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California DSA/SS & OSHPD Requirements for Masonry: An Example of Enhanced Masonry Design

Introduction

The California Building Code (CBC) Masonry design regulations for public schools, community colleges, other state-owned buildings, and hospitals in Chapter 21A differ in a number of respects from the regulations for other buildings in Chapter 21.

The 1933 Long Beach earthquake damaged 75% of public school buildings in the city. Soon after, the Safety of Design and Construction of Public School Buildings Act of 1933, also known as the Field Act, regulated the construction of schools.

Another class of important facilities, hospitals, failed to perform well during the 1971 San Fernando Earthquake. Several hospitals collapsed in the

earthquake and many people died. Consequently, the 1973 Alquist Hospital Safety Act required that new hospital buildings to be designed having higher seismic safety standards.

The current California code contains special provisions for the design and construction of schools and hospitals.

This edition of Masonry Chronicles will discuss the enhanced masonry design requirements of CBC Chapter 21A for schools and hospitals.

Overview of DSA/SS & OSHPD Requirements

Chapter 21A of the California Building Code is applicable to:

1. Public Schools, community colleges, and state-owned or state-leased essential services buildings regulated by the Division of the State Architect, Structural Safety System (DSA/SS) and
2. Hospitals, skilled-nursing facilities, intermediate-care facilities, and correctional treatment centers regulated by the Office of Statewide Health Planning and Development (OSHPD).

Chapter 21 is applicable to all other structures. Although the design fundamentals are the same in Chapter 21A as in Chapter 21, extra precautions have been taken in Chapter 21A to ensure that these essential facilities perform satisfactorily, particularly during a seismic event.

The sections of the code with tougher regulations for schools and hospitals are Material Standards, Mortar and Grout, Construction, Quality Assurance, General Design Requirements, Working Stress Design of Masonry, and Strength Design of Masonry. Significant differences, however, have to do with Construction, Quality

Assurance, and Design Requirements. For simplicity, the above sections of the code are discussed here in same order as they appear in code.

Section 2102A – Material Standards

Some of the UBC and ASTM standards for materials are not adopted for construction of schools and hospitals. These include the UBC Standard 21-11 for cement; ASTM C 34, C56, C212, and C530 and UBC Standard 21-1 for clay or shale units; and UBC Standards 21-2 and 21-9 for calcium silicate. In addition, Chapter 21 does not permit the use of grade NW clay units. Moreover, the application of UBC Standard 21-4 for concrete masonry units is limited to grade N-1.

According to Chapter 21A, open-end concrete masonry units shall be grouted solid and need not comply with the web-thickness requirements of Table 21-4-C, UBC Standard 21-4 (Section 2102A.2).

Section 2103A – Mortar and Grout

Table 21-A, “Mortar Properties for Unit Masonry,” has been modified in Chapter 21A. Mortar types N and O for cement-lime, N for mortar cement, and N and O for masonry cement have been eliminated in Table 21A-A, as shown in Table 1 below.

Mortar. For schools and hospitals mortar shall conform to the proportions shown in Table 21A-A for Type S mortar. Lime shall be the last material added to the mixer. Materials for mortar and grout shall be measured in suitable calibrated devices. Shovel measurements will not be accepted. Aggregates for mortar shall conform to the provisions set forth in ASTM C 144, Aggregates for Masonry Mortar. Mortar shall attain a minimum compressive strength of 1,500 psi (10.34 MPa) at 28 days for masonry with $f'_m = 1,500$ psi (10.34 MPa) for field test specimens prepared according to UBC Standard 21-16 (Section 2103A.3.2).

Grout. There are additional requirements for selecting grout proportions for schools and hospitals. The water content expressed on a saturated surface-dry basis shall not exceed 0.7 times the weight (mass) of cement. For coarse grout, the coarse and fine aggregates shall be combined such that the fine aggregate part is not greater than 80 percent of the total aggregate weight (mass) and at least 90 percent shall pass the 1/2 inch (12.7 mm) sieve. Coarse grout proportioned by weight shall contain not less than 564 pounds of cementitious material per cubic yard (335 kg/m³).

According to Section 2103A.4.3 aggregate for grout shall conform to the requirements set forth in ASTM C 404, Aggregates for Grout. Coarse grout shall be used in grout spaces 2 inches (51 mm) or more in width and in all filled-cell masonry construction.

