to be increased by a factor of 1.5. Each of these checks is intended to increase flexural ductility while decreasing the potential for brittle shear failure.

Stiffness Distribution—In Chapter 1 of the 2008 MSJC, prescriptive seismic detailing requirements for masonry shear walls are related to an implicit level of inelastic ductile capacity. Because these detailing provisions apply primarily to shear walls, which in turn provide the principal lateral force-resistance mechanism for earthquake loads, the 2008 MSJC requires that the seismic lateral force-resisting system consist mainly of shear wall elements. At each story, and along each line of lateral resistance within a story, at least 80 percent of the lateral stiffness is required to be provided by shear walls. This requirement is intended to ensure that other elements, such as masonry piers and columns, do not contribute a significant amount of lateral stiffness to the system, which might in turn inadvertently change the seismic load distribution



*In lieu of bond beams with No. 4 bars (M #13) at 120 in. (3,048 mm) on center, provide two wires of wire size W1.7 (MW 11) joint reinforcement at 16 in. (406 mm) on center.

Figure 3—Prescriptive Seismic Detailing for Detailed Plain (Unreinforced) Masonry Shear Walls and for Ordinary Reinforced Masonry Shear Walls



*In lieu of bond beams with No. 4 bars (M #13) at 120 in. (3,048 mm) on center, provide two wires of wire size W1.7 (MW 11) joint reinforcement at 16 in. (406 mm) on center.

Figure 4—Prescriptive Seismic Detailing for Intermediate Reinforced Masonry Shear Walls

