SOIL CONSIDERATIONS FOR BUILDERS
The Art and Science of Soil/Rock Mechanics for Residential Structures

Presented by:
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SOIL CONSIDERATIONS FOR BUILDERS

DISCLAIMER

The calculations contained herein are for informational purposes only and should not be utilized unqualified individuals to determine bearing capacity or settlement of foundations.

Objectives

1. An understanding of Pennsylvania soils and the challenges they can pose to residential construction.
2. An understanding of Pennsylvania rocks and the challenges they can pose to residential construction.
3. The importance of pre-construction geotechnical investigations for residential developments and individual structures.
4. An understanding of bearing capacity and its relationship to foundation design.
5. How to make responsible decisions in the field and who is qualified to make them.
Objective One
Pennsylvania Soil

1. Major Soil Types in Pennsylvania
   a. Residual Soils
      i. Derived from weathered bedrock
      ii. Granular or larger – Conglomerate; Sand – Sandstone; Silt and Clay – Mudstone and Shale
   b. Alluvial Soils
      i. Deposited by rivers/flowing water
      ii. Fast flowing deposition = large well-rounded gravel and sand
      iii. Slow moving deposition = clays, silts and fine sands
   c. Colluvial Soils
      i. Deposited by gravity
      ii. Erosions/wasting of mountains
      iii. Wide ranges of soil sizes and angular rock fragments
   d. Glacial Soils
      i. Deposited by Glaciers
      ii. Heterogeneous mixtures of silts, sands, clays and well-rounded rock fragments
      iii. Rock fragments from different bedrock geology
      iv. Typically dense and well compacted and may present excavation difficulties
      v. Northwestern and Northeastern portions of the Commonwealth (see map)
Objective One
Pennsylvania Soil

2. Classifying Soils
   a. Clays (<0.002mm)
      i. Particles stick together (cohesive)
      ii. Will typically roll out in your hand
      iii. Moisture control can be difficult (hard to dry)
   b. Silts (0.075 to 0.002mm)
      i. Particles can stick together, but
      ii. Will typically not roll out in your hand
      iii. Highly frost susceptible and subject to heave
      iv. Difficult to compact if unconfined, i.e. outside of a trench
   c. Sands (0.187 in. to 2.9x10^-3 in.)
   d. Gravel (3 in. to 0.187 in.)
   e. Cobbles (12 in. to 3 in.)
   f. Boulders (12 in. plus)

Objective One
Pennsylvania Soil

3. Soil Challenges
   a. Clays
      i. Most are not significantly expansive, such as those of volcanic origin, i.e. bentonites, montmorillonites, etc.
      ii. Foundations on soft/wet clays can fail locally (punching shear)
      iii. Saturated clays can result in long-term settlement (years)
      iv. Backfilling behind basement walls is not recommended due to very poor drainage
   b. Silts
      i. Typically very weak, i.e. very small internal friction or cohesion
      ii. Can heave if subject to frost action
   c. Sands, Gravels, Cobbles & Boulders
      i. Well-Graded (many different sizes): Easy to compact and maintain strength
      ii. Poorly-Graded (same sized fragments): Difficult to compact (marbles) and can create sump-like condition due to high void space

Objective One
Pennsylvania Soil

4. Natural vs. Fill: Let's be careful...
   a. Fill: Who, What, How and When?
      i. Does it contain foreign matter (concrete, brick, wood, steel, etc.)?
      ii. How was it placed (compacted vs. end dumped)?
      iii. How long has it been there?
      iv. Who placed the fill and were they qualified to do so?
      v. Was the fill tested (nuclear density gauge)?
      vi. Are there environmental concerns?
      vii. Who's taking responsibility?
Objective One
Pennsylvania Soil

5. Summary of Soil Concerns
   a. Moisture sensitive soils (clays/silts)
   b. Frost susceptible soils (clays/silts)
   c. Organic soils (topsoil)
   d. Fill (controlled vs. uncontrolled)
   e. Grain-Size distribution

Objective One
Pennsylvania Soil

Granular Soils

Cohesive Soils

Organic Soils

Objective Two
Pennsylvania Bedrock

1. Types of Bedrock
   a. Sedimentary
      i. Form by mechanical and chemical processes
      ii. Limestone, Sandstone, Shale, Siltstone, Conglomerate
      iii. Predominant bedrock in PA
   b. Igneous
      i. Form by solidification of molten magma
      ii. Granite, Gabbro, Basalt
      iii. Less common but present in southeastern PA
   c. Metamorphic
      i. Form by changing composition and texture through heat and pressure
      ii. Quartzite (sandstone), Gneiss (granite), slate (shale), marble (limestone/dolostone)
      iii. Less common but present in southeastern PA
Objective Two
Pennsylvania Bedrock