Table 1 – Mortar Proportions for Unit Masonry (2001 CBC Table 21-A), Shaded Areas Omitted in Table 21A-A

Mortar	Type	Proportions by Volume (Cementitious Materials)							Aggregate Measured in a damp, loose Condition	
		Portland Cement or Blended Cement	Masonry Cement			Mortar Cement				Hydrated Lime or Lime putty
	M		S	N	M	S	N			
Cement-lime	M	1	-	-	-	-	-	-	¼	Not less than 2¼ and no more than 3 times the sum of the separate volumes of cementitious material.
	S	1	-	-	-	-	-	-	over ¼ to ½	
	N	1	-	-	-	-	-	-	over ½ to 1¼	
	O	1	-	-	-	-	-	-	over 1¼ to 2½	
Mortar cement	M	1	-	-	-	-	-	1	-	
	M	-	-	-	-	1	-	-	-	
	S	½	-	-	-	-	-	1	-	
	S	-	-	-	-	-	1	-	-	
Masonry cement	N	-	-	-	-	-	-	1	-	
	M	1	-	-	-	-	-	-	-	
	M	-	1	-	-	-	-	-	-	
	S	½	-	-	-	1	-	-	-	
	S	-	-	1	-	-	-	-	-	
	N	-	-	-	-	1	-	-	-	
O	-	-	-	-	1	-	-	-		

Section 2104A – Construction

Code regulations for construction of schools and hospitals does not allow masonry to be laid when the outside air temperature is below 40°F (4.5°C) unless approved methods are used during construction to prevent damage to the masonry. Such methods shall include protection of the masonry for a period of at least 48 hours where Type I or II Portland cement is used in the mortar and grout and for a period of 24 hours where Type III Portland cement is used (Section 2104A.3.4).

Chapter 21A limits the projection of mortars into grout spaces to 1/4 inch (Section 2104.6.1); Chapter 21 limits it to 1/2 inch. Two new sub-sections for reinforced grouted masonry (2104A.6.1.1) and reinforced hollow-unit masonry (2104A.6.1.2) have been added in Chapter 21A.

Section 2104A.6.2 requires that grout that is not mechanically vibrated be puddled. Also, joint reinforcement shall not be used as the principal reinforcement in masonry designed by the strength design method.

Section 2105A – Quality Assurance

One of the main differences between the code regulations for schools and hospitals, and regulations for other buildings is how the quality assurance is addressed. The added Section 2105A.3.0 requires that the specified compressive strength, f'_m , be assumed in design to be 1,500 psi (10.34 MPa) for all masonry construction, using materials and details of construction required therein. Where an f'_m greater than 1,500 psi (10.34 MPa) is approved, the architect or structural engineer shall establish a method of quality control of the masonry construction acceptable to the enforcement agency, which shall be described in the contract specifications.

According to Section 2105A.3.1, no fewer than two cores with a diameter of 6 inches (152 mm) shall be taken from each project. Two cores shall be taken from each building for each 5,000 square feet (465 m²) of the greater of the masonry wall area or the floor area or fraction thereof. The architect or structural engineer in responsible charge of the project or his/her representative shall select the areas for sampling. Half of the cores taken shall be tested in shear. The shear wall loadings shall test both joints between the grout core and the outside wythes of the masonry. Core samples shall not be soaked before testing.

For regular buildings, masonry prism testing for masonry and testing of grout during construction is not required when half of the allowable masonry stresses are used in design. For schools and hospitals however,

such tests shall be performed in all cases as Chapter 21A does not contain the half-stress regulations. Figure 1 shows a typical masonry prism. The UBC Standards 21-16 and 21-18 for mortar testing and grout testing are not adopted by the State of California.

