

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

ARCH 331

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FALL 2013

lecture
twenty seven

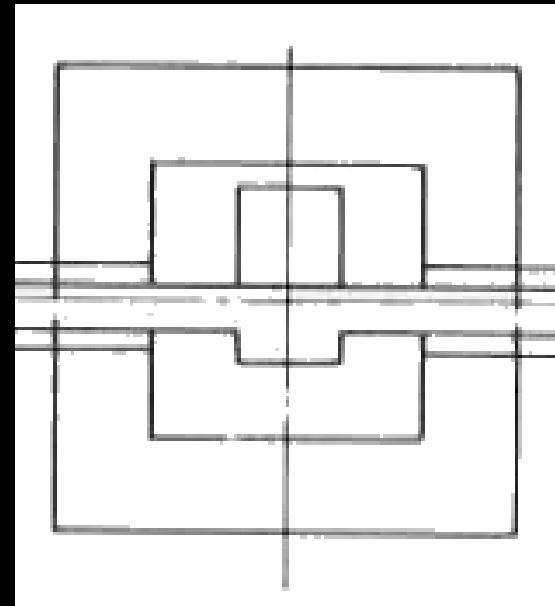
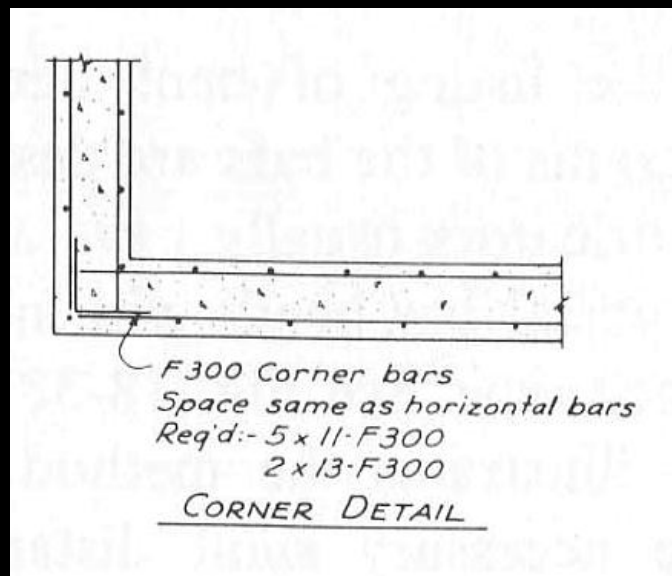
**concrete construction:
foundation design**



Bright Football Complex
www.tamu.edu

Foundation

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



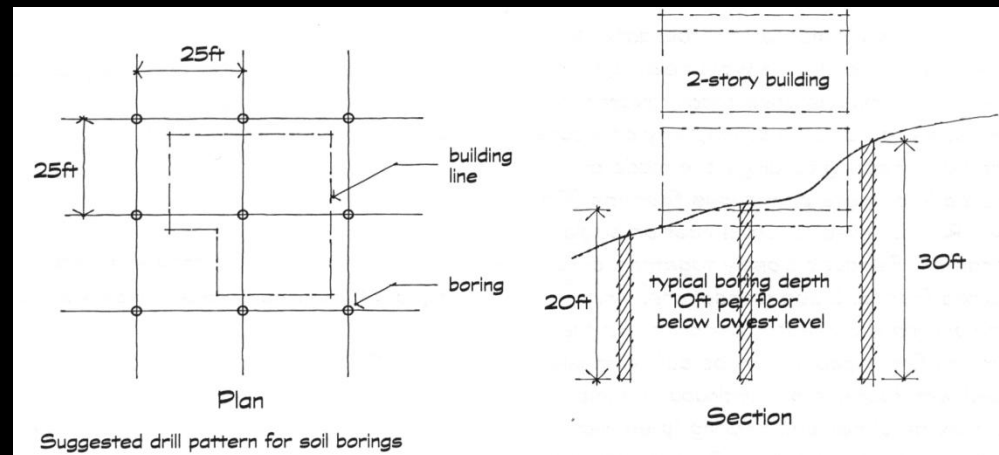
Structural vs. Foundation Design

- *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*



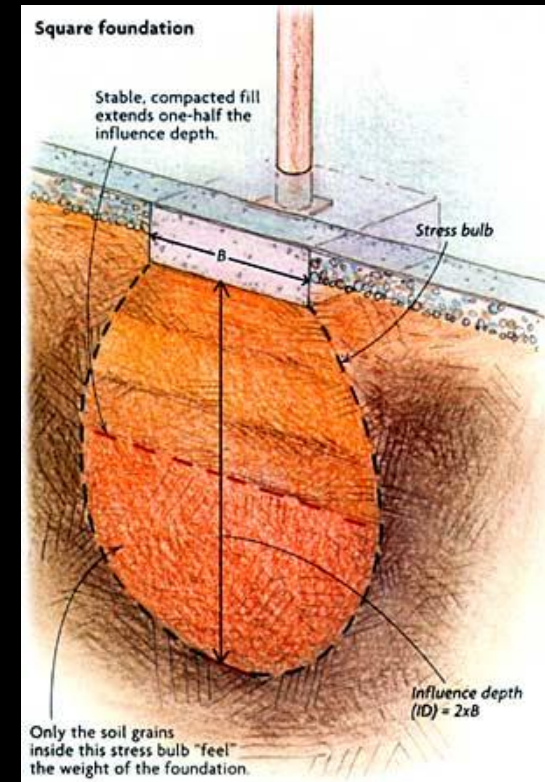
Soil Properties & Mechanics

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



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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

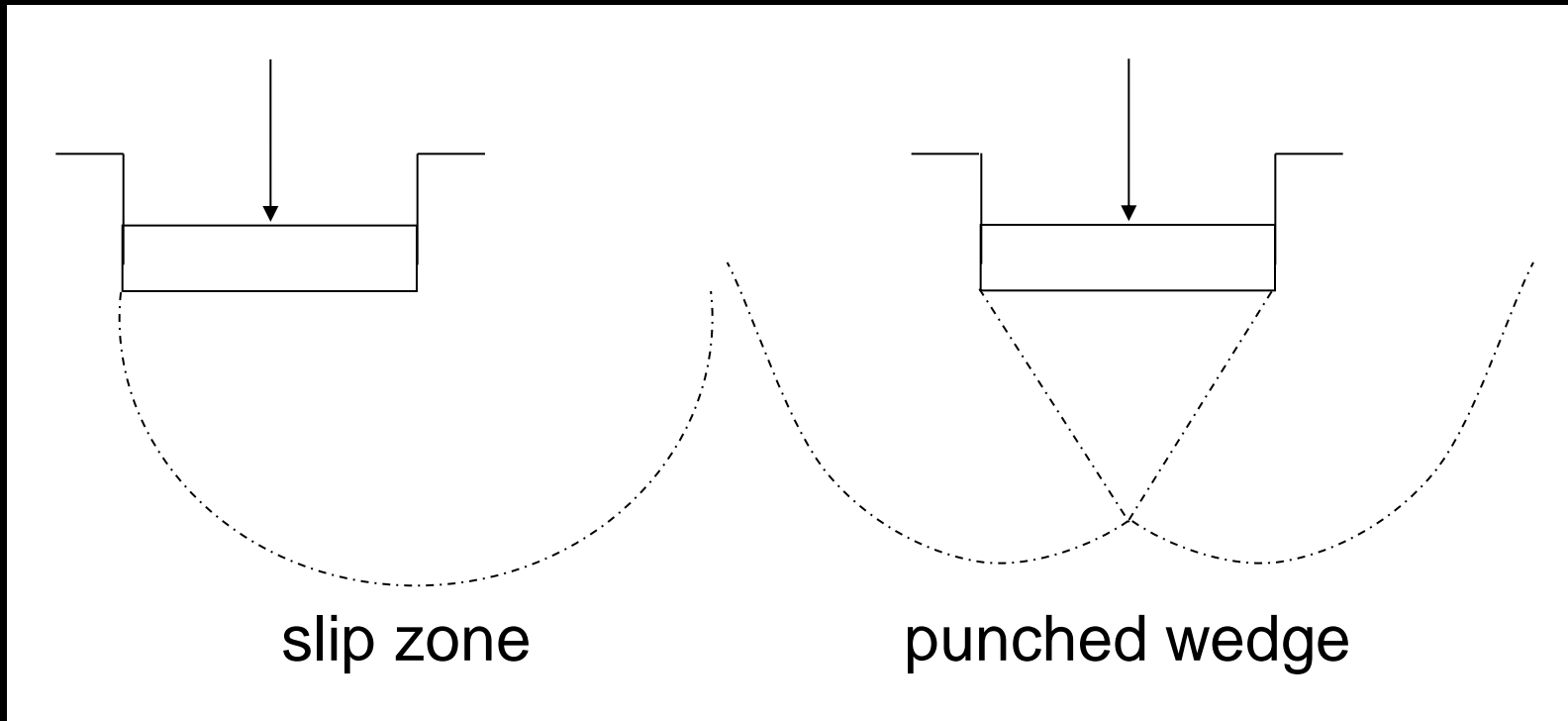
Note a. 1 psf = 47.9 Pa.

