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Concrete Walls

Bearing, Ordinary and Special shear wall

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1-According ACI318

Wall definition

ACI Code Section 2.3 defines a wall as follows:
***"Wall*—**a vertical element designed to carry axial load, lateral load, or both, with a horizontal length-to-thickness ratio greater than three, used to enclose or separate spaces."

1-Types of wall (according SDC) (ref. ACI SP17m(14)

a –Ordinary reinforced concrete structural walls SDC A, B, C

The walls complying with the requirements of chapter 11

b -special reinforced concrete structural walls SDC D, E, F

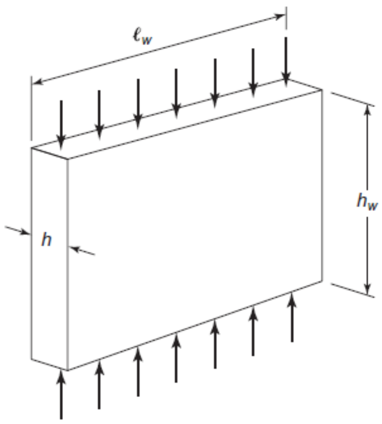
The walls complying with requirements of 18.2.3 through 18.2.8 and 18.10

2-Types of Wall (according loading)

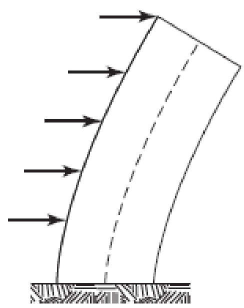
Structural walls can be classified as:

(a) ***Bearing walls***—walls that are laterally supported and braced by the rest of the structure that resist primarily in-plane vertical loads acting downward on the top of the wall (see Fig. a). The vertical load may act eccentrically with respect to the wall thickness, causing *weak-axis bending*

(b) ***Shear walls***—walls that primarily resist lateral loads due to wind or earthquakes acting on the building are called *shear walls* or *structural walls*. These walls often provide lateral bracing for the rest of the structure. (See Fig. b.) They resist gravity loads transferred to the wall by the parts of the structure tributary to the wall, plus lateral-loads (lateral shears) and moments about the *strong axis* of the wall



(a) Bearing wall.



(b) Shear wall.

a-Bearing walls

Walls used primarily to support gravity loads in buildings are referred to as *bearing walls*.
Design of bearing walls normally follows ACI Code Section 11.5.3, which was derived specifically to apply to walls subjected to axial loads and moments due to the axial loads acting at an eccentricity of one-sixth of the thickness of the wall from the mid plane of the wall (i.e., at the kern of the wall). The resulting moments are referred to as *weak-axis bending* moments. ACI Code Section 11.5.2.1 allows the design of bearing walls to be carried out either by:

1. The so-called *simplified design method* in ACI Code Section 11.5.3, or

2.. Using the column design and slenderness requirements in ACI Code Sections 22.2, 22.4 and 11.8

1-Simplified design method

R11.4.1.3 The forces typically acting on a wall are illustrated in Fig. R11.4.1.3.

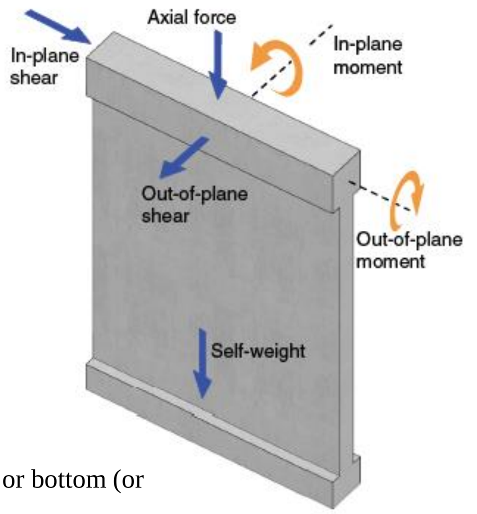


Fig. R11.4.1.3—In-plane and out-of-plane forces.

11.5.3 *Axial load and out-of-plane flexure – simplified design method*

11.5.3.1 If the resultant of all factored loads is located within the middle third of the thickness of a solid wall with a rectangular cross section, P_n shall be permitted to be calculated by:

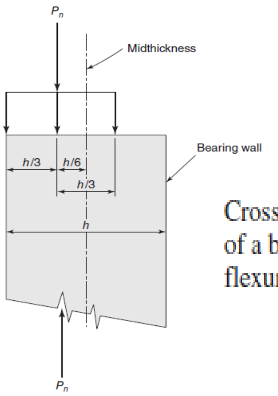
$$\phi P_n = 0.55\phi f'_c A_g\left[1-\left(\frac{k\ell_c}{32h}\right)^2\right]$$

where

l_c is the clear, vertical distance between lateral supports
k is the effective length factor for a wall, taken as
0.8 if the wall is braced against translation at both ends and the top or bottom (or both) is restrained against rotation

1.0 if both ends are effectively hinged
2.0 for walls that are not effectively braced against lateral translation at the top, and therefore must be considered to be freestanding
h is the overall thickness of the wall
Ø is the strength-reduction factor for compression-controlled sections, taken equal to 0.65.

Minimum wall thickness designed with simpified method shall be according ACI 318 table -11.3.1.1



Cross section through the top of a bearing wall showing the flexural compression zone.

The simplified design method applies only

1- Solid rectangular cross sections; all other shapes should be designed in accordance with ACI318 11.5.2.

2- Eccentric axial loads and moments due to out-of-plane forces are used to determine the maximum total eccentricity of the factored axial force P_u. When the resultant axial force for all applicable load combinations falls within the middle third of the wall thickness (eccentricity not greater than $h/6$) at all sections along the length of the UN-deformed wall

Table 11.3.1.1—Minimum wall thickness h

Wall type	Minimum thickness h		
Bearing[1]	Greater of:	100 mm	(a)
		1/25 the lesser of unsupported length and unsupported height	(b)
Nonbearing	Greater of:	100 mm	(c)
		1/30 the lesser of unsupported length and unsupported height	(d)
Exterior basement and foundation[1]	190 mm		(e)

[1]Only applies to walls designed in accordance with the simplified design method of 11.5.3.

The minimum thickness requirements need not be applied to bearing walls and exterior basement and foundation walls designed by ACI318 11.5.2 or analyzed by ACI318-11.8.

2. Using the column design and slenderness requirements

For bearing walls, ***Pn*** and ***Mn*** (in-plane or out-of-plane) shall be calculated in accordance with ACI318 -22.4 as same as column design

According ACI318-11.4.1.3 Slenderness effects shall be calculated in accordance with 6.6.4, 6.7, or 6.8. Alternatively, out-of-plane slenderness analysis shall be permitted using 11.8 for walls meeting the requirements of that section.

ACI318-11.8—Alternative method for out-of-plane slender wall analysis.

This method can used to calculate the out of plan slenderness under the following conditions

(a) Cross section is constant over the height of the wall
(b) Wall is tension-controlled for out-of-plane moment effect
(c) ϕM_n is at least M_{cr}, where M_{cr} is calculated using f_r as provided in 19.2.3
(d) P_u at the mid-height section does not exceed $0.06 f_c' A_g$

(e) Calculated out-of-plane deflection due to service loads, Δ_s, including $P\Delta$ effects, does not exceed $\ell_c/150$

According ACI318 **R11.8.1.1**
This procedure is presented as an alternative to the requirements of 11.5.2.1 for the out-of-plane design of slender wall panels, where the panels are restrained against rotation at the top.
Panels that have windows or other large openings are not considered to have constant cross section over the height of the panel. Such walls are to be designed taking into account the effects of openings.

Many aspects of the design of tilt-up walls and buildings are discussed in ACI 551.2R and Carter et al. (1993).

