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
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, \( q_a \)

\[
q_a = \frac{q_u}{S.F.}
\]

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
Bearing Failure

- shear

slip zone

punched wedge

Lateral Earth Pressure

- passive vs. active

active

(resists movement)

passive

(trying to move wall)

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 - $\Delta \over L$
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
  \[ \frac{A_s}{bh} = 0.002 \text{ grade 40/50 bars} \]
  \[ = 0.0018 \text{ grade 60 bars} \]

Column Connection

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

Reinforcement Length

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

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 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

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**Combined Footing Types**

- rectangular
- trapezoid
- strap or cantilever
  - prevents overturning of exterior column
- raft/mat
  - more than two columns over an extended area

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**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

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

\[ R = P_1 + P_2 \]

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**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

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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

\[ P_1 < P_2 > P_3 \]

\[ q = k_s \cdot s \]

\( k_s \) 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

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” dia, 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)
  \[ R_s = f(\text{adhesion}) \]
  \[ R_p \approx 0 \]

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