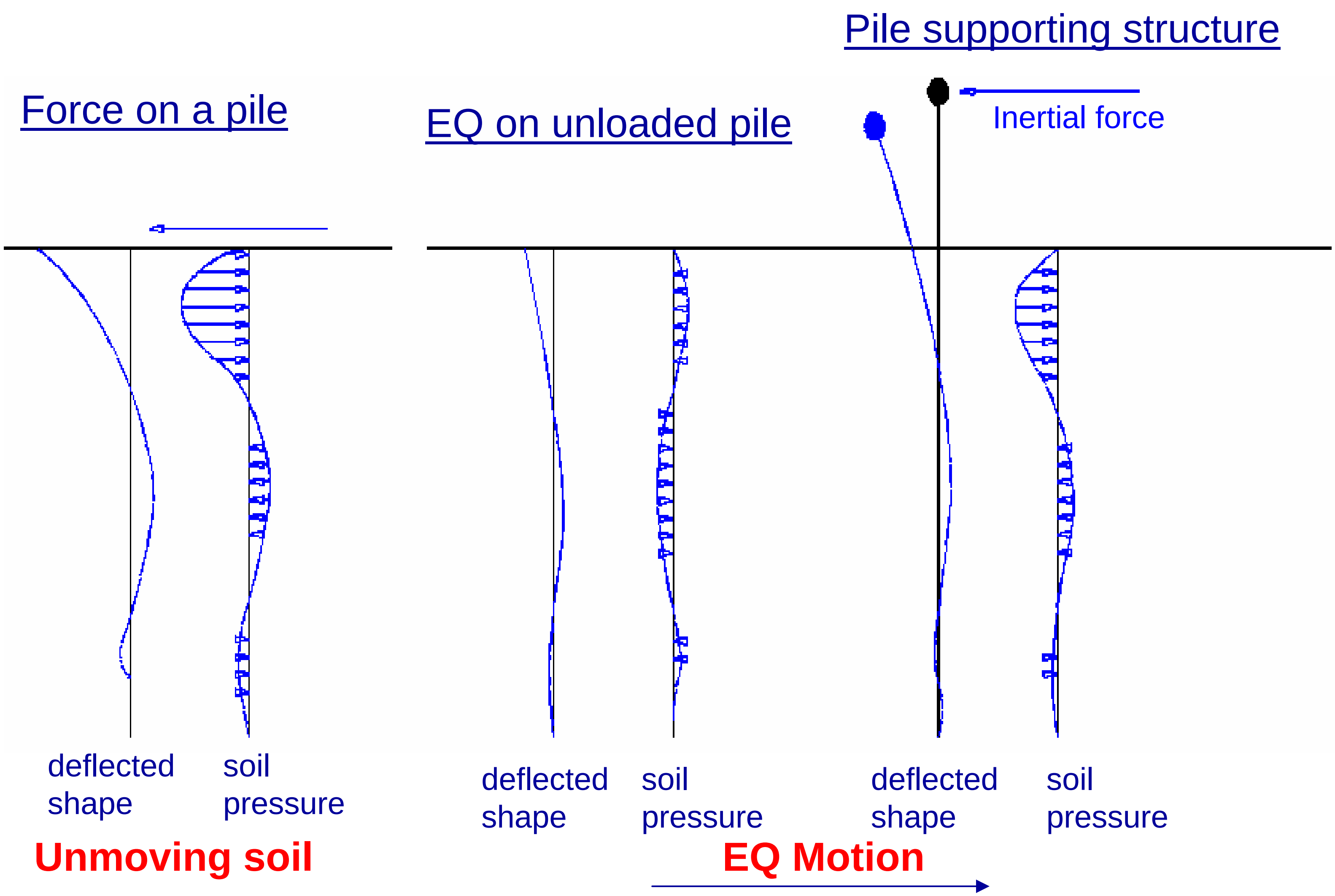
FOUNDATION DESIGN

Proportioning elements for:

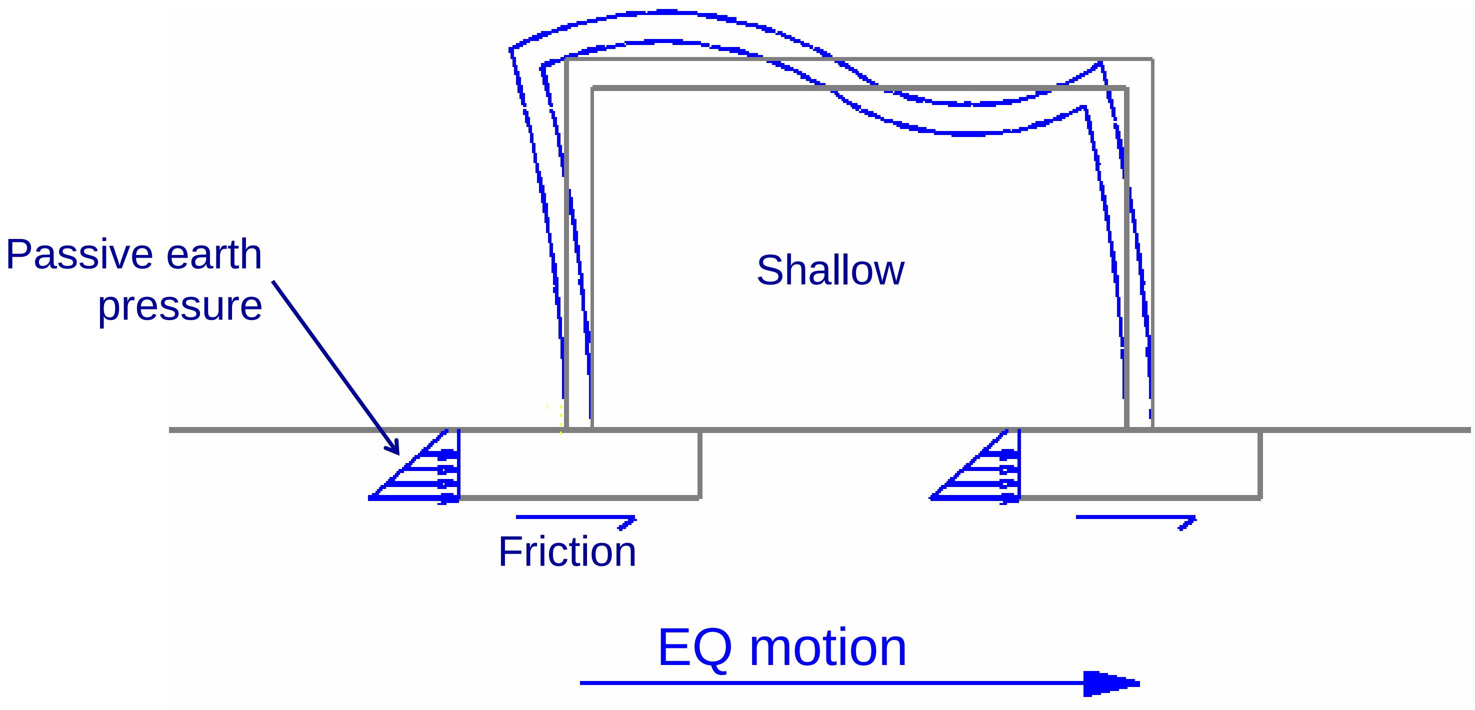
- **Transfer of seismic forces**
- **Strength and stiffness**
- **Shallow and deep foundations**
- **Elastic and plastic analysis**

