ARCHITECTURAL STRUCTURES:
FORM, BEHAVIOR, AND DESIGN
ARCH 331
DR. ANNE NICHOLS
SUMMER 2013

lecture
twenty three

Bright Football Complex
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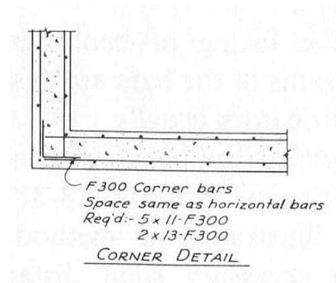
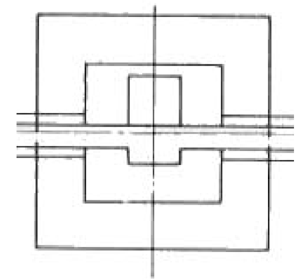
concrete construction: foundation design

Foundation

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



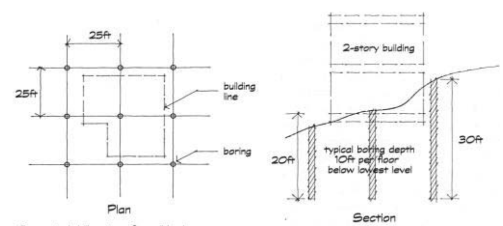


Structural vs. Foundation Design

- 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

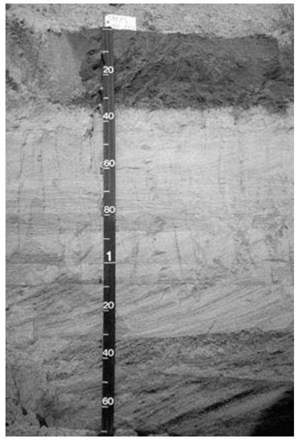
- foundation design
  - cannot specify site materials
  - site is usually predetermined
  - framing/structure predetermined
  - site geology influences foundation choice
  - no site the same
  - no design the same



Suggested drill pattern for soil borings

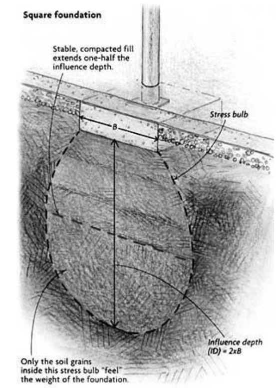
Soil Properties & Mechanics

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



finehomebuilding.com

Soil Properties & Mechanics

- *strength,* q_a

Table 1804.3
PRESUMPTIVE LOADBEARING VALUES OF FOUNDATION MATERIALS

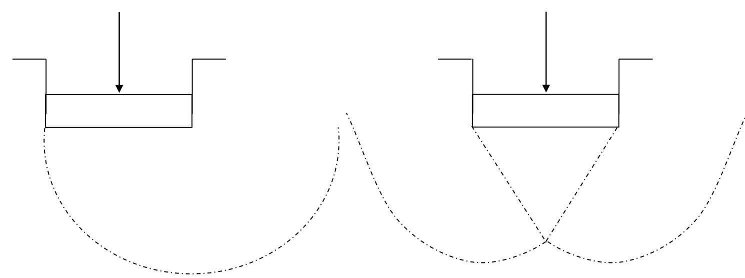
Class of material	Loadbearing pressure (pounds per square foot)[a]
1. Crystalline bedrock	12,000
2. Sedimentary rock	6,000
3. Sandy Gravel	5,000
4. Sand, silty sand, clayey sand, silty gravel and clayey gravel	3,000
5. Clay, sandy clay, silty clay & clayey silt	2,000

