## Appendix A: Guidelines for the Seismic Retrofit of Existing Buildings
## CHAPTER A1

# SEISMIC STRENGTHENING PROVISIONS FOR UNREINFORCED MASONRY BEARING WALL BUILDINGS

### SECTION A101 PURPOSE

The purpose of this chapter is to promote public safety and welfare by reducing the risk of death or injury that may result from the effects of earthquakes on existing unreinforced masonry bearing wall buildings.

The provisions of this chapter are intended as minimum standards for structural seismic resistance, and are established primarily to reduce the risk of life loss or injury. Compliance with these provisions will not nec essarily prevent loss of life or injury, or prevent earthquake damage to rehabilitated buildings.

### SECTION A102 SCOPE

**A102.1 General.** The provisions of this chapter shall apply to all existing buildings having at least one unreinforced masonry bearing wall. The elements regulated by this chapter shall be determined in accordance with Table A1-A. Except as provided herein, other structural provisions of the building code shall apply. This chapter does not apply to the *alteration* of existing electrical, plumbing, mechanical or fire safety systems.

**A102.2 Essential and hazardous facilities.** The provisions of this chapter shall not apply to the strengthening of buildings or structures in Occupancy Category III when assigned to Seismic Design Category C, D, or E or buildings or structures in Occupancy Category IV. Such buildings or structures shall be strengthened to meet the requirements of the *International Building Code* for new buildings of the same occupancy category or other such criteria that have been established by the jurisdiction.

### SECTION A103 DEFINITIONS

For the purpose of this chapter, the applicable definitions in the building code shall also apply.

**BUILDING CODE.** The code currently adopted by the jurisdiction for new buildings.

**COLLAR JOINT.** The vertical space between adjacent wythes. A collar joint may contain mortar or grout.

**CROSSWALL.** A new or existing wall that meets the requirements of Section A111.3 and the definition of Section A111.3. A crosswall is not a shear wall.

**CROSSWALL SHEAR CAPACITY.** The unit shear value times the length of the crosswall, $v_c L_c$.

**DIAPHRAGM EDGE.** The intersection of the horizontal diaphragm and a shear wall.

**DIAPHRAGM SHEAR CAPACITY.** The unit shear value times the depth of the diaphragm, $v_u D$.

**INTERNATIONAL BUILDING CODE.** The *2009 International Building Code* (IBC).

**NORMAL WALL.** A wall perpendicular to the direction of seismic forces.

**OPEN FRONT.** An exterior building wall line without vertical elements of the lateral-force-resisting system in one or more stories.

**POINTING.** The partial reconstruction of the bed joints of an unreinforced masonry wall as defined in UBC Standard 21-8.

**RIGID DIAPHRAGM.** A diaphragm of reinforced concrete construction supported by concrete beams and columns or by structural steel beams and columns.

**UNREINFORCED MASONRY.** Includes burned clay, concrete or sand-lime brick; hollow clay or concrete block; plain concrete; and hollow clay tile. These materials shall comply with the requirements of Section A106 as applicable.

**UNREINFORCED MASONRY BEARING WALL.** A URM wall that provides the vertical support for the reaction of floor or roof-framing members.

**UNREINFORCED MASONRY (URM) WALL.** A masonry wall that relies on the tensile strength of masonry units, mortar and grout in resisting design loads, and in which the area of reinforcement is less than 25 percent of the minimum ratio required by the building code for reinforced masonry.

**YIELD STORY DRIFT.** The lateral displacement of one level relative to the level above or below at which yield stress is first developed in a frame member.

### SECTION A104 SYMBOLS AND NOTATIONS

For the purpose of this chapter, the following notations supplement the applicable symbols and notations in the building code.

$a_n$ = Diameter of core multiplied by its length or the area of the side of a square prism.

$A$ = Cross-sectional area of unreinforced masonry pier or wall, square inches ($10^{-6}$ m$^2$).

$A_b$ = Total area of the bed joints above and below the test specimen for each in-place shear test, square inches ($10^{-6}$ m$^2$).

$D$ = In-plane width dimension of pier, inches ($10^{-3}$ m), or depth of diaphragm, feet (m).

$DCR$ = Demand-capacity ratio specified in Section A111.4.2.

$f'_m$ = Compressive strength of masonry.

$f_{sp}$ = Tensile-splitting strength of masonry.

$F_{wx}$ = Force applied to a wall at level $x$, pounds (N).

$H$ = Least clear height of opening on either side of a pier, inches ($10^{-3}$ m).

$h/t$ = Height-to-thickness ratio of URM wall. Height, $h$, is measured between wall anchorage levels and/or slab-on-grade.

$L$ = Span of diaphragm between shear walls, or span between shear wall and open front, feet (m).

$L_c$ = Length of crosswall, feet (m).

$L_i$ = Effective span for an open-front building specified in Section A111.8, feet (m).

$P$ = Applied force as determined by standard test method of ASTM C 496 or ASTM E 519, pounds (N).

$P_D$ = Superimposed dead load at the location under consideration, pounds (kN). For determination of the rocking shear capacity, dead load at the top of the pier under consideration shall be used.

$p_{D+L}$ = Press resulting from the dead plus actual live load in place at the time of testing, pounds per square inch (kPa).

$P_w$ = Weight of wall, pounds (N).

$R$ = Response modification factor for Ordinary plain masonry shear walls in Bearing Wall System from Table 12.2-1 of ASCE 7, where $R$ = 1.5.

$S_{DS}$ = Design spectral acceleration at short period, in g units.

$S_{D1}$ = Design spectral acceleration at 1-second period, in g units.

$v_a$ = The shear strength of any URM pier, $v_m$A/1.5 pounds (N).

$v_c$ = Unit shear capacity value for a crosswall sheathed with any of the materials given in Table A1-D or A1-E, pounds per foot (N/m).

$v_m$ = Shear strength of unreinforced masonry, pounds per square inch (kPa).

$V_a$ = The shear strength of any URM pier or wall, pounds (N).

$V_{ca}$ = Total shear capacity of crosswalls in the direction of analysis immediately above the diaphragm level being investigated, $v_c L_c$, pounds (N).

$V_{cb}$ = Total shear capacity of crosswalls in the direction of analysis immediately below the diaphragm level being investigated, $v_c L_c$, pounds (N).

$V_p$ = Shear force assigned to a pier on the basis of its relative shear rigidity, pounds (N).

$V_r$ = Pier rocking shear capacity of any URM wall or wall pier, pounds (N).

$v_t$ = Mortar shear strength as specified in Section A106.3.3.5, pounds per square inch (kPa).

$V_{test}$ = Load at incipient cracking for each in-place shear test per UBC Standard 21-6, pounds (kN).

$v_{to}$ = Mortar shear test values as specified in Section A106.3.3.5, pounds per square inch (kPa).

$v_u$ = Unit shear capacity value for a diaphragm sheathed with any of the materials given in Table A1-D or A1-E, pounds per foot (N/m).

$V_{wx}$ = Total shear force resisted by a shear wall at the level under consideration, pounds (N).

$W$ = Total seismic dead load as defined in the building code, pounds (N).

$W_d$ = Total dead load tributary to a diaphragm level, pounds (N).

$W_w$ = Total dead load of a URM wall above the level under consideration or above an open-front building, pounds (N).

$W_{wx}$ = Dead load of a URM wall assigned to level $x$ halfway above and below the level under consideration, pounds (N).

$\Sigma v_u D$ = Sum of diaphragm shear capacities of both ends of the diaphragm, pounds (N).

