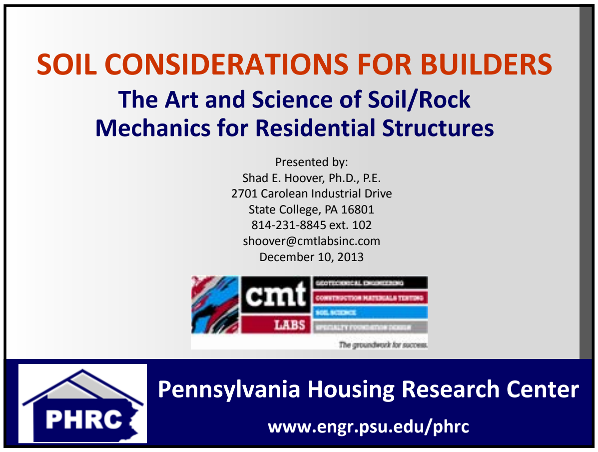

SOIL CONSIDERATIONS FOR BUILDERS

The Art and Science of Soil/Rock Mechanics for Residential Structures

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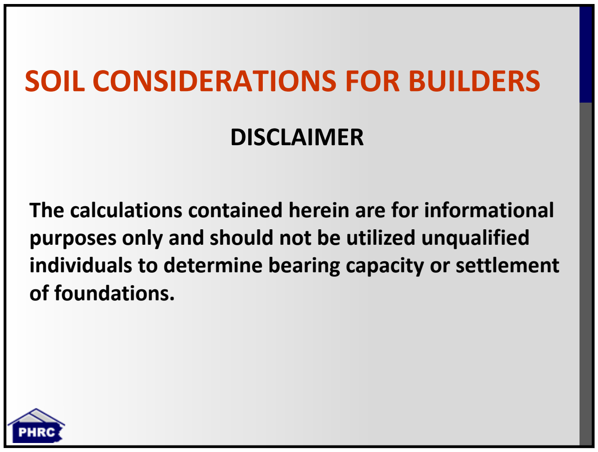
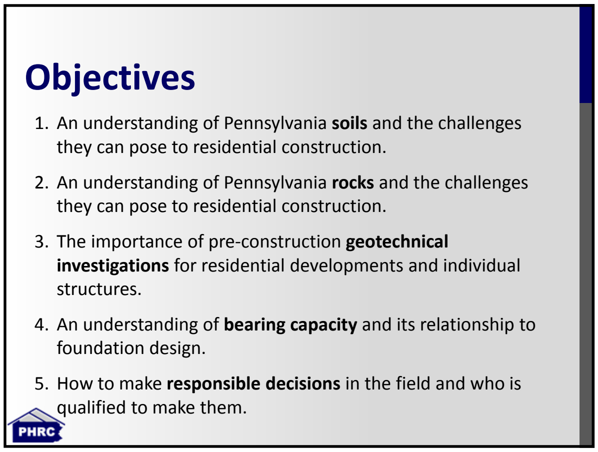


SOIL CONSIDERATIONS FOR BUILDERS

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

---

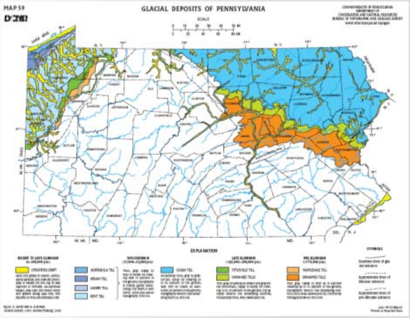
Objective One

Pennsylvania Soil

1. **Major Soil Types in Pennsylvania (Cont'd)**
   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



