Field Analysis of Soils and Sediments

Dr. Dan Larsen
Dr. Roger Meier
Why Are We Here?

In geotechnical engineering, more than in any other field of civil engineering, success depends on practical experience ... Since personal experience is necessarily somewhat limited, the engineer is compelled to rely at least to some extent on the [written] records of the experiences of others. If these records contain adequate descriptions of the soil conditions, they constitute a storehouse of valuable information. Otherwise, they may be misleading.

- Karl Terzaghi
Characteristics Used to Describe Soils
Important Characteristics

- Contacts
- Structure
- Cementation
- Color
- Odor
- Moisture content
- Consistency
- Plasticity

- Grain size
- Grain sorting
- Grain angularity
- Grain shape
- Grain composition
- Grain hardness
### Estimating Particle Size

<table>
<thead>
<tr>
<th>Term</th>
<th>Size Range</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobble</td>
<td>3&quot; to 12&quot;</td>
<td>Grapefruit</td>
</tr>
<tr>
<td>Coarse gravel</td>
<td>$\frac{3}{4}&quot;$ to 3&quot;</td>
<td>Plums</td>
</tr>
<tr>
<td>Fine gravel</td>
<td>#4 sieve to $\frac{3}{4}&quot;$</td>
<td>Grapes</td>
</tr>
<tr>
<td>Coarse sand</td>
<td>#10 to #4 sieve</td>
<td>Peppercorns</td>
</tr>
<tr>
<td>Medium sand</td>
<td>#40 to #10 sieve</td>
<td>Sugar or salt</td>
</tr>
<tr>
<td>Fine sand</td>
<td>#200 to #40 sieve</td>
<td>Ground pepper</td>
</tr>
<tr>
<td>Fines</td>
<td>&lt; #200 sieve</td>
<td>Flour</td>
</tr>
</tbody>
</table>
Cobble (grapefruit)
Coarse gravel
Fine gravel
Coarse sand
Medium sand
Fine sand
Fines
Well graded sand
Gap-graded sand
## Types of Cementation

<table>
<thead>
<tr>
<th>Type</th>
<th>Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium Carbonate</td>
<td>Reaction with dilute HCl</td>
</tr>
<tr>
<td>Iron Oxides</td>
<td>Red or orange color</td>
</tr>
<tr>
<td>Clays</td>
<td>Hard when dry, slakes with wet</td>
</tr>
<tr>
<td>Silica</td>
<td>Hard, dense, no reaction to liquids</td>
</tr>
<tr>
<td>Other cements</td>
<td>Identification requires lab work</td>
</tr>
</tbody>
</table>
Silica and iron cement
## Cementation with CaCO₃

<table>
<thead>
<tr>
<th>Description</th>
<th>Reaction to Dilute HCl</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>No reaction</td>
</tr>
<tr>
<td>Weak</td>
<td>Weak to moderate fizzing, bubbles form slowly</td>
</tr>
<tr>
<td>Strong</td>
<td>Violent fizzing, bubbles form immediately</td>
</tr>
</tbody>
</table>
Fizzzzzzzz test
### Degree of Cementation

<table>
<thead>
<tr>
<th>Description</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weak</td>
<td>Crumbles or breaks with handling or slight finger pressure</td>
</tr>
<tr>
<td>Moderate</td>
<td>Crumbles or breaks with considerable finger pressure</td>
</tr>
<tr>
<td>Strong</td>
<td>Will not crumble or break with finger pressure</td>
</tr>
<tr>
<td>None of the above</td>
<td>None of the above</td>
</tr>
<tr>
<td>Hue</td>
<td>Gley</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------------------</td>
</tr>
<tr>
<td><strong>Value</strong></td>
<td><strong>(8 – 2.5)</strong></td>
</tr>
<tr>
<td></td>
<td>Greenish or bluish gray</td>
</tr>
<tr>
<td></td>
<td>to black</td>
</tr>
<tr>
<td><strong>Chroma</strong></td>
<td><strong>(1 – 8)</strong></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Colors are assigned using Munsell Color Chart
Munsell Color Charts

Gley 7/5GY
## Odor

<table>
<thead>
<tr>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>(none)</em></td>
<td>No odor noticeable</td>
</tr>
<tr>
<td>Earthy</td>
<td>Moldy or musty odor</td>
</tr>
<tr>
<td>Chemical</td>
<td>Includes oily odor</td>
</tr>
<tr>
<td>Organic</td>
<td>Odor from manure or decay</td>
</tr>
</tbody>
</table>
## Moisture content