Conclusion

The Most general method to design the bearing wall as same as columns according ACI318 item 22.4 with considering all slenderness provision 6.6.4, 6.7 or 6.8

Table 11.6.1—Minimum reinforcement for walls with in-plane $V_u \leq 0.5\phi V_c$

Wall type	Type of nonprestressed reinforcement	Bar/wire size	f_y, MPa	Minimum longitudinal[1], ρ_ℓ	Minimum transverse, ρ_t
Cast-in-place	Deformed bars	$\leq$ No. 16	$\geq$ 420	0.0012	0.0020
			< 420	0.0015	0.0025
		> No. 16	Any	0.0015	0.0025
	Welded-wire reinforcement	$\leq$ MW200 or MD200	Any	0.0012	0.0020
Precast[2]	Deformed bars or welded-wire reinforcement	Any	Any	0.0010	0.0010

These reinforcement ratios can be written in terms of the maximum spacing of the bars. Thus, for No16 or smaller bars with *fy* not less than 420MPa, the maximum horizontal and vertical spacing are as follows:
Vertical steel:
sh,max = *Av* /(0.0012*h*)
Horizontal steel:
sv,max = *Ah* /(0.0020*h*)

If the reinforcement is in two layers, *Av* is the total area of vertical bars within the spacing *sh*, and similarly for the horizontal bars.

ACI Code Table 11.6.1 requires more reinforcement horizontally than vertically. This reflects the greater chance that vertical cracks in walls might form as a result of restrained horizontal shrinkage or temperature stresses, compared with a lower chance that horizontal cracks will form as a result of restrained vertical stresses. Generally, if Shrinkage occurs in the vertical direction; the shrinkage stresses are dissipated by vertical compression stresses in the wall.

a-In plan shear

Vn=Vc+Vs

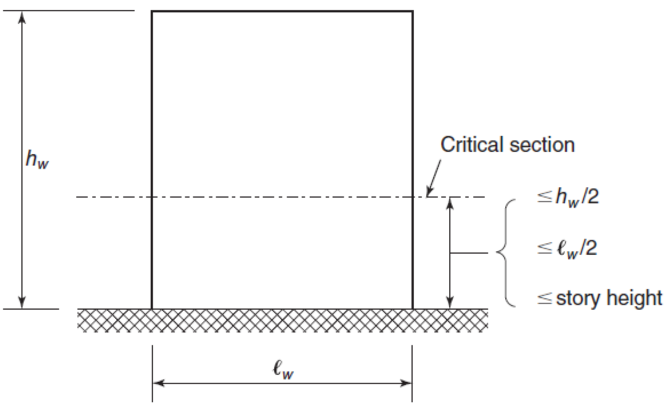
Vn < $0.83\sqrt{fc'}hd$

11.5.4.2 For in-plane shear design, h is thickness of wall and d shall be taken equal to $0.8\ell_w$. A larger value of d, equal to the distance from extreme compression fiber to center of force of all reinforcement in tension, shall be permitted if the center of tension is calculated by a strain compatibility analysis.

Table 11.5.4.6—V_c: nonprestressed and prestressed walls

Calculation option	Axial force		V_c	
Simplified	Compression		$0.17\lambda\sqrt{f_c'}hd$	(a)
	Tension	Greater of:	$0.17\left(1+\frac{0.29N_u}{A_g}\right)\lambda\sqrt{f_c'}hd$	(b)
			0	(c)
Detailed	Tension or compression	Lesser of:	$0.27\lambda\sqrt{f_c'}hd+\frac{N_u d}{4\ell_w}$	(d)
			$\left[0.05\lambda\sqrt{f_c'}+\frac{\ell_w\left(0.1\lambda\sqrt{f_c'}+0.2\frac{N_u}{\ell_w h}\right)}{\frac{M_u}{V_u}-\frac{\ell_w}{2}}\right]hd$ Equation shall not apply if $(M_u/V_u - \ell_w/2)$ is negative.	(e)

11.5.4.7 Sections located closer to wall base than a distance $\ell_w/2$ or one-half the wall height, whichever is less, shall be permitted to be designed for V_c calculated using the detailed calculation options in Table 11.5.4.6 at a distance above the base of $\ell_w/2$ or one-half the wall height, whichever is less.



Shear critical section

R11.5.4.7 The values of V_c calculated from (d) and (e) in Table 11.5.4.6 at a section located a distance above the base of $\ell_w/2$ or $h_w/2$, whichever is lesser, apply to that section and all sections between it and the base. However, the maximum factored shear force V_u at any section, including the base of the wall, is limited to the upper bound on V_n in accordance with 11.5.4.3.

However critical sections located at $h_w/2, l_{w/2}$ or story height the max shear at foundations must not exceed $0.83\sqrt{fc'}hd$

11.5.4.8 V_s shall be provided by transverse shear reinforcement and shall be calculated by:

$$V_s = \frac{A_v f_{yt} d}{s} \qquad (11.5.4.8)$$

b-out of plan shear

According ACI318-14 11.5.5.1

V_n shall be calculated in accordance 22.5

22.5—One-way shear strength

22.5.1 *General*

22.5.1.1 Nominal one-way shear strength at a section, V_n, shall be calculated by:

$$V_n = V_c + V_s \qquad (22.5.1.1)$$

$$V_u \le \phi(V_c + 0.66\sqrt{f_c'}b_w d) \qquad (22.5.1.2)$$

Table 22.5.5.1—V_c for nonprestressed members

Criteria	V_c		
$A_v \geq A_{v,min}$	Either of:	$\left[0.17\lambda\sqrt{f'_c}+\frac{N_u}{6A_g}\right]b_w d$	(a)
		$\left[0.66\lambda(\rho_w)^{1/3}\sqrt{f'_c}+\frac{N_u}{6A_g}\right]b_w d$	(b)
$A_v < A_{v,min}$	$\left[0.66\lambda_s\lambda(\rho_w)^{1/3}\sqrt{f'_c}+\frac{N_u}{6A_g}\right]b_w d$		(c)

Notes:
1. Axial load, N_u, is positive for compression and negative for tension.
2. V_c shall not be taken less than zero.

22.5.8.5.3 V_s for shear reinforcement in 22.5.8.5.1 shall be calculated by:

$$V_s = \frac{A_v f_{yt} d}{s} \qquad (22.5.8.5.3)$$

➢ Reinforcement Limits ACI318-14 -11.60

1- If in plane shear $V_u \leq .5 \phi V_c$

11.6.1 If in-plane $V_u \leq 0.5\phi V_c$, minimum ρ_ℓ and minimum ρ_t shall be in accordance with Table 11.6.1. These limits need not be satisfied if adequate strength and stability can be demonstrated by structural analysis.