$\Sigma\Sigma v_u D$ = For diaphragms coupled with crosswalls, $v_u D$ includes the sum of shear capacities of both ends of diaphragms coupled at and above the level under consideration, pounds (N).

$\Sigma W_d$ = Total dead load of all the diaphragms at and above the level under consideration, pounds (N).

## SECTION A105 GENERAL REQUIREMENTS

**A105.1 General.** The seismic-force-resisting system specified in this chapter shall comply with the building code, except as modified herein.

**A105.2 Alterations and repairs.** Alterations and repairs required to meet the provisions of this chapter shall comply with applicable structural requirements of the building code unless specifically provided for in this chapter.

**A105.3 Requirements for plans.** The following construction information shall be included in the plans required by this chapter:

1. Dimensioned floor and roof plans showing existing walls and the size and spacing of floor and roof-framing members and sheathing materials. The plans shall indicate all existing and new crosswalls and shear walls and their materials of construction. The location of these walls and their openings shall be fully dimensioned and drawn to scale on the plans.
2. Dimensioned wall elevations showing openings, piers, wall classes as defined in Section A106.3.3.8, thickness,

heights, wall shear test locations, cracks or damaged portions requiring repairs, the general condition of the mortar joints, and if and where pointing is required. Where the exterior face is veneer, the type of veneer, its thickness and its bonding and/or ties to the structural wall masonry shall also be noted.

3. The type of interior wall and ceiling materials, and framing.
4. The extent and type of existing wall anchorage to floors and roof when used in the design.
5. The extent and type of parapet corrections that were previously performed, if any.
6. *Repair* details, if any, of cracked or damaged unreinforced masonry walls required to resist forces specified in this chapter.
7. All other plans, sections and details necessary to delineate required retrofit construction.
8. The design procedure used shall be stated on both the plans and the permit application.
9. Details of the anchor prequalification program required by UBC Standard 21-7, if used, including location and results of all tests.

**A105.4 Structural observation, testing and inspection.** Structural observation, in accordance with Section 1709 of the *International Building Code*, shall be required for all structures in which seismic retrofit is being performed in accordance with this chapter. Structural observation shall include visual oservation of work for conformance with the approved construction documents and confirmation of existing conditions assumed during design.

Structural testing and inspection for new construction materials shall be in accordance with the building code, except as modified by this chapter.

## SECTION A106 MATERIALS REQUIREMENTS

**A106.1 General.** Materials permitted by this chapter, including their appropriate strength design values and those existing configurations of materials specified herein, may be used to meet the requirements of this chapter.

**A106.2 Existing materials.** Existing materials used as part of the required vertical-load-carrying or lateral-force-resisting system shall be in sound condition, or shall be repaired or removed and replaced with new materials. All other unreinforced masonry materials shall comply with the following requirements:

1. The lay-up of the masonry units shall comply with Section A106.3.2, and the quality of bond between the units has been verified to the satisfaction of the building official;
2. Concrete masonry units are verified to be load-bearing units complying with UBC Standard 21-4 or such other standard as is acceptable to the building official; and
3. The compressive strength of plain concrete walls shall be determined based on cores taken from each class of concrete wall. The location and number of tests shall be the same as those prescribed for tensile-splitting strength tests in Sections A106.3.3.3 and A106.3.3.4, or in Section A108.1.

The use of materials not specified herein or in Section A108.1 shall be based on substantiating research data or engineering judgment, with the approval of the building official.

**A106.3 Existing unreinforced masonry.**

**A106.3.1 General.** Unreinforced masonry walls used to carry vertical loads or seismic forces parallel and perpendicular to the wall plane shall be tested as specified in this section. All masonry that does not meet the minimum standards established by this chapter shall be removed and replaced with new materials, or alternatively, shall have its structural functions replaced with new materials and shall be anchored to supporting elements.

**A106.3.2 Lay-up of walls.**

**A106.3.2.1 Multiwythe solid brick.** The facing and backing shall be bonded so that not less than 10 percent of the exposed face area is composed of solid headers extending not less than 4 inches (102 mm) into the backing. The clear distance between adjacent full-length headers shall not exceed 24 inches (610 mm) vertically or horizontally. Where the backing consists of two or more wythes, the headers shall extend not less than 4 inches (102 mm) into the most distant wythe, or the backing wythes shall be bonded together with separate headers with their area and spacing conforming to the foregoing. Wythes of walls not bonded as described above shall be considered veneer. Veneer wythes shall not be included in the effective thickness used in calculating the height-to-thickness ratio and the shear capacity of the wall.

**Exception:** Veneer wythes anchored as specified in the building code and made composite with backup masonry may be used for calculation of the effective thickness, where $S_{D1}$ exceeds 0.3.

**A106.3.2.2 Grouted or ungrouted hollow concrete or clay block and structural hollow clay tile.** Grouted or ungrouted hollow concrete or clay block and structural hollow clay tile shall be laid in a running bond pattern.

**A106.3.2.3 Other lay-up patterns.** Lay-up patterns other than those specified in Sections A106.3.2.1 and A106.3.2.2 above are allowed if their performance can be justified.

**A106.3.3 Testing of masonry.**

**A106.3.3.1 Mortar tests.** The quality of mortar in all masonry walls shall be determined by performing in-place shear tests in accordance with the following:

1. The bed joints of the outer wythe of the masonry should be tested in shear by laterally displacing a single brick relative to the adjacent bricks in the same wythe. The head joint opposite the loaded end of the test brick should be carefully excavated

and cleared. The brick adjacent to the loaded end of the test brick should be carefully removed by sawing or drilling and excavating to provide space for a hydraulic ram and steel loading blocks. Steel blocks, the size of the end of the brick, should be used on each end of the ram to distribute the load to the brick. The blocks should not contact the mortar joints. The load should be applied horizontally, in the plane of the wythe. The load recorded at first movement of the test brick as indicated by spalling of the face of the mortar bed joints is $V_{test}$ in Equation (A1-3).

2. Alternative procedures for testing shall be used where in-place testing is not practical because of crushing or other failure mode of the masonry unit (see Section A106.3.3.2).

**A106.3.3.2 Alternative procedures for testing masonry.** The tensile-splitting strength of existing masonry, $f_{sp}$, or the prism strength of existing masonry, $f'_m$ may be determined in accordance with one of the following procedures:

1. Wythes of solid masonry units shall be tested by sampling the masonry by drilled cores of not less than 8 inches (203 mm) in diameter. A bed joint intersection with a head joint shall be in the center of the core. The tensile-splitting strength of these cores should be determined by the standard test method of ASTM C 496. The core should be placed in the test apparatus with the bed joint 45 degrees from the horizontal. The tensile-splitting strength should be determined by the following equation:

$$f_{sp} = \frac{2P}{\pi a_n} \qquad \textbf{(Equation A1-1)}$$

2. Hollow unit masonry constructed of through-the-wall units shall be tested by sampling the masonry by a sawn square prism of not less than 18 inches square (11 613 mm²). The tensile-splitting strength should be determined by the standardtest method of ASTM E 519. The diagonal of the prism should be placed in a vertical position. The tensile-splitting strength should be determined by the following equation:

$$f_{sp} = \frac{0.494P}{a_n} \qquad \textbf{(Equation A1-2)}$$

3. An alternative to material testing is estimation of the $f'_m$ of the existing masonry. This alternative should be limited to recently constructed masonry. The determination of $f'_m$ requires that the unit correspond to a specification of the unit by an ASTM standard and classification of the mortar by type.