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

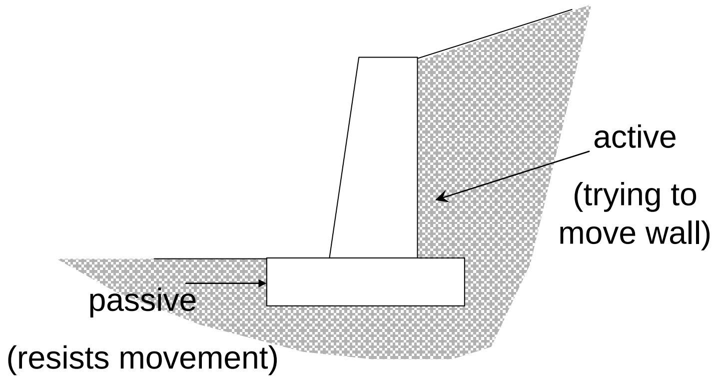
- *shear*



slip zone　　punched wedge

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

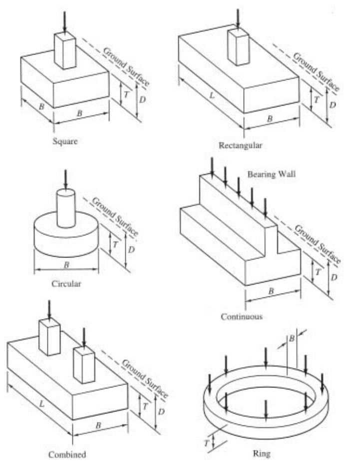
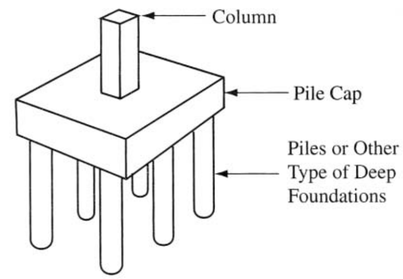


Figure 5.1 Spread footing shapes and dimensions.

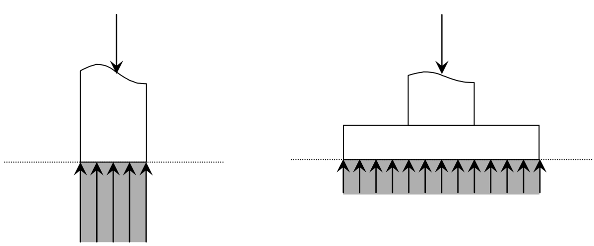
Types of Foundations



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

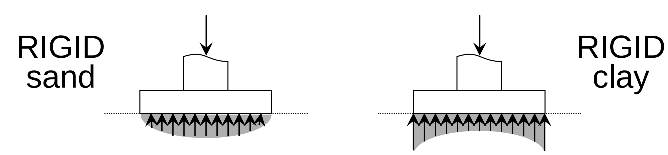
Shallow Footings

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

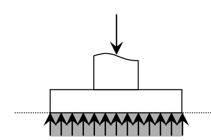


Actual vs. Design Soil Pressure

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



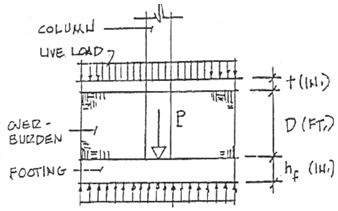
- linear stress distribution assumed



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

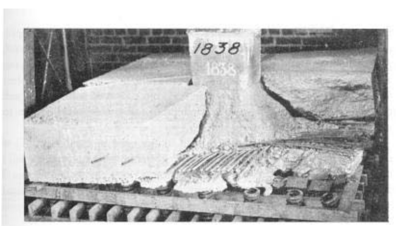


Figure 9.2 "Shear" failure in a spread footing loaded in a laboratory (Talbot, 1913). Observe how this failure actually is a combination of tension and shear.

shear

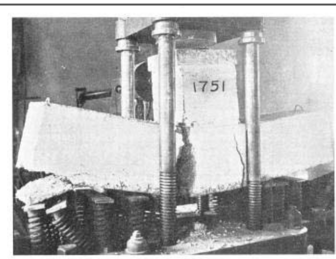
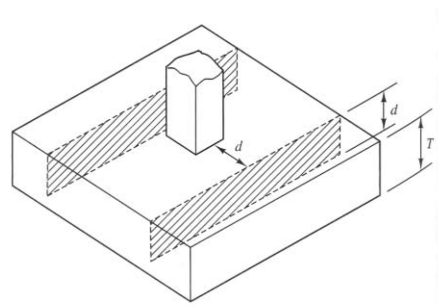


Figure 9.3 Flexural failure in a spread footing loaded in a laboratory (Talbot, 1913).