FIGURE 2.5

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

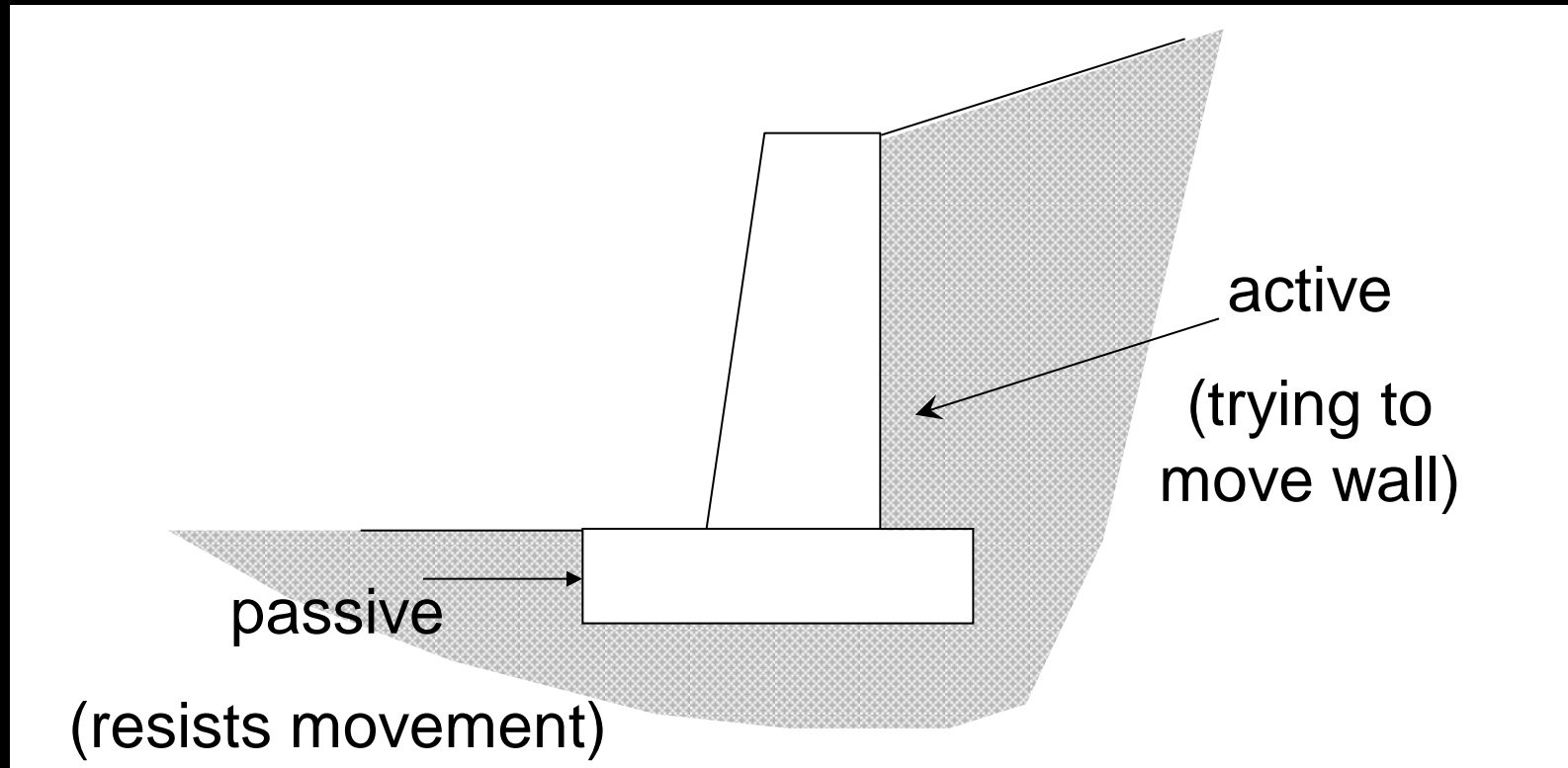
Bearing Failure

- *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

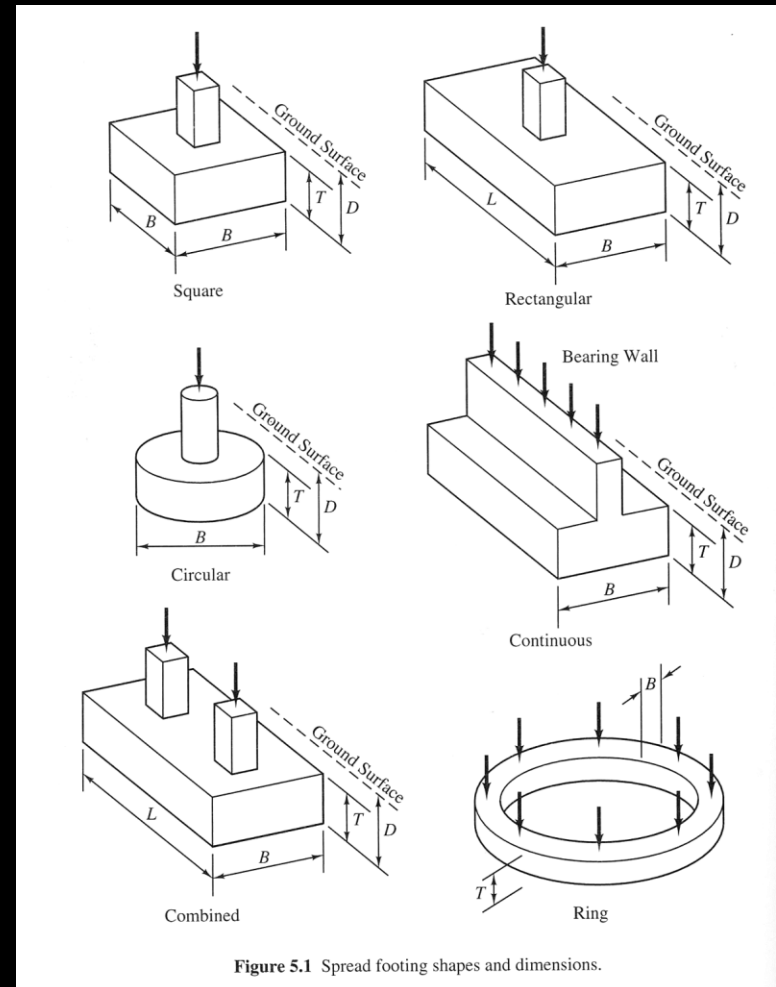
- *safe against instability or collapse*
- *no excessive/damaging settlements*
- *consider environment*
 - *frost action*
 - *shrinkage/swelling*
 - *adjacent structure, property lines*
 - *ground water*
 - *underground defects*
 - *earthquake*
- *economics*

