ELEMENTS OF ARCHITECTURAL STRUCTURES:
FORM, BEHAVIOR, AND DESIGN
ARCH 614
DR. ANNE NICHOLS
SPRING 2013

lecture
twenty six

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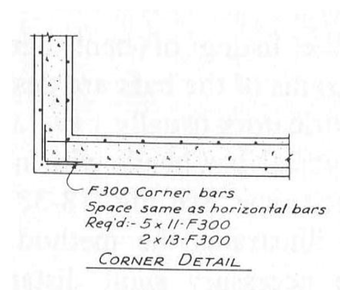
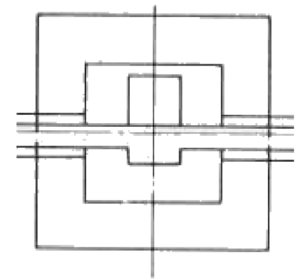
concrete construction: foundation design

Foundation

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



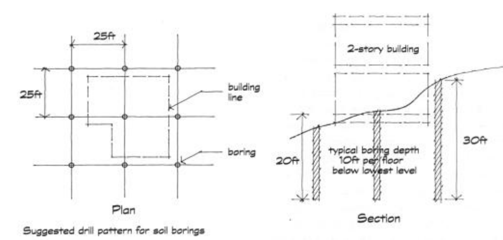


Structural vs. Foundation Design

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

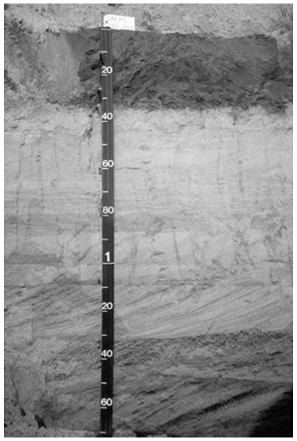
Structural vs. Foundation Design

- 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



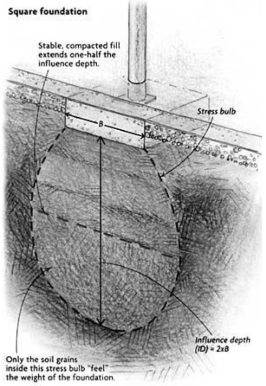
Soil Properties & Mechanics

- unit weight of soil
- allowable soil pressure
- factored net soil pressure
- shear resistance
- backfill pressure
- cohesion & friction of soil
- <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, $q_a = \frac{q_u}{S.F.}$



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Soil Properties & Mechanics

- strength, q_a

Table 1804.3
PRESUMPTIVE LOADBEARING VALUES OF FOUNDATION MATERIALS

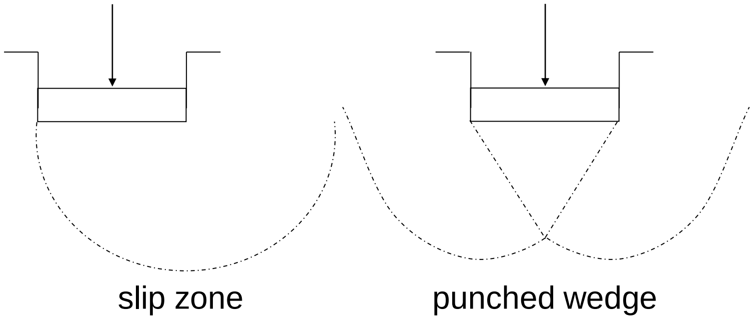
Class of material	Loadbearing pressure (pounds per square foot)[a]
1. Crystalline bedrock	12,000
2. Sedimentary rock	6,000
3. Sandy Gravel	5,000
4. Sand, silty sand, clayey sand, silty gravel and clayey gravel	3,000
5. Clay, sandy clay, silty clay & clayey silt	2,000

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*)

