



# UNIBE

**FACULTY OF ENGINEERING**



## **Soil Mechanics Laboratory Manual**

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## **General Safety Rules in Soils Mechanics Laboratory**

Working in a laboratory brings certain risks and complications, such as breaking any glassware, burning, no good handling of an equipment, possible accidents caused by the negligent use of equipment or risk simply by the characteristics of the substances used.

These complications and risks shall take no negative consequences if certain standards and safety precautions are handled.

- Laboratory use is exclusively for academic work.
- If you do not understand the process of doing something, ask!
- It is encouraged to all lab users that all safety standards **MUST** be followed; the person who does not keep up with the safety standards, so that their actions put his/her safety or that of other students in danger will have to leave the laboratory facility.
- Using robe, helmet, gloves, and goggles is **MANDATORY** from the moment the user enters the lab; the user must use the robe provided by the teacher in charge or otherwise cannot use the services requested. If any other safety equipment shall be use, the professor will inform the class. Moreover, close shoes **MUST** be worn at all times. No **SANDALS**.
- It is strictly prohibited to eat and drink since the measurement of the soil can change if water or food are spilled on it.
- Clean your workstation and keep everything as clear as possible. It is a responsibility of all persons using the lab.
- Do not perform any experiment that was not previously authorized by the professor.
- It is prohibited the use of chemical substances from those permitted in the soils laboratory.
- It is advised to remove any rings or long items from the body to avoid any injuries.

## **Induction to the Laboratory of Soil Mechanics**

The laboratories are conducted from week three to week fifteen (both included), with possible semester variations according to the schedule of practices developed and delivered by the teacher.

The experiments will be performed once. Each student is responsible for recording the measurements in the soil lab equipment, to make a weekly report; this should contain basic procedures (methodology, theoretical foundations of the test, results, etc.). It would be appropriate that the reports contain graphics and drawings (photographs) of the practice.

The report should be written so that anyone can duplicate the experiment and get similar results to those reported. A clear, neat, simple report is a must.

A poorly written report leads the reader to think of an experiment performed poorly. In that order, the report must be well organized: this ensures that the reader easily follow, step by step, the points made in the text.

This involves making an exhaustive search for information, finish the calculations to ensure the accuracy of the data reported. It is assumed that the report will be free of grammatical and spelling errors.

The report will be delivered to the lab the next week before starting the next practice. At the entrance of the laboratory there is a place where you should place your practice report.

### **NOTES**

***The value of the lab is 30% of the value of the total grade, so it is necessary to take a minimum of 21 points of 30, if you want to qualify for the final exam of the theory of Soil Mechanics.***

### **Laboratory report format**

Laboratory reports will have the following format:

1. ***Delivery Letter:*** Professional letter to the teacher delivering the report.

2. ***Presentation:*** Only with the following information:

- a) Name and code of the subject
- b) Descriptive name of the experiment
- c) Date of delivery
- d) Name and student(s) ID

\* It is not necessary to provide an additional page for presentation. Preferably not.

3. ***Table of Contents:***

- a) List of report headers and contents of the appendices.
- b) List of Figures with their titles.
- c) Corresponding page numbers and all pages numbered correctly.

4. ***Objective:*** Summary of a clear and concise research purpose and goals.

5. **Theoretical mark:** Discussion of the physical principles of the experiment, including the premises and validity of them.

6. **Anticipated results:** numerical and qualitative results expected. Include expected values to be compared with the results, expected forms of graphics, etc.

**7. Apparatus:**

a) List and describe the equipment and tools used.

8. **Procedure:** concise and ordered list of all the steps taken by the group to perform the experiment. Do not just copy the manual.

9. **Results:** Objective review of the results obtained. Do not limit yourself to only display tables and graphs. Each object in the report must have a reason and an explanation, are used as support for the review of results and should be referred from the document.

**10. Discussion:**

a) Discuss the accuracy and precision of each result, numerically if possible.

b) Analyze the likely sources of error, its causes, effects and magnitudes.

11. **Conclusion:** the initial objective was fulfilled? Why or why not?

12. **References:** List of references mentioned in the body of the report. All references listed must be referred from the report.

13. **Appendix:** Original data, control data sheets.

**Notes:**

- The practices must be delivered properly stapled sheets without folder or bindings.
- As a rule, less is more. Omit all word and information that is unnecessary. Be austere with sheets and empty space.
- It is strongly recommended to include tables and images (graphics and photos). A good description and narrative about its content is equally important and required.
- The absence of the References section shall be interpreted as academic dishonesty and will be treated in accordance.
- The report should be in black and white.

## Laboratory No. 1: Determination of Moisture Content (ASTM D2216-98)

### Objective

Determine the natural water content of a soil sample.

### Scope of the Experiment

Water is present in different percentages in most naturally occurring soil. Moisture Content of a soil is one of the most important characteristics of a soil. Along with other properties of the soil, the moisture content is part of the weight relationships.

There are vast of co-relation within the water content and other properties. It gives information on the type of soil, the behavior of the soil, resistance, and many other characteristics.

### Equipment

- Thermostatically controlled oven
- Precision balance
- Glass weighting trays 4 test tubes of 750 ml
- Scoop



**Figure 1.** Thermostatically Controlled Oven at the Soils Lab

### Theoretical Fundament

The moisture content of a soil sample is defined as the mass of water in the sample expressed as a percentage of the dry mass, usually heating at 105C, i.e.

$$\text{moisture content, } w = \frac{M}{M} x \quad (\%)$$

where, Mw = mass of water

$M_d = \text{dry mass of sample}$

$M_w = (\text{Mass of Water} + \text{Container}) - (\text{Mass of Dry Sample} + \text{Container})$

$M_d = (\text{Mass of Dry Sample} + \text{Container}) - (\text{Mass of Container})$

The mass required for the test depends on the grading of the soil, as follows;

- a) Fine-grained soils\*, not less than 30 grams
- b) Medium-grained soils\*, not less than 300 grams
- c) Coarse-grained soils\*, not less than 3 kg

\*Soils group

- i) Fine-grained soils: Soils containing not more than 10% retained on a 2 mm test sieve.
- ii) Medium-grained soils: Soils containing more than 10% retained on a 2 mm test sieve but not more than 10% retained on a 20 mm test sieve.
- iii) Coarse-grained soils: Soils containing more than 10% retained on a 20 mm test sieve but not more than 10% retained on a 37.5 mm test sieve.

### **Test Procedure**

- 1) Calibrate the balance.
- 2) Determine the mass of a clean and dry container.
- 3) Place the moist sample in the container and measure the mass of the container and the sample.
- 4) Place the container with the moist sample in the dry oven. The time that the sample shall be in the oven will vary depending on the type of soil. The time will vary from 4h to 16h.
- 5) After the sample has dried, take out of the oven and let it cool down. Determine the mass of the container and the sample. Report you values up to 1%

## Test Sheet – Moisture Content

Name:

Date:

Test:

Visual Description of Soil:

Container No.			
Mass of Container (m1)			
Mass of wet soil+container (m2)			
Mass of dry soil+container (m3)			
<b>Mass of Moisture (Mw=m2-m3)</b>			
<b>Mass of Dry Soil (Md=m3-m1)</b>			
<b>Moisture Content ((Mw/Md)*100%)</b>			
Average			

### Laboratory Guide

- a) Does the water content depend on the location and depth of the soil? Why?
- b) Why do you think is there a difference in the moisture content depending on the soil?
- c) How can you facilitate the drying process of the sample?
- d) Do you think that there was a mistake during the process? How did that affect your results?
- e) How do you result compare to other values of soil of the same type?
- f) Do you think that use of caps on the containers shall be recommended?