2- If in plane shear $V_u \geq .5 \phi V_c$

11.6.2 If in-plane $V_u \geq 0.5\phi V_c$, (a) and (b) shall be satisfied:

(a) ρ_ℓ shall be at least the greater of the value calculated by Eq. (11.6.2) and 0.0025, but need not exceed ρ_t in accordance with Table 11.6.1.

$$\rho_\ell \geq 0.0025 + 0.5(2.5 - h_w/\ell_w)(\rho_t - 0.0025) \qquad (11.6.2)$$

(b) ρ_t shall be at least 0.0025

➢ Reinforcement Detailing

1-Spacing of longitudinal reinforcement

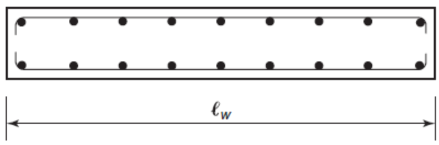
S must not exceed the following

a- 3h

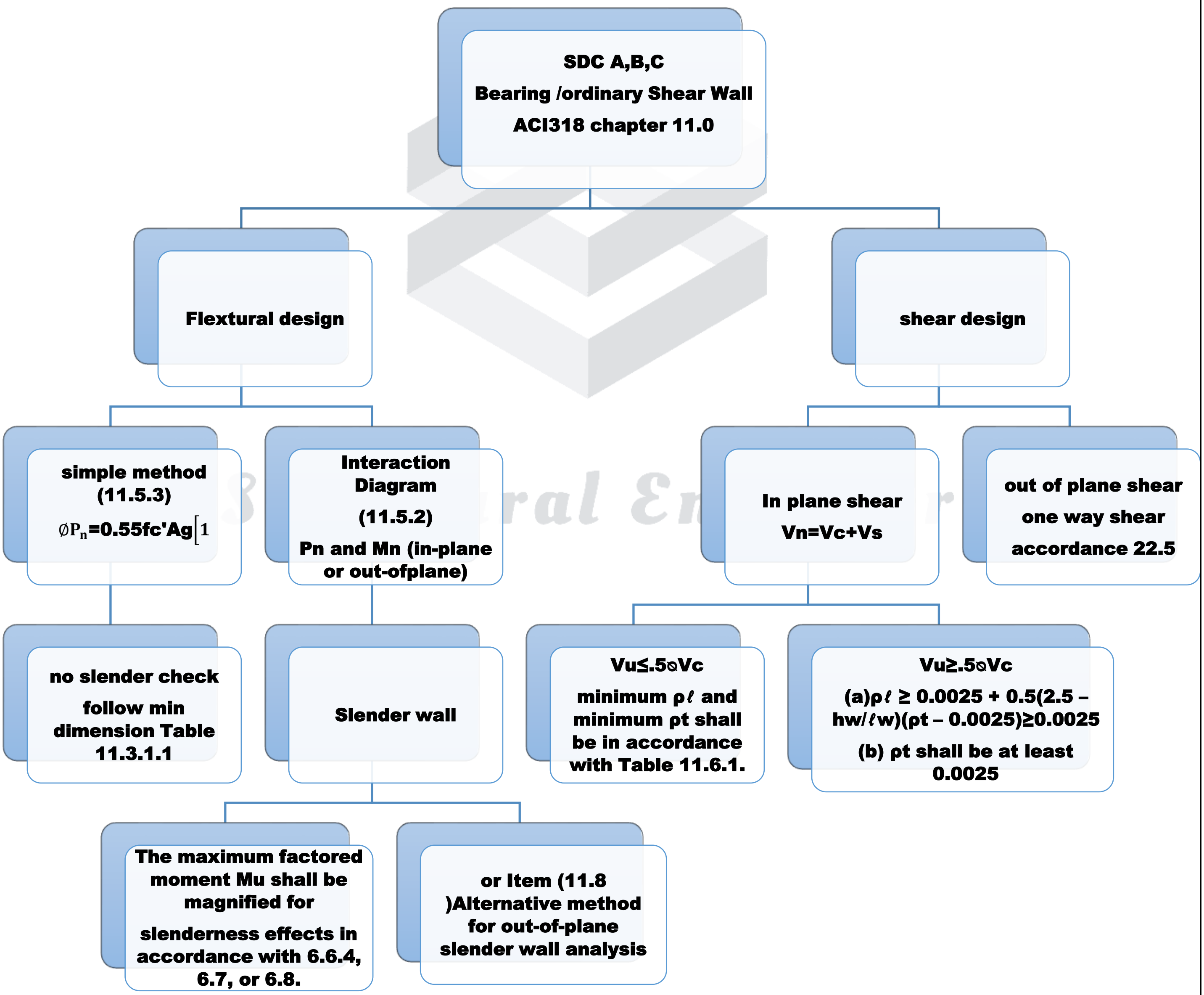
b-$L_w/3$

c-450mm

For walls with thickness > 250 mm, except single story basement walls and cantilever retaining walls, reinforcement shall be placed on at least two layers each side



Typical wall section >250mm



Example-1

Following wall located in zone with Seismic Design Category B, story Height =5.5 m

Given

P_u=4515 KN

In plane

V_u =1045 KN

M_u =25218 KN.m

Out of plane

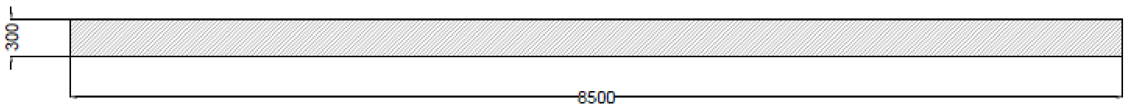
V_u =71 KN

M_u =81 KN.m

Material properties

fc'=35 MPa

fy=420 Mpa



Answer

1-check wall thickness according ACI table 11.3.1.1

However the example follow requirement of section 11.5.2 , table 11.3.1.1 provide indication that the thickness is appropriate

Table 11.3.1.1—Minimum wall thickness *h*

Wall type	Minimum thickness *h*		
Bearing[1]	Greater of:	100 mm	(a)
		1/25 the lesser of unsupported length and unsupported height	(b)
Nonbearing	Greater of:	100 mm	(c)
		1/30 the lesser of unsupported length and unsupported height	(d)
Exterior basement and foundation[1]	190 mm		(e)

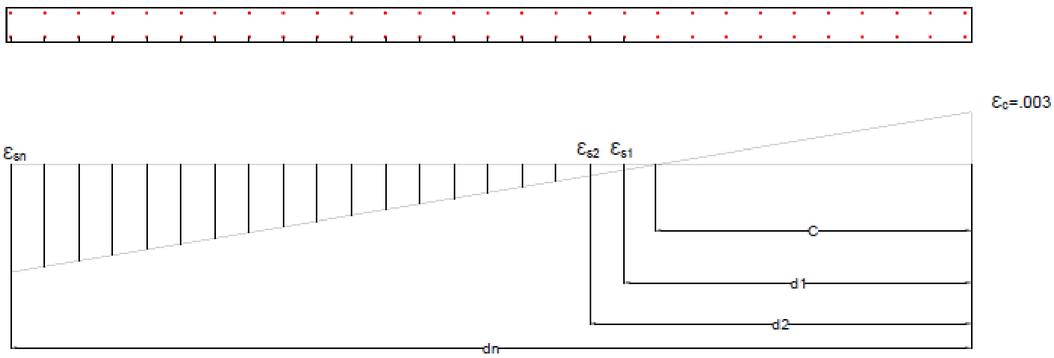
[1]Only applies to walls designed in accordance with the simplified design method of 11.5.3.

The unsupported height controls 5.5m<8.5m

h_{req}=5500/25=220mm $\longrightarrow$ h=300 mm is ok

To design Wall for Axial and Flexural design strength, we will assume initial longitudinal reinforcement and check section accordingly

assume using Ø16@300 mm



Assume initial value of C according following assumption

1-Compression reinforcement are neglected due perpendicular ties are not provided

2-can assume initially tension reinforcement stress 0.6 Fy

0.85fc'*h*0.85C=0.6fy*As/2+Pu/Ø assume Ø=0.9 and to be checked later

0.85*35*300*.85C=0.6*420*29*201+4515000/0.9

C=854.911 assume C=850mm

Fst=600x$\frac{ds-c}{c}$ ≤ fy

n	ds	C	fst caculated	fst	T
1	957	850	75.52941176	75.52941	15181.41
2	1257	850	287.2941176	287.2941	57746.12
3	1557	850	499.0588235	420	84420
4	1857	850	710.8235294	420	84420
5	2157	850	922.5882353	420	84420
6	2457	850	1134.352941	420	84420
7	2757	850	1346.117647	420	84420
8	3057	850	1557.882353	420	84420
9	3357	850	1769.647059	420	84420
10	3657	850	1981.411765	420	84420
11	3957	850	2193.176471	420	84420
12	4257	850	2404.941176	420	84420
13	4557	850	2616.705882	420	84420
14	4857	850	2828.470588	420	84420

