SECTION 9

COMPACTION TEST

References

- ASTM D 698 - Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbs/ft^3 (600 KN-m/m^3)).
- ASTM D 1557 - 12 - Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbs/ft^3 (2,700 KN-m/m^3)).
- Bowles, Joseph E., Engineering Properties of Soils and Their Measurement (4th Edition)
- Lambe, T.W., Soil Testing for Engineers.
- ASTM D 6026 - 06 – using Significant Digits in Geotechnical Data

General Discussion

This laboratory test is performed to determine the relationship between the moisture content and the dry density of a soil for a specified compaction effort. Laboratory compaction tests provide the basis for determining the percent compaction and molding water content needed to achieve the required engineering properties, and for controlling construction to assure that the required compaction and water contents are achieved.

Mechanical compaction is one of the most common and cost effective means of stabilizing soils. An extremely important task of geotechnical engineers is the performance and analysis of field control tests to assure that compacted fills are meeting the prescribed design specifications. Design specifications usually state the required density (as a percentage of the “maximum” density measured in a standard laboratory test), and the water content. Compaction achieves soil stabilization through the input of energy to produce a more dense soil structure than previously existed. The laboratory test supplies compaction energy to the soil in the mold by the impact of rammer. In the field the energy comes from rolling with sheeps-foot, wobble-wheel, or smooth-wheel rollers.

Generally, the compaction effort imparts to the soil:

1. An increase in shear strength since this is a function of unit weight
2. An increase in swell potential
3. An increase in unit weight
4. A decrease in shrinkage potential
5. A decrease in permeability
6. A decrease in compressibility

It has also been found that whether the field compaction water content is on the dry or wet side of the optimum Moisture Content also affects the end result – in particular items 2,4 and 6.

The optimum water content is the water content that results in the greatest density for a specified compaction effort. Compacting at water contents higher than (wet of) the optimum water content results in a relatively dispersed soil structure (parallel particle orientations) that is weaker, more ductile, less pervious, softer, more susceptible to shrinking, and less susceptible to swelling than soil compacted dry of optimum to the same density. The soil compacted lower than (dry of) the optimum water content typically results in a flocculated soil structure (random particle orientations) that has the opposite characteristics of the soil compacted wet of the optimum water content to the same density. The ultimate strength of soils compacted on the dry side of the OMC is higher at low strains and the soil usually fails abruptly by fracture (also called brittle failure). If compacted on the wet side of OMC the failure is gradual and often not clearly defined (a plastic failure) and strength is ultimately lower. The residual strength of the soil compacted on the dry side of optimum is nearly the same as the ultimate strength of soil compacted on the wet side of optimum.

The soil mass involved in the compaction process starts as a three-phase system of soil, water and air. During the initial trials considerable air is present, but the process results in a change of state with more soil and water being present. Even at the OMC there is considerably air present. On the wet side of optimum, the principal effect is to displace more and more air with water. If the process were completely efficient, it might be possible to replace all the air in the voids with water to produce a two-phase system (a condition of zero air voids). Since it is never possible to get all the air out of the voids, which would result in a condition of saturation, S = 100%, any compaction curve will always fall below the zero-air-voids curve.

For any given water content w the zero-air-voids dry unit weight γ_{ZAV} is computed as

$$\gamma_{ZAV} = G_s \gamma_w / (1 + w G_s)$$

Where, G_s = Specific gravity of soil solids

w = water content

γ_w = unit weight of water

The compaction effort is the amount of mechanical energy that is applied to the soil mass. Several different methods are used to compact soil in the field, and some examples include tamping, kneading, vibration, and static load compaction. This laboratory will employ the tamping or impact compaction method using the type of equipment and methodology developed by R. R. Proctor in 1933, therefore, the test is also known as the Proctor test.

