LABORATORY COMPACTION TEST

Application

Compaction of soil is probably one of the largest contributors to the site work economy; in other words-it is important. Large sums of money are spent on it every day. Soil is a very flexible and inexpensive construction material. It can be manipulated to produce a material with a wide range of properties. Control of compaction in the field permits civil engineers to *engineer a soil* to produce a material with properties that are optimized for a project.

Compaction is defined as the reduction in soil void ratio by expulsion of air from the voids. In contrast, the consolidation process is the reduction of void ratio by expulsion of water from the voids. These two processes are similar in that they result in a decrease in void ratio. Compaction occurs instantly with application of a force. Consolidation is a time-dependent process that can take many years to complete after a load is applied to soil. Because compaction involves reducing the void ratio without changing the moisture content, the degree of saturation will increase.

Soil is compacted to improve the following soil properties and aspects of strength-deformation behaviors:

- ❖ Improve shear strength
- ❖ Reduce compressibility
- ❖ Decrease permeability
- ❖ Reduce shrink/swell potential
- ❖ Reduce liquefaction potential
- ❖ Reduce compression due to wetting

The behavior of a soil during compaction and after compaction depends on:

- ❖ soil type (fine vs. coarse grained)
- ❖ compaction moisture condition
- ❖ method of compaction

A variety of methods and machinery are used to compact soil.

Compaction of Fine-Grained Soils

When fine-grained soils are compacted they display a strong dependency on compaction moisture content. Proctor (1933) described this behavior through the concept of the "*moisture – unit weight relationship* ". This is also loosely (and unfortunately all too commonly) referred to as the moisture-density relationship even though the "density" is actually unit weight.

It was found that, for any given amount of energy expended in compacting the soil, there existed an optimum moisture where the dry density was greatest. This relationship is shown in Figure 1 (from Hilf, Chapter 8. "Compacted Fill", Foundation Engineering Handbook, Fang, Editor, 1991).
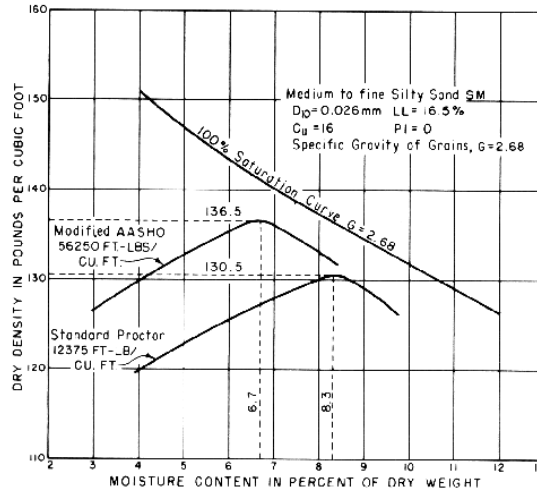

Figure 1 Moisture – unit weight relationships for a soil using two compaction efforts.

The tests shown on Figure 1 are the result of two "Proctor compaction tests" on one soil. In these tests, soil is compacted by a series of blows of a standard hammer in cylindrical molds that have a known standard volume. The hammers are designed to provide a known, repeatable input energy. Table 1 provides the details of each test. The complete moisture – unit weight relationship is obtained by compacting soil at a series of different moisture contents (but using the same effort each time). A smooth curve between the points is drawn and the maximum dry unit weight and optimum water content are determined for a soil at that compaction effort. The maximum dry unit weight is the peak point on the curve and the optimum moisture content is the water content corresponding to that peak dry unit weight.

Table 1. Details of Standard and Modified Proctor Tests.

Test	Mold* Volume	No. of Layers	Blows/ layer	Hammer Weight	Drop Height	Energy Input
Standard Proctor (ASTM D 698)	1/30 ft^3	3	25	5.5 lb	12 in	12,400 ft lb/ft^3
Modified Proctor (ASTM D 1557)	1/30 ft^3	5	25	10 lb	18 in	56,000 ft lb/ft^3

*4.0" diameter x 4.6" tall mold

The influence of standard effort vs. modified effort on the moisture-density relationship is shown in Figure 1. Note as the compaction effort is increased, the maximum density increases and the optimum moisture content decreases. The differences in the tests are in the amount of energy transmitted to the soil with each hammer blow and are shown below.

