QUIZ GT103
Consistency and Compaction of Soil

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► PROBLEMS

PROBLEM 1A

A soil was found to have a liquid limit equal to 38%, a plastic limit of 21%, a natural water content of 27%, and a percentage of clay-sized particles equal to 25%. What is the plasticity index of this soil?

A) PI = 8%

B) PI = 17%

C) PI = 35%

D) PI = 65%

PROBLEM 1B

What is the liquidity index of the soil considered in Problem 1A?

A) LI = 8%

B) LI = 17%

C) LI = 35%

D) LI = 65%

PROBLEM 1C

What is the consistency index of the soil considered in Problem 1A?

A) CI = 8%

B) CI = 17%

C) CI = 35%

D) CI = 65%

PROBLEM 1D

What is the activity of the soil considered in Problem 1A?

A) A = 0.3

B) A = 0.7

C) A = 1.1

D) A = 1.5

PROBLEM 2A

A liquid limit test conducted on a soil sample using the cup device gave the results summarized in the table below.

No. of blows	10	18	25	28	40	45
Water content (%)	62.0	45.1	39.8	34.9	25.2	24.7

It was found that the water contents at which 3-mm diameter threads started to crumble were 20.8% in the first determination, 20.6% in the second determination, and 21.0% in the third. The *in situ* water content of the soil is 32.1% and the specific gravity is G_S = 2.70. The liquid limit and the plastic limit for this soil are, respectively,

A) *LL* = 30% and *PL* = 19.6%

B) *LL* = 30% and *PL* = 20.8%

C) *LL* = 38% and *PL* = 19.6%

D) *LL* = 38% and *PL* = 20.8%

PROBLEM 2B

What is the liquidity index of the soil considered in Problem 2A?

A) *LI* = 22%

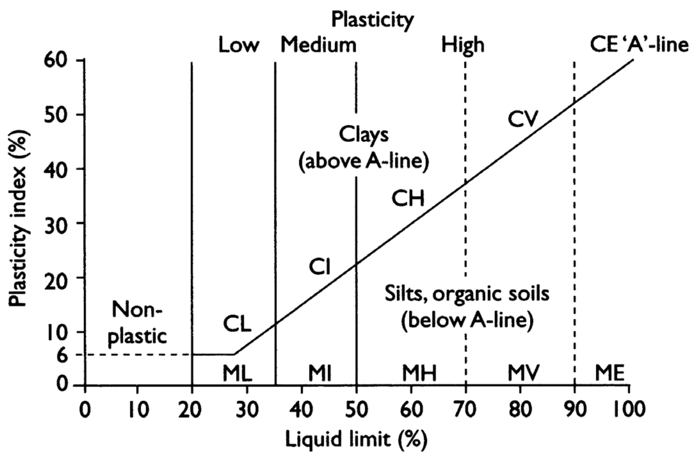
B) *LL* = 44%

C) *LL* = 66%

D) *LL* = 88%

PROBLEM 2C

Using the plasticity chart shown below, classify the soil introduced in Problem 2A.



A) *CL*

B) *CI*

C) *ML*

D) *MH*

PROBLEM 2D

Calculate the void ratio at the liquid limit for the soil introduced in Problem 2A.

A) *e* = 0.69

B) *e* = 0.86

C) *e* = 1.03

D) *e* = 1.20

PROBLEM 3

The results of a fall cone test are shown in the table below.

Cone mass	80-gram cone					
Penetration (mm)	5.5	7.3	14.5	22.1	24.5	34
Water content (%)	39.2	44.5	52.5	60.0	62	67

The liquid limit and the plastic limit for the soil in question are, respectively,

A) *LL* = 44% and *PL* = 18.4%

B) *LL* = 44% and *PL* = 30%

C) *LL* = 58% and *PL* = 18.4%

D) *LL* = 58% and *PL* = 30%

PROBLEM 4A

Below, we have the results of a shrinkage limit test.

Initial volume of soil in a saturated state	24.8 cm^3
Final volume of soil in a dry state	16.3 cm^3
Initial mass in a saturated state	46.0 g
Final mass in a dry state	31.1 g

Recall that the shrinkage ratio of a soil is given by the relation

$$SR = \frac{M_2}{V_f \rho_w}$$

where M_2 is the mass of the dry soil pat, V_f is the volume in the oven-dried pat, and ρ_w is the density of water. The shrinkage limit and the shrinkage ratio can be combined to obtain the specific gravity of a soil. The expression to use is

$$G_s = \frac{1}{\frac{1}{SR} - \frac{SL}{100}}$$

Determine the shrinkage limit of the soil.

