12
Standard Proctor Compaction Test

12.1 Introduction

For the construction of highways, airports, and other structures, it is often necessary to compact soil to improve its strength. Proctor (1933) developed a laboratory compaction test procedure to determine the maximum dry unit weight of compaction of soils which can be used for the specification of field compaction. This test is referred to as the *standard Proctor compaction test* and is based on the compaction of the soil fraction passing U.S. No. 4 sieve.

12.2 Equipment

1. Compaction mold
2. U.S. No. 4 sieve
3. Standard Proctor hammer of weight 5.5 lb (24.4 N)
4. Balance sensitive to 0.01 lb
5. Balance sensitive to 0.1 g
6. Large flat pan
7. Jack
8. Steel straightedge
9. Moisture cans
10. Drying oven
11. Plastic squeeze bottle with water

Figure 12.1 shows the equipment required for the compaction test with the exception of the jack, the balances, and the oven.

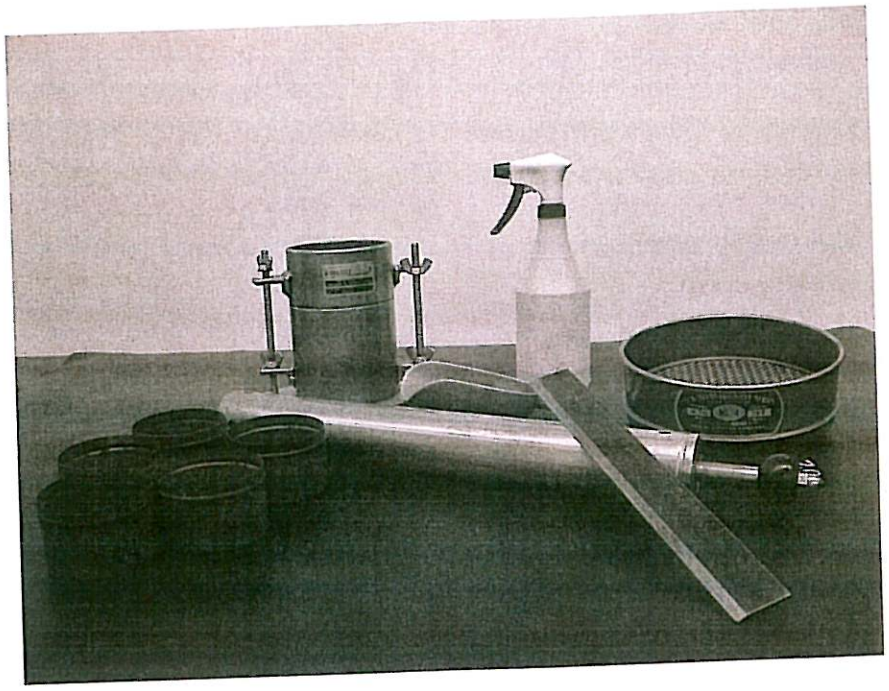

Figure 12.1. Equipment for Proctor compaction test.

12.3 Proctor Compaction Mold and Hammer

A schematic diagram of the Proctor compaction mold, which is 4 in. (101.6 mm) in diameter and 4.584 in. (116.43 mm) in height, is shown in Fig. 12.2(a). There is a base plate and an extension that can be attached to the top and bottom of the mold, respectively. The inside of the mold is 1/30 ft^3 (943 cm^3).

Figure 12.2(b) shows the schematic diagram of a standard Proctor hammer. The hammer can be lifted and dropped through a vertical distance of 12 in. (304.8 mm).

12.4 Procedure

1. Obtain about 10 lb (4.5 kg mass) of air-dry soil on which the compaction test is to be conducted. Break all the soil lumps.
2. Sieve the soil on a U.S. No. 4 sieve. Collect all of the minus 4 material in a large pan. This should be about 6 lb (2.7 kg mass) or more.
3. Add enough water to the minus 4 material and mix it in thoroughly to bring the moisture content up to about 5%.
4. Determine the weight of the Proctor mold + base plate (not the extension), W_1 (lb).
5. Now attach the extension to the top of the mold.
6. Pour the moist soil into the mold in *three* equal layers. Each layer should be compacted uniformly by the standard Proctor hammer 25 times before the next layer of loose soil is poured into the mold (see Fig. 12.3). (*Note:* The layers of loose soil that are being

