

*ELEMENTS OF ARCHITECTURAL STRUCTURES:  
FORM, BEHAVIOR, AND DESIGN*

*ARCH 614*

*DR. ANNE NICHOLS*

*SPRING 2013*

*lecture  
twenty six*

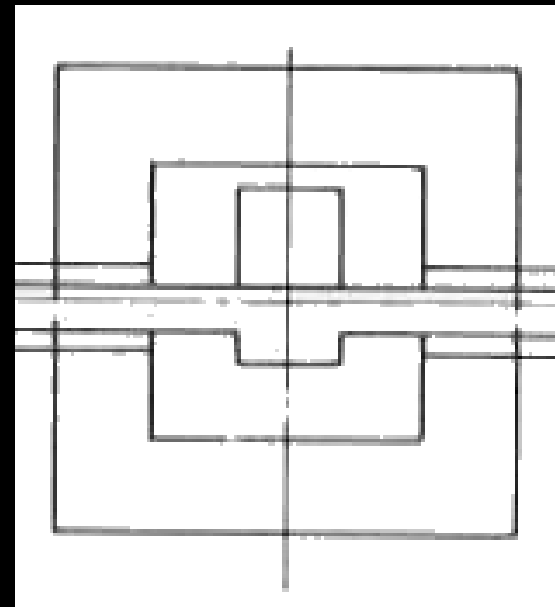
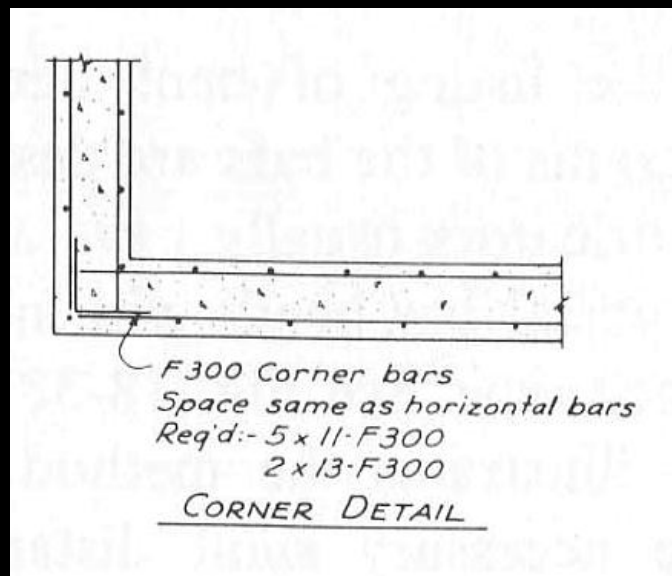


***concrete construction:  
foundation design***

[www.tamu.edu](http://www.tamu.edu)

# Foundation

- *the engineered interface between the earth and the structure it supports that transmits the loads to the soil or rock*



# Structural vs. Foundation Design

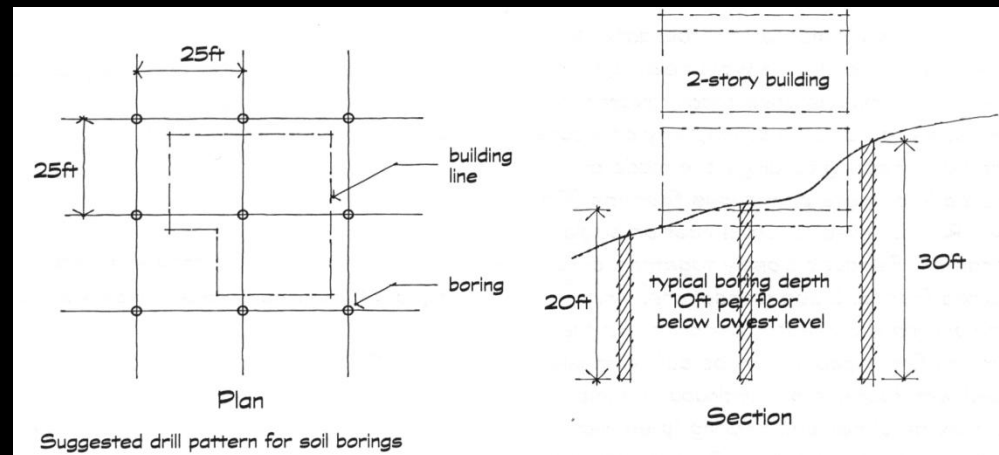
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- *structural design*
  - *choice of materials*
  - *choice of framing system*
  - *uniform materials and quality assurance*
  - *design largely independent of geology, climate, etc.*



# Structural vs. Foundation Design

- *foundation design*
  - *cannot specify site materials*
  - *site is usually predetermined*
  - *framing/structure predetermined*
  - *site geology influences foundation choice*
  - *no site the same*
  - *no design the same*



# Soil Properties & Mechanics

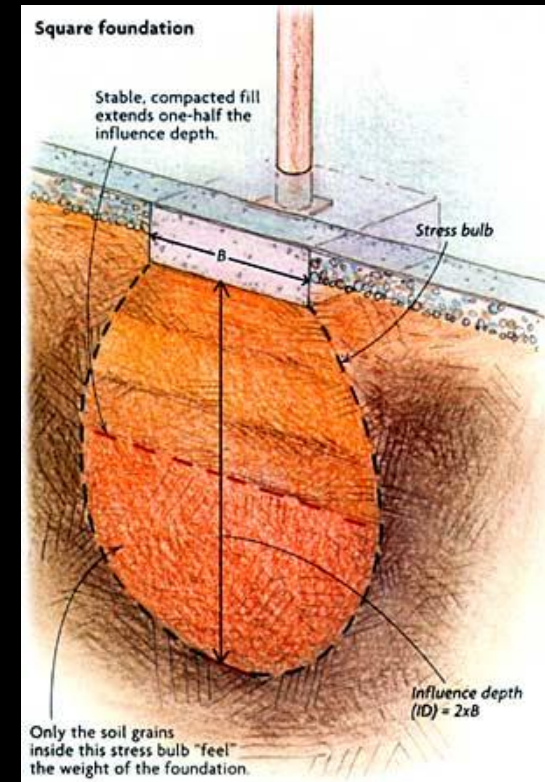
- *unit weight of soil*
- *allowable soil pressure*
- *factored net soil pressure*
- *shear resistance*
- *backfill pressure*
- *cohesion & friction of soil*
- *effect of water*
- *settlement*
- *rock fracture behavior*





# Soil Properties & Mechanics

- *compressibility*
  - *settlements*
- *strength*
  - *stability*
    - *shallow foundations*
    - *deep foundations*
    - *slopes and walls*
  - *ultimate bearing capacity,  $q_u$*
  - *allowable bearing capacity,  $q_a$*



[finehomebuilding.com](http://finehomebuilding.com)

$$q_a = \frac{q_u}{S.F.}$$

# Soil Properties & Mechanics

- strength,  $q_a$

**Table 1804.3**  
**PRESUMPTIVE LOADBEARING VALUES OF FOUNDATION MATERIALS**

Class of material	Loadbearing pressure (pounds per square foot) <sup>a</sup>
1. Crystalline bedrock	12,000
2. Sedimentary rock	6,000
3. Sandy Gravel	5,000
4. Sand, silty sand, clayey sand, silty gravel and clayey gravel	3,000
5. Clay, sandy clay, silty clay & clayey silt	2,000

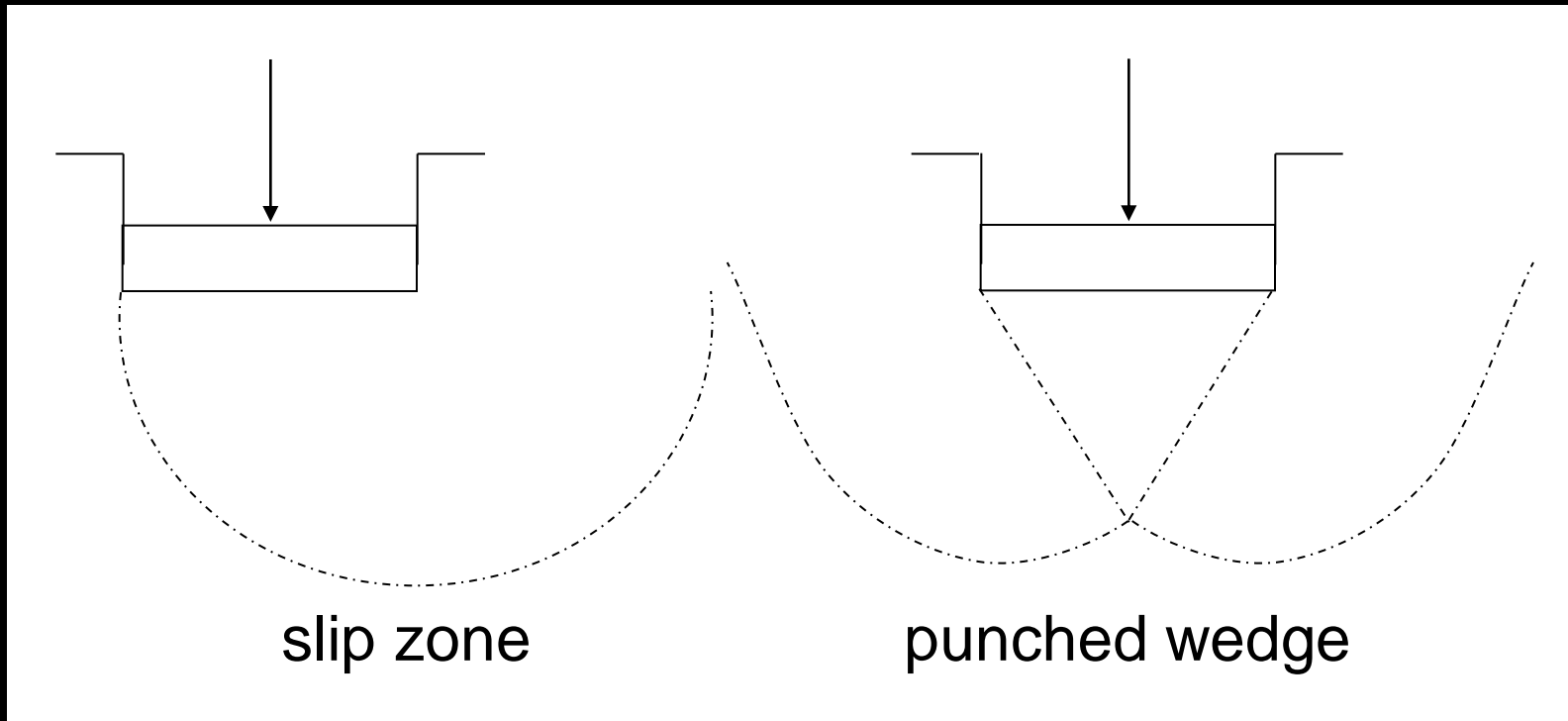
**Note a.** 1 psf = 47.9 Pa.