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)*

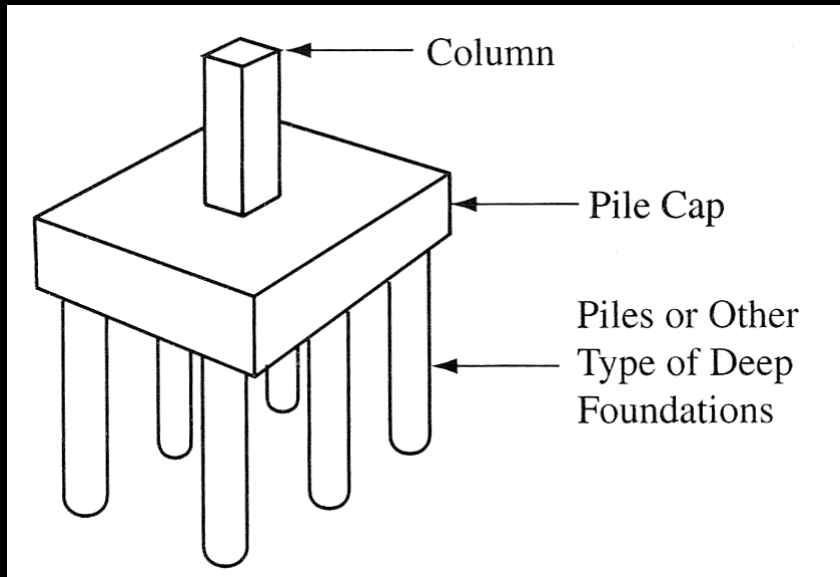
Types of Foundations

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



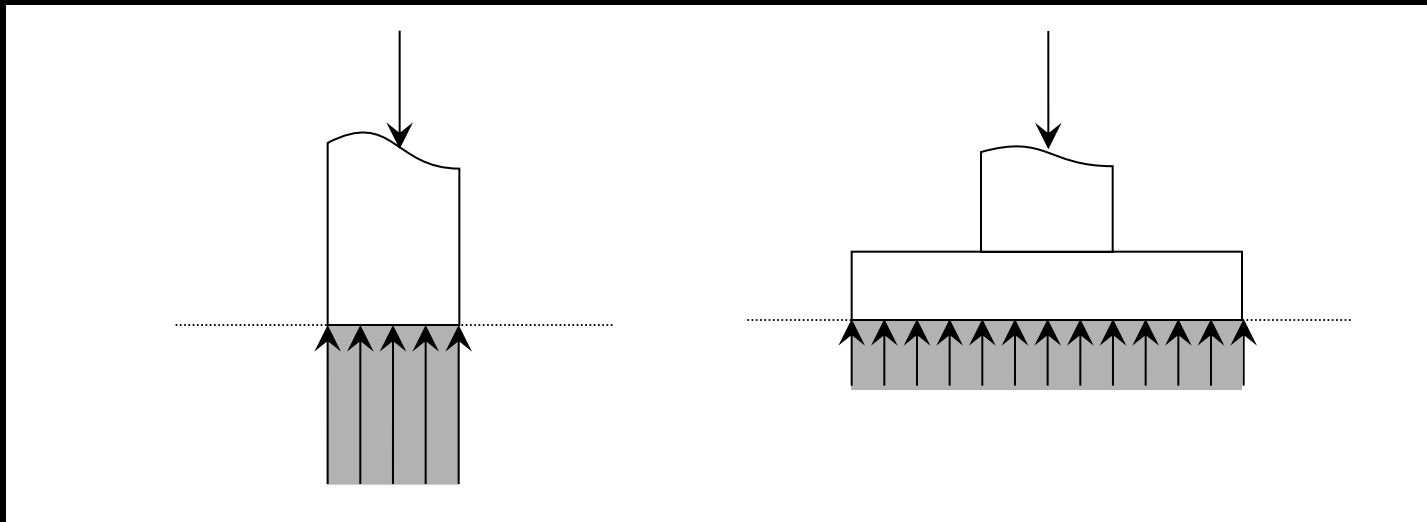
Types of Foundations

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



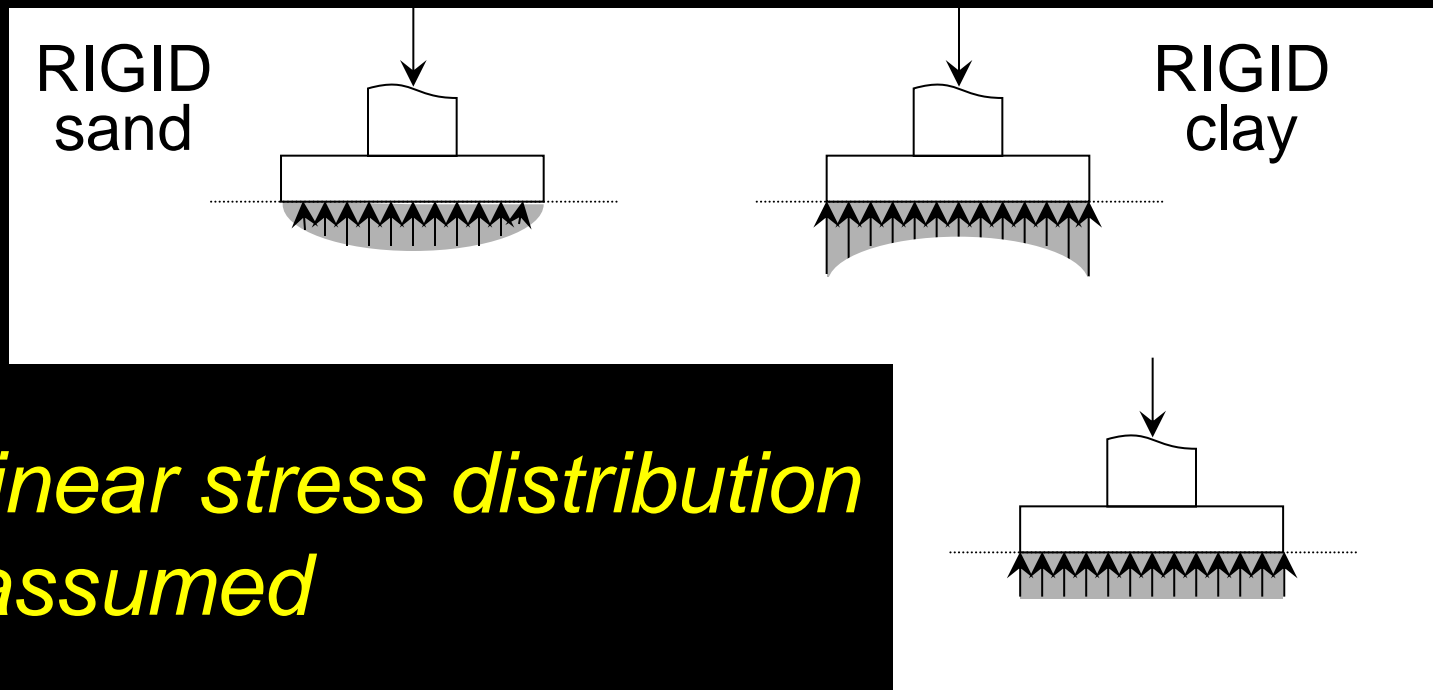
Shallow Footings

- *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*



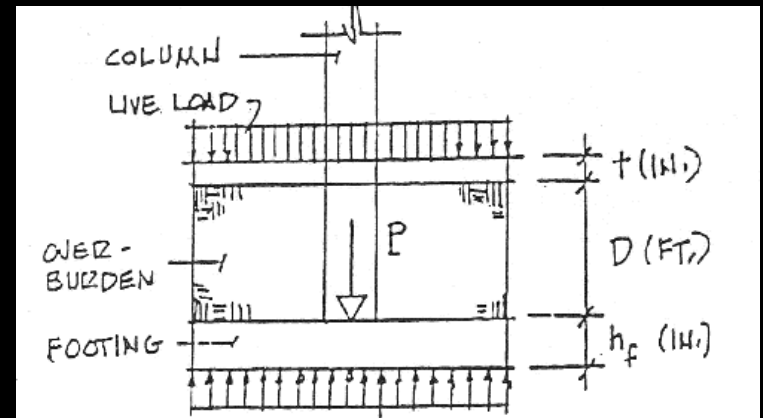
- *linear stress distribution assumed*

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*
 - *$V_u \leq \phi V_c : \phi = 0.75$ for shear*
 - *plain concrete has shear strength*
 - *$M_u \leq \phi M_n : \phi = 0.9$ for flexure*

Concrete Spread Footings

- *failure modes*

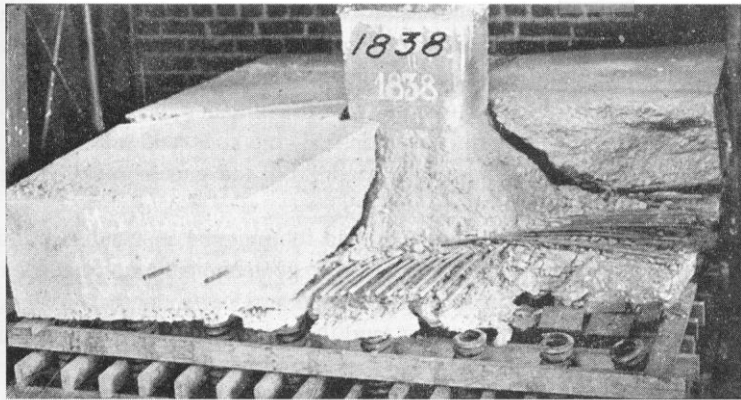


Figure 9.2 "Shear" failure in a spread footing loaded in a laboratory (Talbot, 1913). Observe how this failure actually is a combination of tension and shear.

shear

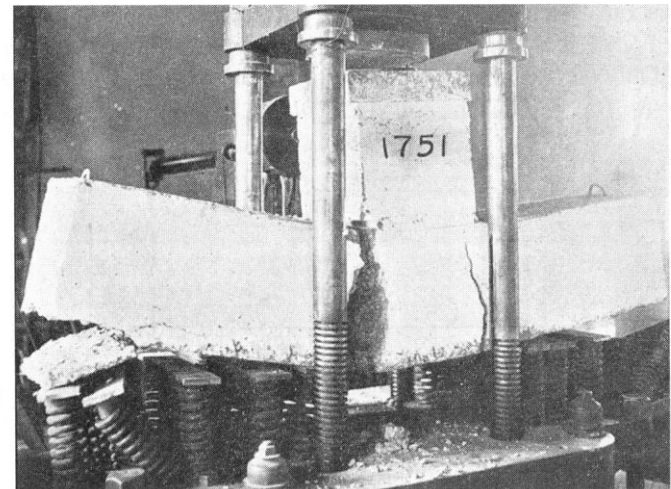
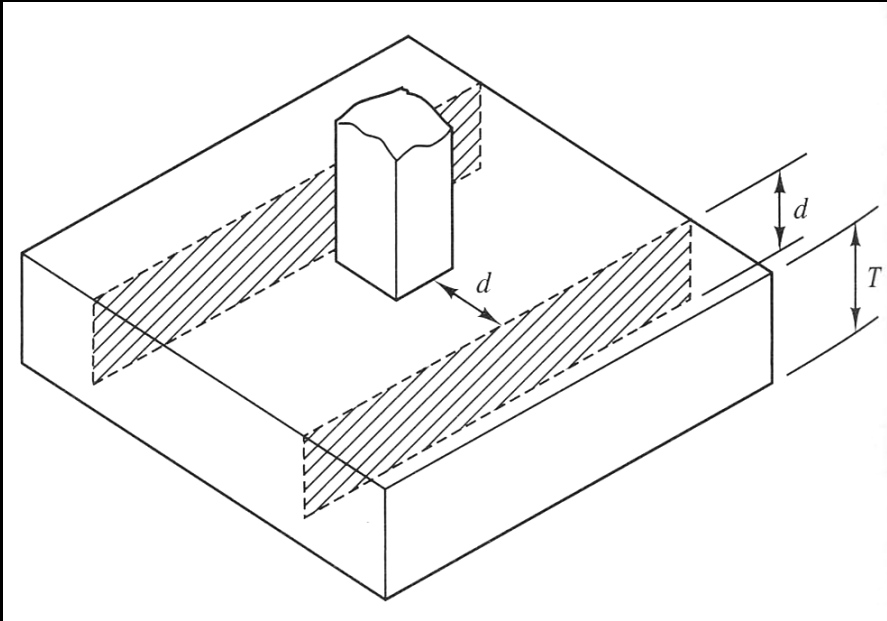


Figure 9.3 Flexural failure in a spread footing loaded in a laboratory (Talbot, 1913).

