Foundations

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

Foundation

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, \( q_a \)

**Bearing Failure**

- shear

![Table 1804.3: Presumptive Loadbearing Values of Foundation Materials](image)

- slip zone
- punched wedge
Lateral Earth Pressure

- passive vs. active

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

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

Reinforcement Length

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

Column Connection

- bearing of column on footing
  \[ P_u \leq \phi P_n = \phi (0.85 f'_c A_1) \]
  \[ \phi = 0.65 \text{ for bearing} \]
  - confined: increase \( \sqrt{\frac{A_2}{A_1}} \leq 2 \)
- 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

\[ P \]

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

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

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

**Guidelines**

- want resultant of load from pressure inside the middle third of base (kern)
  - ensures stability with respect to overturning

\[ SF = \frac{M_{\text{resist}}}{M_{\text{overturning}}} = \frac{R \cdot x}{M} \geq 1.5 \]

- 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

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

\[ R = P_1 + P_2 \]

**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 ≈ 2/5 - 2/3 wall height (H)
  – footing thickness ≈ 1/12 - 1/8 footing size (B)
  – base of stem ≈ 1/10 - 1/12 wall height (H+h_f)
  – top of stem ≥ 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 ≤ φV_c : φ = 0.75 for shear
  – M_u ≤ φM_n : φ = 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 shafts
  - bored piles 2.5’ - 10’/12’ \( \phi \)
  - pressure injected piles

- **piers**

- **caissons**

- **drilled shafts**

- **bored piles**

- **pressure injected piles**
Deep Foundation Types

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)**
  
  \[ P_a = A_p \cdot f_a \]

  for use in soft or loose materials over a dense base

- **friction piles (floating)**

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

  \[ R_p \approx 0 \]

  common in both clay & sand

  tapered: sand & silt

- **combination friction and end bearing**

  \[ P \]

- **uplift/tension piles**

  structures that float, towers

  \[ R_s \]

- **batter piles**

  \[ 1:12 \] to \[ 1:3 \] or \[ 1:4 \] 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**