15	5157	850	3040.235294	420	84420
16	5457	850	3252	420	84420
17	5757	850	3463.764706	420	84420
18	6057	850	3675.529412	420	84420
19	6357	850	3887.294118	420	84420
20	6657	850	4099.058824	420	84420
21	6957	850	4310.823529	420	84420
22	7257	850	4522.588235	420	84420
23	7557	850	4734.352941	420	84420
24	7857	850	4946.117647	420	84420
25	8157	850	5157.882353	420	84420
26	8457	850	5369.647059	420	84420
					2099008

Pn=0.85fc'*300*0.85c-T

Pn=0.85*35*300*.85*850-2099008=4349304<pu/ Ø

Repeat the above procedure with increasing C

Section considers safe if difference between Ø Pn and Pu <5%

And ØMn>Mu

assume C=940mm

n	ds	C	fst caculated	fst	T
1	957	940	10.85106383	10.85106	2181.064
2	1257	940	202.3404255	202.3404	40670.43
3	1557	940	393.8297872	393.8298	79159.79
4	1857	940	585.3191489	420	84420
5	2157	940	776.8085106	420	84420
6	2457	940	968.2978723	420	84420
7	2757	940	1159.787234	420	84420
8	3057	940	1351.276596	420	84420
9	3357	940	1542.765957	420	84420
10	3657	940	1734.255319	420	84420
11	3957	940	1925.744681	420	84420
12	4257	940	2117.234043	420	84420
13	4557	940	2308.723404	420	84420
14	4857	940	2500.212766	420	84420
15	5157	940	2691.702128	420	84420
16	5457	940	2883.191489	420	84420
17	5757	940	3074.680851	420	84420
18	6057	940	3266.170213	420	84420

19	6357	940	3457.659574	420	84420
20	6657	940	3649.148936	420	84420
21	6957	940	3840.638298	420	84420
22	7257	940	4032.12766	420	84420
23	7557	940	4223.617021	420	84420
24	7857	940	4415.106383	420	84420
25	8157	940	4606.595745	420	84420
26	8457	940	4798.085106	420	84420
					2063671

Ø Pn= Ø (0.85*35*300*.85*940-2063671) = 4560.663 KN~ Pu ok

Check Ø

d=0.8 l_w=0.8*8500=6800

c/d=940/68000=0.138 < 0.375 tension failure Ø=0.9

calculate Mn

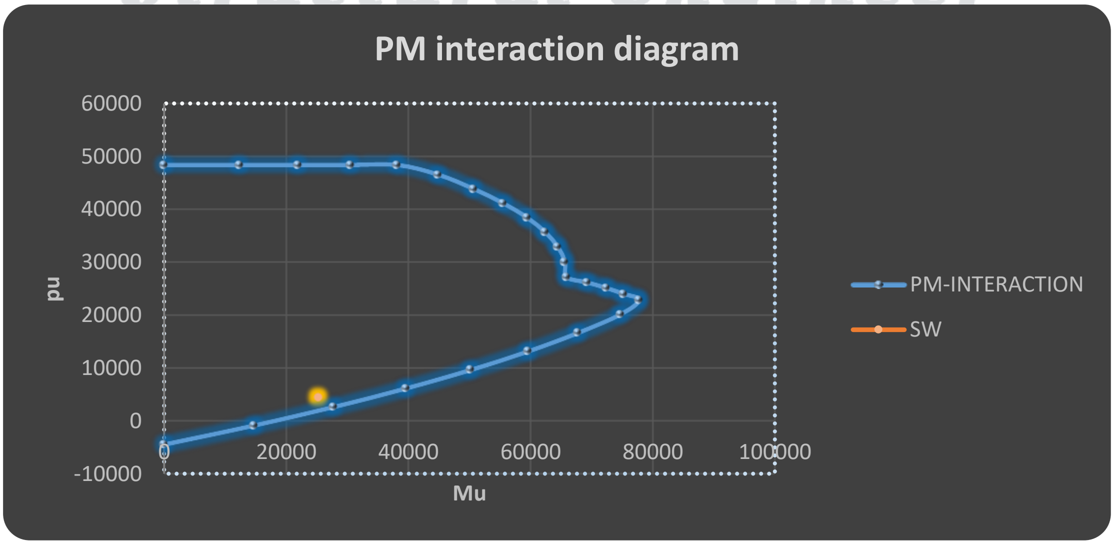
Mn= $\sum T\left(d-\frac{.85c}{2}\right)+pn*\left(\frac{lw}{2}-\frac{0.85c}{2}\right)=45938.9\ KN.m$

ØMn>Mu

Section is safe

Note

Also checking section can be according interaction diagram with any proper software



Check section for in plane shear

V_u =1045 KN

Check V_u<0.5 Ø Vc or not

Table 11.5.4.6—V_c: nonprestressed and prestressed walls

<table>
<tr><th>Calculation option</th><th>Axial force</th><th colspan="2">V_c</th><th></th></tr>
<tr><td rowspan="3">Simplified</td><td>Compression</td><td colspan="2">$0.17\lambda\sqrt{f_c'}hd$</td><td>(a)</td></tr>
<tr><td rowspan="2">Tension</td><td rowspan="2">Greater of:</td><td>$0.17\left(1+\frac{0.29N_u}{A_g}\right)\lambda\sqrt{f_c'}hd$</td><td>(b)</td></tr>
<tr><td>0</td><td>(c)</td></tr>
<tr><td rowspan="2">Detailed</td><td rowspan="2">Tension or compression</td><td rowspan="2">Lesser of:</td><td>$0.27\lambda\sqrt{f_c'}hd+\frac{N_u d}{4\ell_w}$</td><td>(d)</td></tr>
<tr><td>$\left[0.05\lambda\sqrt{f_c'}+\frac{\ell_w\left(0.1\lambda\sqrt{f_c'}+0.2\frac{N_u}{\ell_w h}\right)}{\frac{M_u}{V_u}-\frac{\ell_w}{2}}\right]hd$
Equation shall not apply if $(M_u/V_u-\ell_w/2)$ is negative.</td><td>(e)</td></tr>
</table>

V_c=$0.17\sqrt{fc'}\ hd$

D=0.8 l_w=0.8x8500=6800

V_c=$0.17\sqrt{35}\ 300 * 6800 = 2052KN$

Ø V_c=1539KN

V_c>Vu> 0.5 Ø V_c

ρ_t=0.0025

Ast=.0025*300*300=225 use

Ø16@300 mm

ρ_l≥ .0025+0.5(2.5-h_w/l_w)x(ρ_t-.0025) or .0025

from above equation

ρ_l≥.0025

Ø16@300 mm

2*201/(300*300)=.0044 ≥.0025 ok

Flexure design strength (out of plane)

M_u =81 KN.m

e= M_u/P_u =81/4515=.017 m $<\frac{1}{6}$ h simplified equation can be applied

Pn=0.55(fc')(A_g)$\left[1-\left(\frac{klc}{32h}\right)^2\right]$

ØPn=(.65)0.55(35) (300x8500)$\left[1-\left(\frac{1x5500}{32*300}\right)^2\right]$=21433KN>>4515 ok

Additional long. Reinf. to sustain out of plane moment not needed

With software can produce 3d PMM diagram such as (ETABS, CSI column) can check combination between Pu, Mx, My without last step.

Shear design strength (out of plane)

Vu=71 KN

Vc=0.17$\sqrt{35}$ *8500x250=2137 KN

Vu<<<2137 no stirrups required

According ACI318 11.7.4.1

Vertical reinf not exceed .01Ag and compression reinf are neglected,

Therefore, ties not required to confine the vertical reinforcement.

