The majority of residential buildings in the world are built of masonry - although often to a low level of construction quality. For this reason, photo coverage of earthquake damage from distant villages frequently features piles of bricks or stones that were once homes. While these structures bear little resemblance to our modern reinforced masonry systems, they do illustrate the need for proper structural design.

The seismic experience with masonry in California has shown that modern engineered masonry has generally provided a high level of performance. While this is reassuring for our local region, their experience with old unreinforced masonry structures highlights the need for close attention to our own stock of similar buildings.

LIMIT STATES DESIGN

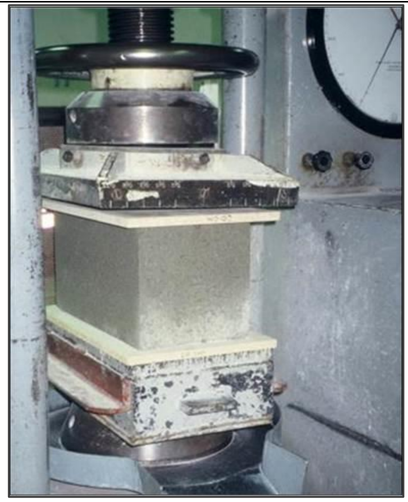
Modern masonry design is similar to limit states design methods for other materials, particularly concrete. *CSA S304-04* Design of Masonry Structures is referenced by the 2005 National Building Code and the 2006 B.C. Building Code.

An updated CSA S304-14 standard has been issued by CSA, is referenced in the 2015 NBCC and will become effective when the new BC Building Code is issued, presumably in 2017.

The following three factors in *CSA S304.1* differentiate masonry design from reinforced concrete design:

- f'_m

f'_m is the masonry compressive design strength. It is less than the masonry unit strength due to the effects of mortar bedding and interaction of the mortar and masonry unit. f'_m is usually determined from the unit strength, as shown below in Table 1.2.1-1. For some projects, such as those utilizing large amounts of high strength units, the alternative method of testing masonry assemblies (prisms) is occasionally used.



Block Testing

- Φ_m

The Φ_m resistance (safety) factor for masonry was increased from 0.55 to 0.60 in the 2004 edition.

- E_m

The elastic modulus for masonry may be taken as $E_m = 850\ f'_m$ (not greater than 20,000 MPa), or may be determined from testing. *CSA S304.1* also provides methods for determining effective moments of inertia for deflection calculations

Value of f'_m for concrete block masonry		
	Specified compressive strength normal to the bed joint, f'_m, for concrete block masonry, MPa	
Specified compressive strength of unit, MPa (average net area) *	Type S mortar	
	Hollow	Solid or grouted
>40	22	17
30	17.5	13.5
20	13	10
15	**9.8**	**7.5**
10	6.5	5

*Linear interpolation is permitted.

Notes: - For grouted walls the area of grout may be ignored and the "Hollow" f'_m value used with the face-shell bedded area. This will be advantageous for larger spacings of grouted cells.
- Alternatively, for partially grouted walls a weighted value

Note that CSA S304.1 now clearly provides for the use of the higher "Hollow" value for f'_m if the grout area is ignored.

between the "Hollow" and the "Solid or Grouted" may be used, based on the percentage of grouted cores.
- Type N mortar is seldom, if ever, used in structural masonry.

REINFORCEMENT

Care should be taken to disperse the rebar throughout the wall, and to avoid congestion in vertical cores. The most common rebar size in reinforced masonry is 15M, followed by 20M. 25M's are occasionally used, but are difficult to handle and require long laps. Vertical bars are typically placed as one layer in the centre of the wall. Horizontal rebar is placed in bondbeam courses, often in pairs that act to centre the vertical steel. Horizontal joint reinforcing is fabricated in ladders of two 3.8mm (9 ga) galvanized wires and embedded in horizontal mortar bed joints at a spacing of 400 or 600mm.

Dowels

MINIMUM SEISMIC REINFORCEMENT

CSA S304.1 (Clause 10.15.2) specifies minimum seismic reinforcement for loadbearing and non-loadbearing walls for a project with a specific seismic hazard index [$IEF_aS_a(0.2)$]. For most cases, the required reinforcement areas must be oriented a minimum of 1/3 in either direction. The larger amount of reinforcement will usually be used vertically.

Vertical steel spacing must not exceed 6(t+10) mm or 1200 mm, whichever is less. The maximum spacing of horizontal reinforcement is:

- 400 mm where only joint reinforcement is used
- 1200 mm where only bond beams are used
- 2400 mm for bond beams, and 400 mm for joint reinforcement where both are used

In many cases, it will be found that this minimum seismic steel will also be adequate for flexural, shear or axial load resistance.

