Concrete Construction: Foundation Design

Architectural Structures: Form, Behavior, and Design
ARCH 331
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Lecture Twenty Three

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
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 showing active and passive forces](image)

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

Horizontal Footings

• 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

RIGID sand
RIGID clay
Proportioning Footings

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

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 \( A_{s,b,d} \)
  - \( \text{max } \rho \) from \( \varepsilon_{\text{steel}} \geq 0.004 \)
  - minimum for slabs & footings of uniform thickness
    \( \frac{A_s}{bh} = 0.002 \) grade 40/50 bars
    \( = 0.0018 \) grade 60 bars

Reinforcement Length

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

Column Connection

• bearing of column on footing
  - \( P_u \leq \phi P_n = \phi (0.85 f' c A_1) \)
  - \( \phi = 0.65 \) for bearing
  - confined: increase \( x \sqrt{\frac{A_2}{A_1}} \leq 2 \)
• 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
**Eccentrically Loaded Footings**

- footings subject to moments

  - soil pressure resultant force may not coincide with the centroid of the footing

\[ M = P e \]

- 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 \( p_{\text{max}} \)

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

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

**Guidelines**

- want resultant of load from pressure inside the middle third of base (kern)
  - 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 (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, \( B \) \( \approx \) 2/5 - 2/3 wall height (H)
  - footing thickness \( \approx \) 1/12 - 1/8 footing size (B)
  - base of stem \( \approx \) 1/10 - 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

Deep Foundation Types

- piles - usually driven, 6”-8” φ, 5’ +
  - piers
  - caissons
  - drilled shafts
  - bored piles
  - pressure injected piles

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

- buttress wall

- bridge abutment

- basement frame wall (large basement areas)
Deep Foundation Types

- 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)
  \[ P = A_p \cdot f_a \]
  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