14.330 SOIL MECHANICS

Exam #1: Soil Composition, Soil Classification, Soil Compaction, Hydraulic Conductivity, and Soil Stresses.

Questions (2 Points Each - 20 Points Total):

1. What is the full name and acronym for the soil classification system used predominately in this course? Briefly explain why it is important to have a standard soil classification system.

Unified Soil Classification System - USCS
So everyone can classify soil the same way.

2. Write the equation that relates total stress, pore water pressure, and effective stress in a soil mass. Detail the variables.

\[ \sigma' = \sigma - u \] (Effective Stress = Total Stress – Pore Pressure)

3. You are given the following results of an ASTM D4318 (i.e. Atterberg Limits) soils test: plasticity index = 40, plastic limit = 10. Is this a low or high plasticity fine grained soil?

\[ PI = LL - PL, \text{ therefore } LL = PL + PI \]

\[ LL = 50, \text{ so this is a HIGH plasticity fine grained soil.} \]

4. Write the equation that relates void ratio to specific gravity and detail the variables.

\[ Se = wG_s \]

(Saturation)(Void Ratio) = (Water Content)(Specific Gravity)
5. You are given a soil sample that has 20% gravel, 30% sand, and 50% silt/clay size particles (i.e. particles passing the #200 sieve). The plastic limit is 10%, the liquid limit 60%. What would be the first letter of the USCS symbol for this soil? Justify your answer.

50% Fines = Fine Grained. \[ \text{PI} = \text{LL} - \text{PL} = 50 \]

Using Casagrande's Chart, Soil is a C.

6. Detail how you would determine percent compaction from field compaction testing. Write the relevant equation and detail the variables.

Relative Compaction = RC (%) = \( \frac{\gamma_{d,\text{field}}}{\gamma_{d,\text{max}}} \times 100 \)

\( \gamma_{d,\text{field}} = \text{Field Dry Density} \)

\( \gamma_{d,\text{max}} = \text{Maximum Dry Density (MDD) from Proctor Test} \)

7. Describe the plastic limit of a soil in your own words. What does “plastic” mean?

Plastic limit is the water content at which soil behaves like a plastic material.

Plastic = permanent deformation.

8. A new grading contractor has recently started operations on Cape Cod, Massachusetts. The operations manager of the firm calls you for advice on what equipment to buy. You tell him that the near surface soils in the region primarily consist of poorly graded sands, with some marine clays in spots. After you give him this knowledge, he says “great, all we need is a sheepfoot roller then”. Do you agree with this assessment? Briefly explain your answer.

NO!

Will need a vibratory or smooth drum roller for sands.

9. Describe the effects that decreased compaction effort has on maximum dry density and optimum moisture content.

Decreased compaction effort leads to reduced Maximum Dry Density (\( \gamma_{d,\text{max}} \)) and increased Optimum Moisture Content (OMC).

10. Write the equation for Darcy’s Law and describe the variables.

\[ v = k \cdot i \] (Discharge Velocity = Coefficient of Permeability)(Hydraulic Gradient)
1. You are a field engineer for a construction services testing firm. Your current job assignment is to evaluate fill placement for a new roadway being constructed in Tewksbury, MA. The project specifications for the roadway require fill compaction to 98% of the ASTM D1557 compaction test results. Your lab manager sends you the results of Standard and Modified Proctor compaction testing on the fill being placed. These results are presented in Figure A. Your field compaction test results for the second soil lift taken at the intervals required by the project specifications are listed in Table A.

**Figure A.** Proctor Compaction Testing Results.
Table A. Field Density Testing Results for Soil Lift #2.

<table>
<thead>
<tr>
<th>STA</th>
<th>w (%)</th>
<th>γ (pcf)</th>
<th>γ_{d,field} (pcf)</th>
<th>RC (%)</th>
<th>PASS/FAIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>126 + 30</td>
<td>114.8</td>
<td>10.0</td>
<td>104.4</td>
<td>98.2</td>
<td>Pass</td>
</tr>
<tr>
<td>124 + 15</td>
<td>120.7</td>
<td>12.0</td>
<td>107.8</td>
<td>101.4</td>
<td>Pass</td>
</tr>
</tbody>
</table>

From the provided information, determine the following:

- The compaction characteristics for the ASTM D698 test.

Table A1. Laboratory Compaction Testing Results *(See Figure A).*

<table>
<thead>
<tr>
<th>Test Method</th>
<th>γ_{d,max} (pcf)</th>
<th>OMC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified (D698)</td>
<td>106.3</td>
<td>12.5</td>
</tr>
</tbody>
</table>

- If the fill meets the compaction requirements at the two field density test locations.

**STEPS:**

1. Determine γ_{d,max} and OMC for D698 test results (see Figure A and Table A1).

2. Convert field testing results to γ_{d,field} using \( \gamma_d = \frac{\gamma}{1 + w} \) equation.

3. Calculate % Field Compaction \( R = \frac{\gamma_{d, field}}{\gamma_{d, max}} \times 100 \)

4. Compare % Field Compaction to required Field Compaction from project specification (i.e. 98%).

Calculation results presented in Table A.

