ARCHITECTURAL STRUCTURES: FORM, BEHAVIOR, AND DESIGN

ARCH 331

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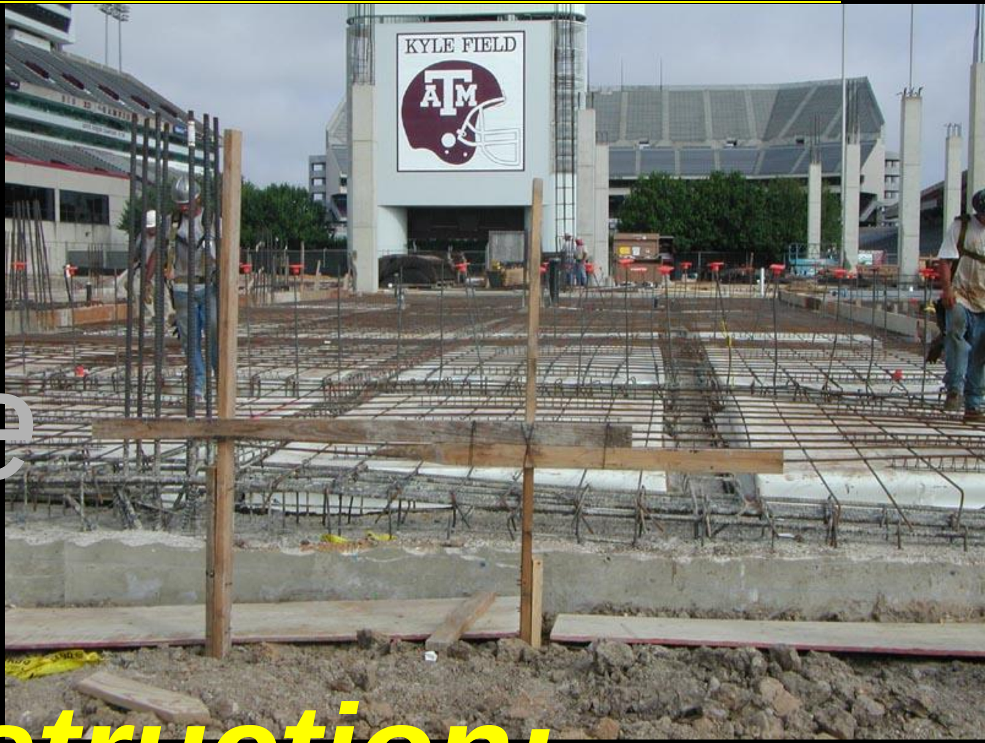
SUMMER 2013

lecture

twenty three



Bright Football Complex
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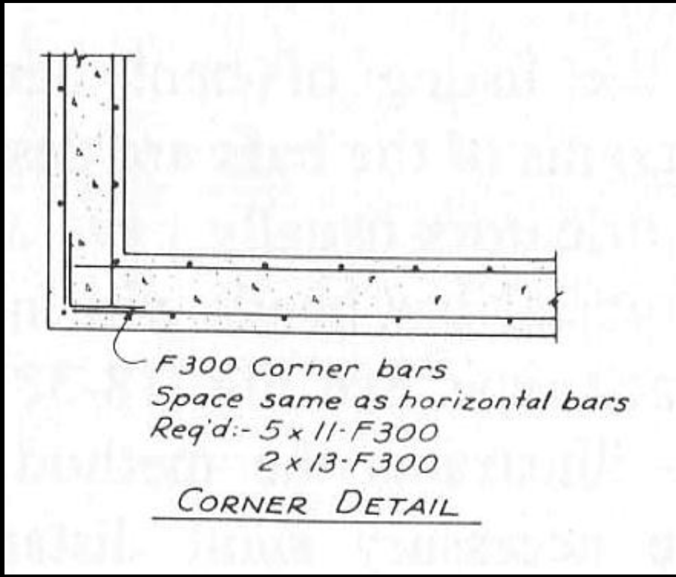
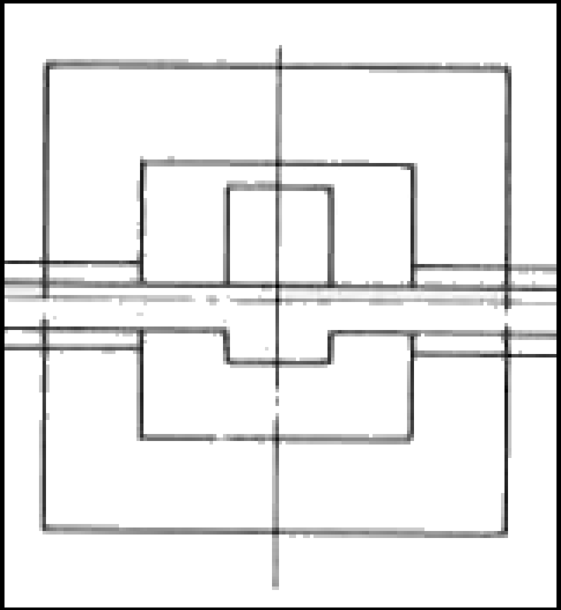
concrete construction: foundation design

Foundation

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



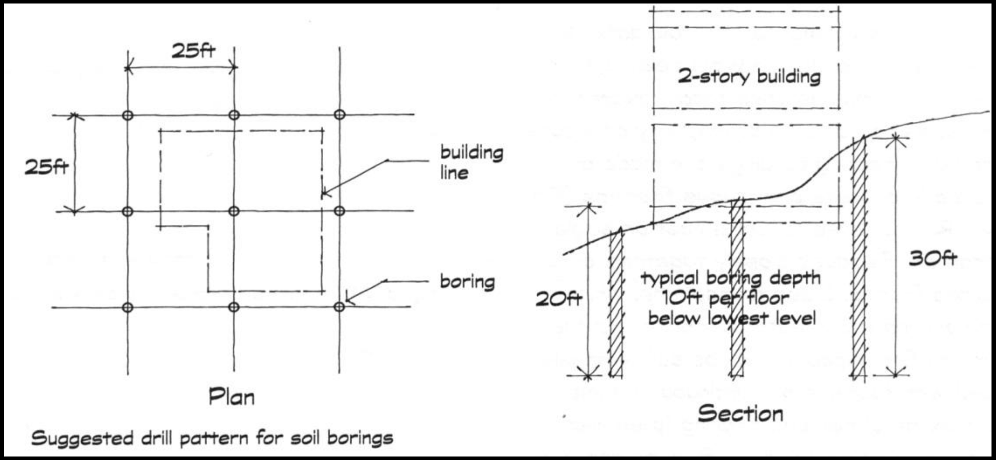


Structural vs. Foundation Design

- *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

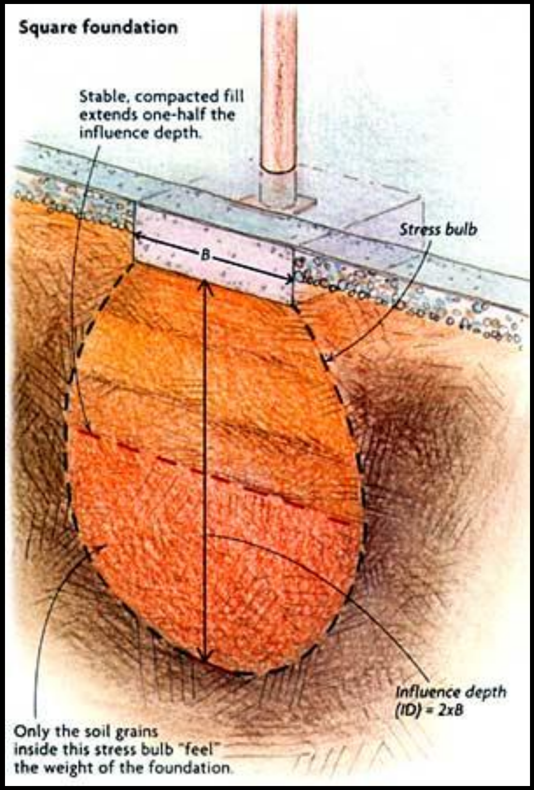


Soil Properties & Mechanics

- *unit weight of soil*
- *allowable soil pressure*
- *factored net soil pressure*
- *shear resistance*
- *backfill pressure*
- *cohesion & friction of soil*
- *<u>effect of water</u>*
- *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, $q_a = \dfrac{q_u}{S.F.}$



