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

ARCH 614
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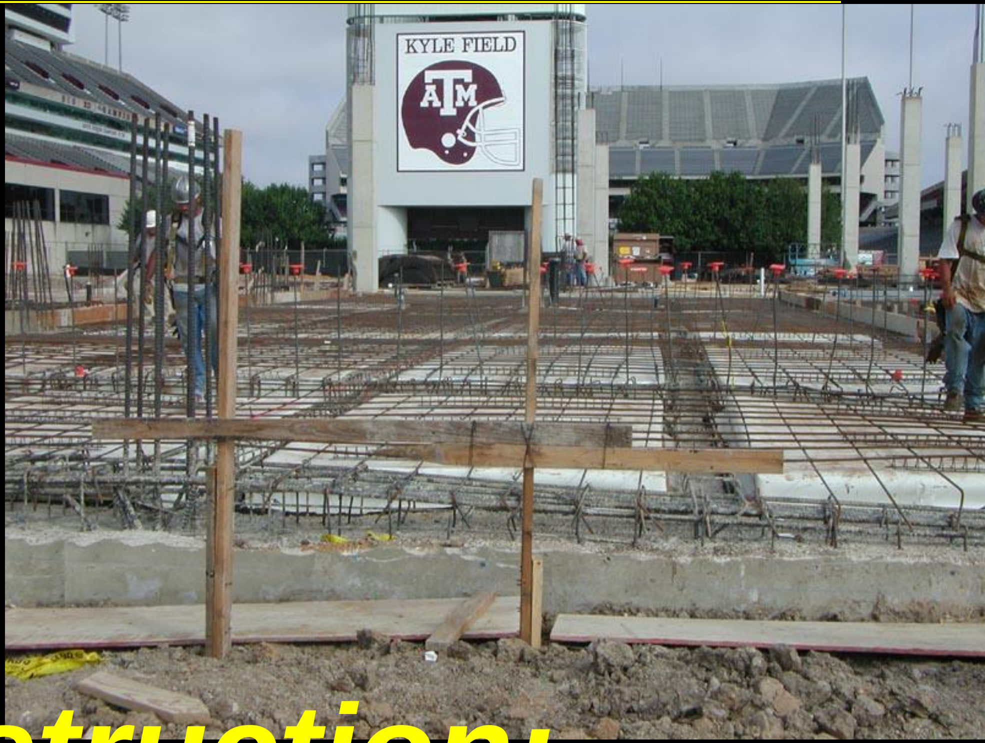
SPRING 2014

lecture
twenty six

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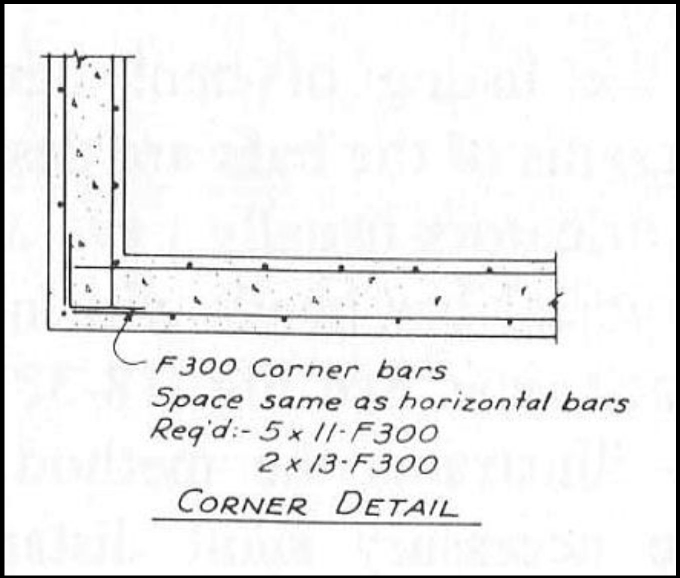
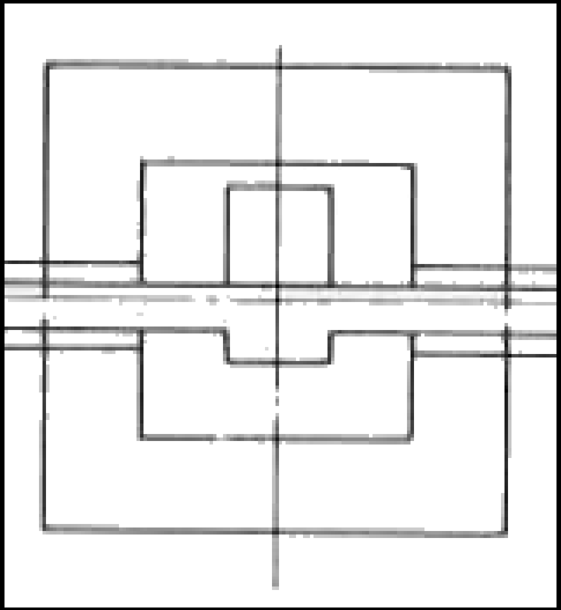
# concrete construction: foundation design

# *Foundation*

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



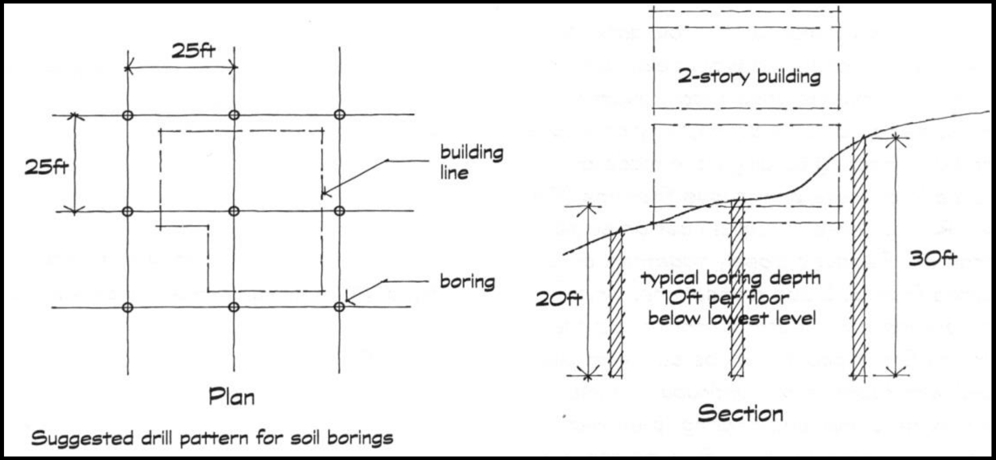



# *Structural vs. Foundation Design*

- *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

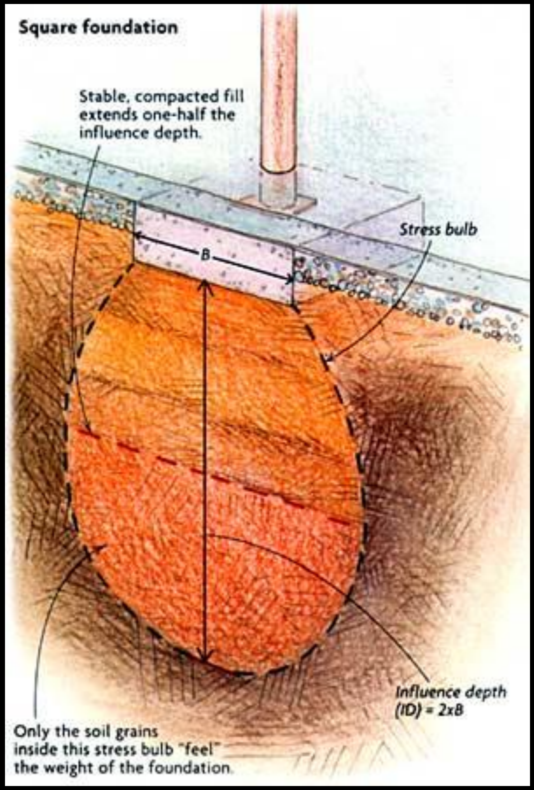


# *Soil Properties & Mechanics*

- *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, $q_a = \dfrac{q_u}{S.F.}$

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# Soil Properties & Mechanics