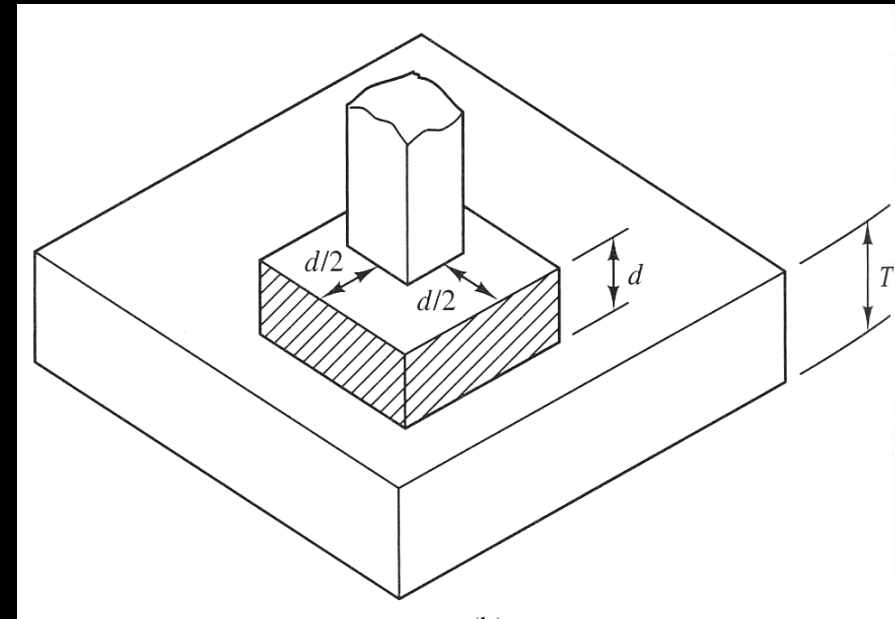
bending

Concrete Spread Footings

- *shear failure*



one way shear



two way shear

Over and Under-reinforcement

- *reinforcement ratio for bending*

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

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

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

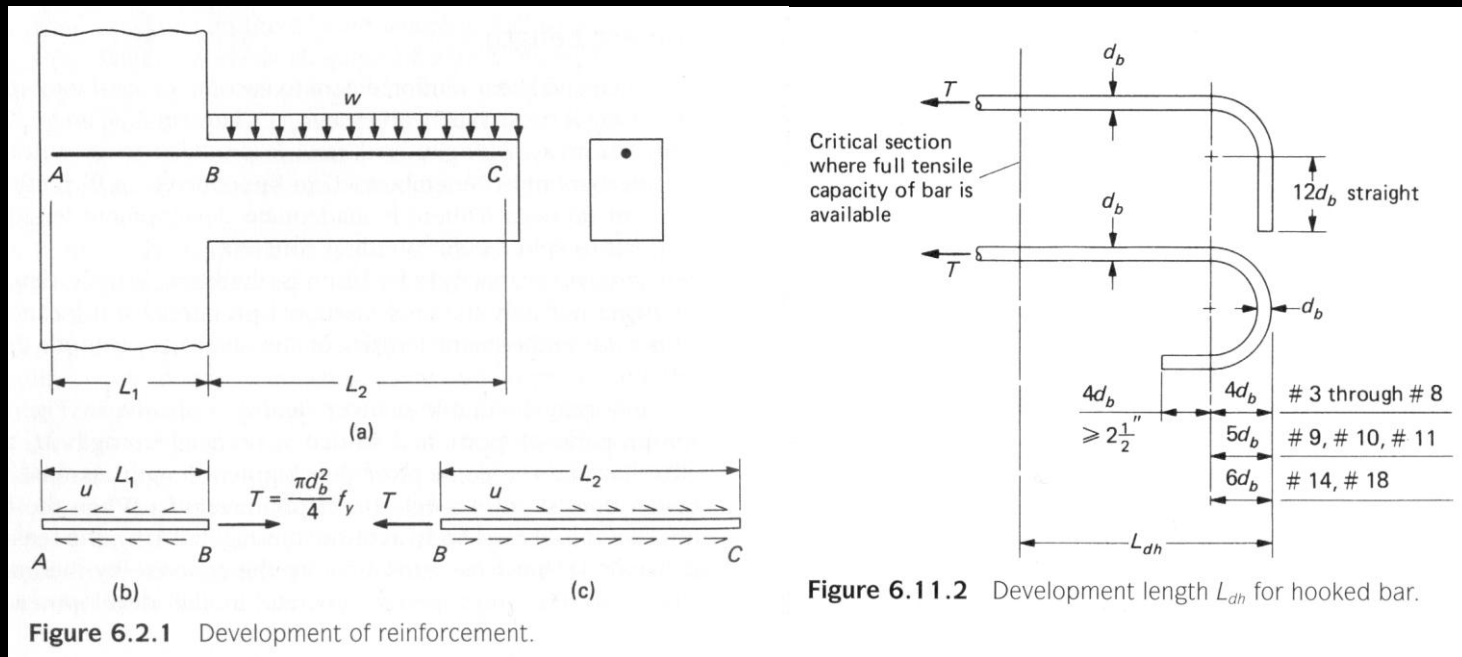
- *minimum for slabs & footings of uniform*

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

- $= 0.0018$ *grade 60 bars*

Reinforcement Length

- need length, ℓ_d
 - bond
 - development of yield strength



Column Connection

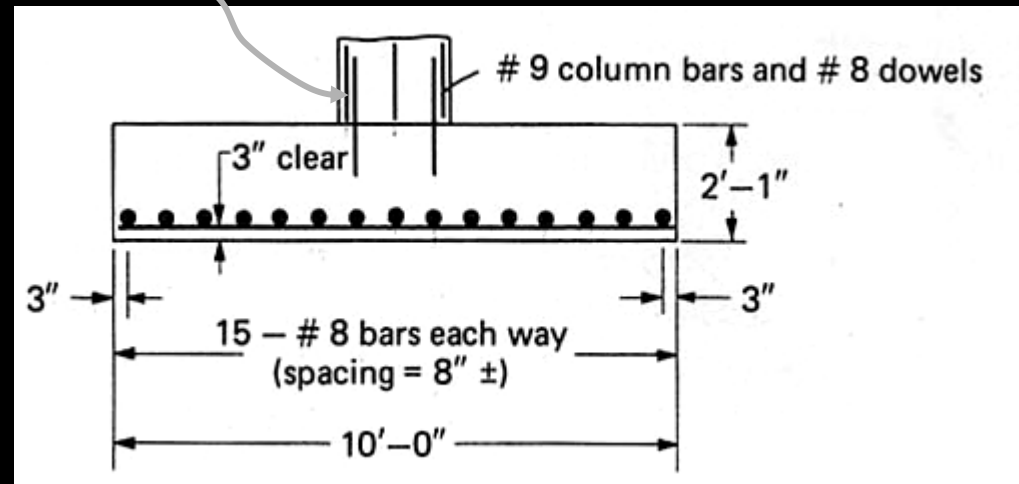
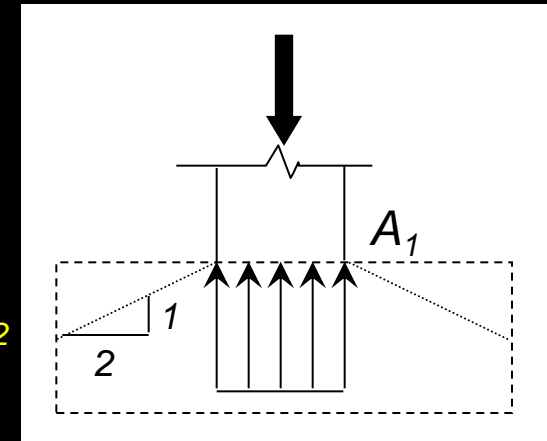
- *bearing of column on footing*