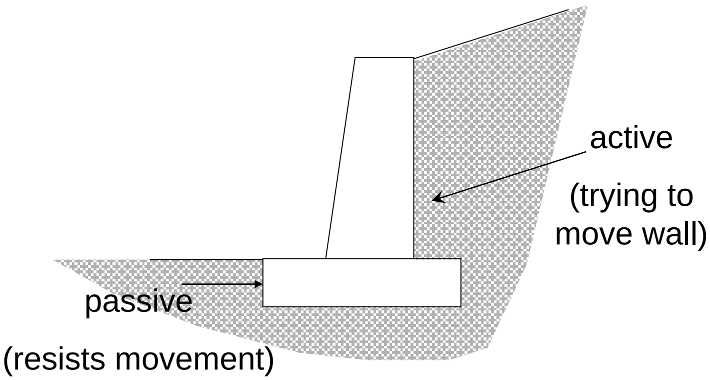
Bearing Failure

- 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

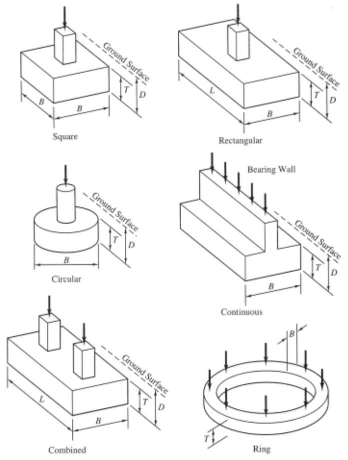
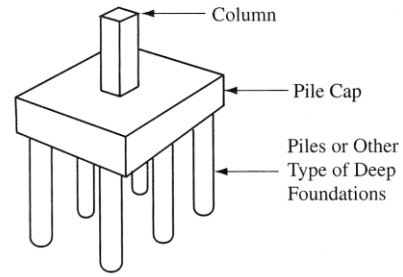


Figure 5.1 Spread footing shapes and dimensions.

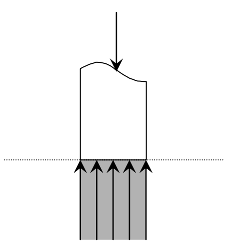
Types of Foundations

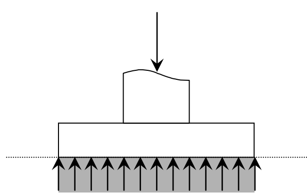


- mat foundations
- retaining walls
- basement walls
- pile foundations
- drilled piers

Shallow Footings

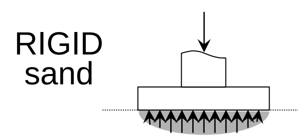
- spread footing
  - a square or rectangular footing supporting a single column
  - reduces stress from load to size the ground can withstand

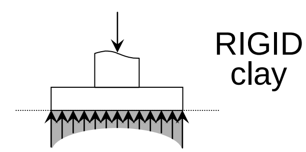




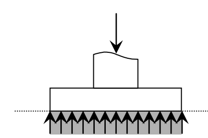
Actual vs. Design Soil Pressure

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





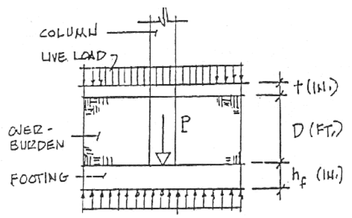
- linear stress distribution assumed



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

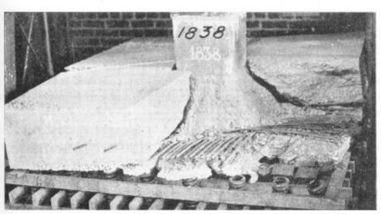


Figure 9.2 "Shear" failure in a spread footing loaded in a laboratory (Talbot, 1913). Observe how this failure actually is a combination of tension and shear.

shear

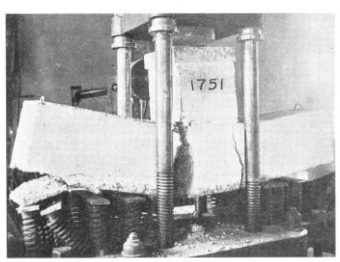
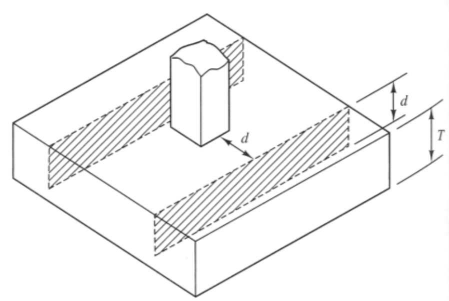


Figure 9.3 Flexural failure in a spread footing loaded in a laboratory (Talbot, 1913).

