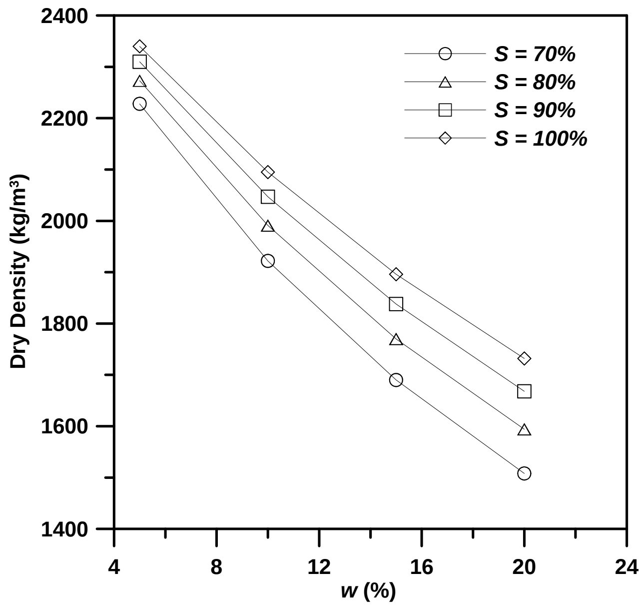
Chapter 6

6.1 $$\rho_d = \frac{G_s \rho_w}{1 + \frac{G_s w}{S}}$$

G_s	ρ_w (kg/m^3)	w (%)	ρ_d @ S (kg/m^3) 70%	80%	90%	100%
2.65	1000	5	**2228**	**2273**	**2310**	**2340**
		10	**1922**	**1991**	**2047**	**2095**
		15	**1690**	**1770**	**1838**	**1896**
		20	**1508**	**1594**	**1668**	**1732**

The plot is shown below.



6.2 Eq. (6.4):

$$\gamma_{zav} = \frac{\gamma_w}{w + \frac{1}{G_s}} = \frac{9.81}{w + \frac{1}{2.68}} = \frac{9.81}{w + 0.3731}.$$

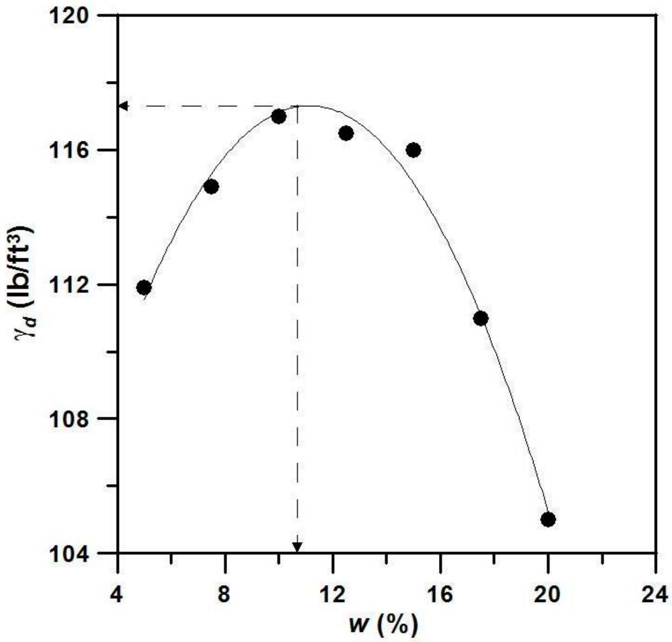
The table can now be prepared.

w (%)	γ_{zav} (kN/m^3)
5	**23.18**
10	**20.73**
15	**18.75**
20	**17.11**
25	**15.74**

6.3

Volume (ft^3)	Weight of soil mass, W (lb)	$\gamma = \frac{W}{V}$ (lb/ft^3)	w (%)	$\gamma_d = \frac{\gamma}{1+\frac{w(\%)}{100}}$ (lb/ft^3)
$\frac{1}{30}$	3.92	117.6	5.0	111.9
$\frac{1}{30}$	4.12	123.6	7.5	114.9
$\frac{1}{30}$	4.29	128.7	10.0	117.0
$\frac{1}{30}$	4.37	131.1	12.5	116.5
$\frac{1}{30}$	4.45	133.5	15.0	116.0
$\frac{1}{30}$	4.35	130.5	17.5	111.0
$\frac{1}{30}$	4.20	126.0	20.0	105.0

a. The plot of γ_d versus w is shown. $\gamma_{d(\max)} \approx$ **117.5 lb/ft³ @ w_{opt} = 10.8%**