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

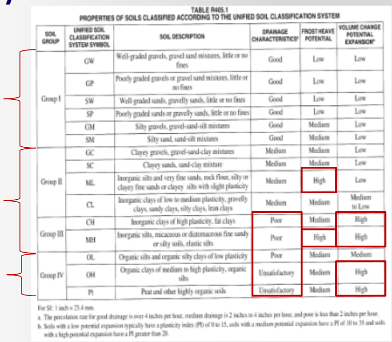


TABLE R405.1
PROPERTIES OF SOILS CLASSIFIED ACCORDING TO THE UNIFIED SOIL CLASSIFICATION SYSTEM

SOIL GROUP	UNIFIED SOIL CLASSIFICATION SYSTEM SYMBOL	SOIL DESCRIPTION	DRAINAGE CHARACTERISTICS[a]	FROST HEAVE POTENTIAL	VOLUME CHANGE POTENTIAL EXPANSION[b]
Group I	GW	Well-graded gravels, gravel sand mixtures, little or no fines	Good	Low	Low
	GP	Poorly graded gravels or gravel sand mixtures, little or no fines	Good	Low	Low
	SW	Well-graded sands, gravelly sands, little or no fines	Good	Low	Low
	SP	Poorly graded sands or gravelly sands, little or no fines	Good	Low	Low
	GM	Silty gravels, gravel-sand-silt mixtures	Good	Medium	Low
	SM	Silty sand, sand-silt mixtures	Good	Medium	Low
Group II	GC	Clayey gravels, gravel-sand-clay mixtures	Medium	Medium	Low
	SC	Clayey sands, sand-clay mixture	Medium	Medium	Low
	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Medium	High	Low
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Medium	Medium	Medium to Low
Group III	CH	Inorganic clays of high plasticity, fat clays	Poor	Medium	High
	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor	High	High
Group IV	OL	Organic silts and organic silty clays of low plasticity	Poor	Medium	Medium
	OH	Organic clays of medium to high plasticity, organic silts	Unsatisfactory	Medium	High
	Pt	Peat and other highly organic soils	Unsatisfactory	Medium	High

For SI: 1 inch = 25.4 mm.

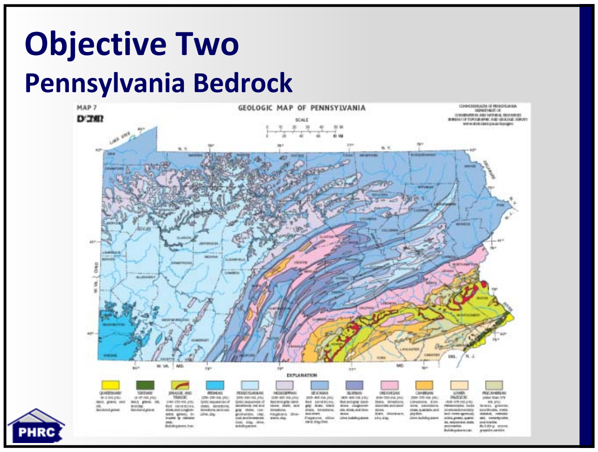
a. The percolation rate for good drainage is over 4 inches per hour, medium drainage is 2 inches to 4 inches per hour, and poor is less than 2 inches per hour.

b. Soils with a low potential expansion typically have a plasticity index (PI) of 0 to 15, soils with a medium potential expansion have a PI of 10 to 35 and soils with a high potential expansion have a PI greater than 20.