<table>
<thead>
<tr>
<th>Description</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>No moisture present, dusty, dry to the touch</td>
</tr>
<tr>
<td>Moist</td>
<td>Some moisture present, damp, no visible water</td>
</tr>
<tr>
<td>Very Moist</td>
<td>Moisture present, but not saturated</td>
</tr>
<tr>
<td>Wet</td>
<td>Saturated, visible free water</td>
</tr>
</tbody>
</table>
## Consistency

<table>
<thead>
<tr>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Soft</td>
<td>Thumb will easily penetrate soil past first knuckle</td>
</tr>
<tr>
<td>Soft</td>
<td>Thumb will penetrate soil up to the first knuckle</td>
</tr>
<tr>
<td>Firm</td>
<td>Thumb will indent soil about $\frac{1}{4}$”</td>
</tr>
<tr>
<td>Stiff</td>
<td>Thumb will not indent soil but thumbnail will</td>
</tr>
<tr>
<td>Hard</td>
<td>Thumbnail barely indents soil</td>
</tr>
</tbody>
</table>
## Plasticity

<table>
<thead>
<tr>
<th>Term</th>
<th>Field Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Plastic</td>
<td>Can’t be rolled to 1/8” thread</td>
</tr>
<tr>
<td>Slightly Plastic</td>
<td>Can be rolled to 1/8” thread with care</td>
</tr>
<tr>
<td>Medium Plastic</td>
<td>Easily rolled to 1/8” thread</td>
</tr>
<tr>
<td>Highly Plastic</td>
<td>Will roll into a thinner thread</td>
</tr>
<tr>
<td>Description</td>
<td>Criteria</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Angular</td>
<td>Sharp edges and relatively plane sides with unpolished surfaces</td>
</tr>
<tr>
<td>Subangular</td>
<td>Rounded edges and relatively plane sides with unpolished surfaces</td>
</tr>
<tr>
<td>Subrounded</td>
<td>Well rounded corners and edges but an irregular or non-spherical shape</td>
</tr>
<tr>
<td>Rounded</td>
<td>Smoothly curved sides with no visible corners or edges</td>
</tr>
</tbody>
</table>
Grain angularity

- Very Angular
- Angular
- Subangular
- Well-Rounded
- Rounded
- Subrounded
<table>
<thead>
<tr>
<th>Description</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat</td>
<td>Width $&gt; 3 \times$ Thickness</td>
</tr>
<tr>
<td>Elongated</td>
<td>Length $&gt; 3 \times$ Width</td>
</tr>
<tr>
<td>Flat &amp; Elongated</td>
<td>Length $&gt; 3 \times$ Width $&gt; 3 \times$ Thickness</td>
</tr>
<tr>
<td>none of the above</td>
<td></td>
</tr>
</tbody>
</table>
Grain hardness

• Describe what happens when coarse sand and larger particles are hit by a hammer
  “Gravel particles fracture with hammer blow”
  “Coarse sand particles crumble with hammer blow”
  “Coarse gravel particles crack with hammer blow”

• If the particles do not crack, fracture, or crumble under a hammer blow, describe them as “hard”
The Unified Soil Classification System
USCS Basics

• The behavior of coarse-grained soil is largely determined by two properties:
  • grain size
  • grain sorting

and one state variable:
  • relative density
Relative Density

$DR = \frac{\text{volume of void spaces}}{\text{volume of soil particles}}$

- **Dense**
  - Minimum void content: 0%
  - Increasing void content: decreasing dry density

- **Loose**
  - Maximum void content: 100%

$D_R$
USCS Basics

- The behavior of fine-grained soil is largely determined by two properties:
  - liquid limit
  - plastic limit

and one state variable:
  - liquidity index
Atterberg Limits

increasing water content

Solid | Putty | Slurry

plastic limit | plasticity index | liquid limit
The A-line

- Liquid Limit
- Plasticity Index

- Clays
- Silts
Liquidity Index

Increasing water content

Solid | Putty | Slurry

Plastic limit: 0%

Liquid limit: 100%

Liquidity index
USCS Decision Tree

Sample with cobbles removed

- < 50% passing No. 200 sieve
  - < 50% passing No. 4 sieve: Gravel
  - > 50% passing No. 4 sieve: Sand

- > 50% passing No. 200 sieve
  - Plots below the A-line: Silt
  - Plots above the A-line: Clay
USCS (Gravel)

Gravel

< 5% fines

Well Graded

Well-graded Gravel

GW

Poorly Graded

Poorly-graded Gravel

GP

> 12% fines

Plots below the A-line

Silty Gravel

GM

Plots above the A-line

Clayey Gravel

GC
USCS (Sand)