Load Path and Transfer to Soil

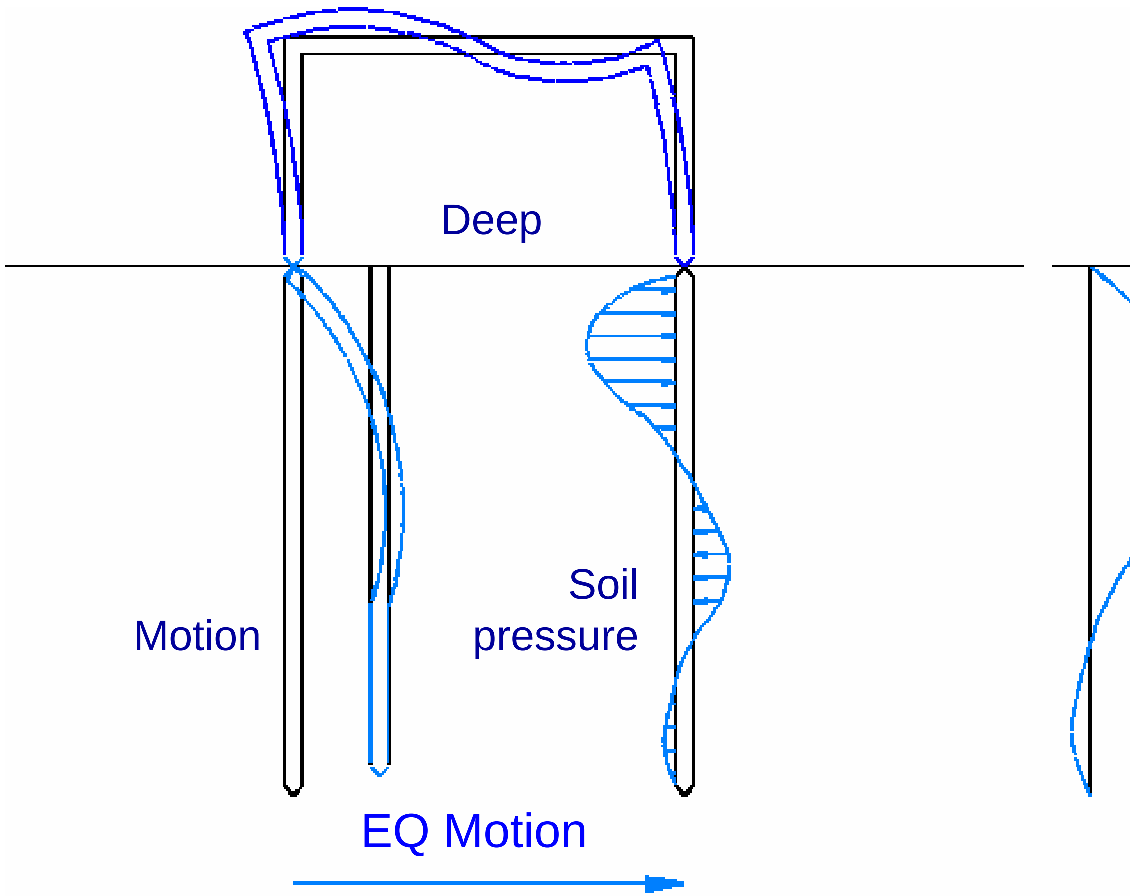
Soil Pressure



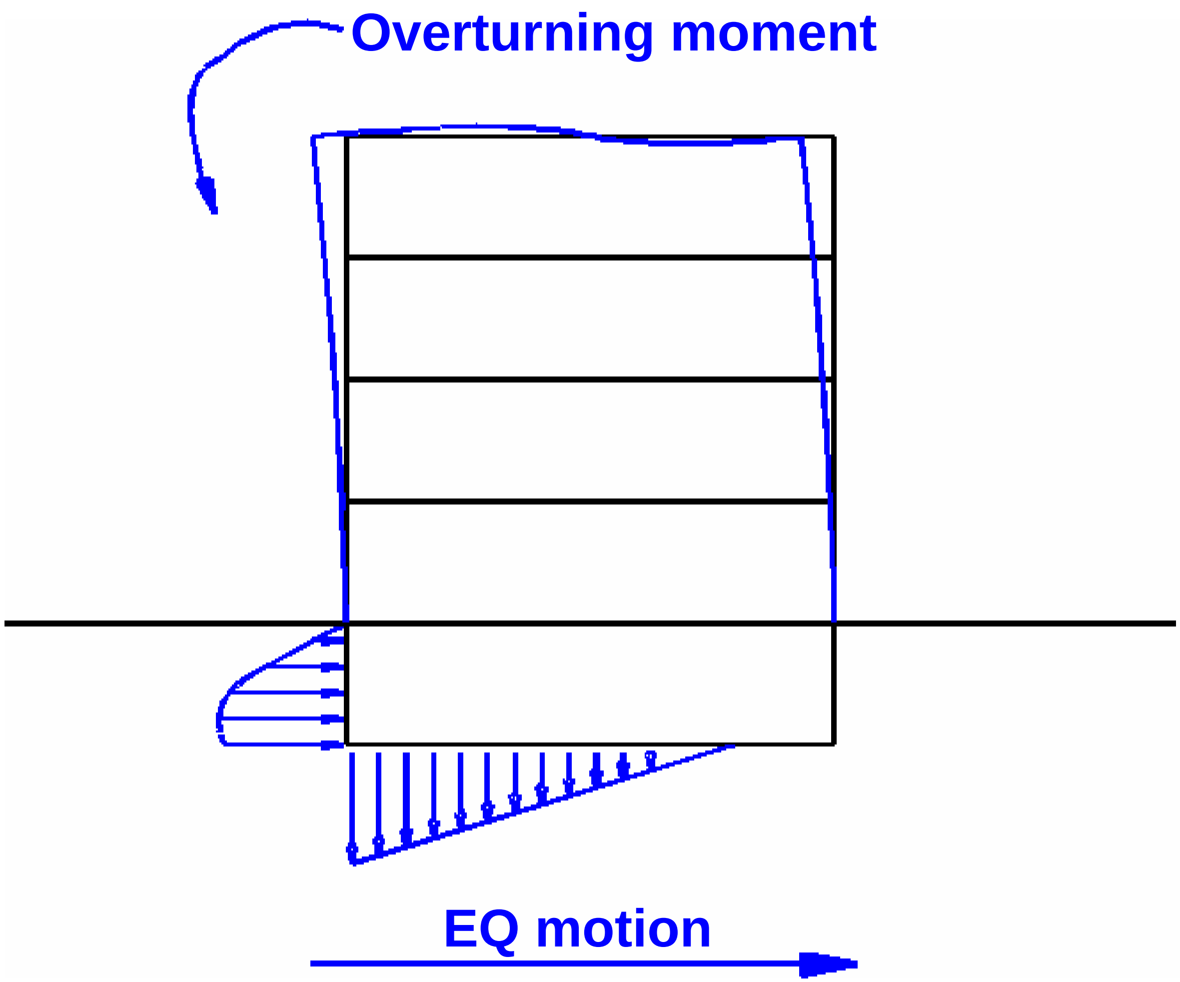
Load Path and Transfer to Soil
Soil-to-foundation Force Transfer



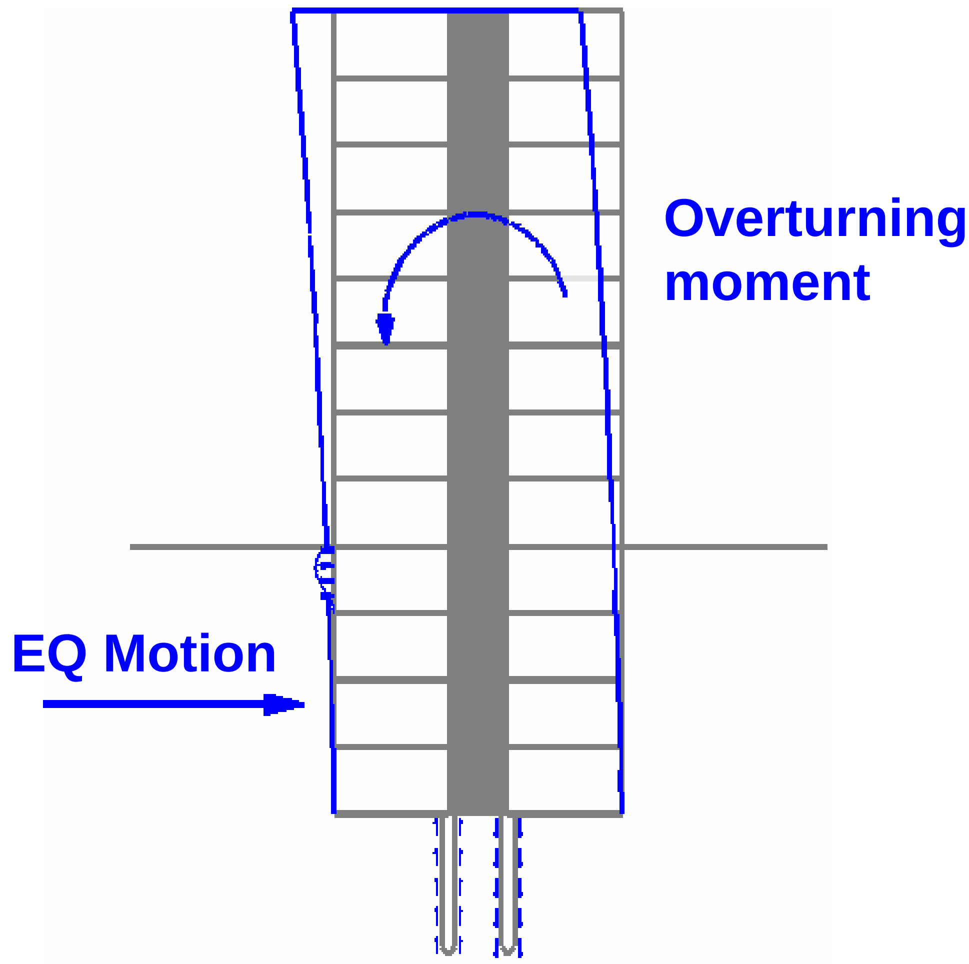
Load Path and Transfer to Soil
Soil-to-foundation Force Transfer



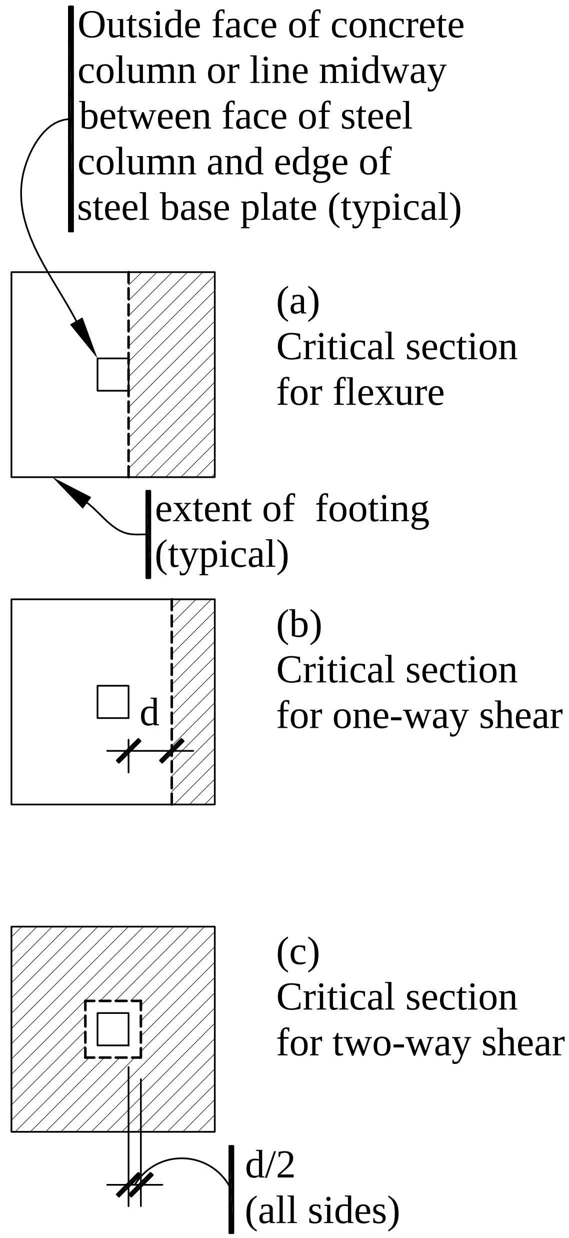
Load Path and Transfer to Soil
V*ertical Pressures - Shallow*



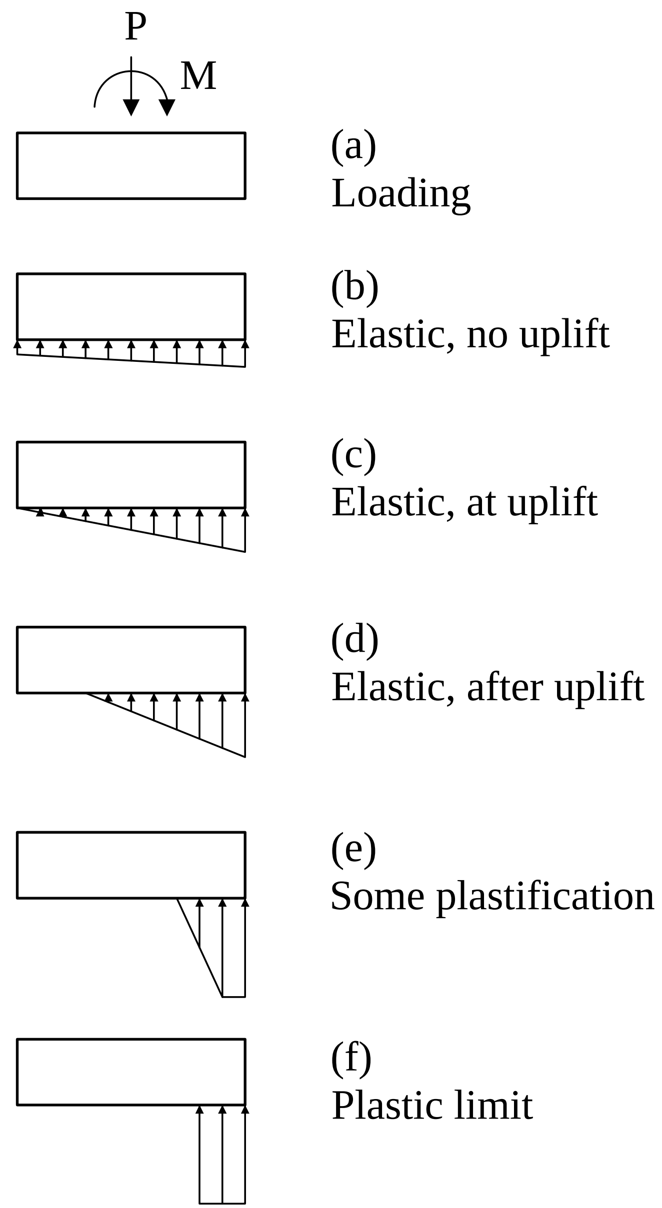
Load Path and Transfer to Soil
Vertical Pressures - Deep

