

# Shear Walls

Unreinforced  
Reinforced  
Wall Connections

Michigan Central Station



# Michigan Central Station



# Michigan Central Station vs. Grand Central Station - NY



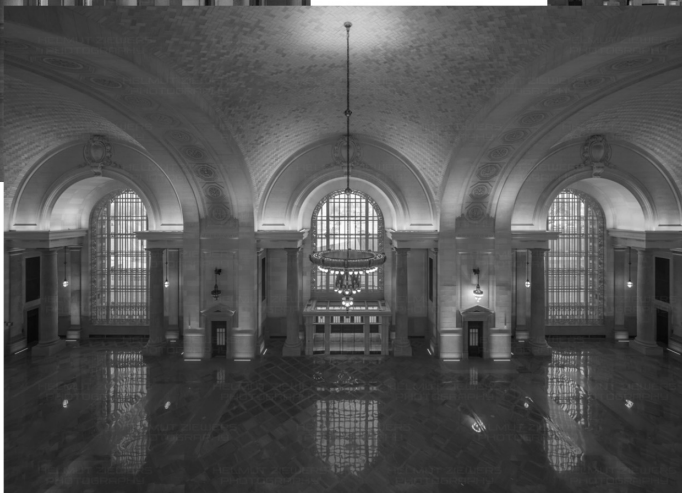
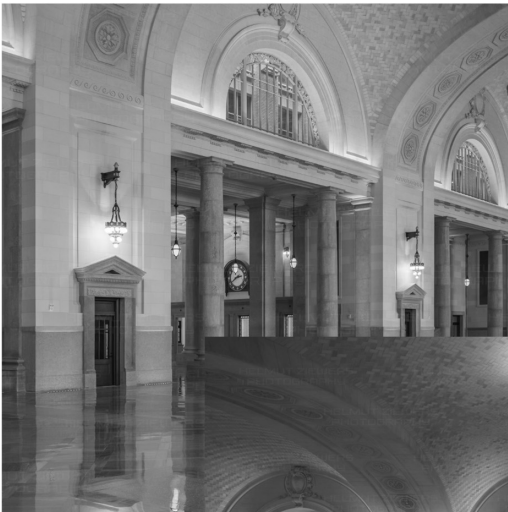
University of Michigan, TCAUP