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

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

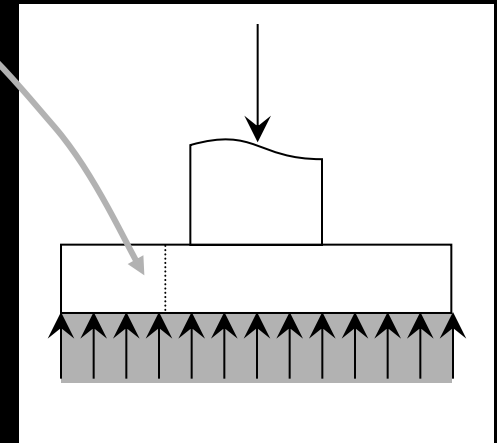
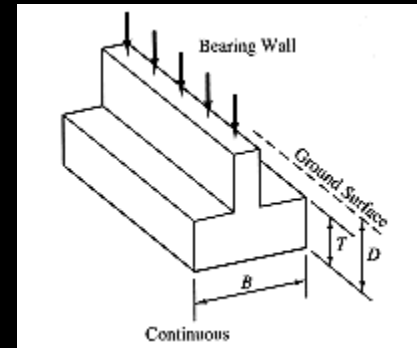
- *dowel reinforcement*

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



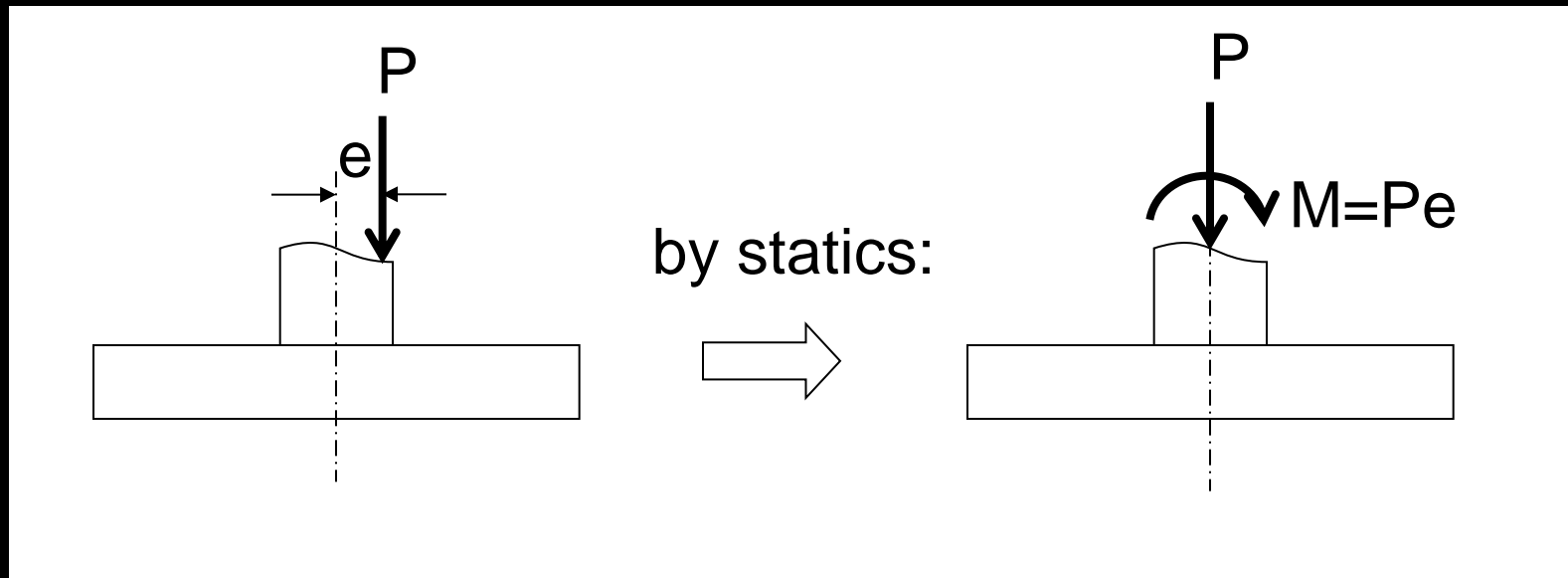
Wall Footings

- 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

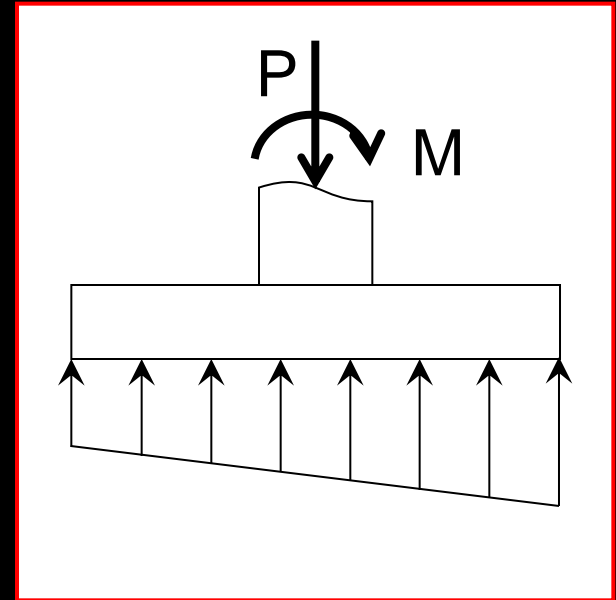
- *footings subject to moments*



– *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*

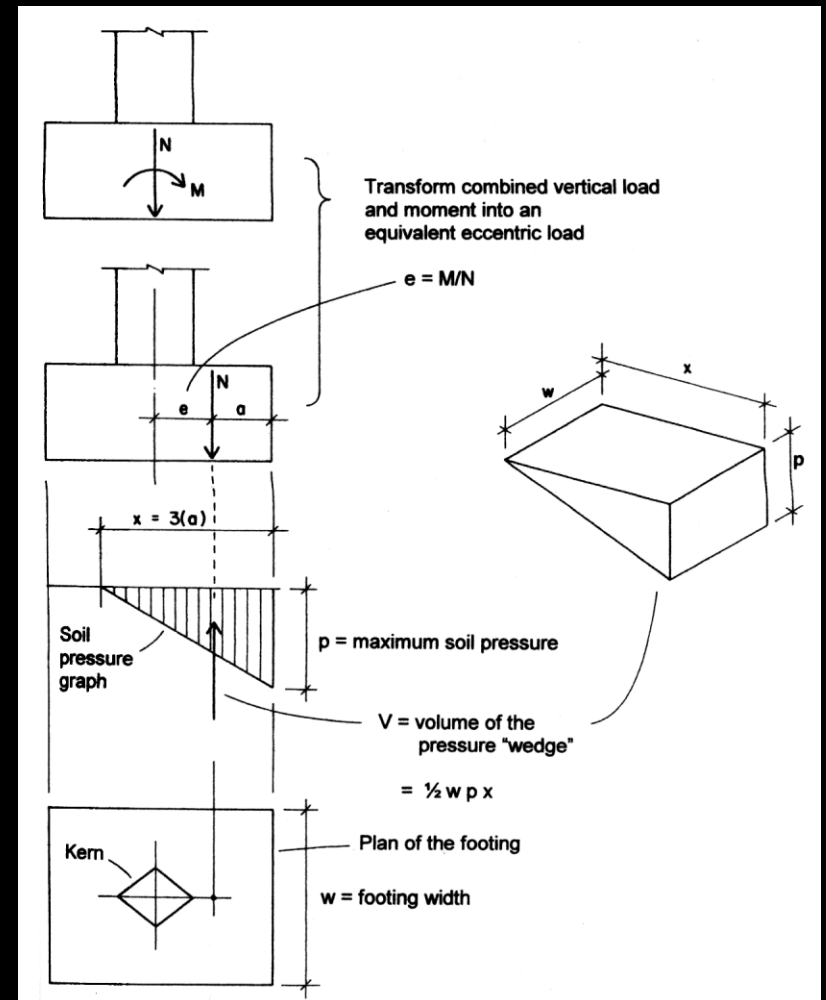


Kern Limit

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

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

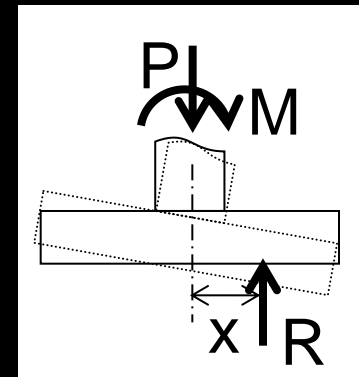
$$p_{max} = \frac{2N}{wx}$$



Guidelines

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

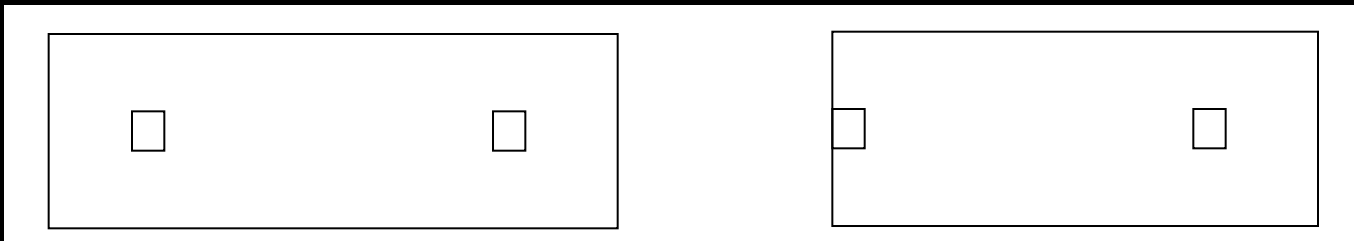
$$SF = \frac{M_{resist}}{M_{overturning}} = \frac{R \cdot x}{M} \geq 1.5$$