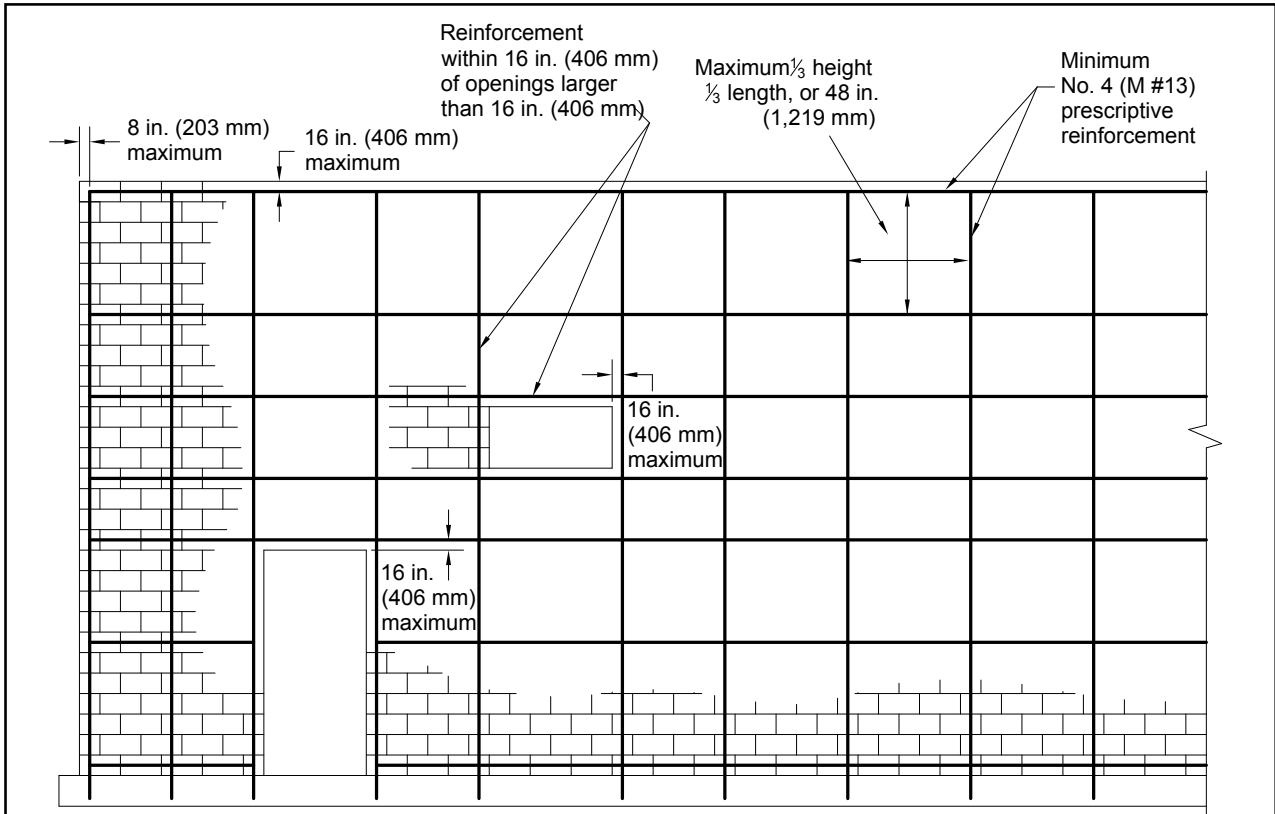


Figure 5—Prescriptive Seismic Detailing for Special Reinforced Masonry Shear Walls