finehomebuilding.com

Soil Properties & Mechanics

- *strength, q_a*

Table 1804.3
PRESUMPTIVE LOADBEARING VALUES OF FOUNDATION MATERIALS

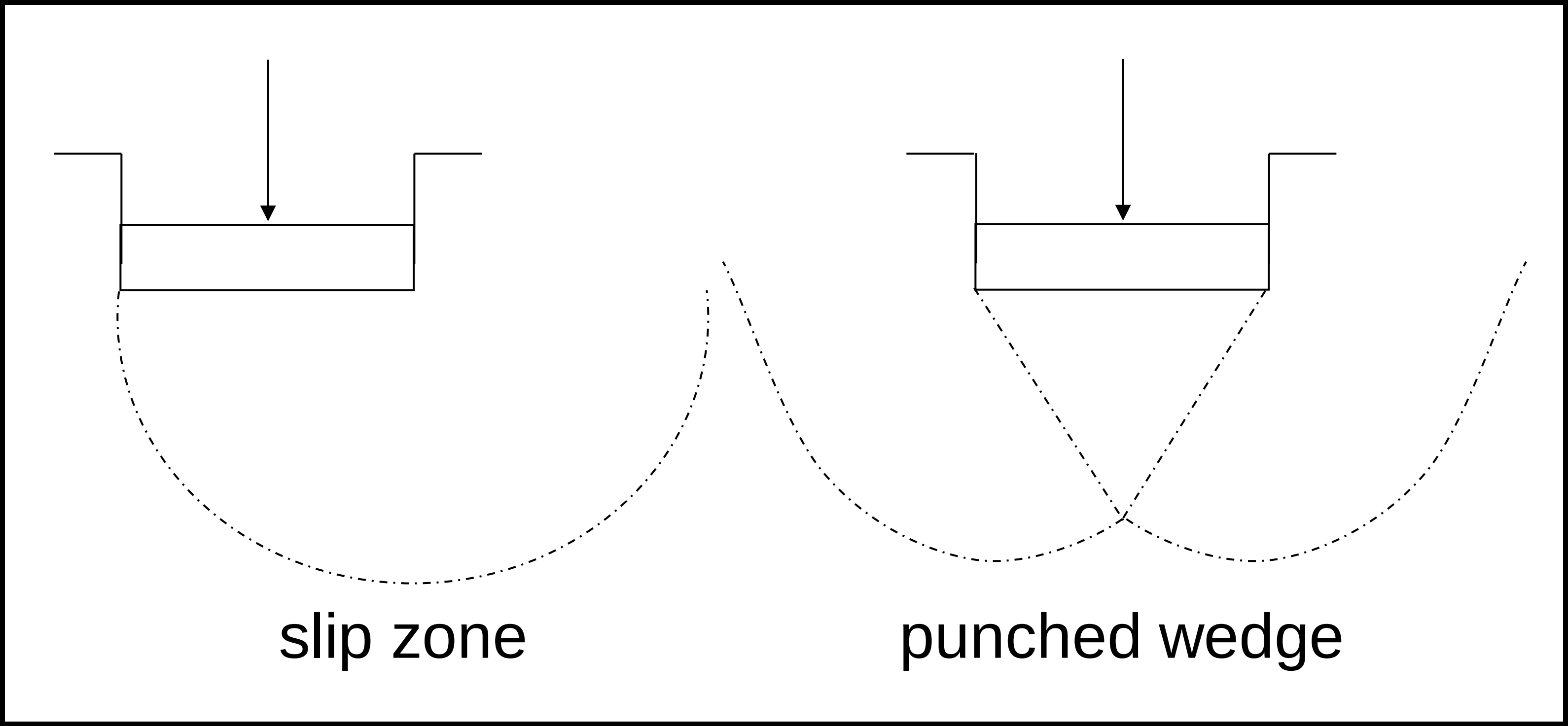
Class of material	Loadbearing pressure (pounds per square foot)[a]
1. Crystalline bedrock	12,000
2. Sedimentary rock	6,000
3. Sandy Gravel	5,000
4. Sand, silty sand, clayey sand, silty gravel and clayey gravel	3,000
5. Clay, sandy clay, silty clay & clayey silt	2,000

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*)

