Architecture 504
Masonry Structures

Shear Walls

Unreinforced
Reinforced
Wall Connections

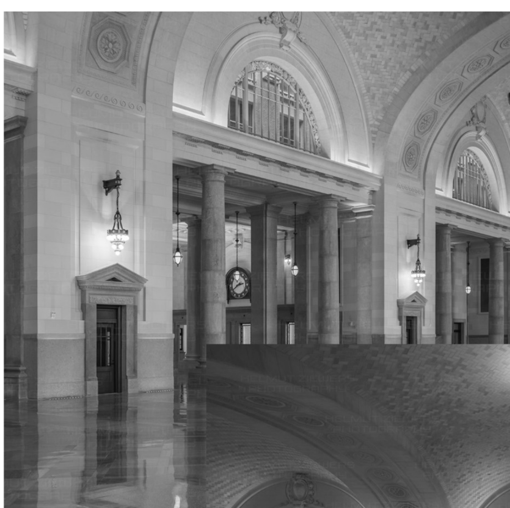
Michigan Central Station

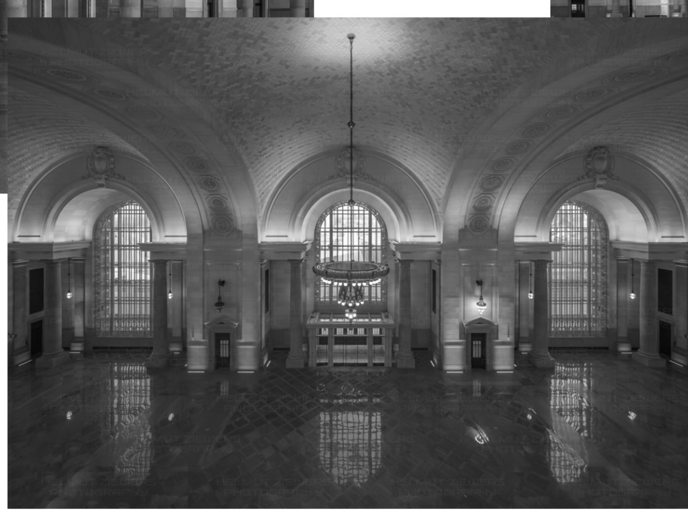
Michigan Central Station

Michigan Central Station vs. Grand Central Station - NY

Michigan Central Station

https://historicdetroit.org/galleries/michigan-central-station-post-renovation-interior





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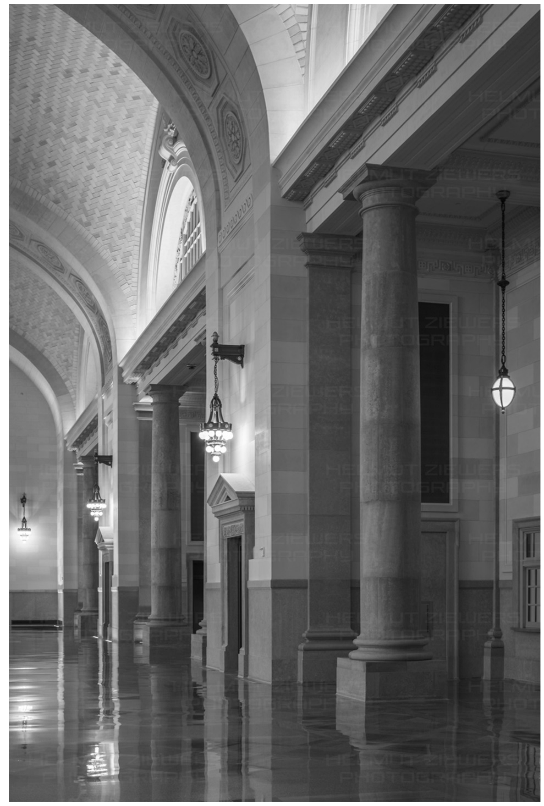