**A106.3.3.3 Location of tests.** The shear tests shall be taken at locations representative of the mortar conditions throughout the entire building, taking into account variations in workmanship at different building height levels, variations in weathering of the exterior surfaces, and variations in the condition of the interior surfaces due to deterioration caused by leaks and condensation of water and/or by the deleterious effects of other substances contained within the building. The exact test locations shall be determined at the building site by the engineer or architect in responsible charge of the structural design work. An accurate record of all such tests and their locations in the building shall be recorded, and these results shall be submitted to the building department for approval as part of the structural analysis.

**A106.3.3.4 Number of tests.** The minimum number of tests per class shall be as follows:

1. At each of both the first and top stories, not less than two tests per wall or line of wall elements providing a common line of resistance to lateral forces.
2. At each of all other stories, not less than one test per wall or line of wall elements providing a common line of resistance to lateral forces.
3. In any case, not less than one test per 1,500 square feet (139.4 m²) of wall surface and not less than a total of eight tests.

**A106.3.3.5 Minimum quality of mortar.**

1. Mortar shear test values, $v_{to}$, in pounds per square inch (kPa) shall be obtained for each in-place shear test in accordance with the following equation:

$$v_{to} = (V_{test}/A_b) - p_{D+L} \qquad \textbf{(Equation A1-3)}$$

2. Individual unreinforced masonry walls with $v_{to}$ consistently less than 30 pounds per square inch (207 kPa) shall be entirely pointed prior to retesting.
3. The mortar shear strength, $v_t$, is the value in pounds per square inch (kPa) that is exceeded by 80 percent of the mortar shear test values, $v_{to}$.
4. Unreinforced masonry with mortar shear strength, $v_t$, less than 30 pounds per square inch (207 kPa) shall be removed, pointed and retested or shall have its structural function replaced, and shall be anchored to supporting elements in accordance with Sections A106.3.1 and A113.8. When existing mortar in any wythe is pointed to increase its shear strength and is retested, the condition of the mortar in the adjacent bed joints of the inner wythe or wythes and the opposite outer wythe shall be examined for extent of deterioration. The shear strength of any wall class shall be no greater than that of the weakest wythe of that class.

**A106.3.3.6 Minimum quality of masonry.**

1. The minimum average value of tensile-splitting strength determined by Equation (A1-1) or (A1-2) shall be 50 pounds per square inch (344.7 kPa). The minimum value of $f'_m$ determined by categorization of the masonry units and mortar should be 1,000 pounds per square inch (6895 kPa).

2. Individual unreinforced masonry walls with average tensile-splitting strength of less than 50 pounds per square inch (344.7 kPa) shall be entirely pointed prior to retesting.
3. Hollow unit unreinforced masonry walls with estimated prism compressive strength of less than 1,000 pounds per square inch (6895 kPa) shall be grouted to increase the average net area compressive strength.

**A106.3.3.7 Collar joints.** The collar joints shall be inspected at the test locations during each in-place shear test, and estimates of the percentage of adjacent wythe surfaces that are covered with mortar shall be reported along with the results of the in-place shear tests.

**A106.3.3.8 Unreinforced masonry classes.** Existing unreinforced masonry shall be categorized into one or more classes based on shear strength, quality of construction, state of *repair*, deterioration and weathering. A class shall be characterized by the allowable masonry shear stress determined in accordance with Section A108.2. Classes shall be defined for whole walls, not for small areas of masonry within a wall.

**A106.3.3.9 Pointing.** Deteriorated mortar joints in unreinforced masonry walls shall be pointed according to UBC Standard 21-8. Nothing shall prevent pointing of any deteriorated masonry wall joints before the tests are made, except as required in Section A107.1.

## SECTION A107 QUALITY CONTROL

**A107.1 Pointing.** Preparation and mortar pointing shall be performed with special inspection.

> **Exception:** At the discretion of the building official, incidental pointing may be performed without special inspection.

**A107.2 Masonry shear tests.** In-place masonry shear tests shall comply with Section A106.3.3.1. Testing of masonry for determination of tensile-splitting strength shall comply with Section A106.3.3.2.

**A107.3 Existing wall anchors.** Existing wall anchors used as all or part of the required tension anchors shall be tested in pull-out according to UBC Standard 21-7. The minimum number of anchors tested shall be four per floor, with two tests at walls with joists framing into the wall and two tests at walls with joists parallel to the wall, but not less than 10 percent of the total number of existing tension anchors at each level.

**A107.4 New bolts.** All new embedded bolts shall be subject to periodic special inspection in accordance with the building code, prior to placement of the bolt and grout or adhesive in the drilled hole. Five percent of all bolts that do not extend through the wall shall be subject to a direct-tension test, and an additional 20 percent shall be tested using a calibrated torque wrench. Testing shall be performed in accordance with UBC Standard 21-7. New bolts that extend through the wall with steel plates on the far side of the wall need not be tested.

> **Exception:** Special inspection in accordance with the building code may be provided during installation of new anchors in lieu of testing.

All new embedded bolts resisting tension forces or a combination of tension and shear forces shall be subject to periodic special inspection in accordance with the building code, prior to placement of the bolt and grout or adhesive in the drilled hole. Five percent of all bolts resisting tension forces shall be subject to a direct-tension test, and an additional 20 percent shall be tested using a calibrated torque wrench. Testing shall be performed in accordance with UBC Standard 21-7. New through-bolts need not be tested.

## SECTION A108 DESIGN STRENGTHS

**A108.1 Values.**

1. Strength values for existing materials are given in Table A1-D and for new materials in Table A1-E.
2. Capacity reduction factors need not be used.
3. The use of new materials not specified herein shall be based on substantiating research data or engineering judgment, with the approval of the building official.

**A108.2 Masonry shear strength.** The unreinforced masonry shear strength, $v_m$, shall be determined for each masonry class from one of the following equations:

1. The unreinforced masonry shear strength, $v_m$, shall be determined by Equation (A1-4) when the mortar shear strength has been determined by Section A106.3.3.1.

$$v_m = 0.56 v_t + \frac{0.75 P_D}{A} \qquad \textbf{(Equation A1-4)}$$

The mortar shear strength values, $v_t$, shall be determined in accordance with Section A106.3.3.5 and shall not exceed 100 pounds per square inch (689.5 kPa) for the determination of $v_m$.

2. The unreinforced masonry shear, $v_m$, shall be determined by Equation (A1-5) when tensile-splitting strength has been determined in accordance with Section A106.3.3.2, Item 1 or 2.

$$v_m = 0.8 f_{sp} + 0.5 \frac{P_D}{A} \qquad \textbf{(Equation A1-5)}$$

3. When $f'_m$ has been estimated by categorization of the units and mortar in accordance with Section 2105.2.2.1 of the *International Building Code*, the unreinforced masonry shear strength, $v_m$, shall not exceed 200 pounds per square inch (1380 kPa) or the lesser of the following:

a) $2.5\sqrt{f'_m}$ or

b) 200 psi or

c) $v + 0.75 \frac{P_D}{A}$ **(Equation A1-6)**

For SI: 1 psi = 6.895 kPa.

where:

$v$ = 62.5 psi (430 kPa) for running bond masonry not grouted solid.

$v$ = 100 psi (690 kPa) for running bond masonry grouted solid.

$v$ = 25 psi (170 kPa) for stack bond grouted solid.

**A108.3 Masonry compression.** Where any increase in dead plus live compression stress occurs, the compression stress in unreinforced masonry shall not exceed 300 pounds per square inch (2070 kPa).