Two types of compaction tests are routinely performed: (1) The Standard Proctor Test, and (2) The Modified Proctor Test. Each of these tests can be performed in three different methods as outlined in the attached Table 9-1. In the Standard Proctor Test, the soil is compacted by a 5.5 lb hammer falling a distance of one foot into a soil filled mould. The mould is filled with three equal layers of soil, and each layer is subjected to 25 drops of the hammer. The Modified Proctor Test is identical to the Standard Proctor Test except it employs, a 10 lb hammer falling a distance of 18 inches, and uses five equal layers of soil instead of three. There are two types of compaction moulds used for testing. The smaller type is 4 inches in diameter and has a volume of about 1/30 ft^3 (944 cm^3), and the larger type is 6 inches in diameter and has a volume of about 1/13.333 ft^3 (2123 cm^3). If the larger mould is used each soil layer must receive 56 blows instead of 25 (See Table 9-1)

Table 9-1: Alternative Proctor Test Methods

	Standard Proctor ASTM 698			Modified Proctor ASTM 1557		
	Method A	Method B	Method C	Method A	Method B	Method C
Material	≤20% Retained on No.4 Sieve	>20% Retained on No.4 ≤20% Retained on 3/8" Sieve	>20% Retained on No.3/8" <30% Retained on 3/4" Sieve	≤20% Retained on No.4 Sieve	>20% Retained on No.4 ≤20% Retained on 3/8" Sieve	>20% Retained on No.3/8" <30% Retained on 3/4" Sieve
For test sample, use soil passing	Sieve No.4	3/8" Sieve	¾" Sieve	Sieve No.4	3/8" Sieve	¾" Sieve
Mold	4" DIA	4" DIA	6" DIA	4" DIA	4" DIA	6" DIA
No. of Layers	3	3	3	5	5	5
No. of blows/layer	25	25	56	25	25	56

Note: Volume of 4" diameter mold = 944 cm^3, Volume of 6" diameter mold = 2123 cm^3 (verify these values prior to testing).

Equipment

The equipment used for this test are listed below (See Figure 9-1):

- Molds.
- Manual or mechanical rammer.
- Extruder.
- Balance.
- Drying oven.
- Mixing pan.
- Trowel.
- Sieve #4.
- Moisture cans.
- Graduated cylinder and
- Straight Edge

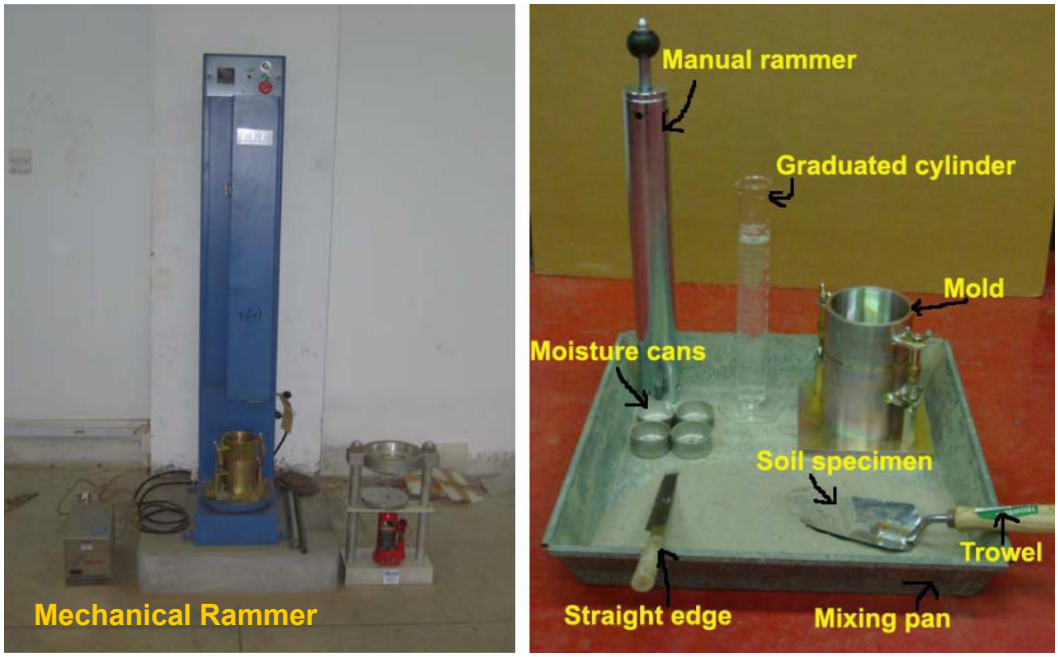


Figure 9-1: Equipment Used for Compaction Test.

Test Procedure

Test procedure for the compaction test is as under:

a. Depending on the type of mold a sufficient quantity of air-dried soil should be taken in large mixing pan. For the 4-inch mold approximately 10 lbs, and for the 6-inch mold thoroughly 15 lbs should be taken. The soil should be pulverized and run through the # 4 sieve.

b. The weight of the soil sample should be determined as well as the weight of the compaction mold with its base (without the collar) by using the balance and the weights should be recorded.

c. The amount of initial water should be computed to add by the following method:

(a) Water content has to be assumed for the first test is 8 percent.