A) *SL* = 17.9%

B) *SL* = 21.1%

C) *SL* = 25.3%

D) *SL* = 29.5%

PROBLEM 4B

Determine the shrinkage ratio and estimate the specific gravity of the soil introduced in the previous problem.

A) *SR* = 1.60 and G_s = 2.24

B) *SR* = 1.72 and G_s = 2.49

C) *SR* = 1.85 and G_s = 2.77

D) *SR* = 1.93 and G_s = 2.95

PROBLEM 5A

The following results were obtained from a standard compaction test.

Water content (%)	5.0	8.8	11.3	13.1	14.4	19.3
Weight of container and compacted soil (N)	35.80	37.30	39.32	40.04	40.07	39.06

The container has a volume of 9.5 cm^3 and a weight of 19.78 N. The specific gravity of the soil particles is 2.53. Determine the maximum dry unit weight and the optimum moisture content of the soil.

A) $(\gamma_d)_{\max}$ = 12.5 kN/m^3 and w_{opt} = 11.2%
B) $(\gamma_d)_{\max}$ = 18.9 kN/m^3 and w_{opt} = 15.0%
C) $(\gamma_d)_{\max}$ = 23.1 kN/m^3 and w_{opt} = 19.1%
D) $(\gamma_d)_{\max}$ = 27.0 kN/m^3 and w_{opt} = 23.7%

PROBLEM 5B

Compute the void ratio and the degree of saturation for the soil at the optimum condition for the soil presented in Problem 5A.

A) e_0 = 0.38 and S = 73.1%
B) e_0 = 0.38 and S = 85.3%
C) e_0 = 0.51 and S = 73.1%
D) e_0 = 0.51 and S = 85.3%

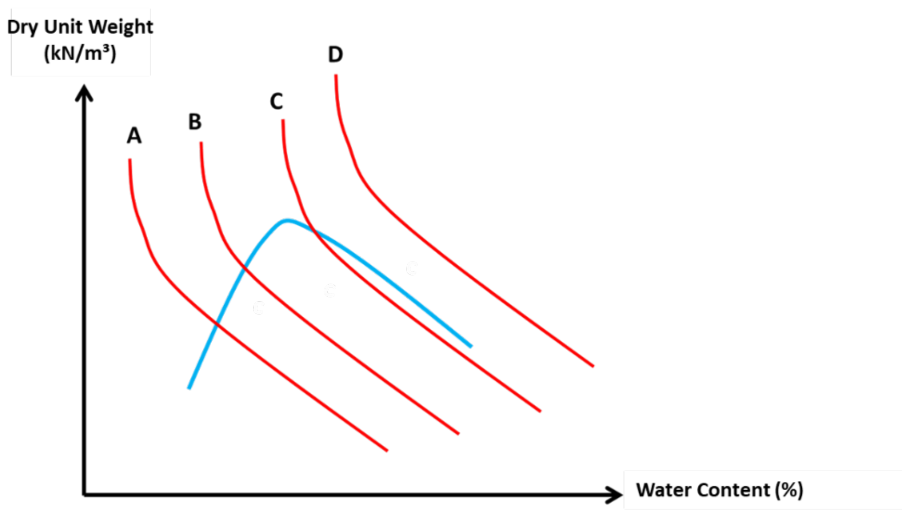
PROBLEM 5C

If the natural moisture content of the soil in Problem 5A is 11.8%, what will be the possible maximum dry density if the soil is compacted with its natural moisture content?

A) $(\gamma_d)_{\max}$ = 10.2 kN/m^3
B) $(\gamma_d)_{\max}$ = 17.6 kN/m^3
C) $(\gamma_d)_{\max}$ = 22.5 kN/m^3
D) $(\gamma_d)_{\max}$ = 27.0 kN/m^3