Sand

- < 5% fines
  - Well Graded
    - Well-graded Sand
      - SW
  - Poorly Graded
    - Poorly-graded Sand
      - SP

- > 12% fines
  - Plots below the A-line
    - Silty Sand
      - SM
  - Plots above the A-line
    - Clayey Sand
      - SC
USCS (Gravel with Fines)

5 - 12% fines

Well-graded
- Plots below the A-line
  - Well-graded Gravel with Silt
    - GW-GM
  - Well-graded Gravel with Clay
    - GW-GC

Poorly-graded
- Plots below the A-line
  - Poorly-graded Gravel with Silt
    - GP-GM
  - Poorly-graded Gravel with Clay
    - GP-GC
- Plots above the A-line
  - Well-graded Gravel with Silt
  - GW-GM
USCS (Sand with Fines)

5 - 12% fines

Well-graded

Plots below the A-line
  - Well-graded Sand with Silt
    - SW-SM

Plots above the A-line
  - Well-graded Sand with Clay
    - SW-SC

Poorly-graded

Plots below the A-line
  - Poorly-graded Sand with Silt
    - SP-SM

Plots above the A-line
  - Poorly-graded Sand with Clay
    - SP-SC
USCS (Silt and Clay)

- **Silt or Clay**
  - **LL < 50**
    - Plots below the A-line
      - **Low Plasticity Silt**
        - ML
    - Plots above the A-line
      - **Low Plasticity Clay**
        - CL
  - **LL > 50**
    - Plots below the A-line
      - **High Plasticity Silt**
        - MH
    - Plots above the A-line
      - **High Plasticity Clay**
        - CH
Silt and Clay

Liquid Limit

Plasticity Index

CH

MH or OH

CL

ML or OL
### Soil Property Estimates

<table>
<thead>
<tr>
<th>USCS Symbol</th>
<th>Permeability when compacted</th>
<th>Shear Strength when compacted and saturated</th>
<th>Compressibility when compacted and saturated</th>
<th>Workability as a construction material</th>
</tr>
</thead>
<tbody>
<tr>
<td>GW</td>
<td>pervious</td>
<td>excellent</td>
<td>negligible</td>
<td>excellent</td>
</tr>
<tr>
<td>GP</td>
<td>very pervious</td>
<td>good</td>
<td>negligible</td>
<td>good</td>
</tr>
<tr>
<td>GM</td>
<td>semi-pervious</td>
<td>good</td>
<td>negligible</td>
<td>good</td>
</tr>
<tr>
<td>GC</td>
<td>impervious</td>
<td>good to fair</td>
<td>very low</td>
<td>good</td>
</tr>
<tr>
<td>SW</td>
<td>pervious</td>
<td>excellent</td>
<td>negligible</td>
<td>excellent</td>
</tr>
<tr>
<td>SP</td>
<td>pervious</td>
<td>good</td>
<td>very low</td>
<td>fair</td>
</tr>
<tr>
<td>SM</td>
<td>semi-pervious</td>
<td>good</td>
<td>low</td>
<td>fair</td>
</tr>
<tr>
<td>SC</td>
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<td>low</td>
<td>good</td>
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## Soil Property Estimates

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</thead>
<tbody>
<tr>
<td>ML</td>
<td>semi-pervious</td>
<td>fair</td>
<td>medium</td>
<td>fair</td>
</tr>
<tr>
<td>CL</td>
<td>impervious</td>
<td>fair</td>
<td>medium</td>
<td>good to fair</td>
</tr>
<tr>
<td>OL</td>
<td>semi-pervious</td>
<td>poor</td>
<td>medium</td>
<td>fair</td>
</tr>
<tr>
<td>MH</td>
<td>semi-pervious</td>
<td>fair to good</td>
<td>high</td>
<td>poor</td>
</tr>
<tr>
<td>CH</td>
<td>impervious</td>
<td>poor</td>
<td>high</td>
<td>poor</td>
</tr>
<tr>
<td>OH</td>
<td>impervious</td>
<td>poor</td>
<td>high</td>
<td>poor</td>
</tr>
<tr>
<td>PT</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Classifying Soils in the Field
Field Kit

Pocket knife or small spatula

~

Jar with tight-fitting lid

~

Small hand lens

~

Water

~

Small bottle containing dilute HCl
(1 part HCl added to 3 parts distilled water)
USCS Field Method

Sample with cobbles removed

- < 50% fines
  - Coarse-Grained Soil
- > 50% fines
  - Fine-Grained Soil
USCS Field Method (Coarse)