**A108.4 Masonry tension.** Unreinforced masonry shall be assumed to have no tensile capacity.

**A108.5 Existing tension anchors.** The resistance values of the existing anchors shall be the average of the tension tests of existing anchors having the same wall thickness and joist orientation.

**A108.6 Foundations.** For existing foundations, new total dead loads may be increased over the existing dead load by 25 percent. New total dead load plus live load plus seismic forces may be increased over the existing dead load plus live load by 50 percent. Higher values may be justified only in conjunction with a geotechnical investigation.

## SECTION A109 ANALYSIS AND DESIGN PROCEDURE

**A109.1 General.** The elements of buildings hereby required to be analyzed are specified in Table A1-A.

**A109.2 Selection of procedure.** Buildings with rigid diaphragms shall be analyzed by the general procedure of Section A110, which is based on the building code. Buildings with flexible diaphragms shall be analyzed by the general procedure or, when applicable, may be analyzed by the special procedure of Section A111.

## SECTION A110 GENERAL PROCEDURE

**A110.1 Minimum design lateral forces.** Buildings shall be analyzed to resist minimum lateral forces assumed to act nonconcurrently in the direction of each of the main axes of the structure in accordance with the following:

$$V = \frac{0.75\, S_{DS} W}{R}$$ **(Equation A1-7)**

**A110.2 Lateral forces on elements of structures.** Parts and portions of a structure not covered in Sections A110.3 shall be analyzed and designed per the current building code, using force levels defined in Section A110.1.

**Exceptions:**

1. Unreinforced masonry walls for which height-to-thickness ratios do not exceed ratios set forth in Table A1-B need not be analyzed for out-of-plane loading. Unreinforced masonry walls that exceed the allowable *h/t* ratios of Table A1-B shall be braced according to Section A113.5.
2. Parapets complying with Section A113.6 need not be analyzed for out-of-plane loading.
3. Walls shall be anchored to floor and roof diaphragms in accordance with Section A113.1.

**A110.3 In-plane loading of URM shear walls and frames.** Vertical lateral-load-resisting elements shall be analyzed in accordance with Section A112.

**A110.4 Redundancy and overstrength factors.** Any redundancy or overstrength factors contained in the building code may be taken as unity. The vertical component of earthquake load ($E_v$) may be taken as zero.

## SECTION A111 SPECIAL PROCEDURE

**A111.1 Limits for the application of this procedure.** The special procedures of this section may be applied only to buildings having the following characteristics:

1. Flexible diaphragms at all levels above the base of the structure.
2. Vertical elements of the lateral-force-resisting system consisting predominantly of masonry or concrete shear walls.
3. Except for single-story buildings with an open front on one side only, a minimum of two lines of vertical elements of the lateral-force-resisting system parallel to each axis of the building (see Section A111.8 for open-front buildings).

**A111.2 Lateral forces on elements of structures.** With the exception of the provisions in Sections A111.4 through A111.7, elements of structures shall comply with Sections A110.2 through A110.4.

**A111.3 Crosswalls.** Crosswalls shall meet the requirements of this section.

**A111.3.1 Crosswall definition.** A crosswall is a wood-framed wall sheathed with any of the materials described in Table A1-D or A1-E or other system as defined in Section A111.3.5. Crosswalls shall be spaced no more than 40 feet (12 192 mm) on center measured perpendicular to the direction of consideration, and shall be placed in each story of the building. Crosswalls shall extend the full story height between diaphragms.

**Exceptions:**

1. Crosswalls need not be provided at all levels when used in accordance with Section A111.4.2, Item 4.
2. Existing crosswalls need not be continuous below a wood diaphragm at or within 4 feet (1219 mm) of grade, provided:
   - 2.1. Shear connections and anchorage requirements of Section A111.5 are satisfied at all edges of the diaphragm.

2.2. Crosswalls with total shear capacity of $0.5S_{D1}\Sigma W_d$ interconnect the diaphragm to the foundation.

2.3. The demand-capacity ratio of the diaphragm between the crosswalls that are continuous to their foundations does not exceed 2.5, calculated as follows:

$$DCR = \frac{(2.1S_{D1}W_d + V_{ca})}{2v_u D} \quad \textbf{(Equation A1-8)}$$

**A111.3.2 Crosswall shear capacity.** Within any 40 feet (12 192 mm) measured along the span of the diaphragm, the sum of the crosswall shear capacities shall be at least 30 percent of the diaphragm shear capacity of the strongest diaphragm at or above the level under consideration.

**A111.3.3 Existing crosswalls.** Existing crosswalls shall have a maximum height-to-length ratio between openings of 1.5 to 1. Existing crosswall connections to diaphragms need not be investigated as long as the crosswall extends to the framing of the diaphragms above and below.

**A111.3.4 New crosswalls.** New crosswall connections to the diaphragm shall develop the crosswall shear capacity. New crosswalls shall have the capacity to resist an overturning moment equal to the crosswall shear capacity times the story height. Crosswall overturning moments need not be cumulative over more than two stories.

**A111.3.5 Other crosswall systems.** Other systems, such as moment-resisting frames, may be used as crosswalls provided that the yield story drift does not exceed 1 inch (25.4 mm) in any story.

**A111.4 Wood diaphragms.**

**A111.4.1 Acceptable diaphragm span.** A diaphragm is acceptable if the point (*L,DCR*) on Figure A1-1 falls within Region 1, 2 or 3.

**A111.4.2 Demand-capacity ratios.** Demand-capacity ratios shall be calculated for the diaphragm at any level according to the following formulas:

1. For a diaphragm without qualifying crosswalls at levels immediately above or below:

$$DCR = 2.1S_{D1}W_d/\Sigma v_u D \quad \textbf{(Equation A1-9)}$$

2. For a diaphragm in a single-story building with qualifying crosswalls, or for a roof diaphragm coupled by crosswalls to the diaphragm directly below:

$$DCR = 2.1S_{D1}W_d/(\Sigma v_u D + V_{cb}) \quad \textbf{(Equation A1-10)}$$

3. For diaphragms in a multistory building with qualifying crosswalls in all levels:

$$DCR = 2.1S_{D1}\Sigma W_d/(\Sigma\Sigma v_u D + V_{cb}) \quad \textbf{(Equation A1-11)}$$

*DCR* shall be calculated at each level for the set of diaphragms at and above the level under consideration. In addition, the roof diaphragm shall also meet the requirements of Equation (A1-10).

4. For a roof diaphragm and the diaphragm directly below, if coupled by crosswalls:

$$DCR = 2.1S_{D1}\Sigma W_d/\Sigma\Sigma v_u D \quad \textbf{(Equation A1-12)}$$

**A111.4.3 Chords.** An analysis for diaphragm flexure need not be made, and chords need not be provided.

**A111.4.4 Collectors.** An analysis of diaphragm collector forces shall be made for the transfer of diaphragm edge shears into vertical elements of the lateral-force-resisting system. Collector forces may be resisted by new or existing elements.

**A111.4.5 Diaphragm openings.**

1. Diaphragm forces at corners of openings shall be investigated and shall be developed into the diaphragm by new or existing materials.
2. In addition to the demand-capacity ratios of Section A111.4.2, the demand-capacity ratio of the portion of the diaphragm adjacent to an opening shall be calculated using the opening dimension as the span.
3. Where an opening occurs in the end quarter of the diaphragm span, the calculation of $v_u D$ for the demand-capacity ratio shall be based on the net depth of the diaphragm.