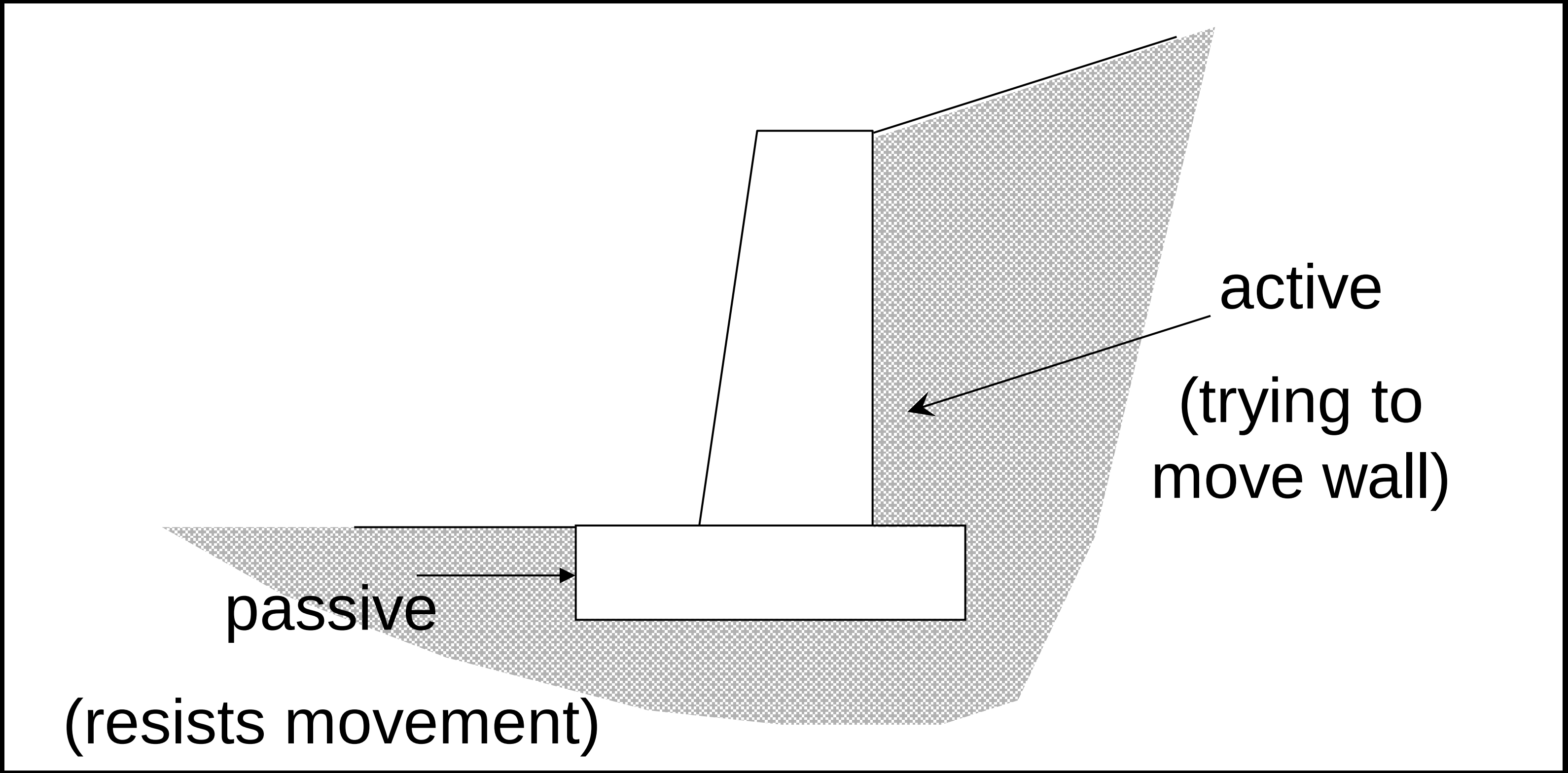
Bearing Failure

- *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

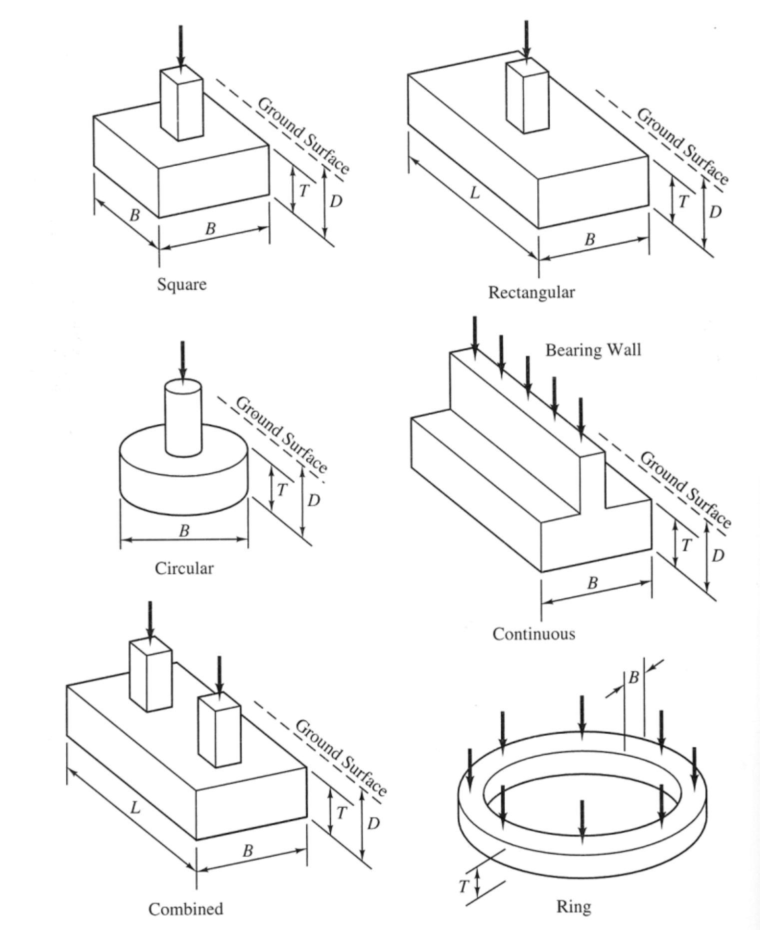
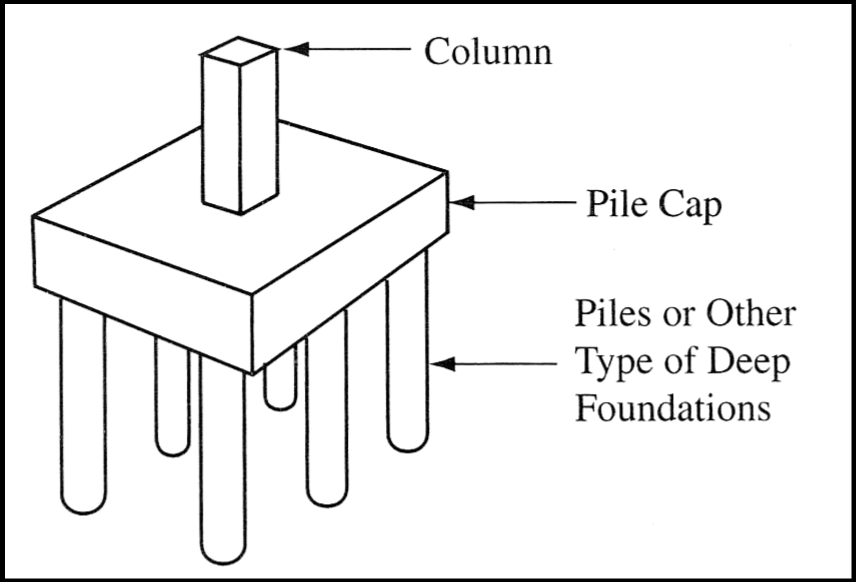


Figure 5.1 Spread footing shapes and dimensions.

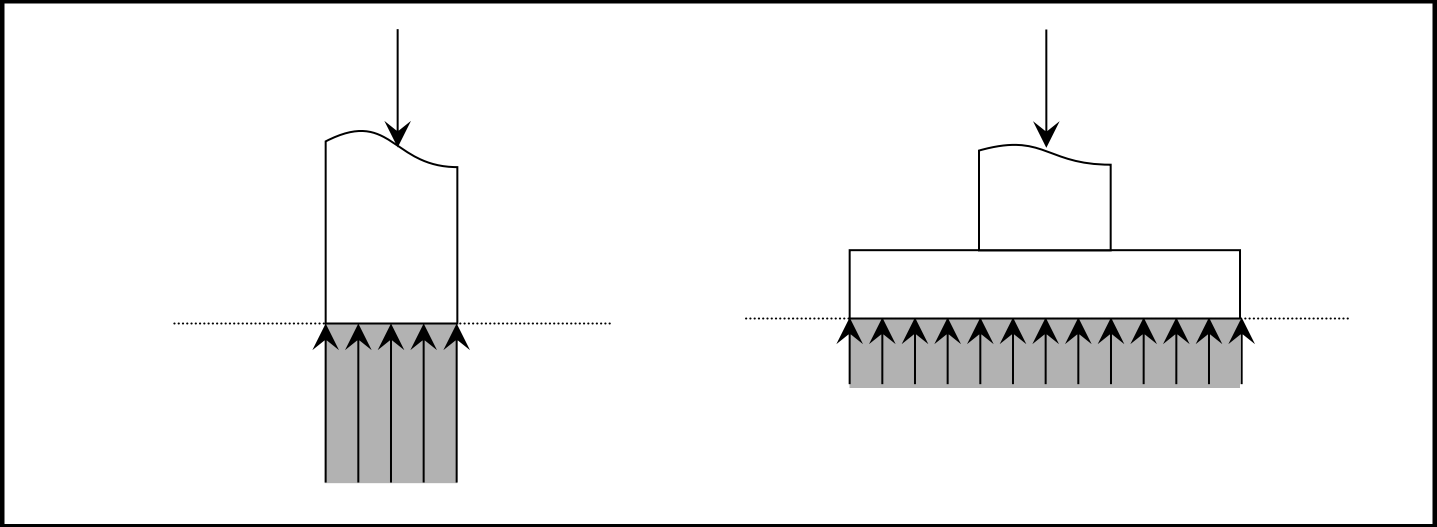
Types of Foundations



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

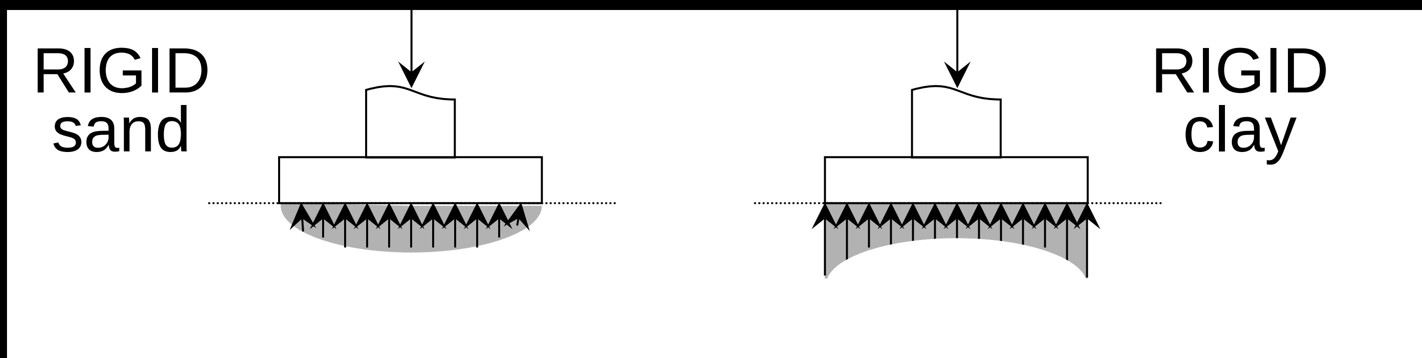
Shallow Footings

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

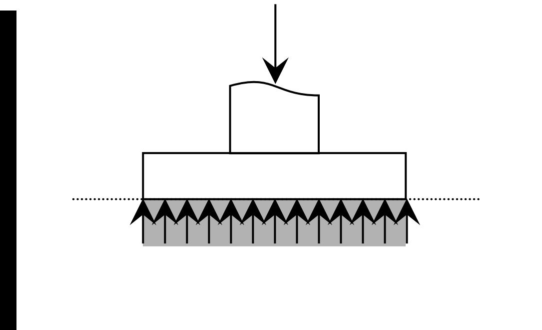


Actual vs. Design Soil Pressure

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



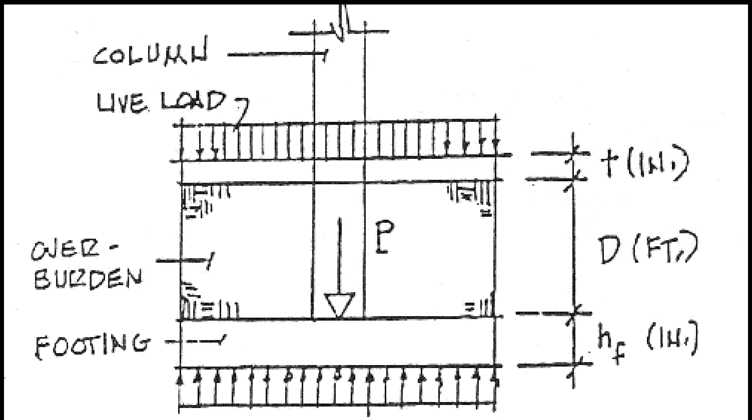
- linear stress distribution assumed



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:

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



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*

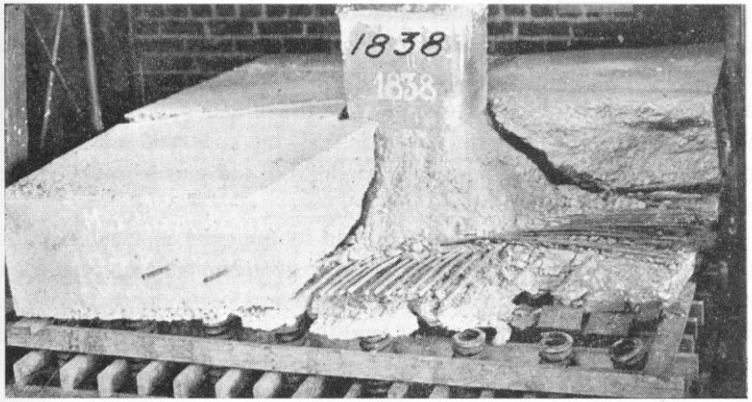


Figure 9.2 "Shear" failure in a spread footing loaded in a laboratory (Talbot, 1913). Observe how this failure actually is a combination of tension and shear.

shear

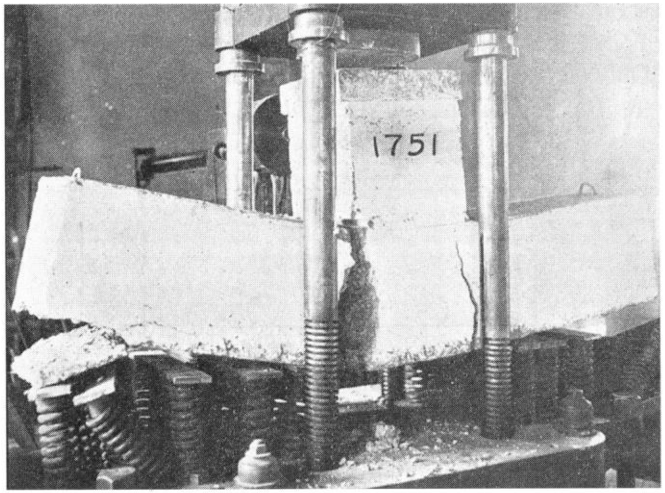
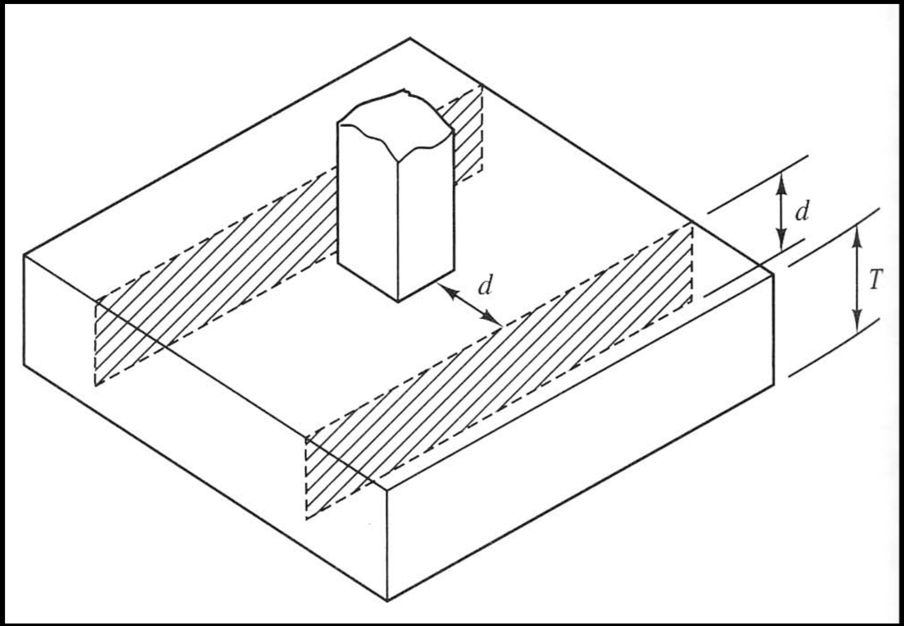


Figure 9.3 Flexural failure in a spread footing loaded in a laboratory (Talbot, 1913).

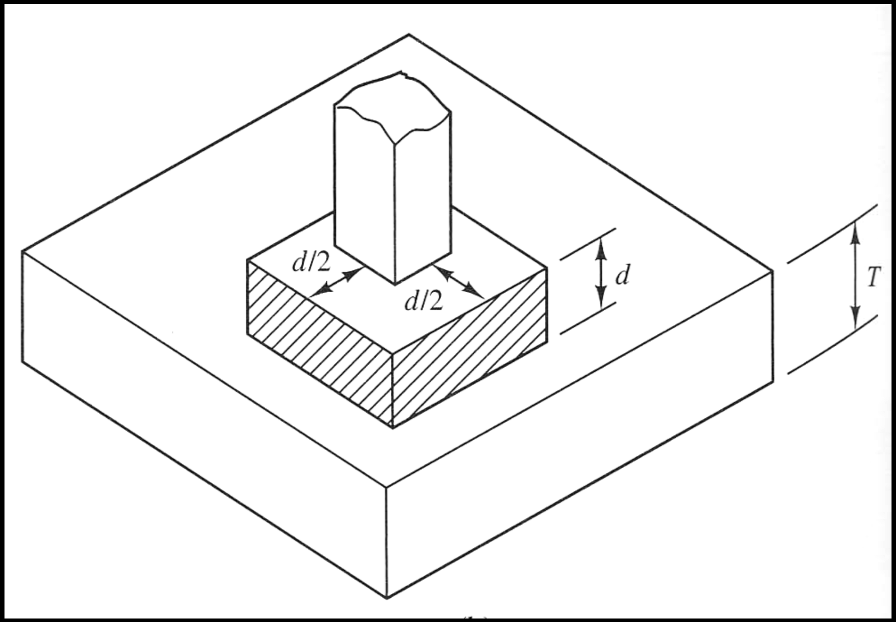
bending

Concrete Spread Footings

- *shear failure*



one way shear



two way shear

Over and Under-reinforcement

- *reinforcement ratio for bending*
  - $\rho = \dfrac{A_s}{bd}$
  - *use as a design estimate to find A_s,b,d*
  - *max ρ 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, ℓ_d
  - bond
  - development of yield strength

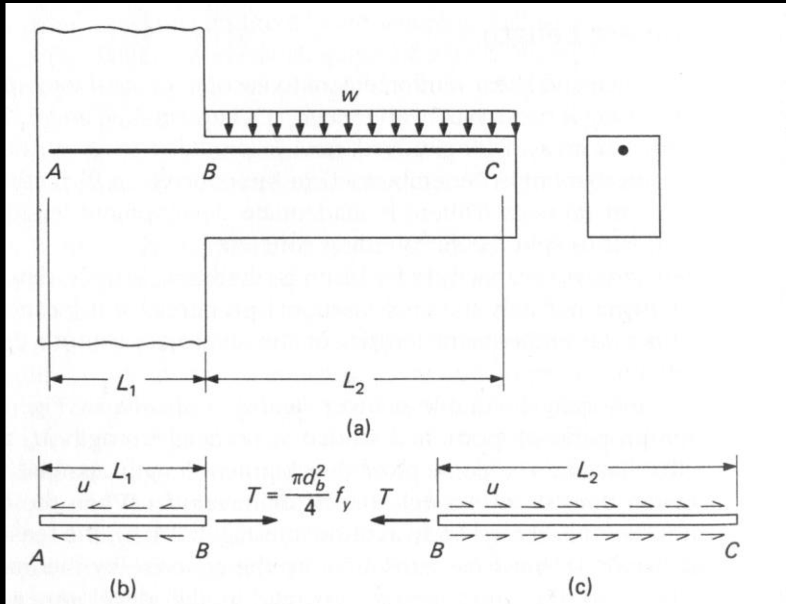


Figure 6.2.1 Development of reinforcement.

