lecture twenty seven

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, $q_a = \frac{q_u}{S.F.}$
Soil Properties & Mechanics

- strength, $q_a$

### Table 1804.3

<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</td>
<td>3,000</td>
</tr>
<tr>
<td>gravel and clayey gravel</td>
<td></td>
</tr>
<tr>
<td>5. Clay, sandy clay, silty clay &amp; clayey</td>
<td>2,000</td>
</tr>
<tr>
<td>silt</td>
<td></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

(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
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, \( q_{\text{net}} \)**
  
  \[ q_{\text{net}} = q_{\text{allowable}} - h_f (\gamma_c - \gamma_s) \]
  
  - considers all extra weight (overburden) from replacing soil with concrete
  
  - can be more overburden

- **design requirement with total unfactored load:**
  
  \[ \frac{P}{A} \leq q_{\text{net}} \]
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.

shear

Figure 9.3  Flexural failure in a spread footing loaded in a laboratory (Talbot, 1913).

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** \( \rho \) **from** \( \varepsilon_{steel} \geq 0.004 \)
- **minimum for slabs & footings of uniform thickness**
  \[ \frac{A_s}{bh} = 0.002 \quad \text{grade 40/50 bars} \]
  \[ = 0.0018 \quad \text{grade 60 bars} \]
Reinforcement Length

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

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**Figure 6.2.1** Development of reinforcement.

**Figure 6.11.2** Development length $L_{dn}$ for hooked bar.
Column Connection

- bearing of column on footing
  \[ P_u \leq \phi P_n = \phi (0.85 f_c' A_1) \]
  \[ \phi = 0.65 \text{ for bearing} \]
  - confined: increase \( \sqrt{\frac{A_2}{A_1}} \leq 2 \)

- dowel reinforcement
  - if \( P_u > P_b \), need compression reinforcement
  - min of 4 - #5 bars (or 15 metric)

\[
A_{fc} \leq \frac{P}{f_y}
\]
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

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

- 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

[Diagram of retaining wall with soil, forces, and key]
Retaining Walls

- overturning
- settlement
- allowable bearing pressure
- sliding
- (adequate drainage)

Figure 2.50
Three failure mechanisms in retaining walls.
Retaining Walls

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

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

\[
SF = \frac{F_{horizontal\text{-resist}}}{F_{sliding}} \geq 1.25 - 2
\]
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
- $V_u \leq \phi V_c : \phi = 0.75$ for shear
- $M_u \leq \phi M_n : \phi = 0.9$ for flexure

Figure 24.12 Typical loading diagrams for stem design: (a) with no surcharge loads; (b) with uniform surcharge load; (c) with point surcharge load.
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)

very tall walls (> 20 - 25 ft)
Deep Foundations

- 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 shafts
- bored piles
- pressure injected piles

Deep Foundation Types

- Drilled, excavated, concreted (with or without steel)
- 2.5’ - 10’/12’ $\phi$
Deep Foundation Types

- **Deep Foundation Types**

  - **Sides straight or tapered**
  - **Grade**: Butt diameter 300-500 mm
  - **Pile may be treated with wood preservative**
  - **Cross section**: 150-250
  - **Tip diameter**: 150-250

- **Typical cross section**
  - **Welded Rail**
  - **Sheet pile**

- **Grade**: 300-450 mm diameter

- **Typical cross section (fluted shell)**
  - **Sides straight or tapered**
  - **Shell thickness**: 3-8
  - **Minimum tip diameter**: 200

- **Grade**: 200-450 diameter
  - **Cross section**: Corrugated shell
  - **Thickness**: 10 ga to 24 ga
  - **Sides straight or tapered**

- **Grade**: 300-600 mm
  - **Note**: reinforcing may be prestressed
  - **300-1400 diam.**

- **Typical cross sections**

**Foundations 41**
Lecture 27

**Architectural Structures**
ARCH 331
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

lift hooks
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)**

  - Soft or loose layer
  - "socketed"

  \[ P_a = A_p \cdot f_a \]
  
  For use in soft or loose materials over a dense base

- **friction piles (floating)**

  - Common in both clay & sand
  - \( R_s = f(\text{adhesion}) \)
  - \( R_p \approx 0 \)

  - Tapered: sand & silt
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