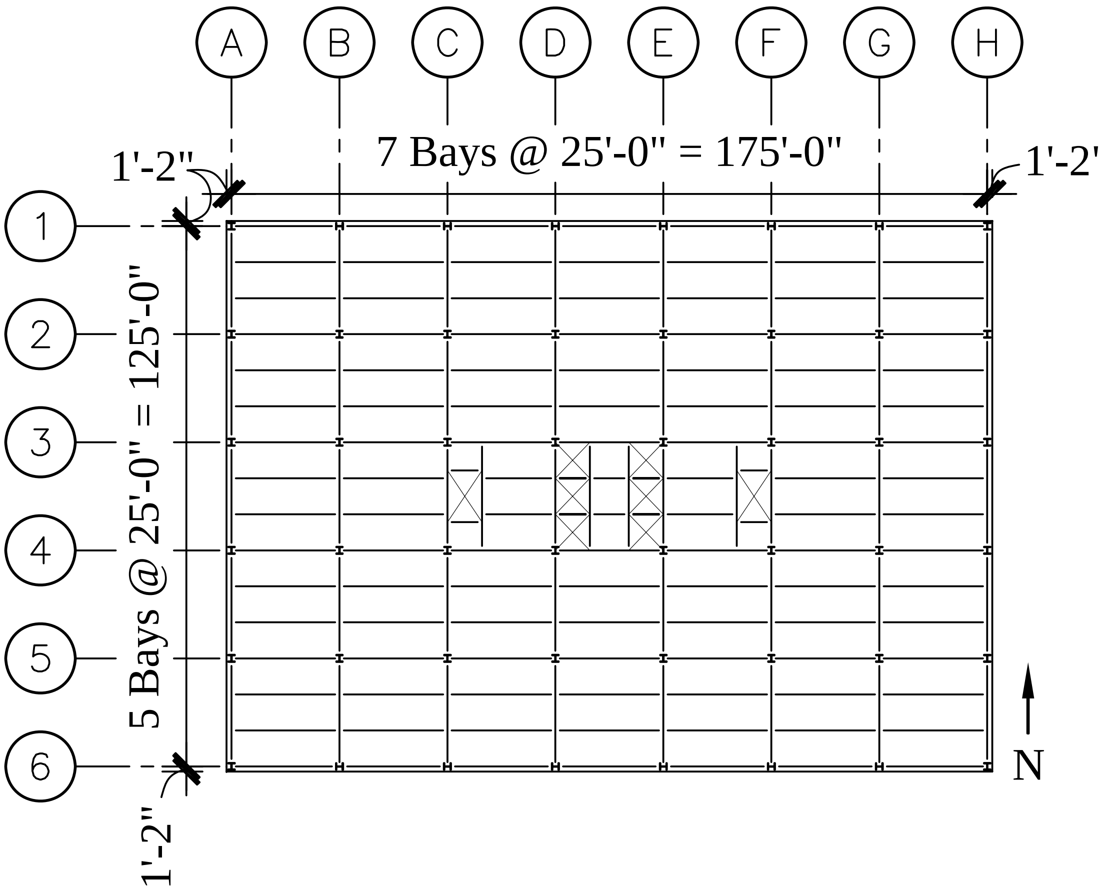


Reinforced Concrete Footings: Basic Design Criteria (concentrically loaded)



Footing Subject to Compression and Moment: Uplift Nonlinear





Example 7-story Building:

Shallow foundations designed for perimeter frame and core bracing.

Shallow Footing Examples

Soil parameters:

- Medium dense sand
- (SPT) N = 20
- Density = 120 pcf
- Friction angle = 33º

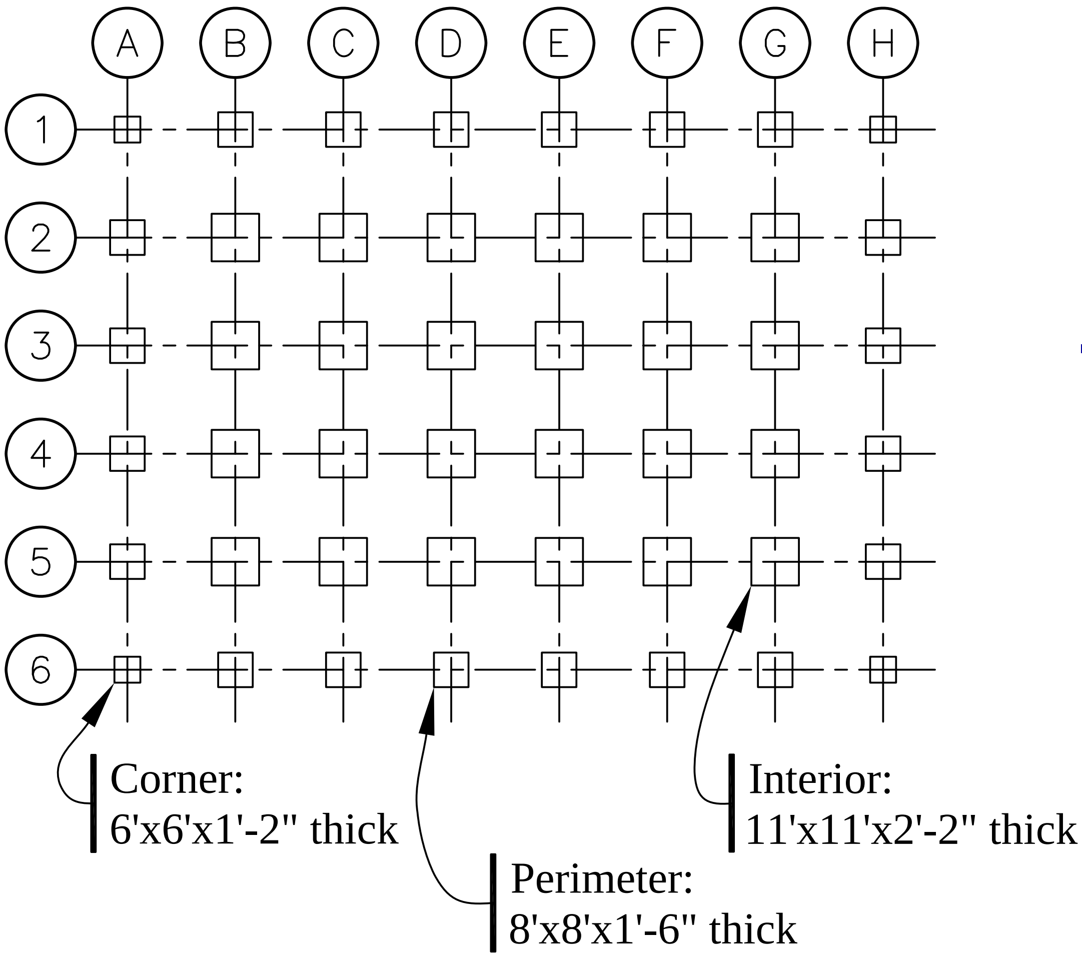
Gravity load allowables

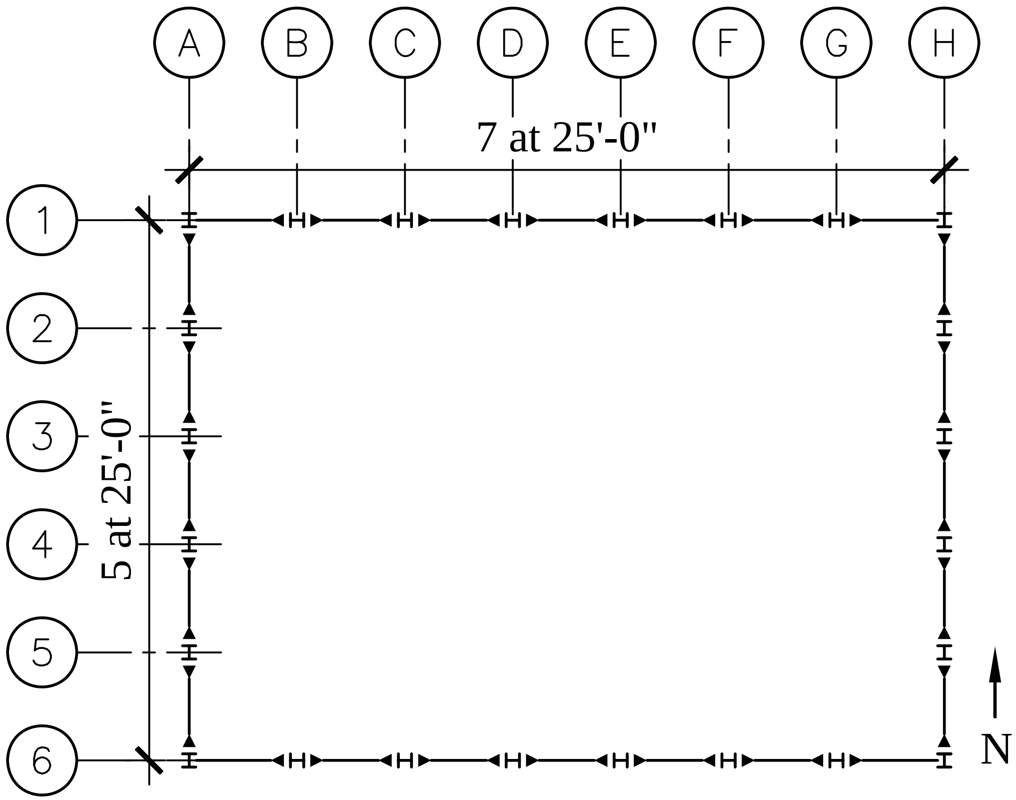
- 4000 psf, B < 20 ft
- 2000 psf, B > 40 ft

Bearing capacity (EQ)

