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. You are given the following results from Atterberg Limits testing on a soil sample ($w_p = 23\%$, $w_L = 50\%$) collected from a boring on a local project site. What is the plasticity index for this soil? If the soil is fine grained, what is the USCS Group Symbol for this soil?

   \[ \text{PI} = \text{LL} - \text{PL}, \text{ therefore } 50 - 23 = 27. \]

   Soil is CH (see ASTM Figure 1 on Page 10)

2. The soil sample from Question #1 had natural moisture content of 56.3\% prior to Atterberg Limits testing. What does the natural moisture content result tell you about the soil in-situ (i.e. “in place”)?

   That the soil has a natural moisture content beyond the LL. The soil will act as a liquid.

3. Write the equation that relates velocity of water thru soils to hydraulic gradient and detail the variables of this equation.

   \[ v = ki \]

   Discharge Velocity = (Coefficient of Permeability)(Hydraulic Gradient)

4. What is the relationship between moist unit weight and dry unit weight? Write the relevant equation and describe the variables.

   \[ \gamma_d = \frac{\gamma}{1 + w} \]

   $\gamma_d$ = Dry Unit Weight, $\gamma$ = Moist Unit Weight, $w$ = Water Content
5. Write the effective stress equation and detail the variables.

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

6. Your firm’s lab manager tells you that the maximum dry density for the soil to be used for fill on your project is 105.2 lbs/ft\(^3\) at an OMC of 11% according to ASTM D698. At the site, you find that that first lift of fill placed has a moist unit weight of 118.3 lbs/ft\(^3\) at a \(w_n\) of 12.1%. What is the percent compaction for the first lift? Is this percent compaction even possible?

\[ \gamma_d = \frac{\gamma}{1 + w} \]

\[ \gamma_{d,\text{field}} = \frac{(118.3 \text{ lbs/ft}^3)/(1+0.121)) = 105.53 \text{ lbs/ft}^3 \]

\[ R (\%) = \left( \frac{105.5 \text{ lbs/ft}^3}{105.2 \text{ lbs/ft}^3} \right) \times 100 = 100.3\%. \text{ Yes.} \]

7. Write the equation that relates saturation to specific gravity of soils and describe the variables.

\[ S_e = w G_s \]

(Saturation)(Void Ratio) = (Water Content)(Specific Gravity)

8. You are given a soil sample that has 10% gravel, 20% sand, and 70% silt/clay size particles (i.e. particles passing the #200 sieve). What compaction equipment would you recommend to a contractor that has to place 2ft of this soil to build up a building pad? Why?

70% Fines = Fine Grained Soil. Use Sheepfoot, since it is better for fine grained soils.

9. For the USCS Soil Classification System, what does the acronym USCS stand for?

Unified Soil Classification System - USCS

10. Describe effective stress in your own words.

The stress the soil “sees”.
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.

![Proctor Compaction Testing Results](image)

**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>123 + 26</td>
<td>10.0</td>
<td>117.5</td>
<td>106.8</td>
<td>92.0</td>
<td>Fail</td>
</tr>
<tr>
<td>140 + 75</td>
<td>11.7</td>
<td>121.1</td>
<td>108.4</td>
<td>93.4</td>
<td>Fail</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 (D1557)</td>
<td>116.1</td>
<td>9.4</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 D1557 test results (see Figure A and Table A1).

2. Convert field testing results to γ_{d,field} using the equation:

   \[
   γ_{d} = \frac{γ}{1 + w}
   \]

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

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? **Dry soils at both Stations and recompact.**
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 1.5 ft to 2.5 ft below the existing ground surface. The second sample was taken between depths of 6.5 ft to 7.5 ft below the existing ground surface. The groundwater table, at the time of the geotechnical exploration, was at a depth of 4.0 ft from the existing ground surface. Classify the soils in accordance with USCS (give group symbol and group name). Relevant portions of ASTM D2487 are attached to the end of this exam.

Sample #1: 1.5 to 2.5 ft Depth.

From Figure B.
% Gravel = 10%
% Sand = 81%  **Coarse Grained Soil (>50% Retained on #200 Sieve)**
% Fines = 9%
Fines are CL (see Casagrande Chart on Sheet 6).

Coefficient of Uniformity = \( C_u = \frac{D_{60}}{D_{10}} = \frac{0.82\text{mm}}{0.085\text{mm}} = 9.64 \)

Coefficient of Curvature (i.e. Gradation) = \( C_c = \frac{(D_{30})^2}{(D_{60} \times D_{10})} = \frac{(0.395\text{mm})^2}{(0.82\text{mm})(0.085\text{mm})} = 2.23 \)

**Determine USCS Classification from Figure 3, ASTM D2487**
Figure 3. ASTM D2487.
Sample #2: 6.5 to 7.5 ft Depth.

From Figure A.

% Gravel = 0%
% Sand = 45%
% Fines = 55%

Fine Grained Soil (≥ 50% Passing #200 Sieve)

PI = LL – PL = 70 – 50 = 20; PL = 20, LL = 70.

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 (or Silty Clay)</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 CL 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.

**Figure C.** Soil Profile for Problem 3.

**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 (4ft 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: $\gamma_{sc} = 115 \text{pcf}$.

