EXAMPLE 4. DESIGN OF RC SHEAR WALL PER IBC 2000

Given Data:

Compressive strength of concrete f'_c = 4000 psi
Yield strength of reinforcements f_y = 60 ksi
Structural system: Building Frame with Special Reinforced Concrete Shear Walls
Site Class: D
S_{DS} = 1.33
S_{D1} = 0.93
C_d = 5.0
Use Group = I
R = 6
Importance Factor, I = 1.0
Redundancy factor, ρ = 1.0
Shear wall thickness, h = 12 in.
Seismic Design Category = E
Base shear, V = 1402 kips
Service-level axial dead load on shear wall = 316 kips
Service-level axial live load on shear wall = 34 kips
The forces due to lateral load are shown in Table E4.1
The displacement at the top of the building along the shear wall line was found to be 0.76 inch by elastic analysis under the code-prescribed forces.
Design displacement (δ_u) = 5.0 x 0.76 = 3.80 in
Note: A shear wall is a structural wall. The terms are used interchangeably here.

Shear Wall Design

The design of one of the shear walls at the base of the structure shown in Figures E4.1 and E4.2 is illustrated in this example. Similar procedures may be followed to design the shear wall at the other floor levels. The design of shear walls by IBC 2000 follows the procedure in ACI 318–99.

Design loads

Table E4.1 shows a summary of the axial force, shear force and bending moment at the base of the example shear wall based on different load combinations.

Required axial load strength, P_u = 520 kips
Required shear strength, V_u = 382 kips
Required flexural strength, M_u = 16,855 ft-kips

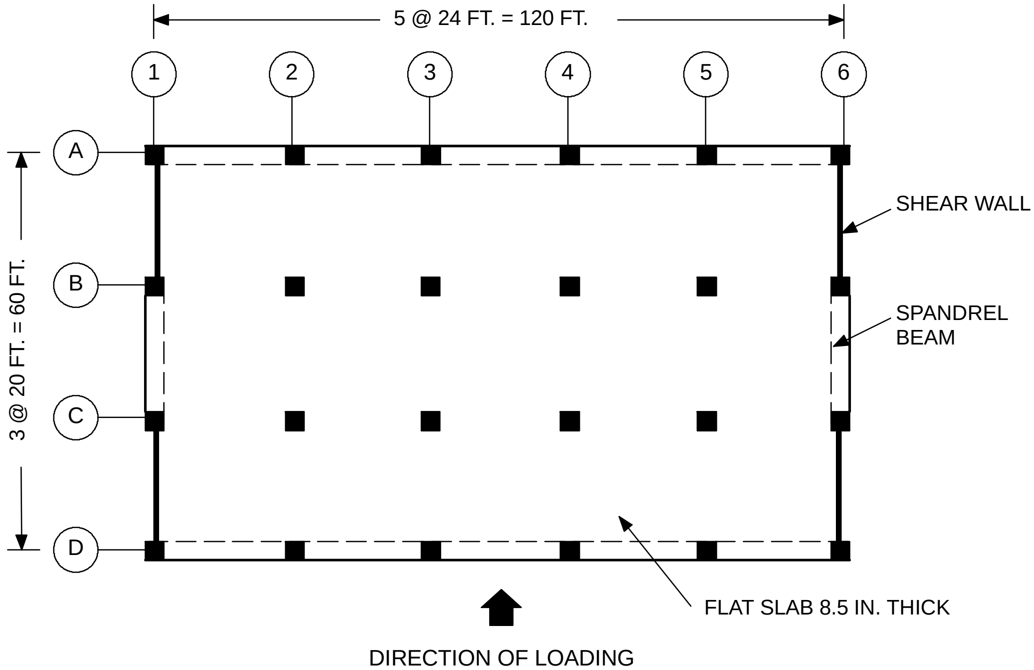
TABLE E4.1. SUMMARY OF DESIGN AXIAL FORCE, SHEAR FORCE AND BENDING MOMENT FOR SHEAR WALL BETWEEN GRADE AND LEVEL 2

Loads	Symbol	Axial Force (kips)	Shear Force (kips)	Bending Moment (ft-kips)
Dead Load	D	316	0	0
Live Load	L	34	0	0
Lateral Load	Q_E	38	382	16,855

Load Combinations				
1	1.4D+1.7L	500	0	0
2	1.2D+(ρQ_E+0.2$S_{DS}D$)+0.5L	520	382	16,855
3	0.9D-(ρQ_E+0.2$S_{DS}D$)	161	-382	-16,855