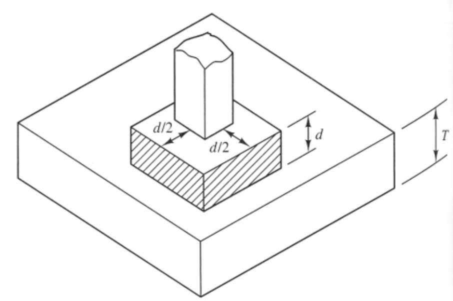
bending

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*

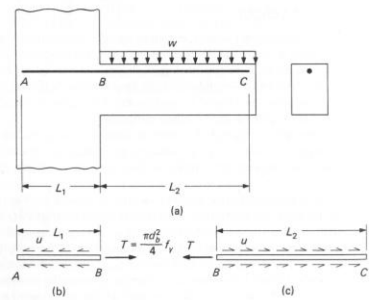


Figure 6.2.1 Development of reinforcement.

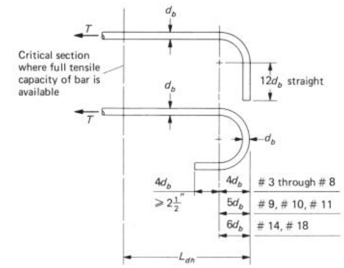
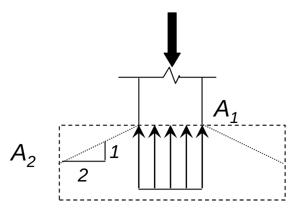


Figure 6.11.2 Development length L_{dh} for hooked bar.

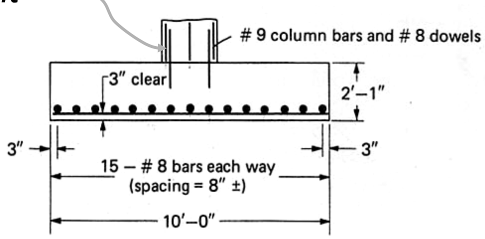
Column Connection

- *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* $\sqrt{A_2/A_1} \leq 2$

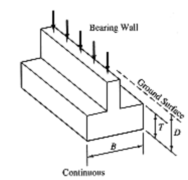


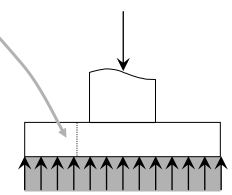
- *dowel reinforcement*
  - *if $P_u > P_b$, need compression reinforcement*
  - *min of 4 - #5 bars (or 15 metric)*



Wall Footings

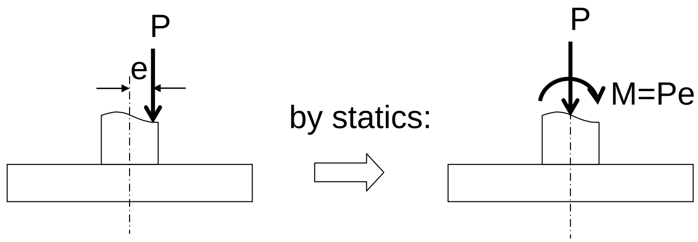
- *continuous strip for load bearing walls*
- *plain or reinforced*
- *behavior*
  - *wide beam shear*
  - *bending of projection*
- *dimensions usually dictated by codes for residential walls*
- *light loads*





Eccentrically Loaded Footings

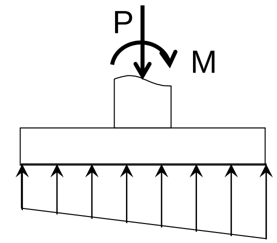
- *footings subject to moments*



– *soil pressure resultant force <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*