**FIGURE 2.5**

**Presumptive surface bearing values of various soils, as given in the BOCA National Building Code/1996. (Reproduced by permission)**

# Bearing Failure

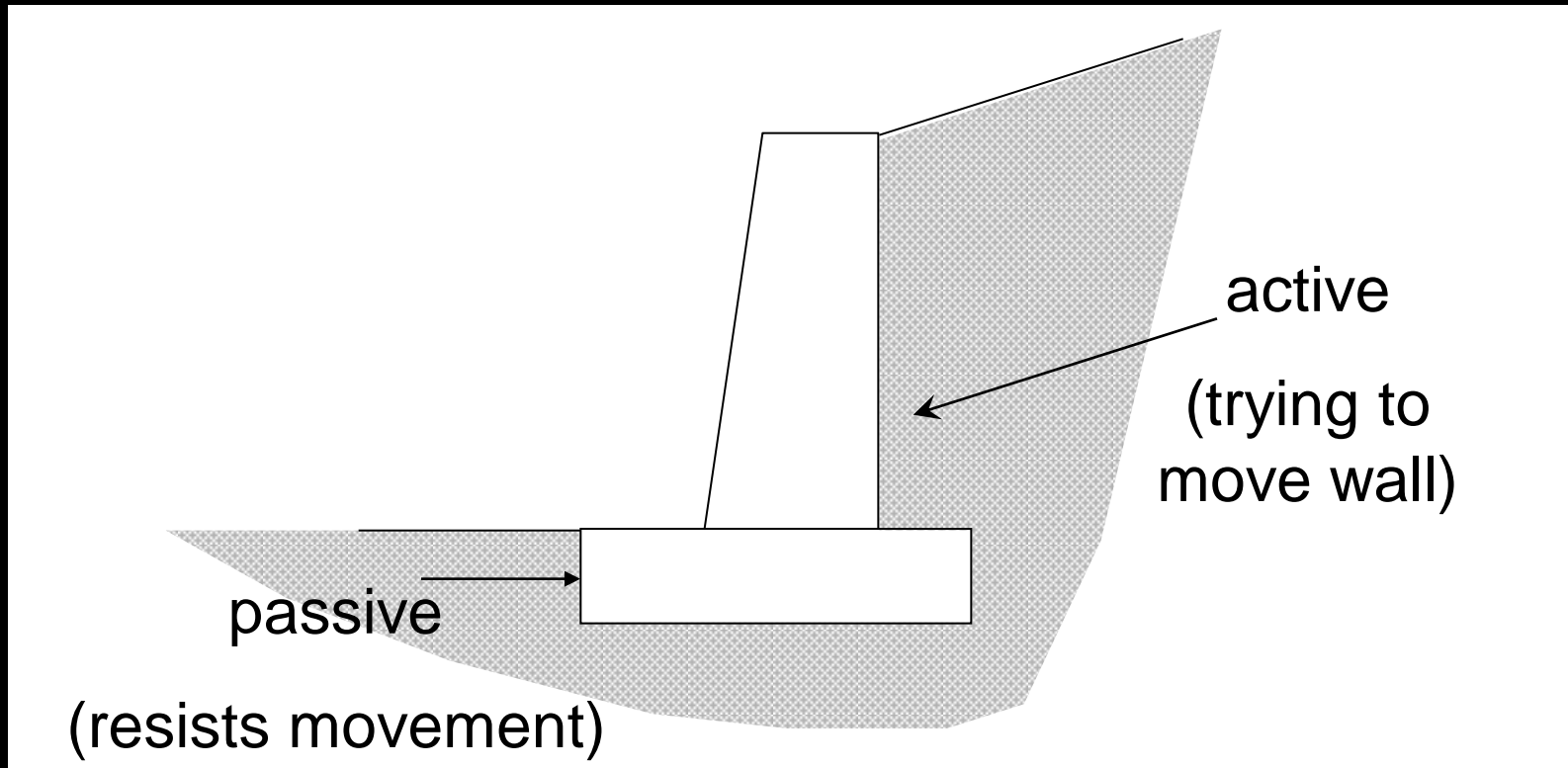
- *shear*





# Lateral Earth Pressure

- *passive vs. active*



# *Foundation Materials*

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- *concrete, plain or reinforced*
  - *shear*
  - *bearing capacity*
  - *bending*
  - *embedment length, development length*
- *other materials (piles)*
  - *steel*
  - *wood*
  - *composite*

# *Basic Foundation Requirements*

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- *safe against instability or collapse*
- *no excessive/damaging settlements*
- *consider environment*
  - *frost action*
  - *shrinkage/swelling*
  - *adjacent structure, property lines*
  - *ground water*
  - *underground defects*
  - *earthquake*
- *economics*

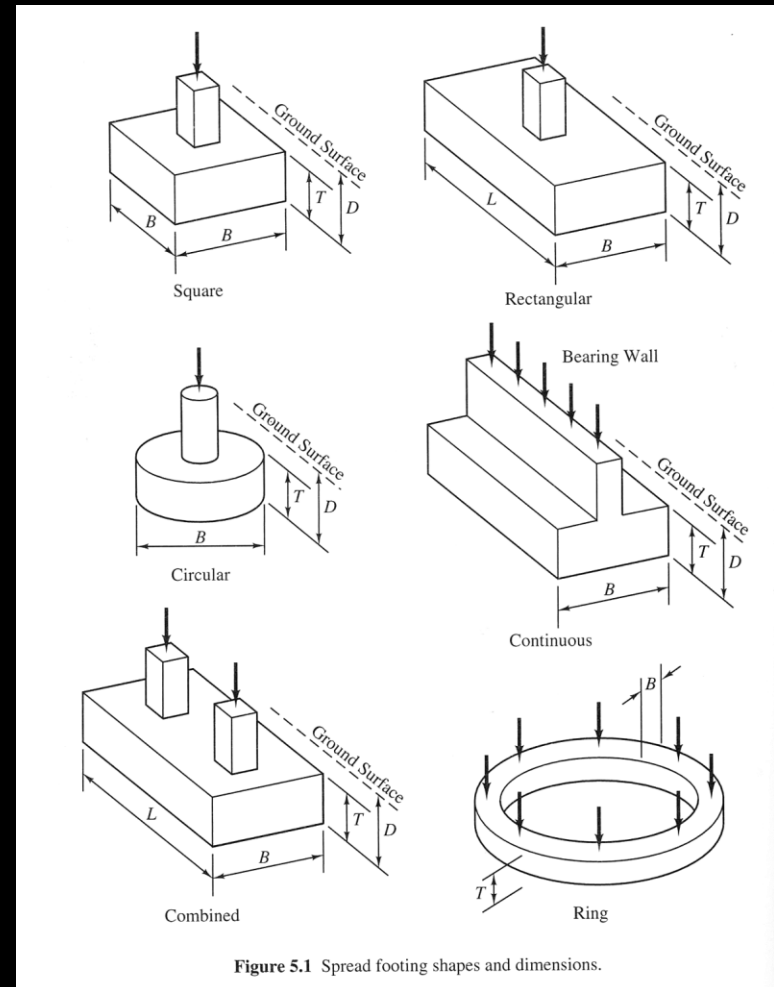
# *Generalized Design Steps*

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- *calculate loads*
- *characterize soil*
- *determine footing location and depth*
- *evaluate soil bearing capacity*
- *determine footing size (unfactored loads)*
- *calculate contact pressure and check stability*
- *estimate settlements*
- *design footing structure\* (factored loads)*

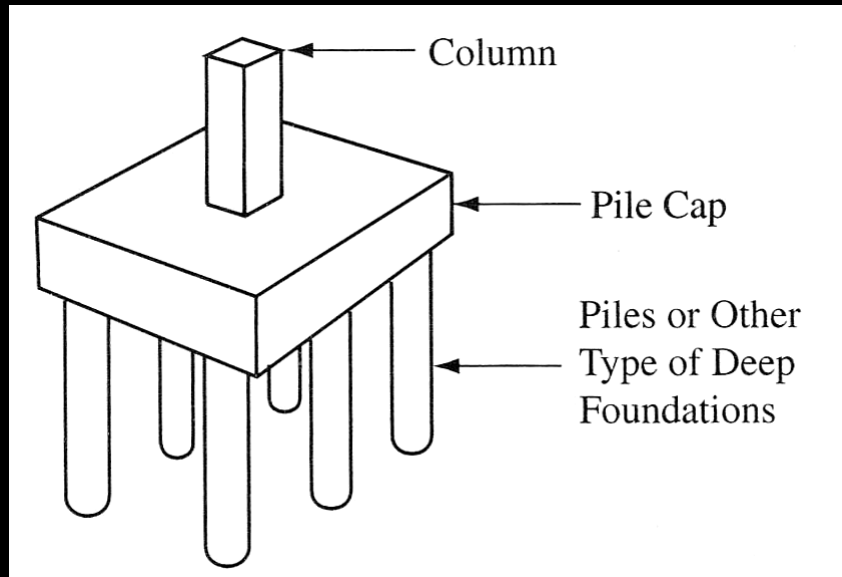
# Types of Foundations

- *spread footings*
- *wall footings*
- *eccentric footings*
- *combined footings*
- *unsymmetrical footings*
- *strap footings*