Masonry

Slide 3 of 21

## Michigan Central Station

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



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Slide 4 of 21

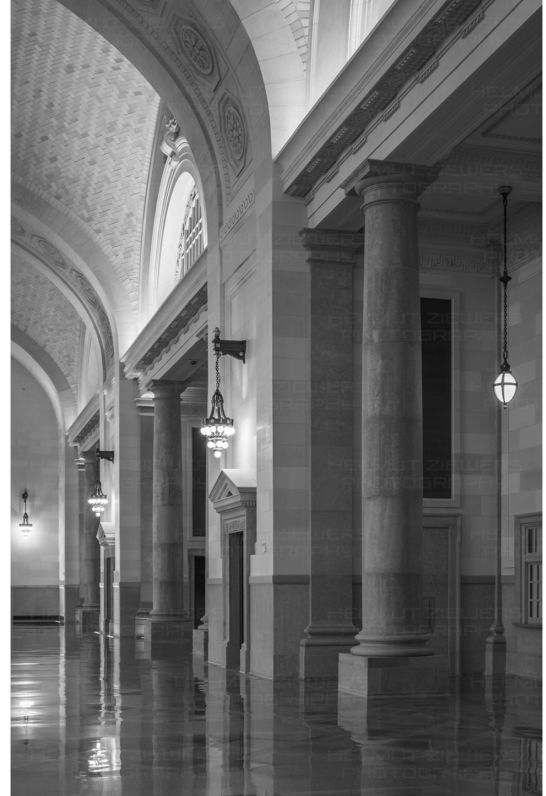
# Michigan Central Station

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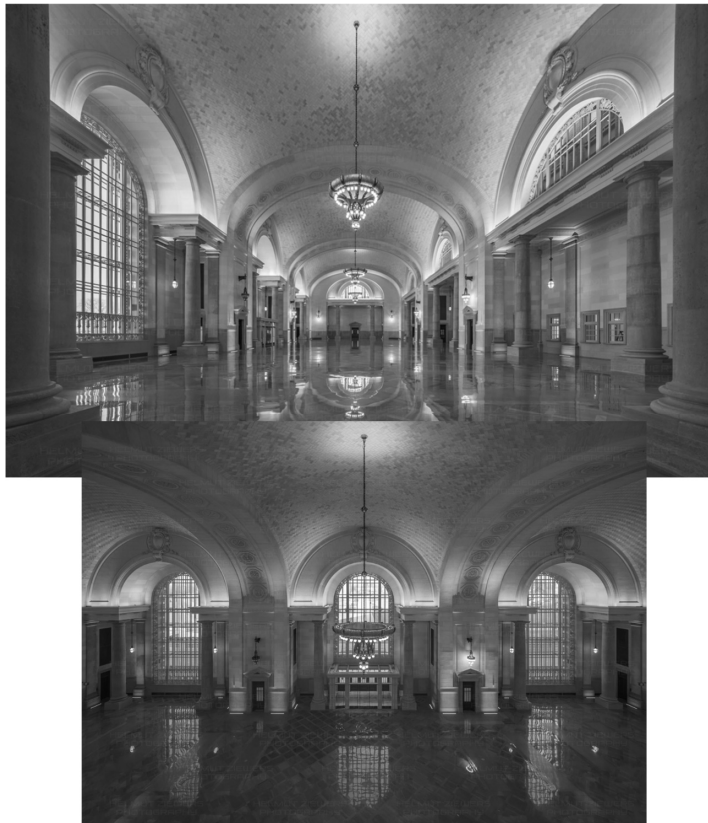
Masonry



Slide 5 of 21

# Michigan Central Station

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



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Slide 6 of 21

# Shear Wall Types and Layouts

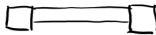


Loadbearing walls can provide lateral bracing


In some cases additional lateral bracing requires shear walls

Usually set in the 2 major axis of the building

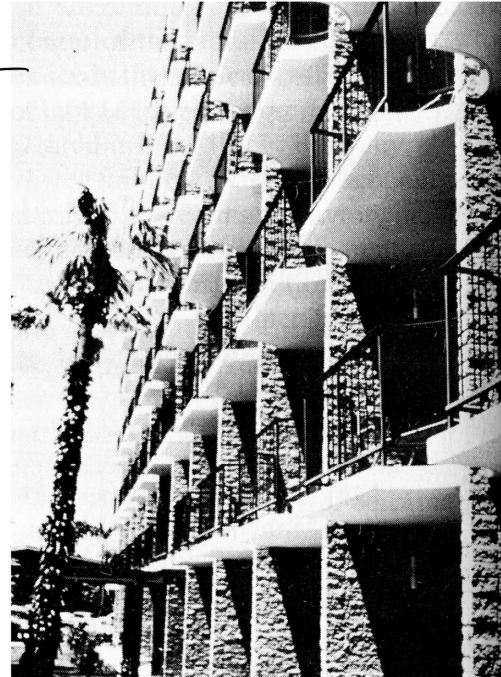
In multistory buildings load is distributed by floors, roofs, rigid diaphragms to the walls

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 

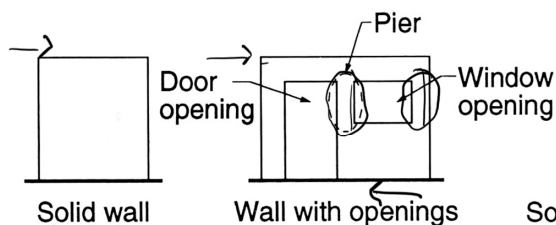
Strength is affected by shape (aspect), openings, boundary elements