- 2000*B* concentric sq.
- 3000*B* eccentric
- $\phi = 0.6$

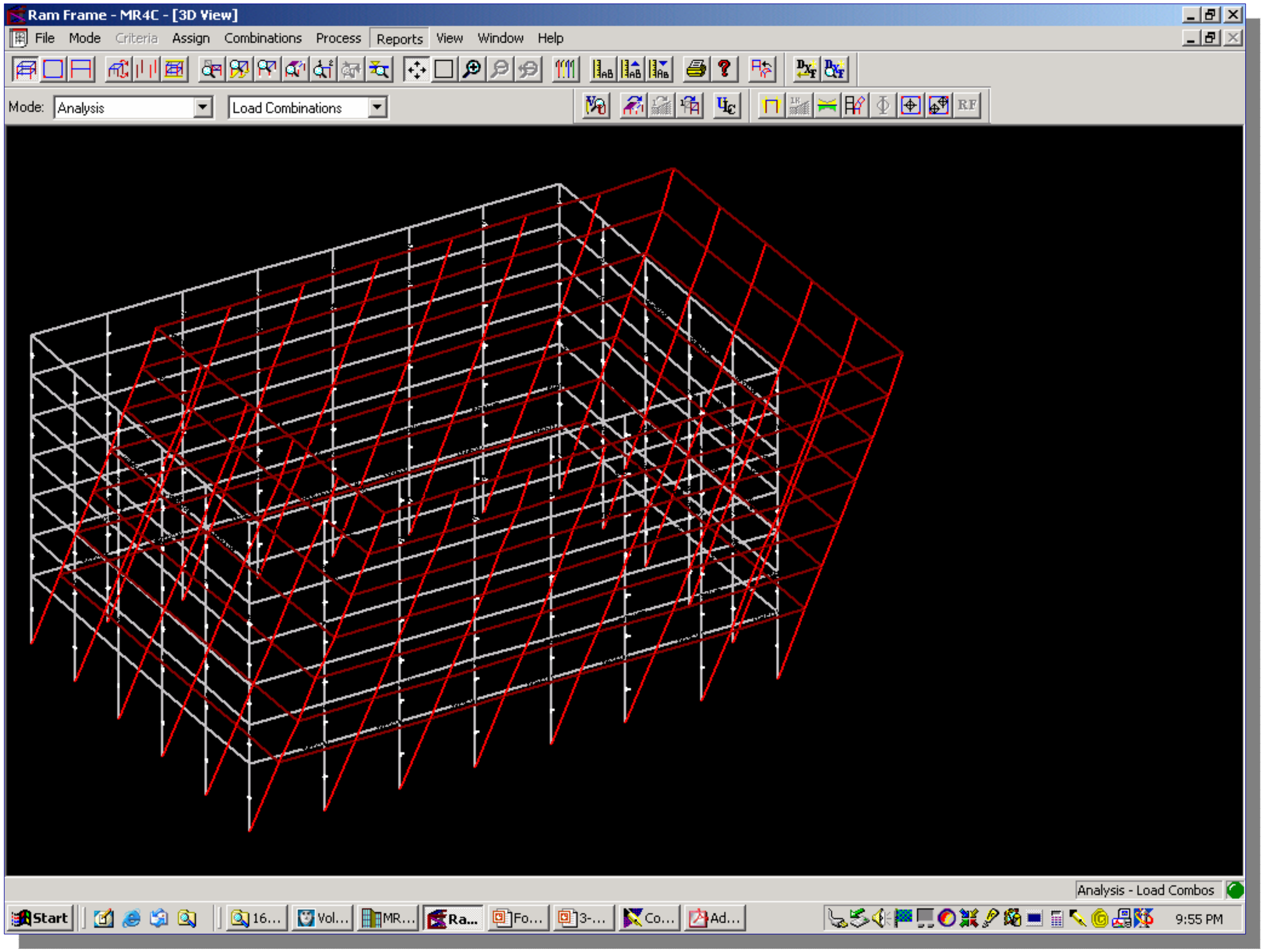
Footings proportioned for gravity loads alone





Design of Footings for Perimeter Moment Frame

7-Story Frame, Deformed



Combining Loads

- Maximum downward load:

  $1.2D + 0.5L + E$

- Minimum downward load:

  $0.9D + E$

- Definition of seismic load effect E:

  $E = \rho_1 Q_{E1} + 0.3\ \rho_2 Q_{E2} +/- 0.2\ S_{DS} D$

  $\rho_x = 1.08 \quad \rho_y = 1.11$ and $S_{DS} = 1.0$

Reactions

Grid		Dead	Live	E_x	E_y
A-5	P M_{xx} M_{yy}	203.8 k	43.8 k	-3.8 k 53.6 k-ft -243.1 k-ft	21.3 k -1011.5 k-ft 8.1 k-ft
A-6	P M_{xx} M_{yy}	103.5 k	22.3 k	-51.8 k 47.7 k-ft -246.9 k-ft	-281.0 k -891.0 k-ft 13.4 k-ft

Reduction of Overturning Moment

- *NEHRP Recommended Provisions* allow base overturning moment to be reduced by 25% at the soil-foundation interface.
- For a moment frame, the column vertical loads are the resultants of base overturning moment, whereas column moments are resultants of story shear.
- Thus, use 75% of seismic vertical reactions.

Additive Load w/ Largest Eccentricity

- At A5: P = 1.4(203.8) + 0.5(43.8) +
  0.75(0.32(-3.8) + 1.11(21.3)) = 324 k
  M_{xx} = 0.32(53.6) + 1.11(-1011.5) = -1106 k-ft
- At A6: P = 1.4(103.5) + 0.5(22.3) +
  0.75(0.32(-51.8) + 1.11(-281)) = -90.3 k
  M_{xx} = 0.32(47.7) + 1.11(-891) = -974 k-ft
- Sum M_{xx} = 12.5(-90.3-324) -1106 -974 = -7258

Counteracting Load with Largest *e*

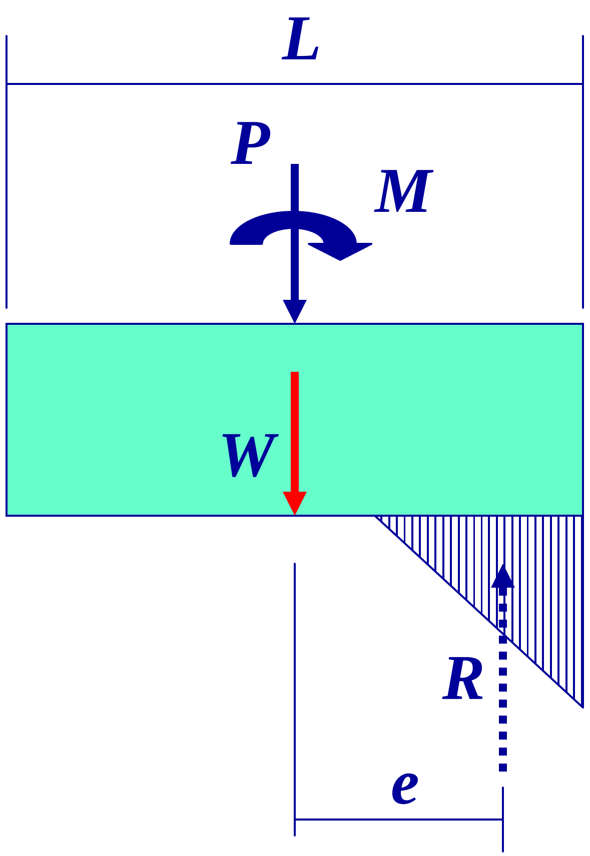
- At A-5: P = 0.7(203.8) + 0.75(0.32(-3.8) + 1.11(21.3)) = 159.5 k

  M_{xx} = 0.32(53.6) + 1.11 (-1011.5) = -1106 k-ft
- At A-6: P = 0.7(103.5) + 0.75(0.32(-51.8) + 1.11(-281)) = -173.9 k

  M_{xx} = 0.32(47.7) + 1.11(-891) = -974 k-ft
- Sum M_{xx} = 6240 k-ft

Elastic Response

- Objective is to set *L* and *W* to satisfy equilibrium and avoid overloading soil.
- Successive trials usually necessary.



Additive Combination

Given P = 234 k, M =7258 k-ft

Try 5 foot around, thus L = 35 ft, B = 10 ft

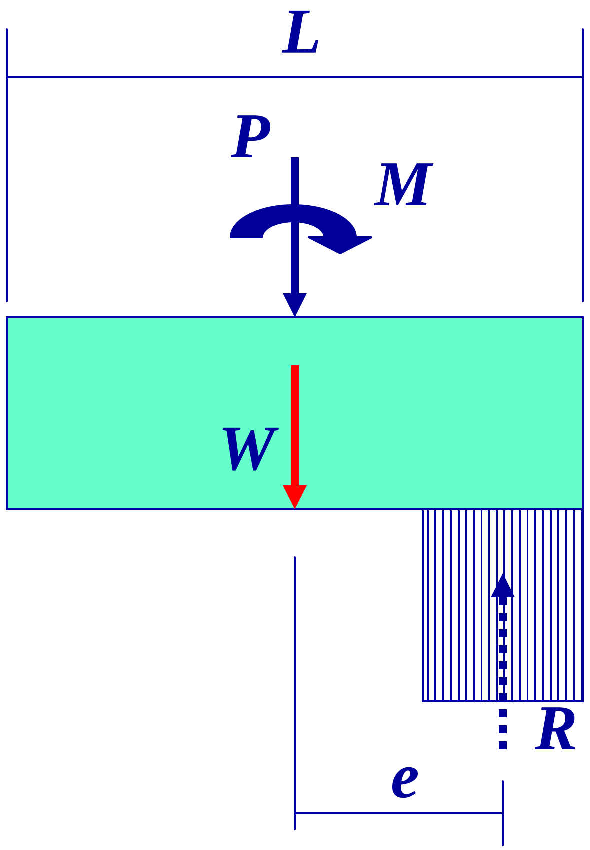
- Minimum $W = M/(L/2) - P$ = 181 k = 517 psf

Try 2 foot soil cover & 3 foot thick footing

- W = 245 k; for additive combo use 1.2W
- $Q_{max} = (P + 1.2W)/(3(L/2 - e)B/2)$ = 9.4 ksf
- $\phi Q_n = 0.6(3)B_{min}$ = 10.1 ksf, OK by Elastic

Plastic Response

- Same objective as for elastic response.
- Smaller footings can be shown OK thus:



Counteracting Case

Given P = -14.4 k; M = 6240

Check prior trial; W = 245 k (use 0.9W)

