REINFORCED MASONRY EXAMPLES

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This program is intended as a preliminary design tool for design professionals who are experienced and competent in masonry design. This program is not intended to replace sound engineering knowledge, experience, and judgment. Users of this program must determine the validity of the results. The International Masonry Institute assumes no responsibility for the use or application of this program.

EXAMPLE A:

Given:

- 8 inch medium weight hollow CMU
- Type S masonry cement mortar
- 12 ft vertical span (simple support)
- Minimum design load is 5 psf out-of-plane
- S_{DS} = 0.5; Seismic Design Category C
- Use the 2012 IBC

Required: Determine required reinforcement.

Solution:

Reinforced masonry design requires that a grout/reinforcement spacing be assumed. The grout spacing affects the wall weight, which in turn affects the seismic load.
Assume a grout spacing of 48 in. o.c.
Check Load Combination G (0.6D + 0.7E). Wall weight is 44 psf, and R = 2.5 for reinforced masonry.

The seismic load is $w_E = \dfrac{1.2 S_{DS} W_p}{\left(\dfrac{R_p}{I_p}\right)} = \dfrac{1.2(0.5)44\,psf}{\left(\dfrac{2.5}{1.0}\right)} = 10.6\,psf$

Since 0.7(10.6 psf) = 7.4 psf, seismic will control.
The maximum moment will occur at mid-height of the wall.

$$M = \frac{0.7 w_E h^2}{8} = \frac{0.7(10.6\,psf)(12\,ft)^2}{8} = 133\,ft-lb/ft$$

The axial force is:

$$P = [0.6 - 0.7(0.2)(S_{DS})]w_{wall}\frac{h}{2} = [0.6 - 0.7(0.2)(0.5)](44\,psf)\frac{12\,ft}{2} = 140.0\,lb/ft$$

Follow the design procedure in the background document.

1. Determine the allowable stresses. F_s = 32,000 psi; $F_b = 0.45f'_m$ = 0.45(1500psi) = 675 psi
2. Determine k for balanced condition, k_b.

$$n = \frac{E_s}{E_m} = \frac{29{,}000{,}000\,psi}{900(1500\,psi)} = 21.5$$

$$k_b = \frac{F_b}{F_b + \dfrac{F_s}{n}} = \frac{675\,psi}{675\,psi + \dfrac{32000\,psi}{21.5}} = 0.312$$

3. Determine k for the applied loading conditions as follows. This assumes that compression controls.

$$k=\frac{3}{d}\left[\frac{d}{2}-\sqrt{\left(\frac{d}{2}\right)^2-\frac{2(12M)}{3F_b b}}\right]$$

$$=\frac{3}{3.8125in.}\left[\frac{3.8125in.}{2}-\sqrt{\left(\frac{3.8125in.}{2}\right)^2-\frac{2(12in/ft)(133ft-lb/ft)}{3(675psi)(12in/ft)}}\right]=0.0274$$

4. If $k \geq k_b$ compression controls. Not true, so tension controls.
5. Since ($k = 0.0274$) < ($k_b = 0.312$) tension controls. The area of steel is determined through an iterative process.
    a. Set k = 0.0274
    b. Calculate M'.

    $$M'=P\left(\frac{t}{2}-\frac{kd}{3}\right)=140lb/ft\left(\frac{7.625in}{2}-\frac{0.0274(3.8125in.)}{3}\right)\frac{1ft}{12in.}$$
    $$=44.1ft-lb/ft$$

    c. Calculate $A_{s.}$

    $$A_s=\frac{12(M-M')}{F_s d\left(1-\frac{k}{3}\right)}=\frac{12in./ft(133ft-lb/ft-44.1ft-lb/ft)}{32000psi(3.8125in)\left(1-\frac{0.0274}{3}\right)}=0.009in^2/ft$$

    d. Calculate ζ.

    $$\zeta=\frac{(P+A_sF_s)n}{F_s b}=\frac{(140lb/ft+(0.009in^2/ft)32000psi)21.5}{32000psi(12in/ft)}=0.0236in.$$

    e. Calculate a new k.