- strength, $q_a$

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

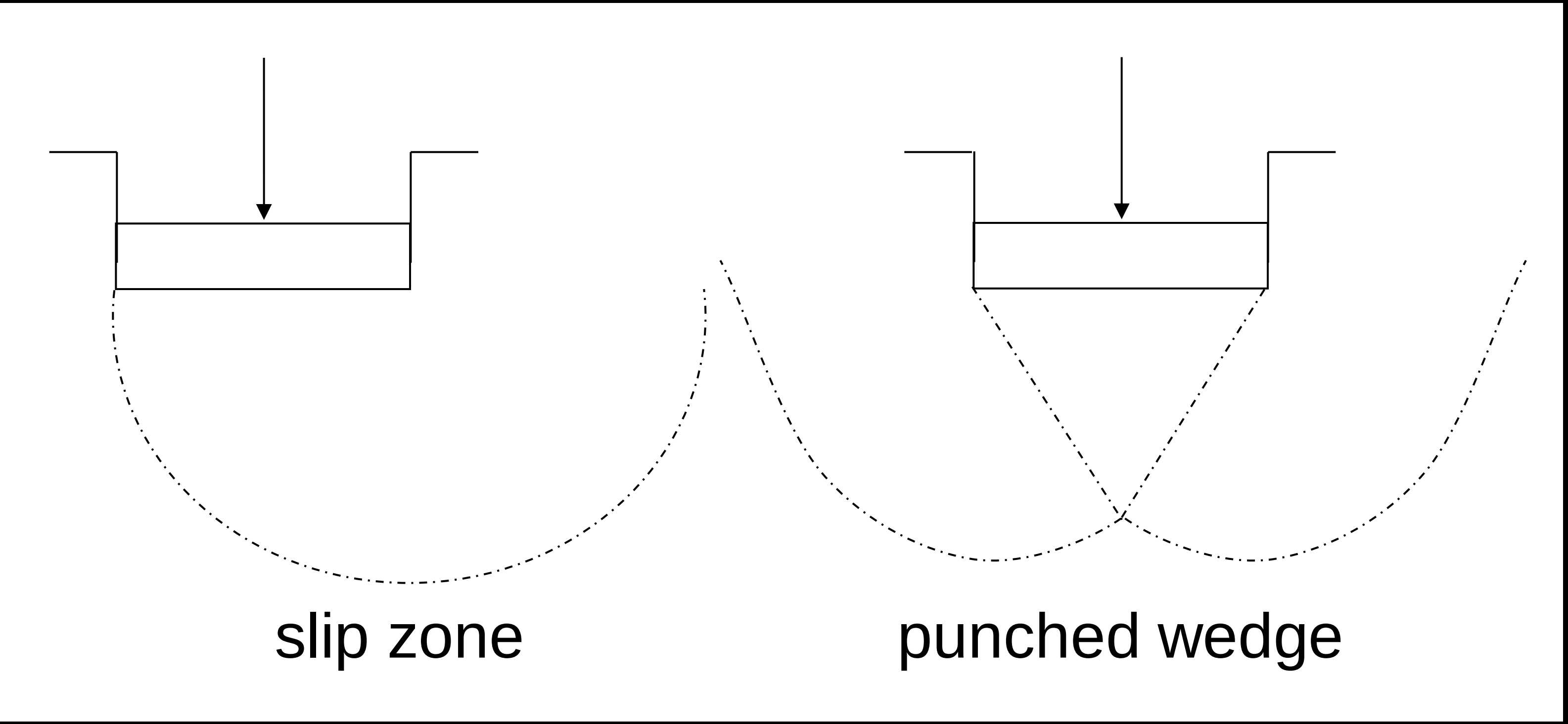
| Class of material | Loadbearing pressure (pounds per square foot)[a] |
|---|---|
| 1. Crystalline bedrock | 12,000 |
| 2. Sedimentary rock | 6,000 |
| 3. Sandy Gravel | 5,000 |
| 4. Sand, silty sand, clayey sand, silty gravel and clayey gravel | 3,000 |
| 5. Clay, sandy clay, silty clay & clayey silt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

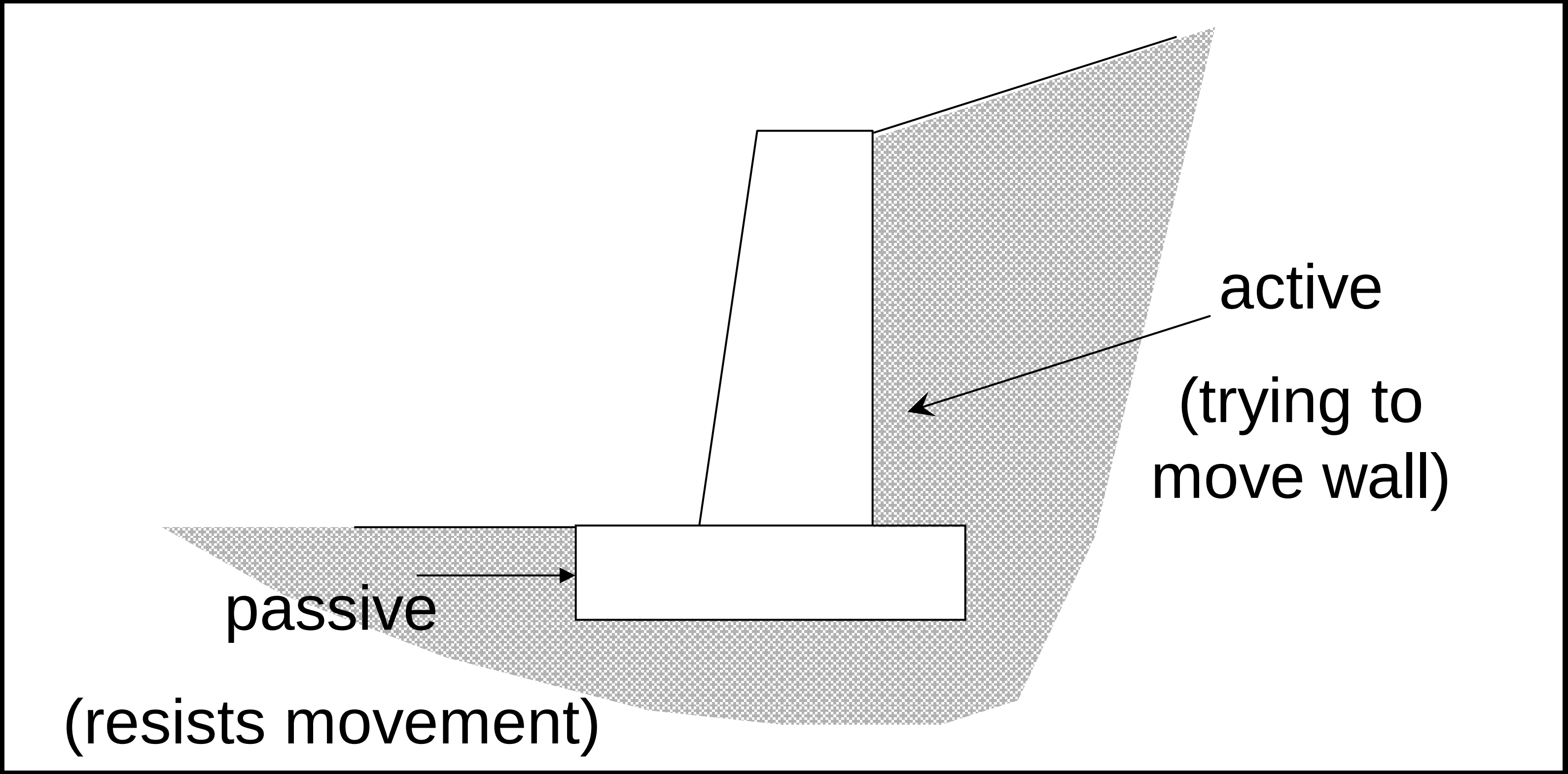
# Bearing Failure

- *shear*



# Lateral Earth Pressure

- *passive vs. active*



# *Foundation Materials*

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

# *Basic Foundation Requirements*

- *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

- 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

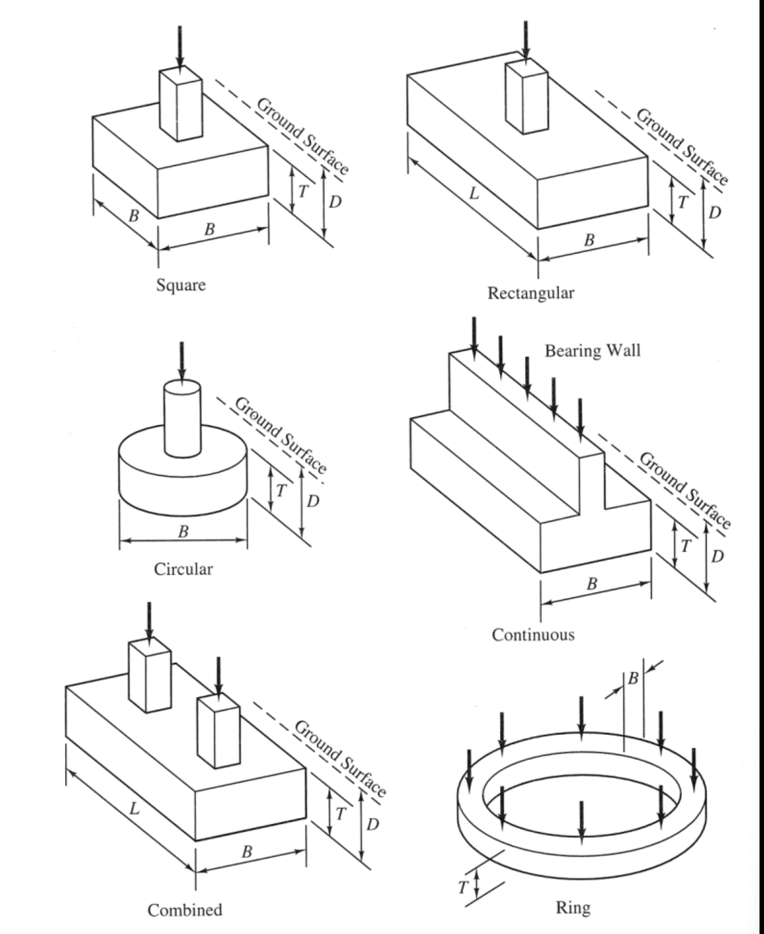
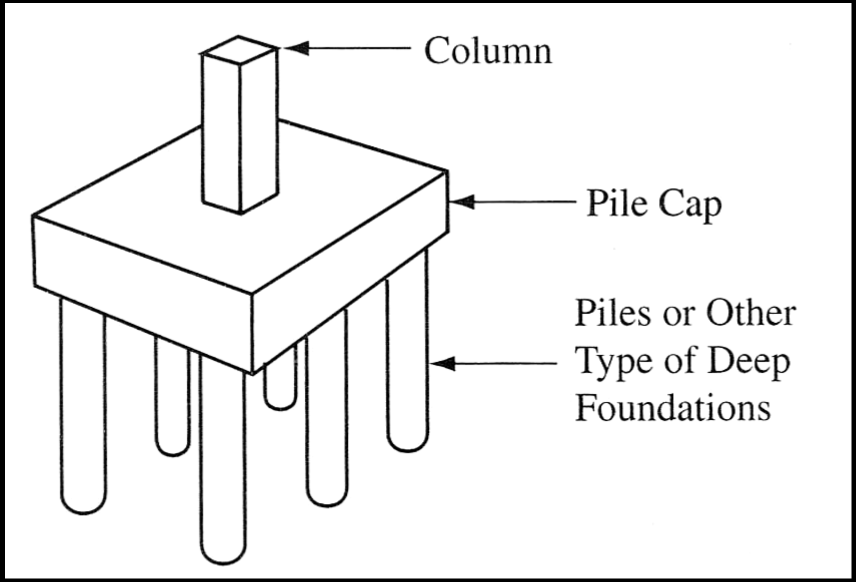