Reinforced Block Structure

SHI*	**Area Required**	**Typical Spec 200mm Wall**
Loadbearing SHI ≥ 0.35	Total 0.002 A_g 2/3 = 0.00133 1/3 = 0.00067	Vertical: 15M @ 800mm (0.00132) Horizontal: 2-15M @ 2400mm + Joint reinforcing @ 400mm (0.00117)
Non-loadbearing SHI ≥ 0.75	Total 0.001 2/3 = 0.00067 1/3 = 0.00033	Vertical: 15M @ 1200mm (0.00088) Horizontal: 1-15M @ 2400mm + Joint reinforcing @ 400mm (0.00073)

* SHI = Seismic Hazard Index $IEF_aS_a(0.2)$

See reinforcement ratio table on page 5. See Guide Structural Notes in Section 3.3 for typical reinforcement for other wall thicknesses.

In addition to flexural, shear and minimum seismic steel, vertical reinforcing is required at each side of openings over 1200mm long, at each side of control joints, and at corners, ends and intersections of walls. *CSA S304.1-04* (Clause 4.6.1) allows unreinforced masonry partitions if they are less than 200 kg/m^2 in mass and 3 m in height., but only for seismic hazard indices < 0.75.

The seismic provisions and ductility categories have been substantially updated in the new CSA S304-14 standard. This standard has been referenced in the 2015 NBCC and will become effective when the new BC Building Code is issued, presumably in 2017. They will be reviewed in this manual as that time approaches.

SEISMIC DESIGN FOR DUCTILE SHEAR WALLS

The minimum seismic requirements described above for “Conventional” reinforced masonry will be all that is required for the vast majority of masonry buildings. However, the *B.C. Building Code 2006* (Table

4.1.8.9) and CSA S304.1-04 Clause 10.16 contain additional provisions for a range of ductile shear wall categories beyond the conventional seismic requirements They are based on the concept of ductility through inelastic behavior in a “plastic hinge” zone at the base of a cantilever shear wall. These detailing and design provisions ensure that the shear capacity exceeds the flexural capacity that is providing the ductile mechanism. They provide values of either 1.5 or 2.0 for R_d, the “ductility related force reduction factor,” used in determining design loads.

The shear wall categories and their maximum building heights for the two higher seismic hazard indices from BCBC Table 4.1.8.9 are shown below:

Reinforcement

			Maximum Height	
		R_d	0.35 - 0.75	> 0.75
1.	Conventional	1.5	30 m	15 m
2.	Limited Ductility	1.5	40 m	30 m
3.	Moderately Ductile	2.0	60 m	40 m
4.	Moderately Duct. Squat	2.0	n/a	n/a

For the cases beyond the Conventional ductility walls there are additional requirements for grouting, and reinforcing spacing and detailing. There are also limits on h/t, compressive strains, and shear resistance. For typical masonry walls designed in the Squat category with h_w /l_w<1, there is an h/(t+10) limit, and requirements for uniform loading and reinforcement ratios.

An R_d of 2.0 for all materials is now required for post-disaster buildings. This can be provided by structural masonry by meeting the requirements of Clause 10.16. The requirements for typical squat masonry walls such as those used for fire halls are contained in Clause 10.16.6.

Reinforcement

Large differences in the ductility of framing systems in orthogonal directions should be avoided.

Wall Reinforcement Ratio $P_\partial = A_s I A_g$

Wire or Bar Size	Spacing S (mm)	Wall Thickness (mm)			
		b=140	b=190	b=240	b=290
2 – 9 ga.	@ 1200	0.00013	0.00010	0.00008	0.00006
	800	0.00020	0.00015	0.00012	0.00010
	600	0.00027	0.00020	0.00015	0.00013
	400	0.00040	0.00029	0.00023	0.00019
	200	0.00080	0.00059	0.00046	0.00038
2 – 8 ga.	@ 1200	0.00016	0.00012	0.00009	0.00008
	800	0.00024	0.00018	0.00014	0.00011
	600	0.00032	0.00023	0.00018	0.00015
	400	0.00048	0.00035	0.00028	0.00023
	200	0.00095	0.00070	0.00055	0.00046
#10	@ 1200	0.00060	0.00044	0.00035	0.00029
	800	0.00089	0.00066	0.00052	0.00043
	600	0.00119	0.00088	0.00069	0.00057
	400	0.00179	0.00132	0.00104	0.00086
	200	0.00357	0.00263	0.00208	0.00172
#15	@ 1200	0.00119	0.00088	0.00069	0.00057
	800	0.00179	0.00132	0.00104	0.00086
	600	0.00238	0.00175	0.00139	0.00115
	400	0.00357	0.00263	0.00208	0.00172
	200	0.00714	0.00526	0.00417	0.00345
#20	@ 1200	0.00179	0.00132	0.00104	0.00086
	800	0.00268	0.00197	0.00156	0.00129
	600	0.00357	0.00263	0.00208	0.00172
	400	0.00536	0.00395	0.00301	0.00259
	200	0.01071	0.00789	0.00625	0.00517
#25	@ 1200	0.00298	0.00219	0.00174	0.00144
	800	0.00446	0.00329	0.00260	0.00216
	600	0.00595	0.00439	0.00347	0.00287
	400	0.00893	0.00658	0.00521	0.00431
	200	0.01786	0.01316	0.01042	0.00862
#30	@ 1200	0.00417	0.00307	0.00243	0.00201
	800	0.00625	0.00461	0.00365	0.00302
	600	0.00833	0.00614	0.00486	0.00402
	400	0.01250	0.00921	0.00729	0.00603
	200	0.02500	0.01842	0.01458	0.01207

This table provides wall reinforcement ratios for various rebar spacings and wall thicknesses.