PROBLEM 6

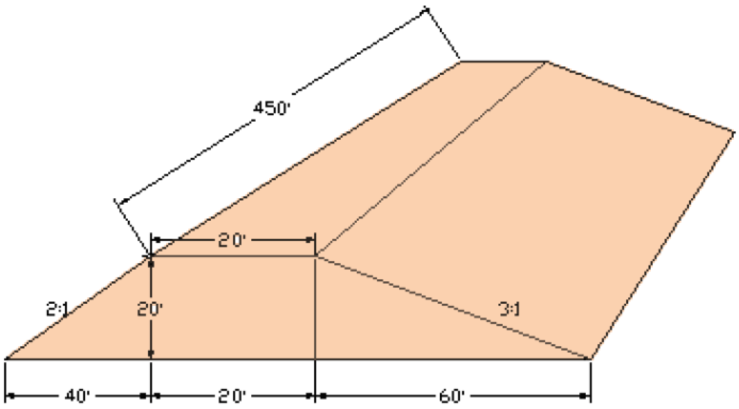
Below we have a generic plot of dry density versus water content. The compaction curve is in blue, and a series of additional curves are given in red. The zero air-voids curve can only be represented by:



A) Curve A.
B) Curve B.
C) Curve C.
D) Curve D.

PROBLEM 7

Suppose we wish to construct a levee with the dimensions shown below. The levee fill is a silty clay soil to be compacted to at least 95% of maximum standard Proctor of γ_d = 106 pcf at an optimum moisture content of 18%. The borrow pit has a silty clay with an in-situ moist density of 112.1 pcf at 18% and G_s = 2.68. When the soil is excavated and loaded onto the trucks, the void ratio of the material is e = 1.47. The trucks can haul 15 cubic yards of material per trip. Determine the required number of truckloads.



A) 2310 truckloads.

B) 2840 truckloads.

C) 3120 truckloads.

D) 3450 truckloads.

PROBLEM 8A

Laboratory compaction results for a clayey soil are given in the next table.

Moisture content (%)	Dry Unit Weight (kN/m³)
6	14.65
8	17.78
9	18.48
11	18.91
12	18.53
14	16.93

Following are the results of a field unit-weight determination test performed on the same soil by means of the sand cone method. Determine the dry unit weight of compaction in the field.

Calibrated dry density of Ottawa sand	1731 kg/m³
Calibrated mass of Ottawa Sand to fill the cone	0.118 kg
Mass of jar + cone + sand (before use)	6.08 kg
Mass of jar + cone + sand (after use)	2.86 kg
Mass of moist soil from hole	3.34 kg
Moisture content of moist soil	12.1%

A) $\gamma_{d,\text{field}}$ = 13.4 kN/m^3

B) $\gamma_{d,\text{field}}$ = 16.2 kN/m^3

C) $\gamma_{d,\text{field}}$ = 19.5 kN/m^3

D) $\gamma_{d,\text{field}}$ = 22.0 kN/m^3

PROBLEM 8B

The following are results of a standard Proctor test performed on the soil presented in Problem 8A. The mold volume is 943.3 cm^3. Find the relative compaction in the field.

Mass of moist soil in the mold (kg)	Moisture content (%)
1.47	10.0
1.83	12.5
2.02	15.0
1.95	17.5
1.73	20.0
1.69	22.5

A) R = 63.9%
B) R = 77.4%
C) R = 88.9%
D) R = 95.4%

▶ SOLUTIONS

P.1 ■ Solution

Part A: The plasticity index of a soil is simply the difference between the liquid limit and the plastic limit,

$$PI = 38 - 21 = \boxed{17\%}$$

▶ The correct answer is **B**.

Part B: The liquidity index follows from the relation

$$LI = \frac{w - PL}{LL - PL} = \frac{27 - 21}{38 - 21} = \boxed{35\%}$$

▶ The correct answer is **C**.

Part C: The consistency index follows from the relation

$$CI = \frac{LL - w}{LL - PL} = \frac{38 - 27}{38 - 21} = 64.7\% \approx \boxed{65\%}$$

▶ The correct answer is **D**.

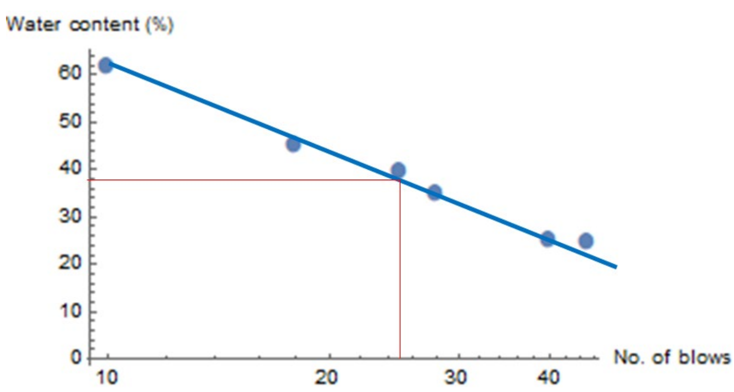
Part D: The activity is the ratio of the soil's plasticity index to the percent of clay-sized particles (less than 2 μm) present in the soil. Hence,

$$A = \frac{PI}{\%\text{Finer than } 2\ \mu\text{m}} = \frac{LL - PL}{[\% < 2\ \mu\text{m}]} = \frac{38 - 21}{25} = 0.68 \approx \boxed{0.7}$$

▶ The correct answer is **B**.