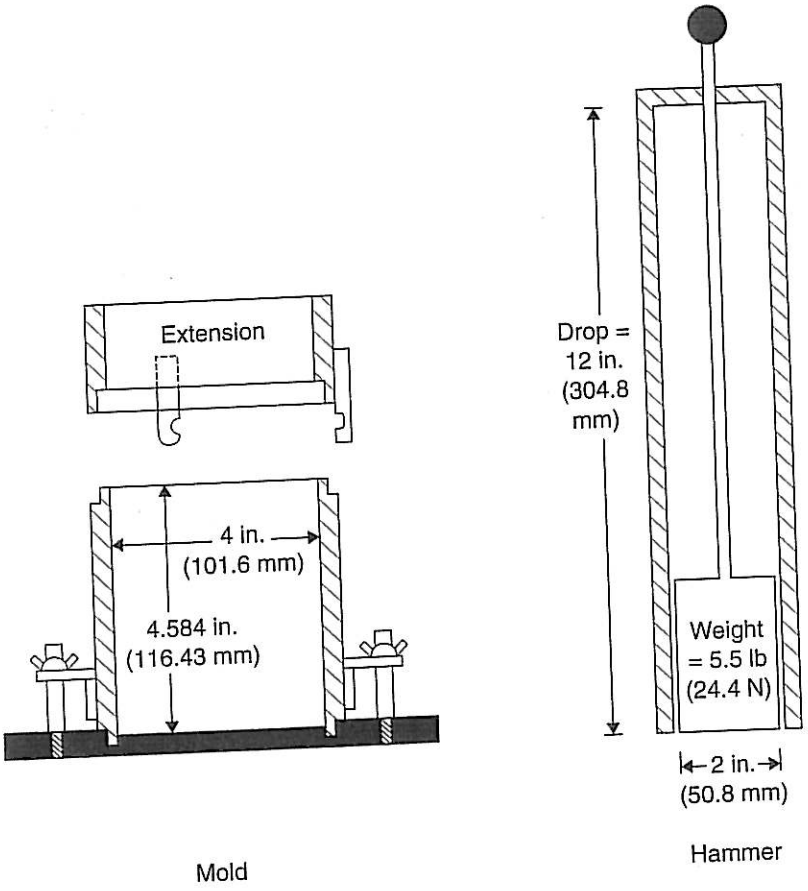

Figure 12.2. Standard Proctor mold and hammer.

poured into the mold should be such that, *at the end of the three-layer compaction,* the soil should extend *slightly above* the top of the rim of the compaction mold.)

7. Remove the top attachment from the mold. Be careful not to break off any of the compacted soil inside the mold while removing the top attachment.
8. Using a straightedge, trim the excess soil above the mold (Fig. 12.4). Now the top of the compacted soil will be even with the top of the mold.
9. Determine the weight of mold + base plate + compacted moist soil in mold, W_2 (lb).
10. Remove the base plate from the mold. Using a jack, extrude the compacted soil cylinder from the mold.
11. Take a moisture can and determine its mass, M_3 (g).
12. From the moist soil extruded in Step 10, collect a moisture sample in the moisture can (Step 11) and determine the mass of the can + moist soil, M_4 (g).
13. Place the moisture can with the moist soil in the oven to dry to a constant weight.
14. Break the rest of the compacted soil (to No. 4 size) by hand and mix it with the leftover moist soil in the pan. Add more water and mix it to raise the moisture content by about 2%.

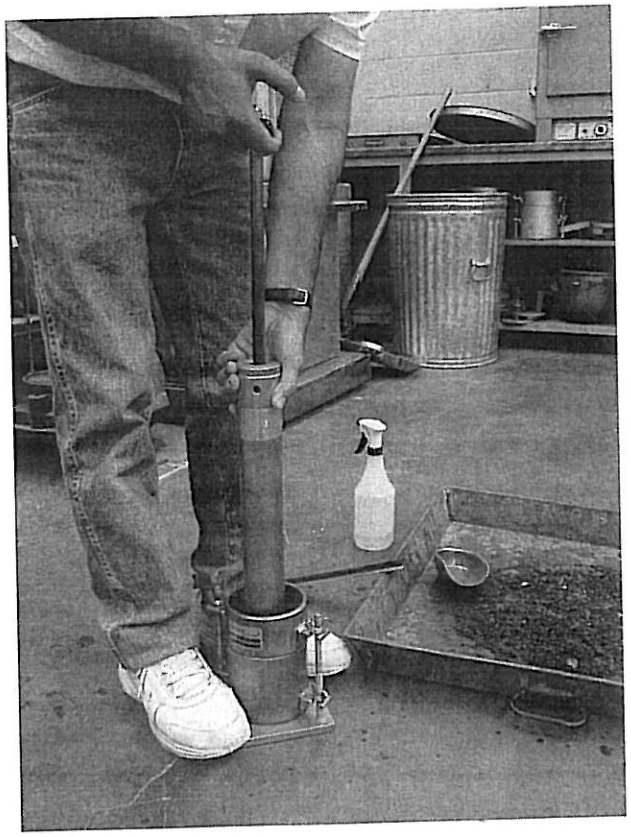

Figure 12.3. Compaction of soil in Proctor mold.

