APPLIED ARCHITECTURAL STRUCTURES:
STRUCTURAL ANALYSIS AND SYSTEMS

ARCH 631
DR. ANNE NICHOLS
FALL 2012

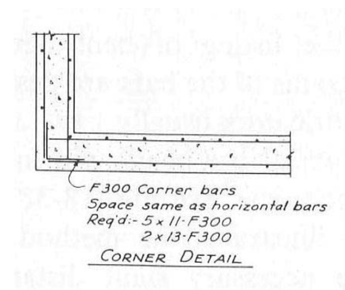
lecture
twenty four

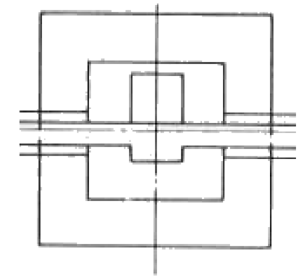
Bright Football Complex
www.tamu.edu

foundations and retaining walls

Foundation

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



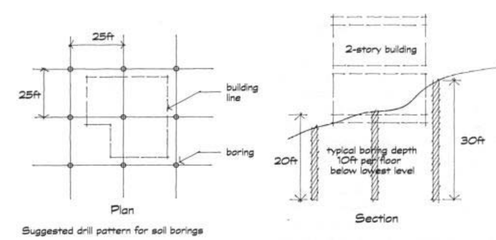


Structural vs. Foundation Design

- 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

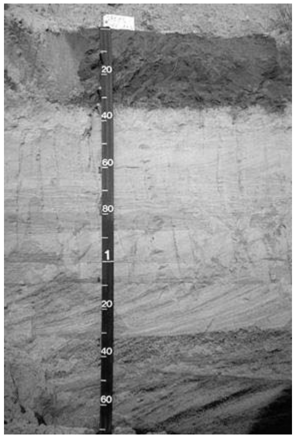


Design Assumptions

- validity dependant on:
  - quality of site investigation
  - construction monitoring
  - your experience
  - flexibility of the design

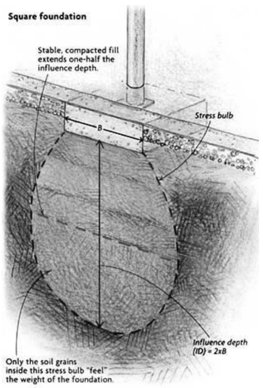
Soil Properties & Mechanics

- 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

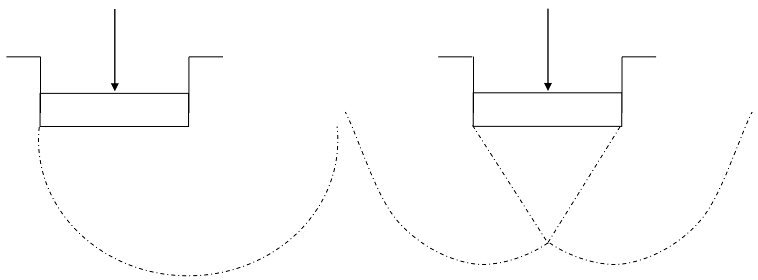
Class of material	Loadbearing pressure (pounds per square foot)[a]
1. Crystalline bedrock	12,000
2. Sedimentary rock	6,000
3. Sandy Gravel	5,000
4. Sand, silty sand, clayey sand, silty gravel and clayey gravel	3,000
5. Clay, sandy clay, silty clay & clayey silt	2,000

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*)

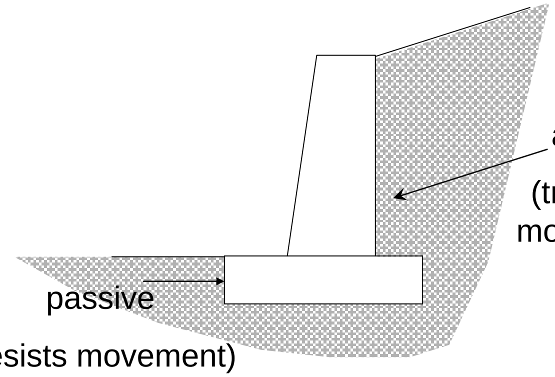
Bearing Failure

- *shear*



Lateral Earth Pressure

- *passive vs. active*



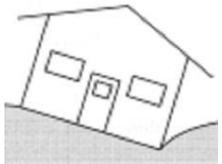
Settlements - Considerations

- *How do we estimate the amount for a given design?*
- *What are the tolerable movements?*
- *If our estimate is greater than the tolerable movement, what do we do?*

www.calculusfoundations.com

Settlements - Components

- *vertical*
  - *immediate (sands)*
  - *consolidation (clays)*
  - *secondary (organic soils/peats)*
- *tilting*
  - *eccentric loads*
  - *non-uniform stress distribution*
- *distortion* - $\frac{\Delta}{L}$