## Laboratory No. 2: Standard Method for Specific Gravity Weight (ASTM D854-02)

### Objective

This test method is used to determine the specific gravity of soil solids.

### Scope of the Experiment

The specific gravity of soil solids is determined to calculate the density of the soil solids. This property work in the phase weight relationship of soils such as void ratio and the degree of saturation.

### Equipment Specifications

- Pycnometer (Min: 250mL)
- Balance
- Thermostatically controlled oven
- Thermometer
- Desiccator
- Entrapped Air Removal Apparatus
- Insulated Container
- Funnel
- Sieve- No4 (4.75mm)
- Drying Oven
- Distilled Water

### Theoretical Fundament

To calculate the mass of the pycnometer and water at the test temperature:

$$M_{p,t} = M_p + (V_p \times \rho_{w,t})$$

Where:

$M_{p,t}$  = mass of the pycnometer and water at the test temperature, g

$M_p$  = mass of the dry pycnometer, g

$V_p$  = Volume of the pycnometer, mL

$\rho_{w,t}$  = density of water at the test temperature, g/mL from Figure 1.

In order to calculate the specific gravity at soil solids the test temperature,  $G_t$ ,

$$G_t = \frac{\rho_s}{\rho_{w,t}} = \frac{M_s}{M_{p,t} - (M_{p,t} - M_s)}$$

Where:

$\rho_s$  = density of soil solids Mg/m<sup>3</sup> or g/cm<sup>3</sup>

$\rho_{w,t}$  = density of water at the test temperature (T<sub>t</sub>), from figure 1, g/mL or g/cm<sup>3</sup>

M<sub>s</sub> = mass of the oven dry soil solid, g

M<sub>pws,t</sub> = mass of pycnometer, water, and soil solids at the test temperature, g

**Table 1. Density of Water and Temperature Coefficient (K) for various Temperatures. (ASTM D854-02)**

Temperature (°C)	Density (g/mL) <sup>B</sup>	Temperature Coefficient (K)	Temperature (°C)	Density (g/mL) <sup>B</sup>	Temperature Coefficient (K)	Temperature (°C)	Density (g/mL) <sup>B</sup>	Temperature Coefficient (K)	Temperature (°C)	Density (g/mL) <sup>B</sup>	Temperature Coefficient (K)
15.0	0.99910	1.00090	16.0	0.99895	1.00074	17.0	0.99878	1.00057	18.0	0.99860	1.00039
.1	0.99909	1.00088	.1	0.99893	1.00072	.1	0.99876	1.00055	.1	0.99858	1.00037
.2	0.99907	1.00087	.2	0.99891	1.00071	.2	0.99874	1.00054	.2	0.99856	1.00035
.3	0.99906	1.00085	.3	0.99890	1.00069	.3	0.99872	1.00052	.3	0.99854	1.00034
.4	0.99904	1.00084	.4	0.99888	1.00067	.4	0.99871	1.00050	.4	0.99852	1.00032
.5	0.99902	1.00082	.5	0.99886	1.00066	.5	0.99869	1.00048	.5	0.99850	1.00030
.6	0.99901	1.00080	.6	0.99885	1.00064	.6	0.99867	1.00047	.6	0.99848	1.00028
.7	0.99899	1.00079	.7	0.99883	1.00062	.7	0.99865	1.00045	.7	0.99847	1.00026
.8	0.99898	1.00077	.8	0.99881	1.00061	.8	0.99863	1.00043	.8	0.99845	1.00024
.9	0.99896	1.00076	.9	0.99879	1.00059	.9	0.99862	1.00041	.9	0.99843	1.00022
19.0	0.99841	1.00020	20.0	0.99821	1.00000	21.0	0.99799	0.99979	22.0	0.99777	0.99957
.1	0.99839	1.00018	.1	0.99819	0.99998	.1	0.99797	0.99977	.1	0.99775	0.99954
.2	0.99837	1.00016	.2	0.99816	0.99996	.2	0.99795	0.99974	.2	0.99773	0.99952
.3	0.99835	1.00014	.3	0.99814	0.99994	.3	0.99793	0.99972	.3	0.99770	0.99950
.4	0.99833	1.00012	.4	0.99812	0.99992	.4	0.99791	0.99970	.4	0.99768	0.99947
.5	0.99831	1.00010	.5	0.99810	0.99990	.5	0.99789	0.99968	.5	0.99766	0.99945
.6	0.99829	1.00008	.6	0.99808	0.99987	.6	0.99786	0.99966	.6	0.99764	0.99943
.7	0.99827	1.00006	.7	0.99806	0.99985	.7	0.99784	0.99963	.7	0.99761	0.99940
.8	0.99825	1.00004	.8	0.99804	0.99983	.8	0.99782	0.99961	.8	0.99759	0.99938
.9	0.99823	1.00002	.9	0.99802	0.99981	.9	0.99780	0.99959	.9	0.99756	0.99936
23.0	0.99754	0.99933	24.0	0.99730	0.99909	25.0	0.99705	0.99884	26.0	0.99679	0.99858
.1	0.99752	0.99931	.1	0.99727	0.99907	.1	0.99702	0.99881	.1	0.99676	0.99855
.2	0.99749	0.99929	.2	0.99725	0.99904	.2	0.99700	0.99879	.2	0.99673	0.99852
.3	0.99747	0.99926	.3	0.99723	0.99902	.3	0.99697	0.99876	.3	0.99671	0.99850
.4	0.99745	0.99924	.4	0.99720	0.99899	.4	0.99694	0.99874	.4	0.99668	0.99847
.5	0.99742	0.99921	.5	0.99717	0.99897	.5	0.99692	0.99871	.5	0.99665	0.99844
.6	0.99740	0.99919	.6	0.99715	0.99894	.6	0.99689	0.99868	.6	0.99663	0.99842
.7	0.99737	0.99917	.7	0.99712	0.99892	.7	0.99687	0.99866	.7	0.99660	0.99839
.8	0.99735	0.99914	.8	0.99710	0.99889	.8	0.99684	0.99863	.8	0.99657	0.99836
.9	0.99732	0.99912	.9	0.99707	0.99887	.9	0.99681	0.99860	.9	0.99654	0.99833
27.0	0.99652	0.99831	28.0	0.99624	0.99803	29.0	0.99595	0.99774	30.0	0.99565	0.99744
.1	0.99649	0.99828	.1	0.99621	0.99800	.1	0.99592	0.99771	.1	0.99562	0.99741
.2	0.99646	0.99825	.2	0.99618	0.99797	.2	0.99589	0.99768	.2	0.99559	0.99738
.3	0.99643	0.99822	.3	0.99615	0.99794	.3	0.99586	0.99765	.3	0.99556	0.99735
.4	0.99641	0.99820	.4	0.99612	0.99791	.4	0.99583	0.99762	.4	0.99553	0.99732
.5	0.99638	0.99817	.5	0.99609	0.99788	.5	0.99580	0.99759	.5	0.99550	0.99729
.6	0.99635	0.99814	.6	0.99607	0.99785	.6	0.99577	0.99756	.6	0.99547	0.99726
.7	0.99632	0.99811	.7	0.99604	0.99783	.7	0.99574	0.99753	.7	0.99544	0.99723
.8	0.99629	0.99808	.8	0.99601	0.99780	.8	0.99571	0.99750	.8	0.99541	0.99720
.9	0.99627	0.99806	.9	0.99598	0.99777	.9	0.99568	0.99747	.9	0.99538	0.99716

<sup>A</sup>Reference: CRC Handbook of Chemistry and Physics, David R. Lide, Editor-in-Chief, 74<sup>th</sup> Edition, 1993–1994.