- 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*

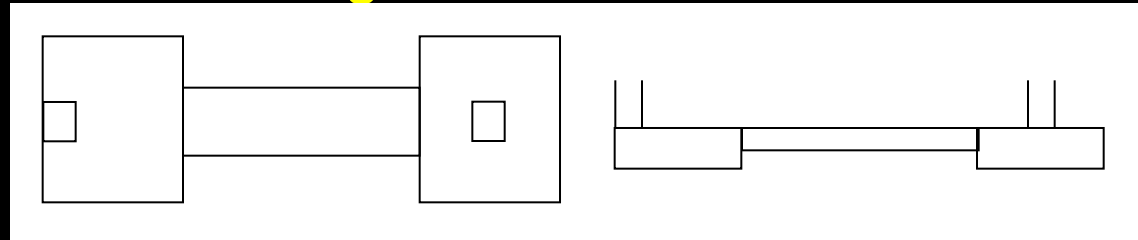
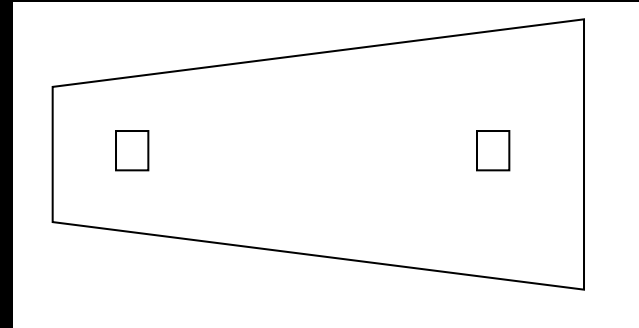
Combined Footing Types

– *rectangular*

– *trapezoid*

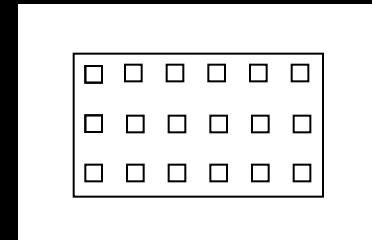
– *strap or cantilever*

- *prevents overturning of exterior column*



– *raft/mat*

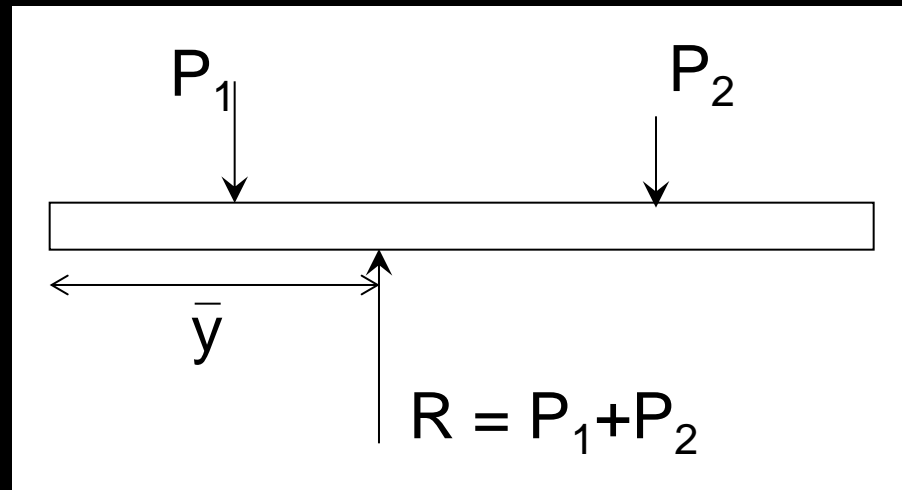
- *more than two columns over an extended area*



Proportioning

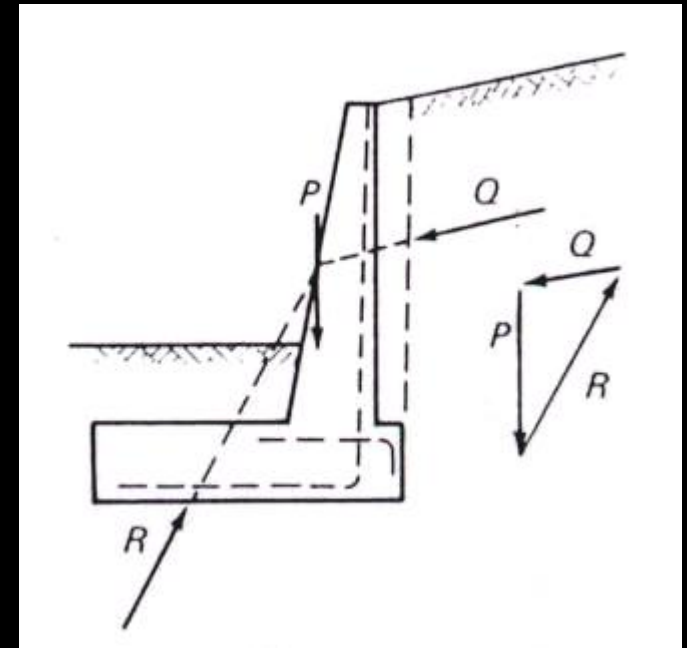
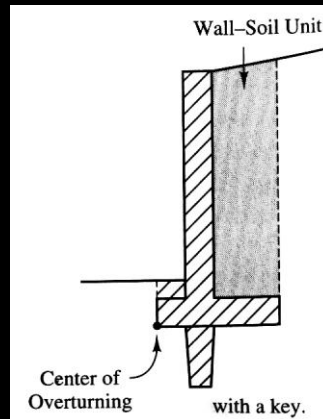
- *uniform settling is desired*
- *area is proportioned with sustained column loads*
- *want the resultant to coincide with centroid of footing area for uniformly distributed pressure assuming a rigid footing*