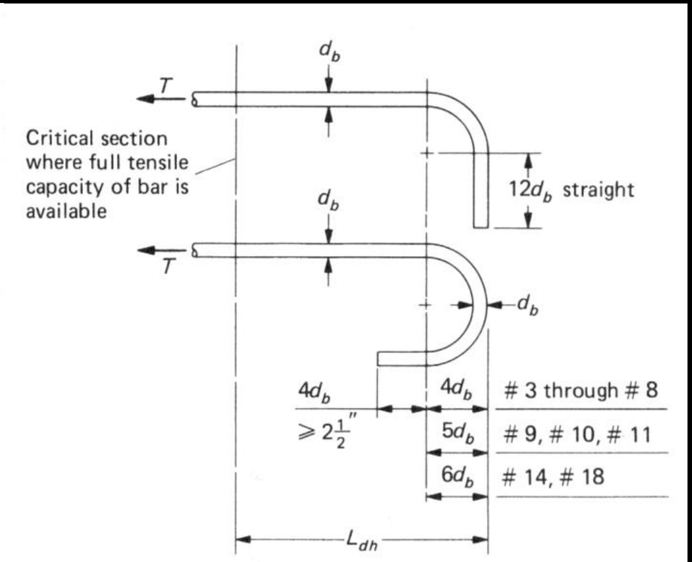
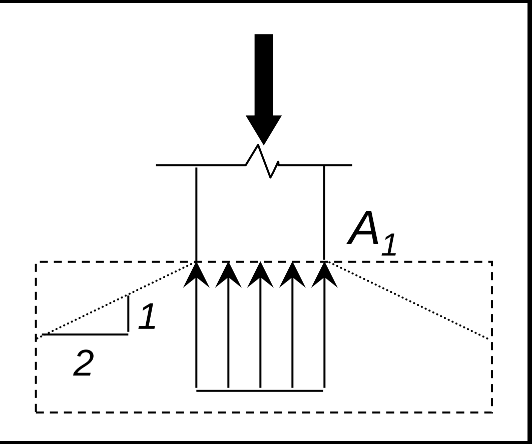


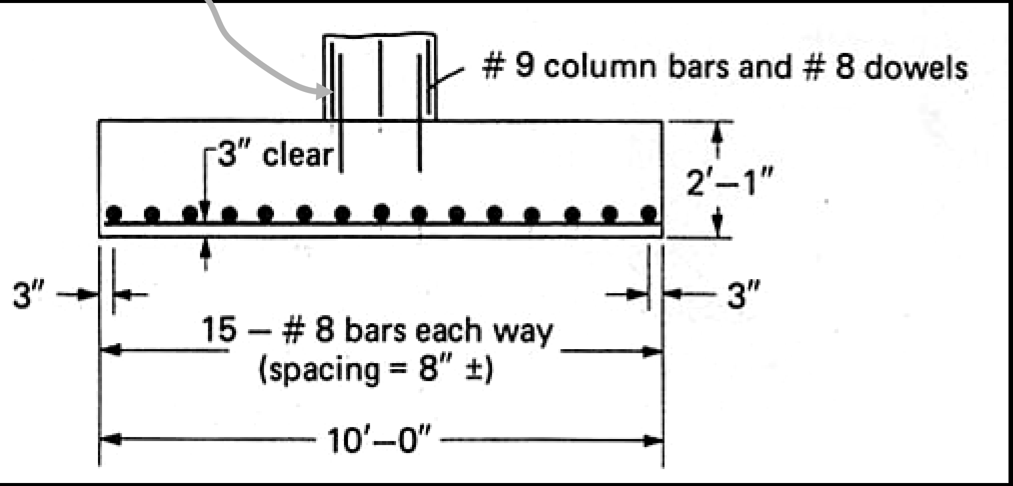
Figure 6.11.2 Development length L_{dh} for hooked bar.