<sup>B</sup>mL = cm<sup>3</sup>.

## Test Procedure

- 1) Record the value and volume mass of the pycnometer with water up to the mark value at room temperature.
- 2) Dry the specimen in the oven and record its moisture content. Once dry, break up any clod or hard pieces carefully trying not to lose any material. Depending on the soil type and the pycnometer, here on Table 2, the mass of the test specimen recommended to be used.

**Table 2. Recommended mass of soil to use for the test. (ASTM D854-02)**

<b>Soil Type</b>	<b>Mass (g) 250mL Pycnometer</b>	<b>Mass (g) 500mL Pycnometer</b>
<b>SP, SP-SM</b>	60 +/- 20	100 +/- 10
<b>SP-SC, SM, SC</b>	45 +/- 10	75 +/- 10
<b>Silt or Clay</b>	35 +/- 5	50 +/- 10

- 3) Place the funnel in the pycnometer and place the soil inside using the funnel. Try to put pycnometer on top of a tray to collect any loose soil in case some runs out. Rinse any remaining soil left in the funnel using a squirt bottle.
- 4) Add water up to  $\frac{1}{3}$  and  $\frac{1}{2}$  of the depth of the pycnometer. Stir the water until a slurry mass is formed.
- 5) Now, the air that is trapped in the pycnometer has to be removed by using the entrapped air device removal. When doing this, agitate the soil to let any air bubble out.
- 6) Fill the pycnometer with deaired water.
- 7) Record the mass of the pycnometer, soil, and water to the nearest 0.01 g.
- 8) Measure the temperature of the soil mixture to the nearest 0.1 °C. This is going to be the test temperature,  $T_t$ .



**Figure 1. 250 mL Pycnometer**

## Test Sheet – Specific Gravity

Name: \_\_\_\_\_

ID: \_\_\_\_\_

Test: \_\_\_\_\_

Information	Data		Average	Units
Mass of pycnometer, $M_p$				g
Volume of Pycnometer, $V_p$				mL
Density of water, $\rho(w,t)$				g/mL
<b>Mass of the pycnometer and water, <math>M_{pw}</math></b>				g
Mass of Dry soil, $M_s$				g
Mass of pycnometer and Water, $M$				g
Mass of pycnometer, water, and soil solids, $M_{pws}$				g
Temperature, $T_t$				°C
<b>Specific Gravity, <math>G_t</math></b>				-

### Laboratory Guide

- a) What are the differences in results between the types of soil?
- b) Why do you think is there a difference in the values?
- c) Where do you think that there is a chance of error?
- d) Do you think that there was a mistake during the process? How did that affect your results?
- e) How do you result compare to other values of soil of the same type?

## Laboratory No. 3: Test Method for Particle Size (ASTM D422-63)

### Objective

This test method shows the distribution of particles sizes in soils.

### Scope of Experiment

In any mass of soil, the size of the grains that it is formed from, vary greatly. In order to estimate the size of the grains, the soil mas has to be subjected to a grains size distribution test.

There are two methods in this test: the sieve test for particles larger than  $75\mu$  (soil retained in the No. 200 sieve) and for the particles passing this sieve, the sedimentation process which includes the use of hydrometer. Once the results are obtained, the process of soil classification begins.

### Equipment Specifications for Sieve and Hydrometer Tests:

- Oven Falling
- Sieve Set
- Tray
- Balance
- Stirring Apparatus
- Hydrometer
- Sedimentation Cylinder
- Thermometer
- Beaker (250 mL)
- Timing Device
- Distilled or Demineralized Water

### Test Procedure

#### *Sieve Test*

- 1- Take the weight of a tray, place your moist sample and record the weight. Proceed to place the sample in the oven for 4hrs. Once the time has passed, remove the soil, let the tray cool down, take the weight of the dry sample.
- 2- Now proceed to wash the dry soil through the No. 200 Sieve. Place a tray at the bottom to collect the finer material.
- 3- After the soil is washed, place in the oven for 4 hrs. Once dry, record the weight of the dry sample. The difference in the two dry weights, it is the eight of the fines.
- 4- Make sure that the sieves are clean if not, use a wire brush to smoothly clean them.
- 5- Stack up the sieves in ascending order. The sieve with the smaller opening are placed at the bottom and the one with the larger opening are placed on top.

- 6- Conduct the sieve operation by placing the material in the shaker machine or start manually.
- 7- Shake it for 5-10 minutes.
- 8- Place a tray on the balance, zero it out, take the material of the larger sieve, and record the weight it. Then, zero out again, and take the next sieve and repeat the same process.
- 9- Proceed to calculate the percent fines.

### Theoretical Fundament

To calculate the percent fines, follow this:

$$\%R = \frac{M \text{ o } S \text{ o } S}{W \text{ o } t \text{ i } S (\sum \text{ o } a \text{ t i } w)} \times$$

Where:

%Retained= mass of soil retained on that sieve, %

Then, calculate the % cumulative soil retained on each sieve by adding the % retained on that sieve plus the % retained on the sieves above:

$$\%C_i = \%R \text{ o } t h a S_i + \%R \text{ o } t h e S_{A}$$

Finally, calculate the % Fine by subtracting from 1 the %cumulative on that sieve:

$$\%F = 1 - \%C_i$$



Sieve Designation	Sieve Opening (mm)
2 in.	50.00
1.5 in.	37.50
1 in.	25.00
3/4 in.	19.00
1/2 in.	12.50
3/8 in.	9.50
No. 4	4.75
No. 8	2.36
No. 16	1.18
No. 30	0.60
No. 50	0.30
No. 100	0.15
No. 200	0.075

Figures 1 and 2. Left picture shows different sizes of sieves. Right shows a list of Standard Sieve and Opening Sizes.

## ***Hydrometer Test***



**Figure 3. Hydrometer used to measure the Soil Particles falling. VintEssensial.**

### **Dispersing Agent**

A solution is needed in order to disperse the well-attached fine clay-silt particles. This solution is composed of sodium hexametaphosphate. The solution uses distilled or demineralized water at the rate of 40g of sodium hexametaphosphate/liter of solution.

### **Hygroscopic Moisture**

When the sample is weighed for the hydrometer test, weigh out an auxiliary portion of 10 to 15 g in a small metal or glass container, dry the sample to a constant mass in an oven at 110°C (230°F), and weigh again. Record the masses.

### **Dispersion of Soil Sample**

When the soil is mostly of the clay and silt sizes, weigh out a sample of air-dry soil of approximately 50 g. When the soil is mostly sand the sample should be approximately 100 g. Place the sample in the 250-mL beaker and cover with 125 mL of sodium hexametaphosphate solution (40 g/L). Stir until the soil is thoroughly wetted. Allow to soak for at least 16 h.

After the time has passed, transfer the soil to the stirring apparatus. If there is leftover material, wash it with distilled water. Then stir for 1min.

### **Meniscus Correction, $C_m$**

Insert the hydrometer in the control cylinder containing about 1000 ml of water. Take readings of the hydrometer at the top and bottom of the meniscus. The difference between the two readings is taken as the meniscus correction ( $C_m$ ) which is a constant for a hydrometer. During the actual sedimentation test, the readings should be taken at the bottom of the meniscus but since the soil slurry is cloudy, readings are taken at the top of meniscus. The meniscus correction is always positive.

### **Composite Correction, Cd**

When the dispersion mixture is added, the composition of the water change. The change of this composition has to be taken into account. Prepare a cylinder with the same mixture as the sedimentation cylinder: dispersing agent and distilled water. Insert the hydrometer and let it adjust its temperature, then take a reading. For hydrometer 151H the composite correction is the difference between the reading and 1. For hydrometer 152H, it is the difference between the reading and zero.