Another method used to identify to use confine ties used in reference ACI SP-17(14) to calculate compression stress and comparing with fc' As following: -

Pu=4515 KN Mu=25218 KN.m

Fc=$\frac{4515000}{300x8500}+\frac{6x25218000000}{300x8500^2}$ =8.75 Mpa <fc'

Confine ties not required

Special Shear Wall According ACI318-14

1- Applied scope (ACI-18.1)

a- SDC B, C (structural systems designated as part of the seismic force-resisting system)

b- SDC D, E and F (applies to both structural systems designated as part of the seismic-force-resisting system and structural systems not designated as part of the seismic-force-resisting system.)

1- Flexural Design

Structural walls and portions of such walls subject to combined flexure and axial loads shall be designed in accordance with 22.4.

a- Check special Boundary Element needed or not

1- According 18.10.6.2, The displacement method hw/ lw ≥2.0

$$c \geq \frac{lw}{600(1.5\delta u\ /\ h_w)}$$

2- According 18.10.6.3, the stress-based method

$$f_c = \frac{Nu}{A} \pm \frac{Mu}{I} y \quad \geq 0.2fc'$$

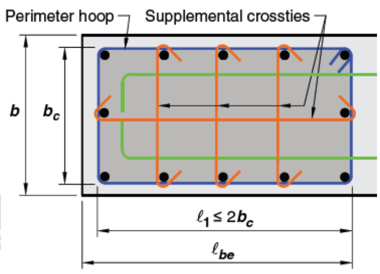
If the limits in Sections 18.10.6.2 or in 18.10.6.3 of ACI318-14 are met. Special boundary elements are defined in section 18.10.6.4(ACI318-14).
If not, wall designed for flexure as same as same as the ordinary wall

b- In Case the Special boundary required Item 18.10.6.4 shall be applied.

18.10.6.4 If special boundary elements are required by 18.10.6.2 or 18.10.6.3, (a) through (k) shall be satisfied:

- 18.10.6.4 a,b and c

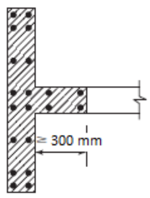
l_{be}=0.5C or C-0.1l_w which is larger



where ***c*** is the largest neutral axis depth calculated for the factored axial force and nominal moment strength consistent with **δ_u**.

b≥$\frac{1}{16}h_u$ ≥ 300

- 18.10.6.4 d



Compression edge of the wall are shown in Fig. ACI Code Section 18.10.6.4(d) also requires that if a specially confined boundary zone is required for a wall with a compression flange, the boundary zone must extend at least 300mm. into the adjacent web

- 18.10.6.4 e,f and g Give the Code requirements for the confinement Ties of the boundary element , if required according 18.10.6.2 or 18.10.6.3
  - 18.10.6.4 e

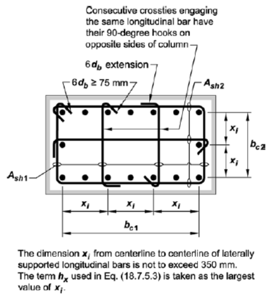


Fig. R18.7.5.2—Example of transverse reinforcement in columns.

The transverse reinforcement in the specially confined boundary elements must satisfy the requirements for column confinement section 18.7.5.2 (a) through (e)
the transverse reinforcement spacing limit of ACI Code Section 18.7.5.3(a) shall be two-third of the least dimension of the boundary element.

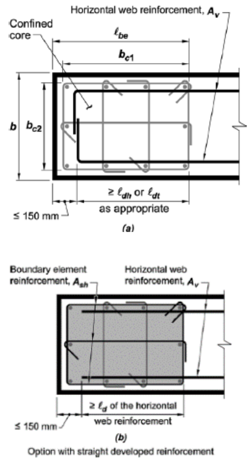
$$hx \leq \frac{2}{3} b \leq 350\text{mm}$$

- 18.10.6.4 f

The transverse reinforcement in the specially confined boundary elements must satisfy the requirements for column confinement reinforcement given in ACI Table 18.10.6.4(f)

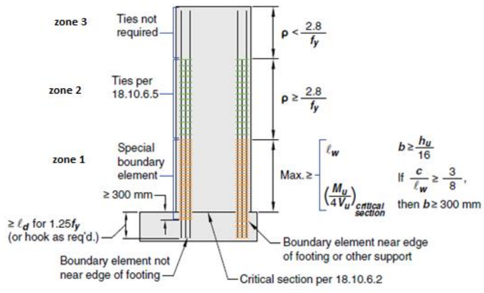
Table 18.10.6.4(f)—Transverse reinforcement for special boundary elements

Transverse reinforcement	Applicable expressions		
A_{sh}/sb_c for rectilinear hoop	Greater of	$0.3\left(\frac{A_g}{A_{ch}}-1\right)\frac{f'_c}{f_{yt}}$	(a)
		$0.09\frac{f'_c}{f_{yt}}$	(b)
ρ_s for spiral or circular hoop	Greater of	$0.45\left(\frac{A_g}{A_{ch}}-1\right)\frac{f'_c}{f_{yt}}$	(c)
		$0.12\frac{f'_c}{f_{yt}}$	(d)



$A_g = b \times l_{be}$ $\quad A_{ch} = b_{c1} \times b_{c2}$

- 18.10.6.4 g

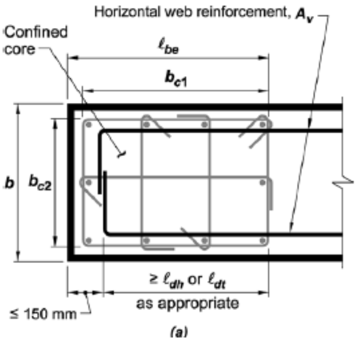


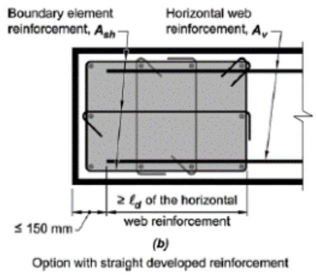
(a) Wall with $h_w/\ell_w \geq 2.0$ and a single critical section controlled by flexure and axial load designed using 18.10.6.2, 18.10.6.4, and 18.10.6.5

longitudinal reinforcement in the special boundary element. Where the special boundary element terminates on a footing, mat, or pile cap, special boundary element transverse reinforcement shall extend at least 300 mm into the footing, mat, or pile cap, unless a greater extension is required by 18.13.2.3.

- 18.10.6.4 h

Horizontal reinforcement in the wall web shall extend to within 150 mm of the end of the wall. Reinforcement shall be anchored to develop f_y within the confined core of the boundary element using standard hooks or heads. Where the confined boundary element has sufficient length to develop the horizontal web reinforcement, and $A_s f_y/s$ of the horizontal web reinforcement does not exceed $A_s f_{yt}/s$ of the boundary element transverse reinforcement parallel to the horizontal web reinforcement, it shall be permitted to terminate the horizontal web reinforcement without a standard hook or head.





2- Shear Design

➢ Design Shear force

Although this study depends mainly on ACI-318-14 but for Design Shear force provided in ACI-318-19 give an efficient and clear way to calculate Ve resulted from M_{pr} as following.