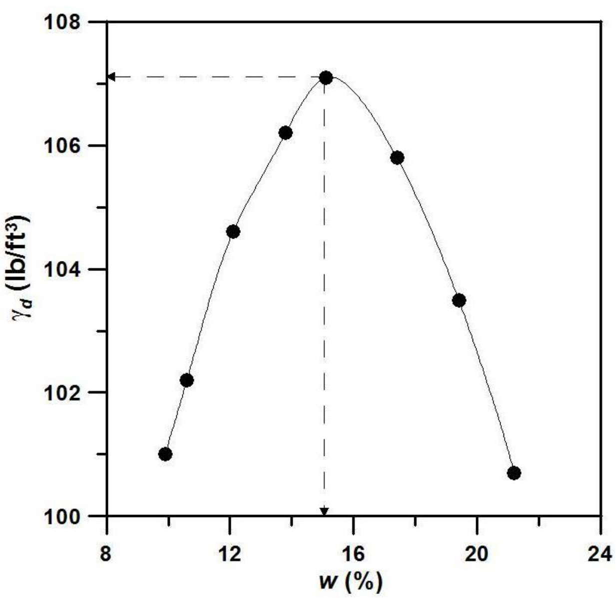
b. $\gamma_d = \frac{G_s\gamma_w}{1+e}$; $117.5 = \frac{(2.68)(62.4)}{1+e}$; $e \approx \mathbf{0.42}$

$$S = \frac{wG_s}{e} = \frac{(0.108)(2.68)}{0.423} = 0.684 = \mathbf{68.4\%}$$

6.4

Volume (ft^3)	Weight of soil mass, W (lb)	$\gamma = \dfrac{W}{V}$ (lb/ft^3)	w (%)	$\gamma_d = \dfrac{\gamma}{1+\dfrac{w(\%)}{100}}$ (lb/ft^3)
$\frac{1}{30}$	3.70	111.0	9.9	101.0
$\frac{1}{30}$	3.77	113.1	10.6	102.2
$\frac{1}{30}$	3.91	117.3	12.1	104.6
$\frac{1}{30}$	4.03	120.9	13.8	106.2
$\frac{1}{30}$	4.11	123.3	15.1	107.1
$\frac{1}{30}$	4.14	124.2	17.4	105.8
$\frac{1}{30}$	4.12	123.6	19.4	103.5
$\frac{1}{30}$	4.07	122.1	21.2	100.7

a. The plot of γ_d versus w is shown. $\gamma_{d(\max)}$ **≈ 107.1 lb/ft³ @ w_{opt} = 15%**



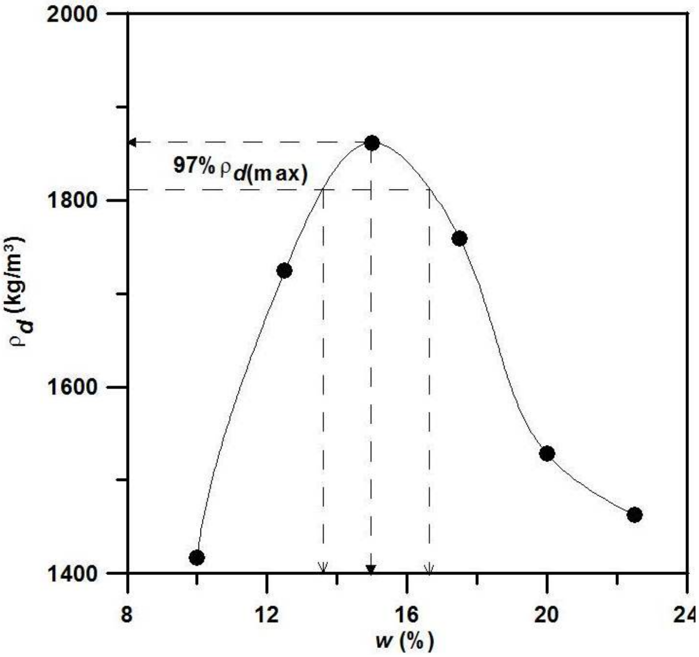
b. $\gamma_d = \dfrac{G_s \gamma_w}{1+e}$; $\quad 107.1 = \dfrac{(2.7)(62.4)}{1+e}$; $\quad e \approx \mathbf{0.57}$