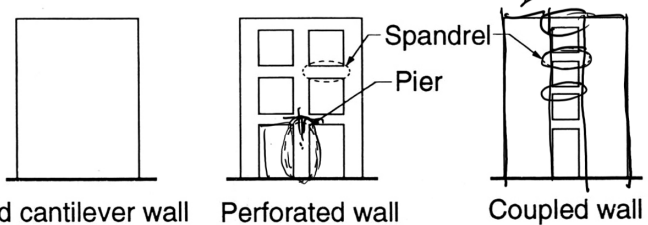
## Shear Wall Layout

Solid better than with openings

Can act as coupled or perforated walls



Solid wall      Wall with openings  
**(a) Single-Story Shear Walls**

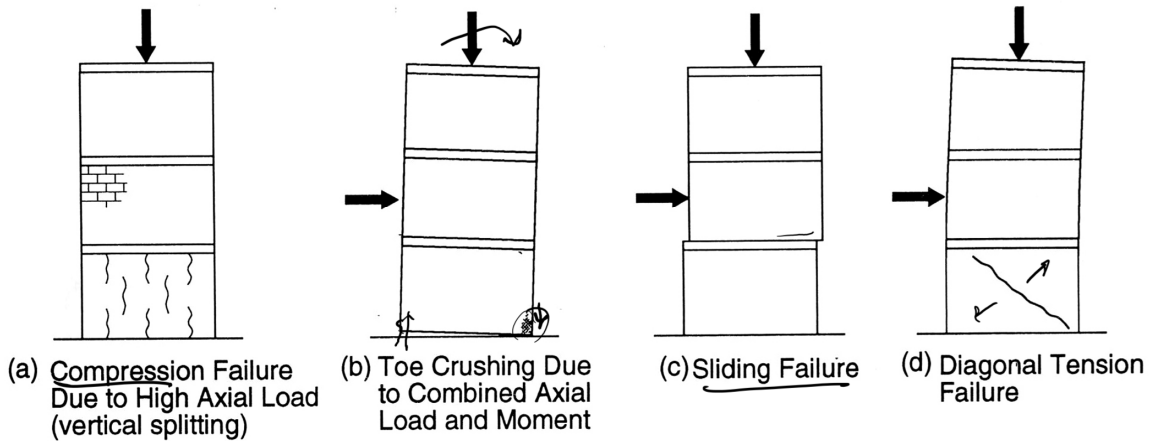


Solid cantilever wall      Perforated wall      Coupled wall  
**(b) Multistory Shear Walls**

# Behavior and Failure Modes

## Factors:

- Loads ✓
- Geometry ✓
- Materials ✓
- Details ✓
- Reinforcement ✓



# Behavior and Failure Modes

## Reinforced:

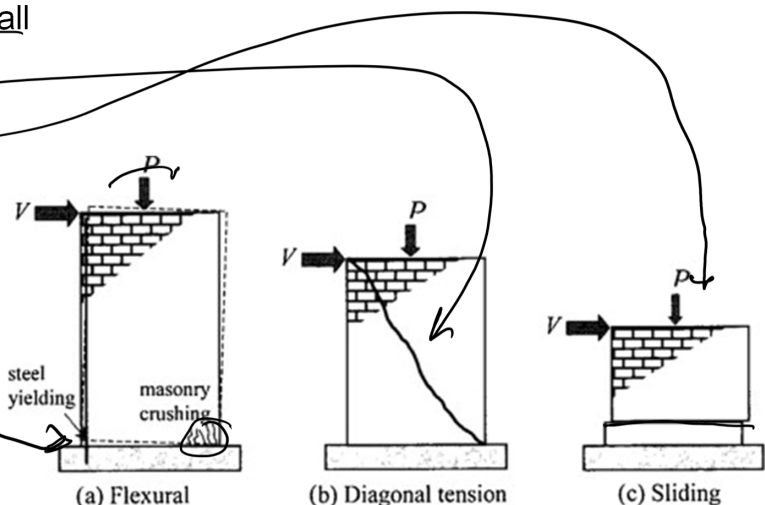
- Ductile modes are better
- Particularly in seismic zones