P.2 ■ Solution

Part A: Plot the water content versus No. of blows in a semilogarithmic plot, obtain a linear fit of the data, and then establish the liquid limit as the water content corresponding to 25 blows. In doing so, we find LL = 38%.



To obtain the plastic limit, we simply take the average of the water contents at which the 3-mm threads crumbled; that is,

$$PL = \frac{20.8 + 20.6 + 21.0}{3} = \boxed{20.8\%}$$

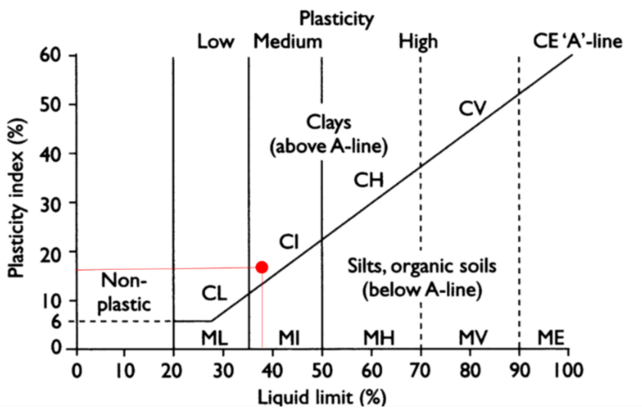
▶ The correct answer is **D**.

Part B: The liquidity index is given by

$$LI = \frac{w - PL}{LL - PL} = \frac{32.1 - 20.8}{38 - 20.8} = 65.7\% \approx \boxed{66\%}$$

▶ The correct answer is **C**.

Part C: The liquid limit is *LL* = 38% and the plasticity index is *PI* = *LL* – *PL* = 17.2%. Using the plasticity chart, we see that the soil belongs to class CI, i.e, the soil is a clay of intermediate plasticity.



▶ The correct answer is **B**.

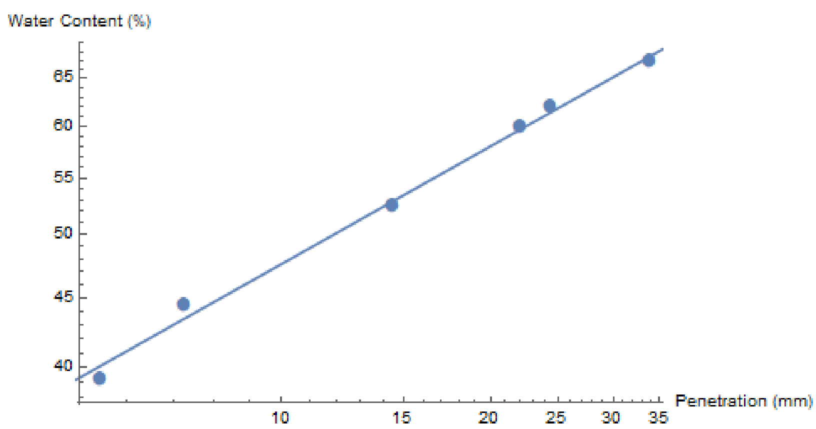
Part D: Assume that the soil is saturated at the liquid limit. For a saturated soil, then, we have $e = wG_s$. Thus,

$$e = wG_s = LL \times G_s = 0.38 \times 2.70 = \boxed{1.03}$$

▶ The correct answer is **C**.

P.3 ■ Solution

We graph the data in a log-log plot of water content versus penetration. A curve fit of the form $y = ax^b$ is then obtained, for example, by using the command *FindFit* in Mathematica. The liquid state line was found to be $y = 24.64x^{0.286}$.