**Figure 5.1** Spread footing shapes and dimensions.

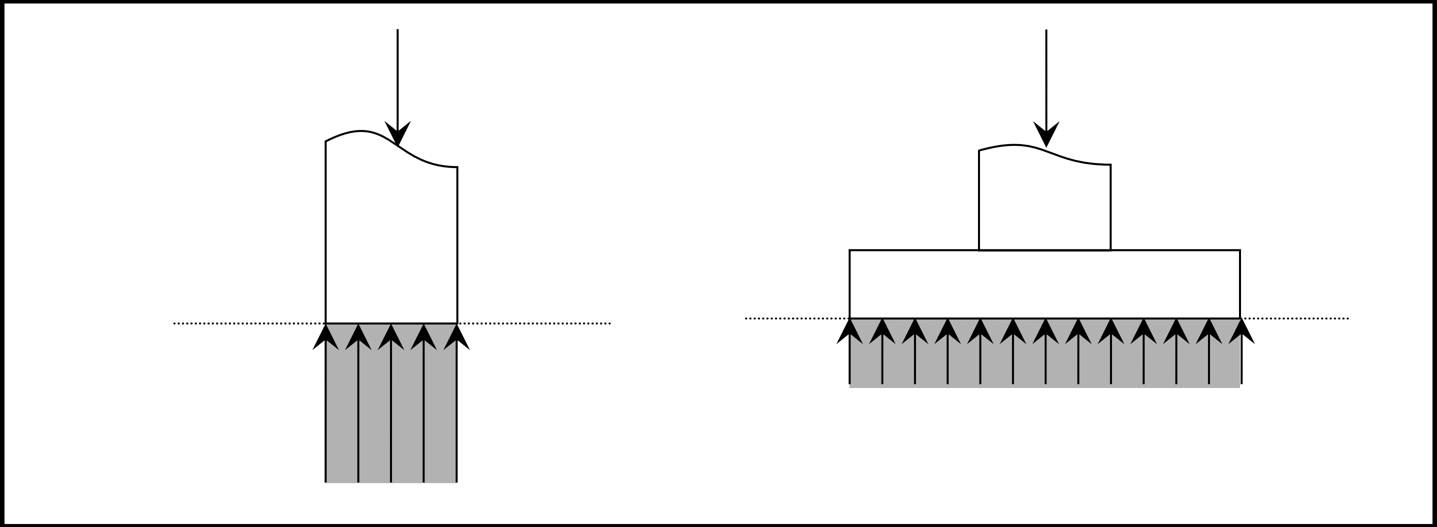
# Types of Foundations




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

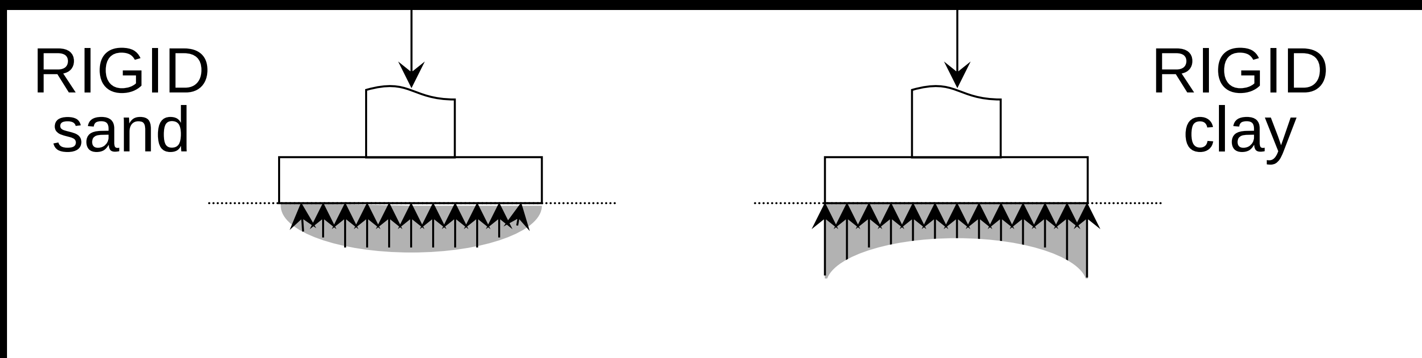
# Shallow Footings

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

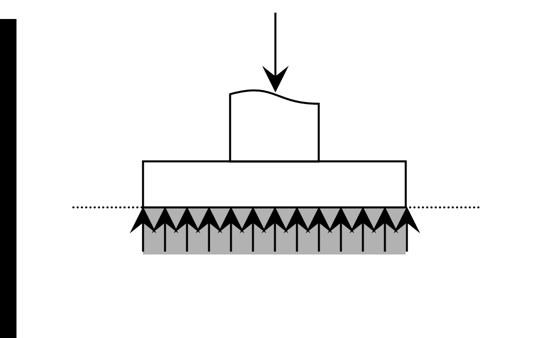


# Actual vs. Design Soil Pressure

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



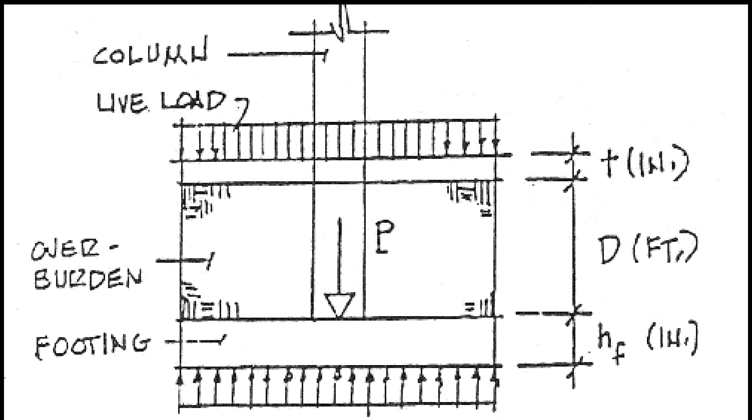

- *linear stress distribution assumed*



# 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

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

# Concrete Spread Footings

- *failure modes*

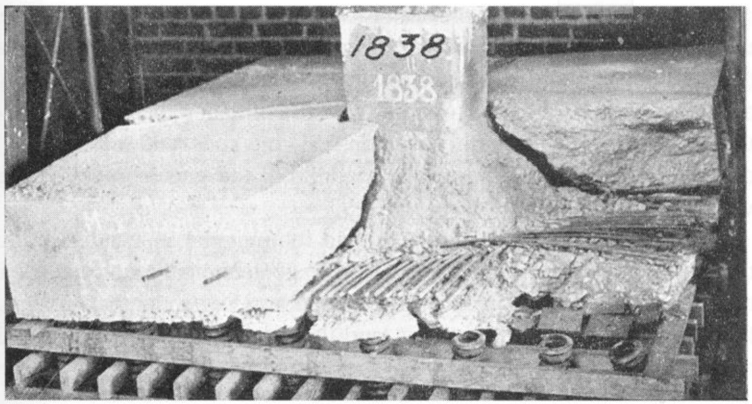



**Figure 9.2** "Shear" failure in a spread footing loaded in a laboratory (Talbot, 1913). Observe how this failure actually is a combination of tension and shear.