Excessive Settlement

- we can try
  - deeper foundation
  - alter structure
  - concrete/soil mat foundation
  - reduce the load
  - move the structure
  - modify the foundation type
  - modify the soil

Foundation Materials

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

Construction

- unique to type of footing
  - excavation
  - sheeting and bracing
  - water control (drainage/stabilization)
  - fill: placement & compaction
  - pile driver or hammer
  - caisson
  - underpinning (existing foundation)

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

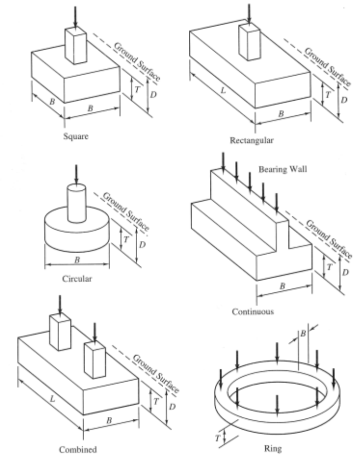
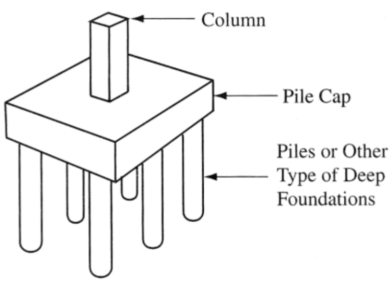


Figure 5.1 Spread footing shapes and dimensions.

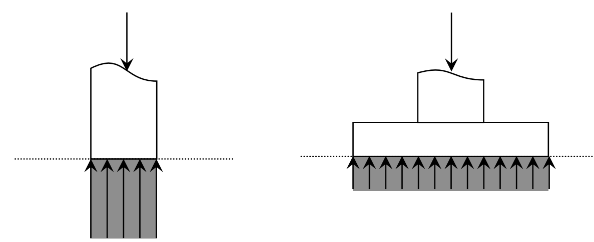
Types of Foundations



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

Shallow Footings

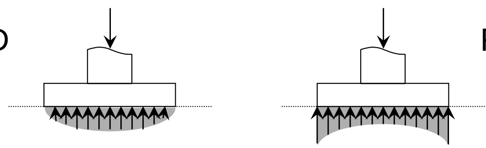
- spread footing
  - a square or rectangular footing supporting a single column
  - reduces stress from load to size the ground can withstand



Actual vs. Design Soil Pressure

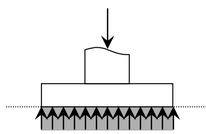
- *stress distribution is a function of*
  - *footing rigidity*
  - *soil behavior*

RIGID sand



RIGID clay

- *linear stress distribution assumed*



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*

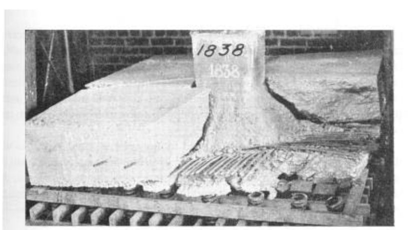


Figure 9.2 "Shear" failure in a spread footing loaded in a laboratory (Talbot, 1913). Observe how this failure actually is a combination of tension and shear.

shear

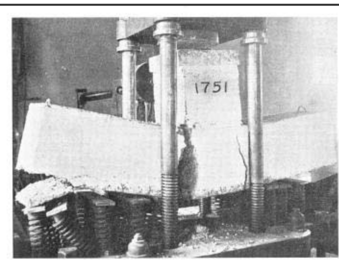
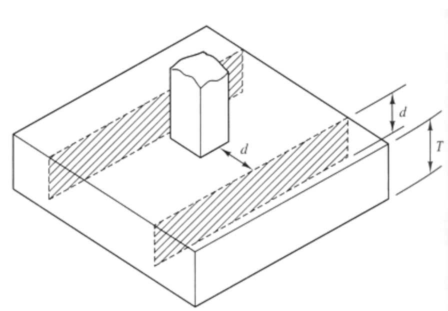


Figure 9.3 Flexural failure in a spread footing loaded in a laboratory (Talbot, 1913).