Objective Two

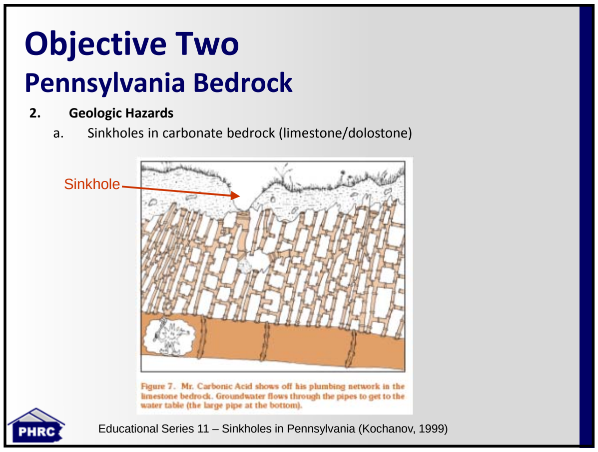
Pennsylvania Bedrock

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



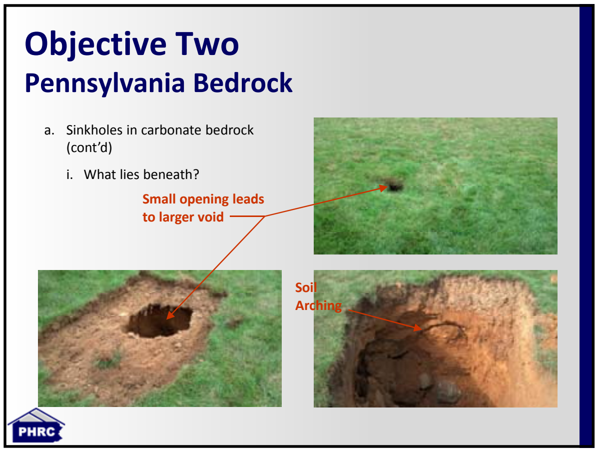
Objective Two

Pennsylvania Bedrock

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

Figure 7. Mr. Carbonic Acid shows off his plumbing network in the limestone bedrock. Groundwater flows through the pipes to get to the water table (the large pipe at the bottom).

Educational Series 11 – Sinkholes in Pennsylvania (Kochanov, 1999)

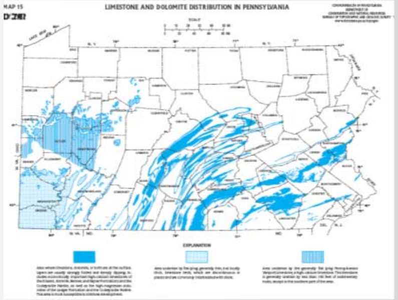


Objective Two

Pennsylvania Bedrock

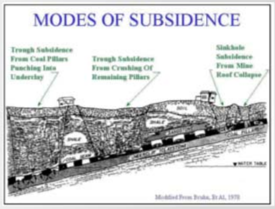
a. Sinkholes in carbonate bedrock (cont'd)
   i. What lies beneath?