**A111.5 Diaphragm shear transfer.** Diaphragms shall be connected to shear walls with connections capable of developing the diaphragm-loading tributary to the shear wall given by the lesser of the following formulas:

$$V = 1.2S_{D1}C_p W_d \quad \textbf{(Equation A1-13)}$$

using the $C_p$ values in Table A1-C, or

$$V = v_u D \quad \textbf{(Equation A1-14)}$$

**A111.6 Shear walls (In-plane loading).**

**A111.6.1 Wall story force.** The wall story force distributed to a shear wall at any diaphragm level shall be the lesser value calculated as:

$$F_{wx} = 0.8S_{D1}(W_{wx} + W_d/2) \quad \textbf{(Equation A1-15)}$$

but need not exceed

$$F_{wx} = 0.8S_{D1}W_{wx} + v_u D \quad \textbf{(Equation A1-16)}$$

**A111.6.2 Wall story shear.** The wall story shear shall be the sum of the wall story forces at and above the level of consideration.

$$V_{wx} = \Sigma F_{wx} \quad \textbf{(Equation A1-17)}$$

**A111.6.3 Shear wall analysis.** Shear walls shall comply with Section A112.

**A111.6.4 Moment frames.** Moment frames used in place of shear walls shall be designed as required by the building code, except that the forces shall be as specified in Section A111.6.1, and the story drift ratio shall be limited to 0.015, except as further limited by Section A112.4.2.

**A111.7 Out-of-plane forces—unreinforced masonry walls.**

**A111.7.1 Allowable unreinforced masonry wall height-to-thickness ratios.** The provisions of Section A110.2 are applicable, except the allowable height-to-thickness ratios given in Table A1-B shall be determined from Figure A1-1 as follows:

1. In Region 1, height-to-thickness ratios for buildings with crosswalls may be used if qualifying crosswalls are present in all stories.
2. In Region 2, height-to-thickness ratios for buildings with crosswalls may be used whether or not qualifying crosswalls are present.
3. In Region 3, height-to-thickness ratios for "all other buildings" shall be used whether or not qualifying crosswalls are present.

**A111.7.2 Walls with diaphragms in different regions.** When diaphragms above and below the wall under consideration have demand-capacity ratios in different regions of Figure A1-1, the lesser height-to-thickness ratio shall be used.

**A111.8 Open-front design procedure.** A single-story building with an open front on one side and crosswalls parallel to the open front may be designed by the following procedure:

1. Effective diaphragm span, $L_i$, for use in Figure A1-1 shall be determined in accordance with the following formula:

$$L_i = 2\,[(W_w/W_d)L + L] \quad \textbf{(Equation A1-18)}$$

2. Diaphragm demand-capacity ratio shall be calculated as:

$$DCR = 2.12S_{D1}(W_d + W_w)/[(v_uD) + V_{cb}] \quad \textbf{(Equation A1-19)}$$

## SECTION A112
## ANALYSIS AND DESIGN

**A112.1 General.** The following requirements are applicable to both the general procedure and the special procedure for analyzing vertical elements of the lateral-force-resisting system.

**A112.2 Existing unreinforced masonry walls.**

**A112.2.1 Flexural rigidity.** Flexural components of deflection may be neglected in determining the rigidity of an unreinforced masonry wall.

**A112.2.2 Shear walls with openings.** Wall piers shall be analyzed according to the following procedure, which is diagramed in Figure A1-2.

1. For any pier,

   1.1. The pier shear capacity shall be calculated as:

$$V_a = v_m A/1.5 \quad \textbf{(Equation A1-20)}$$

   1.2. The pier rocking shear capacity shall be calculated as:

$$V_r = 0.9P_D D/H \quad \textbf{(Equation A1-21)}$$

2. The wall piers at any level are acceptable if they comply with one of the following modes of behavior:

   2.1. **Rocking controlled mode.** When the pier rocking shear capacity is less than the pier shear capacity, i.e., $V_r < V_a$ for each pier in a level, forces in the wall at that level, $V_{wx}$, shall be distributed to each pier in proportion to $P_D D/H$.

   For the wall at that level:

$$0.7\,V_{wx} < \Sigma V_r \quad \textbf{(Equation A1-22)}$$

   2.2. **Shear controlled mode.** Where the pier shear capacity is less than the pier rocking capacity, i.e., $V_a < V_r$ in at least one pier in a level, forces in the wall at the level, $V_{wx}$, shall be distributed to each pier in proportion to $D/H$.

   For each pier at that level:

$$V_p < V_a \quad \textbf{(Equation A1-23)}$$

   and

$$V_p < V_r \quad \textbf{(Equation A1-24)}$$

   If $V_p < V_a$ for each pier and $V_p > V_r$ for one or more piers, such piers shall be omitted from the analysis, and the procedure shall be repeated for the remaining piers, unless the wall is strengthened and reanalyzed.

3. **Masonry pier tension stress.** Unreinforced masonry wall piers need not be analyzed for tension stress.

**A112.2.3 Shear walls without openings.** Shear walls without openings shall be analyzed the same as for walls with openings, except that $V_r$ shall be calculated as follows:

$$V_r = 0.9\,(P_D + 0.5P_w)\,D/H \quad \textbf{(Equation A1-25)}$$

**A112.3 Plywood-sheathed shear walls.** Plywood-sheathed shear walls may be used to resist lateral forces for buildings with flexible diaphragms analyzed according to provisions of Section A111. Plywood-sheathed shear walls may not be used to share lateral forces with other materials along the same line of resistance.

**A112.4 Combinations of vertical elements.**

**A112.4.1 Lateral-force distribution.** Lateral forces shall be distributed among the vertical-resisting elements in proportion to their relative rigidities, except that moment-resisting frames shall comply with Section A112.4.2.

**A112.4.2 Moment-resisting frames.** Moment-resisting frames shall not be used with an unreinforced masonry wall in a single line of resistance unless the wall has piers that have adequate shear capacity to sustain rocking in accordance with Section A112.2.2. The frames shall be designed in accordance with the building code to carry 100 percent of the lateral forces tributary to that line of resistance, as determined from Equation (A1-7). The story drift ratio shall be limited to 0.0075.

## SECTION A113 DETAILED SYSTEM DESIGN REQUIREMENTS

**A113.1 Wall anchorage.**

**A113.1.1 Anchor locations.** Unreinforced masonry walls shall be anchored at the roof and floor levels as required in Section A110.2. Ceilings of plaster or similar materials, when not attached directly to roof or floor framing and where abutting masonry walls, shall either be anchored to the walls at a maximum spacing of 6 feet (1829 mm), or be removed.

**A113.1.2 Anchor requirements.** Anchors shall consist of bolts installed through the wall as specified in Table A1-E, or an approved equivalent at a maximum anchor spacing of 6 feet (1829 mm). All wall anchors shall be secured to the joists to develop the required forces.

**A113.1.3 Minimum wall anchorage.** Anchorage of masonry walls to each floor or roof shall resist a minimum force determined as $0.9S_{DS}$ times the tributary weight or 200 pounds per linear foot (2920 N/m), whichever is greater, acting normal to the wall at the level of the floor or roof. Existing wall anchors, if used, must meet the requirements of this chapter or must be upgraded.

**A113.1.4 Anchors at corners.** At the roof and floor levels, both shear and tension anchors shall be provided within 2 feet (610 mm) horizontally from the inside of the corners of the walls.

**A113.2 Diaphragm shear transfer.** Bolts transmitting shear forces shall have a maximum bolt spacing of 6 feet (1829 mm) and shall have nuts installed over malleable iron or plate washers when bearing on wood, and heavy-cut washers when bearing on steel.

**A113.3 Collectors.** Collector elements shall be provided that are capable of transferring the seismic forces originating in other portions of the building to the element providing the resistance to those forces.

