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

Suggested drill pattern for soil borings
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](image)

**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 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

RIGID sand

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
  – $V_u \leq \phi V_c : \phi = 0.75 \text{ for shear}$
    • 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

bending

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 \( \varepsilon_{steel} \geq 0.004 \)

– 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
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

\[ M = Pe \]

- 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 $p_{\text{max}}$

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

\[ p_{\text{max}} = \frac{2N}{wx} \]
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) ≤ \( q_a \)
– 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 shafts
- bored piles
- pressure injected piles

Drilled, excavated, concreted (with or without steel)
2.5’ - 10’/12’ φ
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
  - Concrete filled steel shell
  - Timber
  - Steel pipe, concrete filled
  - Taper may be omitted
- Typical cross sections
  - 300–600 mm
  - 300–600 diam.
  - Note: reinforcing may be prestressed
  - 300–1400 diam.
  - Sides straight or tapered
  - Typical cross section
    - Corrugated shell
    - Thickness 10 ga to 24 ga

- Butt diameter
  - 300–500 mm
- Pile may be treated with wood preservative
  - Cross section
  - Tip diameter 150–250
- Rail or sheet pile sections can be used as shown below:
  - Welded
  - Rail
- Typical cross section
  - 300–450 mm diameter
- Typical cross section (fluted shell)
  - 250–900 dia.
  - 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)

- 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)

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

\[ R_p \approx 0 \]

common in both clay & sand

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