*shear*

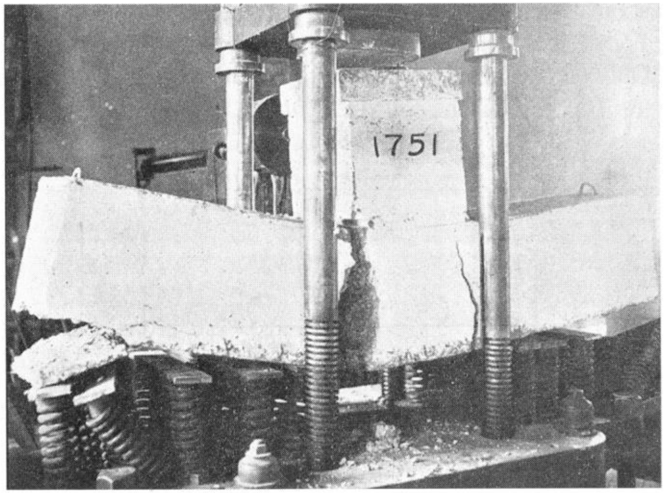
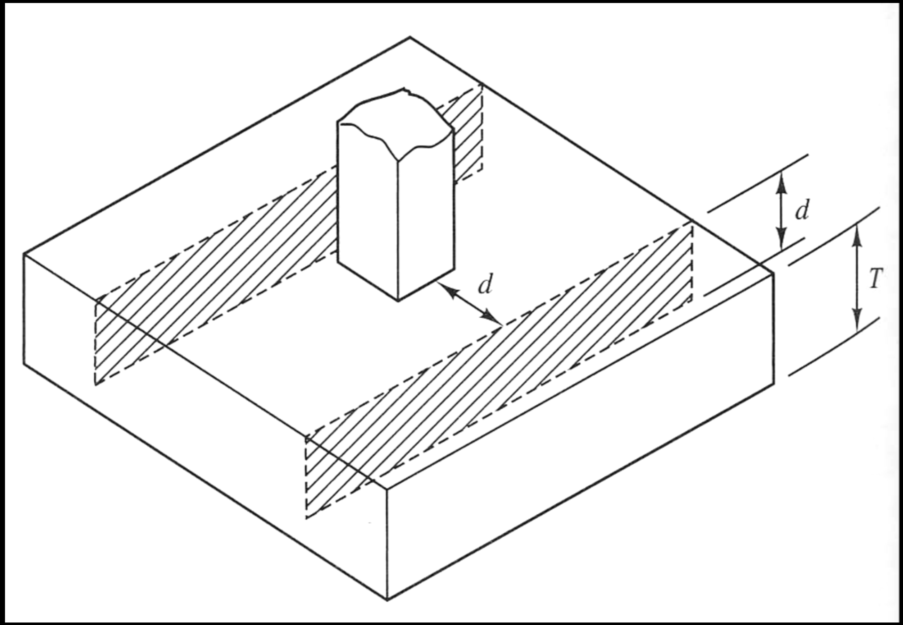


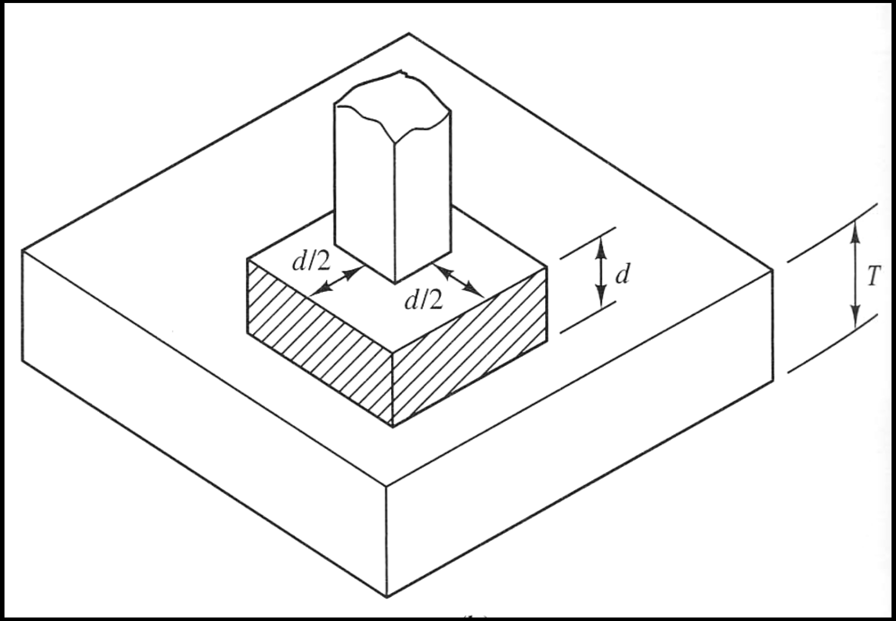

**Figure 9.3** Flexural failure in a spread footing loaded in a laboratory (Talbot, 1913).

*bending*

# Concrete Spread Footings

- *shear failure*




*one way shear*

*two way shear*

# Over and Under-reinforcement

- reinforcement ratio for bending
  - $\rho = \frac{A_s}{bd}$
  - use as a design estimate to find $A_s$,b,d
  - max $\rho$ from $\varepsilon_{steel} \geq 0.004$
  - 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

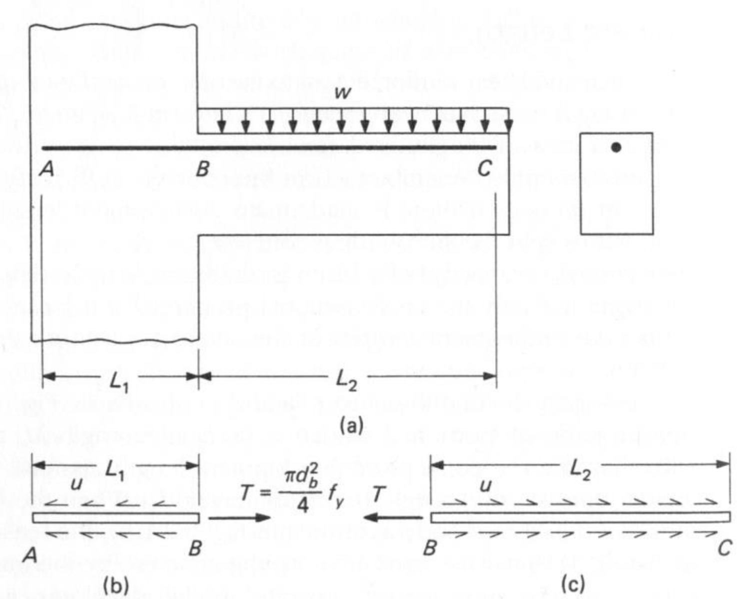



**Figure 6.2.1** Development of reinforcement.

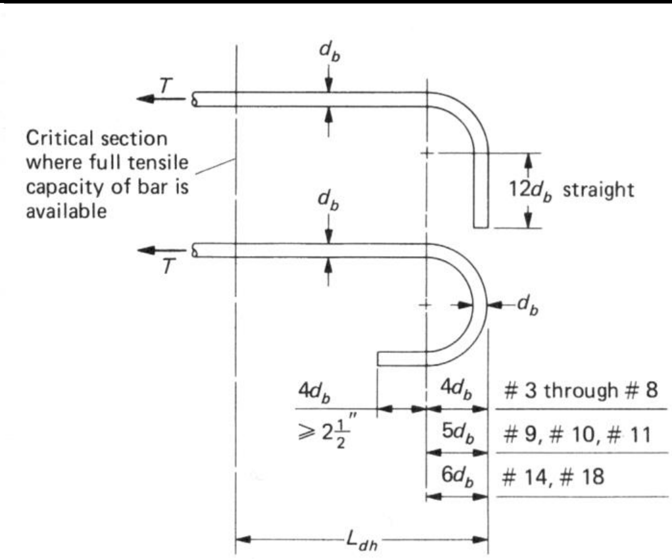
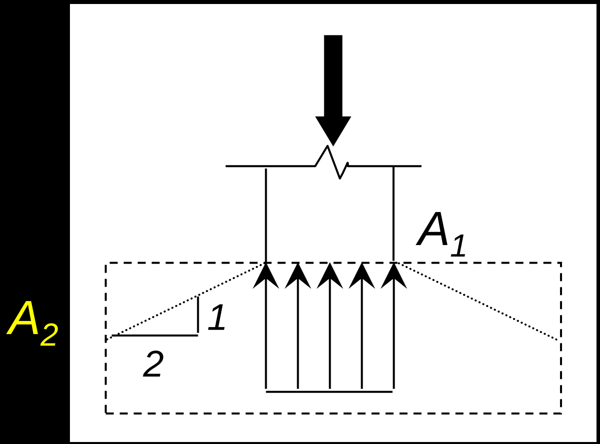


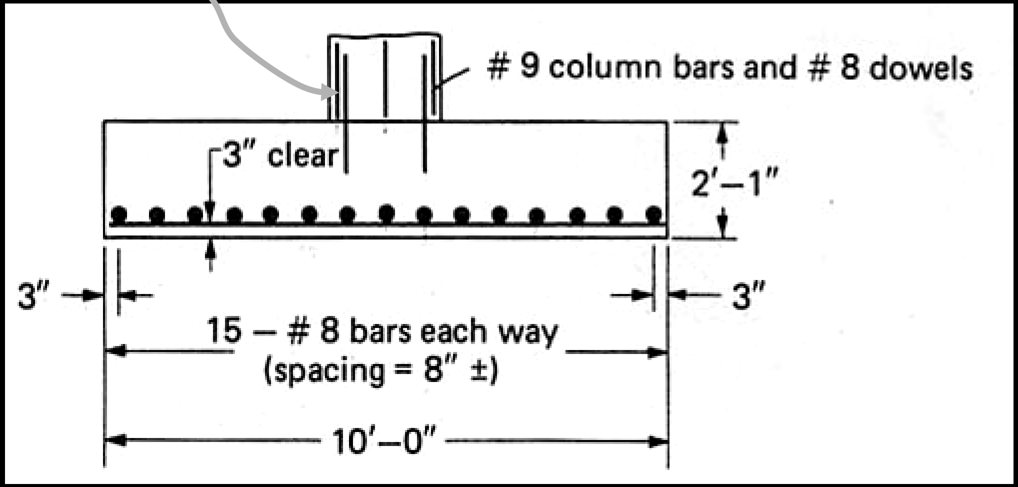

**Figure 6.11.2** Development length $L_{dh}$ for hooked bar.

# Column Connection

- *bearing of column on footing*
  - $P_u \le \phi P_n = \phi(0.85 f_c' A_1)$

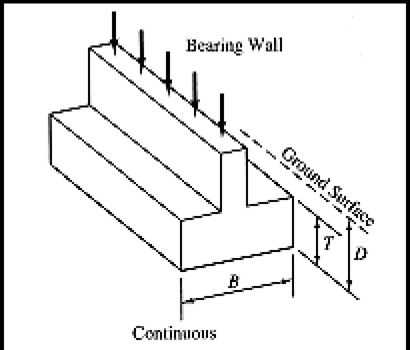
    $\phi = 0.65$ *for bearing*
  - *confined: increase x* $\sqrt{A_2/A_1} \le 2$
- *dowel reinforcement*
  - *if* $P_u > P_b$*, need compression reinforcement*
  - *min of 4 - #5 bars (or 15 metric)*