### **Temperature Correction, Ct**

This is a temperature correction applied to the hydrometer readings since the hydrometer is design to work at 20°C. Table 1 shows the values based on the temperature and hydrometer used.

### **Test Procedure**

- 1- Once the dispersion is over, proceed to pour the slurry into the cylinder. Complete the cylinder up to 1000mL with the de-aired water.
- 2- Place your palm or the rubber cover on top of the cylinder and proceed to mix it by doing 180 ° (upside down and back) for 1 minute. It is recommended to use the cylinder that do not have a peak at the top since some material can be lost.
- 3- Introduce the hydrometer into the cylinder slowly to the floating position and let it float. Start taking measurement at 0.5, 1, 2, 4 minutes and remove the hydrometer and place it in the sedimentation cylinder. Proceed to take reading at 8, 15, 30, 60, 120, 480 minutes. Take two more reading before the 24 hrs. period.
- 4- It is recommended to insert the hydrometer in the cylinder near the last reading, 20 seconds before the scheduled time to allow the hydrometer to settle and adjust its temperature.
- 5- After each reading, take a temperature reading.



**Table 1. Temperature Correction Table. (GeoSystem, 2020)**

TEMP, DEG C.	SPECIFIC GRAVITY OF WATER	VISCOSITY OF WATER	TEMP. CORR. FACTOR FOR 152H	TEMP. CORR. FACTOR FOR 151H
15.0	0.99912	0.01141	-1.14	-0.71
15.5	0.99050	0.01126	-1.02	-0.63
16.0	0.99897	0.01111	-0.90	-0.55
16.5	0.99889	0.01097	-0.78	-0.48
17.0	0.99880	0.01083	-0.67	-0.41
17.5	0.99871	0.01069	-0.56	-0.35
18.0	0.99862	0.01056	-0.46	-0.28
18.5	0.99853	0.01043	-0.35	-0.22
19.0	0.99843	0.01030	-0.25	-0.16
19.5	0.99834	0.01017	-0.15	-0.09
20.0	0.99823	0.01005	-0.04	-0.03
20.5	0.99813	0.00993	0.07	0.04
21.0	0.99802	0.00981	0.18	0.11
21.5	0.99791	0.00969	0.29	0.18
22.0	0.99780	0.00958	0.41	0.25
22.5	0.99769	0.00947	0.53	0.33
23.0	0.99757	0.00936	0.66	0.41
23.5	0.99745	0.00925	0.80	0.50
24.0	0.99733	0.00914	0.95	0.59
24.5	0.99721	0.00904	1.11	0.69
25.0	0.99708	0.00894	1.27	0.79
25.5	0.99695	0.00884	1.45	0.90
26.0	0.99682	0.00874	1.64	1.02
26.5	0.99668	0.00864	1.85	1.15
27.0	0.99655	0.00855	2.07	1.28
27.5	0.99641	0.00846	2.30	1.43
28.0	0.99627	0.00836	2.55	1.58
28.5	0.99613	0.00827	2.81	1.75
29.0	0.99598	0.00818	3.10	1.92
29.5	0.99583	0.00809	3.40	2.11
30.0	0.99568	0.00801	3.72	2.31

### Theoretical Fundament

The percentage of soil that is in suspension, **P**, have to be calculated with the following equation depending on the hydrometer used:

If the hydrometer 151H is used:

$$P = \left[ \left( 1 - \frac{0}{W} \right) x / (G - G_1) \right] (R - G_1)$$

If the hydrometer 152H is used:

$$P = (R / W) x$$

Where:

a = It is a correction factor applied to the reading based on the specific gravity. **Table 1** on the ASTM D422-63 show these values.

R = This is the hydrometer reading with composite correction.

W = This is the oven-dried mass of the soil used for the test sample, g.

G = Specific Gravity of the soil.

G<sub>1</sub> = Specific Gravity of Water, usually 1.0.

To calculate the diameter of the particles, use the following equation (Stoke's Law):

$$D = \sqrt{\frac{3}{9} (G - G_1) \times L/T}$$

Where:

D = Diameter of particles, mm.

μ = coefficient of viscosity of water at the temperature of the suspension at the time of the reading.

L = Distance of the reading, cm. This value change depending on the hydrometer used. **Table 2** on the ASTM D422-63 show these values.

T = The elapsed time from the beginning of the test to the time the reading is taken, min.

For a more effective way to solve the calculation, the following expression is used:

$$D = K\sqrt{L/T}$$

Where:

K = This is a constant based on the temperature of the suspension and specific gravity of the soil. **Table 3** in the ASTM D422-63 have these values.

### TEST SHEET - SIEVE

Name: \_\_\_\_\_

Date: \_\_\_\_\_

Test: \_\_\_\_\_

Sieve	Opening (mm)	Masa Suelo (g)	Retained	Cummulative	Fines
#	mm	g	%	%	%
4	4.75				
10	2				
20	0.85				
40	0.425				
60	0.25				
80	0.18				
100	0.15				
200	0.075				
Tara					
		$\Sigma=$			

## TEST SHEET - HYDROMETER

Name: \_\_\_\_\_

Date: \_\_\_\_\_

Test: \_\_\_\_\_

HYDROMETER:			
COMPOSITE CORRECTION Cd		MENISCUS CORRECTION, Cm	
HYDROMETER VOLUME	Ws, gr.	Gs:	a=

Date	TIME	TIME (min)	R'M	T	CT	RHC	WD1	R'H+CM	L	L/t	K	D	FINER
				°C		%	%		cm	cm/min		mm	%
		30											
		1											
		2											
		4											
		8											
		15											
		30											
		60											
		120											
		480											
		720											
		1440											

% FINER THAN SIEVE N° 200	
---------------------------	--

### Laboratory Guide

- 1- Plot the % Finer graph of the sample. Log of Grain, X, or Sieve size vs Percent Finer, Y.
- 2- Calculate coefficient of curvature, Cc, and the coefficient of uniformity, Cu from the graph:

Cu=	D60/D10
Cc=	$D_{30}^2 / (D_{10} * D_{60})$

- 3- What type of soil are you testing?
- 4- How do you value compare to the other groups?
- 5- Did you present any problems during test? What were they?

## Laboratory No. 4: Atterberg Limits (ASTM D4318-10)

### Objective

This test method is used to determine the liquid limit, plastic limit, and plasticity index of soils.

### Scope of Experiment

This test is used, in conjunction with the sieve analysis, as part of the **Soil Classification**. With this results, we can characterize the fine grained materials. Like the moisture content, engineers use this value to make correlations with other soil quantities.

### Equipment Specifications:

- Liquid Limit Device
- Oven
- Grooving Tool
- Water Content Containers
- Mixing Pan
- Glass Plate
- Spatula
- Wash Bottle
- Washing Pan



**Figure 1.** Casagrande Device

## Theoretical Fundament

The Atterberg limits are a measure of the critical water contents of a fine grained material. The behavior of a fine-grained soil will be different depending on the water content of the material.

Liquid Limit (LL) is the water content at which the soil will change the liquid state to a plastic state. This value is achieved by performing trials in which a portion of the specimen is tread in a brass cup divided in two by a grooving tool.

Plastic Limit (PL) is the water content at which the soil will change from plastic state to a semisolid state. This test is performed by repeating rolling of an ellipsoidal shaped soil (worn like) up to a diameter of 3 mm (1/8 in) until it crumbles.

Plasticity Index (PI) is calculated by subtracting the plastic limit from the liquid limit.  $PI=LL-PL$ . This is the value used to classify the consistency (ease of the material to be deformed) of the material. If the liquid limit or the plastic limit cannot be determined, then the soil is reported as a non-plastic soil, NP.