PHYSICAL PROPERTIES OF CONCRETE BLOCK WALLS

Structural Properties of Concrete Masonry Walls
(per metre or foot length)

Grouted Cells / metre Cell/Dowel Spacing (mm)		**0.00** *none*	**0.83** 1200	**1.00** 1000	**1.25** 800	**1.67** 600	**2.50** 400	**0.00** 200
Nominal Size		**150**	mm		*6*	*inch*		
A_e	$(mm^2 \times 10^3)$ (in^2)	**52.0** *24.6*	**66.7** *31.5*	**69.6** *32.9*	**74.0** *35.0*	**81.3** *38.4*	**96.0** *45.4*	**140.0** *66.2*
I_x	$(mm^4 \times 10^6)$ (in^4)	**172** *126*	**181** *133*	**183** *134*	**186** *136*	**191** *140*	**201** *147*	**229** *168*
S_x	$(mm^3 \times 10^6)$ (in^3)	**2.46** *45.8*	**2.59** *48.2*	**2.62** *48.7*	**2.66** *49.5*	**2.73** *50.7*	**2.87** *53.3*	**3.27** *60.8*
Weight	(kN/m^2) (psf)	**1.90** *39.6*	**2.09** *43.7*	**2.13** *44.6*	**2.19** *45.8*	**2.29** *47.9*	**2.49** *52.0*	**3.08** *64.3*
Nominal Size		**200**	mm		*8*	*inch*		
A_e	$(mm^2 \times 10^3)$ (in^2)	**74.5** *35.6*	**94.5** *44.6*	**98.3** *46.5*	**104.0** *49.2*	**113.6** *53.7*	**132.7** *62.7*	**190.0** *89.8*
I_x	$(mm^4 \times 10^6)$ (in^4)	**442** *324*	**464** *340*	**468** *343*	**475** *347*	**485** *355*	**507** *371*	**572** *419*
S_x	$(mm^3 \times 10^6)$ (in^3)	**4.66** *86.7*	**4.88** *90.9*	**4.93** *91.7*	**5.00** *93.0*	**5.11** *95.0*	**5.34** *99.3*	**6.02** *112.0*
Weight	(kN/m^2) (psf)	**2.46** *51.4*	**2.75** *57.4*	**2.81** *58.6*	**2.89** *60.4*	**3.03** *63.4*	**3.32** *69.4*	**4.18** *87.3*
Nominal Size		**250**	mm		*10*	*inch*		
A_e	$(mm^2 \times 10^3)$ (in^2)	**81.7** *38.6*	**108.1** *51.1*	**113.4** *53.6*	**121.3** *57.3*	**134.5** *63.5*	**160.9** *76.0*	**240.0** *113.4*
I_x	$(mm^4 \times 10^6)$ (in^4)	**816** *598*	**872** *638*	**883** *647*	**900** *659*	**928** *679*	**984** *721*	**1152** *844*
S_x	$(mm^3 \times 10^6)$ (in^3)	**6.80** *126.5*	**7.27** *135.2*	**7.36** *136.9*	**7.50** *139.5*	**7.73** *143.8*	**8.20** *152.5*	**9.60** *178.6*
Weight	(kN/m^2) (psf)	**2.97** *62.0*	**3.35** *70.0*	**3.43** *71.7*	**3.55** *74.1*	**3.74** *78.1*	**4.12** *86.1*	**5.28** *110.3*
Nominal Size		**300**	mm		*12*	*inch*		
A_e	$(mm^2 \times 10^3)$ (in^2)	**88.3** *41.7*	**121.9** *57.6*	**128.6** *60.8*	**138.7** *65.5*	**155.5** *73.5*	**189.2** *89.4*	**290.0** *137.0*
I_x	$(mm^4 \times 10^6)$ (in^4)	**1341** *982*	**1456** *1066*	**1479** *1083*	**1514** *1108*	**1571** *1150*	**1687** *1235*	**2032** *1488*
S_x	$(mm^3 \times 10^6)$ (in^3)	**9.25** *172.1*	**10.04** *186.8*	**10.20** *189.7*	**10.44** *194.1*	**10.83** *201.5*	**11.63** *216.3*	**14.01** *260.6*
Weight	(kN/m^2) (psf)	**3.53** *73.7*	**4.00** *83.6*	**4.10** *85.6*	**4.24** *88.6*	**4.48** *93.6*	**4.95** *103.5*	**6.38** *133.3*

Note: Assume bond beams at 2.4m (8 ft) OC.
Table based on metric blocks and modules (190mm high units).
Assumed weight: 22 kN/m^2 140.4 pcf