- e = 6240/(220.5 – 14.4) = 30.3 > 35/2 NG

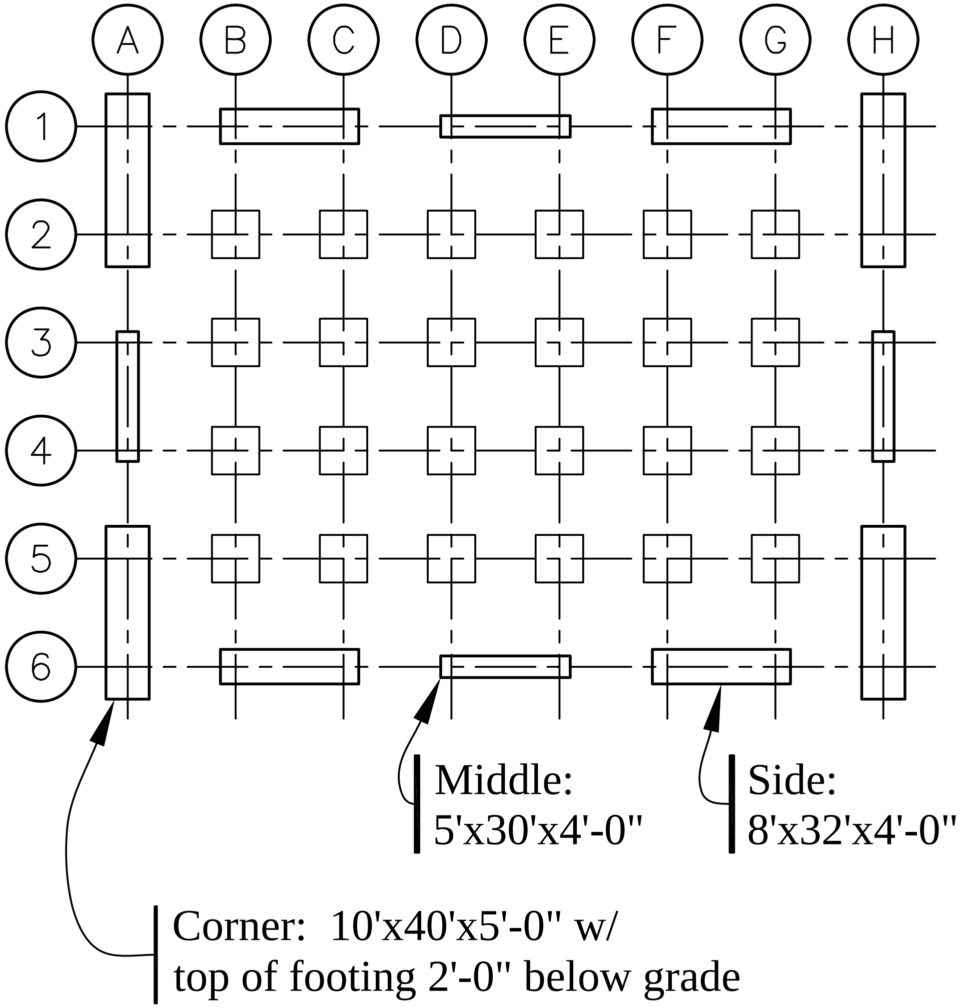
New trial: L = 40 ft, 5 ft thick

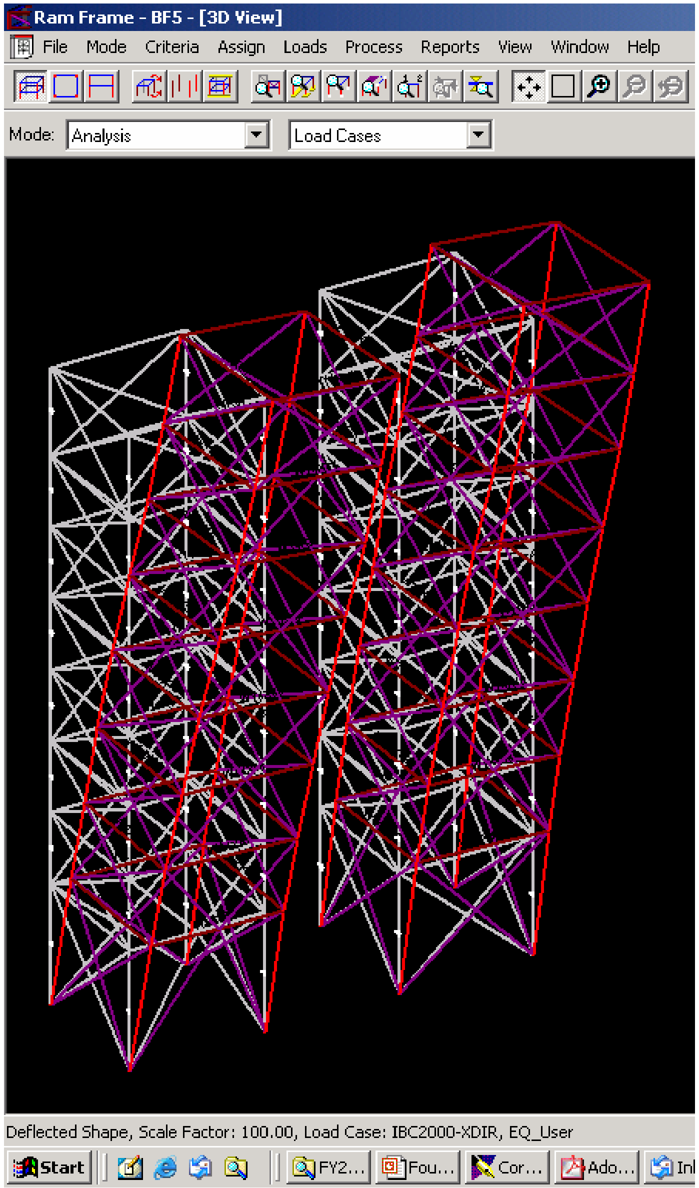
- W = 400 k; e = 18.0 ft; plastic Q_{max}= 8.6 ksf
- ϕQ_n = 0.6(3)4 = 7.2 ksf, close
- Solution is to add 5 k, then e = 17.8 ft and $Q_{max} = \phi Q_n$ = 7.9 ksf

Additional Checks

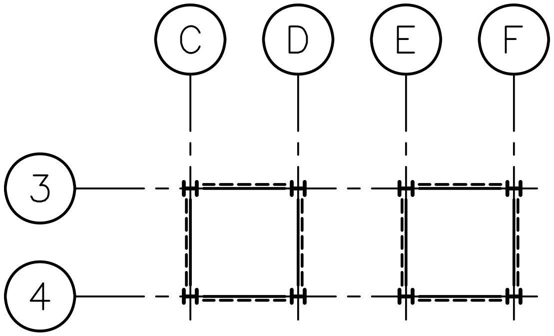
- Moments and shears for reinforcement should be checked for the overturning case.
- Plastic soil stress gives upper bound on moments and shears in concrete.
- Horizontal equilibrium: $H_{max} < \phi\mu(P+W)$
  in this case friction exceeds demand; passive could also be used.