# *Types of Foundations*

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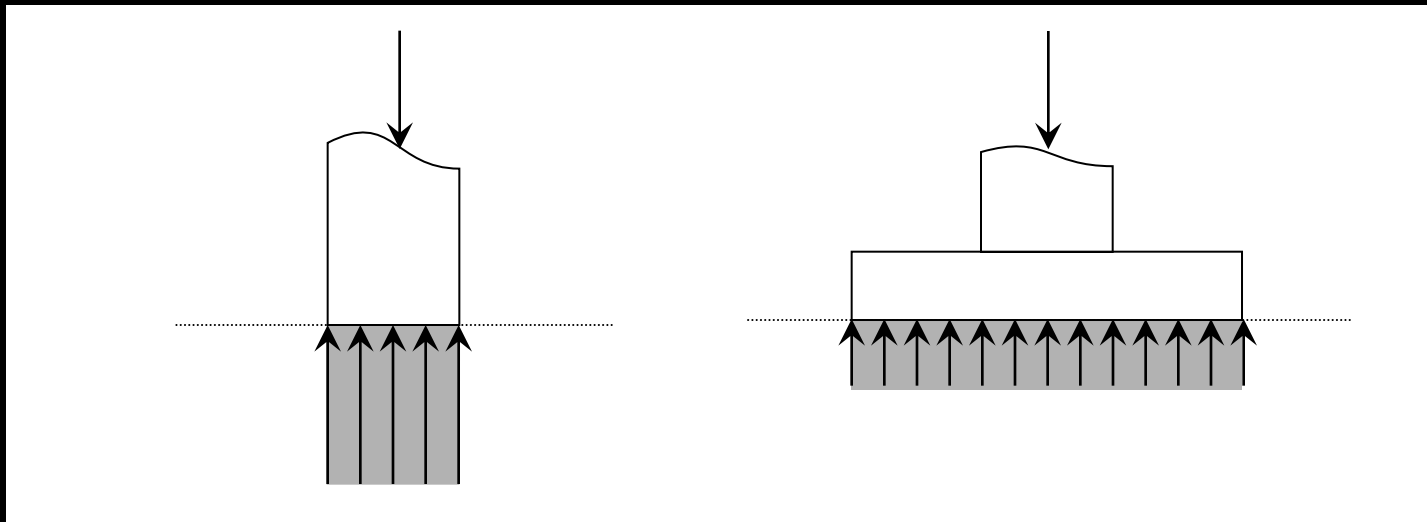


- *mat foundations*
- *retaining walls*
- *basement walls*
- *pile foundations*
- *drilled piers*



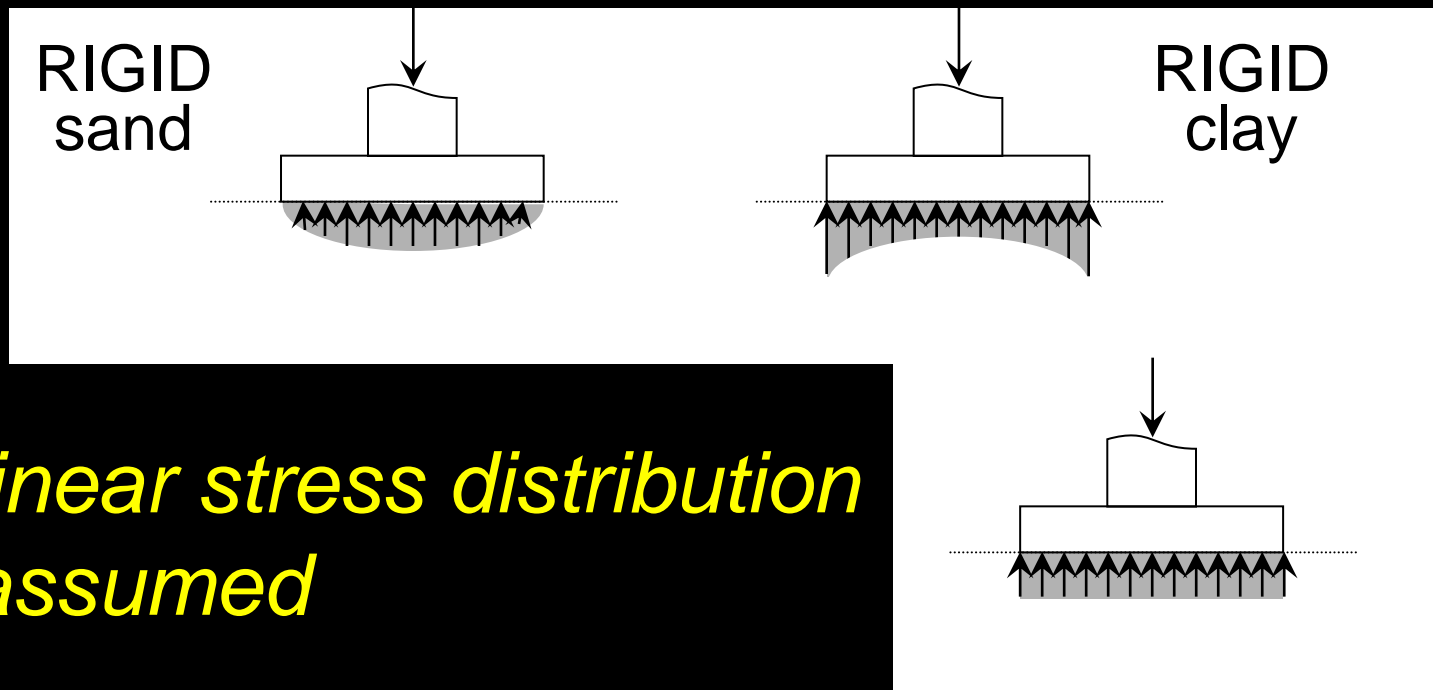
# Shallow Footings

- *spread footing*
  - *a square or rectangular footing supporting a single column*
  - *reduces stress from load to size the ground can withstand*



# Actual vs. Design Soil Pressure

- *stress distribution is a function of*
  - *footing rigidity*
  - *soil behavior*



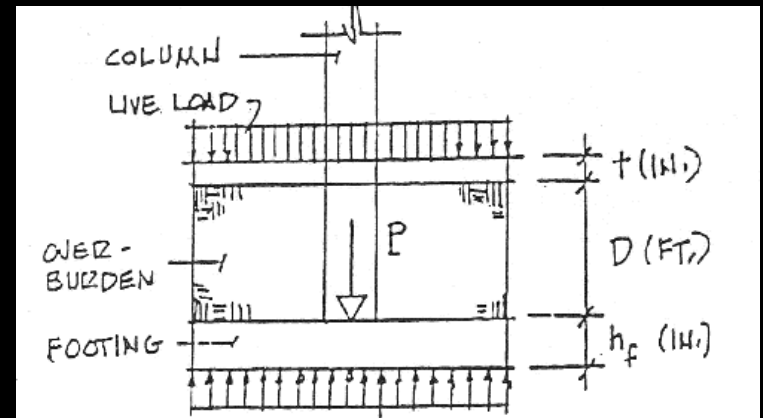
- *linear stress distribution assumed*

# Proportioning Footings

- *net allowable soil pressure,  $q_{net}$* 
  - $q_{net} = q_{allowable} - h_f (\gamma_c - \gamma_s)$
  - *considers all extra weight (overburden) from replacing soil with concrete*
  - *can be more overburden*

- *design requirement with total unfactored load:*

$$\frac{P}{A} \leq q_{net}$$



# Concrete Spread Footings

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- *plain or reinforced*
- *ACI specifications*
- *$P_u =$  combination of factored  $D, L, W$*
- *ultimate strength*
  - *$V_u \leq \phi V_c : \phi = 0.75$  for shear*
    - *plain concrete has shear strength*
  - *$M_u \leq \phi M_n : \phi = 0.9$  for flexure*

# Concrete Spread Footings

- *failure modes*

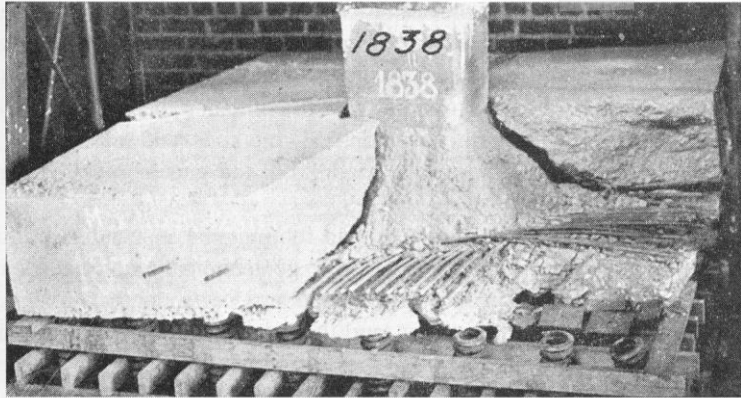


Figure 9.2 "Shear" failure in a spread footing loaded in a laboratory (Talbot, 1913). Observe how this failure actually is a combination of tension and shear.