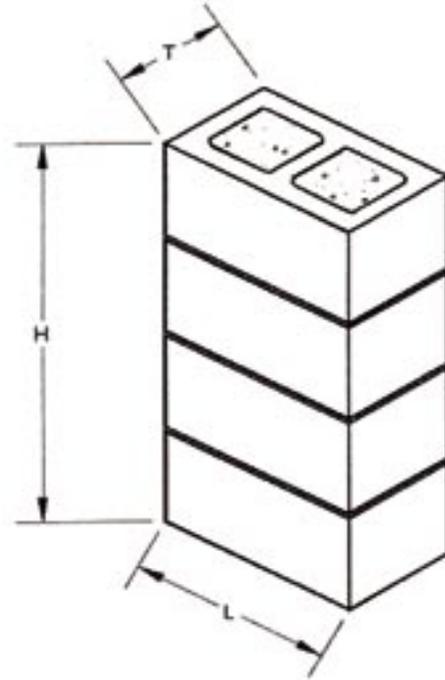


Figure 1 – Masonry Prism for Testing

Section 2106A – General Design Requirements

The most evident differences between code regulations for schools and hospitals, and other buildings are in design requirements. Chapter 21A includes many extra requirements for masonry design. In general, for schools and hospitals, the minimum reinforcement for most masonry elements is higher compared to regular buildings. Section 2106A.1.5.1 requires that all walls be reinforced. The provisions for seismic zones 0, 1, and 2 are not adopted by the State of California. Instead, all masonry structures must conform to the requirements of Section 2106A.1.12.4, special provisions for seismic zones 3 and 4. The following are the specific design requirements for schools and hospitals as they appear in the code.

Wall reinforcement. According to Section 2106A.1.12.4 of Chapter 21A, the total area of reinforcement in reinforced masonry walls shall not be less than 0.003 times the sectional area of the wall. Neither the horizontal nor the vertical reinforcement shall be less than one third of the total. Horizontal and vertical bars shall be spaced at not more than 24 inches (610 mm) center to center. The minimum reinforcing shall be No. 4, with the exception that No. 3 bars may be used for ties and stirrups. Vertical wall steel shall have dowels of equal size and equal matched spacing in all footings.