## Brittle Failure:

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

## Two primary modes of failure

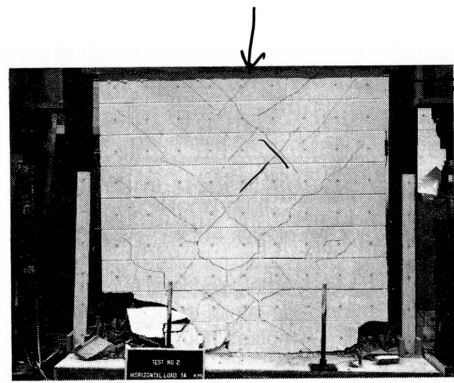
- Flexural failure
  - bed joint cracking ✓
  - yielding of vert. steel ✓
  - toe crushing ✓
- Shear failure
  - diagonal tension cracking ✓
  - sliding ✓



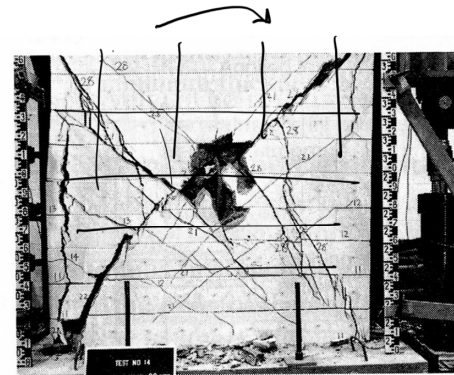
# Behavior and Failure Modes

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)



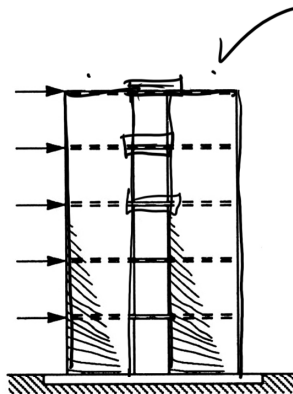
Shear failure mode (Courtesy of B. Shing)

# Behavior and Failure Modes

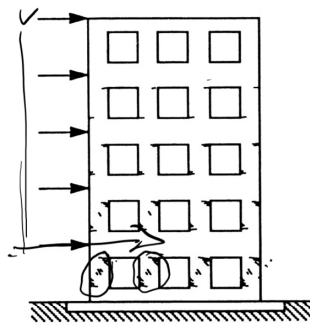
Reinforced shear walls:

Type of wall – effects of openings

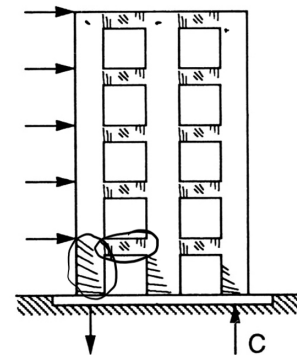
Cantilever type is generally better



(a) Linked Cantilever Wall (Ductile Response)