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

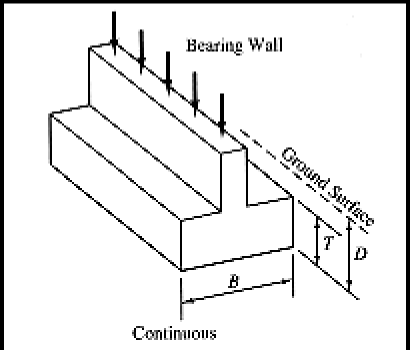
– plain or reinforced

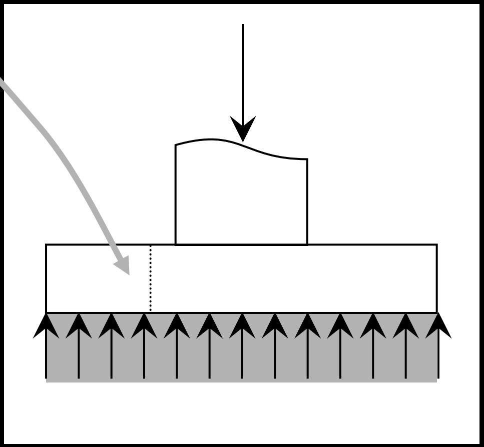
– behavior

- wide beam shear
- bending of projection

– dimensions usually dictated by codes for residential walls

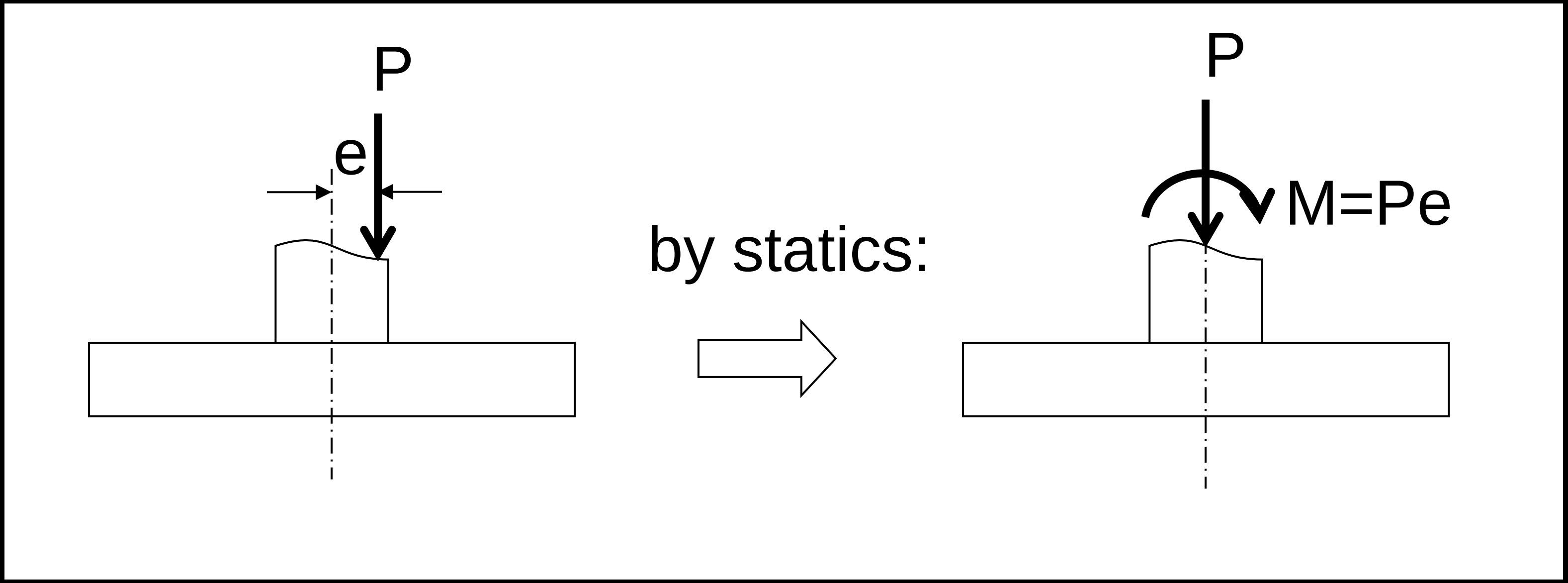
– light loads





Eccentrically Loaded Footings

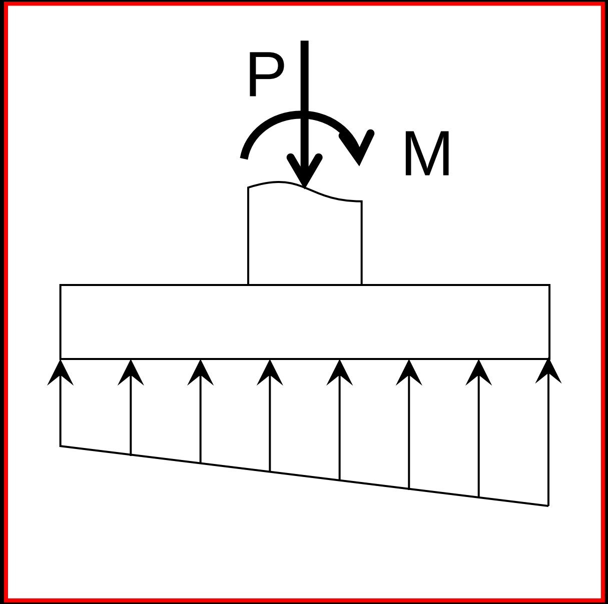
- *footings subject to moments*



  - *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*



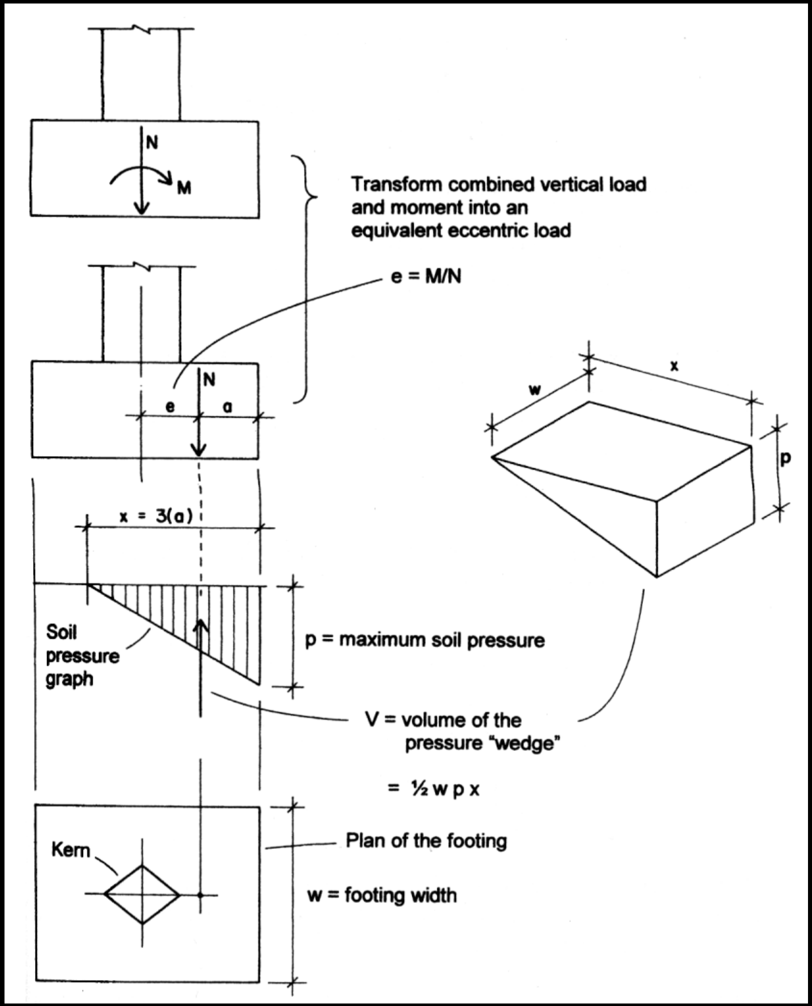
- *for rigid footing, simplification of soil pressure is a linear distribution based on constant ratio of pressure to settlement*

Kern Limit

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

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

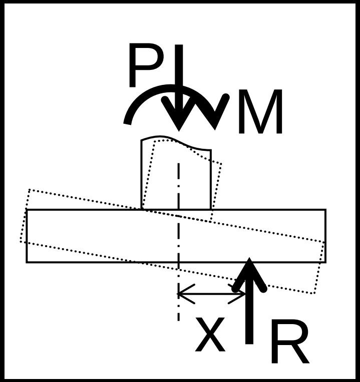
$$p_{\max} = \frac{2N}{wx}$$



Guidelines

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

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

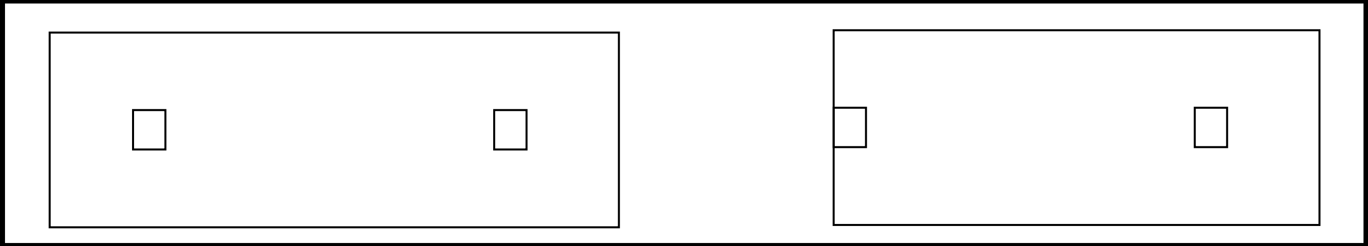


– *pressure under toe (maximum)* $\leq q_a$

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

Combined Footings

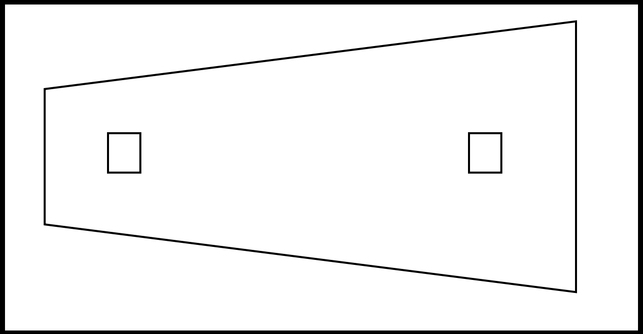
- supports two columns
- used when space is tight and spread footings would overlap or when at property line



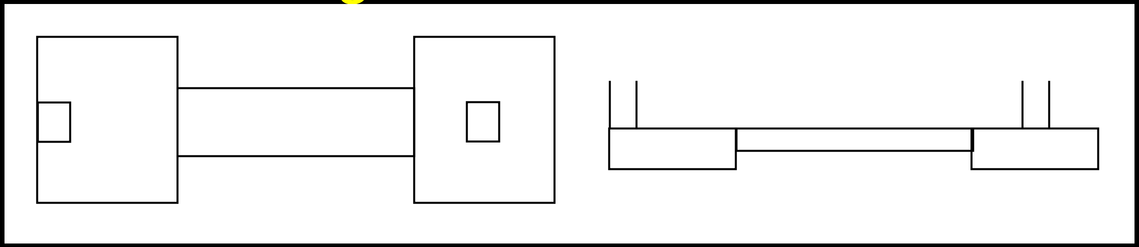
- soil pressure might not be uniform
- proportion so pressure will uniform for sustained loads
- behaves like beam lengthwise

Combined Footing Types

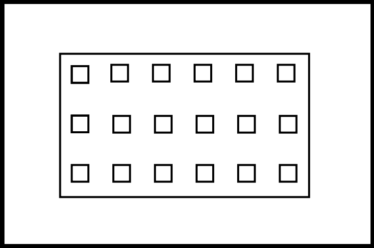
- rectangular
- trapezoid



- strap or cantilever
  - prevents overturning of exterior column



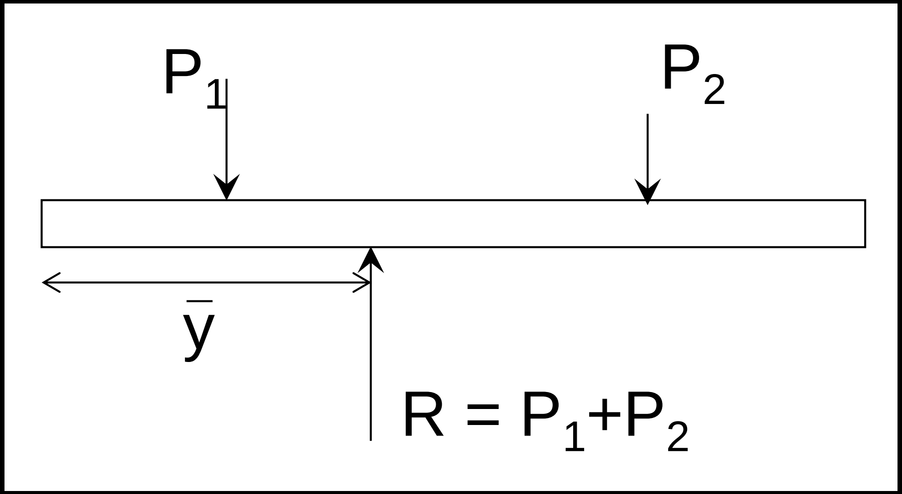
- raft/mat
  - more than two columns over an extended area



Proportioning

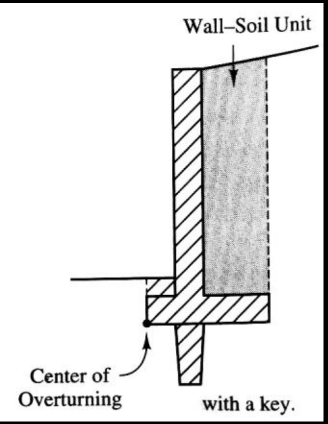
- *uniform settling is desired*
- *area is proportioned with sustained column loads*
- *want the resultant to coincide with centroid of footing area for uniformly distributed pressure assuming a rigid footing*

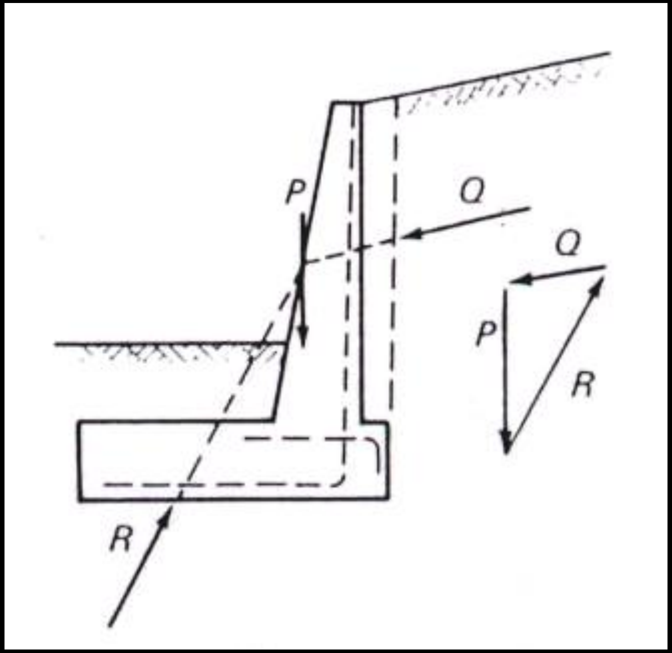
$$q_{max} \le q_a$$



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)