Coarse-Grained Soil

- More gravel than sand
- More sand than gravel

Gravel

Sand
USCS Field Method (Gravel)

- **Gravel**: 
  - **< 10% fines**
    - Well-Graded
      - **Well-graded Gravel ***: GW
    - Poorly-Graded
      - **Poorly-graded Gravel ***: GP
  - **> 10% fines**
    - Silty Fines
      - **Silty Gravel ***: GM
    - Clayey Fines
      - **Clayey Gravel ***: GC

*If there is more than 15% sand present, append the phrase “with sand”*
USCS Field Method (Sand)

Sand

< 10% fines
- Well-Graded
  - Well-graded Sand *
    - SW
- Poorly-Graded
  - Poorly-graded Sand *
    - SP

> 10% fines
- Silty Fines
  - Silty Sand *
    - SM
- Clayey Fines
  - Clayey Sand *
    - SC

*If there is more than 15% gravel present, append the phrase “with gravel”
# Estimating Particle Size

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<th>Size Range</th>
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<td>Grapefruit</td>
</tr>
<tr>
<td>Coarse gravel</td>
<td>¾&quot; to 3&quot;</td>
<td>Plums</td>
</tr>
<tr>
<td>Fine gravel</td>
<td>#4 sieve to ¾&quot;</td>
<td>Grapes</td>
</tr>
<tr>
<td>Coarse sand</td>
<td>#10 to #4 sieve</td>
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<td>Medium sand</td>
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<td>Sugar or salt</td>
</tr>
<tr>
<td>Fine sand</td>
<td>#200 to #40 sieve</td>
<td>Ground pepper</td>
</tr>
<tr>
<td>Fines</td>
<td>&lt; #200 sieve</td>
<td>Flour</td>
</tr>
</tbody>
</table>
Estimating Particle Size

• Rub a small quantity of the soil between the palms of your hands
• Try to shake the material off by rubbing and patting your hands together
• Sand grains will fall off, leaving your palms clean
• Silt and clay will stick in the fine creases, leaving a “dirty” appearance
## Distinguishing Silts and Clays

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Dry Strength</th>
<th>Dilatancy</th>
<th>Toughness Plasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>ML</td>
<td>none to low</td>
<td>slow to rapid</td>
<td>low or none</td>
</tr>
<tr>
<td>CL</td>
<td>medium to high</td>
<td>none to slow</td>
<td>medium</td>
</tr>
<tr>
<td>MH</td>
<td>low to medium</td>
<td>none to slow</td>
<td>low to medium</td>
</tr>
<tr>
<td>CH</td>
<td>high to very high</td>
<td>none</td>
<td>high</td>
</tr>
<tr>
<td>Description</td>
<td>Example</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>-----------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>Specimen crumbles just by handling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>Specimen crumbles with some finger pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td>Specimen crumbles with considerable finger pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>Specimen cannot be broken with finger pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very High</td>
<td>Specimen cannot be broken between the thumb and a hard surface</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Dilatancy

<table>
<thead>
<tr>
<th>Description</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>No visible change in the specimen</td>
</tr>
<tr>
<td>Slow</td>
<td>Water appears slowly on the surface during shaking and disappears slowly upon squeezing</td>
</tr>
<tr>
<td>Rapid</td>
<td>Water appears quickly on the surface during shaking and disappears quickly upon squeezing</td>
</tr>
</tbody>
</table>
Roll sample into ½-inch ball
Flatten into a patty
Tap hand and look for water rising to the surface
## Plasticity

<table>
<thead>
<tr>
<th>Term</th>
<th>Field Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Plastic</td>
<td>Can’t be rolled to 1/8” thread at any moisture content</td>
</tr>
<tr>
<td>Slightly Plastic</td>
<td>Can barely be rolled to 1/8” thread with great care</td>
</tr>
<tr>
<td>Medium Plastic</td>
<td>Easily rolled to 1/8” thread but breaks apart with continued handling</td>
</tr>
<tr>
<td>Highly Plastic</td>
<td>Will roll into a thread thinner than 1/8” and can be remolded and rolled again and again</td>
</tr>
</tbody>
</table>
Roll sample into ½-inch ball
Try to roll it into an 1/8" thread
## Toughness

<table>
<thead>
<tr>
<th>Description</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Only slight pressure is required to roll the thread near the plastic limit; thread is weak and soft</td>
</tr>
<tr>
<td>Medium</td>
<td>Medium pressure is required to roll the thread near the plastic limit; thread is moderately stiff</td>
</tr>
<tr>
<td>High</td>
<td>Considerable pressure is required to roll the thread near the plastic limit; thread is very stiff</td>
</tr>
</tbody>
</table>
**USCS Field Method (CL)**