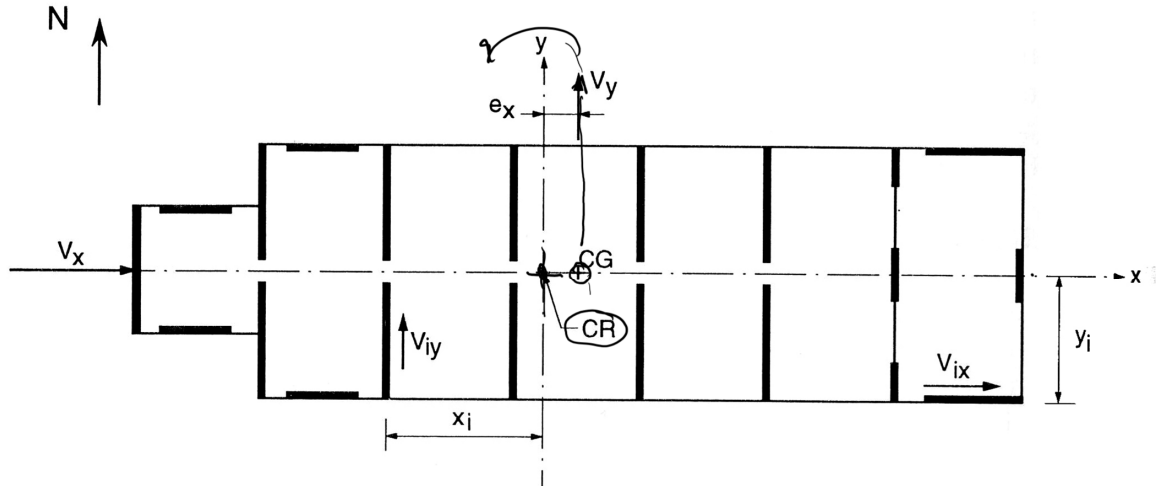
(b) Perforated Shear Wall (Pier Failure)



(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.



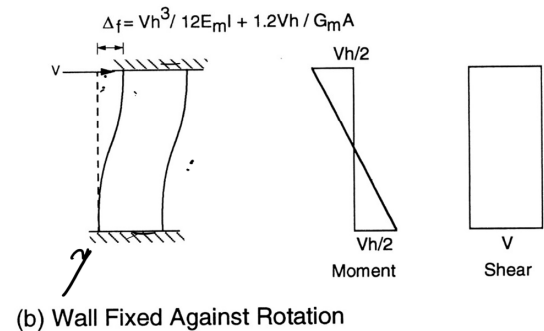
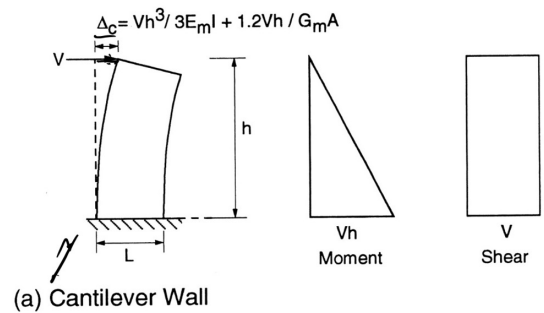
# Effects of Walls Fixed Against Rotation