*shear*

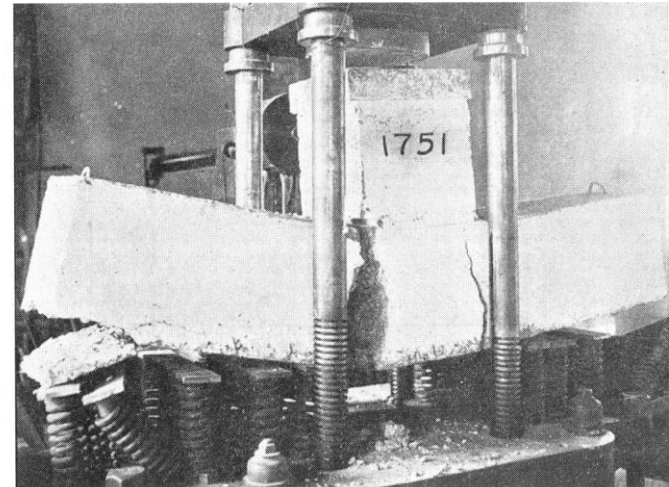
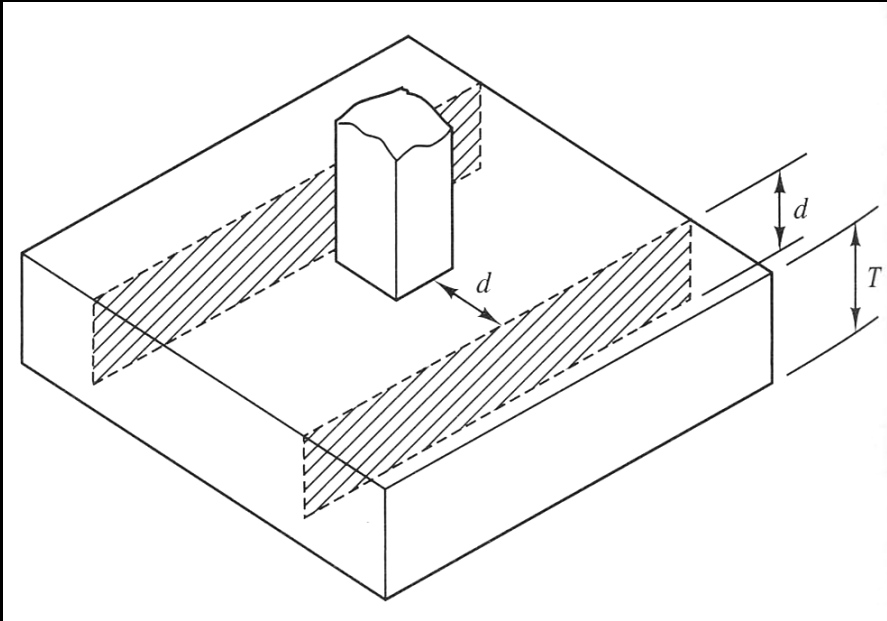


Figure 9.3 Flexural failure in a spread footing loaded in a laboratory (Talbot, 1913).

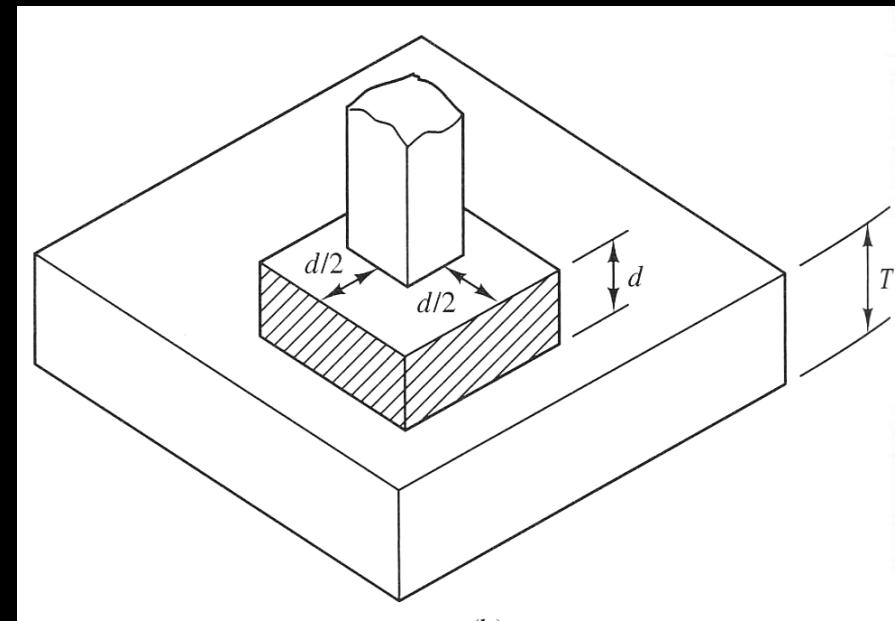
*bending*

# Concrete Spread Footings

- *shear failure*



*one way shear*



*two way shear*



# Over and Under-reinforcement

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- *reinforcement ratio for bending*

- $\rho = \frac{A_s}{bd}$

- *use as a design estimate to find  $A_s, b, d$*

- *max  $\rho$  from  $\varepsilon_{\text{steel}} \geq 0.004$*

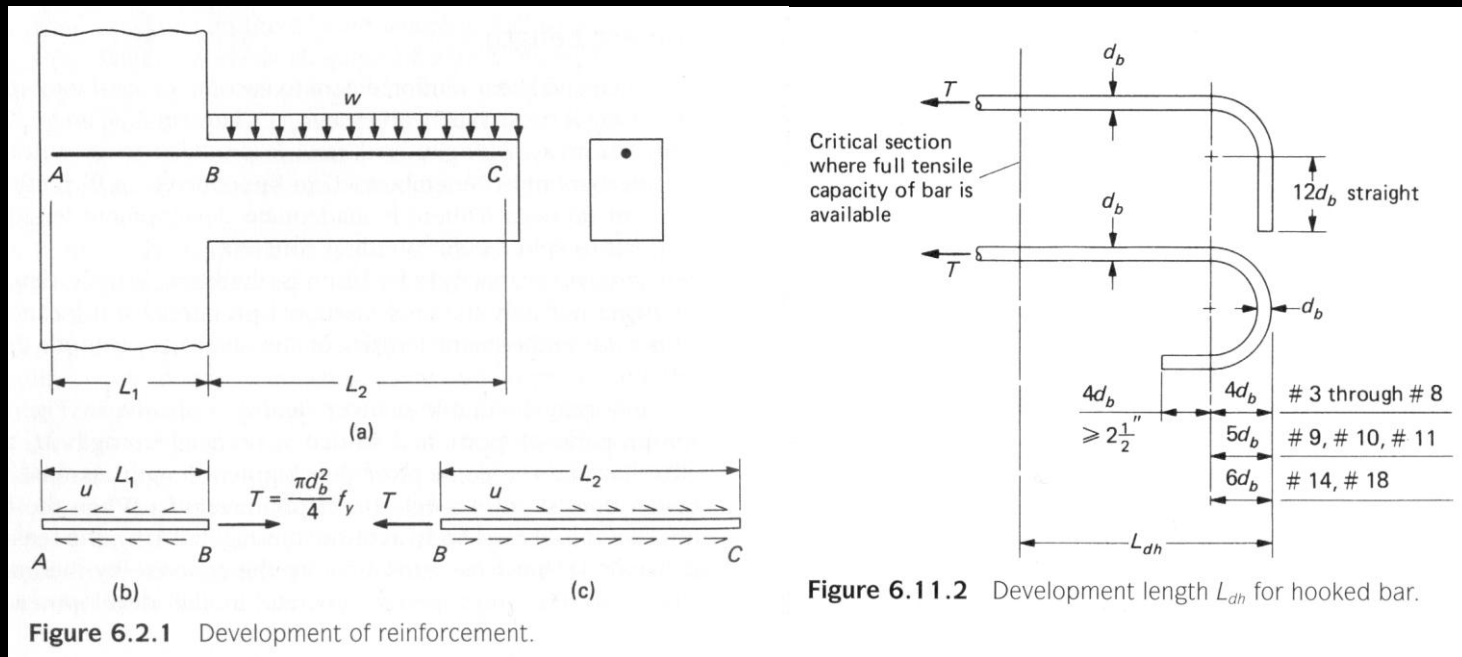
- *minimum for slabs & footings of uniform*

- thickness*  $\frac{A_s}{bh} = 0.002$  *grade 40 / 50 bars*

- $= 0.0018$  *grade 60 bars*

# Reinforcement Length

- need length,  $\ell_d$ 
  - bond
  - development of yield strength



# Column Connection

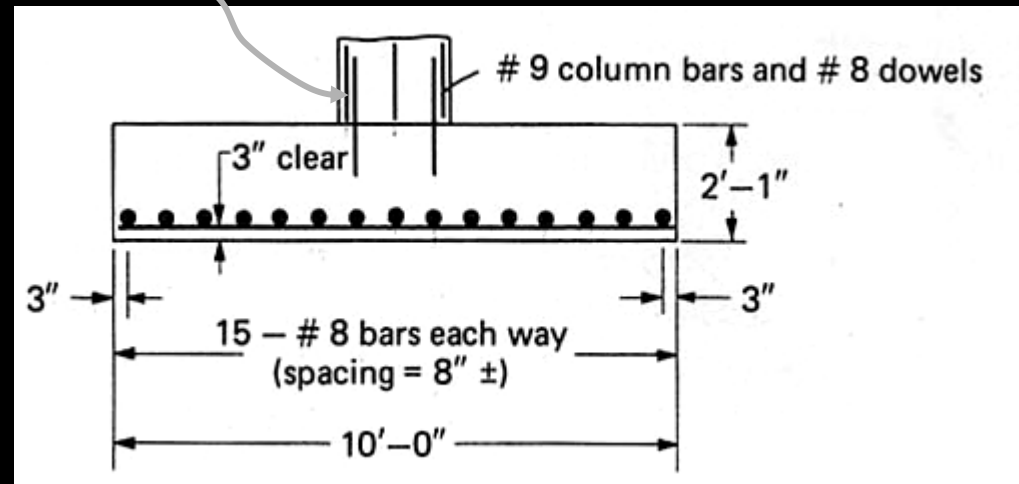
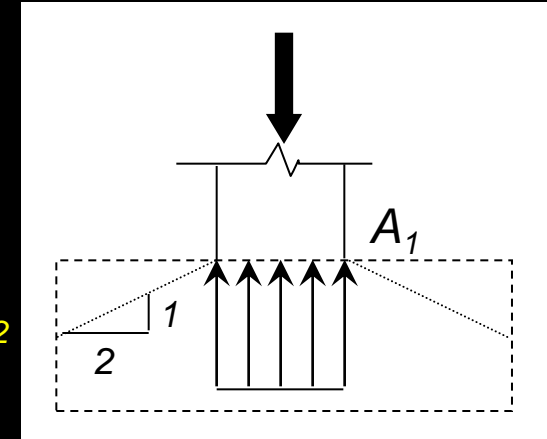
- bearing of column on footing