    $$(k)_2=\frac{\sqrt{\zeta^2+2\zeta d}-\zeta}{d}=\frac{\sqrt{(0.0236in.)^2+2(0.0236in.)(3.8125in.)}-0.0236in.}{3.8125in.}$$
    $$=0.105$$

    f. Check convergence:

    $$\frac{|k_2-k|}{k}=\frac{|0.105-0.027|}{0.027}=2.84$$ Use k=0.105 as new guess. The iterations are summarized in the following table.

k	M'	A_s	ζ	k_2	$\lvert k_2-k\rvert/k$
0.0274	44.1	0.009	0.0236	0.1053	2.84
0.1053	42.9	0.009	0.0243	0.1066	0.0128
0.1066	42.9	0.009	0.0243	0.1067	0.0007

6. Find required bar area as $0.009in^2/ft(48in.)(1ft/12in.)=0.04in^2$
7. Use a #3 bar at 48 in. o.c. The area of steel provided is $0.11in^2$.
8. Calculate the development/lap length.

$$K = \min\{\text{masonry cover}, 9d_b\} = \min\left\{\frac{t\text{-}d_b}{2}, 9d_b\right\} = \min\left\{\frac{7.625in.\text{-}0.375in.}{2}, 9(0.375in.)\right\}$$

$$= \min\{3.625in., 3.375in.\} = 3.375in.$$

$$l_{de} = \frac{0.13d_b^2 f_y \gamma}{K\sqrt{f'_m}} = \frac{0.13(0.375in.)^2(60000\,psi)(1.0)}{3.375in.\sqrt{1500\,psi}} = 8.4in.$$

where d_b is the bar diameter, f_y is the yield strength (60,000 psi), f'_m is the specified compressive strength, γ = 1.0 for #3, #4, and #5 bars, and γ = 1.3 for #6 and #7 bars, and K is determined as the minimum of {masonry cover, $9d_b$}.

The minimum development/lap length is 12 in.

Using the IBC lap length equations, the required lap length would be $96d_b$, which = 96(0.375in.) = 36 inches.

Use 12 inch lap length.

Partition walls in SDC C are required to have prescriptive seismic reinforcement in either the horizontal OR vertical direction in accordance with the following:

(a) Horizontal reinforcement — Two longitudinal wires of W1.7 (9 gage) bed joint reinforcement spaced not more than 16 in. on center, or No. 4 bars spaced not more than 48 in. on center. Horizontal reinforcement needs to be provided within 16 in. of the top and bottom of the wall.

(b) Vertical reinforcement —No. 4 bars spaced not more than 120 in. on center. Vertical reinforcement needs to be provided within 16 in. of the ends of the wall.

The No. 3 bars at 48 in. o.c. provide 0.0275 in^2/ft. The vertical prescriptive reinforcement is equivalent to 0.02in^2/ft. Thus, we believe the vertical reinforcement meets the intent of the code. However, it is recommended that W1.7 (9 gage) bed joint reinforcement at 16 in. (every other course) also be provided. This satisfies the horizontal reinforcement requirements, which in turn satisfies the prescriptive requirements (code requires either the horizontal OR the vertical requirements be met, but both do not have to be met). The bed joint reinforcement also helps with crack control.

Due to the permitted one-third stress increase in the 2009 IBC (2008 MSJC), the design would be the same using the 2009 IBC.

The reaction at the top of wall, R_B, is:

$$R_B = 0.7w_E\frac{h}{2} = 0.7(10.6\,psf)\frac{12\,ft}{2} = 44.5lb/ft$$

Sufficient anchors need to be provided at the top of wall to carry this force.

If this partition wall were part of an egress stairway, the importance factor would be 1.5, which increases the seismic load, w_E, to 15.9 psf, the moment to 200 ft-lb/ft, and the required area of steel to 0.016in^2/ft. A No. 3 bar at 48 in. o.c. still works.