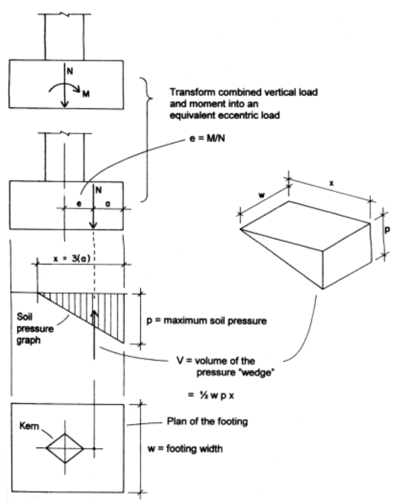
– *for rigid footing, simplification of soil pressure is a linear distribution based on constant ratio of pressure to settlement*

Kern Limit

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

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

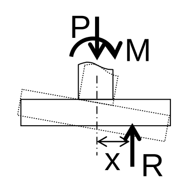
$$p_{\max} = \frac{2N}{wx}$$



Guidelines

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

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



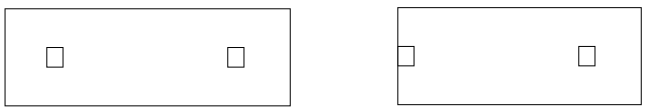
– *pressure under toe (maximum) $\leq q_a$*

– *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*

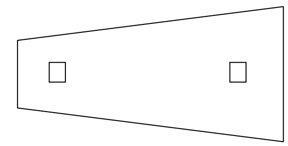
– *proportion so pressure will uniform for sustained loads*

– *behaves like beam lengthwise*

Combined Footing Types

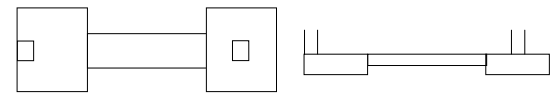
– *rectangular*

– *trapezoid*



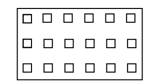
– *strap or cantilever*

- *prevents overturning of exterior column*



– *raft/mat*

- *more than two columns over an extended area*



Proportioning

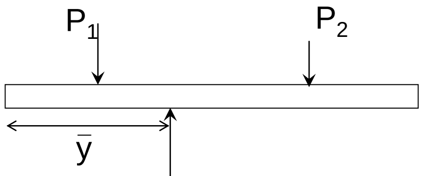
– *uniform settling is desired*

– *area is proportioned with sustained column loads*

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

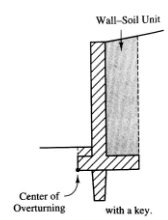
assuming a rigid footing

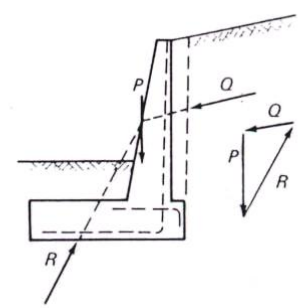
$$q_{max} \le q_a$$



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)*

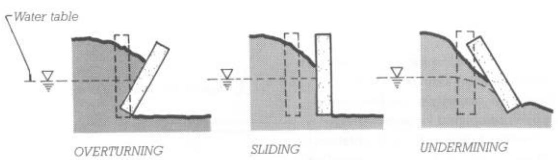
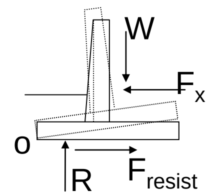


FIGURE 2.50
Three failure mechanisms in retaining walls.

Retaining Walls

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

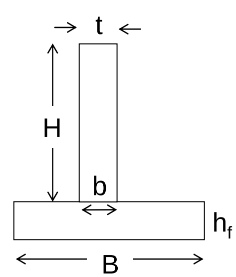


$$SF = \frac{M_{resist}}{M_{overturning}} \geq 1.5 - 2$$

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

Retaining Wall Proportioning

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

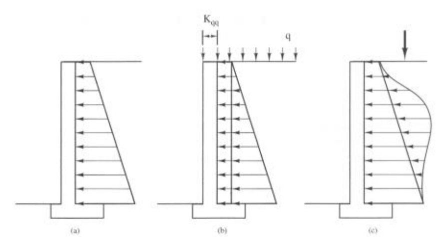
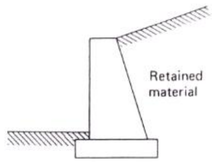


Figure 24.12 Typical loading diagrams for stem design: (a) with no surcharge loads; (b) with uniform surcharge load; (c) with point surcharge load.