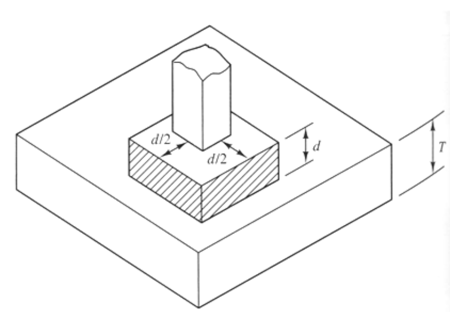
bending

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 $\rho = 0.75\rho_b$
  - 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

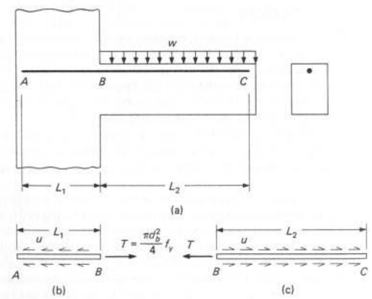


Figure 6.2.1 Development of reinforcement.

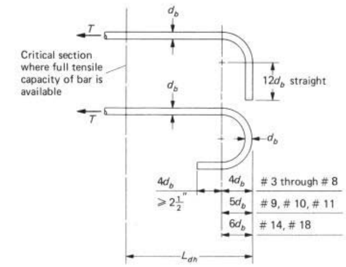
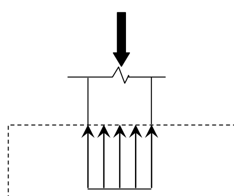


Figure 6.11.2 Development length L_{dh} for hooked bar.

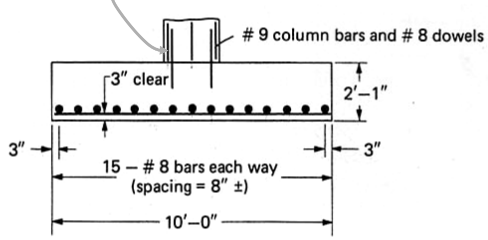
Column Connection

- bearing of column on footing
  - $P_u \leq \phi P_n = \phi(0.85 f'_c A_1)$

    ϕ = 0.65 for bearing

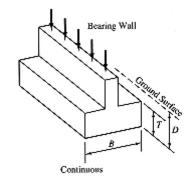


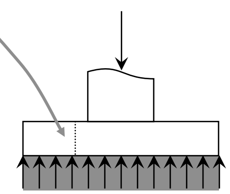
- dowel reinforcement
  - if $P_u > P_b$, need compression reinforcement
  - min of 4 - #5 bars (or 15 metric)



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



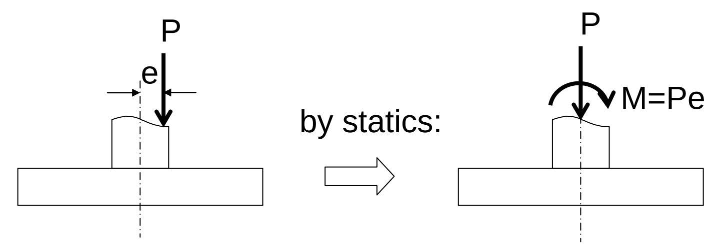


Wall Footings - plain vs. reinforced

- trade off in amounts of material
  - can save time if cost of extra concrete is justified (plain)
  - local codes may not allow plain footings
  - with same load, plain about twice as thick as minimally reinforced footing

Eccentrically Loaded Footings

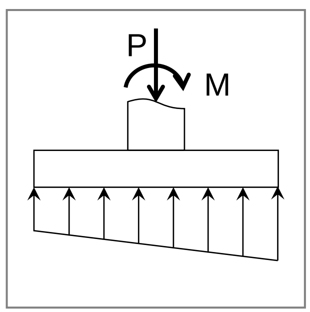
- footings subject to moments



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

Differential Soil Pressure

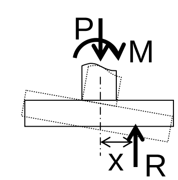
- to avoid large rotations, limit the differential soil pressure across footing
- for rigid footing, simplification of soil pressure is a linear distribution based on constant ratio of pressure to settlement