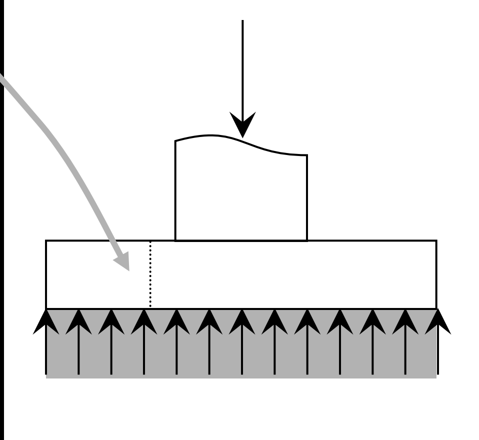


# Wall Footings

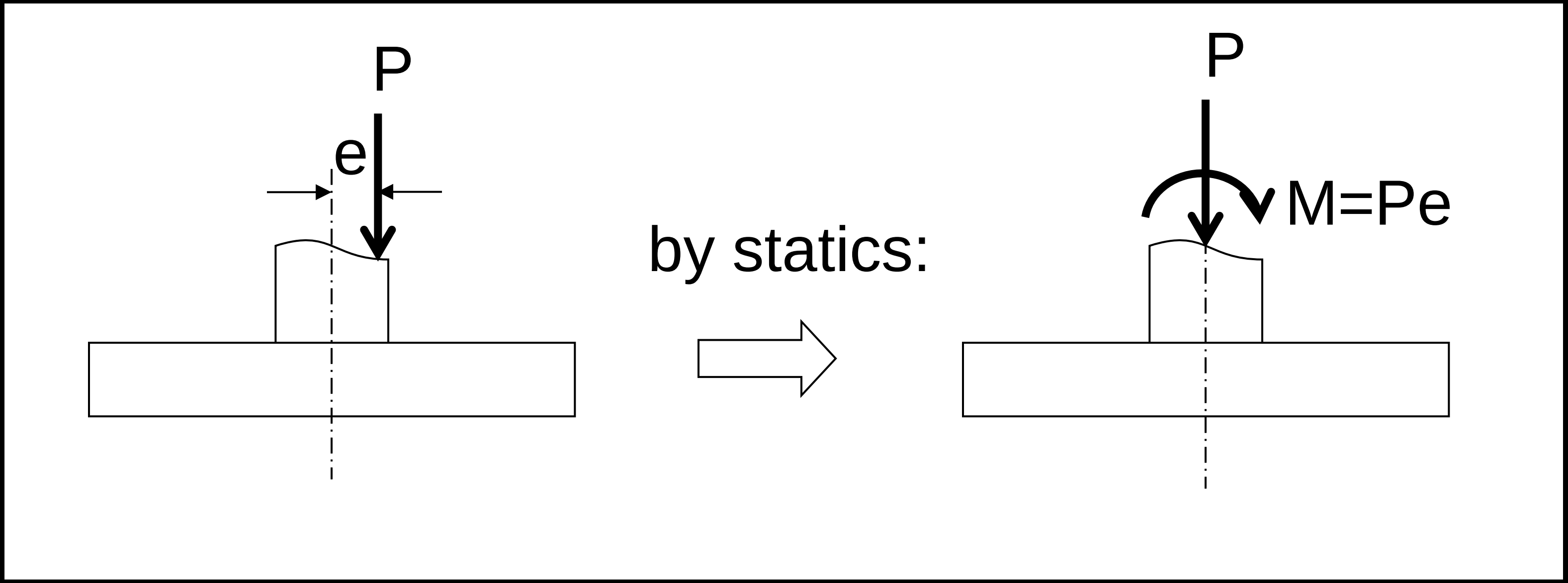
- *continuous strip for load bearing walls*
- *plain or reinforced*
- *behavior*
  - *wide beam shear*
  - *bending of projection*
- *dimensions usually dictated by codes for residential walls*
- *light loads*



# *Eccentrically Loaded Footings*

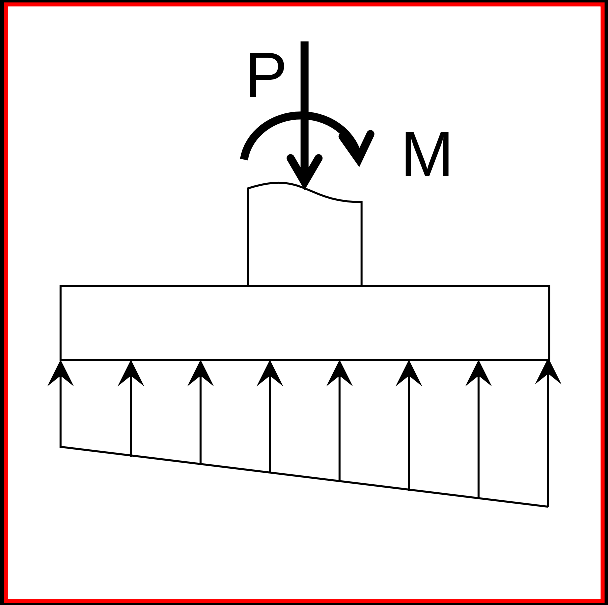
- *footings subject to moments*




  - *soil pressure resultant force <u>may not coincide</u> with the centroid of the footing*

# *Differential Soil Pressure*

- *to avoid large rotations, limit the differential soil pressure across footing*



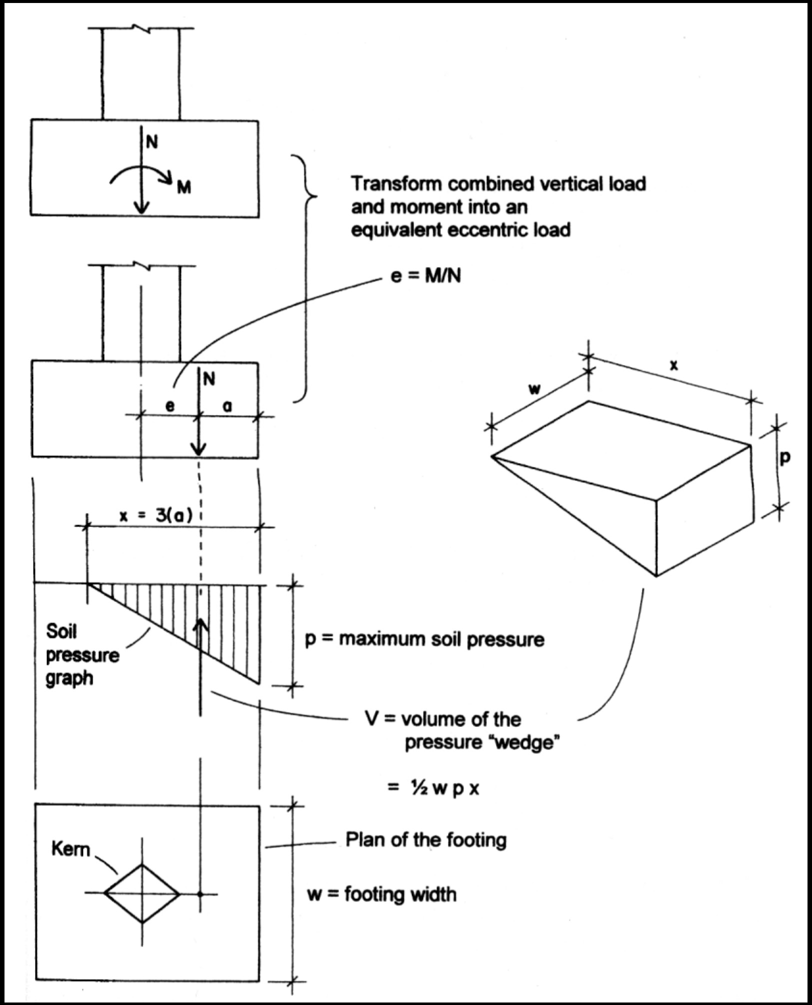

- *for rigid footing, simplification of soil pressure is a linear distribution based on constant ratio of pressure to settlement*

