lecture

tyen three

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
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

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

Figure 5.1 Spread footing shapes and dimensions.
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.

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 \( \varepsilon_{\text{steel}} \geq 0.004 \)
  - 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, $l_d$
  - bond
  - development of yield strength
Column Connection

- **bearing of column on footing**
  - \( P_u \leq \phi P_n = \phi \left( 0.85 f'_c A_1 \right) \)
  - \( \phi = 0.65 \) 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 $p_{\text{max}}$

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

\[
\begin{align*}
   p_{\text{max}} &= \frac{2N}{wx} \\
   w &= \text{footing width}
\end{align*}
\]
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, $B \approx 2/5 - 2/3$ 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

![Diagram of retaining walls forces](image)

*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

- 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

Drilled, excavated, concreted (with or without steel)

2.5’ - 10’/12’ φ
Deep Foundation Types

- **Grade**: 200–900 mm
- **Cross section of plain pipe pile**: Shell thickness 8–12
- **Cross section of pipe pile with steel core**: 300–900 dia.
- **End closure may be omitted**: Socket required for vertical high loads only
- **Pile may be treated with wood preservative**: Butt diameter 300–500 mm
- **Tip diameter**: 150–250
- **Typical combinations**:
  - Cased or uncased concrete
  - Concrete filled steel shell
  - Rock
  - Steel pipe concrete filled
  - Timber
  - HP section
  - Taper may be omitted
- **Typical cross sections**:
  - 300–600 mm
  - 300–600 diam.
  - Note: reinforcing may be prestressed
  - 300–1400 diam.
- **Cross section**:
  - Corrugated shell
  - Thickness 10 ga to 24 ga
  - Sides straight or tapered
- **Typical cross section**:
  - 300–450 mm diameter
  - 300–900 dia.
  - Shell thickness 3–8
  - Minimum tip diameter 200

- **Welded Rail**
- **Sheet pile**
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)

- soft or loose layer
- "socketed"

\[ P_a = A_p \cdot f_a \]

for use in soft or loose materials over a dense base

\[ R_p \approx 0 \]

– friction piles (floating)

- common in both clay & sand

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

- 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