The liquid limit is the water content on the liquid state line that corresponds to a penetration of 20 mm; that is, $LL = y(20) = 24.64 \times 20^{0.286} =$ 58%. The plastic limit, in turn, is obtained by fitting the data to the expression

$$PL = C(2)^m$$

which, when compared to the foregoing data fit, implies that *C* = 24.6 and *m* = 0.286. Accordingly,

$$PL = 24.6(2)^{0.286} = 29.99 \approx \boxed{30\%}$$

▶ The correct answer is **D**.

P.4 ■ Solution

Part A: The shrinkage limit follows from the expression

$$SL = \left(\frac{M_1 - M_2}{M_2}\right) \times 100 - \left(\frac{V_i - V_f}{M_2}\right) \rho_w \times 100$$

where M_1 is the mass of the wet soil pat in the beginning of the test, M_2 is the mass of the dry soil pat in the dish at the beginning of the test, V_i is the initial volume of the wet soil pat, and V_f is the volume of the oven-dried soil pat. In the present case, we have M_1 = 44.0 g, M_2 = 30.1 g, V_i = 24.8 cm³, and V_f = 16.3 cm³. Substituting these quantities in the previous equation, we obtain

$$SL = \left(\frac{44.0 - 30.1}{30.1}\right) \times 100 - \left(\frac{24.8 - 16.3}{30.1}\right) \times 100 = \boxed{17.9\%}$$

► The correct answer is **A**.

Part B: To determine the specific gravity, we resort to the formula

$$G_s = \frac{1}{\frac{1}{SR} - \frac{SL}{100}}$$

where SL is the shrinkage limit and SR is the shrinkage ratio, given by

$$SR = \frac{M_2}{V_f \rho_w} = \frac{30.1}{16.3 \times 1.0} = \boxed{1.85}$$

The specific gravity is estimated as

$$G_s = \frac{1}{\frac{1}{SR} - \frac{SL}{100}} = \frac{1}{\frac{1}{1.85} - \frac{17.9}{100}} = \boxed{2.77}$$

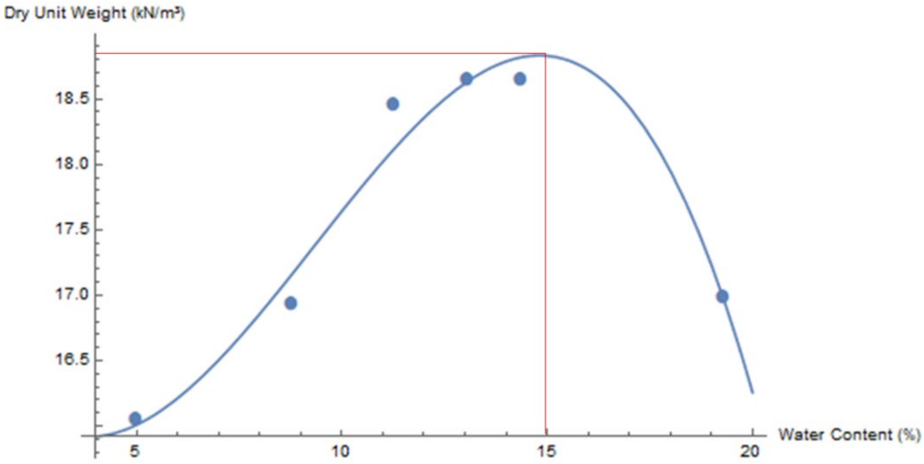
► The correct answer is **C**.

P.5 ■ Solution

Part A: The following table is prepared.

Sample No.	1	2	3	4	5	6
Water content (%)	5	8.8	11.3	13.1	14.4	19.3
Weight of container and compacted soil (N)	35.81	37.30	39.32	40.04	40.07	39.06
Weight of container (N)	19.80	19.80	19.80	19.80	19.80	19.80
Weight of compacted soil (N)	16.01	17.50	19.52	20.24	20.27	19.26
Volume of container (cm³)	950	950	950	950	950	950
Bulk unit weight of compacted soil (kN/m³)	16.85	18.42	20.55	21.31	21.34	20.27
Dry unit weight of compacted soil (kN/m³)	16.05	16.93	18,46	18.84	18.65	16.99

Plotting values of water content (blue row) versus dry unit weight (red row), we obtain the compaction curve. The following is the graph of a third-degree polynomial interpolation for the data.



By inspection, we see that the optimum moisture content is w = 15.0%, at which the maximum dry unit weight equals about 18.9 kN/m³.

► The correct answer is **B**.