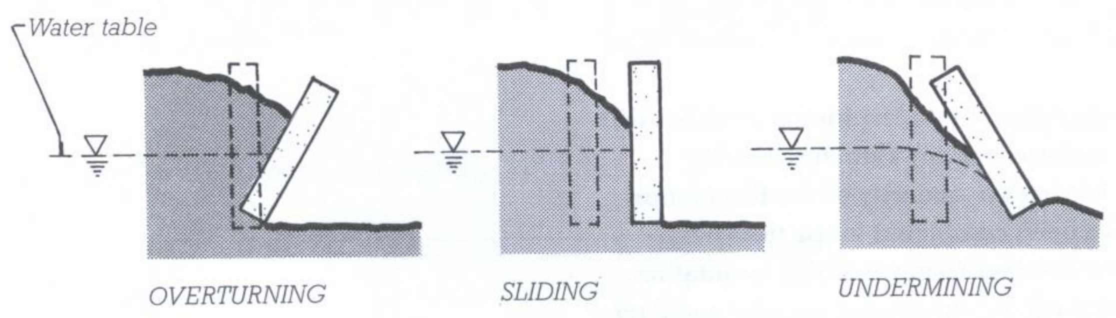
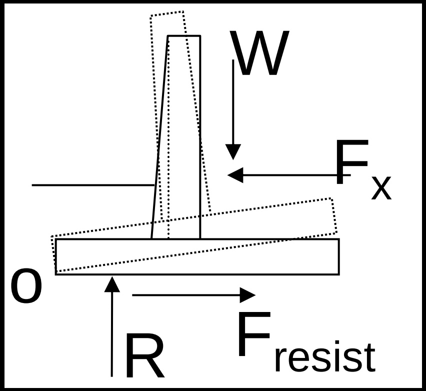


FIGURE 2.50
Three failure mechanisms in retaining walls.

Retaining Walls

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

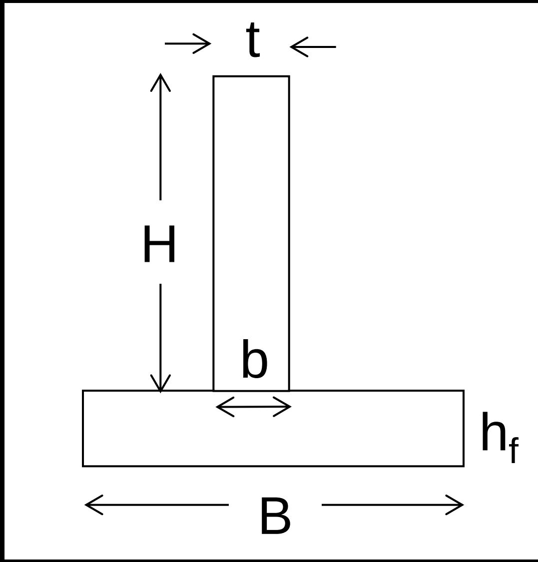


$$SF = \frac{M_{resist}}{M_{overturning}} \geq 1.5 - 2$$

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

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

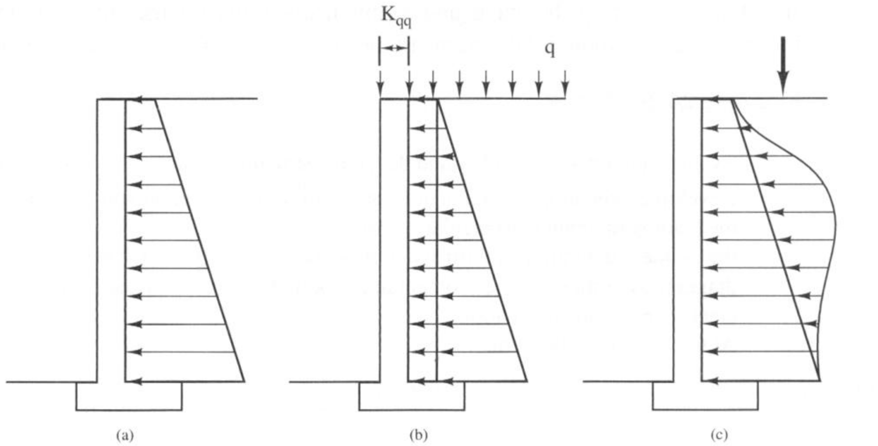
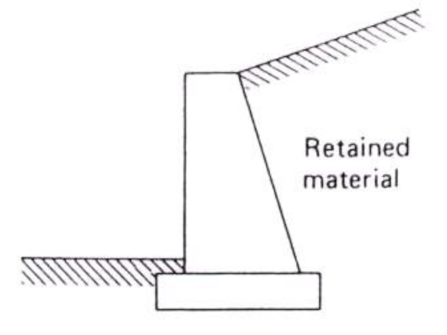


Figure 24.12 Typical loading diagrams for stem design: (a) with no surcharge loads; (b) with uniform surcharge load; (c) with point surcharge load.

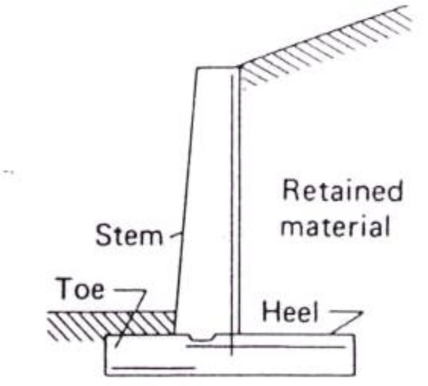
Retaining Wall Types

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



(a) Gravity wall

- *cantilever retaining wall*
  - *common*



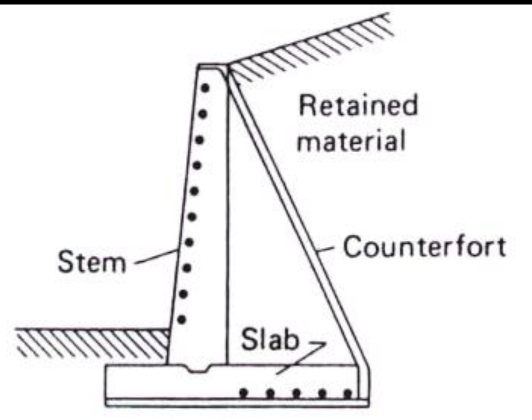
(b) Cantilever retaining wall

Retaining Wall Types

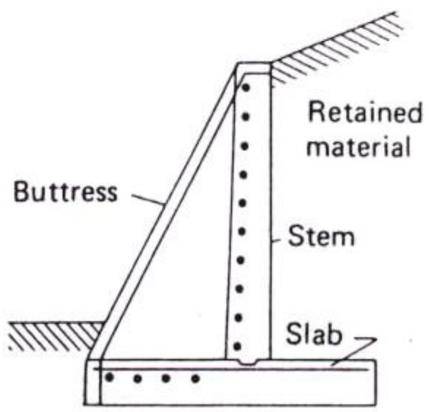
- *counterfort wall*
- *buttress wall*

very tall walls (> 20 - 25 ft)

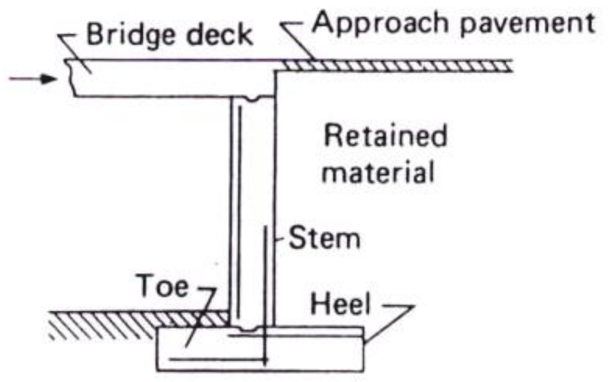
- *bridge abutment*
- *basement frame wall (large basement areas)*