$$S = \frac{wG_s}{e} = \frac{(0.15)(2.7)}{0.57} = 0.71 = \mathbf{71\%}$$

6.5

Volume of mold V (cm^3)	Mass of wet soil M (kg)	$\rho = \frac{M}{V}$ (kg/m^3)	w (%)	ρ_d (kg/m^3)
943.3	1.47	1558.3	10.0	1416.6
943.3	1.83	1940.0	12.5	1724.4
943.3	2.02	2141.4	15.0	1862.0
943.3	1.95	2067.2	17.5	1759.3
943.3	1.73	1833.9	20.0	1528.2
943.3	1.69	1791.5	22.5	1462.4

a. The plot of ρ_d versus w is shown. $\rho_{d(\max)}$ $\approx$ **1870 kg/m^3 @ w_{opt} = 15%**



b. $$R(\%) = \frac{\rho_{d(\text{field})}}{\rho_{d(\max)}} \times 100 = \left(\frac{\rho_{d(\text{field})}}{1870}\right)(100)$$

Therefore, $\rho_{d(\text{field})} = (0.97)(1870) \approx$ **1814 kg/m^3**

From the graph, the acceptable range of moisture content is **13.5% – 16.5%.**

6.6 $\gamma_{(\text{in situ})} = 17.3\ \text{kN/m}^3$; $\gamma_{d(\text{in situ})} = \dfrac{17.3}{1+\dfrac{16}{100}} = 14.91\ \text{kN/m}^3$; $\gamma_{d(\text{compacted})} = 18.1\ \text{kN/m}^3$

Volume of soil to be excavated $= (2000)\left(\dfrac{18.1}{14.91}\right) = \mathbf{2{,}428\ m^3}$

Weight of moist soil to be transported = (2428×17.3) = 42,004 kN

Number of truck loads $= \dfrac{(42004)(1000)}{(20)(2000)(4.45)} = 235.9 \approx \mathbf{236}$

6.7 Dry weight of solids required at the embankment site:

$$W_s = 5000\gamma_d\ \text{kN} = (5000)\left(\frac{G_s \times 9.81}{1.75}\right) = 28{,}029 G_s\ \text{kN}$$

Borrow Pit	W_s (kN)	γ_d at borrow pit (kN/m^3)	Volume to be excavated from borrow pit = $[W_s/\gamma_{d\,(\text{borrow pit})}]$	Cost/m^3 ($)	Total cost ($)
I	74276.8	$\dfrac{2.65\times 9.81}{1+0.8} = 14.44$	**5143.8 m^3**	8	41,150
II	75117.7	$\dfrac{2.68\times 9.81}{1+0.9} = 13.83$	**5431.5 m^3**	5	27,157
III	75958.6	$\dfrac{2.71\times 9.81}{1+1.1} = 12.66$	**5999.8 m^3**	9	53,998
IV	76799.4	$\dfrac{2.74\times 9.81}{1+0.85} = 14.53$	**5285.5 m^3**	12	63,427

a. Shown in table.

b. **Borrow Pit II**

6.8 From Eq. (6.20): $D_r = \left[\dfrac{\gamma_{d(\text{field})} - \gamma_{d(\min)}}{\gamma_{d(\max)} - \gamma_{d(\min)}}\right]\left[\dfrac{\gamma_{d(\max)}}{\gamma_{d(\text{field})}}\right]$

$$0.75 = \left[\frac{\gamma_{d(\text{field})} - 15.5}{18.9 - 15.5}\right]\left[\frac{18.9}{\gamma_{d(\text{field})}}\right]; \quad \gamma_{d(\text{field})} = 17.91\ \text{kN/m}^3$$

$$R\,(\%) = \frac{\gamma_{d\,(\text{field})}}{\gamma_{d\,(\text{max})}}(100) = \left(\frac{17.91}{18.9}\right)(100) = \mathbf{94.8\%}$$

6.9 $$R = 0.935 = \frac{\gamma_{d\,(\text{field})}}{\gamma_{d\,(\text{max})}} = \frac{\gamma_{d\,(\text{field})}}{16.98}; \quad \gamma_{d\,(\text{field})} = \mathbf{15.87\ kN/m^3}$$

$$D_r = \left[\frac{\gamma_{d\,(\text{field})} - \gamma_{d\,(\text{min})}}{\gamma_{d\,(\text{max})} - \gamma_{d\,(\text{min})}}\right]\left[\frac{\gamma_{d\,(\text{max})}}{\gamma_{d\,(\text{field})}}\right] = \left(\frac{15.87 - 14.46}{16.98 - 14.46}\right)\left(\frac{16.98}{15.87}\right) = 0.598 = \mathbf{59.8\%}$$