Part B: Suppose that, at the optimum condition, the void ratio is e_0. Hence,

$$(\gamma_d)_{\max} = \frac{G_s\gamma_w}{(1+e_0)} \rightarrow 18.9 = \frac{2.9\times 9.81}{(1+e_0)}$$

$$\therefore e_0 = \boxed{0.51}$$

To obtain the degree of saturation, we use the formula

$$Se = wG_s \rightarrow S = \frac{wG_s}{e} = \frac{0.15\times 2.9}{0.505} = 0.853 = \boxed{85.3\%}$$

► The correct answer is **D**.

Part C: By inspection of the compaction curve presented in Part 5A, we read that the maximum dry unit weight corresponding to a water content of 10% is $(\gamma_d)_{\max} = 17.6\ \text{kN/m}^3$.

► The correct answer is **B**.

P.6 ■ Solution

The relation between moisture content and dry unit weight for a saturated soil is called the zero air-voids line. Regardless of the compaction effort, it is not feasible to expel all air from the soil. Consequently, the curve in question should never intercept the compaction curve, which of course represents valid soil states only. The only curve that does not intercept the blue compaction line is curve *D*.

► The correct answer is **D**.

P.7 ■ Solution

The volume of the levee can be computed with elementary geometry,

$$\text{Volume of Levee} = [0.5(40\times 20) + 20\times 20 + 0.5(60\times 20)]\times 450 = 23{,}300\ \text{yd}^3$$

To find the volume required from the borrow pit, consider that the weight of solids is the same for the borrow pit and the levee, i.e., $W_{s,\text{borrow}} = W_{s,\text{levee}}$. Now,

$$\gamma_d = \frac{W_s}{V} \rightarrow W_s = \gamma_d V \rightarrow \gamma_{d,\text{borrow}}V_{\text{borrow}} = \gamma_{d,\text{borrow}}V_{\text{borrow}}$$

where $\gamma_{d,\text{borrow}} = \gamma/(1+w) = 112.1/(1+0.18) = 95$ pcf, and $\gamma_{d,\text{levee}} = 0.95\times 106 = 100.7$ pcf. The volume of the borrow pit is then

$$V_{\text{borrow}} = V_{\text{levee}}\times\frac{\gamma_{d,\text{levee}}}{\gamma_{d,\text{borrow}}} = 23{,}300\times\frac{100.7}{95} = 24{,}700\ \text{yd}^3$$

The number of truckloads required is based on the equation

$$W_{s,\text{hauled}} = W_{s,\text{levee}} \rightarrow \gamma_{d,\text{hauled}}V_{\text{hauled}} = \gamma_{d,\text{levee}}V_{\text{levee}}$$

$$\therefore V_{\text{hauled}} = \frac{\gamma_{d,\text{levee}}}{\gamma_{d,\text{hauled}}}\times V_{\text{levee}}\quad(\text{I})$$

We have $\gamma_{d,\text{levee}} = 100.7$ pcf and $\gamma_{d,\text{hauled}}$ is calculated as

$$\gamma_{d,\text{hauled}} = \frac{G_s\gamma_w}{1+e} = \frac{2.68\times 62.4}{1+1.47} = 67.7\ \text{pcf}$$

Substituting the appropriate data in equation (I) gives

$$V_{\text{hauled}} = \frac{100.7}{67.7}\times 23{,}300 = 34{,}650\ \text{yd}^3$$

Thus, the number of truckloads is

$$\text{No. Truck loads} = \frac{V_{\text{hauled}}}{\text{Truck Capacity}} = \frac{34{,}650\ \text{yd}^3}{15\,\dfrac{\text{yd}^3}{\text{truckload}}} = \boxed{2310\ \text{truckloads}}$$

► The correct answer is **A**.

P.8 ■ Solution

Part A: First, we calculate the volume of the hole, V_H, using the relation

$$V_H = \frac{\text{Mass of sand used to fill the hole}}{\text{Dry density of Ottawa sand}}$$

The mass of sand used to fill the hole is the difference between the mass of sand used to fill the hole and cone and the calibrated mass of the Ottawa sand to fill the cone; that is,

$$\text{Mass of sand used to fill the hole} = [6.08 - 2.86] - 0.118 = 3.102 \text{ kg}$$