(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*

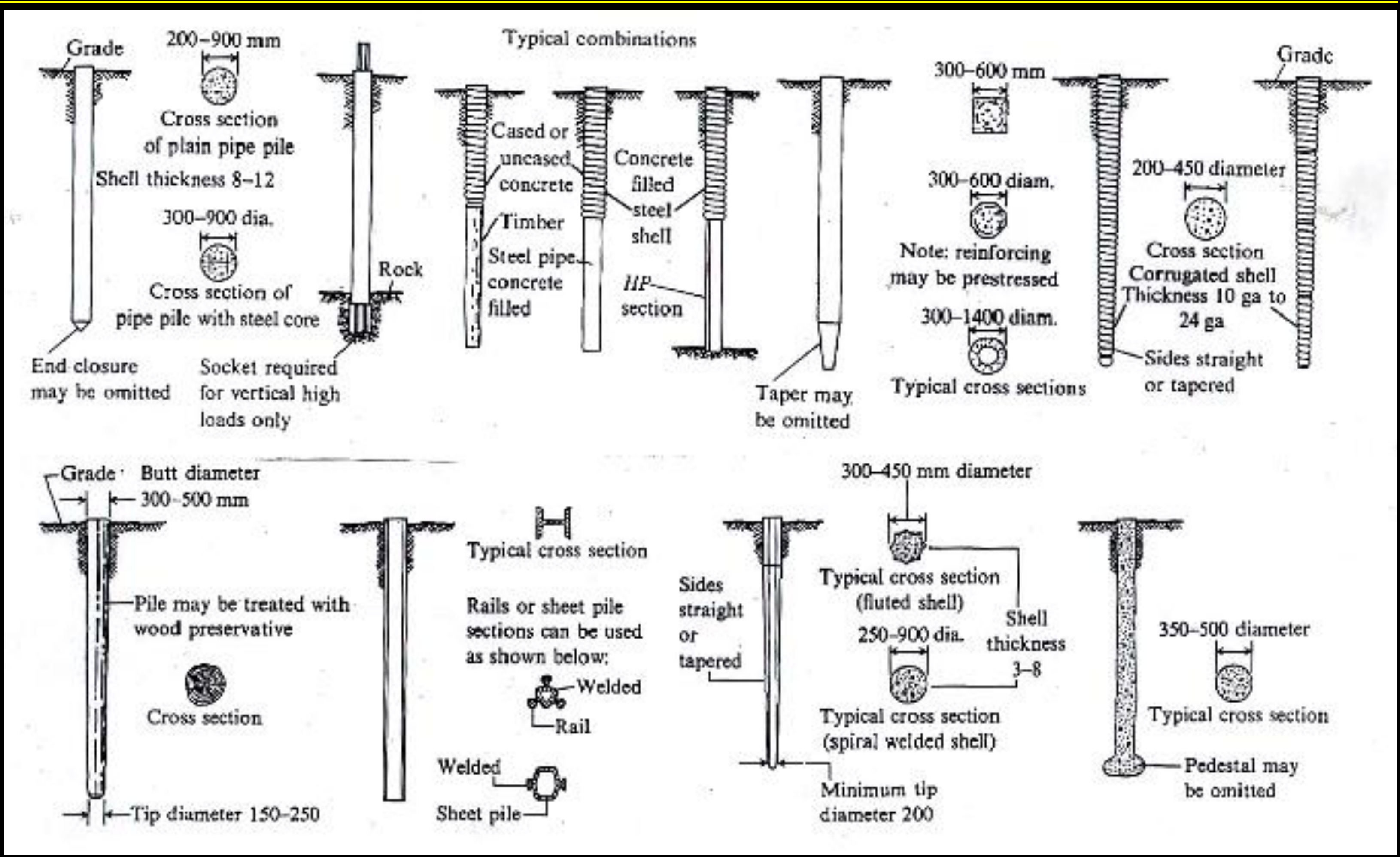
Deep Foundation Types

- *piles - usually driven, 6"-8" ϕ, 5' +*
- *piers*
- *caissons*
- *drilled shafts*
- *bored piles*
- *pressure injected piles*

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

2.5' - 10'/12' ϕ

Deep Foundation Types

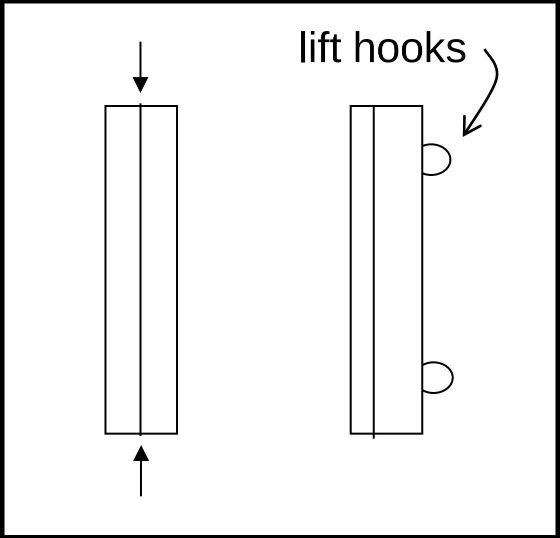


Deep Foundations

- *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*

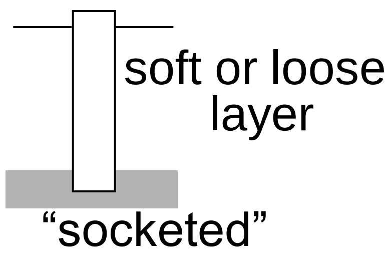


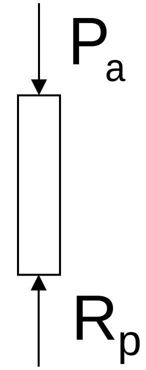
Piles Classified By Material

- *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)

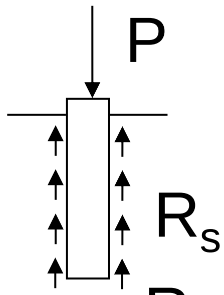




$$P_a = A_p \cdot f_a$$

for use in soft or loose materials over a dense base

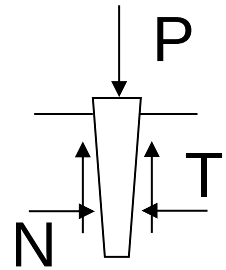
– friction piles (floating)



common in both clay & sand

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

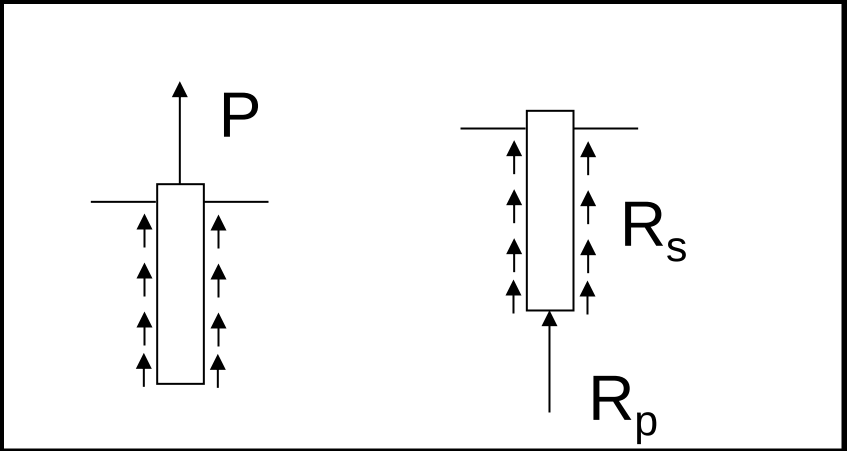
$$R_P \approx 0$$



tapered: sand & silt

Piles Classified By Function

– *combination friction and end bearing*

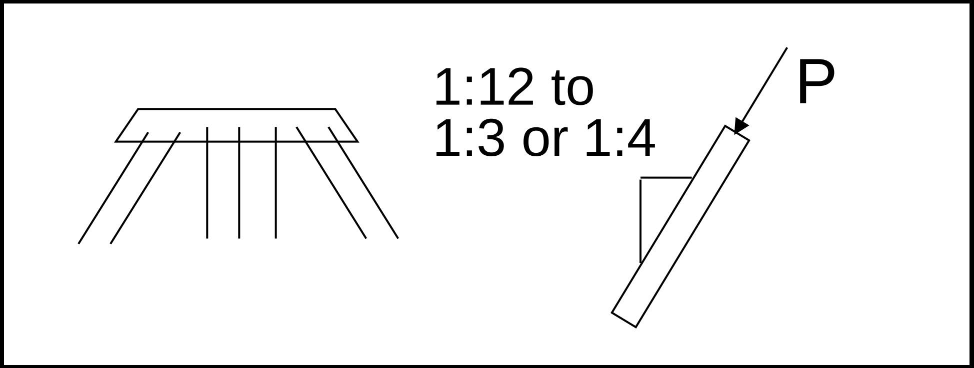


– *uplift/tension piles*

structures that float, towers

– *batter piles*

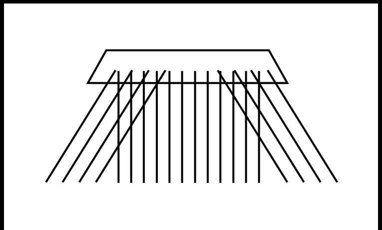
angled, cost more, resist large horizontal loads



Piles Classified By Function

– *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