(b) Water can be computed to add from the following equation:

$$Water\ to\ add\ (ml) = \frac{Soil\ mass\ in\ gm \times 8}{100}$$

It should be remembered that a gm of water is equal to approximately one ml of water.

d. The water should be measured out, added to the soil, and then mixed thoroughly into the soil using the trowel until the soil gets a uniform color (See Figure 9-2).



Figure 9-2: Mixing of Water with Soil.

e. The compaction mold should be assembled to the base, some soil should be placed in the mold and the soil must be compacted in the number of equal layers specified by the type of compaction method employed (See Figure 9-3). The number of drops of the rammer per layer is also dependent upon the type of moud used (See Table 9-1). The drops should be applied at a uniform rate not exceeding around 1.5 seconds per drop, and the rammer should provide uniform coverage of the specimen surface. It should be tried to avoid rebound of the rammer from the top of the guide sleeve



Figure 9-3: Assembly and Compaction of Soil in the Mold.

f. The soil should completely fill the cylinder and the last compacted layer must extend slightly above the collar joint. If the soil is below the collar joint at the completion of the drops, the test point must be ***repeated***. (Note: For the last layer, it should be watched carefully, and added more soil after about 10 drops if it appears that the soil will be compacted below the collar joint.)

g. The collar should be removed carefully and the compacted soil should be trimmed off so that it is completely even with the top of the mold using the trowel. Small bits of soil should be replaced that may fall out during the trimming process (See Figure 9-4).

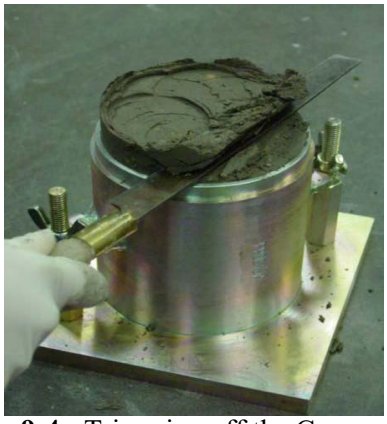


Figure 9-4: Trimming off the Compacted Soil

h. The compacted soil should be weighed while it's in the mold and to the base, and the mass should be recorded (See Figure 9-5). Then the wet mass of the can be determined by subtracting the weight of the mold and base.

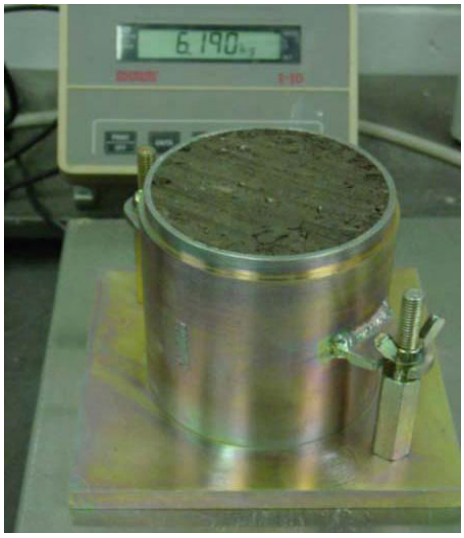


Figure 9-5: Weighing the Compacted Soil with Mold.

j. The soil should be removed from the mold using a mechanical extruder and soil moisture content samples must be taken from the top and bottom of the specimen (See Figure 9-6). The moisture cans should be filled with soil and the water content can be determined.



Figure 9-6: Use of Extruder to take the Compacted Soil Out and Collection of Sample for Moisture Content Determination.

k. The soil specimen should be placed in the large tray and the soil should be broken up until it appears visually as if it will pass through the # 4 sieve, add 3% more water based on the original

sample mass, and re-mix as in step d. Steps e through j has to be repeated until, based on wet mass, a peak value is reached followed by two slightly lesser compacted soil mass. This sequence is repeated a sufficient number of times that a curve of dry unit weight vs. water content can be drawn which has a zero slope (a maximum value) with sufficient points on either side of the maximum unit weight point to accurately define its location.