To the left of optimum moisture the soil is referred to as "on the dry side". Similarly, points to the right of optimum (higher moisture contents) are referred to as "on the wet side".

Relative compaction is typically used as an index to compare the field density with the laboratory density. Relative compaction is defined as:

$$\text{Relative Compaction: } RC = \frac{\gamma_d}{\gamma_{d,\max}} \times 100\% \qquad (1)$$

Where,

γ_d = field density measured in the field

$\gamma_{d,\max}$ = Proctor maximum dry density obtained from a Proctor Test.

This is expressed as a percentage.

Note:

Relative compaction is based on *dry unit weights*. RC greater than 100% is possible.

The Zero Air Voids Line

The zero air voids (ZAV) line is the combination of moisture and density that produce complete saturation of the soil or the γ_d obtained when there is no air in the void spaces. The compaction curve theoretically does not cross this line but becomes parallel to it. Remember that the values of water content, wet unit weight, and specific gravity are not constant throughout the soil. There could also be variability in the test results. Variability can result in points on the compaction curve above the ZAV line (S>100%). These data points should not be thrown out.

Basic weight volume relationships are used to develop and equation for the ZAV line. Recall that:

$$\gamma_d = \frac{W}{V} = \frac{W_s}{V_s + V_v} = \frac{G_s \gamma_w V_s}{V_s + e V_s} = \frac{G_s \gamma_w}{1 + e}$$

Since S = 1 if the saturation is equal to 100 percent, the relationship:

$$G_s w = e$$

can be substituted into the above equation to yield the final equation for the ZAV line:

$$\gamma_d = \frac{G_S \gamma_w}{1 + G_S w} \qquad (2)$$

Note that G_s and γ_w are constants for a given soil. Therefore the ZAV line is a linear function of water content. To draw the ZAV line, simply enter values of *w* and compute the corresponding value of γ_d.

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LABORATORY PROCEDURE (Modified Proctor)

Equipment

Compaction mold	Jack
US Sieve # 4	Steel straight edge
Modified Proctor Hammer	Moisture cans
Balance sensitive to 0.01 lb	Drying oven
Balance sensitive to 0.1 g	Plastic squeeze bottle with water
Large flat pan	

Procedure

1. Obtain approximately 5 lbs. of undried soil passing the No. 4 sieve for each test being performed. A minimum of 5 tests is required, 6 is preferred.

2. Add enough water to each test sample to bring the water content within range of optimum. Test samples should be prepared in approximately 2% increments. First trial water content might be 4%.

3. Determine the weight (W_1) and volume (V) of the Proctor compaction mold or with base plate (do not measure the extension). Use the scale sensitive to 0.1 lb. to determine the weight of the mold.

4. Determine the weight (W_{tin}) of the moisture tins. Use the scale sensitive to .01 g to determine these weights.

5. Assemble and secure the mold and extension to the base plate. Make sure that the apparatus is placed on a rigid foundation (i.e., concrete slab). This is important not only for safety reasons, but to ensure that the compaction effort is applied to the soil and not the foundation.

6. Compact the first test specimen in the mold in five equal layers.

    a. For the first layer, fill the mold about one third with loose soil.

    b. Compact the lift with 25 blows of the compaction hammer. Make sure that the hammer is kept vertical and the guide sleeve is not lifted. Also, take care to evenly distribute the blows over the entire mold.

    c. Score the top of the layer with a metal spatula.

    d. For the second layer, fill up to two third level of the mold.

    e. Repeat steps b and c.

    f. For the final layer, fill to about the midpoint or higher of the extension. This layer is important because after compaction, the top of the layer *must* be equal to or *above* the top of the mold. If it is not the test must be done over.

    g. Repeat step b.

