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.

- 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, \( q_a \)
    \[ q_a = \frac{q_u}{S.F.} \]

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. Cryotill 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>
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</tbody>
</table>

Note: 1 psf = 47.9 Pa.
Lateral Earth Pressure

- passive vs. active

![Diagram of lateral earth pressure with active (trying to move wall) and passive (resists movement) forces.]

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

  RIGID
  sand
  RIGID
  clay

- 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
    - one way shear
    - two way shear
  - bending

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 \( A_s, b, d \)
  - \( \text{max} \ \rho \) 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 \( P_u > P_{br} \), 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

\[ M = P e \]

- 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

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

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

Guidelines

- want resultant of load from pressure inside the middle third of base (kern)

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

- 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

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

\[
P = P_1 + P_2
\]

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

• procedure
  – proportion and check stability with working loads for bearing, overturning and sliding
  – design structure with factored loads

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

\[
SF = \frac{F_{horizontal-resist}}{F_{sliding}} \geq 1.25 - 2
\]

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
- buttress wall
- bridge abutment
- basement frame wall (large basement areas)

Deep Foundation Types

- piles - usually driven, 6”-8” φ, 5’ +
  - piers
  - caissons
    - drilled, excavated, concreted (with or without steel)
  - drilled shafts
  - bored piles
    - 2.5’ - 10’/12’ φ
  - pressure injected piles
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

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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
**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)**
  
  \[ R_p \approx 0 \]

  - common in both clay & sand
  - tapered: sand & silt

- **socketed**

- **end bearing pile (point bearing)**

  - for use in soft or loose materials over a dense base

**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
  
  \[ 1:12 \text{ to } 1:3 \text{ or } 1:4 \]

**Pile Caps and Grade Beams**

- **like multiple column footing**

- **more shear areas to consider**

- **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)