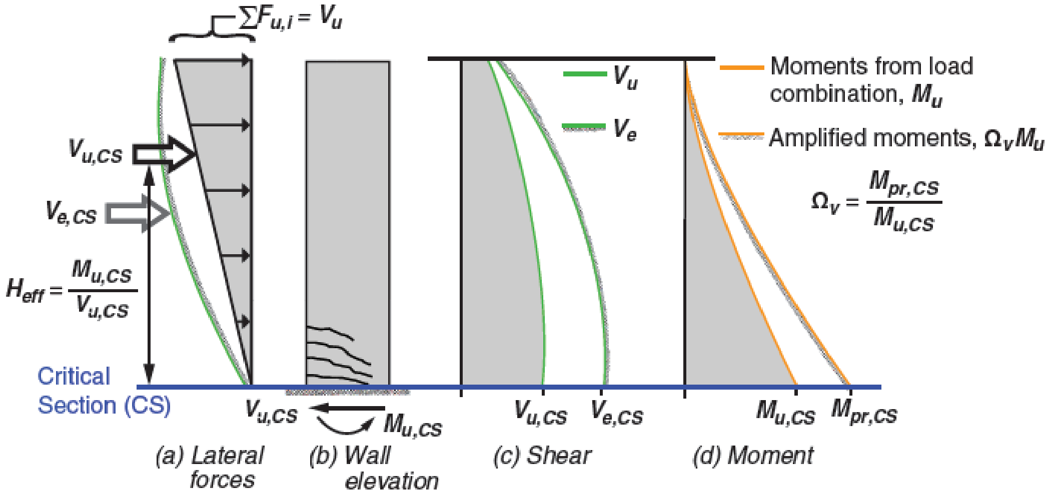


Fig. R18.10.3.1—Determination of shear demand for walls with $h_w/\ell_w \geq 2.0$ (Moehle et al 2011).

Design force (According ACI318-19)

18.10.3.1 The design shear force V_e shall be calculated by:

$V_e = \Omega_v \omega_v V_u \leq 3V_u$ (18.10.3.1)

18.10.3.1.1 V_u is the shear force obtained from code lateral load analysis with factored load combinations

18.10.3.1.2 Ω_v shall be in accordance with Table 18.10.3.1.2.

Table 18.10.3.1.2—Overstrength factor Ω_v at critical section

Condition	Ω_v	
$h_{wcs}/\ell_w > 1.5$	Greater of	M_{pr}/M_u[1]
		1.5[2]
$h_{wcs}/\ell_w \leq 1.5$	1.0	

[1] For the load combination producing the largest value of Ω_v.

[2] Unless a more detailed analysis demonstrated a smaller value, but not less than 1.0.

18.10.3.1.3 For walls with $h_{wcs}/\ell_w < 2.0$, ω_v shall be taken as 1.0. Otherwise, ω_v shall be calculated as:

$$\omega v = 0.9 + \frac{n_s}{10} \qquad n_s \leq 6$$

$$\omega v = 1.3 + \frac{n_s}{30} \leq 1.8 \qquad n_s > 6$$

where n_s shall not be taken less than the quantity $0.00028h_{wcs}$

h_{wcs} = height of entire structural wall above the critical section for flexural and axial loads, mm

R18.10.3.1 Design shears for structural walls are obtained from lateral load analysis with appropriate load factors increased to account for: (i) flexural overstrength at critical sections where yielding of longitudinal reinforcement is expected; and (ii) dynamic amplification due to higher mode effects, as illustrated in Fig. R18.10.3.1. The approach used to determine the amplified shear forces is similar to that used in New Zealand Standard 3101 (2006). Because M_n and M_{pr} depend on axial force, which varies for different load combinations, and loading direction for flanged and coupled walls, the condition producing the largest value of Ω_v should be used. Although the value of 1.5 in 18.10.3.1.2 is greater than the minimum value obtained for the governing load combination with a ϕ factor of 0.9 and a tensile stress of at least $1.25f_y$ in the longitudinal reinforcement, a value greater than 1.5 may be appropriate if provided longitudinal reinforcement exceeds that required. Dynamic amplification is not significant in walls with $h_w/\ell_w < 2$. A limit of $0.007h_{wcs}$ is imposed on n_s to account for buildings with large story heights. The application of Ω_v to V_u does not preclude the application of a redundancy factor if required by the general building code.

➢ <u>Design Shear Strength</u>

$V_n \leq A_{cv}\left(\alpha_c \lambda \sqrt{f_c'} + \rho_t f_y\right)$

Where

α_c is 0.25 for $h_w/l_w \leq 1.5$ is 0.17for $h_w/l_w \geq 2.0$ and varies linearly between 0.25 and 0.17 for h_w/l_w between 1.5 and 2.0

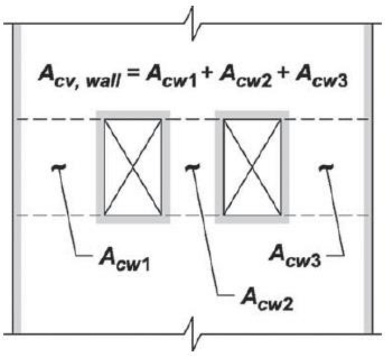
A_{cv} is the gross area of the wall

ρ_t refer to the horizontal reinforcement ≥0.025

If $h_w/l_w \leq 2.0$ ρ_l shall at least equal ρ_t

$V_n \leq 0.66A_{cv}\sqrt{f_c'}$

$V_n \leq 0.83A_{cw}\sqrt{f_c'}$



Where

A_{cw} is the area of concrete section of the individual vertical wall segment considered.

➢ <u>Reinforcement</u>

- The distributed web reinforcement ratios, $\rho\ell$ and ρt, for structural walls shall be at least 0.0025

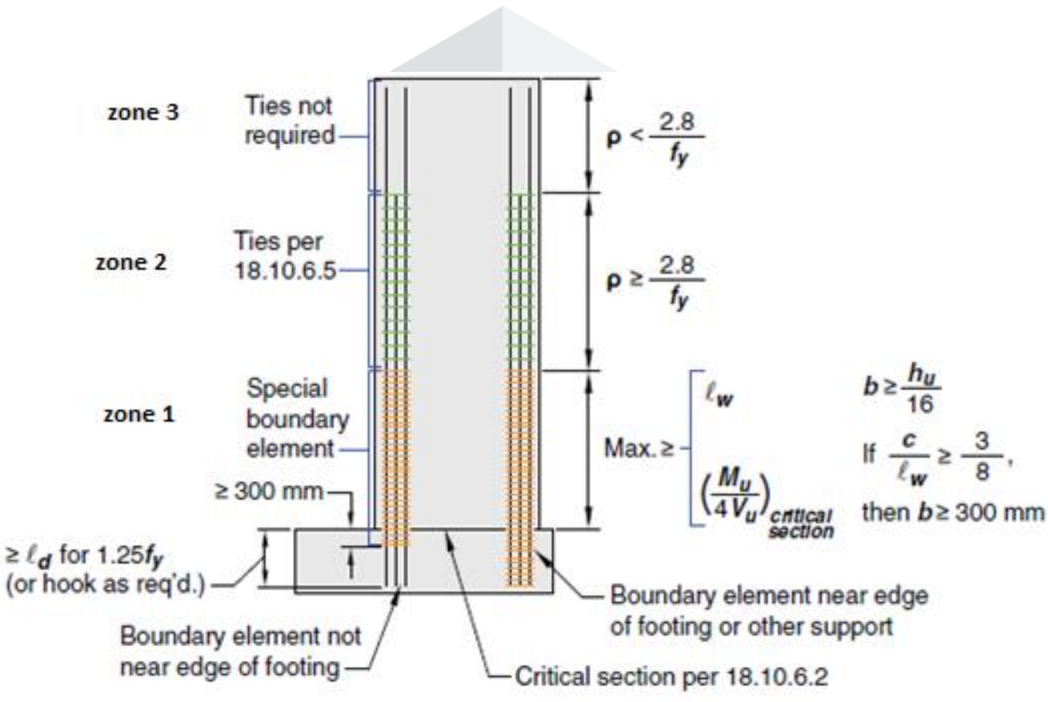
- At least two curtains of reinforcement shall be used in a wall if $V_u > 0.17\lambda \sqrt{f_c'} A_{cv}$ or $h_w/\ell_w \geq 2.0$, in which h_w and ℓ_w refer to height and length of entire wall, respectively.

