**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.

- **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

- strength, \( q_a \)

<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: 1 psi = 41.9 Pa.

Bearing Failure

- shear

- shear

- slip zone

- punched wedge

- ultimate bearing capacity, \( q_u \)
- allowable bearing capacity, \( q_a = \frac{q_u}{S.F.} \)
Lateral Earth Pressure

- passive vs. active

![Diagram showing active and passive lateral earth pressure](active.png)

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

- mat foundations
- retaining walls
- basement walls
- pile foundations
- drilled piers
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

- failure modes

Concrete Spread Footings

- shear failure

Concrete Spread Footings

- plain or reinforced
- ACI specifications
- $P_u =$ 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
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
  \[ \frac{A_s}{bh} = 0.002 \text{ grade } 40/50 \text{ bars} \]
  \[ = 0.0018 \text{ grade 60 bars} \]

Reinforcement Length

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

Column Connection

- bearing of column on footing
  \[ P_d \leq \phi P_n = \phi (0.85 f'_c A_1) \]
  \[ \phi = 0.65 \text{ for bearing} \]
  - confined: increase \( x \sqrt{\frac{A_2}{A_1}} \leq 2 \)
- dowel reinforcement
  - if \( P_d > P_b \), 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

\[ P \]

- 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 \( p_{\text{max}} \)

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

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

**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) \( \leq q_{ta} \)

- 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

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

\[ R = P_1 + P_2 \]

**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 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
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

– piers
  – caissons
  – drilled shafts
  – bored piles
  – pressure injected piles

– drilled, excavated, concreted (with or without steel)

– 2.5’ - 10’/12’ φ
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

- **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

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### Piles Classified By Function

- **end bearing pile (point bearing)**
  
  ![End Bearing Pile Diagram]

  \[ P_a = A_p \cdot f_a \]

  - soft or loose layer
  - "socketed"

  \[ R_p \approx 0 \]

- **friction piles (floating)**

  ![Friction Pile Diagram]

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

  \[ R_p \]

- **combination friction and end bearing**

  ![Combination Pile Diagram]

  \[ P \]

- **uplift/tension piles**

  ![Uplift/Tension Pile Diagram]

  \[ R_s \]

- **batter piles**

  ![Batter Pile Diagram]

  angled, cost more, resist large horizontal loads

- **fender piles, dolphins, pile clusters**

  ![Fender Piles Diagram]

  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**

  ![Pile Caps Diagram]

- **more shear areas to consider**