Substituting 3.102 kg for mass of sand used to fill the hole and 1731 kg/m³ for dry density of Ottawa sand gives

$$V_H = \frac{3.102}{1731} = 0.001792 \text{ m}^3$$

Thence, we substitute 3.34 kg for the mass of the moist soil and 1.79×10^{-3} m³ for the volume of the hole in the equation for moist density of compacted soil; that is,

$$\rho = \frac{\text{Mass of moist soil}}{\text{Volume of hole}} = \frac{3.34}{1.79 \times 10^{-3}} = 1865.9 \text{ kg/m}^3$$

Next, we calculate the moist unit weight of compacted soil from the expression

$$\gamma = \frac{\rho \gamma_w}{\rho_w} = \frac{1852.9 \times 9.81}{1000} = 18.18 \text{ kN/m}^3$$

Finally, to find the dry unit weight, we appeal to the formula

$$\gamma_{d,\text{field}} = \frac{\gamma}{1 + \frac{w(\%)}{100}} = \frac{18.18}{1 + \frac{12.1}{100}} = \boxed{16.2 \text{ kN/m}^3}$$

► The correct answer is **B**.

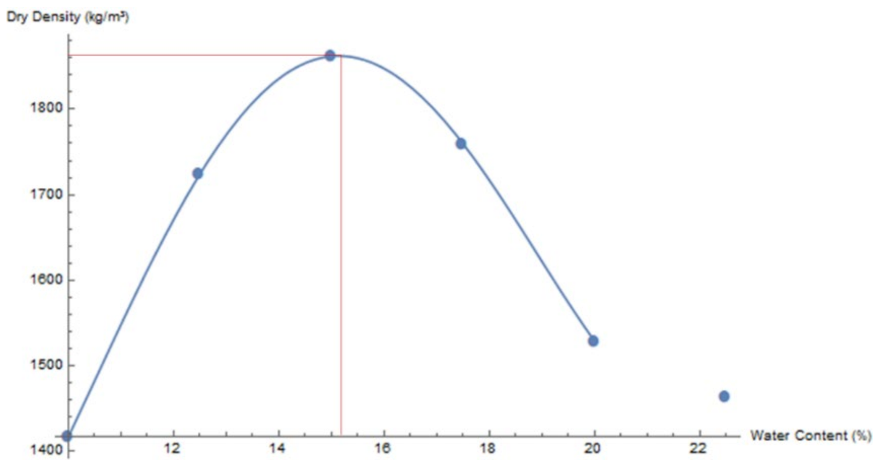
Part B: The relative compaction *R* is given by the expression

$$R = \frac{\gamma_{d,\text{field}}}{\gamma_{d,\text{max}}}$$

thus implying that the maximum dry density, $\rho_{d,\text{max}}$, is necessary. In order to obtain this quantity, we need the compaction curve of the soil. The following table is prepared.

Mold volume (m³)	Mass of soil in the wet mold (kg)	Moist density (kg/m³)	Moisture content (%)	Dry density (kg/m³)
0,0009433	1,47	1558,36	10,0	1416,69
0,0009433	1,83	1940,00	12,5	1724,44
0,0009433	2,02	2141,42	15,0	1862,10
0,0009433	1,95	2067,21	17,5	1759,33
0,0009433	1,73	1833,99	20,0	1528,32
0,0009433	1,69	1791,58	22,5	1462,52

We can now plot the dry density (blue column) against moisture content (red column).



The maximum dry density is found to be $\rho_{d,\max} = 1860 \text{ kN/m}^3$ at an optimum water content $w = 15.3\%$. We are now able to calculate the maximum dry unit weight in the field,

$$\gamma_{d,\max} = \frac{\rho_{d,\max} g}{\rho_w} = \frac{1860 \times 9.81}{1000} = 18.25 \text{ kN/m}^3$$

Finally, the relative compaction R is given by

$$R = \frac{\gamma_{d,\text{field}}}{\gamma_{d,\max}} = \frac{16.22}{18.25} = 0.8887 \approx \boxed{88.9\%}$$

► The correct answer is **C**.

► ANSWER SUMMARY

Problem 1	**1A**	**B**
	1B	**C**
	1C	**D**
	1D	**B**
Problem 2	**2A**	**D**
	2B	**C**
	2C	**B**
	2D	**C**
Problem 3		**D**
Problem 4	**4A**	**A**
	4B	**C**
Problem 5	**5A**	**B**
	5B	**D**
	5C	**B**
Problem 6		**D**
Problem 7		**A**
Problem 8	**8A**	**B**
	8B	**C**

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