- Reinforcement in structural Walls shall be developed or spliced for fy in tension in accordance with 25.4,25.5 and (a)through (c)
  a- Longitudinal reinforcement shall extend beyond the point at which it is no longer required to resist flexure by least 0.8 ℓ_w except at the top of the wall
  b- Splice at the critical section the development length of the longitudinal reinforcement shall be 1.25 L_d

c- Mechanical splices shall confirm 18.2.7&18.2.8

- Special boundary element transverse reinforcement shall extend vertically above and below the critical section a least the greater of ℓw and Mu/4Vu,

- Where special boundary elements are not required by 18.10.6.2 or 18.10.6.3, (a) and (b) shall be satisfied
  a- If the longitudinal reinforcement ratio at the wall boundary exceeds 2.8/fy, the longitudinal spacing of ties stirrups ≥200mm and 8db of the smallest primary flexural reinf.
  b- Except where Vu in the plane of the wall is less than 0.083λ $\sqrt{fc'}$Acv, horizontal reinforcement terminating at the edges of structural walls without boundary elements shall have a standard hook engaging the edge reinforcement or the edge reinforcement shall be enclosed in U-stirrups having the same size and spacing as, and spliced to, the horizontal reinforcement.



(a) Wall with $h_w/\ell_w \geq 2.0$ and a single critical section controlled by flexure and axial load designed using 18.10.6.2, 18.10.6.4, and 18.10.6.5

- **Special Shear Wall Openings**

As per fig R18.10.4.5, opening separate Wall in vertical and horizontal segments

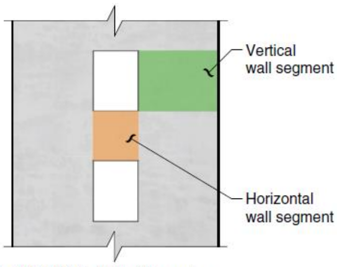


Fig. R18.10.4.5—Wall with openings.

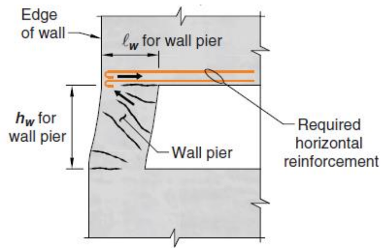
1) Vertical Wall Segment

Vertical Wall segments are designed as Walls, Columns or Wall piers according to the segments geometry as Summarized in ACI318-14 table R18.10.1

Table R18.10.1—Governing design provisions for vertical wall segments[1]

Clear height of vertical wall segment/length of vertical wall segment, (h_w/ℓ_w)	Length of vertical wall segment/wall thickness (ℓ_w/b_w)		
	$(\ell_w/b_w) \le 2.5$	$2.5 < (\ell_w/b_w) \le 6.0$	$(\ell_w/b_w) > 6.0$
$h_w/\ell_w < 2.0$	Wall	Wall	Wall
$h_w/\ell_w \ge 2.0$	Wall pier required to satisfy specified column design requirements; refer to 18.10.8.1	Wall pier required to satisfy specified column design requirements or alternative requirements; refer to 18.10.8.1	Wall

[1]h_w is the clear height, ℓ_w is the horizontal length, and b_w is the width of the web of the wall segment.



In many cases the special structural wall requirements apply. if the wall segment is designed as column, Section 18.10.8.1 requires that special columns or by alternative requires that the special detailing of 18.7.4,18.7.5 and 18.7.6 for columns be applied (ACI 318-14).

Alternatively, Wall piers with (lw/bw)>2.5 shall satisfy (a) through (c)

(a) Ve that can develop Mpr at the ends of the column or Ωo times the factored shear determined by analysis (18.7.6.1 and 18.10.8.1)

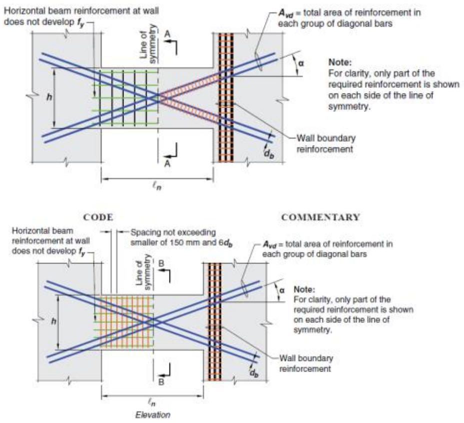
(b) Vertical spacing of transverse reinforcement shall not exceed 150 mm

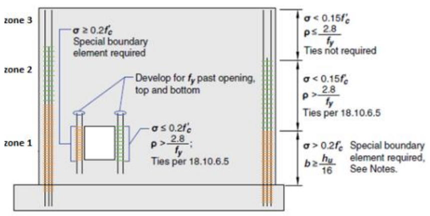
(c) For wall piers at the edge of a wall, horizontal reinforcement shall be provided in adjacent wall segments above and below the wall pier and be designed to transfer the design shear force from the wall pier into the adjacent wall segments.

2- Horizontal Wall Segment

Horizontal wall segment is any portion of wall that is bound by the outer edge of a wall and an edge of an opening.

Horizontal wall segments in special structural walls are designed as special structural walls according to Chapter 18 of ACI 318-14. If horizontal wall segments are part of a coupled special structural wall system, the segment is called a coupling beam. The coupling beam is separated into three categories in ACI 318-14.
(a) If ln/h≥4 the coupling beam is designed as beam in
a special moment frames
(b) If ln/h < 2 and Vu≥0.33Acvλ$\sqrt{fc'}$, design the beam with
diagonally placed bars for a more effective transfer of shear
through the member(c) For other cases, the beam may be designed either as a special beam or with diagonal placed bars





Notes: Requirement for special boundary element is triggered if maximum extreme fiber compressive stress $\sigma \ge 0.2f'_c$. Once triggered, the special boundary element extends until $\sigma < 0.15f'_c$. Since $h_w/\ell_w \le 2.0$, 18.10.6.4(c) does not apply.

(b) Wall and wall pier designed using 18.10.6.3, 18.10.6.4, and 18.10.6.5.

Fig. R18.10.6.4c—Summary of boundary element requirements for special walls.

➢ Modeling requirements reference (prof james-k-weight handbook)

- **Short Wall Effective moment of inertia**

For all of the analysis results given up to this point, only flexural stiffnesses of the walls have been considered. For walls with aspect ratios hw/*l*w less than 3, the effect of shear deformations starts to become more significant. For such walls, it is recommended to use a modified moment of inertia to reflect the increased importance of shear deformations. A value recommended in the PCA Design Handbook [18-15] is

$$I_{mod} = \frac{I_e}{1+\frac{24 I_e}{A_W\, h_w^2}}$$

where I_e is the effective flexural moment of inertia that has been selected based on the prior discussions, and A_w is the wall area,

- **Shear Transfer between Wall Segments in Wall Assemblies**

For the flanges to work with the rest of the cross section of a wall assembly, so-called *Vertical shear stresses* must exist on the interface between the flange and web, even when the wall and the wall segments are constructed monolithically. The stresses to be transferred are calculated in the same manner as for a composite beam, the reinforcement should satisfy ACI Code Section 22.9, *Shear Friction*.