Results for all SRS Footings



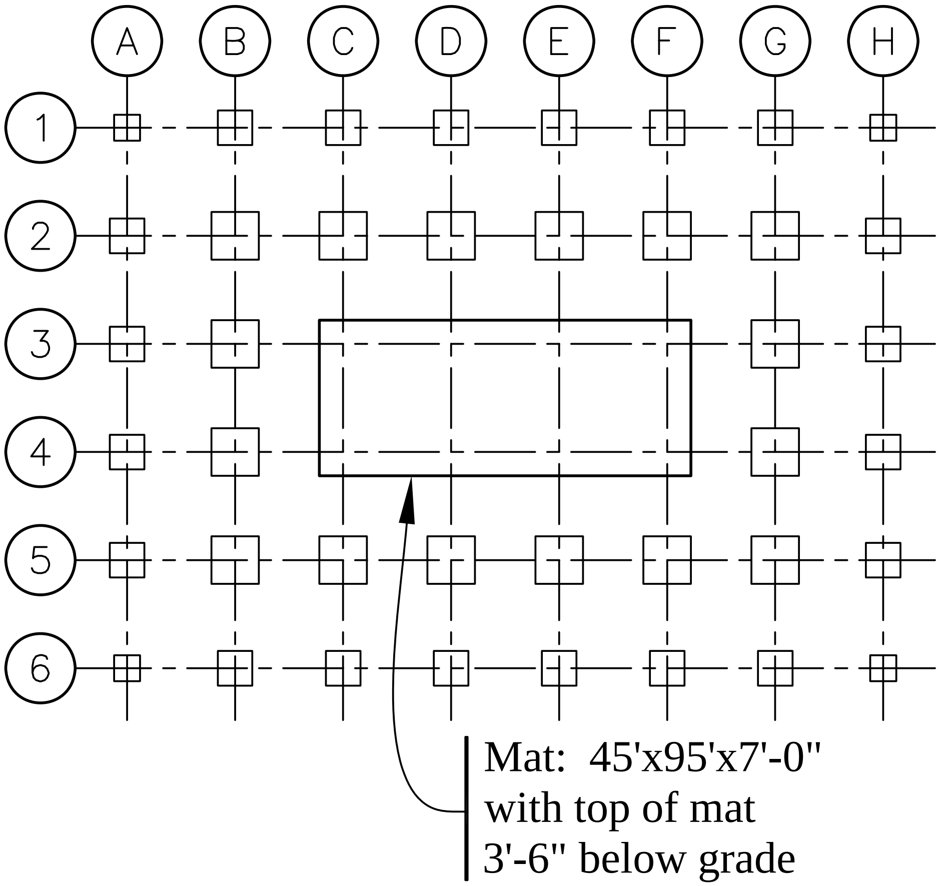


Design of Footings for Core-braced 7-story Building



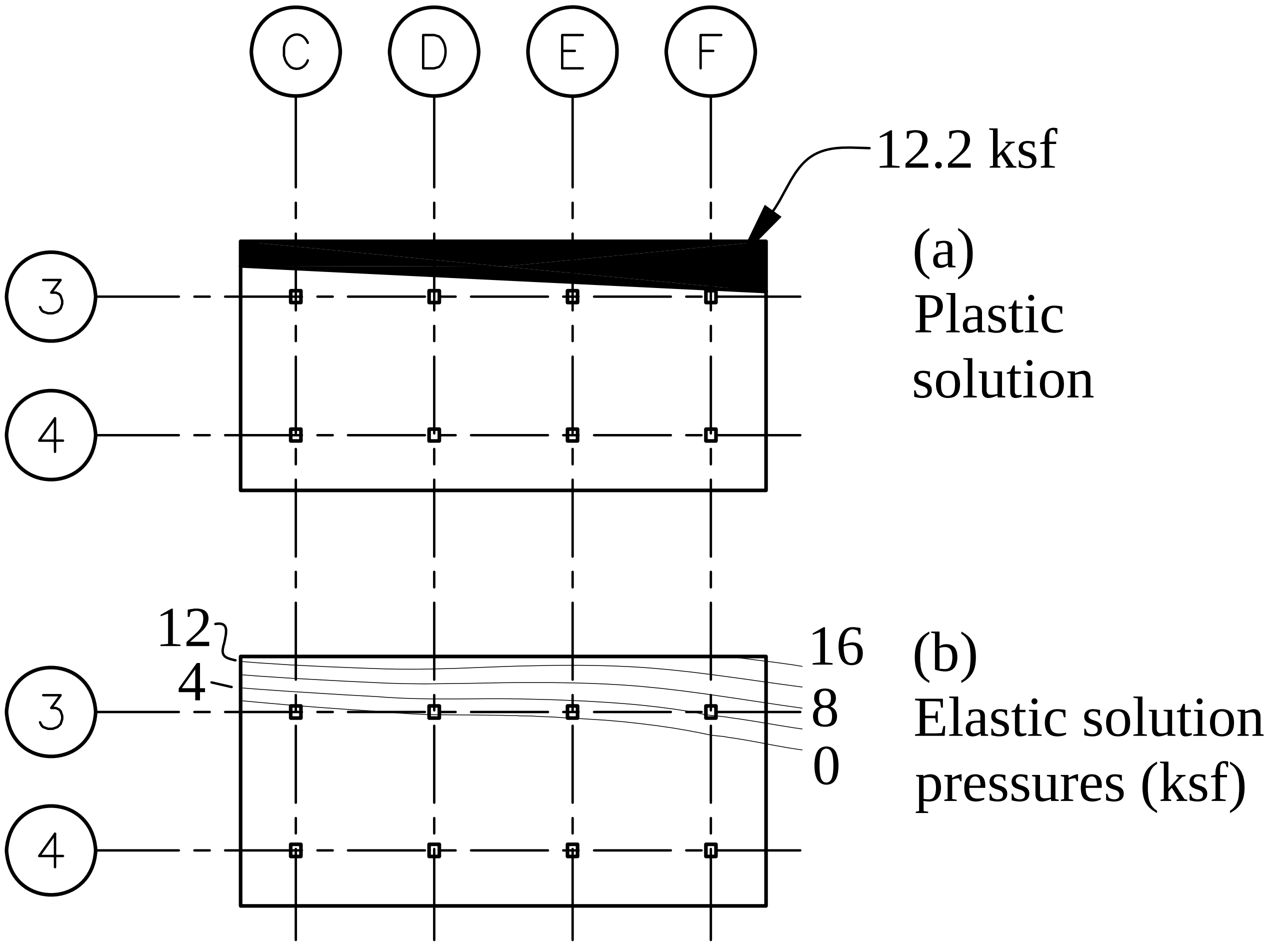
25 foot square bays at center of building

Solution for Central Mat



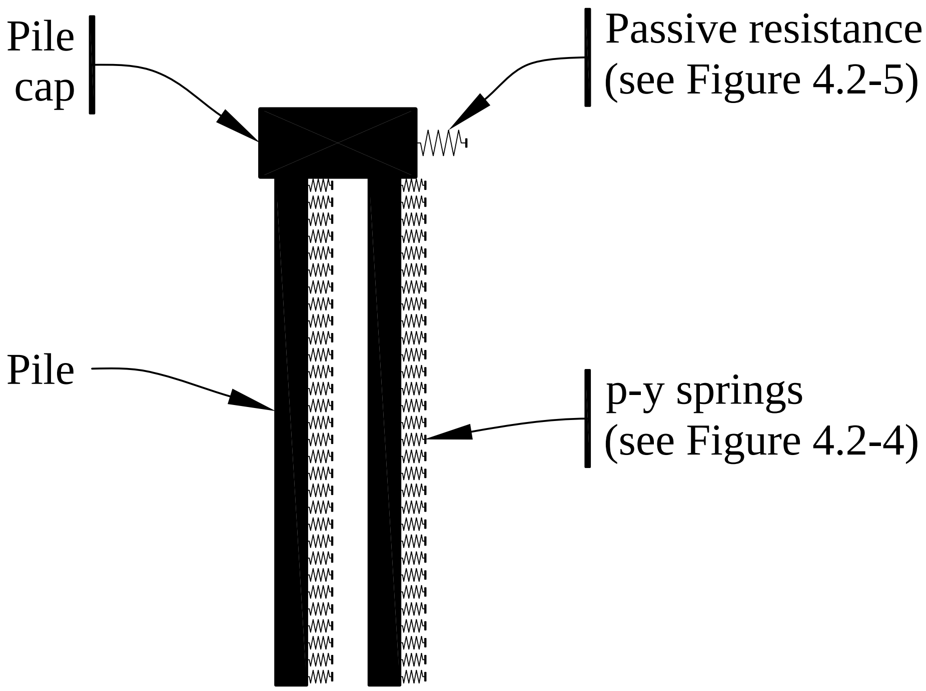
Very high uplifts at individual columns; mat is only practical shallow foundation.

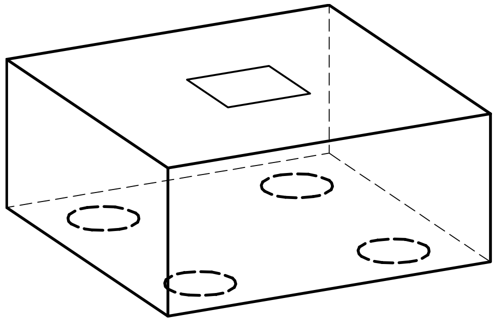
Bearing Pressure Solution



Plastic solution is satisfactory; elastic is not; see linked file for more detail.

Pile/Pier Foundations





View of cap with column above and piles below.

Pile/Pier Foundations

Pile Stiffness:

- Short (rigid)
- Intermediate
- Long

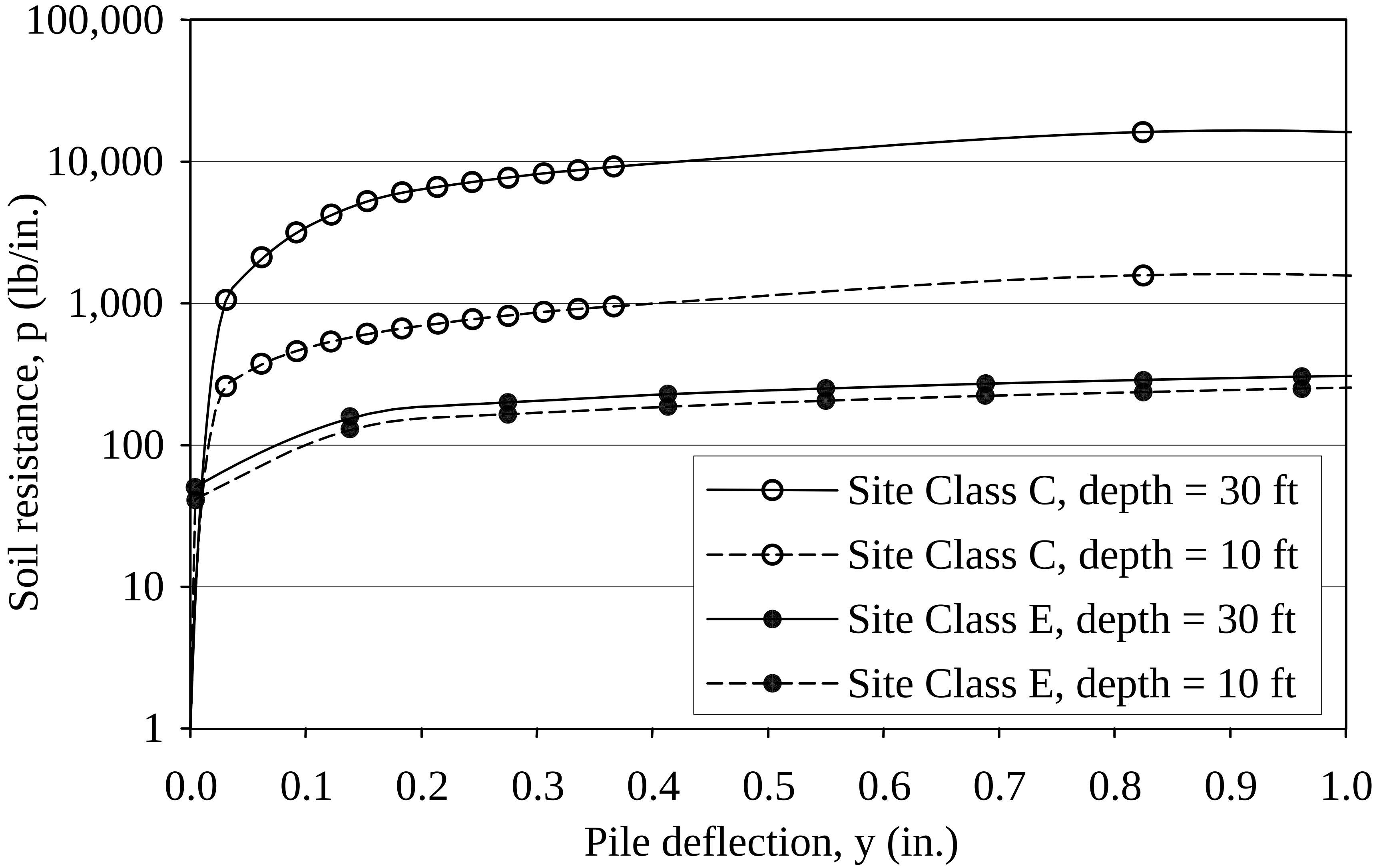
Cap influence

Group action

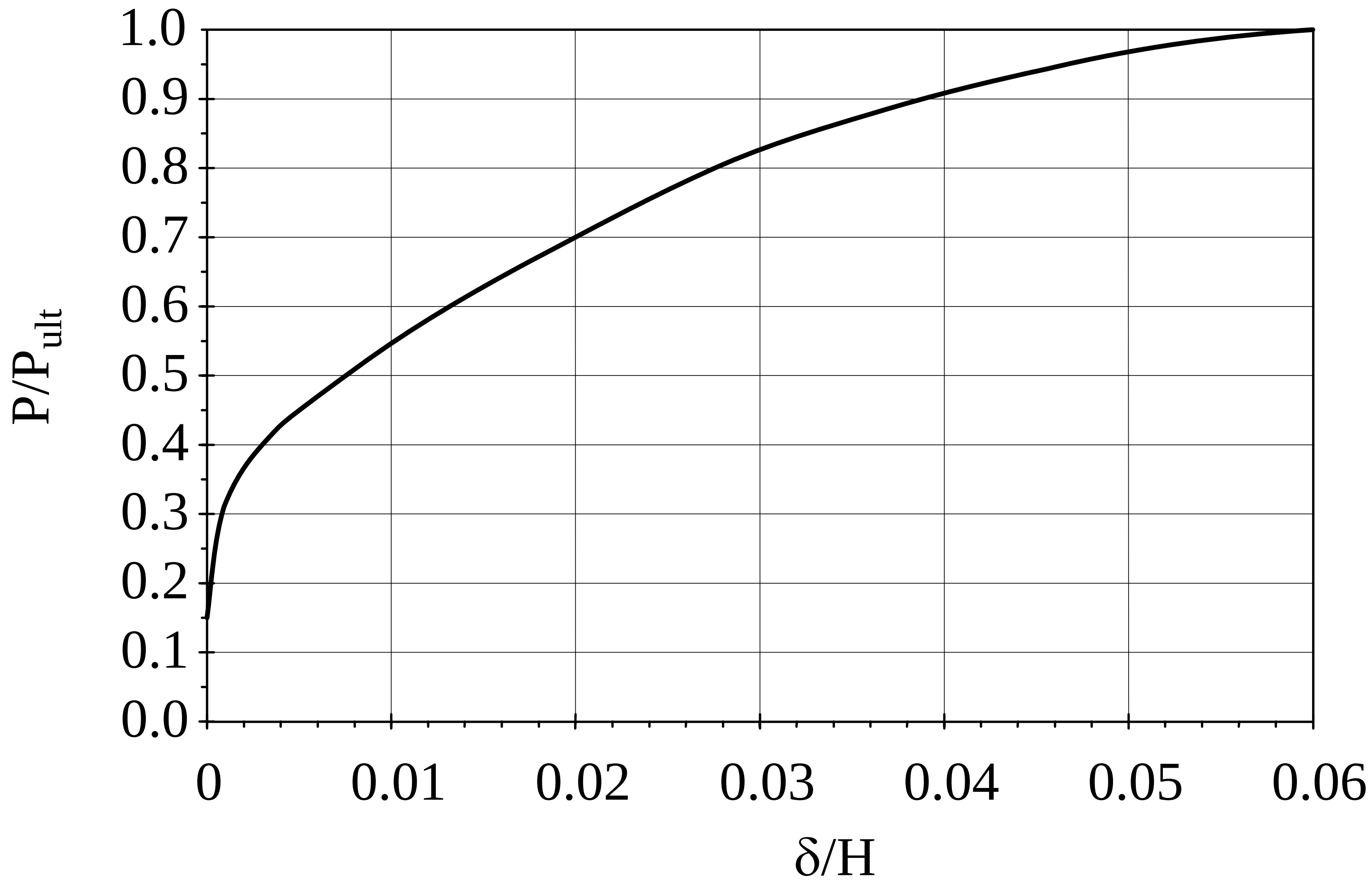
Soil Stiffness

- Linear springs – nomographs e.g. NAVFAC DM7.2
- Nonlinear springs – LPILE or similar analysis

