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</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 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

(trying to move wall)

(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

[Diagram showing actual vs. design soil pressure for RIGID sand and RIGID clay]
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
  - $V_u \leq \phi V_c : \phi = 0.75$ for shear
    - plain concrete has shear strength
  - $M_u \leq \phi M_n : \phi = 0.9$ 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
    \[ \frac{A_s}{bh} = 0.002 \text{ grade 40 / 50 bars} \]
    \[ = 0.0018 \text{ grade 60 bars} \]
Reinforcement Length

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

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**
  
  \[ P_u \leq \phi P_n = \phi \left(0.85 f'_c A_1\right) \]
  
  \[ \phi = 0.65 \text{ for bearing} \]

  - 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

\[ M = P e \]
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 \( p_{max} \)

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

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

\[ q_{\text{max}} \leq q_a \]
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

*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, excavated, concreted (with or without steel)
- drilled shafts
- bored piles
  - 2.5’ - 10’/12’ φ
- pressure injected piles
Deep Foundation Types

- **Grade**: 200–900 mm
  - 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 filled
  - Concrete filled steel shell
  - HP section
  - Taper may be omitted

- **Note**: reinforcing may be prestressed
  - 300–1400 diam.

- **300–600 mm**
  - Cross section
  - Corrugated shell
  - Thickness 10 ga to 24 ga
  - Sides straight or tapered

- **300–600 diam.**
  - Sides straight or tapered

- **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

- **350–500 diameter**
  - Typical cross section

- **Grade**
  - Butt diameter
  - 300–500 mm

- **Pile may be treated with wood preservative**
  - Cross section
  - Tip diameter 150–250

- **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

\[ R_p \]

– 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