- $P_u \leq \phi P_n = \phi(0.85 f'_c A_1)$   
 $\phi = 0.65$  for bearing

- confined: increase  $x \sqrt{\frac{A_2}{A_1}} \leq 2$

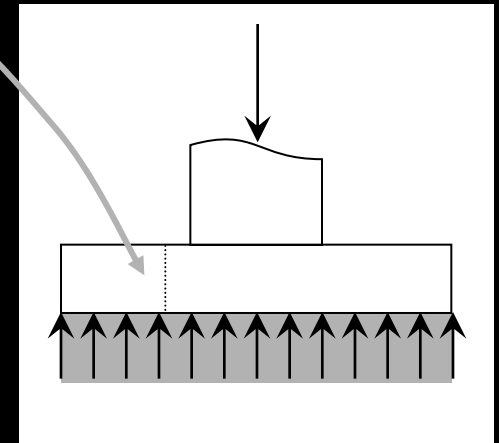
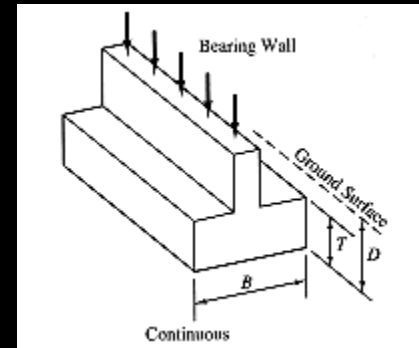
- dowel reinforcement

- if  $P_u > P_b$ , need compression reinforcement
  - min of 4 - #5 bars (or 15 metric)



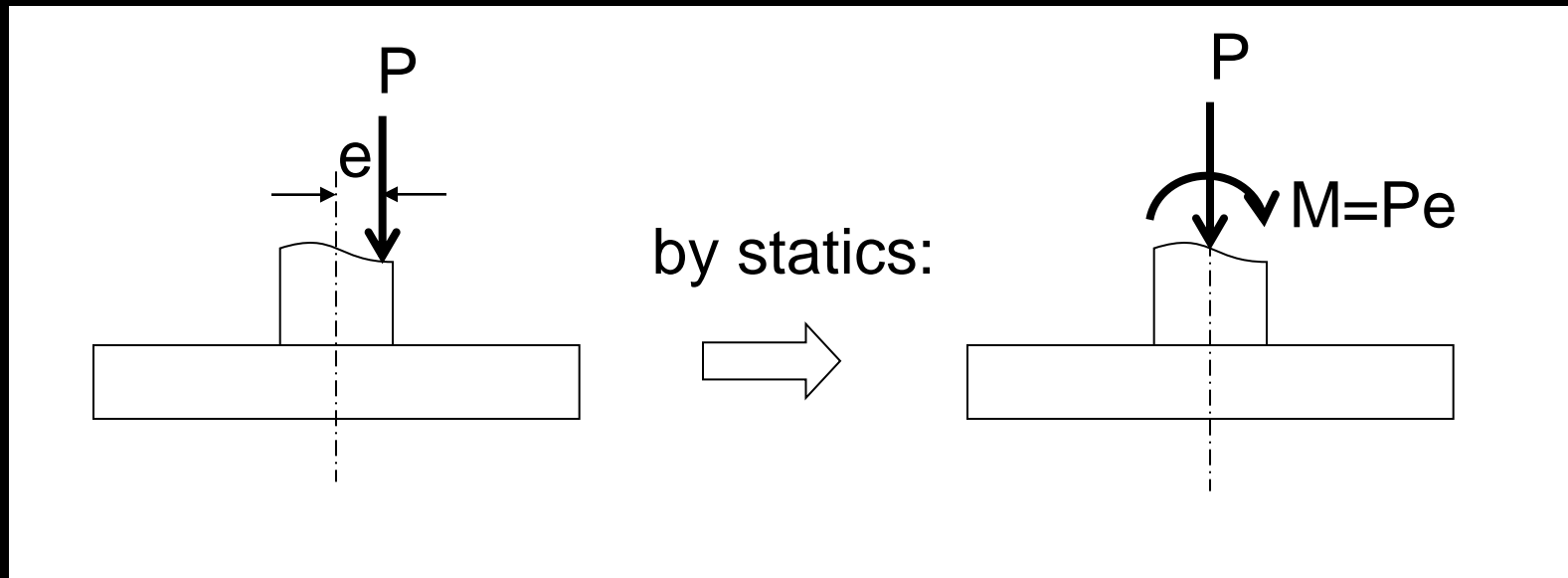
# Wall Footings

- *continuous strip for load bearing walls*
- *plain or reinforced*
- *behavior*
  - *wide beam shear*
  - *bending of projection*
- *dimensions usually dictated by codes for residential walls*
- *light loads*



# *Eccentrically Loaded Footings*

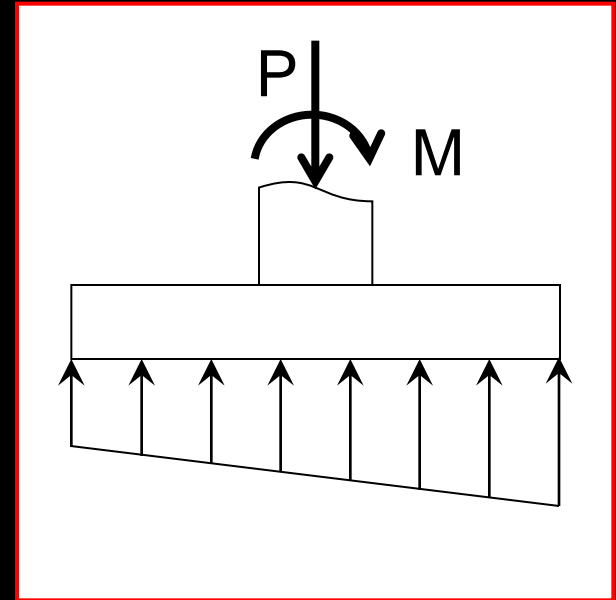
- *footings subject to moments*



– *soil pressure resultant force may not coincide with the centroid of the footing*

# Differential Soil Pressure

- *to avoid large rotations, limit the differential soil pressure across footing*
- *for rigid footing, simplification of soil pressure is a linear distribution based on constant ratio of pressure to settlement*



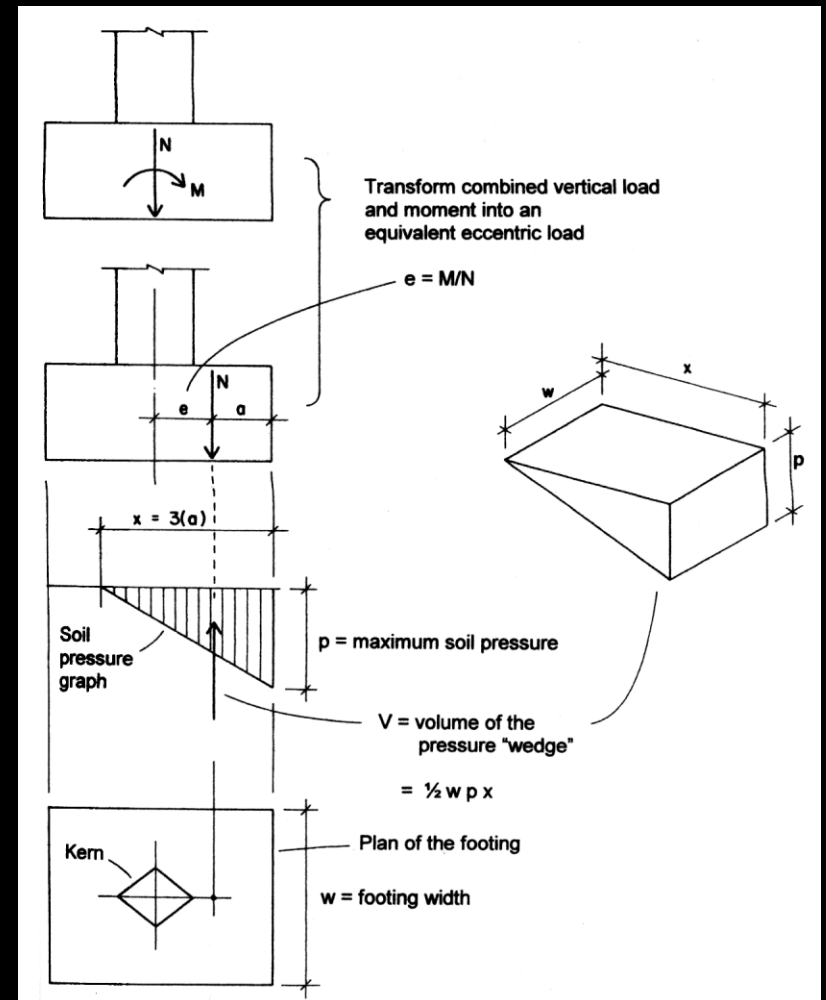


# Kern Limit

- boundary of  $e$  for no tensile stress
- triangular stress block with  $p_{max}$