Deflection of walls due to bending and shear deformation

Effect of aspect ratio 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

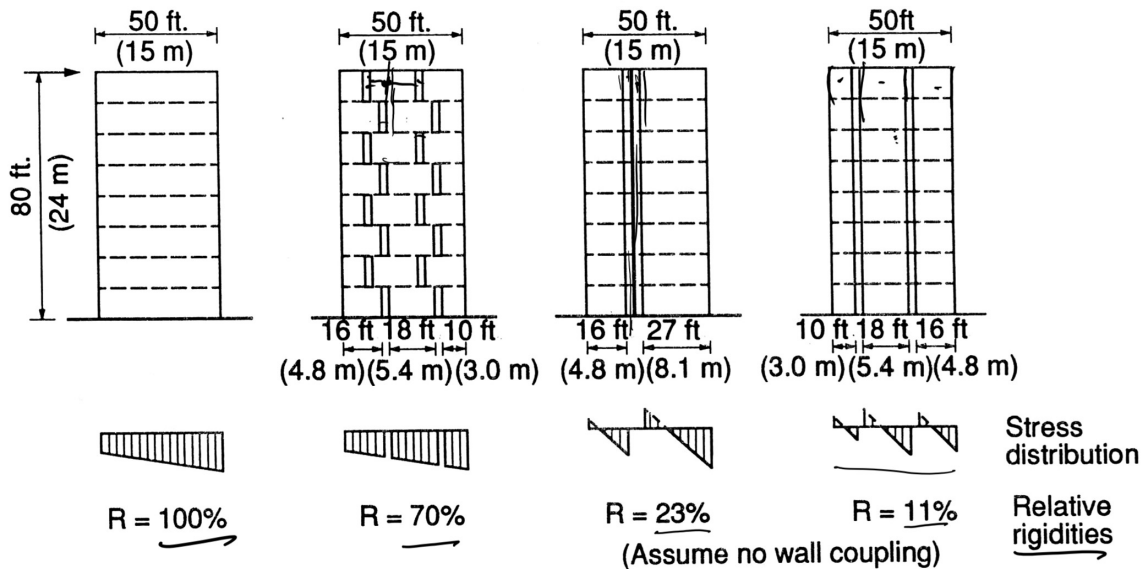


# Effects of Openings in Multistory Walls

Location and spacing of windows has a great effect

Staggered opening is better

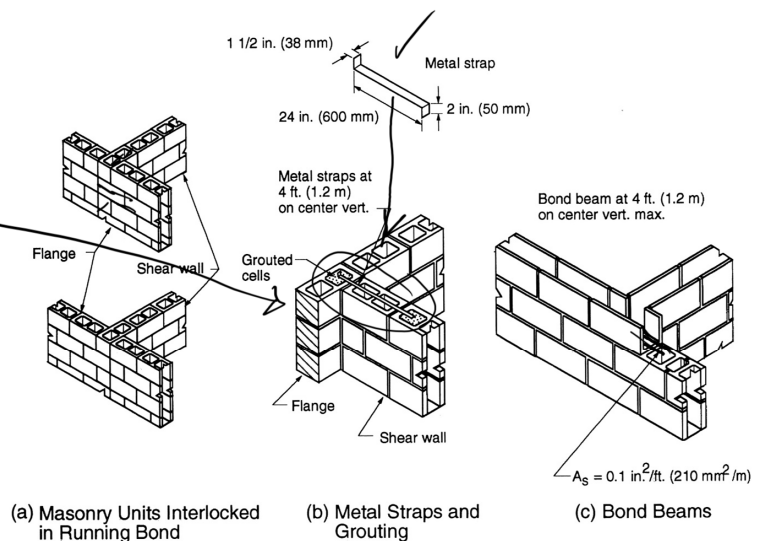
Separate wall strips can be connected by floors or beam – more complex connections



# 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

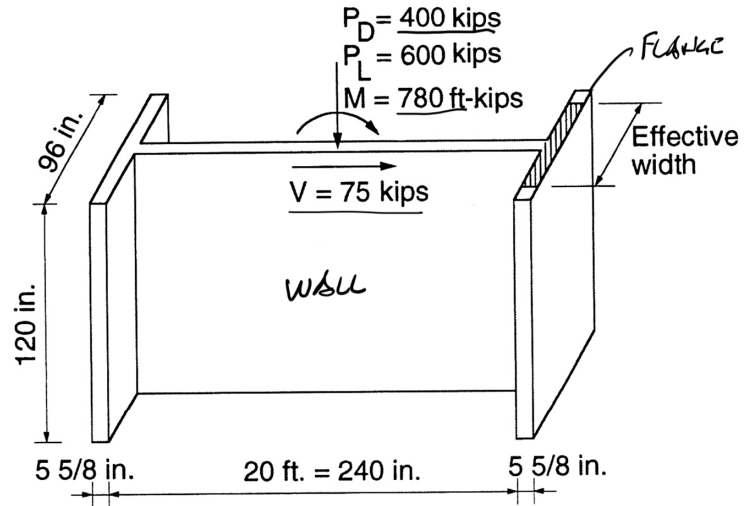
Units: 6" clay brick: ✓

$f'_m = 4000 \text{ psi}$  ✓

Allowable shear stress = 120 psi

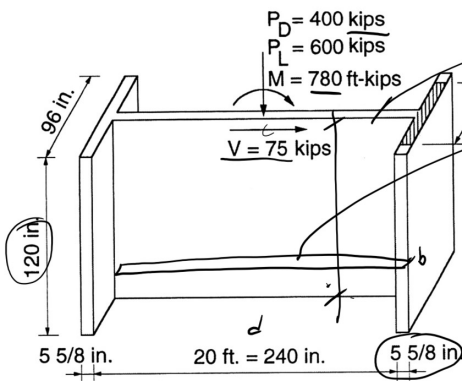
Allowable compression = 1000 psi

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,  $P_D = 400 \text{ kips}$  (1780 kN) (ignoring self-weight).