6.10 a. $$R = 0.88 = \frac{\gamma_{d\,(\text{field})}}{\gamma_{d\,(\text{max})}} = \frac{\gamma_{d\,(\text{field})}}{118}; \quad \gamma_{d\,(\text{field})} = \mathbf{103.84\ lb/ft^3}$$

b. $$D_r = \left[\frac{\gamma_{d\,(\text{field})} - \gamma_{d\,(\text{min})}}{\gamma_{d\,(\text{max})} - \gamma_{d\,(\text{min})}}\right]\left[\frac{\gamma_{d\,(\text{max})}}{\gamma_{d\,(\text{field})}}\right] = \left(\frac{103.84 - 98}{118 - 98}\right)\left(\frac{118}{103.84}\right) = 0.331 = \mathbf{33.1\%}$$

$$\gamma = (1 + w)\gamma_{d\,(\text{field})} = (1 + 0.13)(103.84) = \mathbf{117.33\ \ lb/ft^3}$$

6.11 In the field:

Sand used to fill the hole and cone: 6.08 kg – 2.86 kg = 3.22 kg

Sand used to fill the hole: 3.22 kg – 0.118 kg = 3.102 kg

Volume of the hole: $\frac{3.102\,\text{kg}}{1731\,\text{kg/m}^3} = 0.001792\,\text{m}^3$

Moist density of compacted soil: $\frac{3.34}{0.001792} = 1863.84\ \text{kg/m}^3$

$$\gamma = \frac{(1863.84)(9.81)}{1000} = 18.28\,\text{kN/m}^3$$

a. $$\gamma_d = \frac{\gamma}{1 + \frac{w(\%)}{100}} = \frac{18.28}{1 + \frac{12.1}{100}} = \mathbf{16.3\,kN/m^3}$$

b. From Problem 6.5: $\rho_{d(\text{max})} = 1870\ \text{kg/m}^3$

$$\gamma_{d(\max)} = \frac{(1870)(9.81)}{1000} = 18.34\ \text{kN/m}^3$$

$$R = \frac{\gamma_{d(\text{field})}}{\gamma_{d(\max)}} = \frac{16.30}{18.34} = 0.888 = \mathbf{88.8\%}$$

6.12 $S_N = (1.7)\sqrt{\frac{3}{(D_{50})^2} + \frac{1}{(D_{20})^2} + \frac{1}{(D_{10})^2}} = (1.7)\sqrt{\frac{3}{(1.98)^2} + \frac{1}{(0.31)^2} + \frac{1}{(0.18)^2}} = \mathbf{11.02}$

Rating: **GOOD**

CRITICAL THINKING PROBLEM

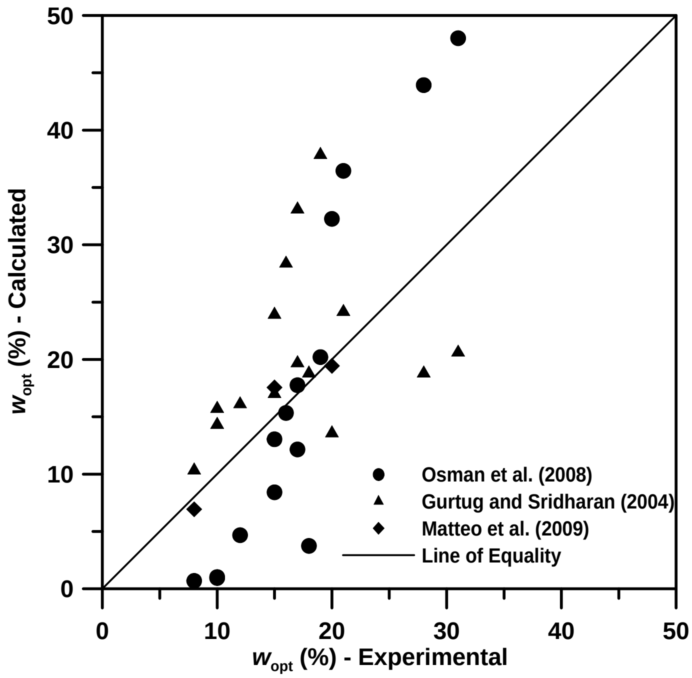
6.C.1 a. Osman et al. (2008) method: Eqs. (6.13) through (6.16) are used to calculate w_{opt} and $\gamma_{d(\max)}$. These values are listed in the following table.