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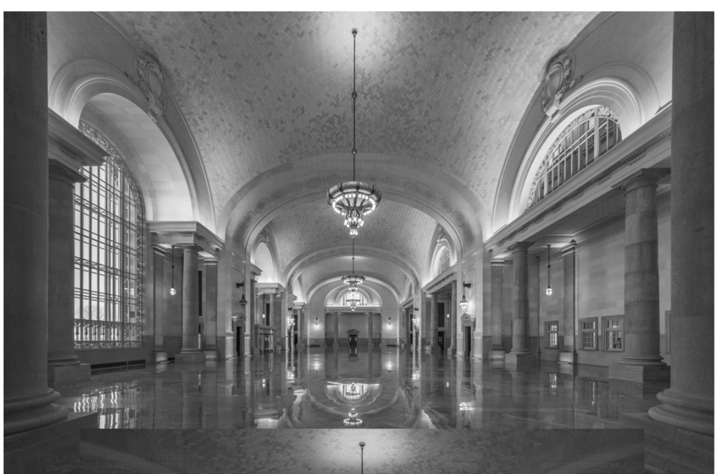
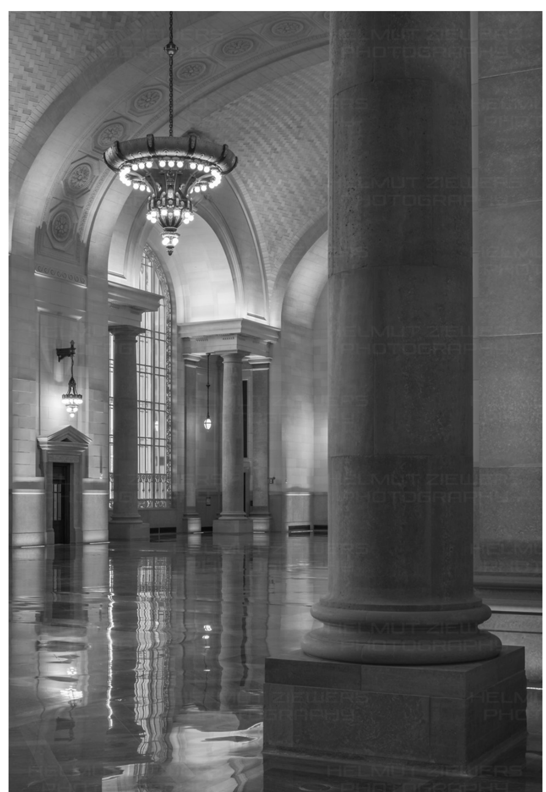




Shear Wall Types and Layouts

Loadbearing walls can provide lateral bracing

In some cases additional lateral bracing requires shear walls

Usually set in the 2 major axis of the building

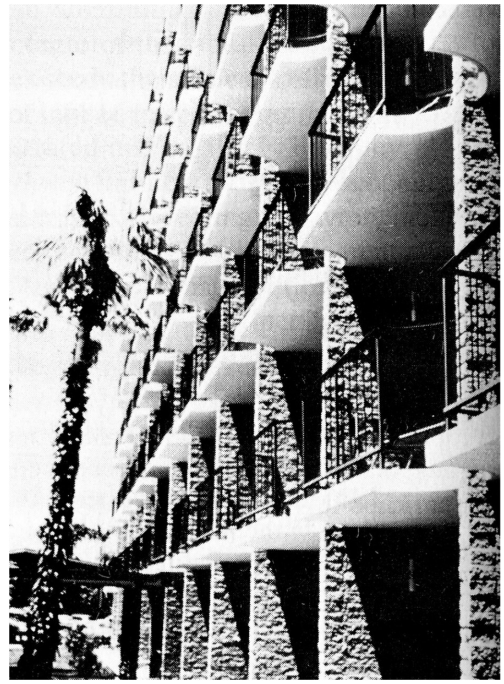
In multistory buildings load is distributed by floors, roofs, rigid diaphragms to the walls

Can be infill between columns

Types by units used: solid, hollow, brick, block, grouted

Types by form: single or multi-wythe, reinforced, unreinforced, rectangular or flanged

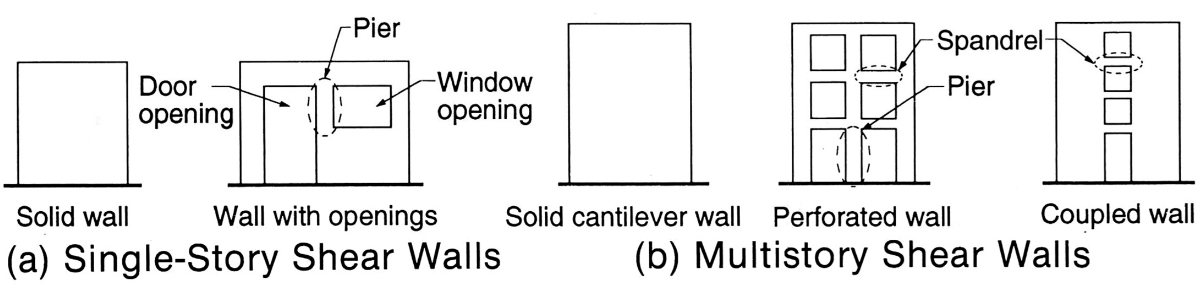
Strength is affected by shape (aspect), openings, boundary elements