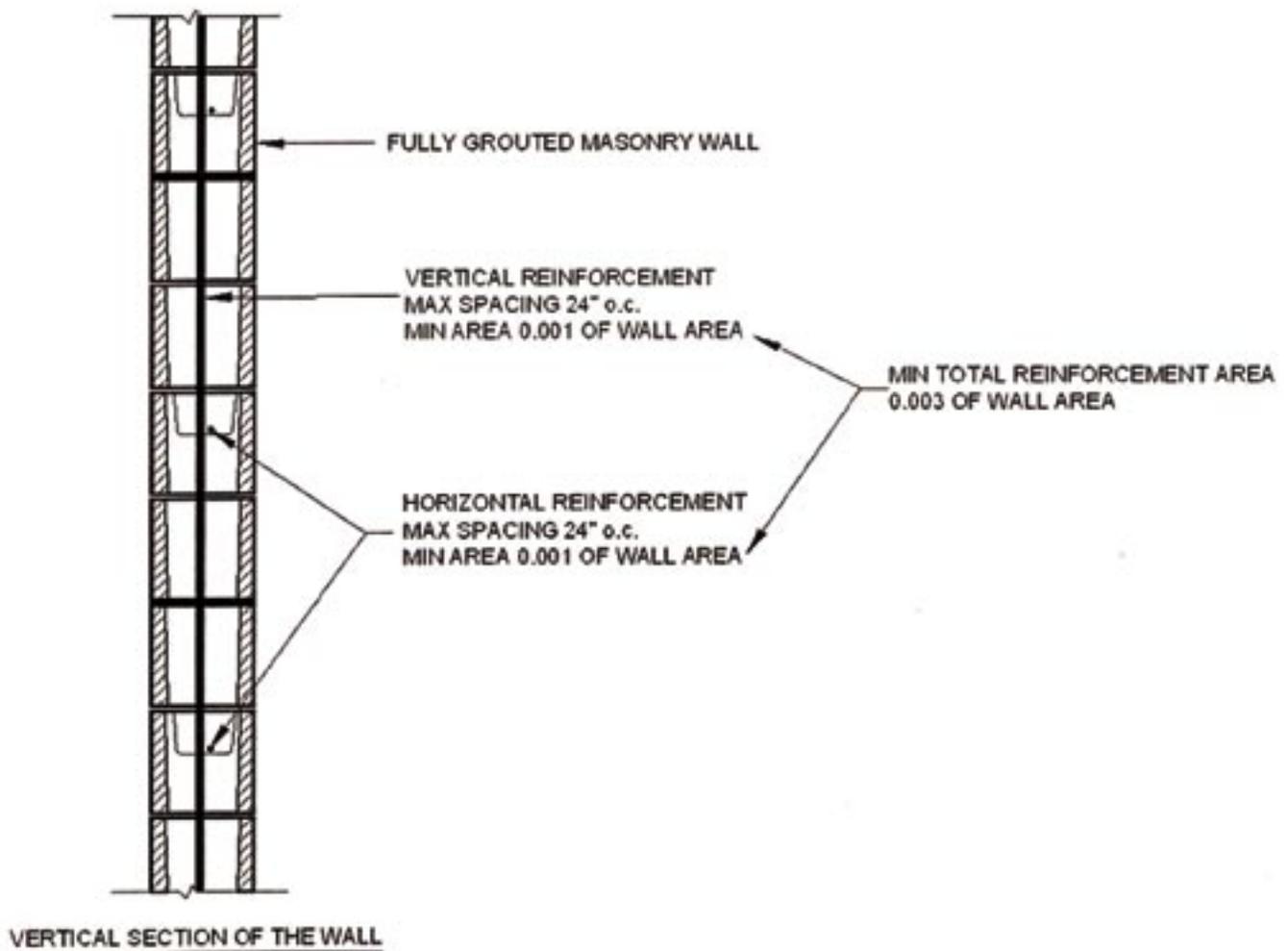


Figure 2 – Minimum Wall Reinforcement for Schools and Hospitals

Reinforcement shall be continuous around wall corners and through intersections. Only reinforcement that is continuous in the wall shall be considered in computing the minimum reinforcement area. Minimum masonry wall reinforcement for schools and hospitals is shown in Figure 2.

Horizontal reinforcement shall be provided at the top of footings, wall openings, and parapet walls and at roof and floor levels. For walls 12 inches (305 mm) (nominal) or more in thickness, reinforcing shall be equally divided into two layers, except where designed as retaining walls. Where reinforcement is added above the minimum requirements, such additional reinforcement need not be so divided.

In bearing walls of every type of reinforced masonry, there shall be at least one No. 5 bar or two No. 4 bars on all sides of, and adjacent to, every opening that exceeds 24 inches (610 mm) in either direction, and such bars shall extend not less than 48 diameters, but in no case less than 24 inches (610 mm), beyond the corners of the opening. The

bars required by this paragraph shall be in addition to the minimum reinforcement required elsewhere.

When the reinforcement in bearing walls is designed, placed, and anchored in position as for columns, the allowable stresses shall be as for columns. The length of the wall shall not exceed the center-to-center distance between loads nor shall it exceed the width of the bearing plus four times the wall thickness.

Column reinforcement. Chapter 21A requires the spacing of column ties not to be greater than 8 bar diameters, 24 tie diameters, or one half the least dimension of the column for the full column height. The top tie shall be within 2 inches (51 mm) of the top of the column or of the bottom of the horizontal bar in the supported beam.

Shear wall reinforcement. Chapter 21A requires that for shear walls, the spacing of reinforcement shall not exceed 24 inches (610 mm) in each direction. The minimum horizontal reinforcement ratio for stack bond and open-end units in Chapter 21 is omitted in Chapter 21A.

Table 2 – Minimum Thickness of Masonry Walls (2001 CBC Table 21A-R)

Type of Masonry	Maximum Ratio Unsupported Height or Length to Thickness	Normal Minimum Thickness (inches)
Bearing or Shear Walls:		
1. Stone masonry	14	16
2. Reinforced grouted masonry	25	6
3. Reinforced hollow-unit masonry	25	6
Nonbearing Walls:		
4. Exterior reinforced walls	30	6
5. Interior partitions reinforced	36	4

Thickness of walls. Chapter 21A Section 2106A.2.3.3 requires that no masonry wall shall exceed the height, length-to-thickness ratio, or minimum thickness as specified in that chapter and set forth in Table 21A-R (see Table 2). This table does not exist in Chapter 21.

Thickness of piers. Section 2106A.2.3.3 requires that every pier or wall section with a width less than three times its thickness shall be designed and constructed as required for columns if such pier is a structural member. Every pier or wall section with a width from three to five times its thickness or less than half the height of adjacent openings shall have all horizontal steel in the form of ties, with the exception that in walls 12 inches (305 mm) thick or less, such steel may be in the form of hairpins.