- If the field test(s) do not meet the project specifications, what remedial actions would you recommend to the contractor? **None needed.**
2. You are given the results of index testing (i.e. ASTM D422 and D4318) of two soil samples collected during a recent geotechnical exploration. The index test results are presented in Figure B. The first sample was taken between depths of 24.5 ft to 25 ft below the existing ground surface. The second sample was taken between depths of 68 ft to 68.5 ft below the existing ground surface. The groundwater table, at the time of the geotechnical exploration, was at a depth of 5.5 ft from the existing ground surface. Classify the soils in accordance with USCS (give symbol and group name). Relevant portions of ASTM D2487 are attached to the end of this exam.

Sample #1: 24.5 to 25 ft Depth.

From Figure B.
% Gravel = 18%
% Sand = 74%  Coarse Grained Soil (>50% Retained on #200 Sieve)
% Fines = 8%
Fines are CL (see Casagrande Chart on Sheet 6).

Coefficient of Uniformity = \( C_u = \frac{D_{60}}{D_{10}} = \frac{0.8\text{mm}}{0.1\text{mm}} = 8 \)

Coefficient of Curvature (i.e. Gradation) = \( C_c = \left( \frac{D_{30}}{D_{60} \times D_{10}} \right)^2 = \left( \frac{0.35\text{mm}}{0.8\text{mm} \times 0.1\text{mm}} \right)^2 = 1.53 \)

Determine USCS Classification from Figure 3, ASTM D2487.

\[ D_{60} = 0.8\text{mm}, D_{10} = 0.1\text{mm} \]

\[ C_u = \frac{D_{60}}{D_{10}} = \frac{0.8\text{mm}}{0.1\text{mm}} = 8 \]

\[ C_c = \left( \frac{D_{30}}{D_{60} \times D_{10}} \right)^2 = \left( \frac{0.35\text{mm}}{0.8\text{mm} \times 0.1\text{mm}} \right)^2 = 1.53 \]

Figure 3. ASTM D2487.
Casagrande Chart for Soil Classification (with Sample #1 and #2 Results Plotted).

Sample #2: 68.5 to 68.5 ft Depth.

From Figure A.

% Gravel = 0%
% Sand = 45%  Fine Grained Soil (≥ 50% Passing #200 Sieve)
% Fines = 55%

PI = LL – PL = 71 – 50 = 21;  PI = 21, LL = 71.

Soil is MH from Figure 4, ASTM D2487 (See above Casagrande Chart)
### SUMMARY:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Depth (ft)</th>
<th>USCS Symbol</th>
<th>USCS Group Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24.5 - 25</td>
<td>SW-SC</td>
<td>Well Graded Sand with Clay and Gravel</td>
</tr>
<tr>
<td>2</td>
<td>68 – 68.5</td>
<td>MH</td>
<td>Sandy Elastic Silt</td>
</tr>
</tbody>
</table>
Figure B. Grain Size Distributions and Atterberg Limits for Problem #2.
3. You have been given the results of a recent geotechnical exploration for a local project in Chelmsford, MA. The groundwater table at the time of exploration was 4 ft from the existing ground surface. This is also the interface between the SC and MH soil layers. Figure C provides the soil profile at the time of geotechnical exploration. From the provided information, calculate total stress, pore pressure, and effective stress with depth and plot them on the provided graphs. You must label numbers on the graphs for full credit.

**SOLUTION:**

Calculate total, pore pressure, and effective stresses with depth at the following points shown in Figure C:

- **Point A:** Bottom of SC Layer and GWT location (4 ft below existing ground surface)
- **Point B:** Middle of CL layer (not needed for this exam, but will be helpful later)
- **Point C:** Bottom of CL Layer (10 ft below existing ground surface)
- **Point D:** Bottom of Given Soil Profile (20 ft below existing ground surface)
Point A:

Use moist unit weight for SC: $\gamma_{sc} = 105$ pcf.

$\sigma_A = \gamma_{sc}(4\text{ft}) = (105 \text{ pcf})(4\text{ft}) = 420 \text{ psf}$

$u_A = 0$ (Above GWT)

$\sigma_A = \sigma'_A$ since $u_A = 0$ psf

Point B:

$\sigma_B = \sigma_A + \gamma_{SAT,CL}(3\text{ft}) = 420 \text{ psf} + (125 \text{ pcf})(3\text{ft}) = 795 \text{ psf}$

$U_B = \gamma_w(3\text{ft}) = (62.4 \text{ pcf})(3\text{ft}) = 187 \text{ psf}$

$\sigma'_B = \sigma_B - U_B = 795 \text{ psf} - 187 \text{ psf} = 608 \text{ psf} = 610 \text{ psf (rounded)}$

Point C:

$\sigma_C = \sigma_B + \gamma_{SAT,CL}(3\text{ft}) = 795 \text{ psf} + (125 \text{ pcf})(3\text{ft}) = 1170 \text{ psf}$