Guidelines

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

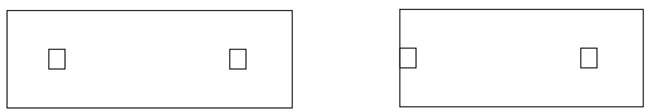
$$SF = \frac{M_{resist}}{M_{overturning}} = \frac{R \cdot x}{M} \geq 1.5$$



- pressure under toe (moment) $\leq q_a$
- shortcut using uniform soil pressure for design moments gives similar steel areas

Combined Footings

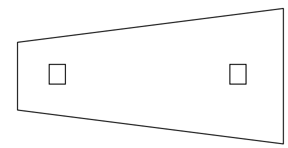
- supports two columns
- used when space is tight and spread footings would overlap or when at property line



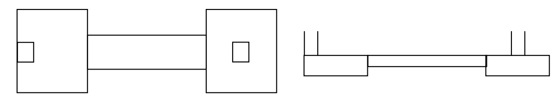
- soil pressure might not be uniform
- proportion so pressure will uniform for sustained loads
- behaves like beam lengthwise

Combined Footing Types

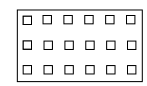
- rectangular
- trapezoid



- strap or cantilever
  - prevents overturning of exterior column

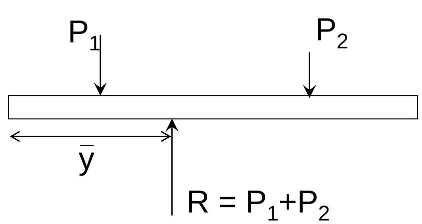


- raft/mat
  - more than two columns over an extended area



Proportioning

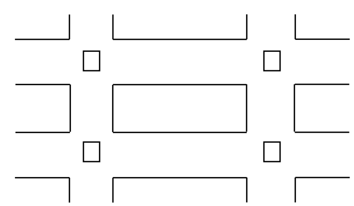
- uniform settling is desired
- area is proportioned with sustained column loads
- resultant coincides with centroid of footing area for uniformly distributed pressure assuming rigid footing



$$q_{max} \leq q_a$$

Multiple Column Footings

- used where bearing capacity of subsoil is so low that large bearing areas are needed
- grid foundation
  - continuous strips between columns
  - treat like rectangular combined footings with moment for beam



Multiple Column Footings

– when bearing capacity is even lower, strips in grid foundation merge into mat
  - upside down flat slab or plate

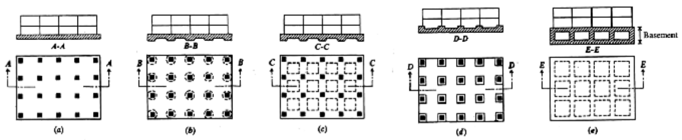


Figure 10-1 Common types of mat foundations. (a) Flat plate; (b) plate thickened under columns; (c) waffle slab; (d) plate with pedestals; (e) basement walls as part of mat.

Settling of Multiple Column Footings

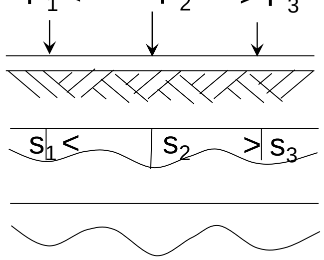
– use if we can't space columns such that the centroid of foundation coincides with load resultant

– geometry helps reduce differential settlement
  - variable soil
  - structure sensitive to differential settlements

Mat Foundations

– rigid foundations
  - soil pressures presumed linear

– flexible foundation
  - settlements and pressures no longer linear

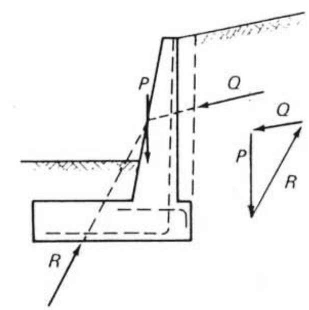


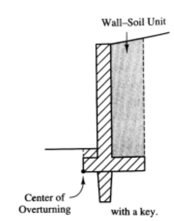
$q = k_s \cdot s$

k_s is a mechanical soil property

Retaining Walls

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



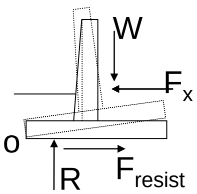


Retaining Walls

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

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

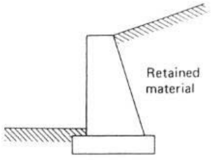
$$SF = \frac{F_{resist}}{F_{sliding}} \geq 1.25 - 2$$