**A113.4 Ties and continuity.** Ties and continuity shall conform to the requirements of the building code.

**A113.5 Wall bracing.**

**A113.5.1 General.** Where a wall height-to-thickness ratio exceeds the specified limits, the wall may be laterally supported by vertical bracing members per Section A113.5.2 or by reducing the wall height by bracing per Section A113.5.3.

**A113.5.2 Vertical bracing members.** Vertical bracing members shall be attached to floor and roof construction for their design loads independently of required wall anchors. Horizontal spacing of vertical bracing members shall not exceed one-half of the unsupported height of the wall or 10 feet (3048 mm). Deflection of such bracing members at design loads shall not exceed one-tenth of the wall thickness.

**A113.5.3 Intermediate wall bracing.** The wall height may be reduced by bracing elements connected to the floor or roof. Horizontal spacing of the bracing elements and wall anchors shall be as required by design, but shall not exceed 6 feet (1829 mm) on center. Bracing elements shall be detailed to minimize the horizontal displacement of the wall by the vertical displacement of the floor or roof.

**A113.6 Parapets.** Parapets and exterior wall appendages not conforming to this chapter shall be removed, or stabilized or braced to ensure that the parapets and appendages remain in their original positions.

The maximum height of an unbraced unreinforced masonry parapet above the lower of either the level of tension anchors or the roof sheathing shall not exceed the height-to-thickness ratio shown in Table A1-F. If the required parapet height exceeds this maximum height, a bracing system designed for the forces determined in accordance with the building code shall support the top of the parapet. Parapet corrective work must be performed in conjunction with the installation of tension roof anchors.

The minimum height of a parapet above any wall anchor shall be 12 inches (305 mm).

**Exception:** If a reinforced concrete beam is provided at the top of the wall, the minimum height above the wall anchor may be 6 inches (152 mm).

**A113.7 Veneer.**

1. Veneer shall be anchored with approved anchor ties conforming to the required design capacity specified in the building code and shall be placed at a maximum spacing of 24 inches (610 mm) with a maximum supported area of 4 square feet (0.372 $m^2$).

   **Exception:** Existing anchor ties for attaching brick veneer to brick backing may be acceptable, provided the ties are in good condition and conform to the following minimum size and material requirements.

   Existing veneer anchor ties may be considered adequate if they are of corrugated galvanized iron strips not less than 1 inch (25.4 mm) in width, 8 inches (203 mm) in length and $^1/_{16}$ inch (1.6 mm) in thickness, or the equivalent.

2. The location and condition of existing veneer anchor ties shall be verified as follows:

   2.1. An approved testing laboratory shall verify the location and spacing of the ties and shall submit a report to the building official for approval as part of the structural analysis.

   2.2. The veneer in a selected area shall be removed to expose a representative sample of ties (not less than four) for inspection by the building official.

**A113.8 Nonstructural masonry walls.** Unreinforced masonry walls that carry no design vertical or lateral loads and that are not required by the design to be part of the lateral-force resisting system shall be adequately anchored to new or existing supporting elements. The anchors and elements shall be designed for the out-of-plane forces specified in the building code. The height- or length-to-thickness ratio between such supporting elements for such walls shall not exceed nine.

**A113.9 Truss and beam supports.** Where trusses and beams other than rafters or joists are supported on masonry, independent secondary columns shall be installed to support vertical loads of the roof or floor members.

**Exception:** Secondary supports are not required where $S_{D1}$ is less than 0.3g.

**A113.10 Adjacent buildings.** Where elements of adjacent buildings do not have a separation of at least 5 inches (127 mm), the allowable height-to-thickness ratios for "all other buildings" per Table A1-B shall be used in the direction of consideration.

## SECTION A114 WALLS OF UNBURNED CLAY, ADOBE OR STONE MASONRY

**A114.1 General.** Walls of unburned clay, adobe or stone masonry construction shall conform to the following:

1. Walls of unburned clay, adobe or stone masonry shall not exceed a height- or length-to-thickness ratio specified in Table A1-G.
2. Adobe may be allowed a maximum value of 9 pounds per square inch (62.1 kPa) for shear unless higher values are justified by test.
3. Mortar for repointing may be of the same soil composition and stabilization as the brick, in lieu of cement-mortar.

**TABLE A1-A—ELEMENTS REGULATED BY THIS CHAPTER**

| BUILDING ELEMENTS | $S_{D1}$ | | | |
|---|---|---|---|---|
| | ≥ $0.067_g$ < $0.133_g$ | ≥ $0.133_g$ < $0.20_g$ | ≥ $0.20_g$ < $0.30_g$ | > $0.30_g$ |
| Parapets | X | X | X | X |
| Walls, anchorage | X | X | X | X |
| Walls, *h/t* ratios | | X | X | X |
| Walls, in-plane shear | | X | X | X |
| Diaphragms[a] | | | X | X |
| Diaphragms, shear transfer[b] | | X | X | X |
| Diaphragms, demand-capacity ratios[b] | | | X | X |

a. Applies only to buildings designed according to the general procedures of Section A110.
b. Applies only to buildings designed according to the special procedures of Section A111.

**TABLE A1-B—ALLOWABLE VALUE OF HEIGHT-TO-THICKNESS RATIO OF UNREINFORCED MASONRY WALLS**

| WALL TYPES | $0.13_g \le S_{D1} < 0.25_g$ | $0.25_g \le S_{D1} < 0.4_g$ | $S_{D1} \ge 0.4_g$ BUILDINGS WITH CROSSWALLS[a] | $S_{D1} > 0.4_g$ ALL OTHER BUILDINGS |
|---|---|---|---|---|
| Walls of one-story buildings | 20 | 16 | 16[b,c] | 13 |
| First-story wall of multistory building | 20 | 18 | 16 | 15 |
| Walls in top story of multistory building | 14 | 14 | 14[b,c] | 9 |
| All other walls | 20 | 16 | 16 | 13 |

a. Applies to the special procedures of Section A111 only. See Section A111.7 for other restrictions.
b. This value of height-to-thickness ratio may be used only where mortar shear tests establish a tested mortar shear strength, $v_t$, of not less than 100 pounds per square inch (690 kPa). This value may also be used where the tested mortar shear strength is not less than 60 pounds per square inch (414 kPa), and where a visual examination of the collar joint indicates not less than 50-percent mortar coverage.
c. Where a visual examination of the collar joint indicates not less than 50-percent mortar coverage, and the tested mortar shear strength, $v_t$, is greater than 30 pounds per square inch (207 kPa) but less than 60 pounds per square inch (414 kPa), the allowable height-to-thickness ratio may be determined by linear interpolation between the larger and smaller ratios in direct proportion to the tested mortar shear strength.