$$volume = \frac{wp_x}{2} = N$$

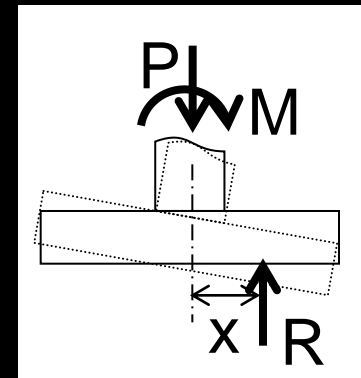
$$p_{max} = \frac{2N}{wx}$$



# Guidelines

- want resultant of load from pressure inside the middle third of base (kern)
  - ensures stability with respect to overturning

$$SF = \frac{M_{resist}}{M_{overturning}} = \frac{R \cdot x}{M} \geq 1.5$$

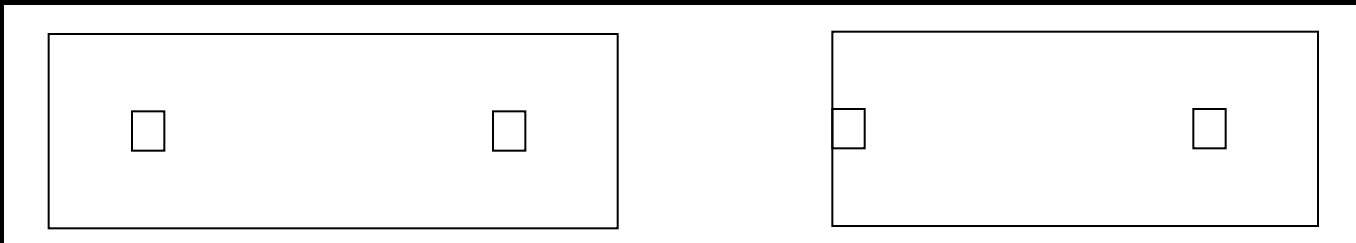


- pressure under toe (maximum)  $\leq q_a$
- shortcut using uniform soil pressure for design moments gives similar steel areas

# Combined Footings

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- *supports two columns*
- *used when space is tight and spread footings would overlap or when at property line*



- *soil pressure might not be uniform*
- *proportion so pressure will uniform for sustained loads*
- *behaves like beam lengthwise*

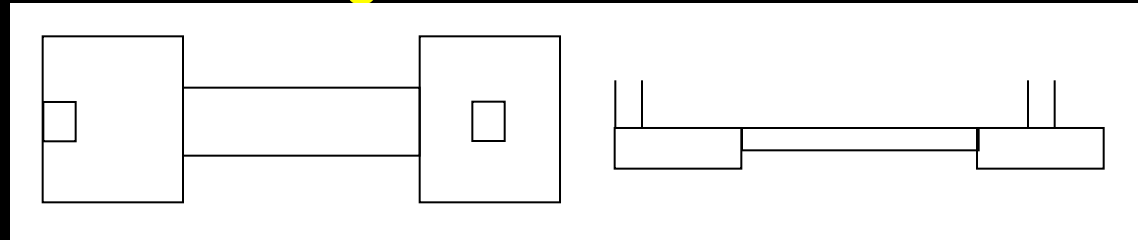
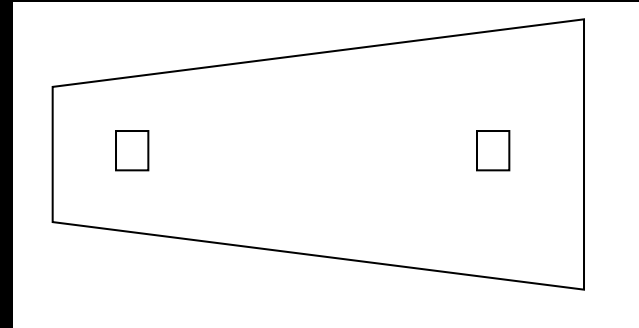
# Combined Footing Types

– *rectangular*

– *trapezoid*

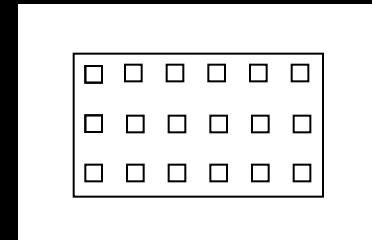
– *strap or cantilever*

- *prevents overturning of exterior column*



– *raft/mat*

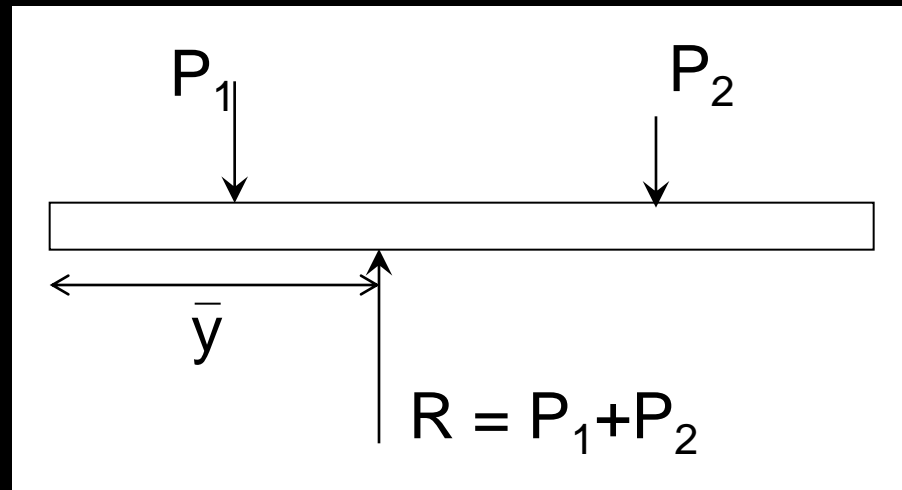
- *more than two columns over an extended area*



# Proportioning

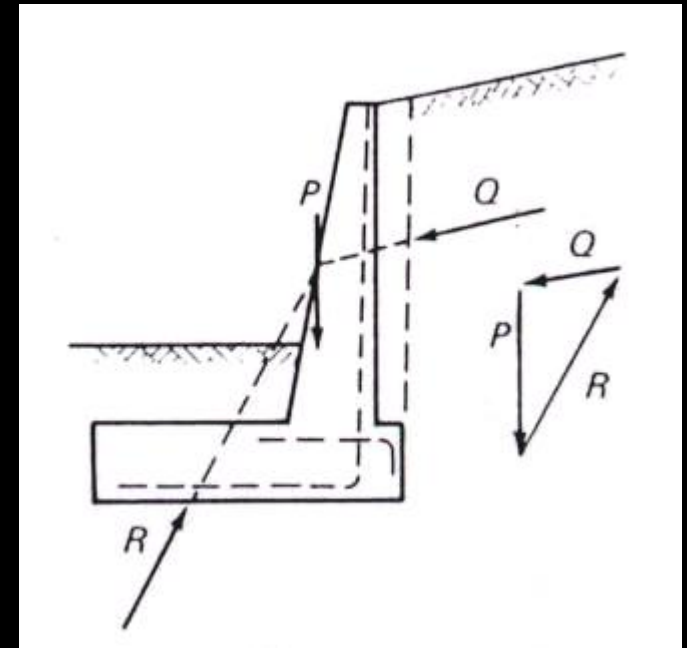
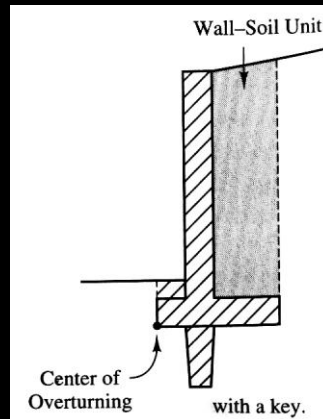
- *uniform settling is desired*
- *area is proportioned with sustained column loads*
- *want the resultant to coincide with centroid of footing area for uniformly distributed pressure assuming a rigid footing*

$$q_{max} \leq q_a$$



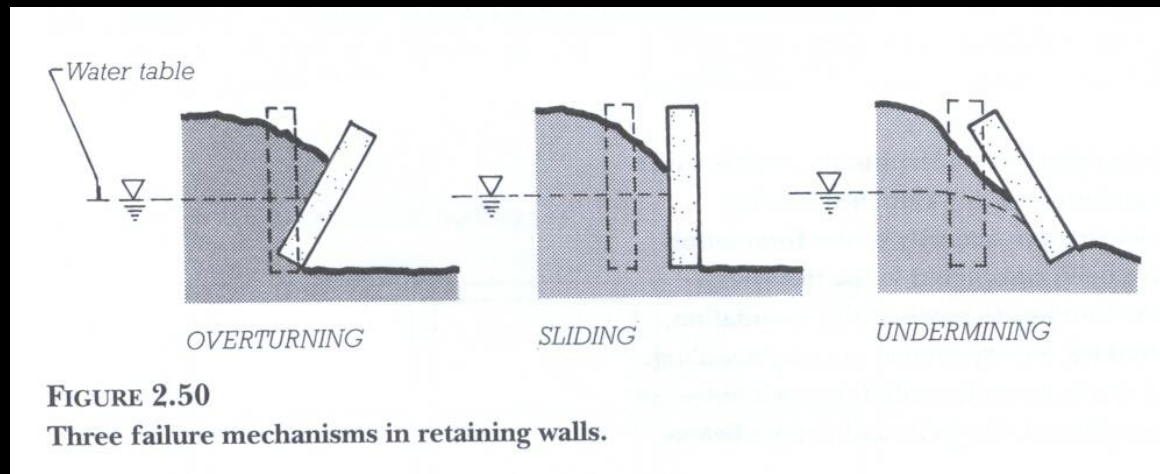
# Retaining Walls

- *purpose*
  - *retain soil or other material*
- *basic parts*
  - *wall & base*
  - *additional parts*
    - *counterfort*
    - *buttress*
    - *key*