7. Remove the extension and base plate.

8. With the steel straight edge level off the sample so it is even with the top and bottom of the mold. Take care not to create divots in the sample during this process.

9. Determine the weight (W_2) of the soil and mold or plus base plate (not the extension). Use scale sensitive to 0.1 lb. to determine this weight.

10. With the aid of the extruder, remove the sample from the mold.

11. Collect a sample of soil from the center of the compacted soil and place it in the moisture tin.

12. Determine the weight ($W_{tin+soil}$) of the moisture tin and soil.

13. Place the moisture tin and soil in the oven over night to dry.

14. Repeat steps 5 through 13 for each of the remaining test specimens.

15. Determine the weight ($W_{tin+dry\ soil}$) of the tin and dry soil for each test specimen.

Calculations

Moisture Content

$$Moisture\ content\ =\ \frac{Weight\ of\ water}{Weight\ of\ dry\ sample}\text{, or}$$

$$w = \left(\frac{W_{tin+soil} - W_{tin+drysoil}}{W_{tin+drysoil} - W_{tin}}\right) \times 100 \qquad (3)$$

Moist Unit Weight

$$Moist\ unit\ weight = \frac{weight\ of\ moist\ soil}{volume\ of\ mold}\text{, or}$$

$$\gamma = \frac{W_2 - W_1}{V} \qquad (4)$$

Dry Unit Weight

$$Dry\ unit\ weight = \frac{weight\ of\ dry\ soil}{volume\ of\ mold}\text{, or}$$

$$\gamma_d = \frac{\gamma}{1 + \dfrac{w}{100}} \qquad (5)$$

Plot the compaction curve, γ_d vs. w. Draw a best-fit curve, using a French curve so the curve is smooth. Determine the optimum water content and maximum dry unit weight from the curve.

Plot the zero air voids curve on the same plot as the compaction curve. Use a French curve and plot at least 4 points to get the general shape of the curve. Plot the Zero Air Voids Curve:

$$\gamma_d = \frac{G_s \gamma_w}{1 + \dfrac{wG_s}{100}} \qquad (6)$$

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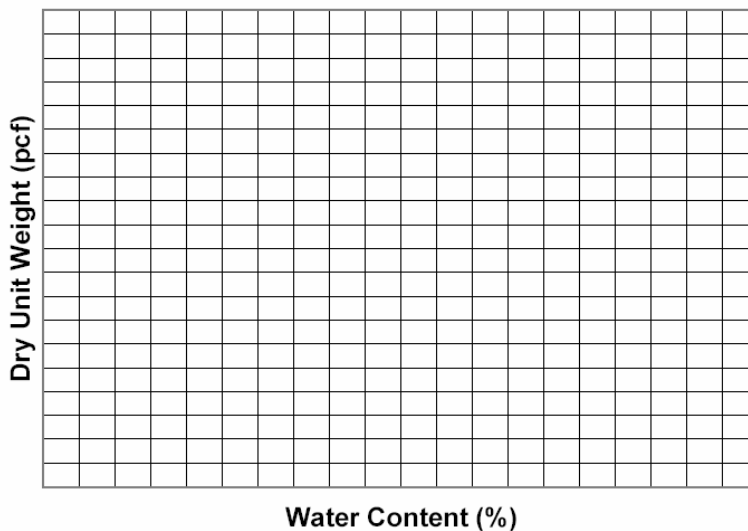# Modified Proctor Compaction Test

Engineer:	Sample:
Date:	Description:

Moisture Content

Can No.	1	2	3	4	5
Weight of tin, W_{tin}					
Weight of tin + wet soil, $W_{tin+soil}$					
Weight of tin + dry soil, $W_{tin+dry\,soil}$					
Moisture content, w					

Unit Weight

Weight of mold, W_1					
Weight of mold + soil, W_2					
Volume of mold, V					
Unit weight, γ					
Dry unit weight, γ_d					

Compaction Curve

Dry Unit Weight (pcf)

Water Content (%)

Optimum water content

_____

Maximum dry density

_____