Foundations

- the engineered interface between the earth and the structure it supports that transmits the loads to the soil or rock

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

- **structural design**
  - choice of materials
  - choice of framing system
  - uniform materials and quality assurance
  - design largely independent of geology, climate, etc.
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, \( q_a = \frac{q_u}{S.F.} \)

Bearing Failure

- shear

---

Table 1804.3

<table>
<thead>
<tr>
<th>Class of material</th>
<th>Loadbearing pressure (pounds per square foot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Gravel material</td>
<td>12,000</td>
</tr>
<tr>
<td>2. Sedimentary rock</td>
<td>5,000</td>
</tr>
<tr>
<td>3. Sandy Gravel</td>
<td>3,000</td>
</tr>
<tr>
<td>4. Sand, silty sand, clayey sand, silty</td>
<td>2,000</td>
</tr>
<tr>
<td>5. Clay, sandy clay, silty clay &amp; clayey silt</td>
<td>12,000</td>
</tr>
</tbody>
</table>

Note: 1 psf = 47.9 Pa
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

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

- failure modes
  - shear
  - bending

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
  - \( M_u \leq \phi M_n : \phi = 0.9 \text{ for flexure} \)
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

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 bars and 0.005\( A_g \)

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

  ![Diagram of eccentrically loaded footing](image)

  \[ M = P e \]

  - 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

  ![Diagram of differential soil pressure](image)

  - 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

  ![Diagram of kern limit](image)

- triangular stress block with \( p_{\text{max}} \)

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

**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) \( \leq q_{\text{a}} \)

  - 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

\[ q_{max} \leq q_a \]

\[ R = P_1 + P_2 \]

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 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

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

$SF = \frac{F_{horizontal-resist}}{F_{sliding}} \geq 1.25 - 2$
Retaining Wall Types

- “gravity” wall
  - usually unreinforced
  - economical & simple

- cantilever retaining wall
  - common

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

Retaining Wall Types

- counterfort wall
  { very tall walls (> 20 - 25 ft)

- buttress wall

- bridge abutment

- basement frame wall (large basement areas)

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)

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

- 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

Deep Foundations

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)**
  - $P_a = A_p \cdot f_a$
  - for use in soft or loose materials over a dense base
  - soft or loose layer
  - "socketed"

- **friction piles (floating)**
  - common in both clay & sand
  - tapered: sand & silt
  - $R_s = f(\text{adhesion})$
  - $R_p \approx 0$

**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

1:12 to 1:3 or 1:4

**Pile Caps and Grade Beams**

- 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)

- like multiple column footing

- more shear areas to consider