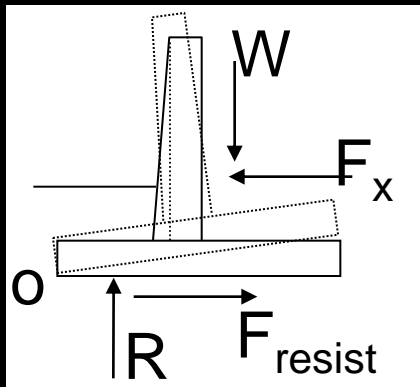
# Retaining Walls

- *considerations*
  - *overturning*
  - *settlement*
  - *allowable bearing pressure*
  - *sliding*
  - *(adequate drainage)*



# Retaining Walls

- *procedure*
  - *proportion and check stability with working loads for bearing, overturning and sliding*
  - *design structure with factored loads*



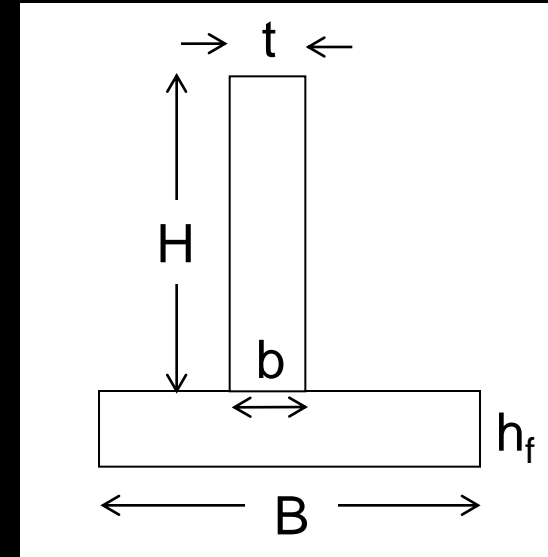
$$SF = \frac{M_{resist}}{M_{overturning}} \geq 1.5 - 2$$

$$SF = \frac{F_{horizontal-resist}}{F_{sliding}} \geq 1.25 - 2$$



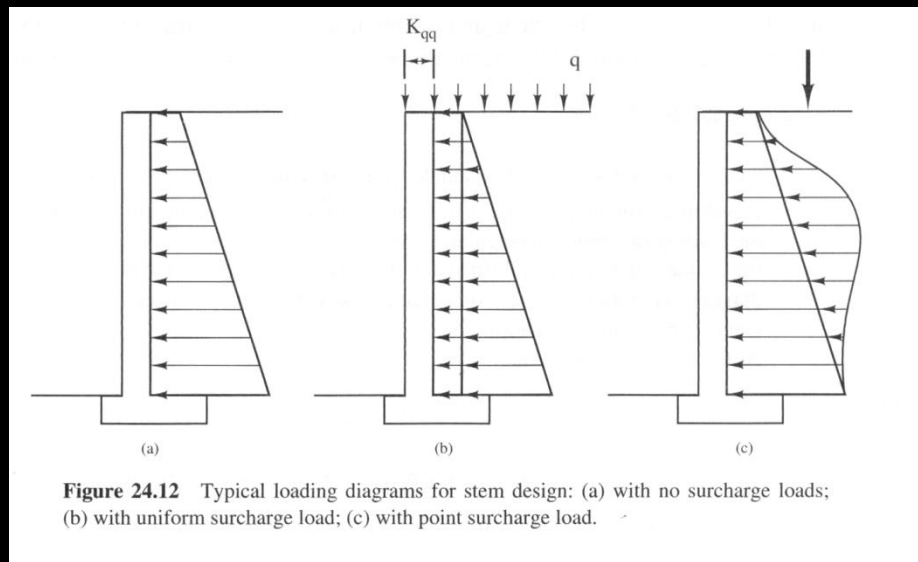
# Retaining Wall Proportioning

- *estimate size*
  - footing size,  $B$   $\approx 2/5 - 2/3$  wall height ( $H$ )
  - footing thickness  $\approx 1/12 - 1/8$  footing size ( $B$ )
  - base of stem  $\approx 1/10 - 1/12$  wall height ( $H+h_f$ )
  - top of stem  $\geq 12''$



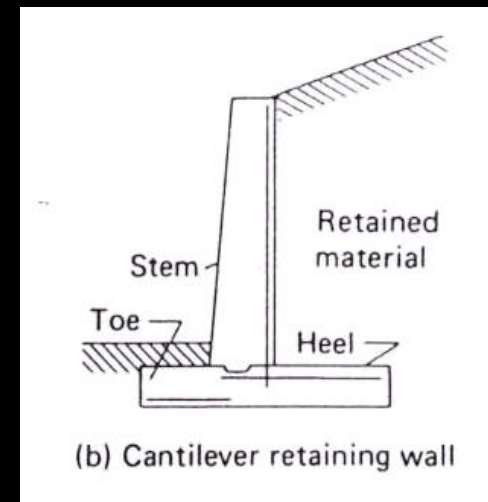
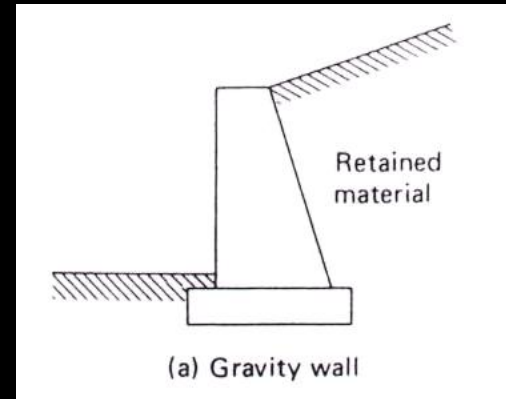
# Retaining Walls Forces

- *design like cantilever beam*
  - $V_u$  &  $M_u$  for reinforced concrete
  - $V_u \leq \phi V_c$  :  $\phi = 0.75$  for shear
  - $M_u \leq \phi M_n$  :  $\phi = 0.9$  for flexure



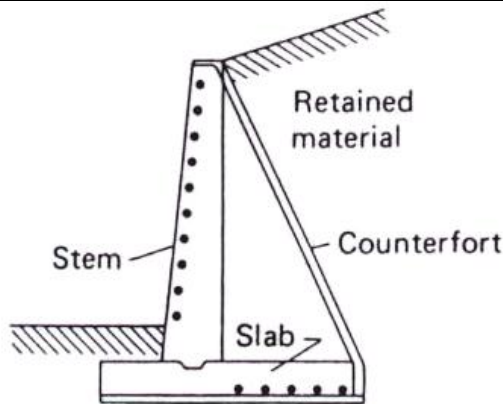
# Retaining Wall Types

- *“gravity” wall*
  - *usually unreinforced*
  - *economical & simple*
  
- *cantilever retaining wall*
  - *common*

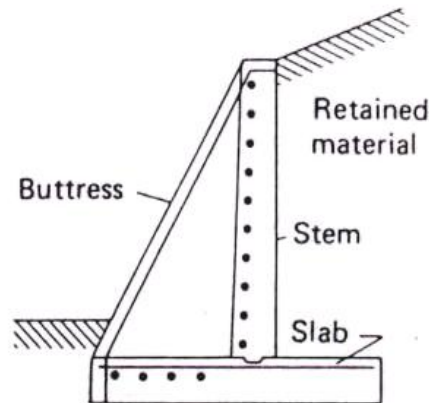


# Retaining Wall Types

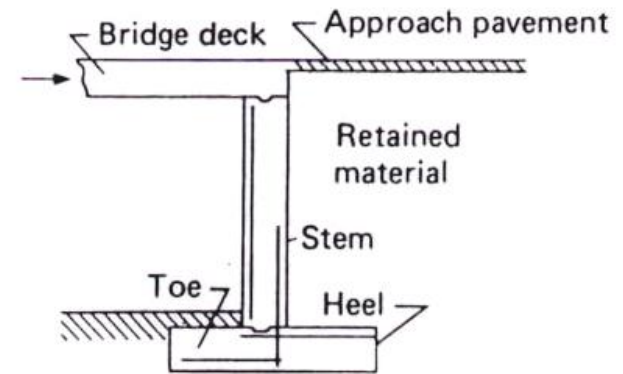
- *counterfort wall*
  - *buttress wall*
  - *bridge abutment*
  - *basement frame wall (large basement areas)*
- } very tall walls (> 20 - 25 ft)



(c) Counterfort wall



(d) Buttress wall



# Deep Foundations

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- *usage*
  - *when spread footings, mats won't work*
  - *when they are required to transfer the structural loads to good bearing material*
  - *to resist uplift or overturning*
  - *to compact soil*
  - *to control settlements of spread or mat foundations*

# Deep Foundation Types

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– piles - usually driven, 6"-8"  $\phi$ , 5' +