Shear Wall Layout

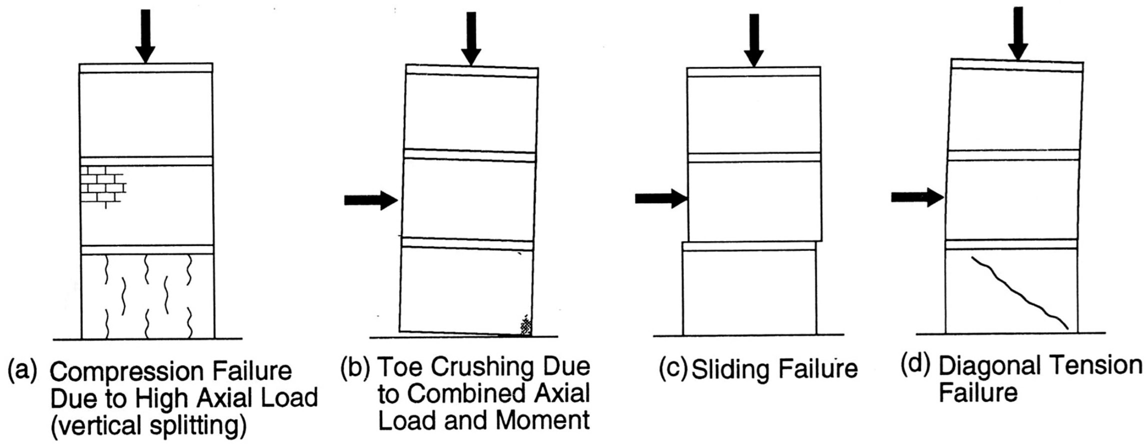
Solid better than with openings

Can act as coupled or perforated walls



Behavior and Failure Modes

Factors:
- Loads
- Geometry
- Materials
- Details
- Reinforcement

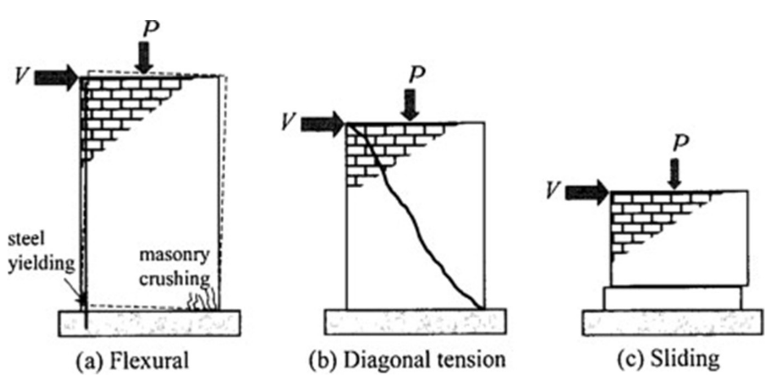


Behavior and Failure Modes

Reinforced:
- Ductile modes are better
- Particularly in seismic zones

Brittle Failure:
- Premature crushing at toe of wall
- Loss of anchorage
- Diagonal tension failure
- Bed joint slip

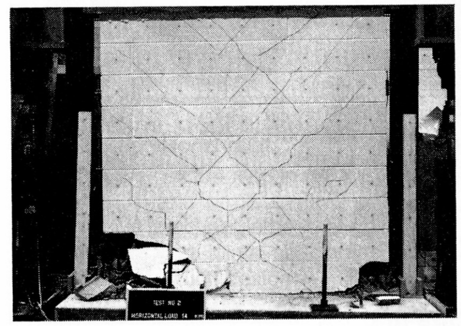
Two primary modes of failure
- Flexural failure
  - bed joint cracking
  - yielding of vert. steel
  - toe crushing
- Shear failure
  - diagonal tension cracking
  - sliding



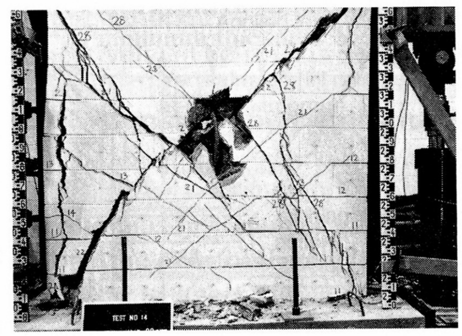
Behavior and Failure Modes

Other factors:

- Increased axial load helps
- Either horizontal or vertical reinforcement
- Even distribution of reinforcing is better rather than concentrated at ends
- Low levels of steel fail soon after cracking
- High levels fail at higher loads after cracking
- Around 2% steel is optimum
- Horizontal reinf. Seems better
  - more uniform cracking
  - increased ultimate strength
  - increased deformation capacity



Flexural failure mode (*Courtesy of B. Shing*)



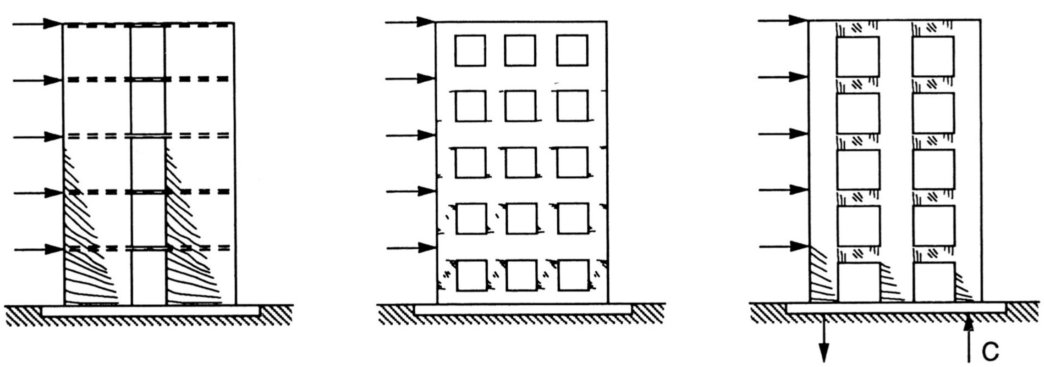
Shear failure mode (*Courtesy of B. Shing*)

Behavior and Failure Modes

Reinforced shear walls:

Type of wall – effects of openings

Cantilever type is generally better



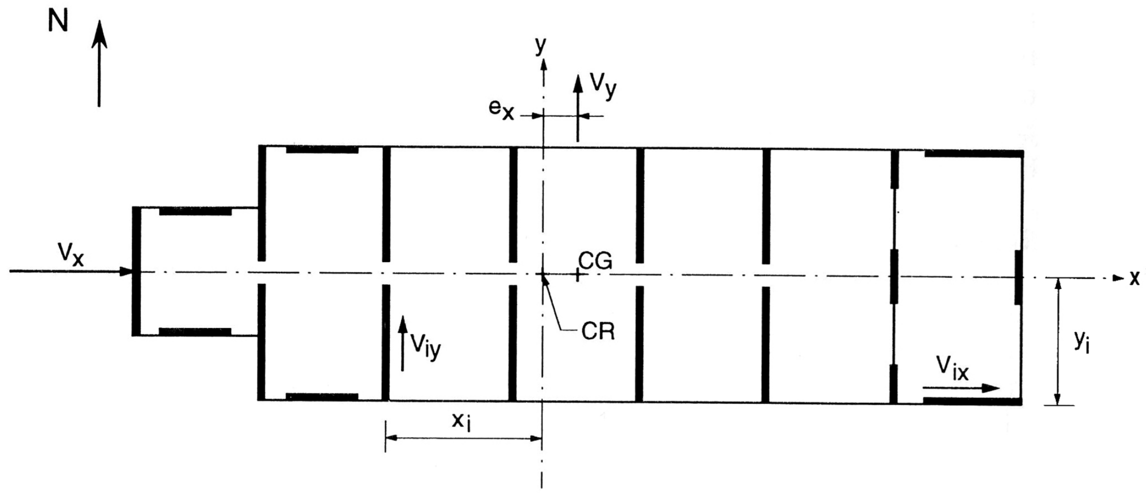
(a) Linked Cantilever Wall (Ductile Response)

(b) Perforated Shear Wall (Pier Failure)

(c) Perforated Shear Wall (Spandrel Failure)

Additional Shear Load Due to Torsion

When the center of rigidity of the walls (CR) does not coincide with the center of gravity of the loads, an additional torsional load results.