Objective Two
Pennsylvania Bedrock

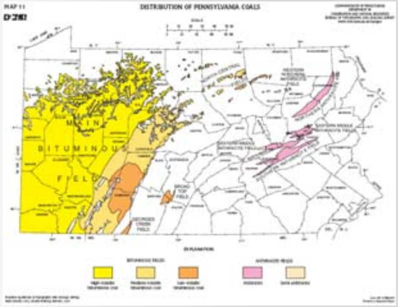


Objective Two
Pennsylvania Bedrock

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

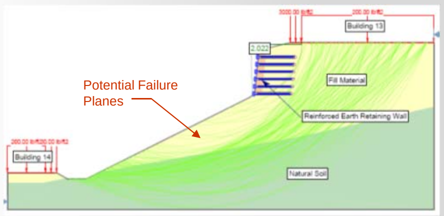


Objective Two
Pennsylvania Bedrock

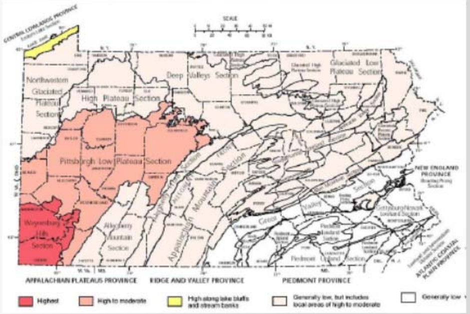


Objective Two
Pennsylvania Bedrock

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

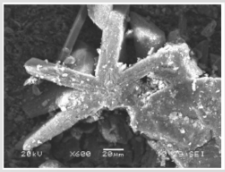


Objective Two
Pennsylvania Bedrock



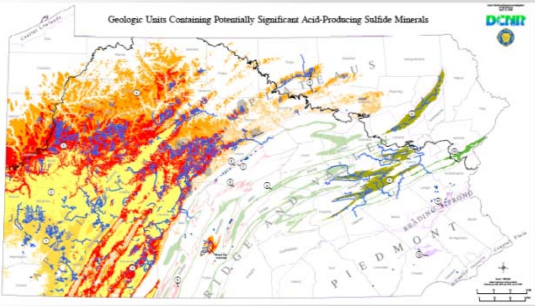
Objective Two
Pennsylvania Bedrock

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

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Objective Three

Geotechnical Investigations

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

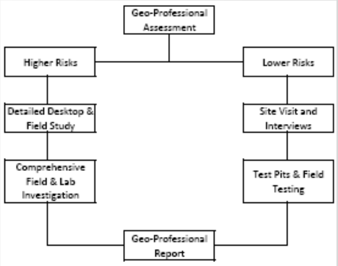
Test Boring

Test Pit

Objective Three

Geotechnical Investigations

TYPICAL GEO-DECISION FLOW CHART



Geo-Professional Assessment

Higher Risks

Lower Risks

Detailed Desktop & Field Study

Site Visit and Interviews

Comprehensive Field & Lab Investigation

Test Pits & Field Testing

Geo-Professional Report

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

Footing Width

$$q_u := c \cdot N_c \cdot F_{cs} \cdot F_{cd} \cdot F_{ci} + q' \cdot N_q \cdot F_{qs} \cdot F_{qd} \cdot F_{qi} + 0.5 \cdot \gamma \cdot B \cdot N_\gamma \cdot F_{\gamma s} \cdot F_{\gamma d} \cdot F_{\gamma i}$$

cohesion

surcharge

Allowable Bearing Capacity

$$q_a := \frac{q_u}{FS}$$

Factor-of-Safety

Net Allowable Bearing Capacity

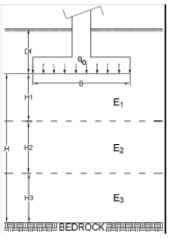
$$q_{na} := \frac{\left(q_u - q'\right)}{FS}$$

Objective Four
Bearing Capacity

Immediate Settlement (Bowles, 1996)

$$\Delta H := q_o \cdot B' \cdot \frac{\left(1 - \mu^2\right)}{E_{save}} \cdot 4 \cdot I_s \cdot I_F$$

q_o = bearing pressure
B` = pressure area width
E_{save} = modulus of deformation of underlying soil
I_s = soil depth and foundation width influence factor
I_F = foundation depth influence factor

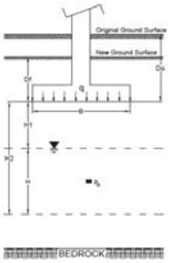


Objective Four
Bearing Capacity

Consolidation Settlement (Das, 2006)

$$S_c := \begin{cases} \frac{C_c H}{1+e_o} \cdot \log\left(\frac{p'_o + \Delta p'}{p'_o}\right) & \text{if } p'_o > p'_c \quad \text{(NC)} \\ \frac{C_s H}{1+e_o} \cdot \log\left(\frac{p'_o + \Delta p'}{p'_o}\right) & \text{if } p'_o + \Delta p' \le p'_c \quad \text{(OC)} \\ \frac{C_s H}{1+e_o} \cdot \log\left(\frac{p'_c}{p'_o}\right) + \frac{C_c H}{1+e_o} \cdot \log\left(\frac{p'_o + \Delta p'}{p'_c}\right) & \text{otherwise} \end{cases}$$

C_c = compression index (lab)
C_s = swell index (lab)
H = height of compressible zone
e_o = void ratio (lab)
p`$_o$ = max. past overburden pressure
Δp` = effective pressure increase
p`$_c$ = preconsolidation pressure (lab)
NC = normally consolidated (lab)
OC = 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

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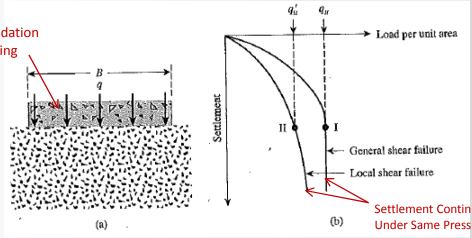
Objective Four
Bearing Capacity

Bearing Capacity Failures (Das, 2006)

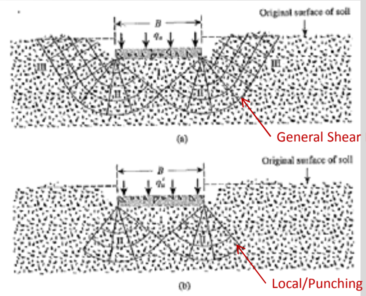


Foundation Loading

Settlement Continues Under Same Pressure

Objective Four
Bearing Capacity

Bearing Capacity Failures (Das, 2006)