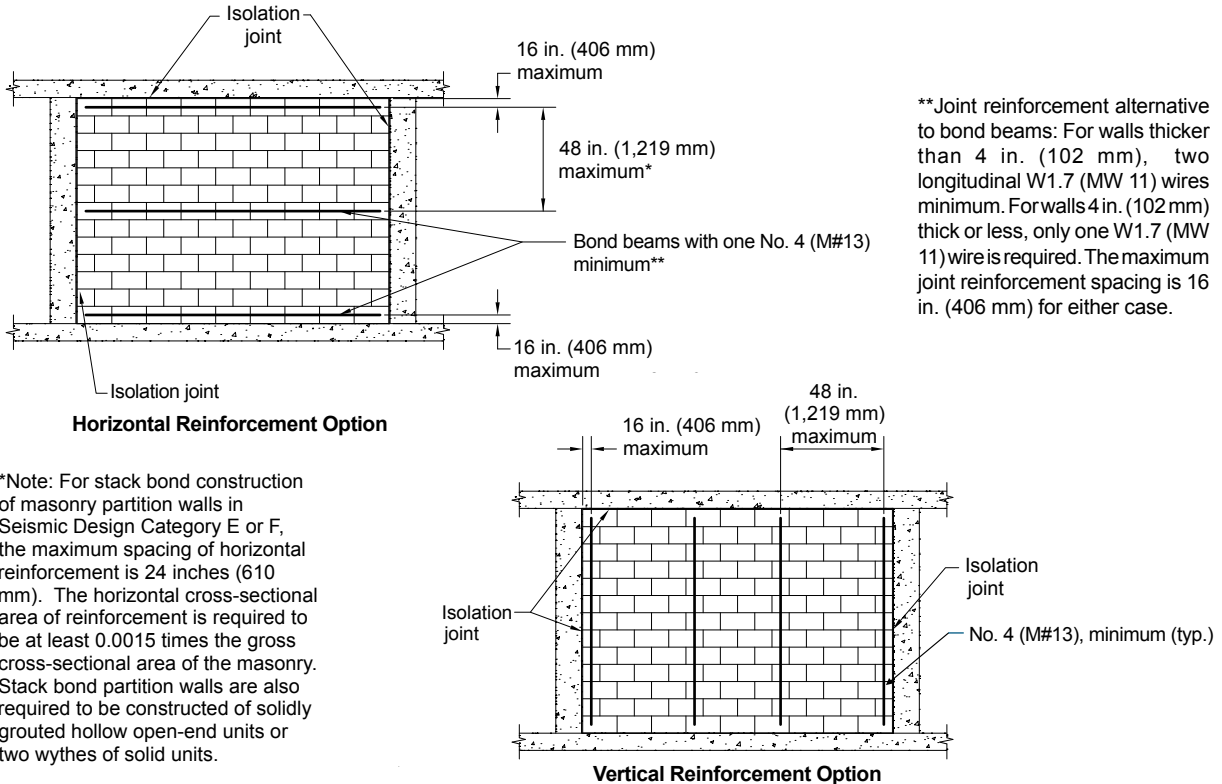


Figure 6—Reinforcement Options for Nonloadbearing Elements in SDC C and Higher

from that assumed in design. The 2008 MSJC does permit, however, the unlimited use of non-shear wall elements such as piers and columns provided that design seismic loads are determined using a seismic response modification factor, R , of 1.5 or less, consistent with the assumption of essentially elastic response to the design earthquake. In previous editions of the MSJC, these requirements were imposed only for masonry designed by the strength design method. In the 2008 MSJC, this requirement applies to all structures assigned to SDC C or higher.

Support of Discontinuous Elements—New to the 2008 MSJC, which was previously found in the 2006 IBC provisions, are the prescriptive detailing requirements for masonry columns, pilasters, and beams supporting discontinuous stiff elements that are part of the seismic force-resisting system. Such elements can impose actions from gravity loads, and also from seismic overturning, and therefore require that the columns, pilasters and beams supporting them have stricter prescriptive reinforcement requirements. These requirements apply only to structures assigned to SDC C and higher.

System Response Factors for Prestressed Masonry—In determining seismic base shear and story drift for structures whose seismic lateral force-resisting system consists of prestressed masonry shear walls, the value of the response modification coefficient, R , and of the deflection amplification factor, C_d , are required to be taken equal to those used for ordinary plain (unreinforced) masonry shear walls. The requirement previously existed as a recommendation in the MSJC Code Commentary. These values, as they apply to all types of masonry shear walls, are summarized in Table 4.

Table 4—Seismic Design Coefficients and Factors for Masonry Bearing Wall Systems

Shear wall type:	Response modification coefficient, R	Systems overstrength factor, Ω_o	Deflection amplification factor, C_d
Empirical	Not applicable	Not applicable	Not applicable
Ordinary plain (unreinforced)	1.5	2.5	1.25
Detailed plain (unreinforced)	2	2.5	1.75
Ordinary reinforced	2	2.5	1.75
Intermediate reinforced	3.5	2.5	2.25
Special reinforced	5	2.5	3.5
Prestressed	1.5	2.5	1.75

REFERENCES

1. *Building Code Requirements for Masonry Structures*, Reported by the Masonry Standards Joint Committee.
 - a. 2005 Edition: ACI 530-05/ASCE 5-05/TMS 402-05
 - b. 2008 Edition: TMS 402-08/ACI 530-08/ASCE 5-08
2. *Minimum Design Loads for Buildings and Other Structures*, ASCE 7-05. American Society of Civil Engineers, 2005.
3. *International Building Code*. International Code Council.
 - a. 2006 Edition
 - b. 2009 Edition
4. *Empirical Design of Concrete Masonry Walls*, TEK 14-08B, Concrete Masonry & Hardscapes Association, 2008.
5. *ASD of Concrete Masonry (2012 IBC & 2011 MSJC)*, TEK 14-07C, Concrete Masonry & Hardscapes Association, 2004.
6. *Strength Design Provisions for Concrete Masonry*, TEK 14-04B, Concrete Masonry & Hardscapes Association, 2008.
7. *Post-Tensioned Concrete Masonry Wall Design*, TEK 14-20A, Concrete Masonry & Hardscapes Association, 2002.
8. *Concrete Masonry Veneers*, TEK 03-06C, Concrete Masonry & Hardscapes Association, 2012.

ABOUT CMHA

The Concrete Masonry & Hardscapes Association (CMHA) represents a unification of the Interlocking Concrete Pavement Institute (ICPI) and National Concrete Masonry Association (NCMA). CMHA is a trade association representing US and Canadian producers and suppliers in the concrete masonry and hardscape industry, as well as contractors of interlocking concrete pavement and segmental retaining walls. CMHA is the authority for segmental concrete products and systems, which are the best value and preferred choice for resilient pavement, structures, and living spaces. CMHA is dedicated to the advancement of these building systems through research, promotion, education, and the development of manufacturing guides, design codes and resources, testing standards, and construction practices.

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