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, $q_a = \frac{q_u}{S.F.}$

Soil Properties & Mechanics

- strength, $q_a$

Bearing Failure

- shear

slip zone
punched wedge

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. Crushed 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>

Notes: 1. 1 psf = 47.6 Pa.
Lateral Earth Pressure

- passive vs. active

*active (trying to move wall)*

*passive (resists movement)*

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Foundation Materials

- concrete, plain or reinforced
  - shear
  - bearing capacity
  - bending
  - embedment length, development length

- other materials (piles)
  - steel
  - wood
  - composite

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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

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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

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

- **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

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

**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 \( x \)

- **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

by statics:

\[ M = Pe \]

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 \( \epsilon \) 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) \( \leq q_a \)

– 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 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 shafts**
  - **bored piles**
  - **pressure injected piles**

  drilled, excavated, concreted (with or without steel)

  2.5’ - 10’/12’ \( \phi \)
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

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

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

- **batter piles**
  - angled, cost more, resist large horizontal loads
  - 1:12 to 1:3 or 1:4 angled

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**