$$q_{max} \leq q_a$$



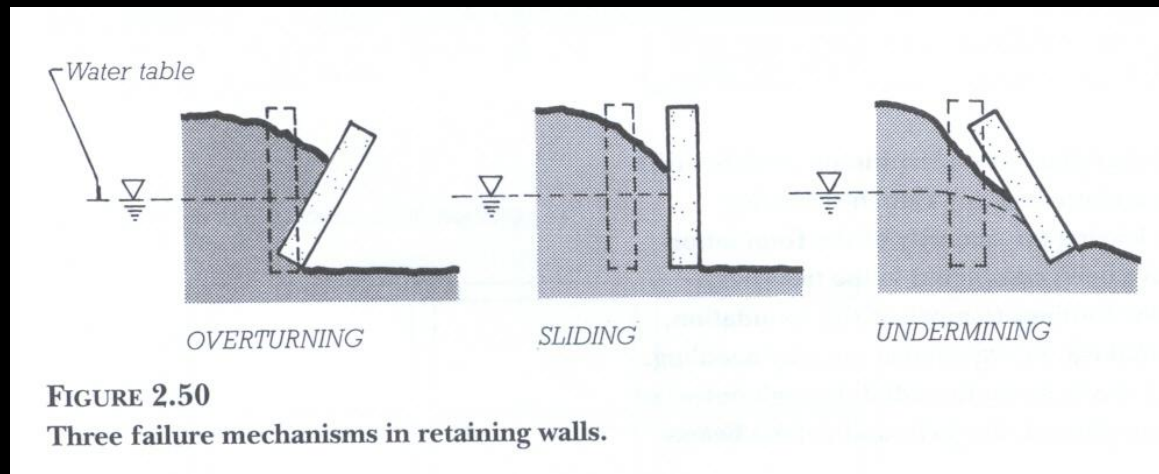
Retaining Walls

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



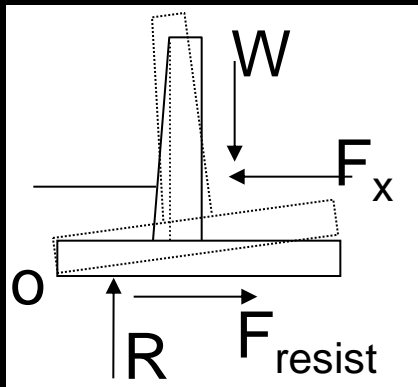
Retaining Walls

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



Retaining Walls

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

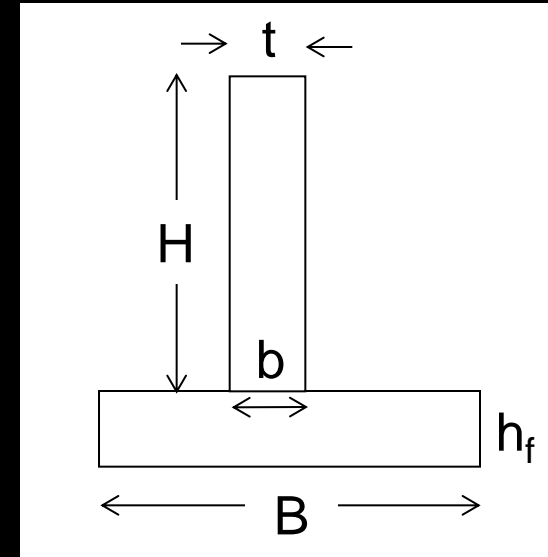


$$SF = \frac{M_{resist}}{M_{overturning}} \geq 1.5 - 2$$

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

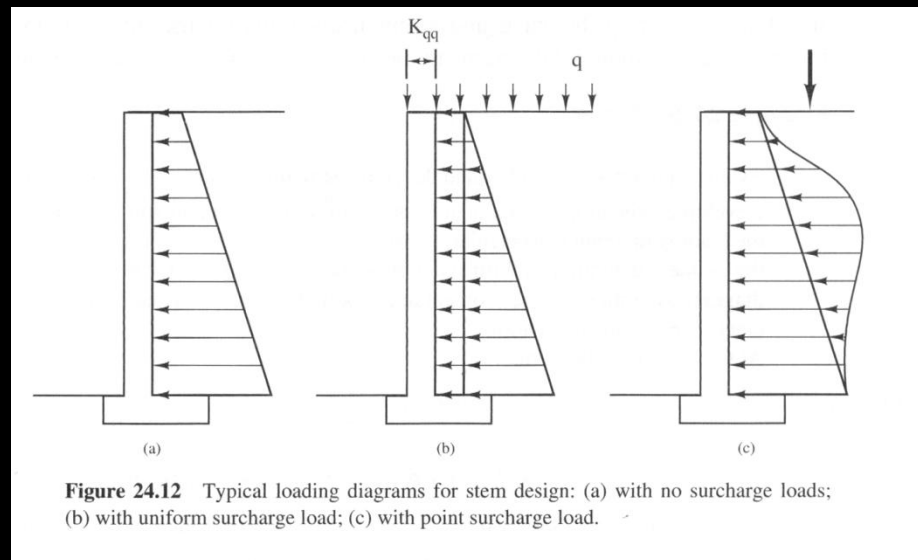
Retaining Wall Proportioning

- *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

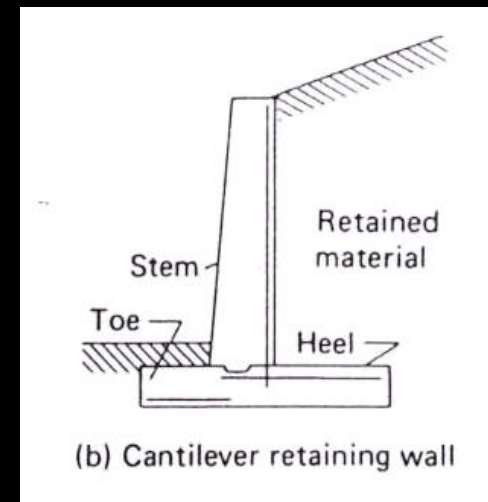
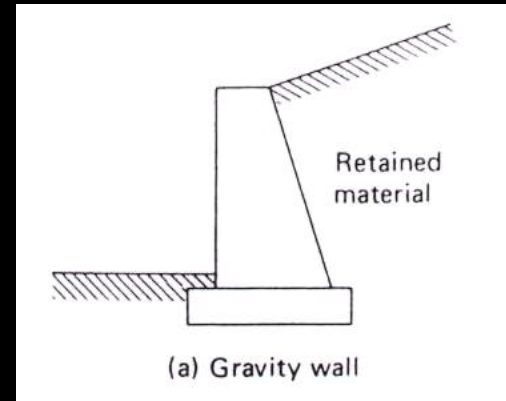
- *design like cantilever beam*
 - V_u & M_u for reinforced concrete
 - $V_u \leq \phi V_c$: $\phi = 0.75$ for shear
 - $M_u \leq \phi M_n$: $\phi = 0.9$ for flexure



Retaining Wall Types

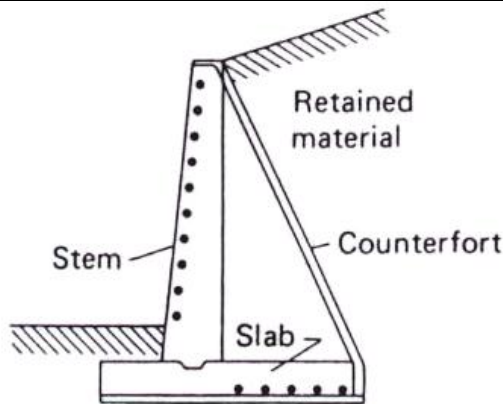
- “gravity” wall
 - usually unreinforced
 - economical & simple

- cantilever retaining wall
 - common

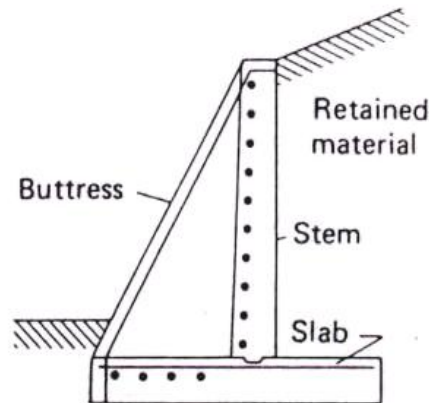


Retaining Wall Types

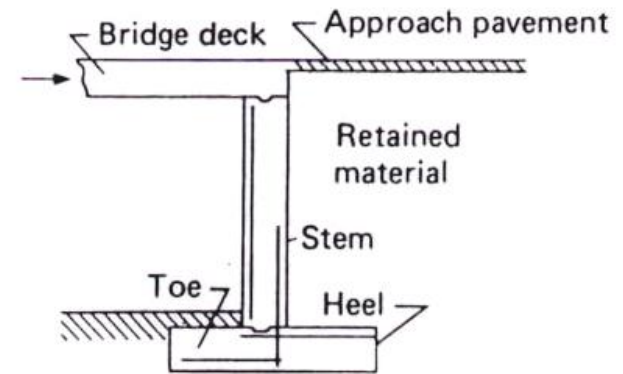
- *counterfort wall*
 - *buttress wall*
 - *bridge abutment*
 - *basement frame wall (large basement areas)*
- } very tall walls (> 20 - 25 ft)



(c) Counterfort wall



(d) Buttress wall



Deep Foundations

- *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" ϕ , 5' +

– piers

– caissons

– drilled shafts

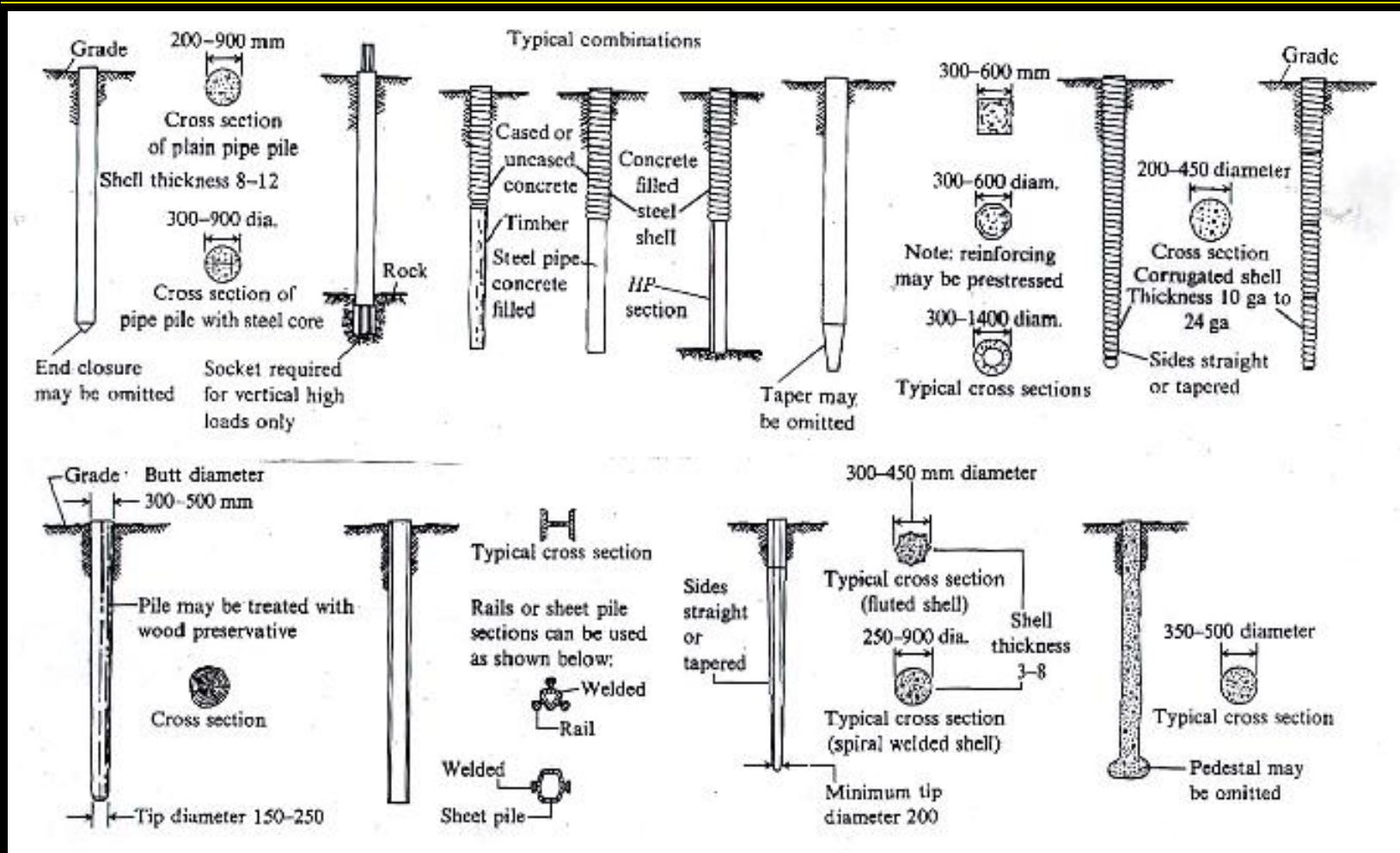
– bored piles

drilled, excavated,
concreted (with or
without steel)