# Kern Limit

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

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

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

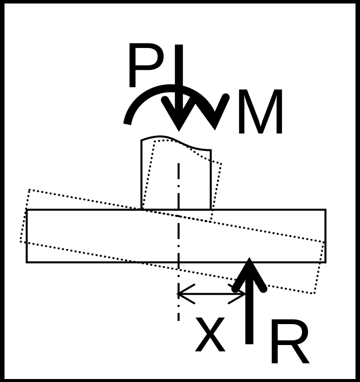


# *Guidelines*

– *want resultant of load from pressure inside the middle third of base (kern)*

- *ensures stability with respect to overturning*

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



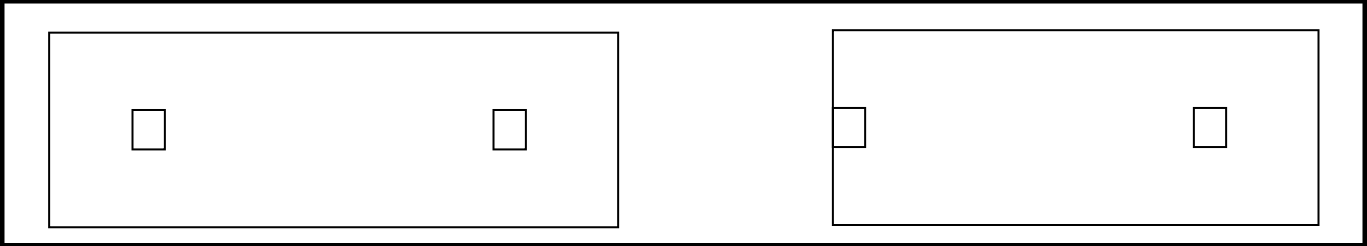

– *pressure under toe (maximum)* $\leq q_a$

– *shortcut using uniform soil pressure for design moments gives similar steel areas*

# Combined Footings

– supports two columns

– used when space is tight and spread footings would overlap or when at property line



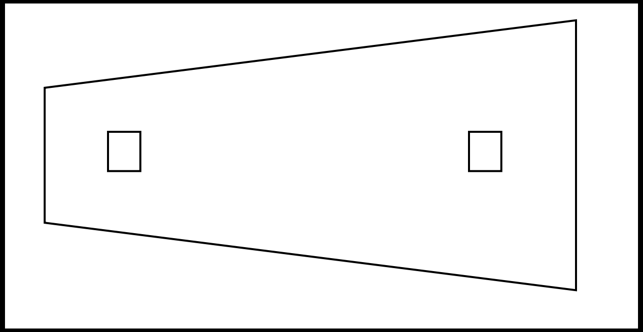
– soil pressure might not be uniform

– proportion so pressure will uniform for sustained loads

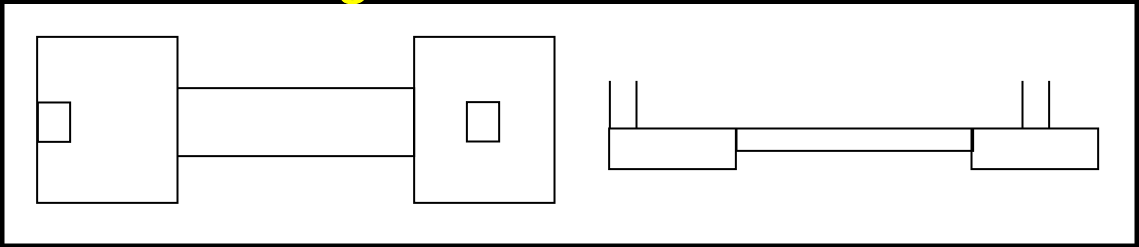
– behaves like beam lengthwise

# Combined Footing Types

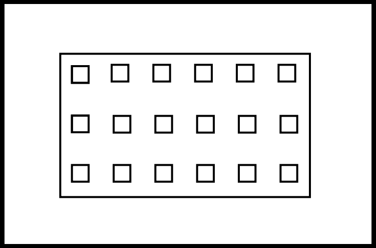
- *rectangular*
- *trapezoid*



- *strap or cantilever*
  - *prevents overturning of exterior column*



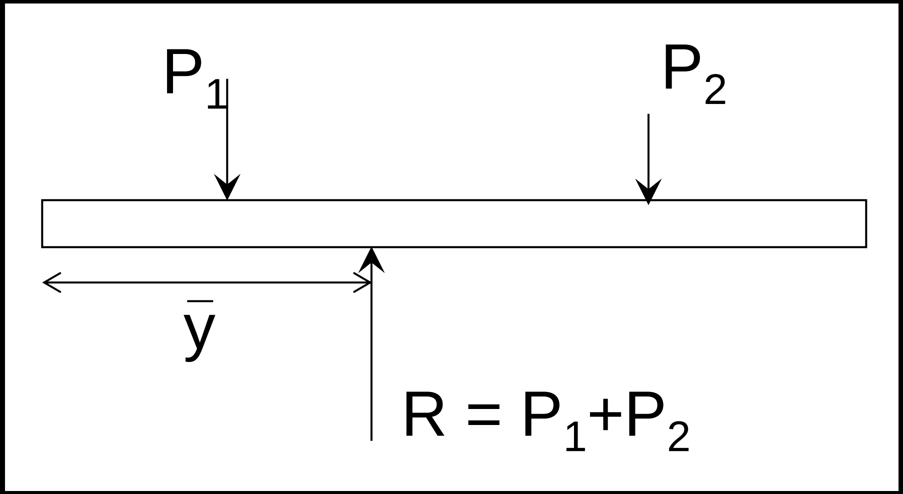
- *raft/mat*
  - *more than two columns over an extended area*



# *Proportioning*

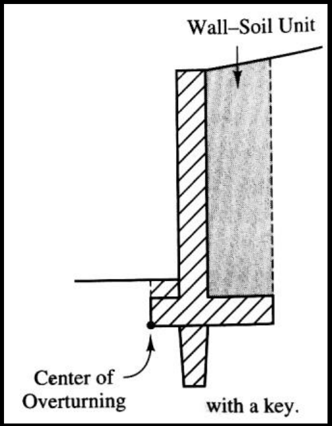
- *uniform settling is desired*
- *area is proportioned with sustained column loads*
- *want the resultant to coincide with centroid of footing area for uniformly distributed pressure assuming a rigid footing*

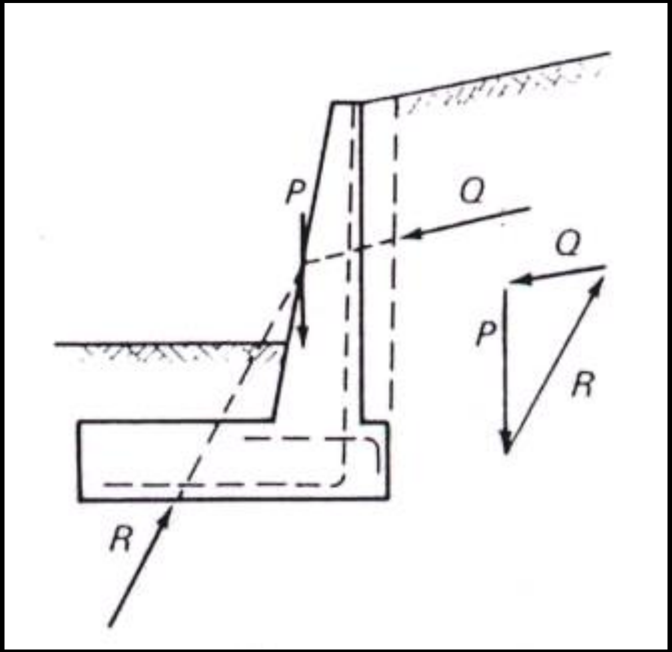
$$q_{max} \leq q_a$$



# 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)*

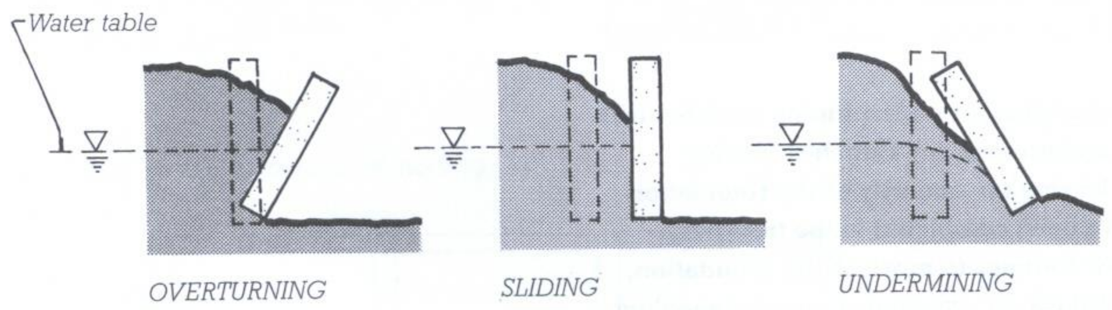
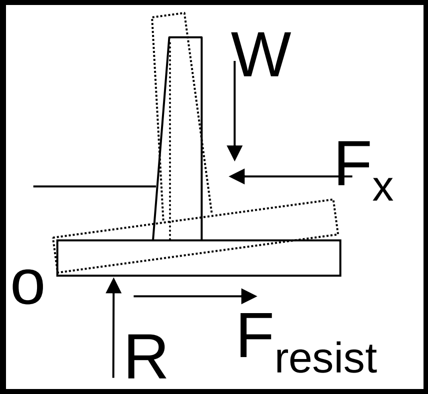