2. Geologic Hazards
   a. Sinkholes in carbonate bedrock (limestone/dolostone)

   What lies beneath?
   Small opening leads to larger void

   Sinkhole

   Soil Arching
Objective Two
Pennsylvania Bedrock

b. Coal Extraction Hazards
   i. Subsurface mining resulting in surface subsidence (room & pillar, long wall, etc.)
   ii. Strip mining resulting in placement of large quantities of uncompacted spoils
Objective Two
Pennsylvania Bedrock

c. Landslides/Slope Stability
   i. Weak bedrock and soil layers
   ii. Water reduces strength of bedrock and soil
   iii. Aggressive cut slopes into weak layers


Objective Two
Pennsylvania Bedrock

d. Expansive Pyritic Shales
   i. Black/Carbonaceous Shales are known to have microscopic (highly reactive) pyrite
   ii. Pyrite oxidizes to form sulfuric acid, which reacts with any calcium carbonate resulting in the formation of hydrous sulfate crystals, i.e. gypsum
   iii. Example: Coal Bearing Shales (Acid Mine Drainage – AMD), Marcellus Formation, Reedsville Formation
Objective Two
Pennsylvania Bedrock

Objective Three
Geotechnical Investigations

1. What is a geotechnical investigation?
   a. Desktop study (soils, geology, topography, etc.)
   b. Test borings, test pits and/or geophysical (seismic, ground penetrating radar, electrical imaging, etc.)
   c. Laboratory testing (soil/rock type, strength, compaction characteristics, etc.)
   d. Engineering analysis (bearing capacity, settlement, stability, etc.)
   e. Authored by Professional Engineer with geotechnical experience

2. Why are geotechnical investigations important?
   a. Responsibility, Responsibility, and Responsibility
   b. Whoever makes decisions regarding soils, rock, bearing capacity, stability, etc. is taking responsibility for the structure
   c. Helps prepare and educate the builder/owner about potential issues with the soil and rock

3. What factors dictate the intensity of the geotechnical effort?
   a. Risk Assessment
      i. Sinkholes
      ii. Slopes/Landslides
      iii. Problem Soils/Rock
      iv. Weather
   b. Construction Type
      i. Residential Development Phase
      ii. Individual Structure
Objective Three
Geotechnical Investigations

TYPICAL GEO-DECISION FLOW CHART

Objective Four
Bearing Capacity

1. Residential structures are typically supported by exterior wall/strip footings and interior spread/column footings.
2. The ultimate bearing capacity (q_u) is the pressure that will cause failure in the supporting soil/rock.
3. Footings are designed by a Structural Engineer that uses the allowable bearing capacity (q_a), which is the ultimate bearing capacity divided by a factor-of-safety (typically 3 or 4).
4. Bearing capacity is a very complicated concept that is based upon the following:
   a. Shear strength of the soil (c)
   b. Surcharge of the surrounding soil (q)
   c. Width of the footing (B)
   d. Depth to groundwater (d)
   e. Soil angle of internal friction (Ø)
   f. Shape, depth, inclination factors
Objective Four
Bearing Capacity

Bearing Capacity Equations (Das, 2006)

Ultimate Bearing Capacity

$Q_u = \frac{V_o}{F} + T_s + 2T_f + \frac{1}{2} T_k + T_1$

Footing Width

cohesion

$Q_u = \frac{C_o}{F}$

surcharge


Allowable Bearing Capacity

$Q_a = \frac{Q_u}{2k}$

Net Allowable Bearing Capacity

Immediate Settlement (Bowles, 1996)

$\Delta t = \frac{r_o}{E_s} \left[ \frac{B}{\lambda} - \frac{B}{\lambda_t} \right]$

consolidation settlement

$\Delta t = \frac{r_o}{E_s} \left[ \frac{B}{\lambda} - \frac{B}{\lambda_t} \right]$

$Q_o = \text{bearing pressure}$

$B = \text{pressure area width}$

$E_s = \text{modulus of deformation of underlying soil}$

$\lambda = \text{soil depth and foundation width influence factor}$

$\lambda_t = \text{foundation depth influence factor}$

Consolidation Settlement (Das, 2006)

$C_c = \text{compression index (lab)}$

$C_s = \text{swell index (lab)}$

$H = \text{height of compressible zone}$

$e_o = \text{void ratio (lab)}$

$p_o = \text{max. past overburden pressure}$

$\Delta p = \text{effective pressure increase}$

$p_c = \text{preconsolidation pressure (lab)}$

$NC = \text{normally consolidated (lab)}$

$OC = \text{over-consolidated (lab)}$
Objective Four
Bearing Capacity

5. Soil Failures
   a. General Shear Failure: Soil bulges up around the outside of the foundation
   b. Local/Punching Shear Failure: Footing plunges into the soil that fails locally below foundation
   c. Settlement beyond tolerable limits of the structure
      i. Elastic: Soil compresses almost immediately without under the weight of the foundation
      ii. Primary Consolidation: Water squeezes out of the soils under the weight of the foundation
      iii. Secondary Consolidation: Fine particle rearrangement under the weight of the foundation

