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)</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, \( q_{\text{net}} \)**
  - \( q_{\text{net}} = q_{\text{allowable}} - h_f (\gamma_c - \gamma_s) \)
  - 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
  – $V_u \leq \phi V_c : \phi = 0.75$ 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

\[ \frac{A_s}{bh} = 0.002 \quad \text{grade 40/50 bars} \]
\[ = 0.0018 \quad \text{grade 60 bars} \]
Reinforcement Length

- need length, \( l_d \)
  - bond
  - development of yield strength
Column Connection

- **bearing of column on footing**
  - \( P_u \leq \phi P_n = \phi (0.85 f'_c A_1) \)
  - \( \phi = 0.65 \) 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

\[ M = P e \]

- 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 $p_{\text{max}}$

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

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

- 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

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

\[
SF = \frac{F_{horizontal-resist}}{F_{sliding}} \geq 1.25 - 2
\]
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)
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
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
Concrete filled steel shell

300–600 mm
300–600 diam.
Note: reinforcing may be prestressed
300–1400 diam.

Taper may be omitted

Typical cross sections

Grade 300–500 mm
 Butt diameter

Pile may be treated with wood preservative
Cross section

Tip diameter 150–250

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

Sides straight or tapered

Typical cross section (fluted shell)
250–900 dia.
Shell thickness 3–8

Minimum tip diameter 200

Typical cross section (spiral welded shell)

Pedestal may be omitted

Grade 200–450 diameter
Cross section
Corrugated shell
Thickness 10 ga to 24 ga

Sides straight or tapered

Grade 300–450 mm diameter

Typical cross section
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”
- for use in soft or loose materials over a dense base

\[ P_a = A_p \cdot f_a \]

\[ R_p \]

Piles Classified By Function

– friction piles (floating)

- common in both clay & sand

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

\[ R_p \approx 0 \]

- tapered: sand & silt

\[ P \]

\[ N \]

\[ T \]
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