concrete construction: foundation design

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
- 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, $q_a = \frac{q_u}{S.F.}$

Soil Properties & Mechanics

- strength, $q_a$

<table>
<thead>
<tr>
<th>Presumptive Loadbearing Values of Foundation Materials</th>
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<tbody>
<tr>
<td>Class of material</td>
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<tr>
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<tr>
<td>1. Claystone bedrock</td>
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<tr>
<td>2. Sedimentary rock</td>
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<td>3. Sandy Gravel</td>
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<tr>
<td>4. Sand, silty sand, clayey sand, silty gravel &amp; clayey gravel</td>
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<tr>
<td>5. Clay, clayey silty clay &amp; clayey silt</td>
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</tbody>
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Note: 1 psf = 47.9 Pa

Bearing Failure

- shear

- slip zone
- punched wedge
Lateral Earth Pressure

- passive vs. active

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

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 failure
    - one way shear
    - two way 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 $\varepsilon_{steel} \geq 0.004$
  - minimum for slabs & footings of uniform thickness
    $A_s = \frac{bh}{0.002 \text{ grade } 40/50 \text{ bars}}$
    $A_s = \frac{bh}{0.0018 \text{ grade } 60 \text{ bars}}$

Reinforcement Length

- need length, $\ell_d$
  - bond
  - development of yield strength

Column Connection

- bearing of column on footing
  - $P_u \leq \phi P_n = \phi (0.85 f'_{c} A_i)$
  - $\phi = 0.65$ 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

\[ P \]

\[ e \]

\[ M = P e \]

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

Eccentrically Loaded Footings

- footings subject to moments

\[ P \]

\[ e \]

\[ M = P e \]

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

\[ \text{volume} = \frac{w p x}{2} = N \]

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

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

\[ \begin{align*}
  V_u & \leq \phi V_c : \phi = 0.75 \text{ for shear} \\
  M_u & \leq \phi M_n : \phi = 0.9 \text{ for flexure}
\end{align*} \]
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” φ, 5’ +
  - 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
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- **piers**

- **caissons**

- **drilled shafts**
  - drilled, excavated, concreted (with or without steel)

- **bored piles**
  - 2.5’ - 10’/12’ φ

- **pressure injected piles**
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

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Piles Classified By Function

- end bearing pile (point bearing)
  - for use in soft or loose materials over a dense base
  - $P_a = A_p \cdot f_a$
  - $R_p \approx 0$
  - soft or loose layer
  - "socketed"

- friction piles (floating)
  - common in both clay & sand
  - $R_s = f(\text{adhesion})$
  - tapered: sand & silt

- combination friction and end bearing

- uplift/tension piles
  - structures that float, towers

- batter piles
  - angled, cost more, resist large horizontal loads
  - 1:12 to 1:3 or 1:4 angled

- 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