Distribution of concentrated vertical loads in walls. According to Section 2106A.2.7, structural members framing into or supported by walls or columns shall be securely anchored. The end support of girders, beams, or other concentrated loads on masonry shall have at least 3 inches (76 mm) in length upon solid bearing not less than 4 inches (102 mm) thick or upon metal bearing plate of adequate design and dimensions to distribute the loads safely on the wall or pier, or upon a continuous reinforced masonry member projecting not less than 3 inches (76 mm) from the face of the wall, or other approved methods. Joists shall have bearing at least 3 inches (76 mm) in length upon solid masonry at least 2 1/2 inches (64 mm) thick, or other provisions shall be made to distribute safely the loads on the wall or pier.

Placement of embedded anchor bolts. Section 2106A.2.14.1 requires that the anchor bolts be hex-headed bolts conforming to ASTM A 307 with the dimensions of the hex head conforming to ANSI/ASME B18.2.1 or plain rod conforming to ASTM A 36 with threaded ends and double hex nuts at the anchored end. Bent bar anchor bolts shall not be used. The maximum size anchor shall be 1/2-inch (13-mm) diameter for 6-inch (152-mm) nominal masonry, 3/4-inch (19-mm) diameter

for 8-inch (203-mm) nominal masonry, 7/8-inch (22-mm) diameter for 10-inch (254-mm) nominal masonry, and 1-inch (25-mm) diameter for 12-inch (305-mm) nominal masonry.

The minimum embedment length of anchor bolts l_b has been doubled from Chapter 21, to eight bolt diameters but not less than 4 inches. The minimum spacing between bolts is also specified as eight bolt diameters but not less than 4 inches.

Lateral ties. Section 2106A.3.6 requires that the ties be at least No. 3 bars. Chapter 21 allows for 1/4-inch-diameter ties for No.7 or smaller longitudinal bars.

Section 2107A – Working Stress Design of Masonry

The differences between design requirements for schools and hospitals, and other buildings are most pronounced when working stress method is chosen. Chapter 21 Section 2107.1.2 allows for not having special inspection during construction if half of the allowable masonry stresses are used in design. Chapter 21A does not contain any such provision.

Section 2107A.1.3.1 does not allow any masonry bearing wall to have a nominal thickness of less than 6 inches, whereas Chapter 21 permits some 4-inch-thick walls. Section 2107A.1.3.2 limits the least nominal dimension of a reinforced masonry column to 12 inches (305 mm). The unsupported length of such columns is limited to 20 times their least dimension.

Tensile forces are to be resisted only by the tensile reinforcement. Reinforcement is to be completely surrounded by and bonded to the masonry materials so that they work together as a homogeneous material within the range of working stresses. Masonry elements shall not be used as components for the design of rigid frames except as permitted in Section 2108A.2.6.

Section 2107A.2.2.1 limits the maximum size of reinforcement to No. 9 bars. The diameter of a bar is also limited to one fourth of the least dimension of a cell. Maximum reinforcement area in cells shall be 4 percent of the cell area without splices and 8 percent of the cell area with splices. Chapter 21 allows for maximum reinforcement size of No. 11 bars with maximum cell reinforcement area of 6 percent without splices and 12 percent with splices.

According to Section 2107A.2.2.6, splices may be made only at such points and in such a manner that the structural strength of the member reduced. Bars of size No. 8 and larger resisting tensile stresses shall be spliced by welding or by approved mechanical connectors.

Section 2107A.2.9 requires that in calculations of shear or diagonal tension stresses, shear walls that resist seismic forces be designed to resist 1.5 times the forces required by Section 1629A.1.

The section for design of unreinforced masonry is not adopted by the State of California.

Section 2108A – Strength Design of Masonry

There also are some differences between design requirements for schools and hospitals, and other buildings when strength design method is chosen. In Chapter 21, the maximum embedment length of reinforcement, l_{db} , is limited to $52d_b$. Chapter 21A contains no such limitation.

Section 2108A2.3.9 limits the distance between lateral supports of a column to 20 times the nominal width of the column. In Chapter 21, this limitation is 30 times the nominal width of the column.

In calculations of the effects of axial forces and deflection on moments, Chapter 21A limits f'_m to 2,500 psi. In Chapter 21, the limit is 6,000 psi. In Chapter 21A, the minimum nominal thickness of walls is 8 inches; in Chapter 21 it is 6 inches.

The R value to determine the compressive strain in boundary members is 1.0 in Chapter 21A; in Chapter 21 it is 1.1.