**FIGURE 2.50**
**Three failure mechanisms in retaining walls.**

# *Retaining Walls*

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

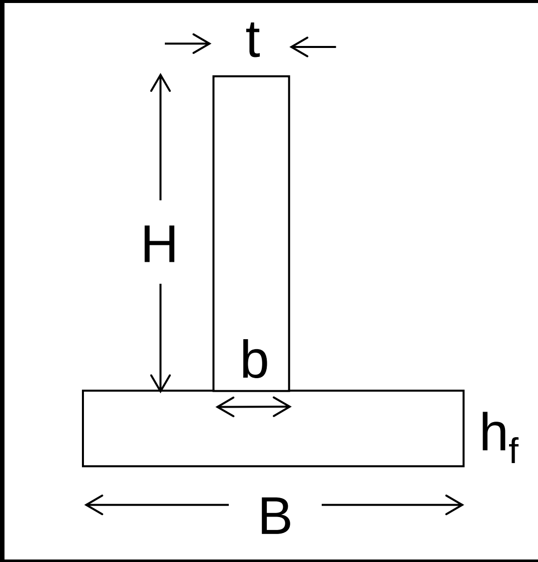



$$SF = \frac{M_{resist}}{M_{overturning}} \geq 1.5 - 2$$

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

# Retaining Wall Proportioning

- estimate size
  - footing size, B ≈ 2/5 - 2/3 wall height (H)
  - footing thickness ≈ 1/12 - 1/8 footing size (B)
  - base of stem ≈ 1/10 - 1/12 wall height ($H+h_f$)
  - top of stem ≥ 12"



# Retaining Walls Forces

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

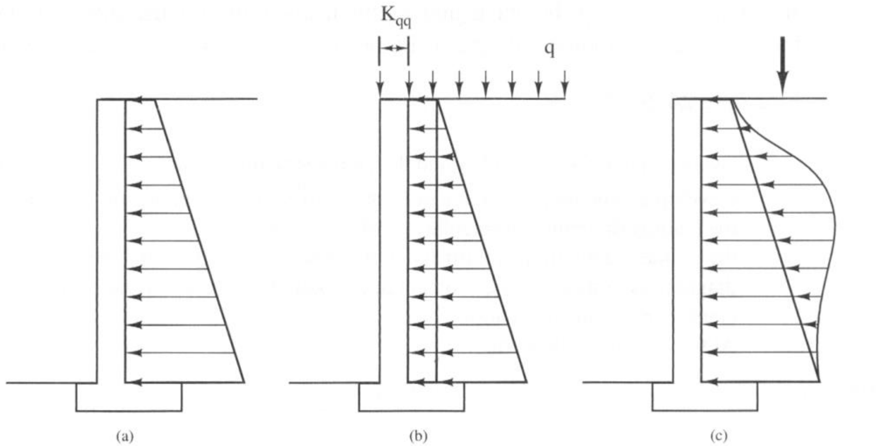
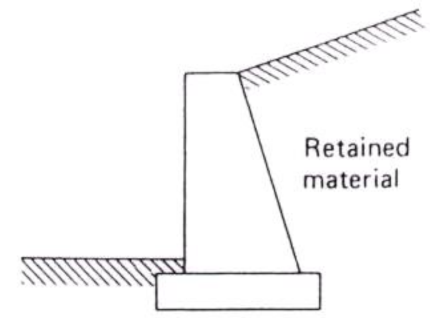



**Figure 24.12** Typical loading diagrams for stem design: (a) with no surcharge loads; (b) with uniform surcharge load; (c) with point surcharge load.

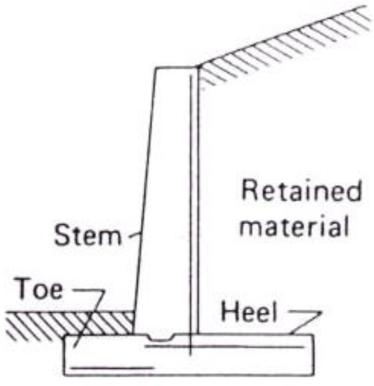
# Retaining Wall Types

- *"gravity" wall*
  - *usually unreinforced*
  - *economical & simple*




(a) Gravity wall

- *cantilever retaining wall*
  - *common*



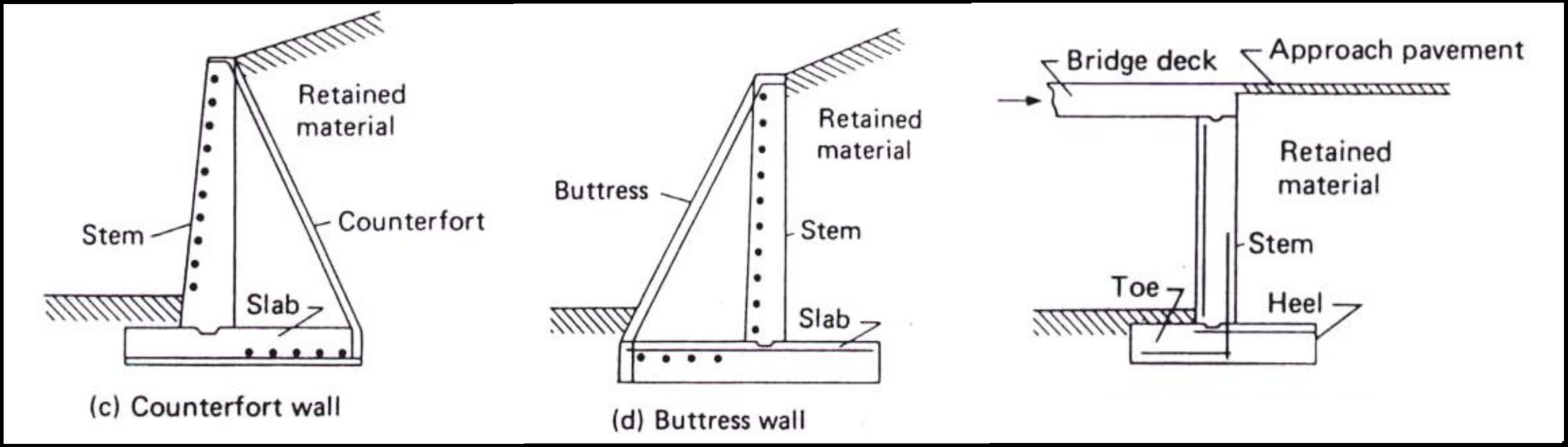

(b) Cantilever retaining wall

# Retaining Wall Types

- *counterfort wall*
- *buttress wall*

} very tall walls (> 20 - 25 ft)

- *bridge abutment*
- *basement frame wall (large basement areas)*



# *Deep Foundations*

- *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*

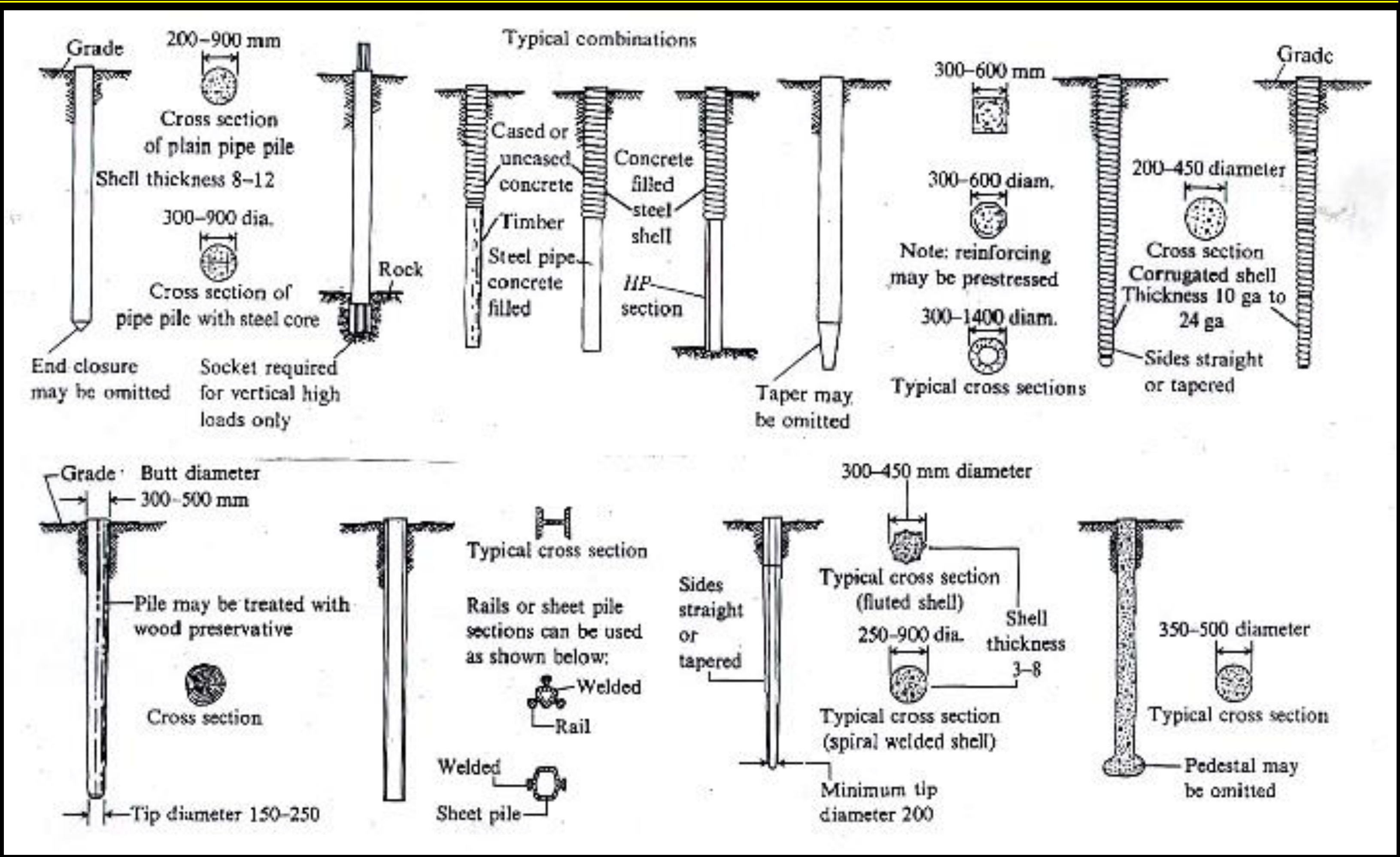
# *Deep Foundation Types*

- *piles - usually driven, 6”-8” $\phi$, 5’ +*
- *piers*
- *caissons*
- *drilled shafts*
- *bored piles*
- *pressure injected piles*

