lecture twenty six

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.
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, \( q_a = \frac{q_u}{S.F.} \)

\[ S.F. = \frac{q_u}{q_a} \]
Soil Properties & Mechanics

- strength, $q_a$

Table 1804.3
PRESumptIVE LOADBEARING VALUES OF FOUNDATION MATERIALS

<table>
<thead>
<tr>
<th>Class of material</th>
<th>Loadbearing pressure (pounds per square foot) $^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Crystalline bedrock</td>
<td>12,000</td>
</tr>
<tr>
<td>2. Sedimentary rock</td>
<td>6,000</td>
</tr>
<tr>
<td>3. Sandy Gravel</td>
<td>5,000</td>
</tr>
<tr>
<td>4. Sand, silty sand, clayey sand, silty gravel and clayey gravel</td>
<td>3,000</td>
</tr>
<tr>
<td>5. Clay, sandy clay, silty clay &amp; clayey silt</td>
<td>2,000</td>
</tr>
</tbody>
</table>

**Note a.** 1 psf = 47.9 Pa.

**Figure 2.5**
Presumptive surface bearing values of various soils, as given in the BOCA National Building Code/1996. (Reproduced by permission)
Bearing Failure

- shear

slip zone

punched wedge
Lateral Earth Pressure

• passive vs. active
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
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
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

- plain or reinforced
- ACI specifications
- $P_u = \text{combination of factored } D, L, W$
- ultimate strength
  - $V_u \leq \phi V_c : \phi = 0.75 \text{ for shear}$
    - plain concrete has shear strength
  - $M_u \leq \phi M_n : \phi = 0.9 \text{ for flexure}$
Concrete Spread Footings

- failure modes

Figure 9.2  "Shear" failure in a spread footing loaded in a laboratory (Talbot, 1913). Observe how this failure actually is a combination of tension and shear.

Figure 9.3  Flexural failure in a spread footing loaded in a laboratory (Talbot, 1913).
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 \( \rho \) from \( \varepsilon_{\text{steel}} \geq 0.004 \)
  - minimum for slabs & footings of uniform thickness
    \[ \frac{A_s}{bh} = 0.002 \text{ grade } 40/50 \text{ bars} \]
    \[ = 0.0018 \text{ grade } 60 \text{ bars} \]
Reinforcement Length

- **need length,** $l_d$
  - bond
  - development of yield strength

Figure 6.2.1 Development of reinforcement.

Figure 6.11.2 Development length $L_{dh}$ for hooked bar.
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
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)
  - 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

\[ q_{\text{max}} \leq q_a \]
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
Retaining Wall Types

- **counterfort wall**
- **buttress wall**
- **bridge abutment**
- **basement frame wall** (large basement areas)

\( \{ \text{very tall walls (> 20 - 25 ft)} \)
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” $\phi$, 5’ +
- piers
- caissons
drilled, excavated, concreted (with or without steel)
- drilled shafts
- bored piles 2.5’ - 10’/12’ $\phi$
- pressure injected piles
Deep Foundation Types

- Cross section of plain pipe pile
  - Shell thickness 8–12
  - 300–900 dia.

- Cross section of pipe pile with steel core
  - End closure may be omitted
  - Socket required for vertical high loads only

- Typical combinations
  - Cased or uncased concrete
  - Timber
  - Steel pipe, concrete filled
  - HP section
  - Concrete filled steel shell

- Typical cross sections
  - 200–450 diameter
  - Cross section: Corrugated shell
  - Thickness: 10 ga to 24 ga
  - Sides straight or tapered

- Butt diameter
  - 300–500 mm

- Pile may be treated with wood preservative

- Typical cross section
  - Rails or sheet pile sections can be used as shown below:
  - Welded Rail

- Welded Sheet pile

- Tip diameter: 150–250

- 300–450 mm diameter

- Typical cross section
  - Fluted shell
  - Shell thickness: 3–8

- Typical cross section
  - Spiral welded shell
  - Minimum tip diameter: 200

- Pedestal may be omitted
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)

- For use in soft or loose materials over a dense base

\[ P_a = A_p \cdot f_a \]

- Common in both clay & sand

\[ R_p \approx 0 \]

– friction piles (floating)

- Tapered: sand & silt

\[ R_s = f(\text{adhesion}) \]
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