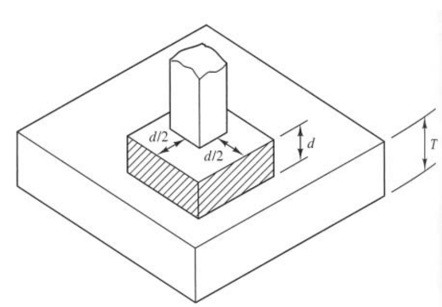
bending

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 $\dfrac{A_s}{bh} = 0.002\ \ grade\ 40/50\ bars$
    $= 0.0018\ \ grade\ 60\ bars$

Reinforcement Length

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

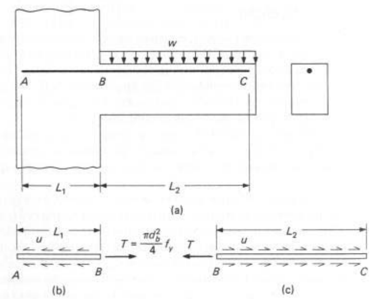


Figure 6.2.1 Development of reinforcement.

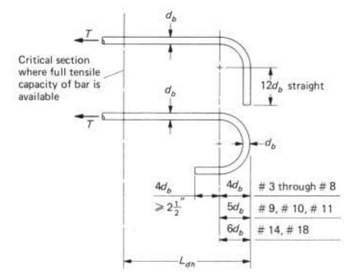
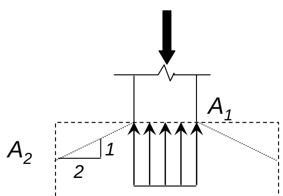


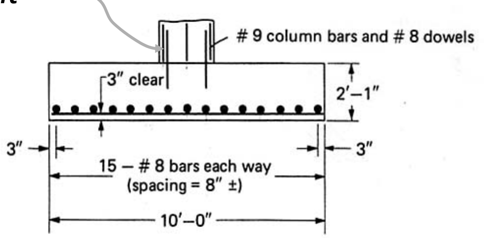
Figure 6.11.2 Development length L_{dh} for hooked bar.

Column Connection

- bearing of column on footing
  - $P_u \leq \phi P_n = \phi(0.85 f'_c A_1)$
    $\phi =$ 0.65 for bearing
  - confined: increase x $\sqrt{A_2/A_1} \leq 2$

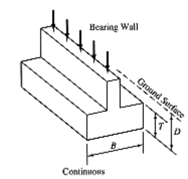


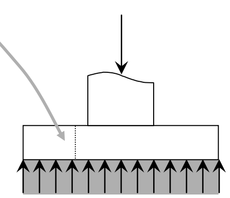
- dowel reinforcement
  - if $P_u > P_b$, need compression reinforcement
  - min of 4 - #5 bars (or 15 metric)



Wall Footings

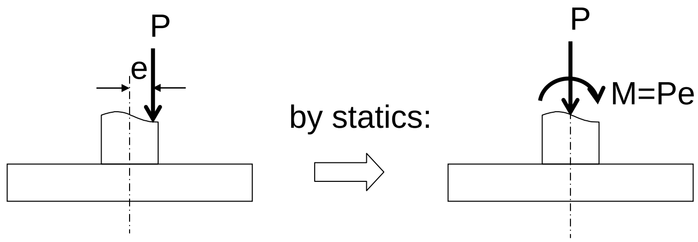
- continuous strip for load bearing walls
- plain or reinforced
- behavior
  - wide beam shear
  - bending of projection
- dimensions usually dictated by codes for residential walls
- light loads





Eccentrically Loaded Footings

- *footings subject to moments*

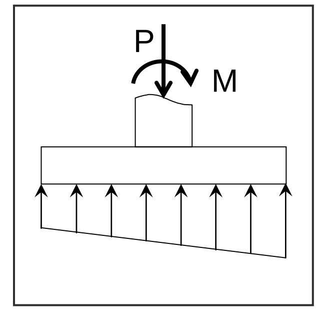


– *soil pressure resultant force may not coincide with the centroid of the footing*