**TABLE A1-C—HORIZONTAL FORCE FACTOR, $C_p$**

| CONFIGURATION OF MATERIALS | $C_p$ |
|---|---|
| Roofs with straight or diagonal sheathing and roofing applied directly to the sheathing, or floors with straight tongue-and-groove sheathing. | 0.50 |
| Diaphragms with double or mulitple layers of boards with edges offset, and blocked plywood systems. | 0.75 |
| Diaphragms of metal deck without topping: | |
| Minimal welding or mechanical attachment. | 0.6 |
| Welded or mechanically attached for seismic resistance. | 0.68 |

**TABLE A1-D—STRENGTH VALUES FOR EXISTING MATERIALS**

| EXISTING MATERIALS OR CONFIGURATION OF MATERIALS[a] | | STRENGTH VALUES |
|---|---|---|
| | | × 14.594 for N/m |
| Horizontal diaphragms | Roofs with straight sheathing and roofing applied directly to the sheathing. | 300 lbs. per ft. for seismic shear |
| | Roofs with diagonal sheathing and roofing applied directly to the sheathing. | 750 lbs. per ft. for seismic shear |
| | Floors with straight tongue-and-groove sheathing. | 300 lbs. per ft. for seismic shear |
| | Floors with straight sheathing and finished wood flooring with board edges offset or perpendicular. | 1,500 lbs. per ft. for seismic shear |
| | Floors with diagonal sheathing and finished wood flooring. | 1,800 lbs. per ft. for seismic shear |
| | Metal deck welded with minimal welding.[c] | 1,800 lbs, per ft. for seismic shear |
| | Metal deck welded for seismic resistance.[d] | 3,000 lbs. per ft. for seismic shear |
| Crosswalls[b] | Plaster on wood or metal lath. | 600 lbs. per ft. for seismic shear |
| | Plaster on gypsum lath. | 550 lbs. per ft. for seismic shear |
| | Gypsum wallboard, unblocked edges. | 200 lbs. per ft. for seismic shear |
| | Gypsum wallboard, blocked edges. | 400 lbs. per ft. for seismic shear |
| Existing footing, wood framing, structural steel, reinforcing steel | Plain concrete footings. | $f'_c$ = 1,500 psi (10.34 MPa) unless otherwise shown by tests |
| | Douglas fir wood. | Same as D.F. No. 1 |
| | Reinforcing steel. | $F_y$ = 40,000 psi (124.1 N/mm$^2$) maximum |
| | Structural steel. | $F_y$ = 33,000 psi (137.9 N/mm$^2$) maximum |

a. Material must be sound and in good condition.
b. Shear values of these materials may be combined, except the total combined value should not exceed 900 pounds per foot (4380 N/m).
c. Minimum 22-gage steel deck with welds to supports satisfying the standards of the Steel Deck Institute.
d. Minimum 22-gage steel deck with $^3/_4$ ϕ plug welds at an average spacing not exceeding 8 inches (203 mm) and with sidelap welds appropriate for the deck span.

**TABLE A1-E—STRENGTH VALUES OF NEW MATERIALS USED IN CONJUNCTION WITH EXISTING CONSTRUCTION**

| NEW MATERIALS OR CONFIGURATION OF MATERIALS | | STRENGTH VALUES |
|---|---|---|
| Horizontal diaphragms | Plywood sheathing applied directly over existing straight sheathing with ends of plywood sheets bearing on joists or rafters and edges of plywood located on center of individual sheathing boards. | 675 lbs. per ft. |
| Crosswalls | Plywood sheathing applied directly over wood studs; no value should be given to plywood applied over existing plaster or wood sheathing. | 1.2 times the value specified in the current building code. |
| | Drywall or plaster applied directly over wood studs. | The value specified in the current building code. |
| | Drywall or plaster applied to sheathing over existing wood studs. | 50 percent of the value specified in the current building code. |
| Tension bolts[e] | Bolts extending entirely through unreinforced masonry wall secured with bearing plates on far side of a three-wythe- minimum wall with at least 30 square inches of area.[b,c] | 5,400 lbs. per bolt<br>2,700 lbs. for two-wythe walls |
| Shear bolts[e] | Bolts embedded a minimum of 8 inches into unreinforced masonry walls; bolts should be centered in $2^1/_2$-inch-diameter holes with dry-pack or nonshrink grout around the circumference of the bolt. | The value for plain masonry specified for solid masonry in the current building code; no value larger than those given for $^3/_4$-inch bolts should be used. |
| Combined tension and shear bolts | Through-bolts—bolts meeting the requirements for shear and for tension bolts.[b,c] | Tension—same as for tension bolts<br>Shear—same as for shear bolts |
| | Embedded bolts—bolts extending to the exterior face of the wall with a $2^1/_2$-inch round plate under the head and drilled at an angle of $22^1/_2$ degrees to the horizontal; installed as specified for shear bolts.[a,b,c] | Tension—3,600 lbs. per bolt<br>Shear—same as for shear bolts |
| Infilled walls | Reinforced masonry infilled openings in existing unreinforced masonry walls; provide keys or dowels to match reinforcing. | Same as values specified for unreinforced masonry walls |
| Reinforced masonry[d] | Masonry piers and walls reinforced per the current building code. | The value specified in the current building code for strength design. |
| Reinforced concrete[d] | Concrete footings, walls and piers reinforced as specified in the current building code. | The value specified in the current building code for strength design. |

For SI: 1 inch = 25.4 mm, 1 square inch = 645.16 $mm^2$, 1 pound = 4.4 N.

a. Embedded bolts to be tested as specified in Section A107.4.

b. Bolts to be $^1/_2$ inch (12.7 mm) minimum in diameter.

c. Drilling for bolts and dowels shall be done with an electric rotary drill; impact tools should not be used for drilling holes or tightening anchors and shear bolt nuts.

d. No load factors or capacity reduction factor shall be used.

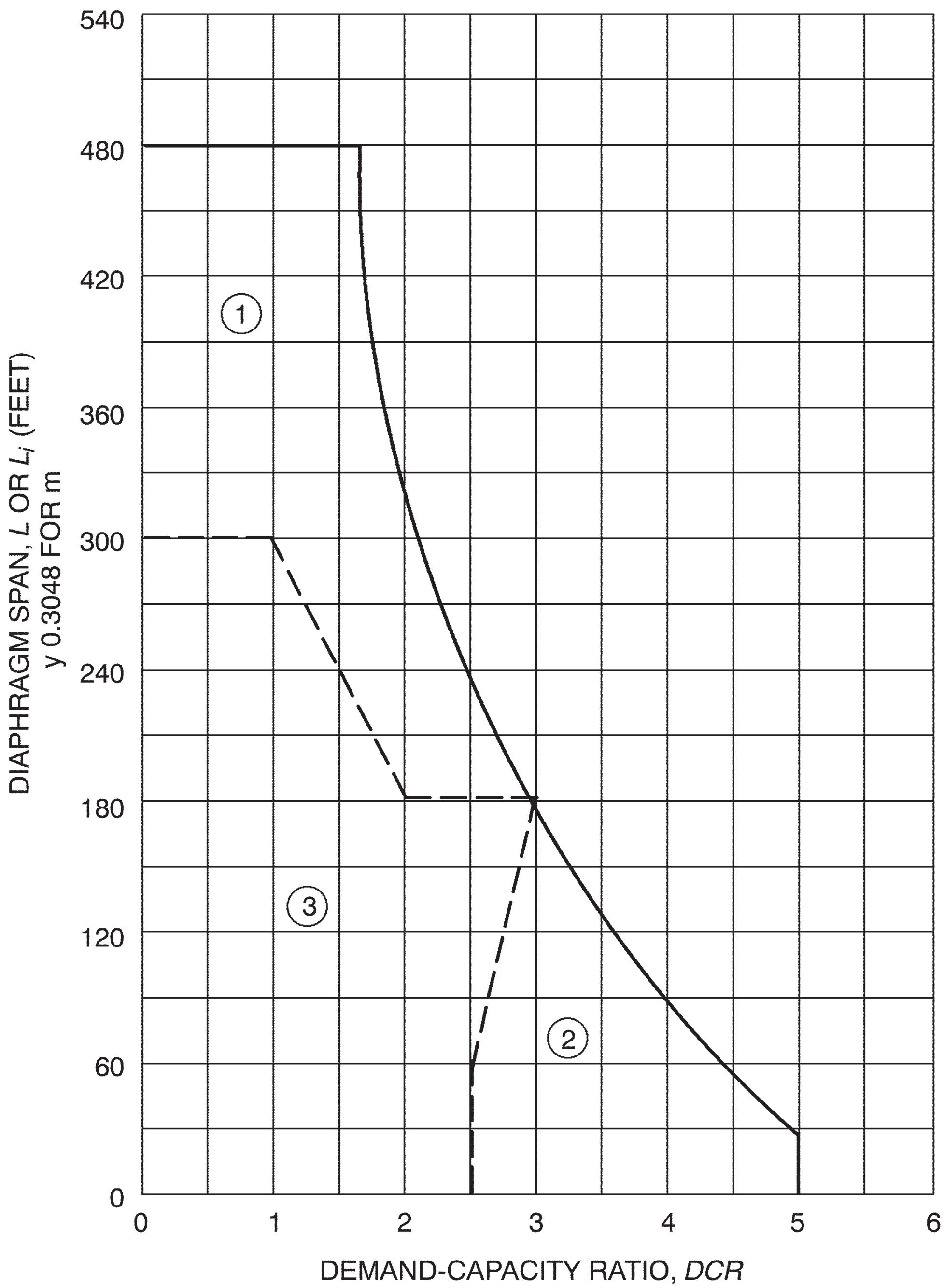
e. Other bolt sizes, values and installation methods may be used, provided a testing program is conducted in accordance with UBC Standard 21-7. The useable value shall be determined by multiplying the calculated allowable value, as determined by UBC Standard 21-7, by 3.0, and the useable value shall be limited to a maximum of 1.5 times the value given in the table. Bolt spacing shall not exceed 6 feet (1829 mm) on center and shall not be less than 12 inches (305 mm) on center.