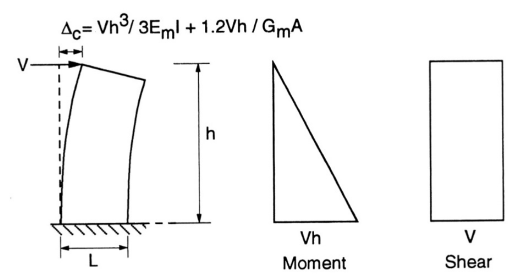
Effects of Walls Fixed Against Rotation

Deflection of walls due to bending and shear deformation

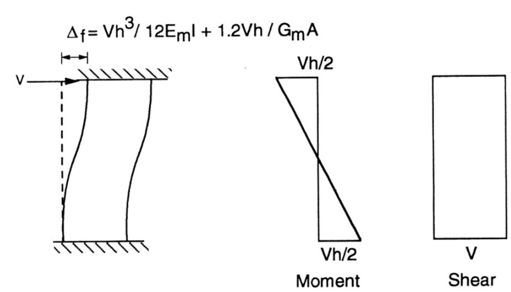
Effect of aspect ration on shear deflection

TABLE 10.1 EFFECT OF ASPECT RATIO ON DEFLECTION DUE TO SHEAR

Aspect ratio, h/L	Percentage deflection due to shear	
	Cantilever wall	Fixed-end wall
0.25	92	98
1	43	75
2	16	43
4	5	16
8	1	4.5



(a) Cantilever Wall



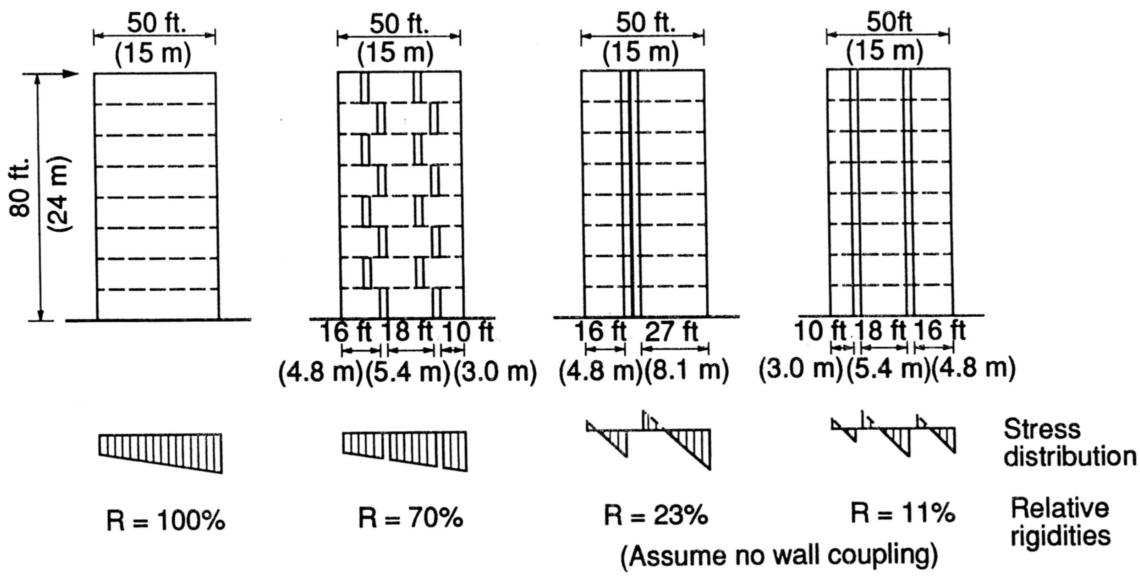
(b) Wall Fixed Against Rotation

Effects of Openings in Multistory Walls

Location and spacing of windows has a great effect

Staggered opening is better

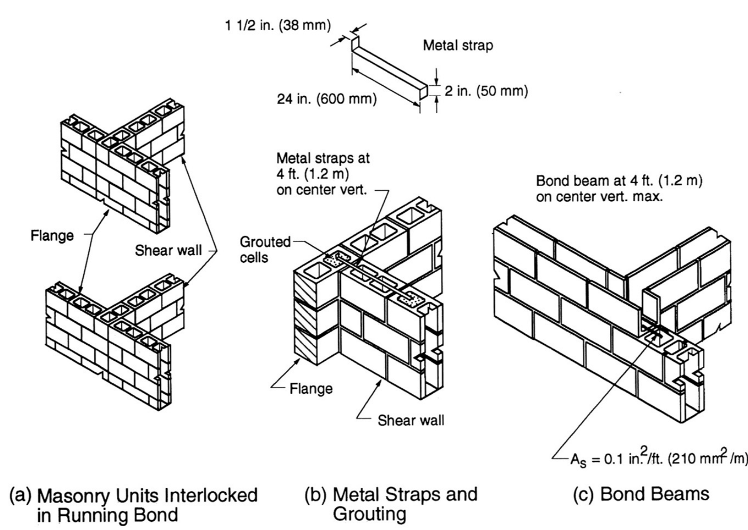
Separate wall strips can be connected by floors or beam – more complex connections