Before performing the test. The equipment shall be calibrated. Verify that the equipment is clean of any other sediment and that it does not show any wear. There shall be an adjustment of the height-drop of the device. The height that the device shall rise is 10 mm.

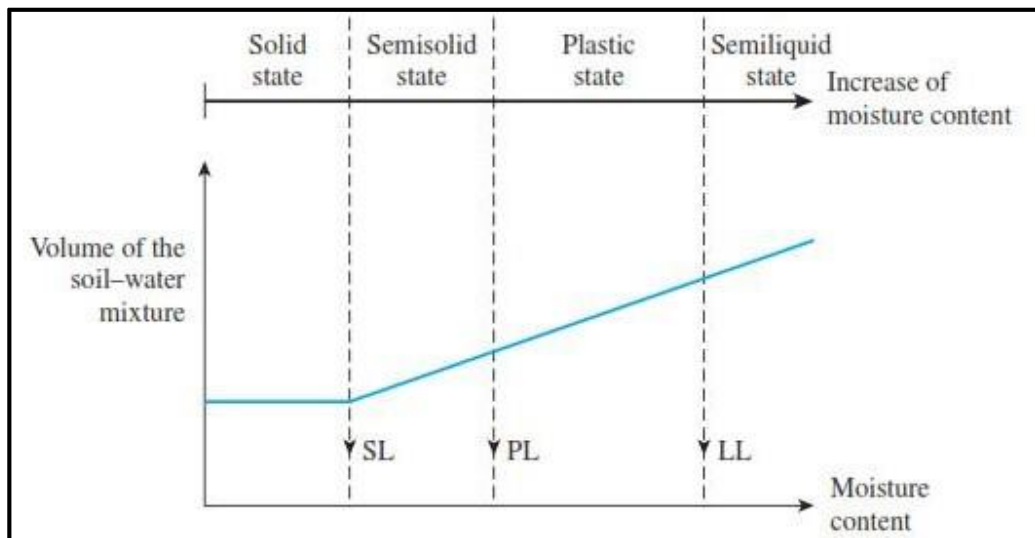


Figure 2. Limits of the different states of the soil. Principles of Foundation Engineering, 2011.

## Experimental Procedure Liquid Limit

- 1) Take sufficient sampled that passes the No. 40 sieve (425- $\mu\text{m}$ ) about 150 to 200g.
- 2) Place some soil in a dish and mix it. Adjust its water content until it requires 25 to 35 blows to close the grove.
- 3) Using a spatula, place some material in the cup, spread it into the cup to a depth of 10 mm. Make sure that there are no bubbles in the soil. Cover the unused material in the dish with a wet towel to avoid losing it water content.

- 4) Take the grooving tool and mark a line in the center of the mass of the material by joining the highest with the lowest point. Try to maintain the tool perpendicular as possible.
- 5) Lift and drop the cup at about 2 drops per second until the two shares of the soil pat come together along a distance of 13mm (1/2 inch). Record the number of blows, N.
- 6) Measure the weight of a container and remove a slice of soil approximately the width of the spatula and place it in the container.
- 7) Take all the mix, place it with the remaining soil and add distilled water to increase the water content. Repeat the same process but try to get a number from 20 and 30, and then another trial from 15 to 25 blows.
- 8) Determine the water content of all three samples.
- 9) Plot the relationship between the water content,  $W_n$ , and the corresponding number of drops, N, of the cup on a semilogarithmic graph with the water content as the x-axis on the arithmetical scale, and the number of drops as y-axis on a logarithmic scale. Draw the best straight line through the three points. The LL value will be the water content corresponding to the 25 blow.

### **Experimental Procedure Plastic Limit**

- 1) Select a soil sampled from the previous mix of 20-g. Reduce the water content until it is able to be rolled without sticking to the hand.
- 2) From the mixture, take about 1.5 to 2.0 g of mass. Form the mass into an ellipsoidal (worm-like) shape. Roll the soil until it measures 3.2 mm in diameter. Once it reached 3.2 mm, break the thread in pieces and squeeze them together. Form the worm once again until you reach the desire diameter.
- 3) Rolled the soil until it is not possible to roll it to the diameter desired.
- 4) Place the soil on a known mass container.
- 5) Repeat the process with another portion of the soil two more time.
- 6) Determine the water content of all three samples.

### **Plasticity Index**

Now, calculate the plasticity index:  $PI = LL - PL$

If one of the limits could not be calculated, then it is said the soil is non-plastic, NP.

With the information obtained from sieve analysis test and the limits, you can proceed to use the soil classification system to obtain the type of soil.

## TEST SHEET - LIMITS

Name: \_\_\_\_\_

ID: \_\_\_\_\_

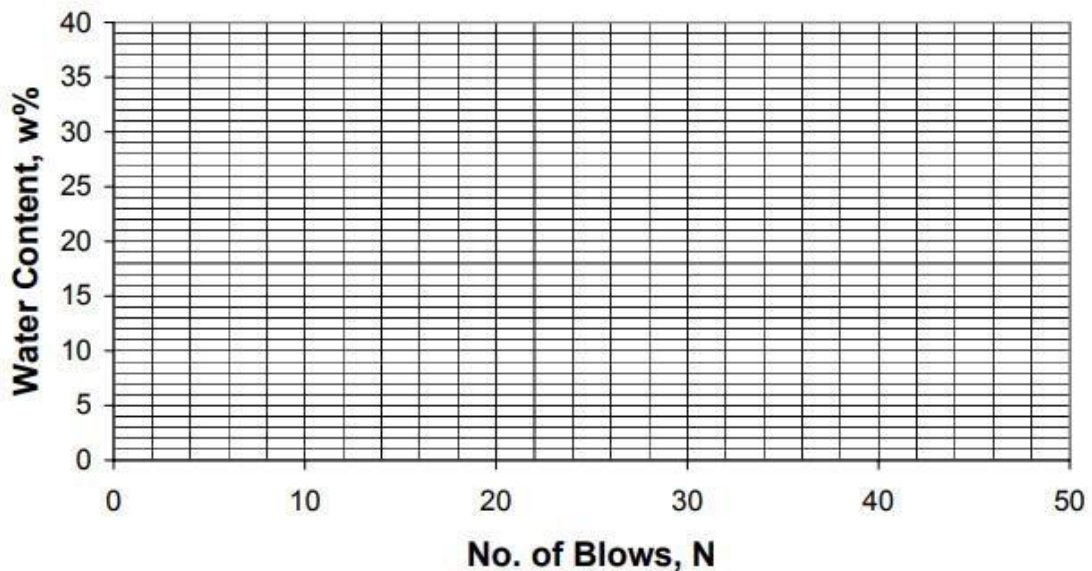
Test: \_\_\_\_\_

Run No	1	2	3
Weight of Water + Tare			
Weight of Dry Soil + Tare			
Tare Mass			
Blows			
<b>Moisture Content</b>			
<b>Liquid Limit, LL</b>			

Run No.	1	2	3
Weight of Water + Tare			
Weight of Dry Soil + Tare			
Tare Mass			
<b>Moisture Content</b>			
<b>Plastic Limit</b>			

PI=LL-PL	
----------	--

### LIQUID LIMIT CHART





### **Laboratory Guide**

- a) What problems did you incur during the test?
- b) Did you have great differences in the results for each sample?
- c) What type of soil tend to be Non-Plastic soil?
- d) Plot the water content table and check your values.

## Laboratory No. 5A: Permeability Test with Constant Head (ASTM D2434-68)

### Objective

The main purpose of this test is to measure the soil coefficient of permeability in coarse grained soil.