**TABLE A1-F—MAXIMUM ALLOWABLE HEIGHT-TO-THICKNESS RATIOS FOR PARAPETS**

| | $S_{D1}$ | | |
|---|---|---|---|
| | $0.13_g \le S_{D1} < 0.25_g$ | $0.25_g \le S_{D1} < 0.4_g$ | $S_{D1} \ge 0.4_g$ |
| Maximum allowable height-to-thickness ratios | 2.5 | 2.5 | 1.5 |

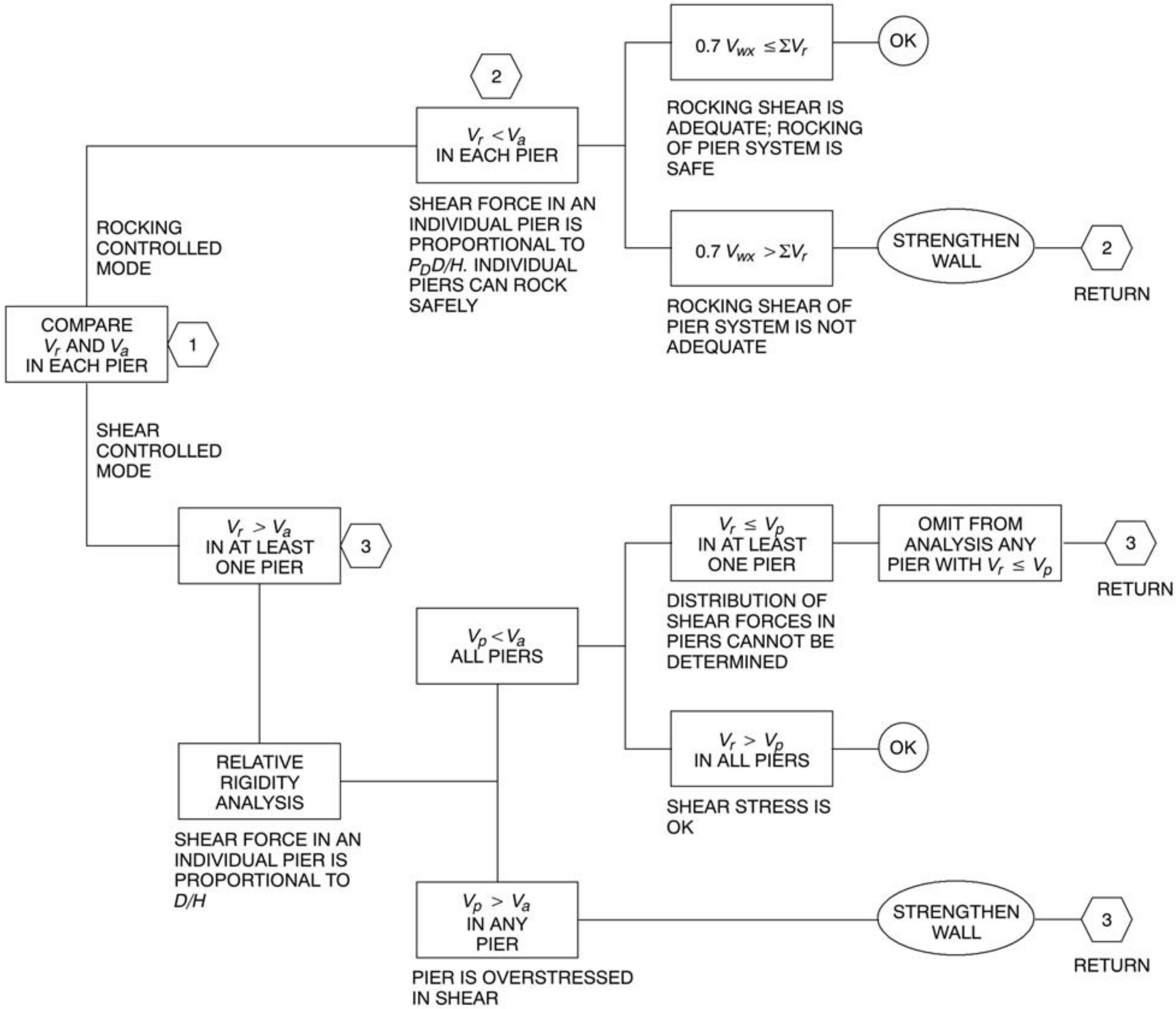
**TABLE A1-G—MAXIMUM HEIGHT-TO-THICKNESS RATIOS FOR ADOBE OR STONE WALLS**

| | $S_{D1}$ | | |
|---|---|---|---|
| | $0.13_g \# S_{D1} < 0.25_g$ | $0.25_g \# S_{D1} < 0.4_g$ | $S_{D1} \ge 0.4_g$ |
| One-story buildings | 12 | 10 | 8 |
| Two-story buildings | | | |
| First story | 14 | 11 | 9 |
| Second story | 12 | 10 | 8 |




1. Region of demand-capacity ratios where crosswalls may be used to increase *h/t* ratios.
2. Region of demand-capacity ratios where *h/t* ratios of "buildings with crosswalls" may be used, whether or not crosswalls are present.
3. Region of demand-capacity ratios where *h/t* ratios of "all other buildings" shall be used, whether or not crosswalls are present.

**FIGURE A1-1**
**ACCEPTABLE DIAPHRAGM SPAN**




$V_a$ = Allowable shear strength of a pier.
$V_p$ = Shear force assigned to a pier on the basis of a relative shear rigidity analysis.
$V_r$ = Rocking shear capacity of pier.
$V_{wx}$ = Total shear force resisted by the wall.
$\Sigma V_r$ = Rocking shear capacity of all piers in the wall.

**FIGURE A1-2**
**ANALYSIS OF URM WALL IN-PLANE SHEAR FORCES**