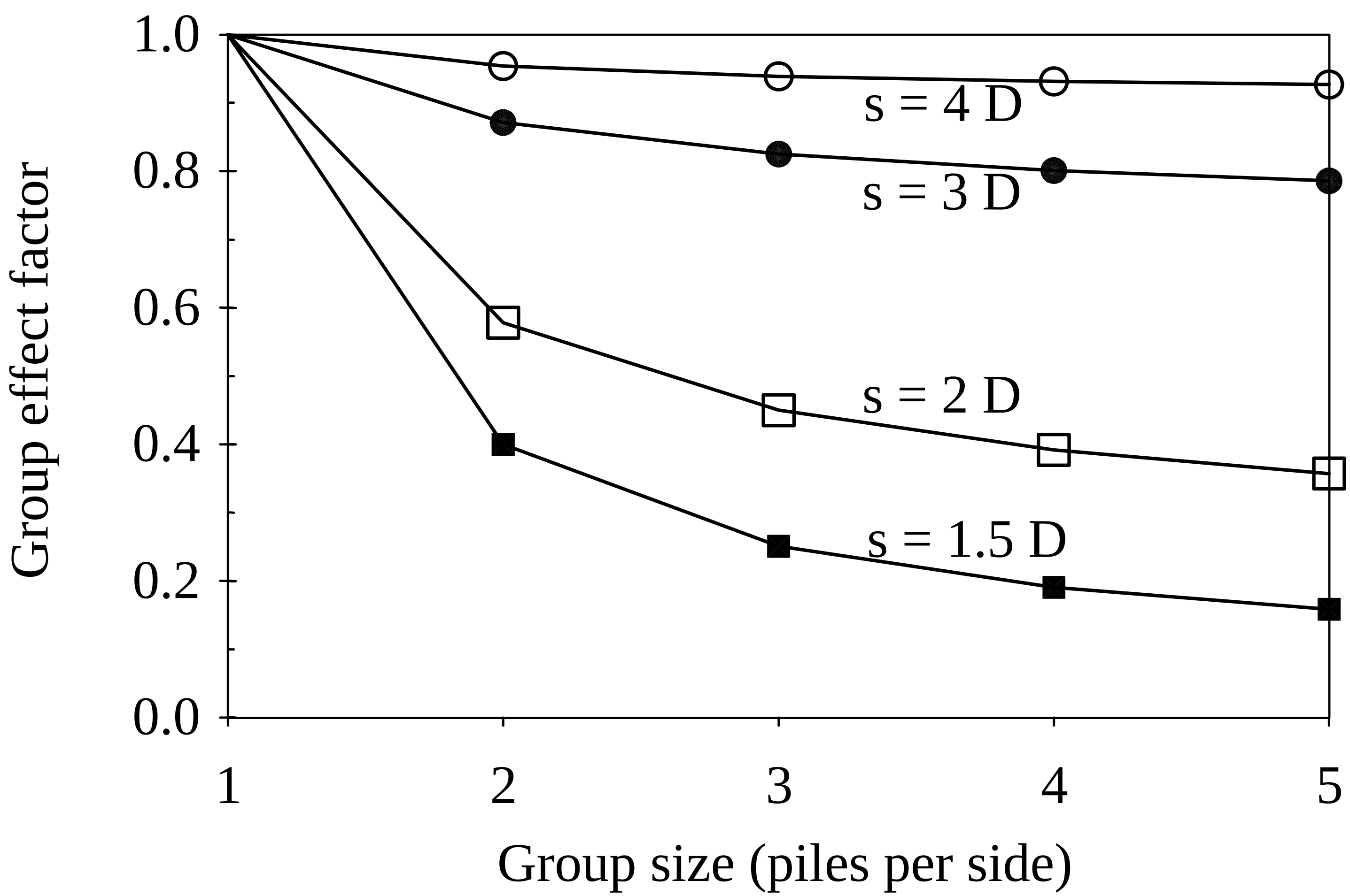
Sample *p-y* Curves



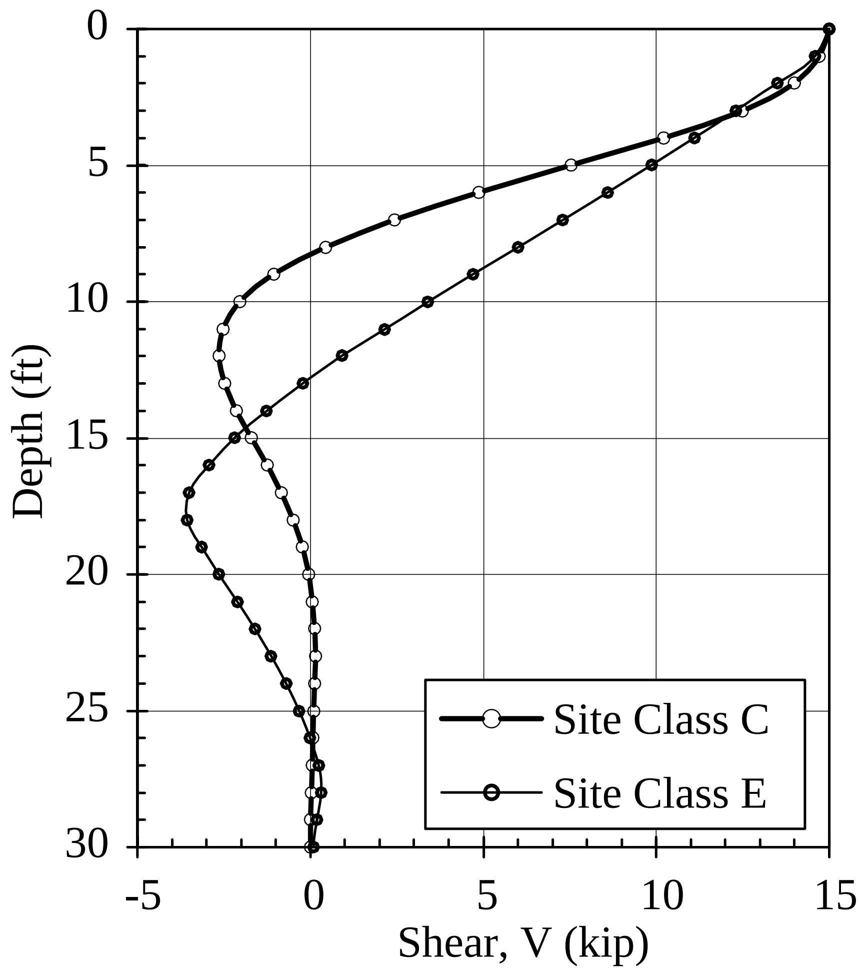
Passive Pressure



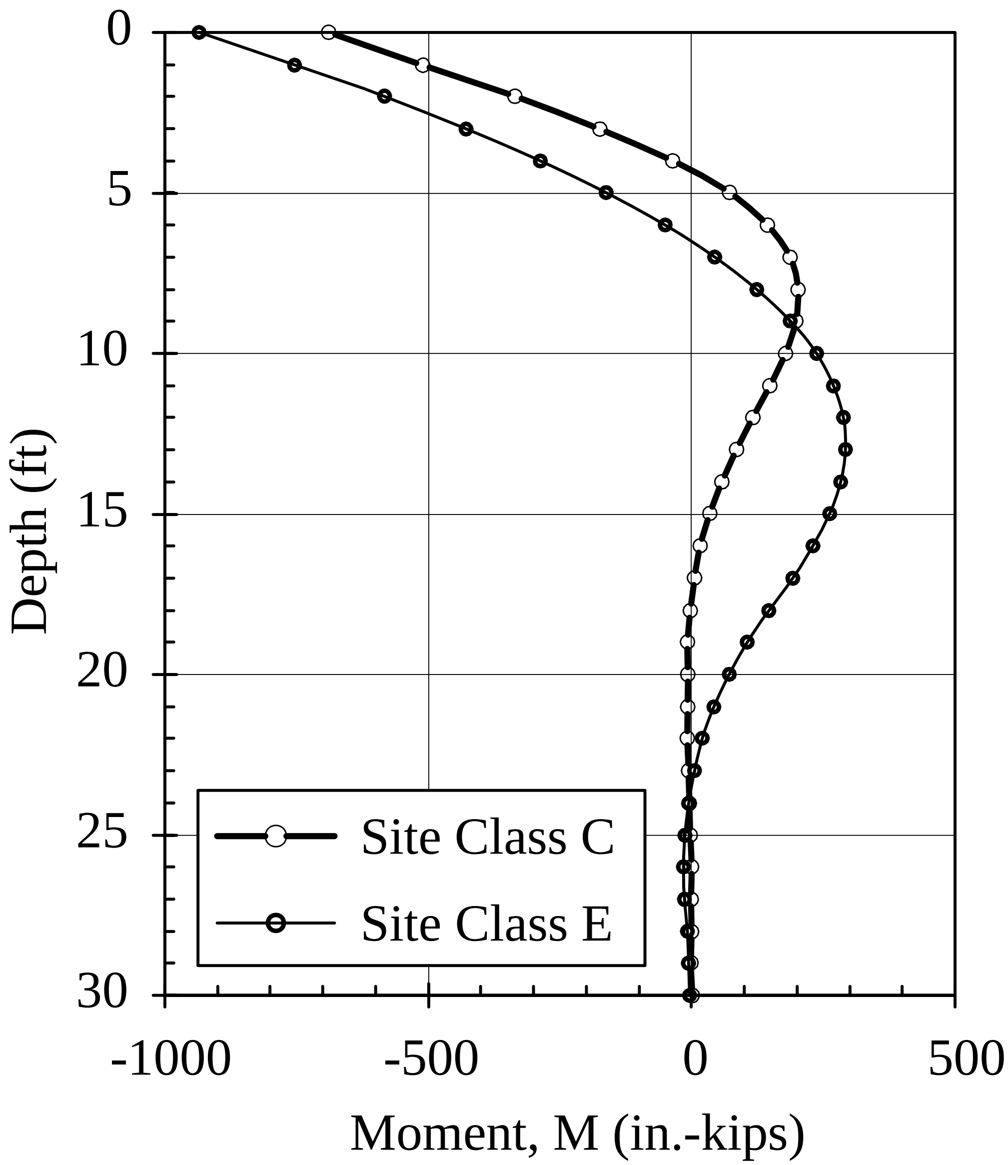
Group Effect

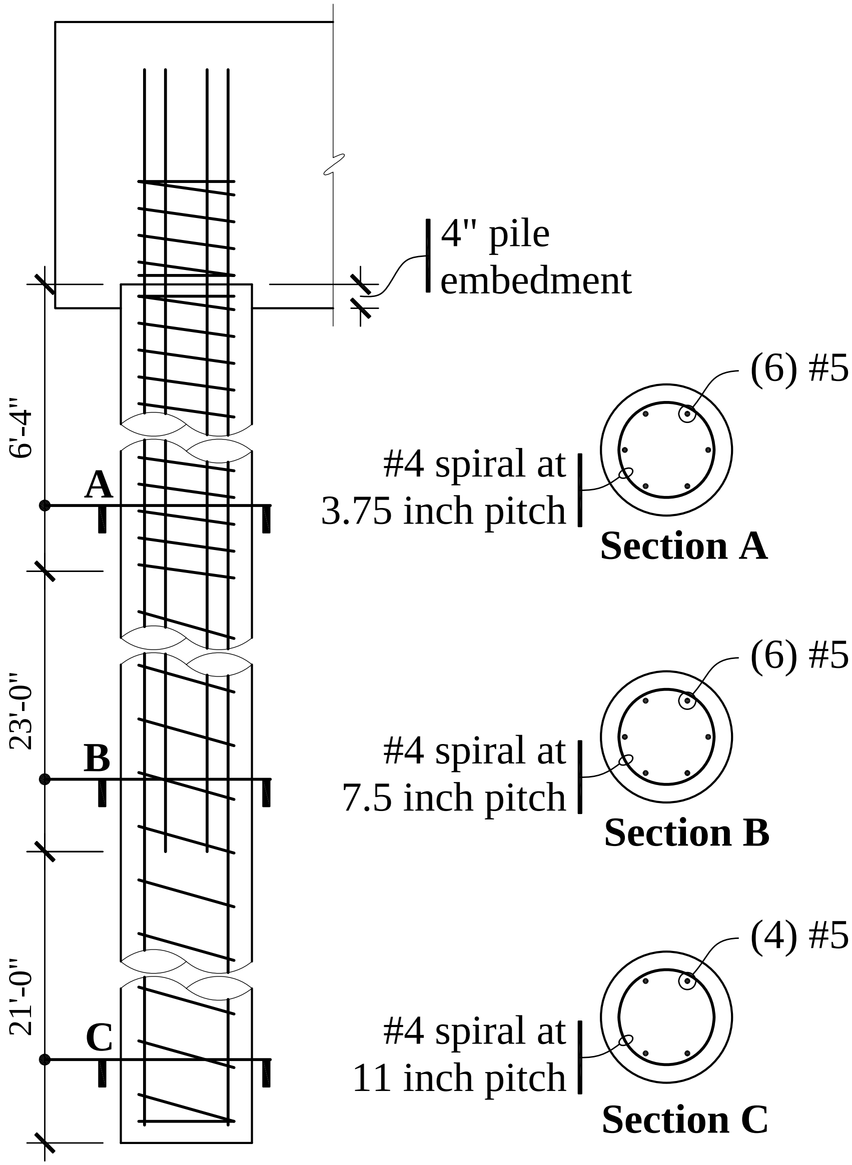


Pile Shear: Two Soil
Stiffnesses



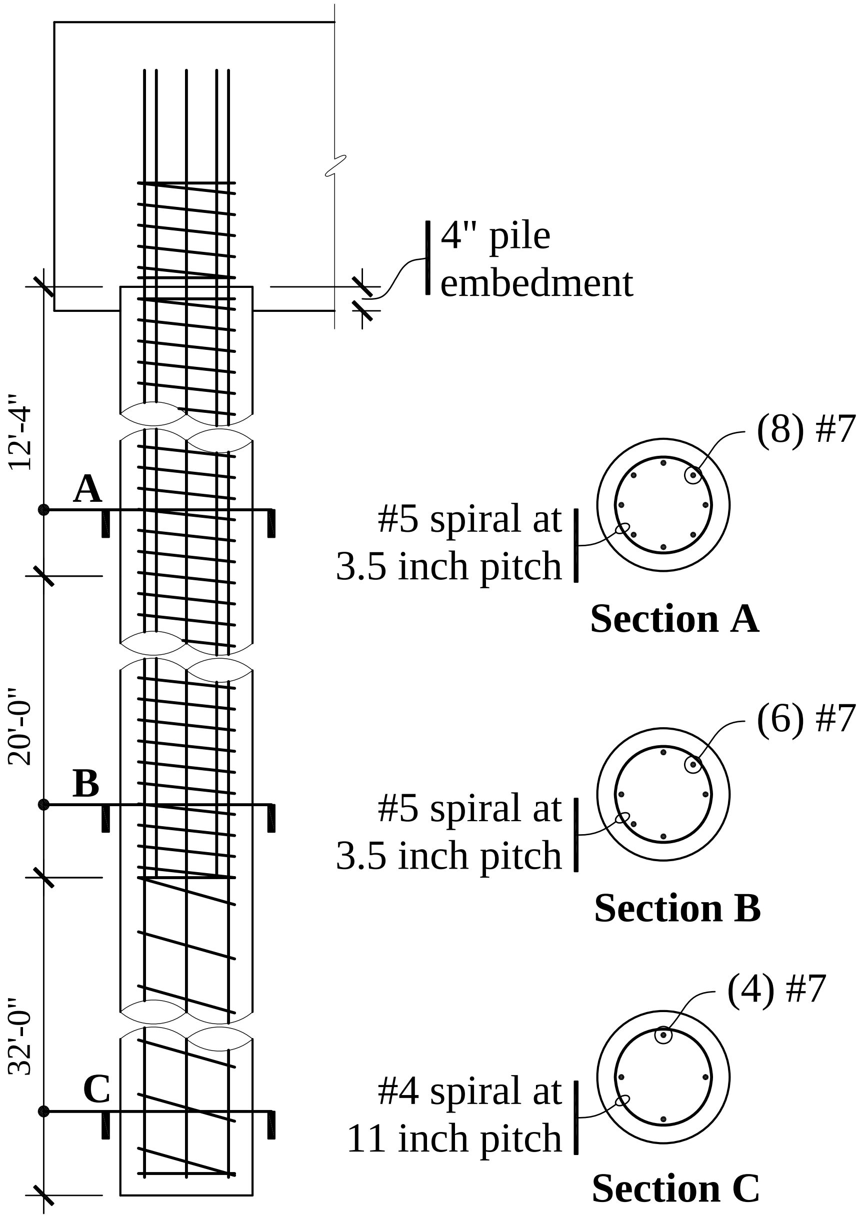
Pile Moment vs Depth





Pile Reinforcement

- Site Class C
- Larger amounts where moments and shears are high
- Minimum amounts must extend beyond theoretical cutoff points
- “Half” spiral for 3D



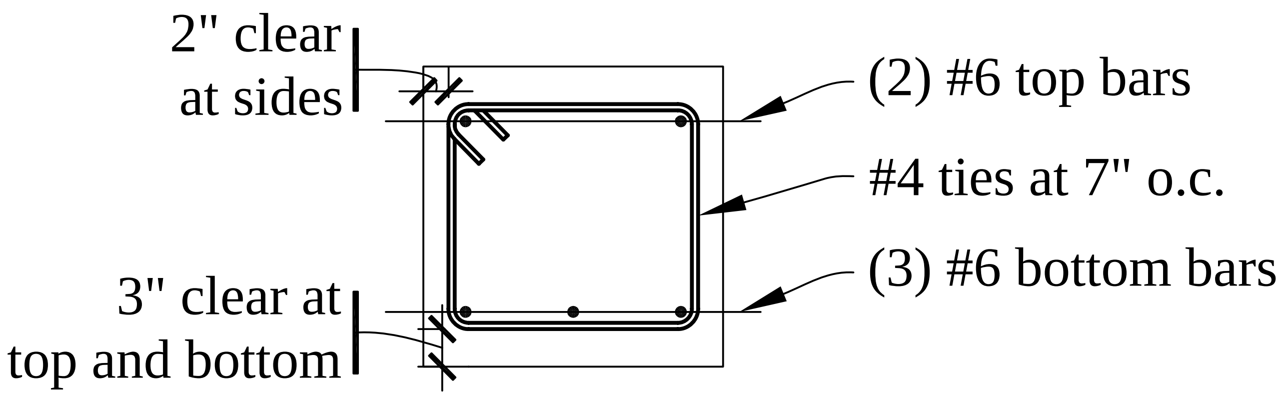
Pile Design

- Site Class E
- Substantially more reinforcement
- "Full" spiral for 7D
- Confinement at boundary of soft and firm soils (7D up and 3D down)

Other Topics for Pile Foundations

- Foundation Ties: $F = P_G(S_{DS}/10)$
- Pile Caps: high shears, rules of thumb; look for 3D strut and tie methods in future
- Liquefaction: another topic
- Kinematic interaction of soil layers

Tie Between Pile Caps



- Designed for axial force (+/-)
- Pile cap axial load times S_{DS}/10
- Often times use grade beams or thickened slabs one grade