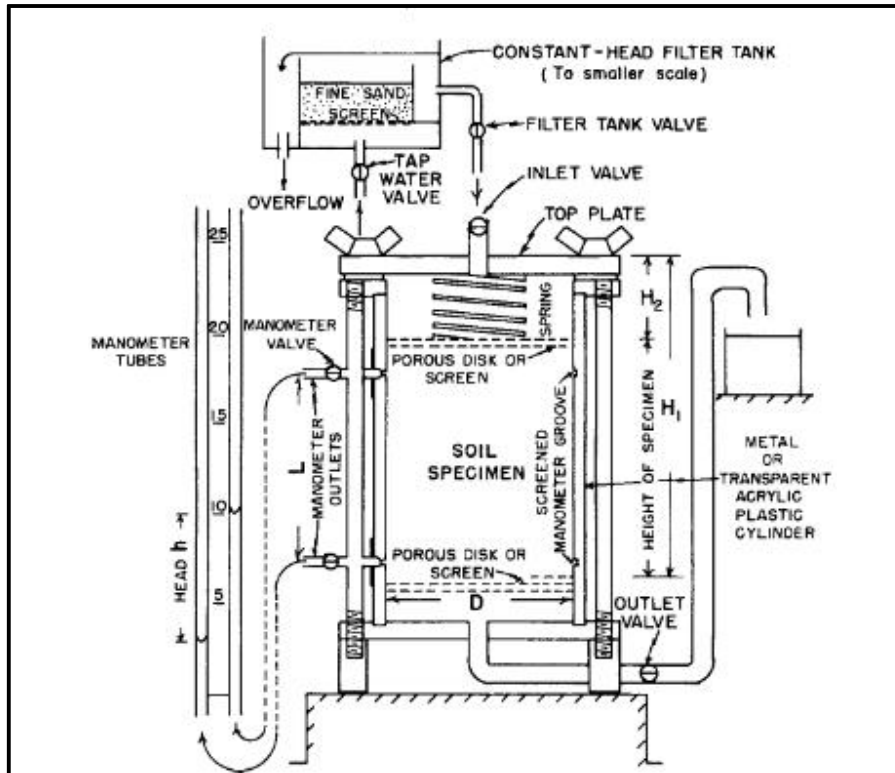


Figure 1. Constant Head Permeameter. ASTM D 2434-68.

### Scope of Experiment

In any soil structure, we know that there are voids, air, and solids and that water flows through the voids. The coefficient that it's going to be determined is important because it is use to estimate the permeability in dam embankments and base course material on pavement.

As it is stated in the name of the lab, a constant flow of water must be kept during the test. Soil have to be saturated as well in order to eliminate air bubbles.

## Equipment Specifications

- Permeameter
- Constant Head Tank. Reservoir Tank (to maintain the flow of water)
- Balance
- Porous Stones
- Manometer Tubes
- Funnel
- Compaction Equipment
- Vacuum Pump
- Thermometer

## Theoretical Fundament

The main concept behind this test is to measure the permeability of the soil. It is an important properties of soil because it helps to find out how water flows through the soil.

As it was mentioned before, a constant supply of water must be kept at all time to avoid air to flow into the soil.

The coefficient of permeability shall be calculated, k:

$$k = \frac{Q}{A h}$$

Where:

k= coefficient of permeability

A= area of the specimen

h= head difference

L= distance between the manometers

Q= Volume flow rate (discharge)

t= total time of discharge

## Soil Preparation

The sample obtained should not contain more than 10% of material passing the No. 200 sieve. If the sample contains particles larger than 19mm, they have to be removed. Record the weight of your sample. Take a small portion of the sample for moisture content calculation.

Before commencing the test, some readings have to be taken. Measure and record the diameter, D, of the permeameter at three different places. Measure the length between the manometer lengths, L. Also, measure the depth, H, from the upper surface of the top plate of the permeameter to the top of the porous stone. Proceed later to calculate the area, A, of the sample.

Make sure that the bottom porous stone is in place and saturated. Now proceed to place the soil in the device. Place the soil in different layers and in a cylindrical motion to ensure a distributed soil placement to the top of the chamber if it is a compacted soil. Place the top porous stone and measure the final height of the sample.

Proceed to connect the vacuum pump and evacuate the air out of the sample to 15min. After that, start the saturation (slow motion) of the sample from the bottom to push out any remaining air trapped. Once the sample is saturated, proceed to close the valves with care to avoid any air coming in. Connect and fill all remaining tubes and make sure that they are free of air.

### **Experimental Procedure**

- 1) Open the inlet valve from the reservoir tank slightly and wait for stabilization. Once occurred, measure the time, and head (difference in the level of the manometers), quantity of flow, and water temperature.
- 2) Increase the head by 0.5 cm. Repeat this process two more times.
- 3) Once the test is completed and water is drained out, check the sample and search for dark and light zones. If found, this indicated that the fines were segregated.

## Test Sheet

Name:	
Date:	
Test:	
Visual Description of Soil:	

Sample Information	Data	Units
Diameter, D		cm
Area, A		cm <sup>2</sup>
Length, L		cm
Height Before, H1		cm
Height After, H2		cm
Moisture Content, W		%

Permeability Test Results									
Test No.	Manometers		Head, h	Q	t	Q/At	h/L	Temp.	k
	H1	H2	cm	cm <sup>3</sup>	s			°C	cm/s
1									
2									
3									

### Laboratory Guide

- a) How do your values compare to the other person?
- b) Why is it important to keep a constant head?
- c) Did you experience any problem during the test?
- d) Does your coefficient correspond to the common values?

## Laboratory No. 5B: Permeability Test with Variable Head (ASTM D5084-00)

### Objective

The main purpose of this test is to measure the soil coefficient of permeability in fine grained soil.

### Scope of Experiment

This coefficient is important because it is used to estimate the permeability in dam embankments. As it is stated in the name of the lab, a variable flow of water will occur during the test. Soil has to be saturated as well in order to eliminate air bubbles.

### Equipment Specifications

- Hydraulic System
- Reservoir containing the influent liquid
- Balance
- Porous Stones
- Manometer Tubes
- Funnel
- Compaction Equipment
- Vacuum Pump
- Thermometer
- Stand Pipe

### Theoretical Fundament

The main concept behind this test is to measure the permeability of the soil. It is an important property of soil because it helps to find out how water flows through the soil.

In contrast with the Constant Head Test, a constant supply of water does not have to be in place at all time since water will flow slower than in coarse grained soil.

The coefficient of permeability shall be calculated, k:

$$k = \frac{a}{A} * \ln \frac{h_1}{h_2}$$

Where:

k= coefficient of permeability

a= cross-sectional area of stand pipe

A= cross-sectional area of the specimen

$h_1, h_2$ = head difference

$L$ = Length of the sample

$Q$ = Volume flow rate (discharge)

$t$ = total time elapsed

### **Soil Preparation**

The sample obtained should have a minimum diameter and height of 25mm (1 inch). These dimensions shall be measured at three different points and recorded. The sample shall not contain particles 6 times greater than any of the dimensions. If found, that have to be removed. Record the weight of your sample. Take a small portion of the sample for moisture content calculation.

Measure the length between the manometer lengths,  $L$ . Also, measure the depth,  $H$ , from the upper surface of the top plate of the permeameter to the top of the porous stone. Proceed later to calculate the area,  $A$ , of the sample.

Make sure that the bottom porous stone is in place. Place the top porous stone and measure the final height of the sample.

Proceed to connect the vacuum pump and evacuate the air out of the sample to 15min. After that, start the saturation (slow motion) of the sample from the bottom to push out any remaining air trapped. Once the sample is saturated, proceed to close the valves with care to avoid any air coming in. Connect and fill all remaining tubes and make sure that they are free of air.