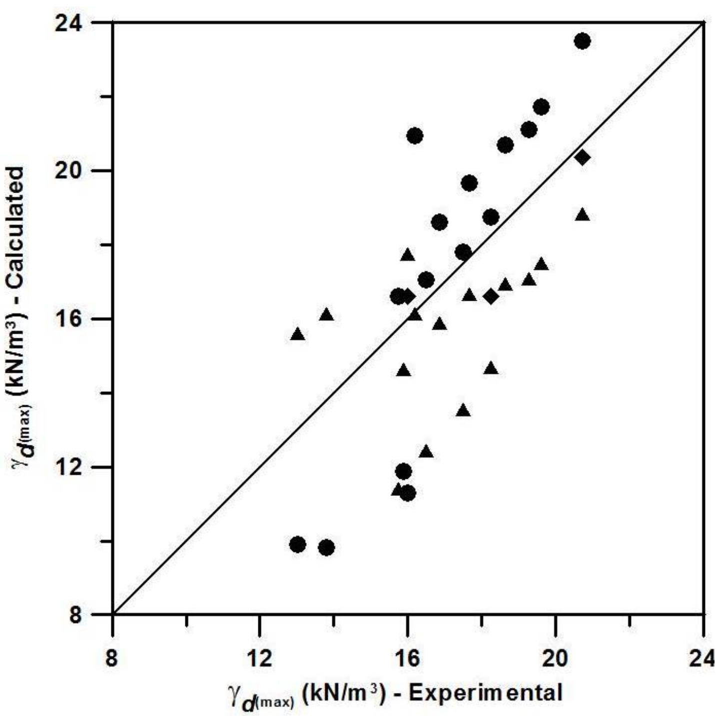
b. Gurtug and Sridharan (2004) method: Eqs. (6.11) and (6.12) are used to calculate w_{opt} and $\gamma_{d(\max)}$. These values are listed in the following table.

c. Matteo et al. (2009) method: Eqs. (6.17) and (6.18) are used to calculate w_{opt} and $\gamma_{d(\max)}$, only for the modified Proctor tests. These values are listed in the following table.

Soil	E (kN-m/m^3)	w_{opt} (Exp.) (%)	$\gamma_{d(\max)}$ (Exp.) (kN/m^3)	Part a		Part b		Part c	
				w_{opt} (%)	$\gamma_{d(\max)}$ (kN/m^3)	w_{opt} (%)	$\gamma_{d(\max)}$ (kN/m^3)	w_{opt} (%)	$\gamma_{d(\max)}$ (kN/m^3)
1	2700	8	20.72	0.69	23.52	10.34	18.77	6.94	20.37
	600	10	19.62	0.93	21.73	14.31	17.46		
	354	10	19.29	1.02	21.11	15.70	17.02		
2	2700	20	16.00	32.26	11.31	13.57	17.69	19.44	16.6
	600	28	13.80	43.92	9.82	18.78	16.08		
	354	31	13.02	48.01	9.90	20.61	15.55		
3	2700	15	18.25	13.04	18.74	23.91	14.64	17.56	16.62
	1300	16	17.5	15.33	17.80	28.37	13.50		
	600	17	16.5	17.76	17.07	33.09	12.38		
	275	19	15.75	20.20	16.61	37.85	11.34		
4	600	21	15.89	36.45	11.89	24.15	14.58		
5	600	18	16.18	3.74	20.95	18.78	16.08		
6	600	17	16.87	12.15	18.62	19.67	15.82		
7	600	12	18.63	4.67	20.69	16.10	16.89		
8	600	15	17.65	8.41	19.65	16.99	16.62		

d. The plots of calculated values against experimental results are shown in the figures below. The 45° line of equality is also drawn in both figures.





e. Prediction of w_{opt}: For both the Osman et al. (2008) and Gurtug and Sridharan (2004) models, several data points are closely packed around the 45° line suggesting reasonable agreement between the calculated and experimental values. For the remaining soils, a poor agreement is observed. All 3 points for the Matteo (2009) model plot near the equality line showing close agreement.

Prediction of $\gamma_{d(max)}$: Most data points for all models show good agreement between the calculated and the experimental values.

Empirical models are often limited to the materials, test methods, and environmental conditions (among other factors) under which the experiments were conducted and the models developed. For new materials and conditions, the predicted values may not be reliable.