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*

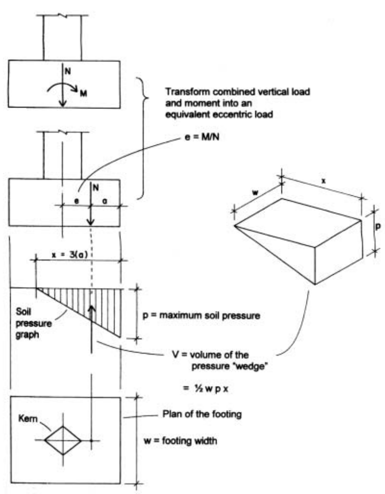


Kern Limit

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

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

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

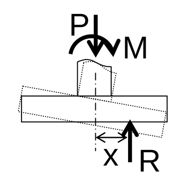


Guidelines

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

- *ensures stability with respect to overturning*

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



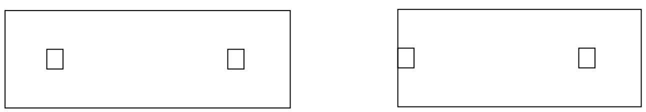
– *pressure under toe (maximum) $\leq q_a$*

– *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*

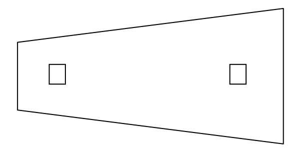
– *proportion so pressure will uniform for sustained loads*

– *behaves like beam lengthwise*

Combined Footing Types

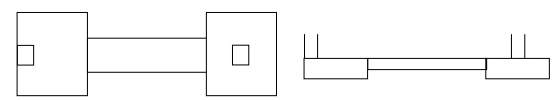
– *rectangular*

– *trapezoid*



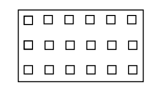
– *strap or cantilever*

- *prevents overturning of exterior column*



– *raft/mat*

- *more than two columns over an extended area*

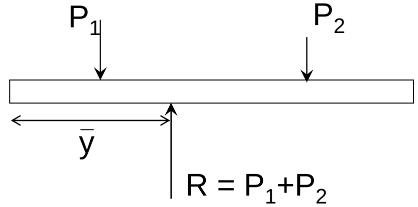


Proportioning

– *uniform settling is desired*

– *area is proportioned with sustained column loads*

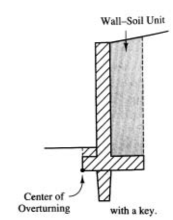
– *want the resultant to coincide with <u>centroid</u> of footing area for uniformly distributed pressure assuming a rigid footing*

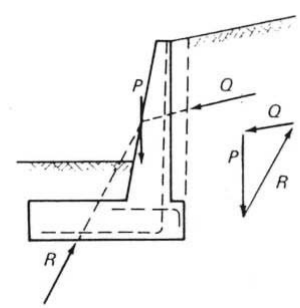


$$q_{max} \leq q_a$$

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)*

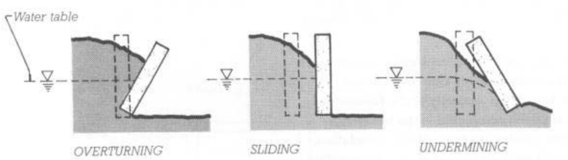
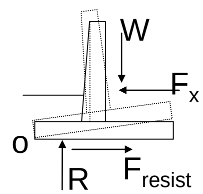


FIGURE 2.50
Three failure mechanisms in retaining walls.

Retaining Walls

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

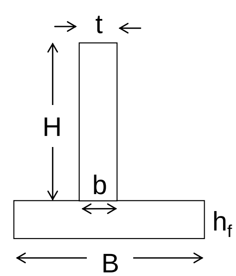


$$SF = \frac{M_{resist}}{M_{overturning}} \geq 1.5 - 2$$

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

Retaining Wall Proportioning

- *estimate size*
  - *footing size, B* $\approx$ *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*

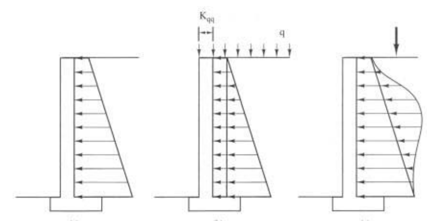
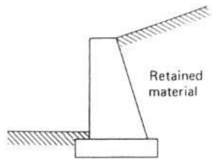


Figure 24.12 Typical loading diagrams for stem design: (a) with no surcharge loads; (b) with uniform surcharge load; (c) with point surcharge load.