Shear Wall Design

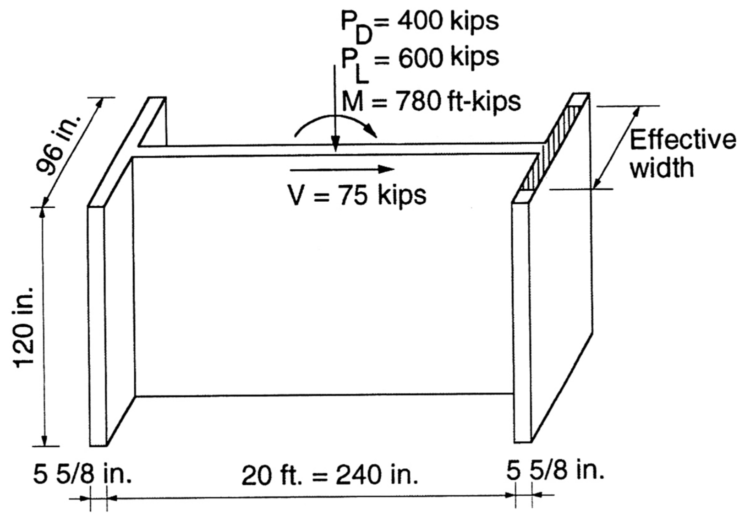
Unreinforced:

- Fail along weaker planes
  - bed joints
  - bed joints + head joints
- Flexural tension not allowed
- For intersecting walls, flanges can be effective in resisting bending provided there is a good connection:
  - 50% of units interlock
  - mechanical connections (steel anchors)
  - reinforced bond beam



Shear Wall Design – **unreinforced example**

Design a solid unreinforced shear wall for the given loads:



Part 1: wall without flanges

Part 2: wall with flanges

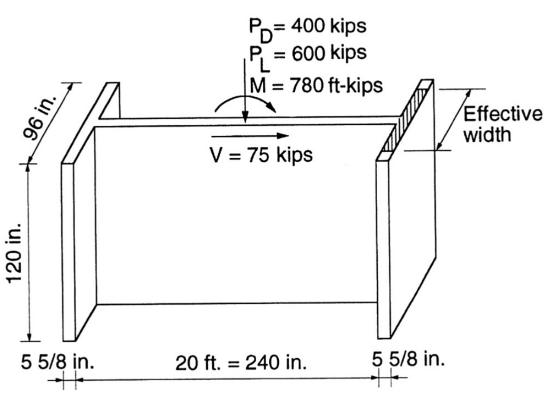
moment due to overturning load of floors above

Units: 6" clay brick:

f'm = 4000 psi
Allowable shear stress = 120 psi
Allowable compression = 1000 psi
Allowable flexure (comp.) = 1330 psi

Shear Wall Design - unreinforced example pt.1

Assume flange walls are not connected:



1. Section properties

$$A = (5.625)(240) = 1350 \text{ in.}^2$$

$$I = 5.675(240)^3/12 = 6{,}480{,}000 \text{ in.}^4$$

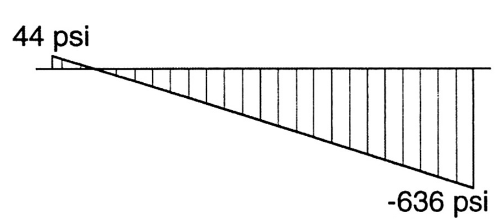
2. Normal stresses (consider the bottom section of the wall): For tension controlled capacity, P_D = 400 kips (1780 kN) (ignoring self-weight).

$$M = 780 + 75 \times \frac{120}{12} = 1530 \text{ ft-kips}$$

$$f_m = -\frac{P}{A} \pm \frac{My}{I} = -\frac{400 \times 1000}{1350} \pm \frac{1530 \times 12000 \times 120}{6480000}$$