Data Analysis

Analysis of test data is done following the after mentioned procedure:

a. The moisture content of each compacted soil specimen can be calculated by using the average of the two water contents.

b. The wet density in grams per cm^3 of the compacted soil sample can be computed by dividing the wet mass by the volume of the mold used.

c. The dry density can be computed using the wet density and the water content determined in step 1. The following formula should be used:

$$\rho_d = \frac{\rho}{1 + w}$$

Where, w = moisture content in percent divided by 100, and ρ = wet density in grams per cm^3.=

d. The dry density values on the y-axis and the moisture contents on the x-axis should be plotted. A 'best fitting' smooth curve should be drawn connecting the plotted points.

e. On the same graph a curve of complete saturation or "zero air voids curve" should be drawn. The values of dry density and corresponding moisture contents for plotting the curve can be computed from the following equation:

$$w_{sat} \quad \frac{\rho_w}{\rho_d} - \frac{1}{G_s} \times 100$$

or,

$$\rho_d = \frac{\rho_w}{\frac{w}{100} + \frac{1}{G_s}}$$

Where,

ρ_d = dry density of soil grams per cm^3.

G_s = specific gravity of the soil being tested (assume 2.70 if not given).

ρ_w = density of water in gm per cm^3 (approximately1 g/cm^3).

w_{sat} = moisture content in percent for complete saturation.

Example Calculations:

G_s=2.7 (assumed)

ρ_w=1.0 g/cm^3

Assumed w_{sat}%	Calculated ρ_d (g/cm^3)
8	2.22
10	2.13
12	2.04
14	1.96
16	1.89
18	1.82

f. The optimum moisture content and the maximum dry density should be identified and recorded. It should be made sure that the method of compaction used (e.g., Standard Proctor, Method A) on data sheet has been recorded.

Significant Figures

1. The value of dry density should be expressed to 3 or 4 significant digits.
2. The value of water content should be expressed to nearest 0.1.

WORKED OUT EXAMPLE

Compaction Test

Test Serial No.: **09**
Test Method: **Standard Proctor, Method A (ASTM 698)**

Date Tested: **October 05, 2008**

Tested By:

Project Name: **Airport Road – Rokeya Sharoni Link Road Project**

Sample Number: **Bag-1, 2'-6″**

Visual Classification of Soil: **Gray silty clay, trace fine sand, low plasticity, moist, CL**

Density Determination:
Mould Volume=944 cm^3

Compacted Soil - Sample No	**1**	**2**	**3**	**4**	**5**
Assumed water content, w_a%	**10**	**12**	**14**	**16**	**18**
Actual average water content, w%	**8.0**	**11.0**	**12.8**	**15.65**	**17**
Mass of compacted soil and mould (gm)	**3457.2**	**3721.2**	**3909.0**	**3782.5**	**3715.2**
Mass of mould (gm)	**1933**	**1933**	**1976.0**	**1849.5**	**1782.2**
Wet mass of soil in mould (gm)	**1524.2**	**1788.2**	**2176**	**2149**	**2082**
Wet density, ρ , (g/cm^3)	**1.615**	**1.894**	**2.093**	**1.959**	**1.888**
Dry density, ρ_d , (g/cm^3)	**1.50**	**1.71**	**1.86**	**1.69**	**1.61**

Sample Calculations (For Sample No 1)

Wet density, ρ = 1524.2 / 944 = 1.615

Dry density, ρ_d = 1.615 / (1 + 0.08) = 1.495 ≈ 1.5

Water Content Determination:

Compacted Soil - Sample no.	1		2		3		4		5	
Water content - Sample no.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B
Moisture can number	1	2	3	4	5	6	7	8	9	10
M_C = Mass of empty, clean can (gm)	7.78	7.83	7.71	7.9	7.5	7.9	8.1	7.6	7.7	7.65
M_{CMS} = Mass of can + moist soil (gm)	11.78	11.05	10.71	11.1	10.7	12 .0	11. 1	10.2	10.3	10.33
M_{CDS} = Mass of can + dry soil (gm)	11.48	10.81	10.41	10.75	10.3	11.52	10.70	9.84	10.02	9.92
M_S = Mass of soil solids (gm)	3.70	2.98	2.7	2.85	2.84	3.62	2.60	2.24	2.32	2.27
M_W = Mass of pore water (gm)	0.29	0.24	0.30	0.35	0.40	0.53	0.40	0.35	0.4	0.39
w = Water content, w%	7.9	8.1	11.1	10.9	12.5	13.1	15.3	16.0	17. 1	17.6