Walls According ECP 203/2018

Wall defined as vertical plate have (length / thickness) > 5.0, min thickness =120mm

Types of Walls

a- Reinforcement Concrete wall

b- Semi Reinforcement Concrete wall (out of study scope)

Reinforcement Concrete wall

1- Bearing Wall
2- Un bearing wall, sustain own weight and Lateral Load
3- Ductile Walls, Wall part of Seismic resistance system

Reinforcement Concrete wall Design

Example-2

Following wall located in zone with Seismic Design Category B, story Height =5.5 m, total height =28 m $\delta u = 61mm$ C_d=5.0

Given

P_u=4515 KN

In plane

V_u =2090 KN

M_u =50436 KN.m

Out of plane

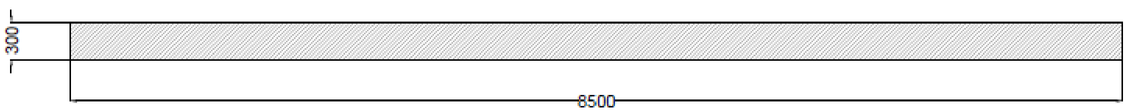
V_u =142 KN

M_u =163 KN.m

Material properties

fc'=35 MPa

fy=420 Mpa



Solution

1-Geometry

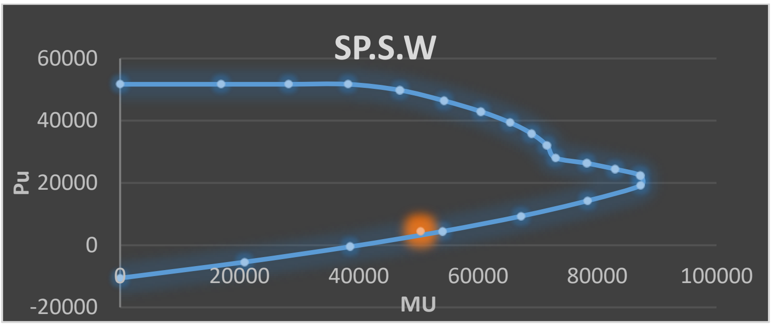
This Wall follows the requirements of chapter 18, therefore doesn't need to meet the requirements of table 11.3.1.1(ACI318) however table 11.3.1.1 can provide an appropriate thickness dimension.

Hreq=5500/25=220 <300 ok

2-Axial and Flexural design in plane

Assume initial reinforcement to produce initial interaction Diagram

Assume vertical reinforcement is uniform distributed T25@300mm



Reference the above interaction diagrams the submitted reinforcement are enough to sustain the applied loads.

Calculate C Value

Although assuming all tension reinforcement have been yielded, but can be sufficient to calculate initial Value of C (reference prof James k. wight)

$$C=\left(\frac{\alpha+\omega}{0.85\beta_1+2\omega}\right) lw$$

$$\rho_l = \frac{58*490}{300x8500} = .0111$$

$$\omega = \rho_l \frac{f_y}{f_c'} = .011\frac{420}{35} = 0.1337$$

$$\alpha = \frac{N_u}{hl_w f_c'} = \frac{4515E3}{300x8500x35} = 0.0506$$

$$C=\left(\frac{.1337+0.0506}{0.85x0.85+2x0.1337}\right)8500 = 1582.53$$

$$T = A_{st}f_y\left(\frac{\ell_w - c}{\ell_w}\right) \quad (18\text{-}25a)$$

$$C_s = A_{st}f_y\left(\frac{c}{\ell_w}\right) \quad (18\text{-}25b)$$

$$C_c = 0.85f'_c h\beta_1 c \quad (18\text{-}25c)$$

and

$$C = C_s + C_c \quad (18\text{-}25d)$$

The percentage of total longitudinal reinforcement is

$$\rho_\ell = \frac{A_{st}}{h\ell_w} \quad (18\text{-}26a)$$

and the longitudinal reinforcement index is

$$\omega = \rho_\ell \frac{f_y}{f'_c} \quad (18\text{-}26b)$$

Finally, Cardenas et al. defined an axial stress parameter as,

$$\alpha = \frac{N_u}{h\ell_w f'_c} \quad (18\text{-}27)$$

where N_u represents the factored axial load, positive in compression.

Enforcing section equilibrium leads to

$$C_c + C_s - T = N_u$$

$$0.85f'_c h\beta_1 c + A_{st}f_y\left(\frac{c}{\ell_w}\right) - A_{st}f_y\left(\frac{\ell_w - c}{\ell_w}\right) = N_u$$

Combining some terms and dividing both sides of this force equilibrium expression by $h\ell_w f'_c$ results in

$$0.85\beta_1\frac{c}{\ell_w} - \left(1 - \frac{2c}{\ell_w}\right)\frac{A_{st}}{h\ell_w}\frac{f_y}{f'_c} = \frac{N_u}{h\ell_w f'_c}$$

Substituting the definitions from Eqs. (18-26) and (18-27), we can solve for the distance to the neutral axis from the compression edge of the wall,

$$c = \left(\frac{\alpha + \omega}{0.85\beta_1 + 2\omega}\right)\ell_w \quad (18\text{-}28)$$

With this value for c, we can use Eq. (18-25) to find all of the section forces. Then, summing moment about the compression force, C, in Fig. 18-15c, we get the following expression for the nominal moment strength of the wall section.

a-Check if special Boundary required

1- According section 18.10.6.2.
   h_w/l_w=*28000/8500=3.29>2.0   18.10.6.2. applicable*

$$\delta u/h_w = \frac{\delta u x C_d}{h_w} = \frac{61x5}{28000} = .0109$$

$$\frac{lw}{600(1.5\delta u/h_w)} = \frac{8500}{600(1.5x.0109)} = 866\ mm\ < C$$

Special Edge Boundary is required accordingly

2- according section 18.10.6.3.

$$f_C = \frac{Nu}{A} + \frac{Mu}{I}y$$

$$f_C = \frac{4515E3}{300x8500} + \frac{6x50436E6}{300x8500^2} = 15.73 > 0.2fc'$$

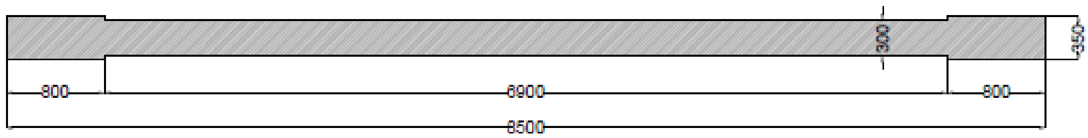
Special Edge Boundary is required accordingly

b-Special boundary geometry according ACI 18.10.6.4

Thickness shall not be less than h/16=5500/16=344mm, b_{be}=350mm

The boundary element must extend horizontally from extreme compression fiber a distance at least the greater of C-0.1l_w and C/2

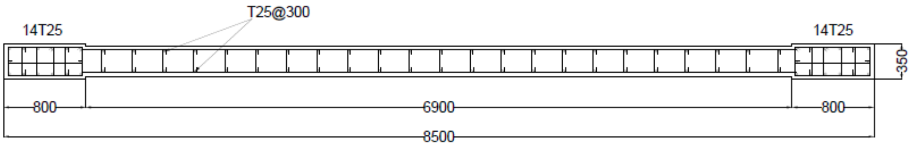
*l_{be}=1582-0.1*8500=732 or 1582/2=791 l_{be} can be taken as 800mm*

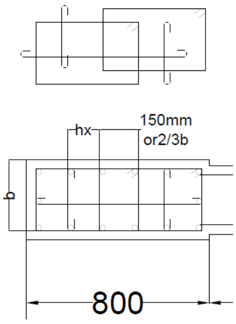


After obtaining the section with the special boundary element, following 18.10.6.4 requirements for reinforcements details

f) Transverse reinforcement shall be arranged such that the spacing h_x between laterally supported longitudinal bars around the perimeter of the boundary element shall not exceed the lesser of 350 mm and two-thirds of the boundary element thickness. Lateral support shall be provided by a seismic hook of a crosstie or corner of a hoop. The length of a hoop leg shall not exceed two times the boundary element thickness, and adjacent hoops shall overlap at least the lesser of 150 mm and two-thirds the boundary element thickness.

hx=2x350/3=233<350





Structural Engineer