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 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

Foundation

• the engineered interface between the earth and the structure it supports that transmits the loads to the soil or rock
**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, $q_{a} = \frac{q_u}{S.F.}$

- 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
Bearing Failure

- shear

slip zone
punched wedge

Lateral Earth Pressure

- passive vs. active

active (trying to move wall)
passive (resists movement)

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
- \( P_u = \) 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
    \[ \frac{A_s}{bh} = 0.002 \text{ grade 40/50 bars} \]
    \[ = 0.0018 \text{ grade 60 bars} \]

Reinforcement Length

- need length, \( l_d \)
  - bond
  - development of yield strength

Column Connection

- bearing of column on footing
  \[ P_u \leq \phi P_n = \phi (0.85 f'_c A_t) \]
  \( \phi = 0.65 \) 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

  \[ M = Pe \]

  - 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

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

\[ R = P_1 + P_2 \]

**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

![Multiple Column Footings](image)

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
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

\[ SF = \frac{F_{\text{resist}}}{F_{\text{sliding}}} \geq 1.25 - 2 \]

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, excavated, concreted (with or without steel)
- drilled shafts
- bored piles 2.5’ - 10’/12’ φ
- 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)
  \[ R_s = f(\text{adhesion}) \]
  \[ R_p = 0 \]

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