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About the Author

Dr. Mohsen Kargahi earned his Ph.D. in Civil Engineering from the University of Southern California in 2002. He began working with Weidlinger Associates in 2001, and since has performed extensive computer modeling and analysis for a variety of structures. His expertise is in the area of analysis of reinforced concrete and steel structures for seismic rehabilitation purposes as well as structural analysis and design of reinforced concrete, steel and masonry structures. Dr. Kargahi has been a licensed California professional engineer since 2004 and designs reinforced masonry structures for construction in Southern California.

Summary

The additional code requirement for schools and hospitals in Chapter 21A of CBC may significantly affect the design and construction of masonry structures. These extra regulations are enforced to ensure that these essential facilities perform well during earthquakes. Table 3 contains a brief summary of the main requirements of Chapter 21A that will affect design and construction of schools and hospitals.

For schools and hospitals construction in low temperatures is not allowed. Also there are more restrictions for preparation of spaces for grouting, grout itself, and use of joint reinforcement. These regulations will guarantee that the masonry elements will be able to develop their design properties.

The absence of half-stress provisions in Chapter 21A is of particular importance when building schools and hospitals. To guarantee a high level of quality assurance, the option to tests and inspections by not taking full advantage of the masonry properties is not available for construction of schools and hospitals.

To achieve better performance, for schools and hospitals, compared to other structures, both the minimum dimensions and the minimum reinforcement ratios for masonry elements are larger, while the maximum reinforcement spacings are lower.

The combination of higher construction standards, higher level of quality assurance, and tougher design requirements will result in safer structures for schools and hospitals that perform better during earthquakes. As a result, the cost of construction for these buildings will be higher compared to other structures.

References

[1] International Conference of Building Officials (ICBO), 2001 California Building Code, International Conference of Building Officials, Whittier, California, 2002.

Table 3 – Code Requirements for Schools and Hospitals

Section	Item
Material Standards	<ul style="list-style-type: none"> - Grade N-1 only for hollow and solid load-bearing concrete masonry units - Open-end concrete masonry units shall be grouted and need not comply with the web-thickness requirements of Table 21-4-C
Mortar and Grout	<ul style="list-style-type: none"> - Mortar and grout measured in suitable calibrated devices, shovel measurements not accepted - Mortar minimum compressive strength 1,500 psi - Grout water content not exceeding 0.7 times weight of cement
Construction	<ul style="list-style-type: none"> - No masonry be laid when outside temperature is below 40°F - Projection of mortar into grout space limited to ¼ inch - Grout that is not mechanically vibrated shall be puddle - Joint reinforcement shall not be used for strength design
Quality Assurance	<ul style="list-style-type: none"> - Masonry compressive strength, f'm, 1,500 psi, higher values based on tests and subject to approval - Minimum two cores per project, two cores per each 5,000 Square feet of masonry wall or floor area, shall be taken and tested - Masonry prism testing and testing of grout required
General Design Requirements	<ul style="list-style-type: none"> - All walls shall be reinforced - Minimum total area of reinforcement in walls 0.003 times the sectional area, minimum for horizontal or vertical reinforcement no less than one third of 0.003 - Maximum spacing of horizontal or vertical reinforcement in walls 24 inches, minimum reinforcement size No. 4 bars - Horizontal bars required in walls at the top of footings, top of wall openings, at roof and floor levels, and at top of parapets - Spacing of column ties no more than 8 bar diameter, 24 tie diameter, or one half column least dimension - Height to thickness ratio for walls limited to the values in Table 21A-R - Structural members framing into or supported by walls or columns shall be securely anchored - Maximum anchor bolt sizes ½-inch, ¾-inch, 7/8-inch and 1-inch for 6-inch, 8-inch, 10-inch, and 12-inch nominal masonry respectively - Minimum embedment length of anchor bolts and minimum spacing between bolts eight bolt diameters but not less than 4 inches - Minimum tie size No. 3 bars
Working Stress Design of Masonry	<ul style="list-style-type: none"> - No half-stress regulations: special inspection for all structures - Minimum nominal thickness of walls 6 inches - Minimum column dimension 12 inches, maximum unsupported length 20 times the least dimension - Maximum size of reinforcement No.9 bars - Splice for No. 8 and larger bars in tension by welding or by approved mechanical connectors - Shear walls must resist 1.5 times the seismic forces
Strength Design of Masonry	<ul style="list-style-type: none"> - No 52d_b limitation for reinforcement embedment length - Maximum unsupported length for columns 20 times the least dimension



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