### **Experimental Procedure**

- 1) Make sure that the soil is saturated and the stand pipes are filled with deaired water.
- 2) Commence the test by letting water to flow through the specimen until the water reaches a lower limit. The time that the took the standpipe to go from one level to other must be recorded.
- 3) Once the test is completed, repeat the test two more times.

## **TEST SHEET**

Name:	
Date:	
Test:	
Visual Description of Soil:	

Sample Information	Data	Units
Diameter, D		cm
Area, A		cm <sup>2</sup>
Length, L		cm
a, standpipe		cm <sup>2</sup>
Moisture Content, w		%

Falling Head Permeability Test Results									
Test No.	Standpipe		Head, h	Q	t1	t2	t1-t2	Temp.	k
	H1	H2	cm	cm <sup>3</sup>	s	s	s	°C	cm/s
1									
2									
3									

### Laboratory Guide

- Are your results different than the one from the Constant Head?
- Why do you think there is a difference in the values?
- Does your result correspond to the type of soil used?



## Laboratory No. 6: Consolidation Test (ASTM D2435-04)

### Objective

This test method is used to determine the magnitude and rate of consolidation of soil when restrained laterally and loaded axially.

### Scope of Experiment

During this test, the soil specimen, which is in a saturated state and especially fine-grained soil, is restrained to move laterally and is going to be loaded axially with total stress increments. Each increment is kept until the pore water pressure are dissipated. The change in height of the specimen is recorded and with this data, we shall be able to determine the consolidation settlement and time consolidation as well as the relationship between the effective stress and void ratio or strain.

This values are used to estimate how much a soil is going to settle based on the load of a structure during a certain time.



Figure 1. Consolidation Equipment at the Soil Mechanics Lab.

### Equipment Specifications:

- Loading Device
- Consolidometer
- Balances
- Deformation Indicator
- Trimming Device
- Drying Oven
- Porous Disks/Stones

- Water Content Containers
- Time Device
- Fixed Rings
- Specimen Diameter shall be minimum 50 mm (2.0 in). Minimum height shall be 12 mm (0.5 in). It shall not be less than ten times the max particle diameter.

### **Specimen Preparation**

It is recommended to have a not altered, in natural condition sample. Reduce as much disturbance soil or any change in moisture observed. Trim the specimen and insert it into the consolidation ring. When specimens come from undisturbed soil collected using sample tubes, the inside diameter of the tube shall be at least 5 mm (0.25 in.) greater than the inside diameter of the consolidation ring.

- 1) Determine the weight of the ring.
- 2) Determine the initial mass of the soil sample by subtracting the weight of the ring.
- 3) Determine the initial height of the sample to the nearest 0.025 mm (0.001 in) by taking the average at four different places.
- 4) Calculate the **volume** of the sample by using the diameter and the **height** previously calculated.
- 5) Determine three **water content** from trims obtained from the sample.

### **Experimental Procedure**

- 1) The assembly will depend on the type of soil being tested. If soils sensitive to moisture increase (swelling or collapsing soils) are being tested, the stone should be placed dry. When testing softer clays, the stone should be wet, and it may be covered by a wet filter paper. No filter paper shall be used for the stiffer and moisture sensitive soils.
- 2) The ring and specimen shall be placed centrally on the bottom porous stone, and the upper porous stone and then the loading cap shall be placed on top. The top stone shall be placed dry or wet, and with or without filter paper.
- 3) The consolidometer shall be placed in position in the loading device and suitably adjusted. The dial gauge is then clamped into position for recording the relative movement between the base of the consolidation cell and the loading cap. A seating pressure of 5 kPa (100 lb/ft<sup>2</sup>) shall be applied to the specimen and record the initial reading and time.
- 4) If the load will cause the sample to shirk, remove some load, or add more weight to avoid the sample from swelling.
- 5) The consolidation cell shall be filled with water, preferably with distilled water. The type of water used shall be noted in the data sheet.

- 6) Now, the specimen will be subjected to increments of constant total stress. The regular load increment ratio (LIR) schedule consist of doubling the pressure on the soil to obtain 12, 25, 50, 100, 200, 400, kPa (250, 500, 1000, 2000, 4000 psf). For the unloading process, we will be using the same schedule but in reverse order.
- 7) Before applying the next increment, the height or change in height must be recorded,  $d_f$ .
- 8) The specimen shall then be allowed to reach equilibrium for 24 hours. The recommended reading time schedule is 0.1, 0.25, 0.5, 1, 2, 4, 8, 15, and 30 min, and 1, 2, 4, 8, and 24h. It is recommended to take reading at the end of the pressure increment.
- 9) To reduce the risk of swelling during disassembly, set the load again to the seating load, 5 kPa. Once the sample has reached equilibrium, remove the equipment, excess water, and quickly measure the mass of the sample. Subtract the tare mass of the ring to calculate the wet sampled mass,  $M_t$ . Determine the water content of the sample.

### Theoretical Fundament

Calculate the dry mass the sample,  $M_d$ :

$$M_d = \frac{M_t}{1 + w}$$

Where:

$M_t$  = moist mass of the soil after the test

$w$  = water content of the sample after the test

Calculate the initial and final water content, in percent, as follows:

Water contents :

$$w_0 = \frac{M_{t0} - M_d}{M_d} \times 100$$

$$w_f = \frac{M_t - M_d}{M_d} \times 100$$

Where:

$M_{t0}$  = moist mass of specimen before the test, g.

Estimate the initial dry density of the sample:

$$\rho_d = \frac{M_d}{V_0}$$

Where:

$\rho_d$  = dry density of specimen, g/cm<sup>3</sup>.

$V_0$  = initial volume of specimen, cm<sup>3</sup>.

Let us calculate the volume of the solids:

$$V_s = \frac{M_d}{G_w}$$

Where:

$G$  = specific gravity of the solids.

$P_w$  = density of water, 1 g/cm<sup>3</sup>.

The cross-sectional area of the specimen is constant throughout the test, we can the term “equivalent height of solids,” defined as follows:

$$H_s = \frac{V_s}{A}$$

Another property of the sample that we will be using is the void ratio. We can now estimate the void ratio at the beginning and at the end of the test, respectively:

$$e_c = \frac{H_0 - H_s}{H_s}$$

$$e_f = \frac{H_f - H_s}{H_s}$$

Where:

$H_0$  and  $H_f$  represent the height of the soil at the beginning of the tests and at the end, cm.

The dry unit weight density can also be estimated with the value of the dry density, kN/m<sup>3</sup>:

$$\gamma_d = 9.8 \times \rho_d$$

- We have to proceed to tabulate a table with the change in deformation,  $df$ .
- Calculate the change in height,  $\Delta H = d - d_0$ .
- Calculate the void ratio for each change,  $e = e_0 - (\Delta H / H_s)$
- Calculate the vertical strain in percent,  $\epsilon = (\Delta H / H_0) * 100$
- Calculate the vertical stress:  $\sigma_v = P/A$ ;  $P$  = applied load in N and  $\sigma_v$  = vertical stress kPa

## Practice 1 - Load Deformation Properties:

Once these values have been obtained, proceed to **plot the deformation results** (void ratio or strain) vs effective stress. From this plot, estimate the pre-consolidation pressure using this method:

Point B – Estimate the point of max curvature on the curve

Point C – Draw a tangent line of the consolidation curvature.

Point D – Draw a horizontal line through the point extended towards increasing values on the abscissa.

Point E – Bisect line between line C and D.

Point F – Draw an extension tangent line from the “straight portion” of the curve (Low strain and high stress) up to the bisecting line.