General Shear Failure

Local/Punching Shear Failure

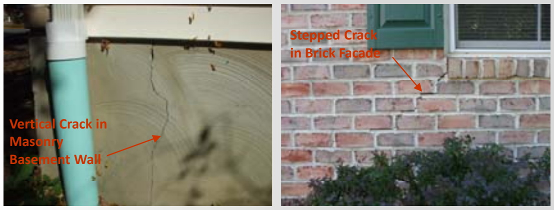
Objective Four
Bearing Capacity

Differential Settlement From Bearing on Fill Materials

Differential Settlement From Possible Sinkhole Activity

Objective Four
Bearing Capacity

Differential Settlement From Poor Fill Materials



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

Installing Micropiles

Preparing to Underpin

PHRC

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?

PHRC

Objective Four
Bearing Capacity

6. **The International Residential Code (IRC) – Cont'd**
   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?

PHRC

Objective Four

Bearing Capacity

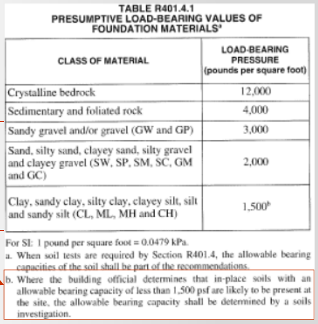


TABLE R401.4.1
PRESUMPTIVE LOAD-BEARING VALUES OF FOUNDATION MATERIALS[a]

CLASS OF MATERIAL	LOAD-BEARING PRESSURE (pounds per square foot)
Crystalline bedrock	12,000
Sedimentary and foliated rock	4,000
Sandy gravel and/or gravel (GW and GP)	3,000
Sand, silty sand, clayey sand, silty gravel and clayey gravel (SW, SP, SM, SC, GM and GC)	2,000
Clay, sandy clay, silty clay, clayey silt, silt and sandy silt (CL, ML, MH and CH)	1,500[b]

For SI: 1 pound per square foot = 0.0479 kPa.

a. When soil tests are required by Section R401.4, the allowable bearing capacities of the soil shall be part of the recommendations.

b. Where the building official determines that in-place soils with an allowable bearing capacity of less than 1,500 psf are likely to be present at the site, the allowable bearing capacity shall be determined by a soils investigation.

Bearing capacity determined by USCS Classification

Building Official to determine the presence of poor soils?

Objective Four

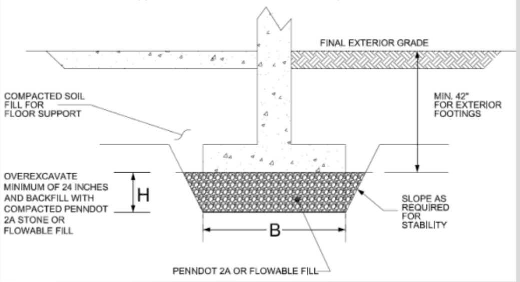
Bearing Capacity

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

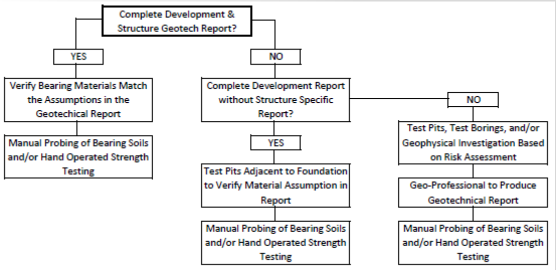


Objective Five
Field Decisions

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)

Objective Five
Field Decisions

Field Decision Flow Chart



Complete Development & Structure Geotech Report?

YES

Verify Bearing Materials Match the Assumptions in the Geotechical Report

Manual Probing of Bearing Soils and/or Hand Operated Strength Testing

NO

Complete Development Report without Structure Specific Report?

YES

Test Pits Adjacent to Foundation to Verify Material Assumption in Report

Manual Probing of Bearing Soils and/or Hand Operated Strength Testing

NO

Test Pits, Test Borings, and/or Geophysical Investigation Based on Risk Assessment

Geo-Professional to Produce Geotechnical Report

Manual Probing of Bearing Soils and/or Hand Operated Strength Testing

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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 it's 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

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