$\sigma_A = \gamma_{sc}(4\text{ft}) = (115 \text{pcf})(4\text{ft}) = 460 \text{ psf}$

$u_A = 0 \text{ (Above GWT)}$

$\sigma_A = \sigma_A' \text{ since } u_A = 0 \text{ psf}$

Point B:

$\sigma_B = \sigma_A + \gamma_{SAT,CL}(3\text{ft}) = 460 \text{ psf} + (120 \text{ pcf})(3\text{ft}) = 820 \text{ psf}$

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

$\sigma'_B = \sigma_B - U_B = 820 \text{ psf} - 187 \text{ psf} = 633 \text{ psf} = 635 \text{ psf (rounded)}$

Point C:

$\sigma_C = \sigma_B + \gamma_{SAT,CL}(3\text{ft}) = 820 \text{ psf} + (120 \text{ pcf})(3\text{ft}) = 1180 \text{ psf}$

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

$\sigma'_C = \sigma_C - U_C = 1180 \text{ psf} - 374 \text{ psf} = 806 \text{ psf} = 805 \text{ psf (rounded)}$

Point D:

$\sigma_D = \sigma_C + \gamma_{SAT,SM}(10\text{ft}) = 1180 \text{ psf} + (118\text{pcf})(10\text{ft}) = 2360 \text{ psf}$

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

$\sigma'_D = \sigma_D - u_D = 2360 \text{ psf} - 998 \text{ psf} = 1360 \text{ psf (rounded)}$
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: 175 ft.
H = 25 ft
H₁ = 35 ft
The depth of Point A below the dam is 16 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 in the piezometer rise relative to the water level on the right side of the dam? What is the pore pressure at Point A?

From Figure D:
Change in Head from Left Side of Dam to Right Side of Dam = H = 25 ft
Number of Drops ($N_d$) = 8

Therefore, Change in Head per drop = $H/8 = 3.125$ ft/drop

Number of drops from back side to Point A = 6.5. Therefore, water in a piezometer at Point A would drop $6.5H/8$ (20.3 ft) from the water level on the Left Side of the Dam. Conversely, the water level would rise $1.5H/8$ (4.7 ft) 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 = $H_1 = 6.5H/8 = 35$ ft – 6.5(25)/8 = 14.69 ft.

Height of water above Point A = 14.69 ft + 16 ft = 30.69 ft.

Pore Pressure = $(30.69)(62.4 \text{ lb/ft}^3) = 1915$ psf.

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?

**GRAVEL**

- **% gravel > % sand**
  - >12% fines
  - <6% fines
    - $C_1 < 6$ and/or $[C_1 < 1 \text{ or } C_2 > 3]$:
      - $C_2 > 6$ and/or $C_1 \leq 3$:
        - $< 5\%$ fines: $C_6 > 4 \text{ and } C_6 \leq 3$
      - $C_2 \geq 4 \text{ and } C_6 \leq 3$
        - $< 15\%$ sand:
          - $< 15\%$ sand:
            - Well-graded gravel with sand
          - $15\%$ sand:
            - Poorly graded gravel with sand
        - $15\%$ sand:
          - Well-graded gravel with silt
        - $>15\%$ sand:
          - Well-graded gravel with clay (or silty clay)
      - $< 15\%$ sand:
        - Poorly graded gravel with silt
      - $15\%$ sand:
        - Poorly graded gravel with clay (or silty clay)
    - $< 15\%$ sand:
      - Poorly graded gravel with clay and sand
    - $>15\%$ sand:
      - Silty gravel
    - $15\%$ sand:
      - Silty gravel with sand
  - $5-12\%$ fines
    - $5-12\%$ fines
      - $< 15\%$ sand:
        - Well-graded gravel
      - $15\%$ sand:
        - Poorly graded gravel with sand
      - $>15\%$ sand:
        - Poorly graded gravel with clay and sand
      - $15\%$ sand:
        - Clayey gravel
      - $>15\%$ sand:
        - Clayey gravel with sand
    - $15\%$ sand:
      - Silty, clayey gravel
    - $>15\%$ sand:
      - Silty, clayey gravel with sand

**SAND**

- **% sand > % gravel**
  - >12% fines
  - <6% fines
    - $C_2 \geq 6$ and/or $C_2 \leq 3$
      - $< 15\%$ gravel:
        - Well-graded sand
      - $15\%$ gravel:
        - Poorly graded sand
      - $>15\%$ gravel:
        - Poorly graded sand with gravel
    - $15\%$ gravel:
      - Poorly graded sand with silt
    - $>15\%$ gravel:
      - Poorly graded sand with clay and gravel
    - $15\%$ gravel:
      - Well-graded sand with clay (or silty clay)
    - $>15\%$ gravel:
      - Well-graded sand with clay and gravel
    - $15\%$ gravel:
      - Poorly graded sand with clay and gravel
    - $>15\%$ gravel:
      - Silty, clayey sand
    - $15\%$ gravel:
      - Silty sand
    - $>15\%$ gravel:
      - Clayey sand
  - $5-12\%$ fines
    - $5-12\%$ fines
      - $< 15\%$ gravel:
        - Well-graded sand with silt
      - $15\%$ gravel:
        - Poorly graded sand with silt
      - $>15\%$ gravel:
        - Poorly graded sand with silt and gravel
      - $15\%$ gravel:
        - Well-graded sand with clay (or silty clay)
      - $>15\%$ gravel:
        - Well-graded sand with clay and gravel
      - $15\%$ gravel:
        - Poorly graded sand with clay and gravel
      - $>15\%$ gravel:
        - Silty, clayey sand with gravel
\[ C_u = \frac{D_{60}}{D_{10}} \]

\[ C_c = \frac{(D_{30})^2}{(D_{60} \times D_{10})} \]

\[ \Delta q = k \frac{H}{N_d} \]

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)