- **< 15% coarse**
  - Lean clay
- **15-30% coarse**
  - More gravel than sand
    - Lean clay with gravel
  - More sand than gravel
    - Lean clay with sand
- **> 30% coarse**
  - More gravel than sand
    - Gravelly lean clay*
  - More sand than gravel
    - Sandy lean clay**

* If there is more than 15% sand present, append the phrase “with sand”
** If there is more than 15% gravel present, append the phrase “with gravel”
USCS Field Method (ML)

- **< 15% coarse**
  - Silt
  - More gravel than sand
    - Silt with gravel

- **15-30% coarse**
  - More sand than gravel
    - Silt with sand

- **> 30% coarse**
  - More gravel than sand
  - More sand than gravel
    - Gravelly Silt *
    - Sandy Silt **

---

* If there is more than 15% sand present, append the phrase “with sand”

** If there is more than 15% gravel present, append the phrase “with gravel”
USCS Field Method (CH)

< 15% coarse
- Fat clay

15-30% coarse
- More gravel than sand
  - Fat clay with gravel
- More sand than gravel
  - Fat clay with sand

> 30% coarse
- More gravel than sand
  - Gravelly fat clay*
- More sand than gravel
  - Sandy fat clay**

* If there is more than 15% sand present, append the phrase “with sand”
** If there is more than 15% gravel present, append the phrase “with gravel”
USCS Field Method (MH)

MH

- < 15% coarse
  - Elastic silt
- 15-30% coarse
  - More gravel than sand
    - Elastic silt with gravel
  - More sand than gravel
    - Elastic silt with sand
- > 30% coarse
  - More gravel than sand
    - Gravelly elastic silt*
  - More sand than gravel
    - Sandy elastic silt **

* If there is more than 15% sand present, append the phrase “with sand”

** If there is more than 15% gravel present, append the phrase “with gravel”
Estimating Size Fractions

Jar method

Wash test
Jar Method

• Place soil in jar or test tube and note the height of the soil column
• Add water and shake vigorously to place the soil particles in suspension
• Let the mixture settle
• Sand particles will settle in 20-30 seconds
• Note the height of the settled soil column to estimate the percentage of sand
Jar with graduations is best
Dry sediment volume
Settled sand volume
The void content of well sorted soils and sediments may be as high as 35% to 40%
The void content of poorly sorted soils and sediments may be as low as 25% to 30%.
Wash Test

• Select and moisten enough sands and fines to form a 1" cube of soil
• Cut the cube in half, set one half aside and place the other half in a small dish
• Wash and decant the fines from the dish until the wash water is clear
• Compare the two samples to estimate the percentages of sand and fines
Sample Descriptions
Example 1

*Well-Graded Gravel with Sand (GW)* – About 75% fine to coarse, hard, subangular gravel, quartz and chert; about 25% fine to coarse, hard, subangular sand, quartz; trace of fines; maximum size, 75 mm; brown (7.5YR 5/3); dry; no reaction with HCl.
Example 2

Silty Sand with Gravel (SM) – About 60% fine sand; about 25% silty fines with low plasticity, low toughness, low dry strength, rapid dilatancy; about 15% fine, hard, subrounded gravel, some particles fracture with hammer blow, quartz and chert; maximum size: 25 mm; no HCl reaction.

In-Place Conditions – Firm, stratified, contains lenses of silt 25 to 50 mm thick, moist, brown to gray (10YR 5/3 to 10YR 5/1).
Example 3

Silty Sand with Organic Fines (SM) – About 75% fine to coarse, hard, subangular reddish-brown (2.5YR 5/4) sand, quartz with iron-oxide coatings; about 25% organic and silty dark brown (7.5YR 3/3) nonplastic fines with no dry strength and slow dilatancy; wet; maximum size: coarse sand; weak reaction with HCl.
Example 4

*Poorly Graded Gravel with Sand (GP)* – About 75% fine to coarse, hard, subrounded to subangular gravel, chert and limestone; about 15% fine, hard, subrounded to subangular sand; about 10% silty nonplastic fines; moist, brown (7.5 YR 5/3); no reaction with HCl; original field sample had about 5% (by volume) hard, subrounded cobbles, chert and limestone, with a maximum dimension of 6 in. (150 mm).
Example 5

*Organic Soil (OL/OH)* – About 100% fines with low plasticity, slow dilatancy, low dry strength, and low toughness; wet, dark brown (10YR 3/3), organic odor; weak reaction with HCl.