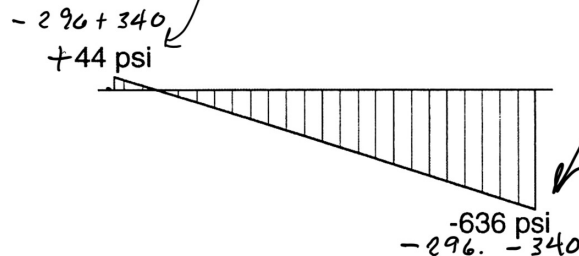
$$M = 780 + 75 \times \frac{120}{12} = 1530 \text{ ft-kips}$$

$$= 296.3 + 340$$

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

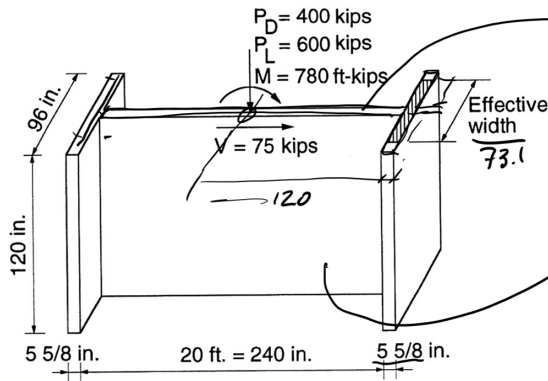
$$= 44 \text{ psi tension or } 636 \text{ psi compression}$$

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  $t$



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

1. Section properties:

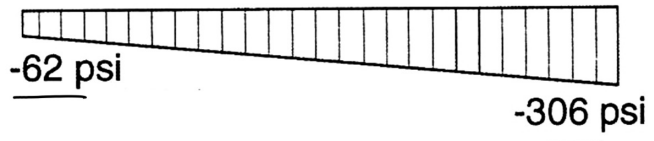
$$A = 1350 + (73.1)(5.625) = 2172 \text{ in.}^2$$

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

2. Normal stresses:

For the distance from the centroid to the extreme fiber of  $y = 125.62 \text{ in.}$

$$f_m = \frac{C}{A} P \pm \frac{M}{I} y = \frac{1000}{2172} \pm \frac{780 \times 12}{18,883,452} \times 125.62 = 62 \text{ psi compression or } 306 \text{ psi compression}$$



# Shear Wall Design – reinforced example

Design a grouted reinforced shear wall for the given loads:

moment is due to overturning load of floors above

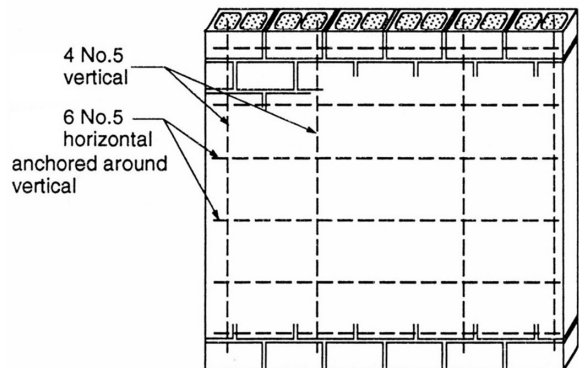
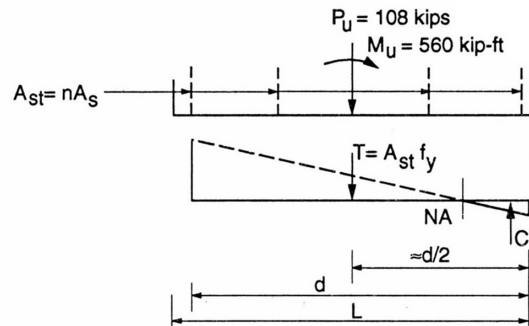
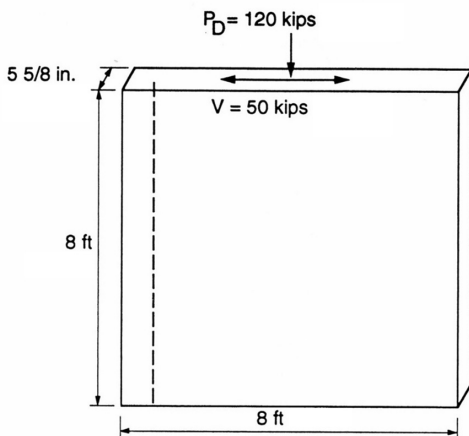
Units: 6" CMU – fully grouted:

