concrete construction: 
foundation design

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

• 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
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, \( q_a = \frac{q_u}{S.F.} \)

Strength, \( q_a \)

![Strength Table](image1)

Bearing Failure

- shear

![Shear Diagram](image2)
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

Types of Foundations

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

- **shear failure**
  - one way shear
  - two way shear

**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 \( \frac{A_s}{bh} = 0.002 \) grade 40/50 bars
    \( = 0.0018 \) 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

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

\[ \begin{align*}
& P \\
& e \\
& M = Pe \\
& \text{by statics:}
\end{align*} \]

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

- 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

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

\[ R = P_1 + P_2 \]

**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 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

• 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 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” \( \phi \), 5’ +

– piers

– caissons \{ drilled, excavated, concreted (with or without steel) \}

– drilled shafts

– bored piles
  \{ 2.5’ - 10’/12’ \( \phi \) \}

– pressure injected piles
Deep Foundation Types

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

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

• 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)**

  ![Diagram](image1)

  

  $P_a = A_p \cdot f_a$

  for use in soft or loose materials over a dense base

  $R_p \approx 0$

- **friction piles (floating)**

  ![Diagram](image2)

  $R_s = f(\text{adhesion})$

  $P$ common in both clay & sand

  tapered: sand & silt

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

  ![Diagram](image3)

  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**