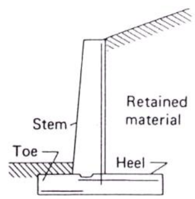
Retaining Wall Types

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



(a) Gravity wall

- *cantilever retaining wall*
  - *common*



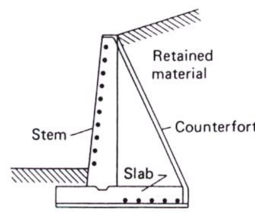
(b) Cantilever retaining wall

Retaining Wall Types

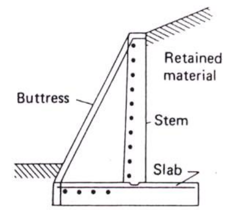
- *counterfort wall*
- *buttress wall*

} very tall walls (> 20 - 25 ft)

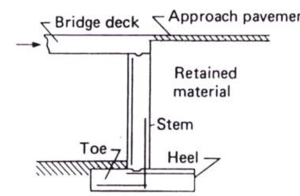
- *bridge abutment*
- *basement frame wall (large basement areas)*



(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

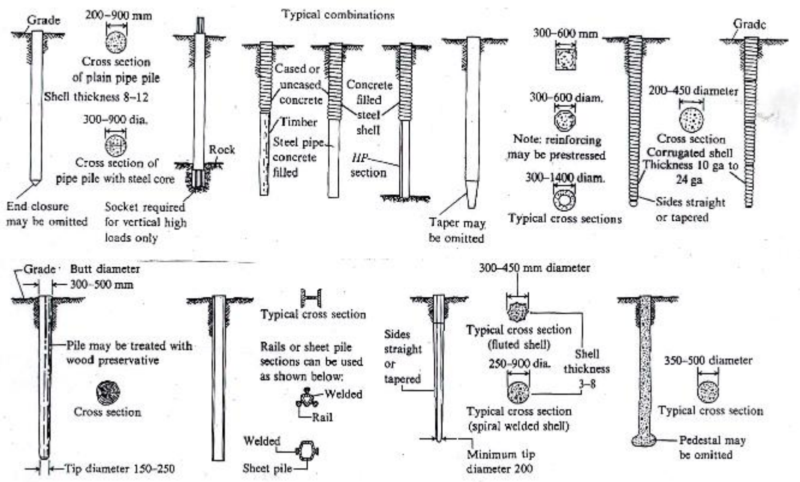
- *piles - usually driven, 6"-8"ϕ, 5' +*
- *piers*
- *caissons*
- *drilled shafts*
- *bored piles*

} *drilled, excavated, concreted (with or without steel)*

2.5' - 10'/12'ϕ

- *pressure injected piles*

Deep Foundation Types

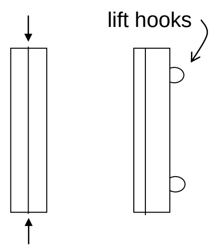


Deep Foundations

- 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

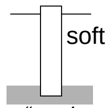


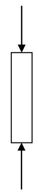
Piles Classified By Material

- 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

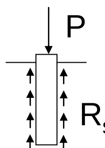
– *end bearing pile (point bearing)*



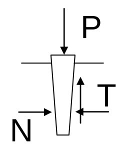


for use in soft or loose materials over a dense base

– *friction piles (floating)*



common in both clay & sand



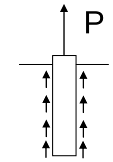
tapered: sand & silt

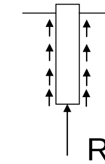
Piles Classified By Function

– *combination friction and end bearing*

– *uplift/tension piles*

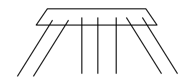
structures that float, towers



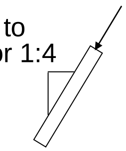


– *batter piles*

angled,
cost more,
resist large horizontal loads



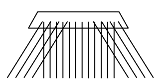
1:12 to 1:3 or 1:4



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*