$f'_m = 3000 \text{ psi}$

$E_m = 2500 \text{ ksi}$

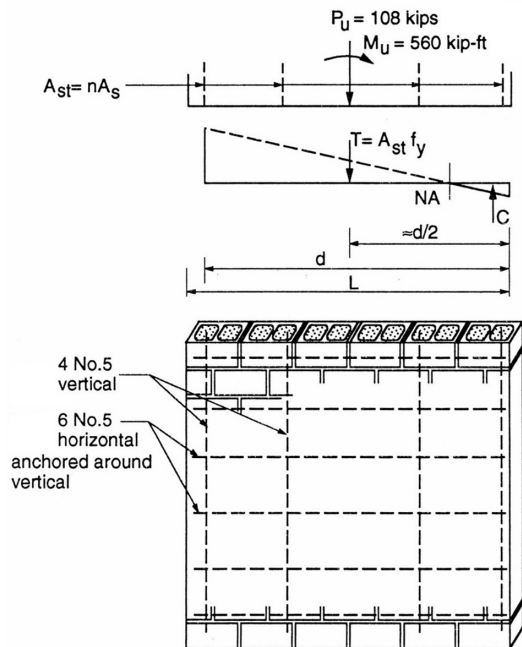
Load combination:

$0.9 D + 1.4 E$



## Shear Wall Design – reinforced example

Design a grouted reinforced shear wall for the given loads:



Vertical steel:  
Assume bars yield

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

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

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

$$L = 96''$$

$$\phi = 0.85$$

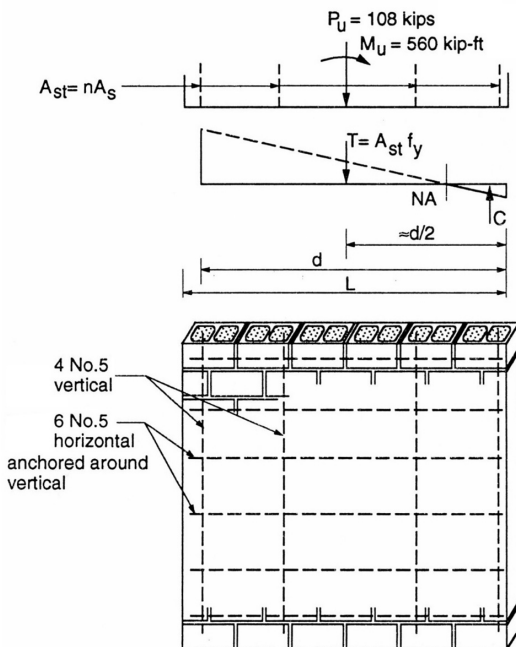
$$A_s = 0.99 \text{ in}^2$$

Use 4 x #5 bar:

$$A_s = 4 \times 0.31 = 1.24 \text{ in}^2$$

## Shear Wall Design – reinforced example

Design a grouted reinforced shear wall for the given loads:



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

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

and

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

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  
 $\Phi_s$  = 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.

$$\#5 \text{ bar} = 0.31 \text{ in}^2$$