EXAMPLE B:

Given:

- 8 inch medium weight hollow CMU
- Type S masonry cement mortar
- 16 ft vertical span (simple support)
- Minimum design load is 5 psf out-of-plane
- Building located in Salt Lake City, Utah.
- Soil Site Class D ("stiff soil")
- Use the 2012 IBC

Required: Determine required reinforcement.

Solution:
The U.S. Seismic Design Maps Web Application, http://geohazards.usgs.gov/designmaps/us/application.php, is used to determine S_{DS} = 1.02 and S_{D1}=0.56. The Seismic Design Category is Category D.

Reinforced masonry design requires that a grout/reinforcement spacing be assumed. The grout spacing affects the wall weight, which in turn affects the seismic load.
Assume a grout spacing of 48 in. o.c.

Check Load Combination G (0.6D + 0.7E). Wall weight is 44 psf, and R = 2.5 for reinforced masonry.
The seismic load is $w_E = \dfrac{1.2 S_{DS} W_p}{\left(\dfrac{R_p}{I_p}\right)} = \dfrac{1.2(1.02)44\,psf}{\left(\dfrac{2.5}{1.0}\right)} = 21.5\,psf$

Since 0.7(21.5 psf) = 15.1 psf, seismic will control.
The maximum moment will occur at mid-height of the wall.

$$M = \frac{0.7 w_E h^2}{8} = \frac{0.7(21.5\,psf)(20\,ft)^2}{8} = 754\,ft-lb/\,ft$$

The axial force is:

$$P = [0.6 - 0.7(0.2)(S_{DS})]w_{wall}\frac{h}{2} = [0.6 - 0.7(0.2)(0.5)](44\,psf)\frac{20\,ft}{2} = 201\,lb/\,ft$$

Follow the design procedure in the background document; see Example A for details.
After three iterations, k = 0.240 and A_s = 0.0743 in^2/ft.
The required bar area of steel is 0.0743in^2/ft(4ft) = 0.297 in^2.
Use a #5 bar at 48 in. o.c.

Partition walls in SDC D are required to have prescriptive seismic reinforcement in either the horizontal OR vertical direction in accordance with the following:

(a) Horizontal reinforcement — Two longitudinal wires of W1.7 (9 gage) bed joint reinforcement spaced not more than 16 in. on center, or No. 4 bars spaced not more than 48 in. on center. Horizontal reinforcement needs to be provided within 16 in. of the top and bottom of the wall.

(b) Vertical reinforcement —No. 4 bars spaced not more than 48 in. on center. Vertical reinforcement needs to be provided within 16 in. of the ends of the wall.

The No. 5 bars at 48 in. o.c. satisfy the minimum prescriptive requirements. Although not required, it is recommended that W1.7 (9 gage) bed joint reinforcement at 16 in. (every other course) also be provided.

If this partition wall were part of an egress stairway, the importance factor would be 1.5, which increases the seismic load, w_E, to 32.2 psf. The required area of steel is 0.467 in^2, which would require a #7 bar at 48 in. o.c. Many designers would prefer to use a smaller bar; one reason would be to decrease the required lap length. As the spacing of the bar decreases, the wall weight increases. The table below shows the results of various bar spacings.

Bar spacing	Required reinforcement
48 in.	#7 @ 48 in.
40 in.	#6 @ 40 in.
32 in.	#6 @ 32 in.
24 in.	#5 @ 24 in.
16 in.	#5 @ 16 in.
16 in. (full grout)	A_s is 121% of maximum for #7 - Redesign
8 in.	#6 @ 8 in.

Often walls that require reinforcement at 16 in. (or even 24 in.) are fully grouted, as it is more economical to fully grout the wall than grout every other cell. The full grout adds to the weight of the wall, and hence the seismic force. For this particular wall, the allowable compression stress controls for full grouting with bars at 16 in. o.c. Reinforcement is not used efficiently when the allowable masonry compression stress controls, which is why the large amount of reinforcement is required.

This example shows that economical reinforced masonry partition walls can be designed for large spans (in this case 20 ft), in high seismic areas, and for critical locations (egress stairways).