15. Repeat Steps 6 through 12. In this process, the weight of the mold + base plate + moist soil (W_2) will first increase with the increase in moisture content and then decrease. Continue the test until at least two successive down readings are obtained.
16. The next day, determine the mass of the moisture cans + soil samples, M_5 (g) (from Step 13).

12.5 Calculations

Dry Unit Weight and Moisture Content at Compaction

The sample calculations for a standard Proctor compaction test are given in Table 12.1. Referring to Table 12.1,

Line 1. Weight of mold and base plate W_1, to be determined from test (Step 4).
Line 2. Weight of mold and base plate + moist compacted soil W_2, to be determined from test (Step 9).
Line 3. Weight of moist compacted soil, $= W_2 - W_1$ (line 2 − line 1).

Figure 12.4. Excess soil being trimmed (Step 8).

Line 4. Moist unit weight,

$$\gamma = \frac{\text{weight of compacted moist soil}}{\text{volume of mold}} = \frac{W_2 - W_1\,(\text{lb})}{1/30(\text{ft}^3)}$$

$$= 30\,(\text{lb/ft}^3) \times \text{line 3}$$

Line 6. Mass of moisture can M_3, to be determined from test (Step 11).
Line 7. Mass of moisture can + moist soil M_4, to be determined from test (Step 12).
Line 8. Mass of moisture can + dry soil M_5, to be determined from test (Step 16).
Line 9. Compaction moisture content M_5,

$$w\,(\%) = \frac{M_4 - M_5}{M_5 - M_3} \times 100$$

Line 10. Dry unit weight,

$$\gamma_d = \frac{\gamma}{1 + (w(\%)/100)} = \frac{\text{line 4}}{1 + (\text{line 9}/100)}$$

Table 12.1. Determination of Dry Unit Weight—Standard Proctor Compaction Test

Description of soil Light brown clayey silt Sample no. 2

Location

Volume of mold 1/30 ft^3 Weight of hammer 5.5 lb

Number of blows/layer 25 Number of layers 3

Tested by Date

Test	1	2	3	4	5	6
1. Weight of mold and base plate, W_1 (lb)	10.35	10.35	10.35	10.35	10.35	10.35
2. Weight of mold and base plate + moist soil, W_2 (lb)	14.19	14.41	14.53	14.63	14.51	14.47
3. Weight of moist soil, $W_2 - W_1$ (lb)	3.84	4.06	4.18	4.28	4.16	4.12
4. Moist unit weight, $\gamma = \frac{W_2 - W_1}{1/30}$ (lb/ft^3)	115.2	121.8	125.4	128.4	124.8	123.8
5. Moisture can number	202	212	222	242	206	504
6. Mass of moisture can, M_3 (g)	54.0	53.3	53.3	54.0	54.8	40.8
7. Mass of can + moist soil, M_4 (g)	253.0	354.0	439.0	490.0	422.8	243.0
8. Mass of can + dry soil, M_5 (g)	237.0	326.0	401.0	441.5	374.7	211.1
9. Moisture content, $w\,(\%) = \frac{M_4 - M_5}{M_5 - M_3} \times 100$	8.7	10.3	10.9	12.5	15.0	18.8
10. Dry unit weight of compaction, $\gamma_d (lb/ft^3) = \frac{\gamma}{1+(w\,(\%)/100)}$	106.0	110.4	113.0	114.1	108.5	104.2

Table 12.2. Zero-Air-Void Unit Weight—Standard Proctor Compaction Test

Description of soil *Light brown clayey silt* Sample no. *2*

Location _____

Tested by _____ Date _____

Specific Gravity of Soil Solids G_s	Assumed Moisture Content w (%)	Unit Weight of Water γ_w (lb/ft^3)	γ^*_{zav} (lb/ft^3)
2.68	10	62.4	131.9
2.68	12	62.4	126.5
2.68	14	62.4	121.6
2.68	16	62.4	117.0
2.68	18	62.4	112.8
2.68	20	62.4	108.7

*Equation (12.1).