Objective Four
Bearing Capacity

Bearing Capacity Failures (Das, 2006)

Foundation Loading

Load per unit area

General shear failure
Local shear failure
Settlement continues under same pressure

Objective Four
Bearing Capacity

Bearing Capacity Failures (Das, 2006)

General shear failure
Local/Punching Shear Failure
Objective Four
Bearing Capacity

6. Repairing Foundation Failures
   a. Very expensive and intrusive remediation
   b. Must be directed and designed by an experienced Geo-Professional
   c. Remediation methods
      i. Micropiles
      ii. Grouting
      iii. Helical Piers
Objective Four
Bearing Capacity

6. The International Residential Code (IRC)
   a. R401.4 Soil tests: “Where quantifiable data created by accepted soil science methodologies indicate expansive, compressible, shifting or other questionable soil characteristics are likely to be present, the building official shall determine whether to require a soil test to determine the soil’s characteristics at a particular location. This test shall be done by an approved agency using an approved method.”
      i. This statement places tremendous responsibility on the building official.
      ii. What is an acceptable soil science methodology?
      iii. Who defines an approved agency and approved method?

b. R401.4.1 Geotechnical Evaluation: “In lieu of a complete geotechnical evaluation, the load-bearing values in Table 401.4.1 shall be assumed.”
   i. This table takes a conservative approach by basing “load-bearing pressure” on USCS Classifications. Who is classifying these soils?

c. R401.4.2 Compressible or Shifting Soil: “Instead of a complete geotechnical evaluation, when top or subsoils are compressible or shifting, they shall be removed to a depth and width sufficient to assure stable moisture content in each active zone and shall not be used as fill or stabilized within each active zone by chemical, dewatering or presaturation.”
   i. Stabilization methodologies are more complicated than bearing capacity and settlement calculations. Who will make these decisions in the field?
Objective Four
Bearing Capacity

Bearing capacity determined by USCS Classification

Building Official to determine the presence of poor soils?

<table>
<thead>
<tr>
<th>CLASS OF MATERIAL</th>
<th>LOAD-BEARING PRESSURE (pounds per square foot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystalline bedrock</td>
<td>12,000</td>
</tr>
<tr>
<td>Sedimentary and brecciated rock</td>
<td>2,000</td>
</tr>
<tr>
<td>Sandy gravel and/or gravel (GW and GP)</td>
<td>7,500</td>
</tr>
<tr>
<td>Sand, silty sand, clayey sand, silty gravel and gravel gravel (SW, SP, SM, SC, GC and GC)</td>
<td>7,500</td>
</tr>
<tr>
<td>Clay, sandy clay, silty clay, silty and sandy silt (CL, ML, MH and ML)</td>
<td>1,500</td>
</tr>
</tbody>
</table>

For all 1 pound per square foot = 145 kPa

1. When soil tests are required by Section 609.4, the allowable bearing capacity shall be at least the minimum value of the determination.

7. Remediating poor soil conditions in order to meet bearing capacity and settlement requirements

   a. Must be directed and supervised by an experienced geo-professional (Professional Engineer w/ geotechnical focus)

   i. Utilize past geotechnical data and appropriate field testing to direct remediation efforts

   ii. Identify depth and extent of poor soils that could result in bearing capacity failure and/or excessive immediate and/or long term settlement

   iii. Determine the most appropriate backfill material, i.e. engineered stone (PennDOT 2A), flowable fill or lean concrete

   iv. Provide testing and inspection oversight during repair

Objective Four
Bearing Capacity

Typical Overexcavation and Replacement Detail
Objective Five
Field Decisions

1. Who is qualified to make field decisions?
   a. Residential Development Geotechnical Investigation and Structure Specific Recommendations
      i. Experienced Soils Engineering Technician Supervised by Professional Engineer (Geo-Professional)
   b. Residential Development Geotechnical Investigation Without Structure Specific Recommendations
      i. Project Engineer or Engineer-in-Training (EIT) Supervised by Professional Engineer (Geo-Professional)
   c. No Residential Development Geotechnical Investigation
      i. Professional Engineer (Geo-Professional)

SUMMARY

1. Bearing capacity is a complex science that requires the involvement of a Geo-Professional
2. Pennsylvania Soils and Geology vary widely from region to region and each carries its own specific risk
3. Soils related decisions require careful judgment by the Geo-Professional using established laboratory/field testing
4. Extreme caution is warranted when referencing IRC tables
5. Potential bearing capacity issues need to be remediated from the bottom up and not the top down, i.e. adding reinforcement to footings
6. Fixing foundation problems is extremely costly and intrusive to the occupant
REFERENCES