– piers

– caissons

– drilled shafts

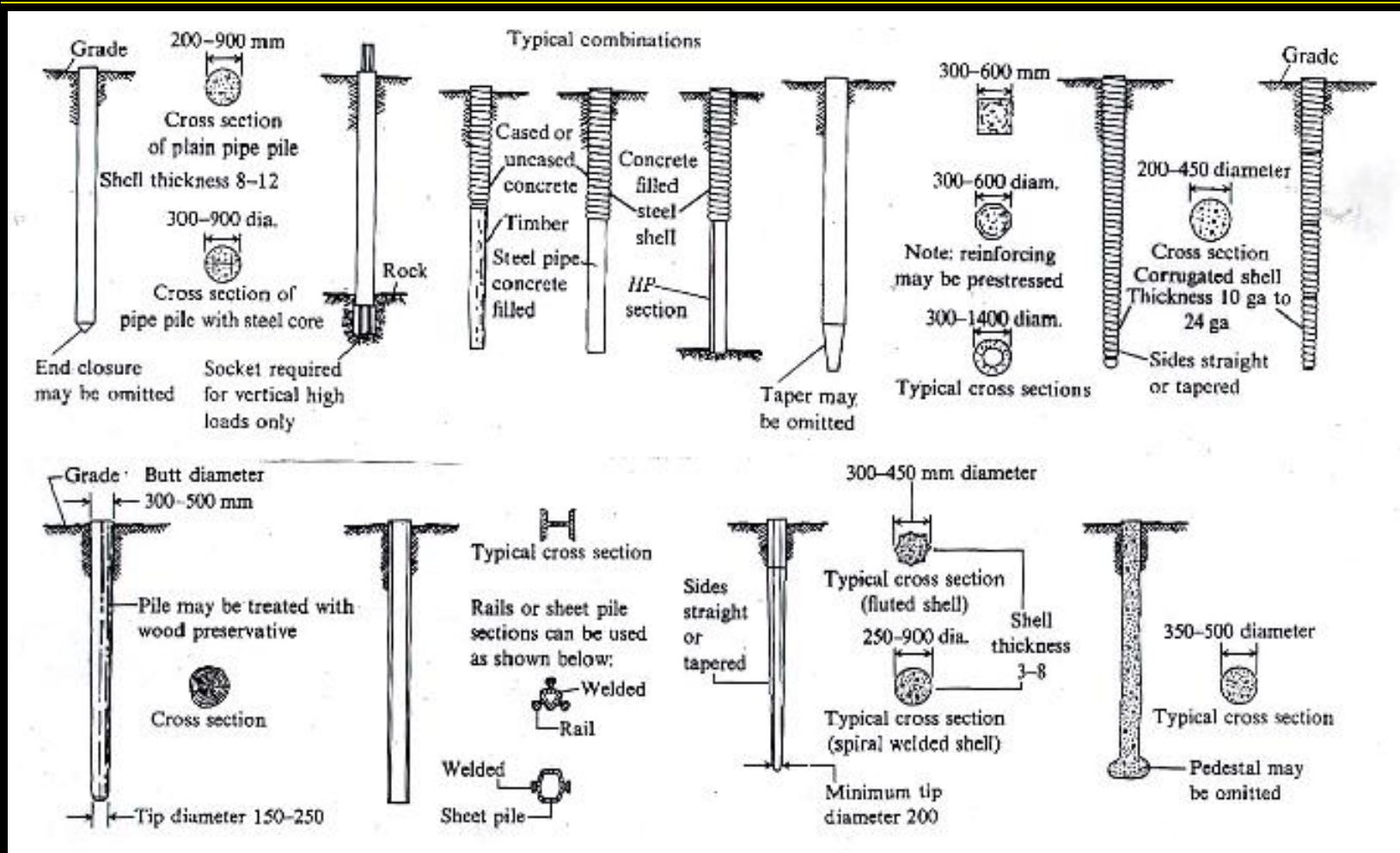
– bored piles

drilled, excavated,  
concreted (with or  
without steel)

2.5' - 10'/12'  $\phi$

– pressure injected piles

# Deep Foundation Types



# Deep Foundations

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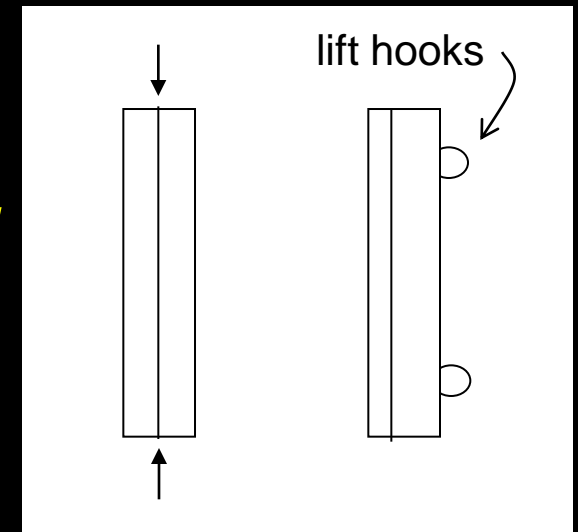
- *classification*
  - *by material*
  - *by shape*
  - *by function (structural, compaction...)*
- *pile placement methods*
  - *driving with pile hammer (noise & vibration)*
  - *driving with vibration (quieter)*
  - *jacking*
  - *drilling hole & filling with pile or concrete*



# Piles Classified By Material

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- *timber*
  - use for temporary construction
  - to densify loose sands
  - embankments
  - fenders, dolphins (marine)
- *concrete*
  - precast: ordinary reinforcement or prestressed
  - designed for axial capacity and bending with handling



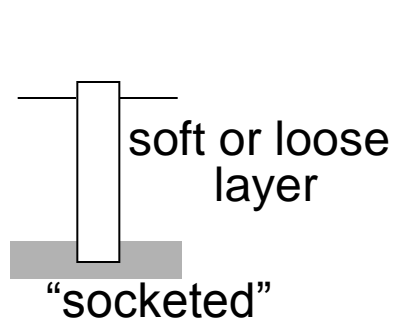
# *Piles Classified By Material*

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- *steel*
  - *rolled HP shapes or pipes*
  - *pipes may be filled with concrete*
  - *HP displaces little soil and may either break small boulders or displace them to the side*

# Piles Classified By Function

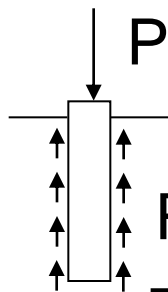
## – end bearing pile (point bearing)



$$P_a = A_p \cdot f_a$$

for use in soft or loose materials over a dense base

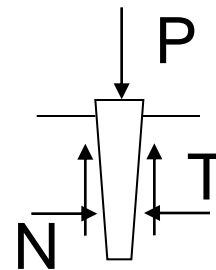
## – friction piles (floating)



common in both clay & sand

$$R_s = f(\text{adhesion})$$

$$R_p \approx 0$$



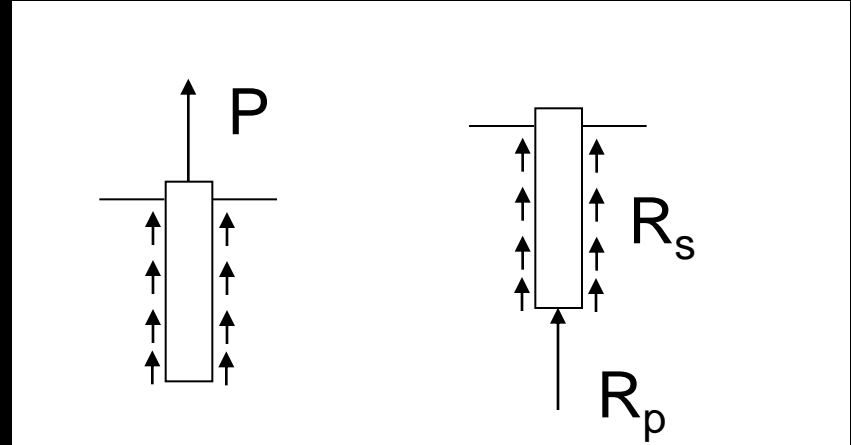
tapered:  
sand & silt

# Piles Classified By Function

– combination friction and end bearing

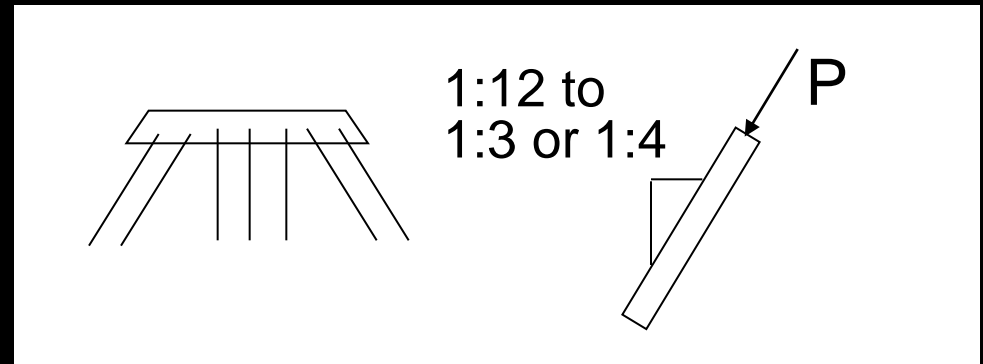
– *uplift/tension piles*

structures that float,  
towers



– *batter piles*

angled,  
cost more,  
resist large  
horizontal loads

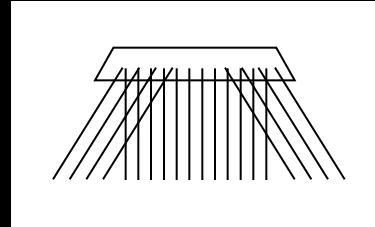


# *Piles Classified By Function*

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*– fender piles, dolphins, pile clusters*

large # of piles  
in a small area



*– compaction piles*

- *used to densify loose sands*

*– drilled piers*

- *eliminate need for pile caps*
- *designed for bearing capacity (not slender)*

# Pile Caps and Grade Beams

- like multiple column footing
- more shear areas to consider