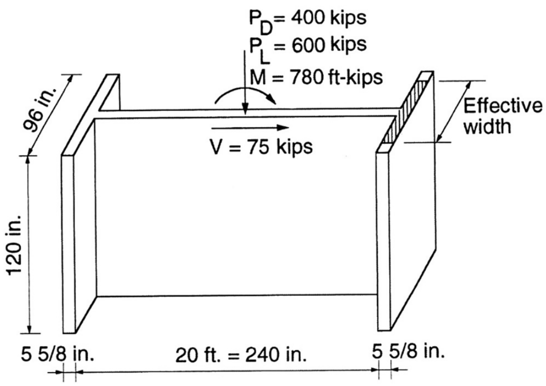
= 44 psi tension or 636 psi compression

The resulting stress distribution is shown in Fig. 10.27(b). Because tensile stresses occur, the section should be reinforced (see Sec. 10.6.1).



Shear Wall Design - unreinforced example pt.2

Assume flange walls are connected to the shear wall
effective width of flange, b_{eff} = 6t (both sides) + wall t



$$b_{\text{eff}} = 5.625 + 2\,(6 \times 5.625) = 73.1 \text{ in.}$$

1. Section properties:

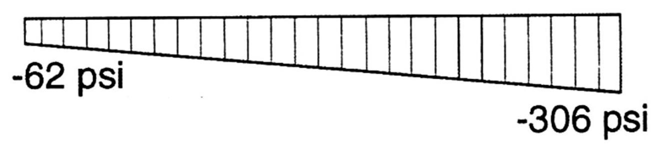
$$A = 1350 + (73.1)(5.625) = 2172 \text{ in.}^2$$

$$I = \frac{5.625(240)^3}{12} + 2\left[\frac{73.1(5.625)^3}{12} + 73.1 \times 5.625 \times (122.8)^2\right] = 18{,}883{,}452 \text{ in.}^4$$

2. Normal stresses:
For the distance from the centroid to the extreme fiber of y = 125.62 in.

$$f_m = -\frac{P}{A} \pm \frac{My}{I}$$

= 62 psi compression or 306 psi compression



Shear Wall Design – reinforced example

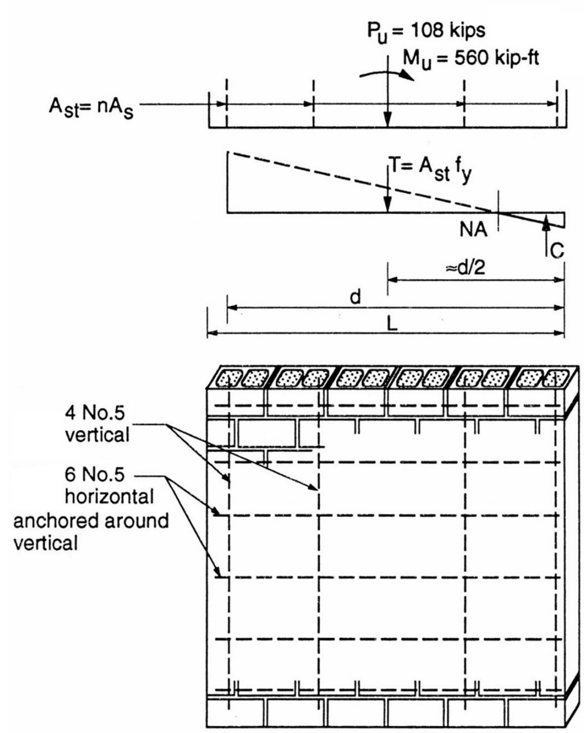
Design a grouted reinforced shear wall for the given loads:

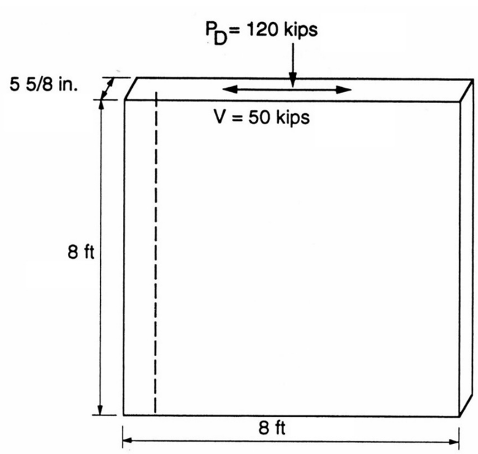
moment is due to overturning load of floors above