Zero-Air-Void Unit Weight

The maximum theoretical dry unit weight of a compacted soil at a given moisture content will occur when there is no air left in the void spaces of the compacted soil. This can be given by

$$\gamma_{d(\text{theory}-\max)} = \gamma_{zav} = \frac{\gamma_w}{(w\,(\%)\,/100) + (1/G_S)} \tag{12.1}$$

where γ_{zav} = zero-air-void unit weight
γ_w = unit weight of water
w = moisture content
G_s = specific gravity of soil solids

Since the values of γ_w and G_s will be known, several values of w (%) can be assumed and γ_{zav} can be calculated. Table 12.2 shows the calculations for γ_{zav} for the soil tested and reported in Table 12.1.

12.6 Graphs

Plot a graph showing γ_d (line 10, Table 12.1) versus w (%) (line 9, Table 12.1) and determine the *maximum dry unit weight of compaction* $\gamma_{d(\max)}$. Also determine the *optimum moisture*

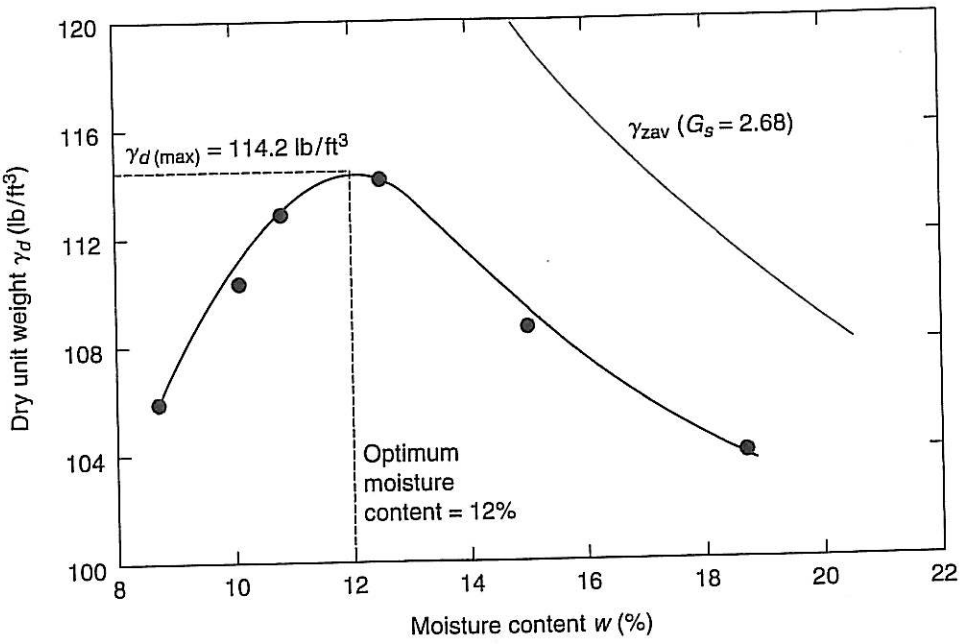

Figure 12.5. Plots of γ_d vs. w (%) and γ_{zav} vs. w (%) for test results reported in Tables 12.1 and 12.2.

content w_{opt}, which is the moisture content corresponding to $\gamma_{d\,(max)}$. On the same graph, plot γ_{zav} versus w (%). (*Note:* For a given soil, *no portion* of the experiment curve of γ_d versus w(%) should plot to the *right* of the zero-air-void curve.)

Figure 12.5 shows the results of the calculations made in Tables 12.1 and 12.2.

12.7 General Comments

A. Units

1. The test presented in this chapter uses English units to express γ or γ_d. If there is a need for conversion to SI units,

$$\gamma \text{ or } \gamma_d \left(\text{kN/m}^3\right) = 0.15706\,\gamma \text{ or } \gamma_d \left(\text{lb/ft}^3\right)$$

2. In several instances, referring to Steps 4 and 9 (Section 12.4, Procedure), the mass is determined in kg. In that case,
   - Mass of Proctor mold + base plate, M_1 (kg) (compare with Procedure, Step 4)
   - Mass of mold + base plate + compacted moist soil in mold, M_2 (kg) (compare with Procedure, Step 9)

- Moist density,

$$\rho\,(\text{kg/m}^3) = \frac{M_2 - M_1\,(\text{kg})}{943 \times 10^{-6}\,(\text{m}^3)}$$

(compare with line 4 in Table 12.1)

- Dry density,

$$\rho_d\,(\text{kg/m}^3) = \frac{\rho\,(\text{kg/m}^3)}{1 + w\,(\%)/100}$$

(compare with line 10 in Table 12.1)

- Zero-air-void density,

$$\rho_{d\,(\text{theory}-\text{max})} = \rho_{\text{zav}}\,(\text{kg/m}^3) = \frac{\rho_w}{(w\,(\%)\,/100) + (1/G_s)}$$

where ρ_w is the density of water, = 1000 kg/m^3 [compare with Eq. (12.1)].

