concrete construction: foundation design

Bright Football Complex
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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.
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, \( q_a = \frac{q_u}{S.F.} \)

S.F. = stress factor
Soil Properties & Mechanics

- strength, $q_a$

**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. 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</td>
<td>3,000</td>
</tr>
<tr>
<td>gravel and clayey gravel</td>
<td></td>
</tr>
<tr>
<td>5. Clay, sandy clay, silty clay &amp; clayey</td>
<td>2,000</td>
</tr>
<tr>
<td>silt</td>
<td></td>
</tr>
</tbody>
</table>

Note a. 1 psf = 47.9 Pa.

**Figure 2.5**
Presumptive surface bearing values of various soils, as given in the BOCA National Building Code/1996. (Reproduced by permission)
Bearing Failure

- shear

slip zone

punched wedge
Lateral Earth Pressure

• **passive vs. active**

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

- **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

Figure 5.1 Spread footing shapes and dimensions.
Types of Foundations

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

- 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
Concrete Spread Footings

• failure modes

**Figure 9.2** "Shear" failure in a spread footing loaded in a laboratory (Talbot, 1913). Observe how this failure actually is a combination of tension and shear.

shear

**Figure 9.3** Flexural failure in a spread footing loaded in a laboratory (Talbot, 1913).

bending
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 \( \varepsilon_{steel} \geq 0.004 \)
- 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

**Figure 6.2.1** Development of reinforcement.

**Figure 6.11.2** Development length \( L_{dh} \) for hooked bar.
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 - #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

\[ M = Pe \]

– 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

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

**Figure 2.50**
Three failure mechanisms in retaining walls.
Retaining Walls

• procedure
  – proportion and check stability with working loads for bearing, \textit{overturning} and \textit{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

*Figure 24.12* Typical loading diagrams for stem design: (a) with no surcharge loads; (b) with uniform surcharge load; (c) with point surcharge load.
Retaining Wall Types

• “gravity” wall
  – usually unreinforced
  – economical & simple

• cantilever retaining wall
  – common
Retaining Wall Types

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

very tall walls (> 20 - 25 ft)
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
Deep Foundation Types

- piles - usually driven, 6”-8” ø, 5’ +
- piers
- caissons
- drilled shafts
- bored piles
- pressure injected piles

- drilled, excavated, concreted (with or without steel)
- 2.5’ - 10’/12’ ø
Deep Foundation Types

- **Grade**
  - 200–900 mm
  - Cross section of plain pipe pile
  - Shell thickness 8–12
  - 300–900 dia.
  - Cross section of pipe pile with steel core
  - End closure may be omitted
  - Socket required for vertical high loads only

- **Typical combinations**
  - Cased or uncased concrete
  - Steel pipe concrete filled
  - Concrete filled steel shell
  - Timber
  - HP section
  - Taper may be omitted

- **300–600 mm**
  - 300–600 diam.
  - Note: reinforcing may be prestressed
  - 300–1400 diam.
  - Typical cross sections
  - Sides straight or tapered

- **200–450 diameter**
  - Cross section
  - Corrugated shell
  - Thickness 10 ga to 24 ga
  - Sides straight or tapered

- **Grade**
  - Butt diameter
  - 300–500 mm
  - Pile may be treated with wood preservative
  - Cross section
  - Tip diameter 150–250
  - Welded Rail
  - Sheet pile
  - Welded Rail

- **300–450 mm diameter**
  - Typical cross section
  - Fluted shell
  - 250–900 dia.
  - Shell thickness 3–8
  - Sides straight or tapered
  - Minimum tip diameter 200

- **350–500 diameter**
  - Typical cross section
  - Pedestal may be omitted

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Foundations 41
Lecture 27

Architectural Structures
ARCH 331

S2015abn
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)

- soft or loose layer
- “socketed”

\[ P_a = A_p \cdot f_a \]
for use in soft or loose materials over a dense base

\[ R_p \]

– friction piles (floating)

- tapered: sand & silt

\[ P \]
\[ R_s = f(\text{adhesion}) \]
\[ R_p \approx 0 \]
Piles Classified By Function

– combination friction and end bearing

– uplift/tension piles
  structures that float, towers

– batter piles
  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