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

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

Concrete Spread Footings

- shear failure
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, \( \ell_d \)
  - bond
  - development of yield strength

Column Connection

- bearing of column on footing
  - \( P_u < \phi P_n = \phi(0.85 f'_c A_t) \)
    \[ \phi = 0.65 \text{ for bearing} \]
- dowel reinforcement
  - if \( P_u > P_b \), need compression reinforcement
  - min of 4 - #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

Eccentically 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

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

\[ R = P_1 + P_2 \]

**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

**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
  
  \[ P_1 < P_2 > P_3 \]

  \[ S_1 < S_2 > S_3 \]

  \[ q = k_s \cdot s \]

  \[ k_s \text{ is a mechanical soil property} \]

**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

**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” Ø, 5’ +
- piers
- caissons
  - drilled, excavated, concreted (with or without steel)
- drilled shafts
- bored piles 2.5’ - 10’/12’ Ø
- 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)

\[
R_p \approx 0
\]

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