$U_C = \gamma_w(6\text{ft}) = (62.4 \text{ pcf})(6\text{ft}) = 374 \text{ psf}$

$\sigma'_C = \sigma_C - U_C = 1170 \text{ psf} - 374 \text{ psf} = 796 \text{ psf} = 795 \text{ psf (rounded)}$

Point D:

$\sigma_D = \sigma_C + \gamma_{SAT,SM}(10\text{ft}) = 1170 \text{ psf} + (120\text{pcf})(10\text{ft}) = 2370 \text{ psf}$

$u_D = \gamma_w(16\text{ft}) = (62.4 \text{ pcf})(16\text{ft}) = 998 \text{ psf}$

$\sigma'_D = \sigma_D - u_D = 2370 \text{ psf} - 998 \text{ psf} = 1370 \text{ psf (rounded)}$
4. You are given the flow net for the gravity dam shown in Figure D. A piezometer (i.e. standpipe) is installed at Point A. The following are some dimensions of the flow net:

- Dam Length: 135 ft.
- \( H = 17 \) ft
- \( H_1 = 39 \) ft
- The depth of Point A below the dam is 27 ft.

How much would the water in the piezometer drop below the water level on the left side of the dam? How much would the water level rise relative to the water level on the right side of the dam? What is the pore pressure at Point A?

**Figure D.** Flow Net underneath a Gravity Dam
(Note Figure is NTS: Not To Scale).

**From Figure D:**

- Change in Head from Left Side of Dam to Right Side of Dam = \( H = 17 \) ft
- Number of Drops \((N_d) = 8\)
Therefore, Change in Head per drop = H/8 = 2.125ft/drop

Number of drops from left side to Point A = 3.5. Therefore, water in a piezometer at Point A would drop 3.5H/8 (i.e. 7.44ft) from the water level on the Left Side of the Dam. Conversely, the water level would rise 4.5H/8 (i.e. 9.56ft) from the water level on the Right Side of the Dam.

Pore Pressure = Water Pressure = (Height of Water)(Unit Weight of Water)

Level of Water above bottom of dam = H – 3.5H/8 = 39 ft – 4.5(17)/8 = 31.56 ft.

Height of water above Point A = 31.56 ft + 27 ft = 58.56 ft.

**Pore Pressure = (58.56)(62.4 lb/ft³) = 3654 psf = 3655 psf (rounded).**

**EXTRA CREDIT:** (5 points)

Name three methods for determining change in vertical stresses within a soil mass due to foundation loading. Briefly explain which method you would use and why.

**Boussinesq (Both column and strip. Conservative. No soil layers)**

**Westergaard (Both column and strip. Less conservative. Factors in layers)**

**2V:1H Approximation Method (Middle of rectangular footing only. Back of the envelope, quick calculation)**
HELPFUL INFORMATION?

\[ C_u = \frac{D_{60}}{D_{10}} \quad C_c = \frac{(D_{30})^2}{(D_{60} \times D_{10})} \quad \Delta q = k \frac{H}{N_d} \]

\[ E = mc^2 \quad \text{Inflow} = \text{Outflow} \]

\[ \text{At the End Condition, } \text{Love}_{\text{you take}} = \text{Love}_{\text{you make}} \]
For classification of fine-grained soils and fine-grained fraction of coarse-grained soils:

**Equation of A-line**
Horizontal at PI = 4 to LL = 25.5, then PI = 0.73 (LL = 20)

**Equation of U-line**
Vertical at LL = 16 to PI = 7, then PI = 0.9 (LL = 8)

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**Gravel**

<table>
<thead>
<tr>
<th>% gravel &gt; % sand</th>
<th>% gravel &gt; 12%</th>
<th>&lt;15% sand</th>
<th>&lt;15% sand</th>
<th>15% sand</th>
<th>15% sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;5% fines</td>
<td>$C_2 \geq 4$ and $1 \leq C_3 \leq 3$</td>
<td>Well-graded gravel</td>
<td>Well-graded gravel with sand</td>
<td>Poorly graded gravel</td>
<td>Poorly graded gravel with sand</td>
</tr>
<tr>
<td></td>
<td>$C_2 \leq 4$ and/or ($C_1 &lt; 1$ or $C_3 &gt; 3$)</td>
<td>Well-graded gravel with silty gravel</td>
<td>Well-graded gravel with clay and silt and sand</td>
<td>Poorly graded gravel with silty gravel</td>
<td>Poorly graded gravel with clay and silt and sand</td>
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**Sand**

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<td>Well-graded sand</td>
<td>Well-graded sand with gravel</td>
<td>Poorly graded sand</td>
<td>Poorly graded sand with gravel</td>
</tr>
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<td></td>
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<td>Well-graded sand with sand and gravel</td>
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**Notes:**

- The chart uses a graph to illustrate the classification of soils based on their plasticity index (PI) and liquid limit (LL).
- The chart is divided into different sections based on the percentage of gravel and sand.
- Each section contains the classification of the soil type based on the PI and LL values.