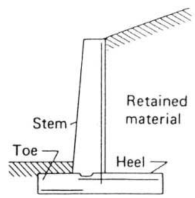
Retaining Wall Types

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



(a) Gravity wall

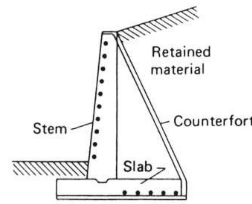
- *cantilever retaining wall*
  - *common*



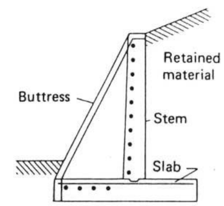
(b) Cantilever retaining wall

Retaining Wall Types

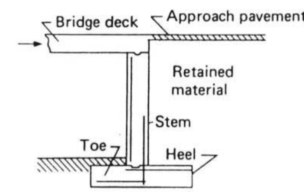
- *counterfort wall* } very tall walls (> 20 - 25 ft)
- *buttress wall*
- *bridge abutment*
- *basement frame wall (large basement areas)*



(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*

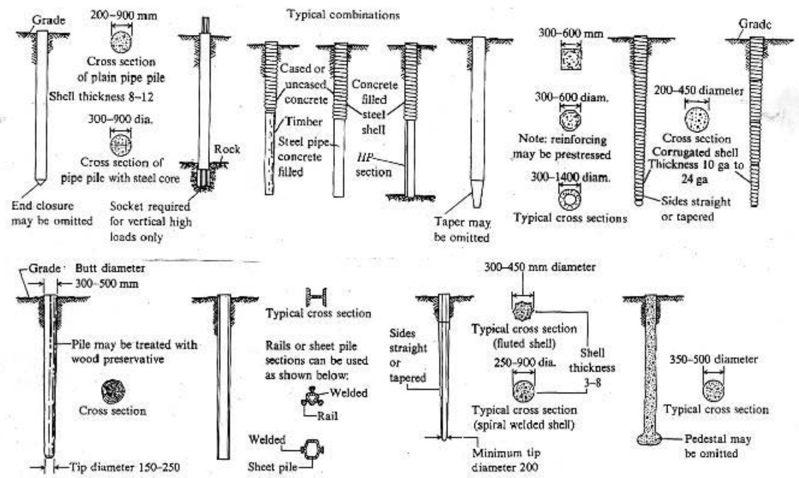
Deep Foundation Types

- *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

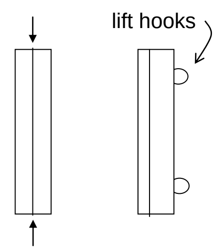


Deep Foundations

- *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*

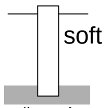


Piles Classified By Material

- *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*

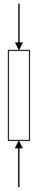
Piles Classified By Function

– *end bearing pile (point bearing)*



soft or loose layer

"socketed"

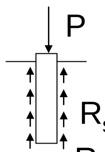


$P_a = A_p \cdot f_a$

R_p

for use in soft or loose materials over a dense base

– *friction piles (floating)*

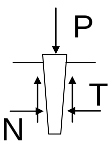


P

common in both clay & sand

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

$R_P \approx 0$



P T N

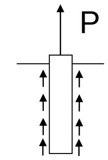
tapered: sand & silt

Piles Classified By Function

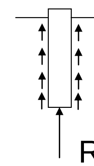
– *combination friction and end bearing*

– *uplift/tension piles*

structures that float, towers



P

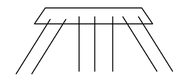


R_s

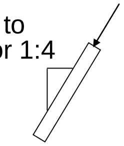
R_p

– *batter piles*

angled,
cost more,
resist large horizontal loads



1:12 to
1:3 or 1:4

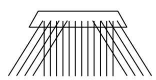


P

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*