Foundations and retaining walls

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.

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

• 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

- compressibility
  - settlements

- strength
  - stability
    - shallow foundations
    - deep foundations
    - slopes and walls
  - ultimate bearing capacity, $q_u$
  - allowable bearing capacity, $q_a = \frac{q_u}{S.F.}$

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

- strength, $q_a$
Bearing Failure

- shear

![Diagram showing slip zone and punched wedge]

Lateral Earth Pressure

- passive vs. active

![Diagram showing active and passive forces]

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?

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

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

Concrete Spread Footings

- plain or reinforced
- ACI specifications
- $P_u = \text{combination of factored } D, L, W$
- 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
  - shear
  - 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 $\rho = 0.75 \rho_b$
  - minimum for slabs & footings of uniform thickness
    \[ \frac{A_s}{bh} = 0.002 \text{ grade } 40/50 \text{ bars} \]
    \[ = 0.0018 \text{ grade } 60 \text{ bars} \]

Reinforcement Length

- need length, $\ell_d$
  - bond
  - development of yield strength

Column Connection

- bearing of column on footing
  - $P_u \leq \phi P_n = \phi (0.85 f'c A_t)$
    \[ \phi = 0.65 \text{ for bearing} \]
- dowel reinforcement
  - if $P_u > P_b$, need compression reinforcement
  - min of 4 bars and 0.005$A_g$

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

\[
P \rightarrow M = Pe
\]

- 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

Guidelines

- want resultant of load from pressure inside the middle third of base
  - ensures stability with respect to overturning
  \[
  SF = \frac{M_{\text{resist}}}{M_{\text{overturning}}} = \frac{R \cdot x}{M} \geq 1.5
  \]
  
  - 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

\[ q_{\text{max}} \leq q_{\text{a}} \]

\[ R = P_1 + P_2 \]

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

![Image](https://example.com/image1.png)  
Figure 1: Common types of mat foundation. (a) For plan, (b) plan enclosed under column, (c) wall slab, (d) plan with potential of foundation walls as part of slab.

### 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

\[
P_1 < P_2 > P_3
\]

\[
s_1 < s_2 > s_3
\]

\[
q = k_s \cdot s
\]

\[k_s\] is a mechanical soil property

### Retaining Walls

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

![Image](https://example.com/image2.png)  
Figure 2: Retaining wall diagram.
Retaining Walls

• considerations
  – overturning
  – settlement
  – allowable bearing pressure
  – sliding

\[ SF = \frac{M_{\text{resist}}}{M_{\text{overturning}}} \geq 1.5 - 2 \]

– (adequate drainage)

• procedure
  – proportion and check stability with working loads
  – design structure with factored loads

Retaining Wall Types

• “gravity” wall
  – usually unreinforced
  – economical & simple

• cantilever retaining wall
  – common

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

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)
  \[ P_a = A_p \cdot f_s \]
  for use in soft or loose materials over a dense base

- friction piles (floating)

- combination friction and end bearing

- uplift/tension piles
  structures that float, towers

- batter piles
  angled, cost more, resist large horizontal loads

- 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