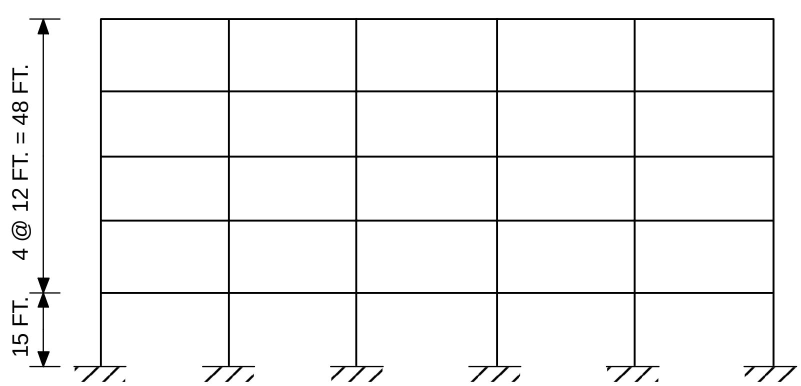
Load Combinations	Load Factors		
	D	L	Q_E
1	1.4	1.7	0
2	1.47	0.5	1
3	0.63	0	-1

EXAMPLE 4—(continued)



PLAN OF EXAMPLE BUILDING CONSIDERED

FIGURE E4.1



ELEVATION OF EXAMPLE BUILDING CONSIDERED

FIGURE E4.2

EXAMPLE 4—(continued)

Check strength under flexure and axial load

Draw P-M interaction diagram for the shear wall with assumed dimensions of wall and assumed longitudinal reinforcement in boundary elements and web. Check to see that all the points representing strength demand (from the three load combinations shown in Table 1) are within the design strength interaction diagram.

In this example, the shear wall dimensions and reinforcement, as shown in Figure E4.3, are considered.

Using 12 #8 bars in each boundary element, the reinforcement ratio in the elements is, (12 × 0.79)/(18 × 18) = 2.93%. This is high, but not excessive, and was judged to be acceptable.

Figure E4.4 shows the P-M interaction diagrams for the example shear wall. As can be seen, all the points representing required strength are within the design strength curve.

One other quantity needs to be determined at this stage. That is the neutral axis depth, *c,* corresponding to the maximum axial force (in the presence of lateral force).

P_u = 520 kips

c = 26 in. (using an in-house computer program)

Design for shear

Height of the shear wall, $h_w = 63$ ft

Length of the shear wall, $\ell_w = 20 + 18/12 = 21.5$ ft

$h_w/\ell_w = 63/21.5 = 2.93$

ACI 318 Section 21.6.4.4

V_u must not exceed $\phi 8 A_{cv}\sqrt{f'_c}$

$A_{cv} = 12 \times (20 \times 12 + 18) = 3096 \text{ in.}^2$

Take $\phi = 0.85$, since a wall with $h_w/\ell_w = 2.93$ is not going to be governed by shear in its failure mode.

$\phi 8 A_{cv}\sqrt{f'_c} = 0.85 \times 8 \times 3096\sqrt{4000}/1000$

$= 1331 \text{ kips} > 382 \text{ kips } (V_u)$ OK

ACI 318 Section 21.6.2.2

At least two curtains of reinforcement must be used if $V_u > 2A_{cv}\sqrt{f'_c}$

$2A_{cv}\sqrt{f'_c} = 2 \times 3096\sqrt{4000}/1000$

$= 392 \text{ kips} > 382 \text{ kips}$

Theoretically, 1 curtain needs to be provided. However, provide two curtains of reinforcement.

ACI 318 Section 21.6.2.1

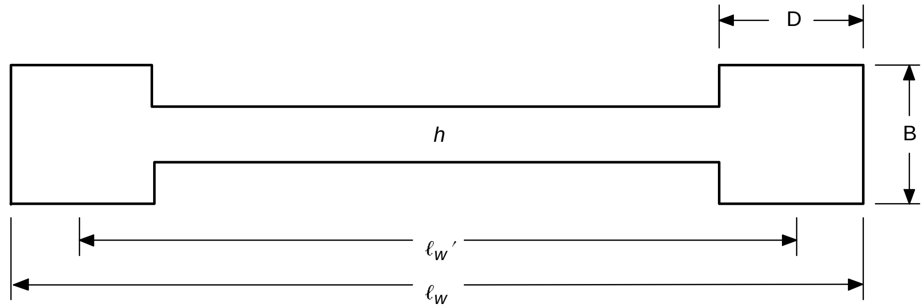
For 2 #5 horizontal bars @ 18 inches o.c.