B. Relative Compaction

In most specifications for earth work it is required to achieve a compacted field dry unit weight of 90–95% of the maximum dry unit weight obtained in the laboratory. This is sometimes referred to as relative compaction R, or

$$R\,(\%) = \frac{\gamma_{d\,(\text{field})}}{\gamma_{d\,(\text{max}-\text{lab})}} \times 100 \tag{12.2}$$

For granular soils it can be shown that

$$R\,(\%) = \frac{R_0}{1 - D_r\,(1 - R_0)} \times 100 \tag{12.3}$$

where D_r is the relative density of compaction and

$$R_0 = \frac{\gamma_{d\,(\text{max})}}{\gamma_{d\,(\text{min})}} \tag{12.4}$$

Compaction of cohesive soils will influence their structure, coefficient of permeability, one-dimensional compressibility, and strength. For further discussion on this topic, refer to Das (2006).

Summary of ASTM Proctor Test Specifications

In this chapter the laboratory test outlines given for compaction tests use the following:

Volume of mold = 1/30 ft^3 (943 cm^3)
Number of blows = 25

Table 12.3. Summary of Standard Proctor Compaction Test Specifications (ASTM D-698)

Description	Method A*	Method B†	Method C‡
Mold			
Volume	1/30 ft^3 (943 cm^3)	1/30 ft^3 (943 cm^3)	1/13.33 ft^3 (2124 cm^3)
Height	4.584 in. (116.43 mm)	4.584 in. (116.43 mm)	4.584 in. (116.43 mm)
Diameter	4 in. (101.6 mm)	4 in. (101.6 mm)	6 in. (152.4 mm)
Weight of hammer	5.5 lb (24.4 N)	5.5 lb (24.4 N)	5.5 lb (24.4 N)
Height of hammer drop	12 in. (304.8 mm)	12 in. (304.8 mm)	12 in. (304.8 mm)
Number of layers of soil	3	3	3
Number of blows per layer	25	25	56
Test on soil fraction passing sieve	No. 4 (4.75 mm)	3/8 in. (9.5 mm)	3/4 in. (19.0 mm)

* May be used if 20% or less by mass of material is retained on No. 4(4.75-mm) U.S. sieve.

† May be used if more than 20% by mass of material is retained on No. 4 (4.75-mm) U.S. sieve and 20% or less by mass of material is retained on 3/8-in. (9.5-mm) U.S. sieve.

‡ May be used if more than 20% by mass of material is retained on 3/8-in. (9.5-mm) U.S. sieve and less than 30% by mass of material is retained on 3/4-in. (19.0-mm) U.S. sieve.

These values are generally used for fine-grained soils that pass through No. 4 U.S. sieve. However, ASTM has three different methods for the standard Proctor compaction test that reflect the size of the mold, the number of blows per layer, and the maximum particle size in a soil used for testing. Summaries of these methods are given in Table 12.3.

Standard Proctor Compaction Test

Determination of Dry Unit Weight

Description of soil _____ Sample no. _____

Location _____

Volume of mold _____ ft^3 Weight of hammer _____ lb

Number of blows/layer _____ Number of layers _____

Tested by _____ Date _____

Test	1	2	3	4	5	6
1. Weight of mold and base plate, W_1 (lb)						
2. Weight of mold and base plate + moist soil, W_2 (lb)						
3. Weight of moist soil, $W_2 - W_1$ (lb)						
4. Moist unit weight, $\gamma = \frac{W_2 - W_1}{1/30}$ (lb/ft^3)						
5. Moisture can number						
6. Mass of moisture can, M_3 (g)						
7. Mass of can + moist soil, M_4 (g)						
8. Mass of can + dry soil, M_5 (g)						
9. Moisture content, $w\,(\%) = \frac{M_4 - M_5}{M_5 - M_3} \times 100$						
10. Dry unit weight of compaction, γ_d (lb/ft^3) $= \frac{\gamma}{1 + (w\,(\%)/100)}$						

Standard Proctor Compaction Test

Zero-Air-Void Unit Weight

Description of soil _____ Sample no. _____

Location _____

Tested by _____ Date _____

Specific Gravity of Soil Solids G_s	Assumed Moisture Content w (%)	Unit Weight of Water γ_w (lb/ft^3)	γ^*_{zav} (lb/ft^3)

*Equation (12.1).