Foundations 1
Lecture 23
Architectural Structures
ARCH 331
F2008abn

Foundations 2
Lecture 27
Architectural Structures
ARCH 331
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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
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, \( q_a = \frac{q_u}{S.F.} \)

Bearing Failure

- shear
Lateral Earth Pressure
• passive vs. active

![Diagram of lateral earth pressure with active and passive pressures]

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

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

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
Proportioning Footings

- net allowable soil pressure, $q_{net}$
  - $q_{net} = q_{allowable} - h_f(\gamma_c - \gamma_s)$
  - considers all extra weight (overburden) from replacing soil with concrete
  - can be more overburden
- design requirement with total unfactored load:
  $$\frac{P}{A} \leq q_{net}$$

Concrete Spread Footings

- failure modes
  - shear
  - bending

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
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 \( \rho \) from \( \varepsilon_{\text{steel}} \geq 0.004 \)
- 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
  \[ P_u \leq \phi P_n = \phi (0.85 f'_c A_1) \]
  \[ \phi = 0.65 \text{ for bearing} \]
  - confined: increase \( x \)
  \[ \frac{A_2}{A_1} \leq 2 \]
- 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
Eccentrically Loaded Footings

- footings subject to moments

\[ P \]

by statics:

\[ M = P e \]

- 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

Kern Limit

- boundary of e for no tensile stress

- triangular stress block with \( p_{\text{max}} \)

\[ \text{volume} = \frac{wp_x}{2} = N \]

\[ p_{\text{max}} = \frac{2N}{wx} \]

Guidelines

- want resultant of load from pressure inside the middle third of base (kern)

\[ SF = \frac{M_{\text{resist}}}{M_{\text{overturning}}} = \frac{R \cdot x}{M} \geq 1.5 \]

- pressure under toe (maximum) \( \leq q_a \)

- 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
- want the resultant to coincide with centroid of footing area for uniformly distributed pressure assuming a rigid footing

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

\[
R = P_1 + P_2
\]

**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)

Retaining Walls

- procedure
  - proportion and check stability with working loads for bearing, overturning and sliding
  - design structure with factored loads

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

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

Retaining Wall Proportioning

- estimate size
  - footing size, \( B \approx \frac{2}{5} - \frac{2}{3} \) wall height \((H)\)
  - footing thickness \( \approx \frac{1}{12} - \frac{1}{8} \) footing size \((B)\)
  - base of stem \( \approx \frac{1}{10} - \frac{1}{12} \) wall height \((H+h_f)\)
  - top of stem \( \geq 12'' \)

Retaining Walls Forces

- design like cantilever beam
  - \( V_u \) & \( M_u \) for reinforced concrete
  - \( V_u \leq \phi V_c : \phi = 0.75 \) for shear
  - \( M_u \leq \phi M_n : \phi = 0.9 \) for flexure
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

Retaining Wall Types

• counterfort wall
  – very tall walls (> 20 - 25 ft)

• buttress wall

• bridge abutment

• basement frame wall (large basement areas)

Deep Foundation Types

– piles - usually driven, 6”-8” ø, 5’ +
  – piers
  – caissons
  – drilled shafts
  – bored piles
  – pressure injected piles
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)**
  
  ![Diagram of end bearing pile]

  \[ P_a = A_p \cdot f_a \]

  for use in soft or loose materials over a dense base

- **friction piles (floating)**
  
  ![Diagram of friction piles]

  \[ R_s = f(adhesion) \]

  \[ R_p \approx 0 \]

  common in both clay & sand

  tapered: sand & silt

- **combination friction and end bearing**
  
  ![Diagram of combination friction and end bearing]

  \[ P \]

  uplift/tension piles

  structures that float, towers

- **batter piles**
  
  ![Diagram of batter piles]

  angled, cost more, resist large horizontal loads

  \[ P \]

  1:12 to 1:3 or 1:4

  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**
  
  ![Diagram of pile caps and grade beams]

- **more shear areas to consider**