$\rho_n = \frac{2 \times 0.31}{12 \times 18} = 0.00287 > 0.0025$ OK

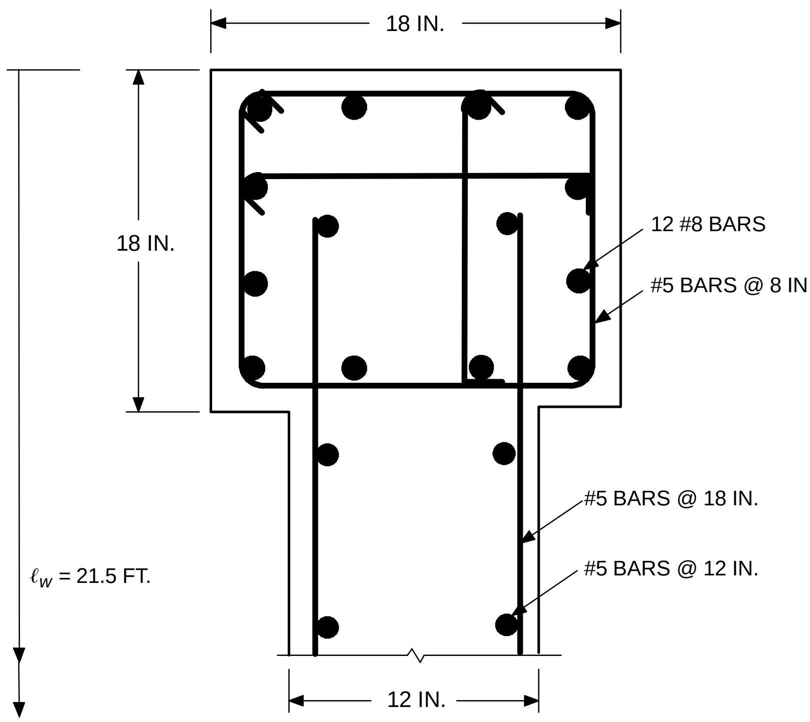
$s = 18 \text{ in.} \leq 18 \text{ in.}$ OK

Use 2 #5 horizontal bars @ 18 inches o.c.

EXAMPLE 4—(continued)



PLAN OF SHEAR WALL



PLAN AND REINFORCEMENT DETAILS OF SHEAR WALL

FIGURE E4.3

<u>ACI 318 Section 21.6.4.3</u>

The vertical reinforcement ratio (ρ_v) must not be less than the horizontal reinforcement ratio (r_n) if the ratio h_w/ℓ_w < 2.0. As h_w/ℓ_w = 2.93 > 2.0, this clause is not applicable.

Provide 2 #5 vertical bars @ 12 inches o.c.

ρ_v= 0.0043 > 0.0025 (21.6.2.1) OK

<u>ACI 318 Section 21.6.4.1</u>

For h_w/ℓ_w = 2.93 > 2.0

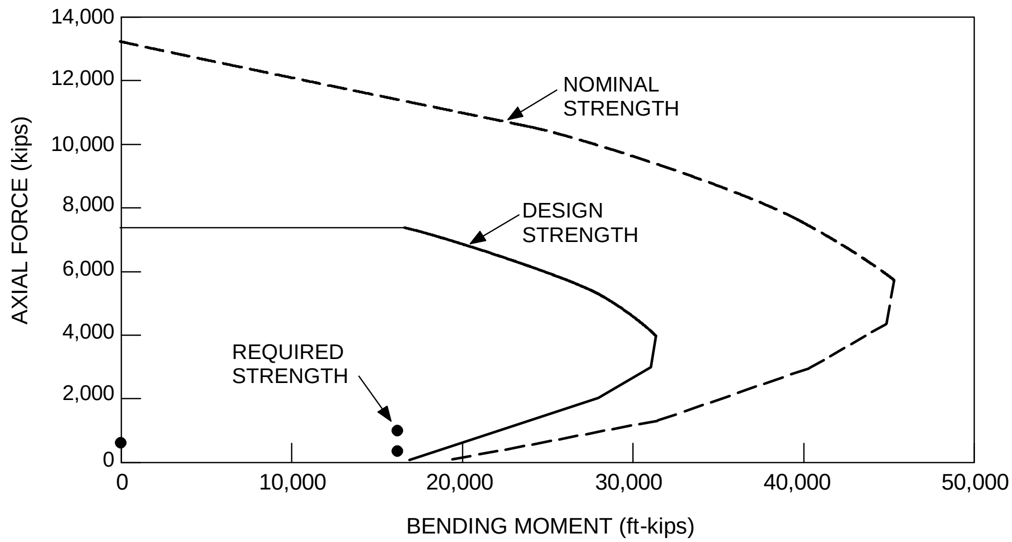
$\alpha_c = 2$

$V_n = A_{cv}(\alpha_c\sqrt{f'_c} + \rho_n f_y)$ (ACI 318 Equation 21-7)

$\phi V_n = 0.85 \times 3096[2\sqrt{4000} + 0.00287 \times 60,000]/1000$

$= 786$ kips > 382 kips OK

EXAMPLE 4—(continued)



M-P INTERACTION DIAGRAM FOR SHEAR WALL C1-D1
(BETWEEN GRADE AND LEVEL 2)

FIGURE E4.4

Design for flexure and axial loads *(ACI 318 Section 21.6.5)*

ACI 318 Section 21.6.5.1

Shear walls and portions of such walls subject to combined flexural and axial loads shall be designed in accordance with Sections 10.2 and 10.3, i.e., the provisions applied to columns. Boundary elements and the wall web are considered effective.