2.5' - 10'/12' ϕ

– pressure injected piles

Deep Foundation Types

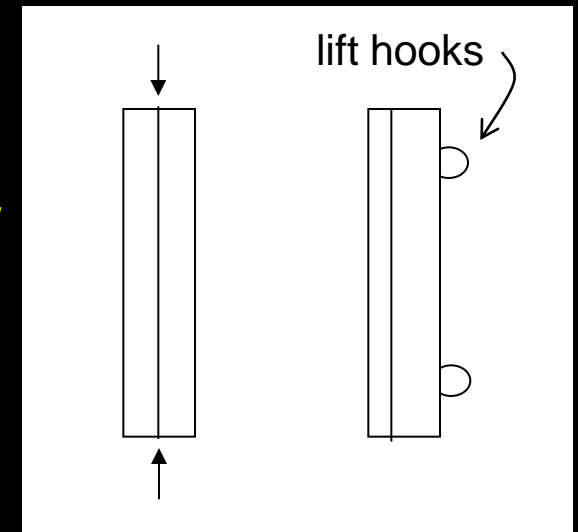


Deep Foundations

- *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*

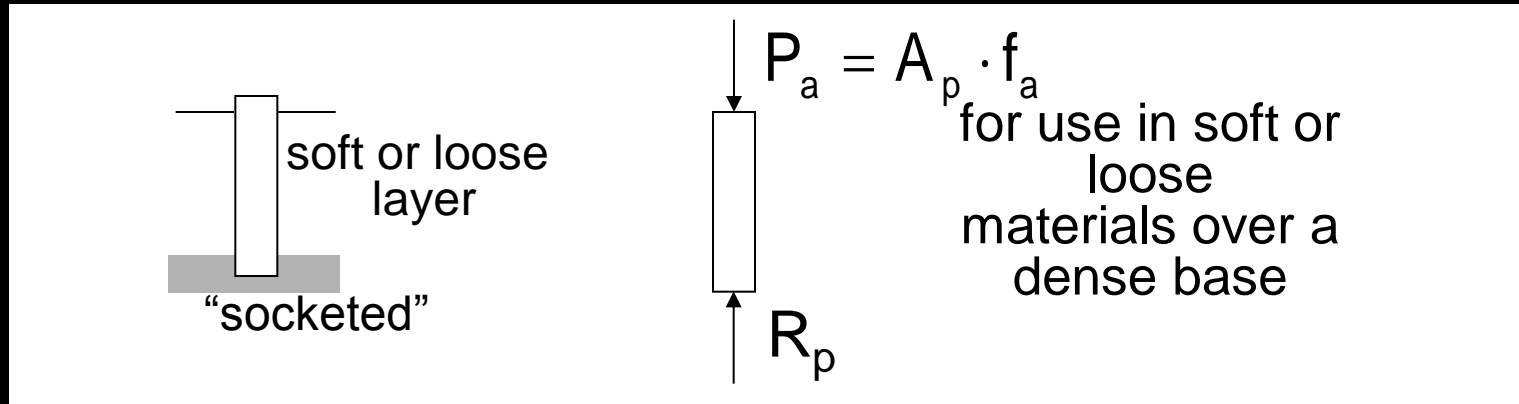


Piles Classified By Material

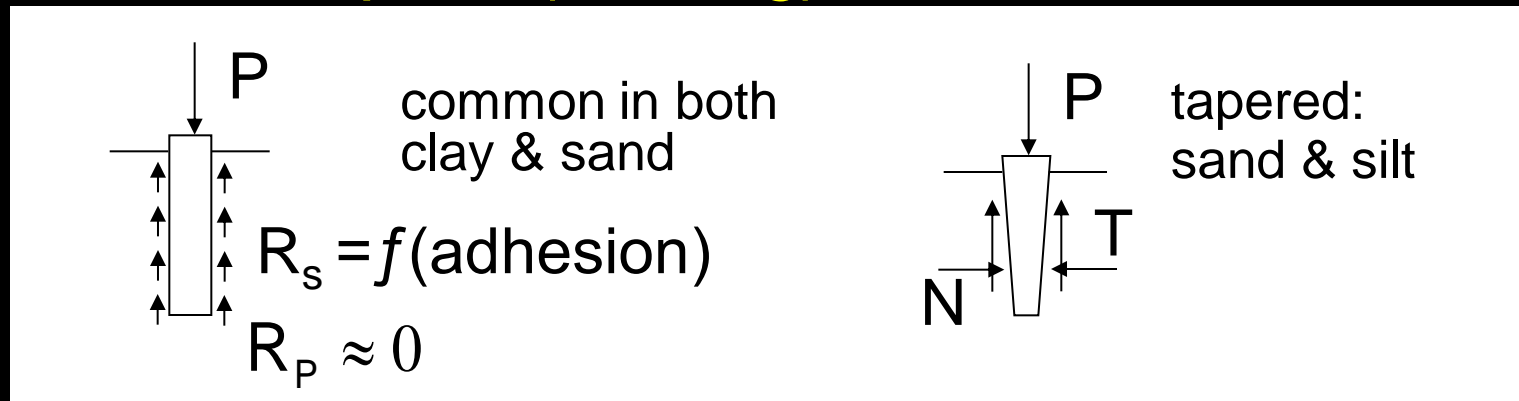
- *steel*
 - *rolled HP shapes or pipes*
 - *pipes may be filled with concrete*
 - *HP displaces little soil and may either break small boulders or displace them to the side*

Piles Classified By Function

– end bearing pile (point bearing)



– friction piles (floating)

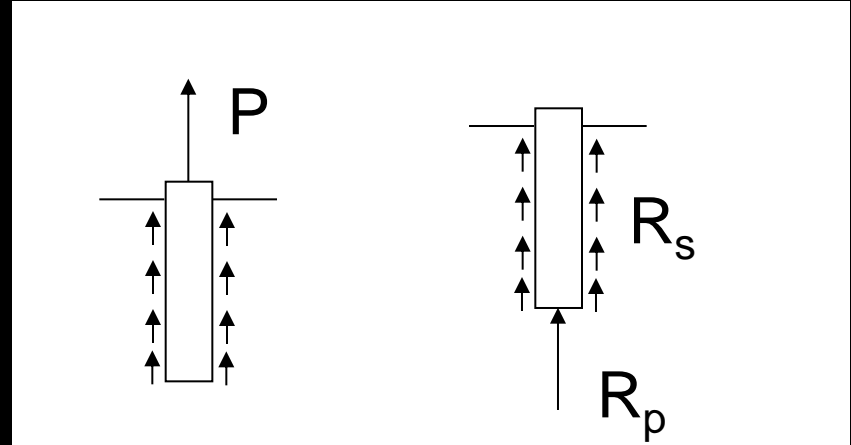


Piles Classified By Function

– combination friction and end bearing

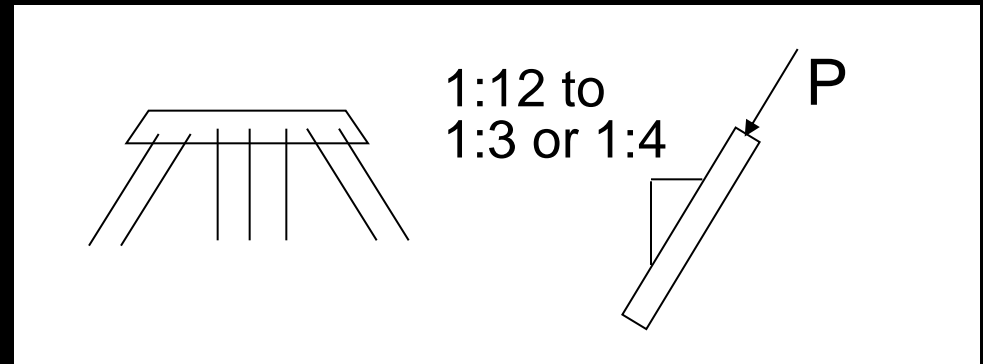
– uplift/tension piles

structures that float,
towers



– batter piles

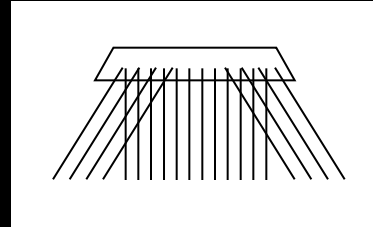
angled,
cost more,
resist large
horizontal loads



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