Units: 6” CMU – fully grouted:

f’m = 3000 psi
Em = 2500 ksi

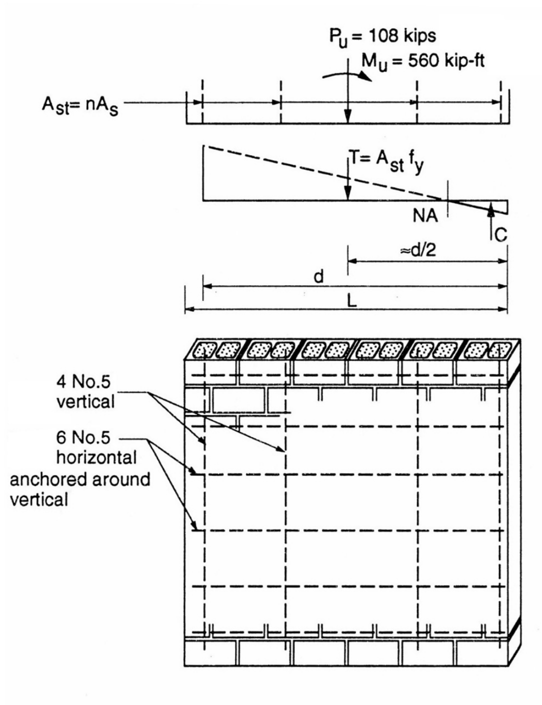
Load combination:
0.9 D + 1.4 E





Shear Wall Design – reinforced example

Design a grouted reinforced shear wall for the given loads:



Vertical steel:
Assume bars yield

$$M_n = A_{st} f_y \frac{d}{2} + P_n \frac{L}{2}$$

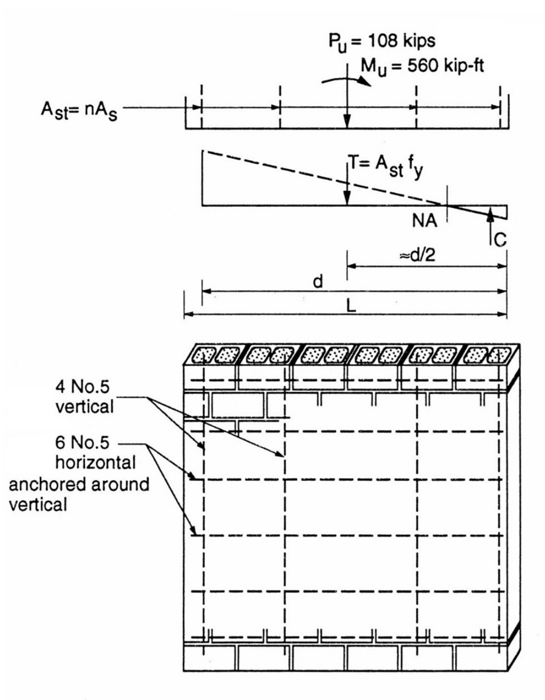
$$M_u = \Phi \left\{ A_{st} f_y \frac{d}{2} + P_u \frac{L}{2} \right\}$$

$$\frac{560 \times 12}{0.85} = A_s(60)\left(\frac{96-4}{2}\right) + 108\left(\frac{96}{2}\right)$$

L = 96”
phi = 0.85
As = 0.99 in^2
Use 4 x #5 bar:
As = 4 x 0.31 = 1.24 in^2

Shear Wall Design – reinforced example

Design a grouted reinforced shear wall for the given loads:



Horizontal steel:
Assume bars yield
Vu = 1.7(50k)

$$A_v = \frac{V_u s}{\Phi_s f_y d} \qquad \text{for } M/Vd > 1.0$$

and

$$A_v = \frac{V_u s}{\Phi_s f_y L} \qquad \text{for } M/Vd < 1.0$$

where V_u = ultimate shear force
s = vertical spacing of horizontal reinforcement
f_y = yield strength of horizontal reinforcement
d = effective depth of vertical tension reinforcement
L = wall length
Φ_s = strength reduction factor = 0.80

$$A_v = \frac{V_u s}{\Phi_s F_y d}$$

and by assuming a vertical spacing of 16 in.

$$A_v = \frac{1.7(50)(16)}{(0.8)(60)(88)} = 0.32 \text{ in}^2/16 \text{ in.}$$

Therefore use No. 5 bar at 16 in. spacing o.c.

#5 bar = 0.31 in^2