Boundary Elements of Special RC structural walls *(ACI 318 Section 21.6.6)*

ACI 318 Section 21.6.6.1

The need for special boundary elements at the edges of shear walls needs to be evaluated in accordance with ACI 318 Section 21.6.6.2 (displacement-based approach) or ACI 318 Section 21.6.6.3 (stress-based approach). In this example, the displacement-based approach is followed.

ACI 318 Section 21.6.6.2(a) Displacement-Based Approach

Compression zones must be reinforced with special boundary elements where:

$$c \geq c_r = \frac{\ell_w}{600(\delta_u/h_w)} \qquad \text{(ACI 318 Section Equation 21-8)}$$

As computed earlier,

c = 26 in.

ℓ_w = 21.5 ft

h_w = 63 ft

δ_u = 3.8 in along the wall line

δ_u/h_w = $3.8/(63 \times 12)$ = 0.005 < 0.007 = > Use δ_u/h_w = 0.007

$$c_r = \frac{21.5 \times 12}{600 \times 0.007} = 61.4 \text{ in.} > c = 26 \text{ in.}$$

Therefore, boundary zone details per ACI 318 Section 21.6.6.4 are not needed. However, for illustration purposes, the detailing will be shown in this example.

ACI 318 Section 21.6.6.2 (b) Height of special boundary element

The special boundary element reinforcement must extend vertically from the critical section a distance not less than the larger of ℓ_w or $M_u/4V_u$.

ℓ_w = 21.5 ft . . . governs

$$M_u/4V_u = \frac{16,855}{4 \times 382} = 11 \text{ ft}$$

EXAMPLE 4—(continued)

Shear wall Special Boundary Element Details *(ACI 318 Section 21.6.6.4)*

ACI 318 Section 21.6.6.4 (a) Length of special boundary element

Special boundary element must extend horizontally from the extreme compression fiber a distance not less than the larger of $c - 0.1\ell_w$ and $c/2$.

$c - 0.1\,\ell_w = 26 - 0.1 \times 21.5 \times 12 = 0.2$ in.

$c/2 = 26/2 = 13.0$ in. . . . governs

Since the length of needed special boundary element (= 13 in) does not exceed the depth of boundary column (= 18 in), the entire boundary column is confined.

ACI 318 Section 21.6.6.4 (c) Transverse reinforcement

Special boundary element transverse reinforcement must satisfy the requirements of ACI 318 Sections 21.4.4.1 through 21.4.4.3, except ACI 318 Equation (21-3) need not be satisfied.

Boundary column confinement

Minimum area of rectangular hoop reinforcement (ACI 318 Section 21.4.4.1b)

$A_{sh} = 0.09\, s\, h_c f'_c / f_{yh}$ (Equation 21-4)

As there are 4 layers of longitudinal reinforcement in the boundary column, minimum number of legs (hoops and ties) needed to support alternate bars is 3.

Maximum horizontal spacing of hoop or crosstie legs, $h_x = (18 - 2 \times 2.5)/3 = 4.33$ in

According to Section 21.4.4.2, the spacing of transverse reinforcement must not exceed (a) one-quarter of the minimum member dimension, (b) six times the diameter of the longitudinal reinforcement, and (c) s_x, as defined by Equation (21-5).

$s_x = 4 \text{ in.} \leq 4 + (14 - h_x)/3 \leq 6$ in. (Equation 21-5)

$s_x = 4 \text{ in.} \leq 7.2 \text{ in.} \leq 6$ in. ← Use $s_x = 6$ in

$s \leq 6$ in. ← governs

$\leq 6d_b = 6 \times 1.0 = 6.0$ in.

$\leq$ minimum plan dimension/4 = 4.5 in.

$h_c = 18 - 2 \times 1.5 - 5/8 = 14.4$ in.

$A_{sh} \geq 0.09 \times 4.5 \times 14.4 \times 4/60 = 0.39 \text{ in.}^2$

With one tie all around the longitudinal reinforcement and one crosstie in either direction (as shown in Fig. E.4.3),

A_{sh} provided $= 3 \times 0.31 = 0.93 \text{ in.}^2 > 0.39 \text{ in.}^2$ OK