*drilled, excavated, concreted (with or without steel)* (piers, caissons, drilled shafts, bored piles)

*2.5’ - 10’/12’$\phi$*

# Deep Foundation Types

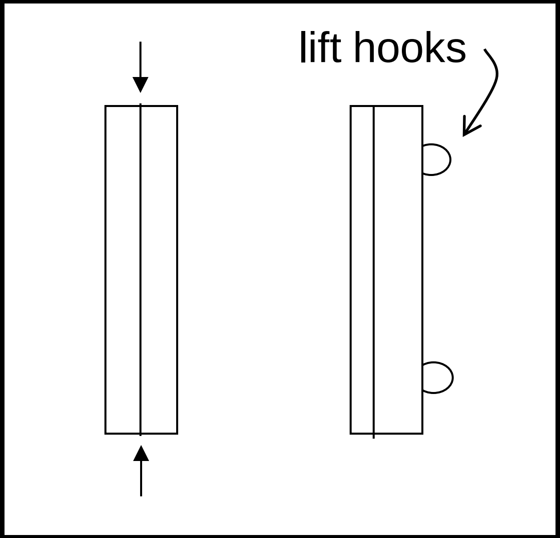


# *Deep Foundations*

- *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

- 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

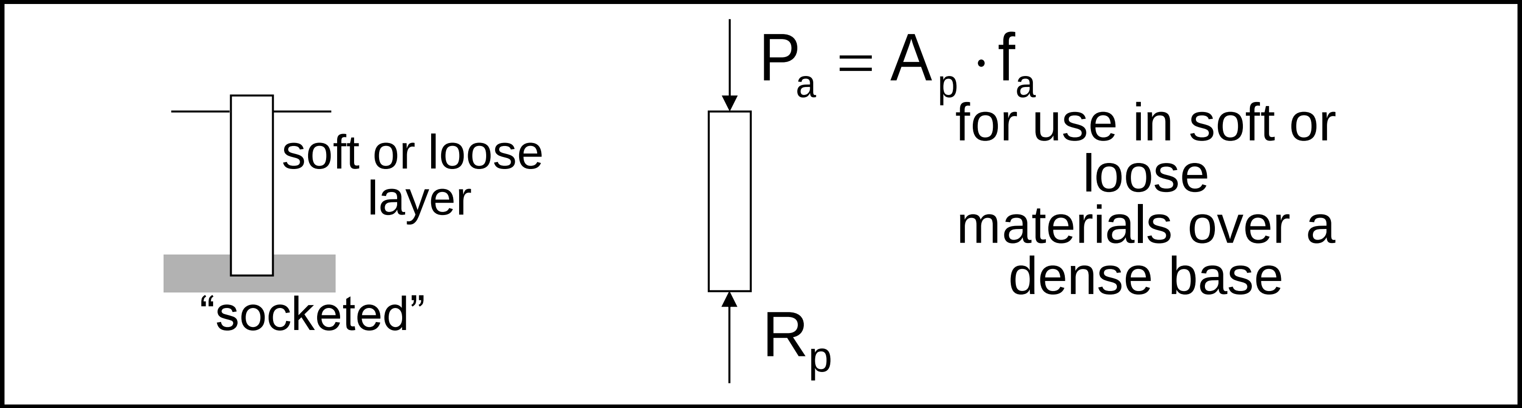


# *Piles Classified By Material*

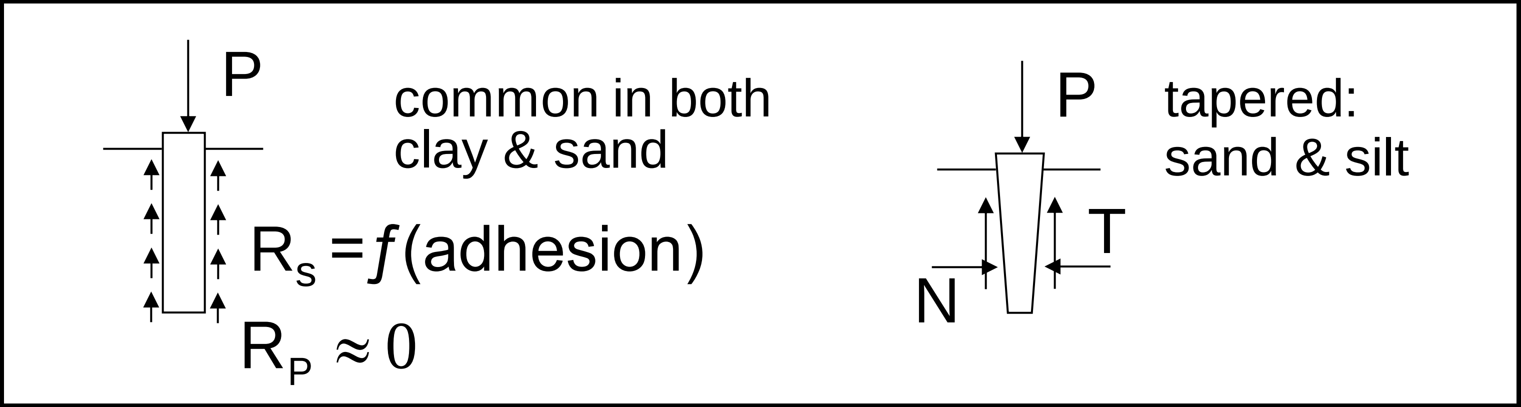
- *steel*
  - *rolled HP shapes or pipes*
  - *pipes may be filled with concrete*
  - *HP displaces little soil and may either break small boulders or displace them to the side*

# *Piles Classified By Function*

- *end bearing pile (point bearing)*

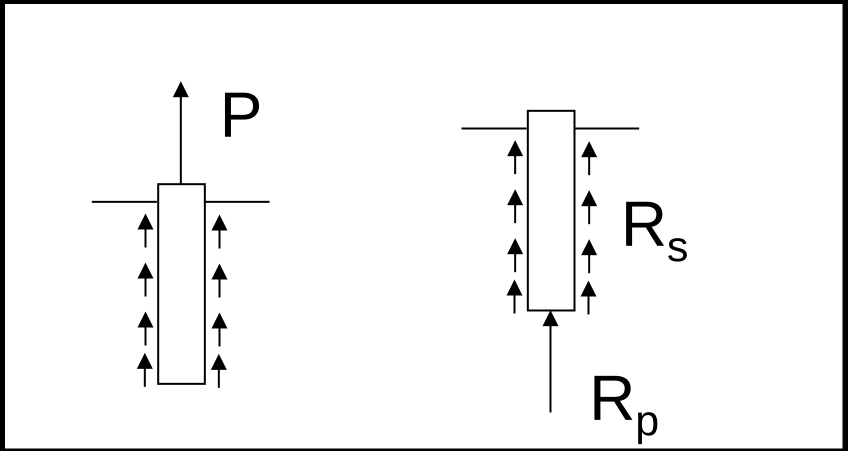



- *friction piles (floating)*



# *Piles Classified By Function*

- *combination friction and end bearing*

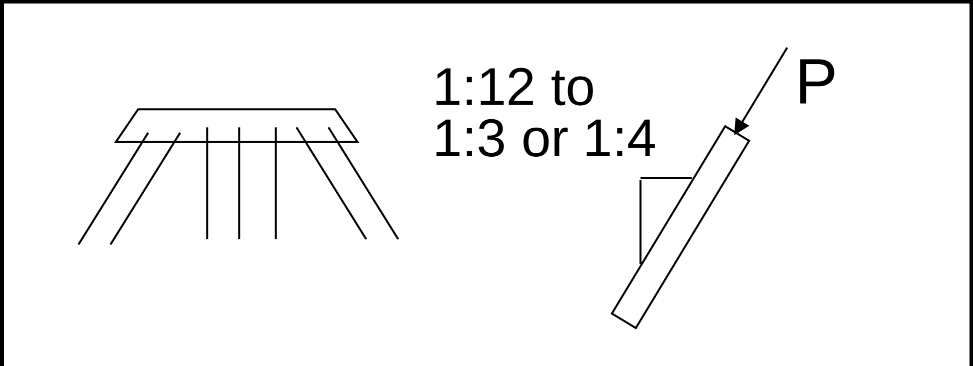



- *uplift/tension piles*

  structures that float,
  towers

- *batter piles*

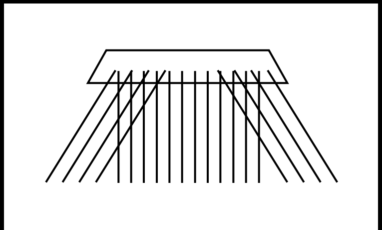
  angled,
  cost more,
  resist large
  horizontal loads



# *Piles Classified By Function*

– *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