- *procedure*
  - *proportion and check stability with working loads*
  - *design structure with factored loads*

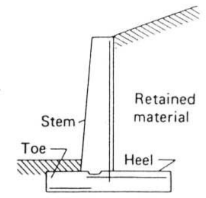
Retaining Wall Types

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



(a) Gravity wall

- *cantilever retaining wall*
  - *common*



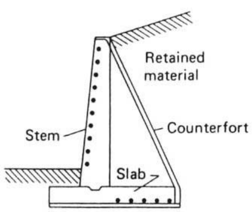
(b) Cantilever retaining wall

Retaining Wall Types

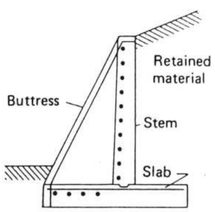
- *counterfort wall*
- *buttress wall*

} very tall walls (> 20 - 25 ft)

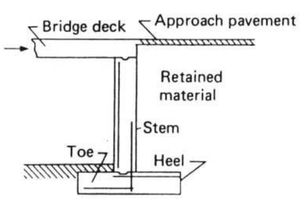
- *bridge abutment*
- *basement frame wall (large basement areas)*



(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*

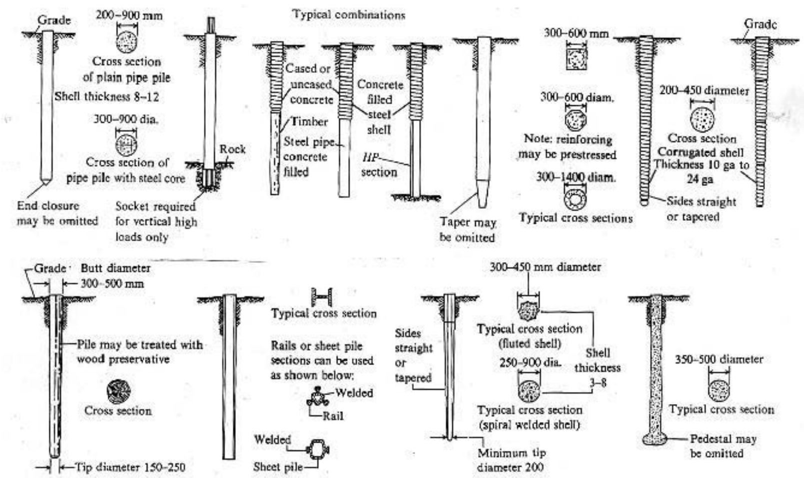
Deep Foundation Types

- 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

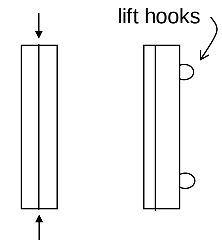


Deep Foundations

- 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

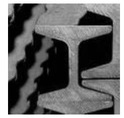
Piles Classified By Material

- 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

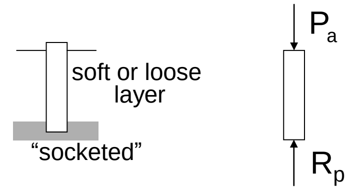
- *steel*



  – *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*

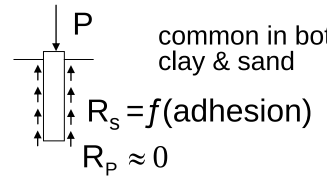
Piles Classified By Function

– *end bearing pile (point bearing)*

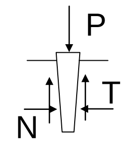


for use in soft or loose materials over a dense base

– *friction piles (floating)*



common in both clay & sand



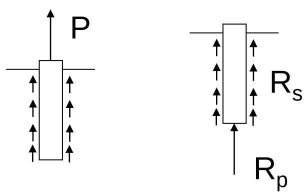
tapered: sand & silt

Piles Classified By Function

– *combination friction and end bearing*

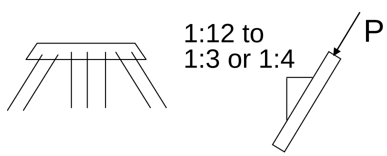
– *uplift/tension piles*

structures that float, towers



– *batter piles*

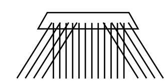
angled,
cost more,
resist large horizontal loads



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*