Point G – The point where these lines intersect, is the estimated pre-consolidation pressure.

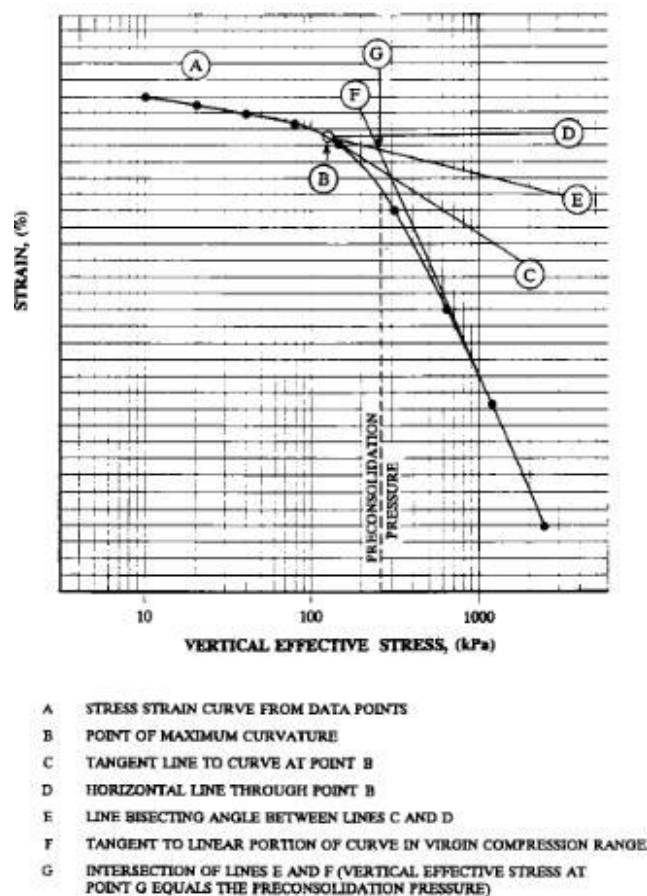


Figure 2. Plot of Vertical Stress Vs Strain to get Pre-Consolidation Pressure. Casagrande Method. From ASTM D2435-04.

## Practice 2 - Time-Deformation Properties:

The **coefficient of consolidation**,  $C_v$  (length/time), is the rate at which the specimen undergoes consolidation when subjected to an increase of pressure.

The formula to calculate this value is:

$$c_v = \frac{T H_{D5}^2}{t}$$

Where:

$T$  = it is a dimensionless time factor. If using the log method, use  $T=T_{50}=0.197$ . If using the SQRT method,  $T=T_{90}=0.848$ .

$t$  = is the time corresponding to the particular degree of consolidation. Method 1 use  $t=t_{50}$  and for method 2, use  $t=t_{90}$ , s or min.

$H_{D50}$  = Length of the drainage at 50%. For a double-drained case, the total thickness is half the specimen of the height. For one sided drainage case, use the full specimen height.

There are two methods to calculate  $C_v$ : the log time and the SQRT of the time.

For the log method, plot the deformation readings,  $d$ , vs the log of time in minutes for all load increments.

Point C – Draw a straight line through the points representing the final readings which exhibit a straight line trend and constant slope

Point D – Draw a second straight line tangent to the steepest part of the deformation-log time curve.

Point E – The intersection represents the deformation,  $d_{100}$ , and time,  $t_{100}$ , corresponding to 100% primary consolidation.

Then, find the deformation representing 0 % primary consolidation by selecting any two points that have a time ratio of 1 to 4. The deformation at the larger of the two times should be greater than 1/4, but less than 1/2 of the total deformation for the load increment. The deformation corresponding to 0 % primary consolidation is equal to the deformation at the smaller time, less the difference in deformation for the two selected times.

The deformation,  $d_{50}$ , corresponding to 50 % primary consolidation is equal to the average of the deformations corresponding to the 0 and 100 % deformations. The time,  $t_{50}$ , required for 50 % consolidation may be found graphically from the deformation-log time curve by observing the time that corresponds to 50 % of the primary consolidation on the curve.

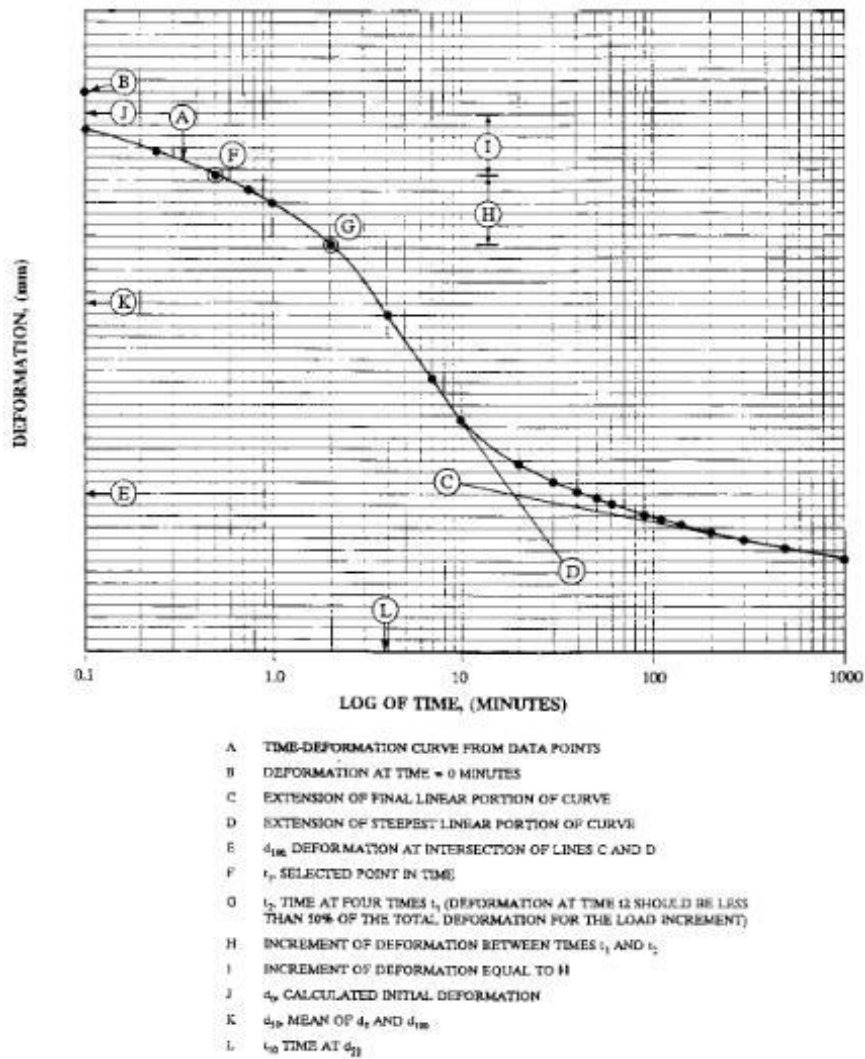


Figure 3. Plot of Deformation vs Log of Time. From ASTM D2435-04.

The other method, the SQRT method, proceed to plot the deformation versus the SQRT of the time un minutes.

First draw a straight line through the points representing the initial readings that show a straight line trend. Extrapolate the line back to  $t = 0$  and obtain the deformation ordinate representing 0 % primary consolidation.

Follow by drawing a second straight line through the 0% ordinate so that the abscissa of this line is 1.15 times the abscissa of the first straight line through the data. The intersection of this second line with the deformation-square root of time curve is the deformation,  $d_{90}$ , and time,  $t_{90}$ , corresponding to 90% primary consolidation.

The deformation,  $d_{50}$ , corresponding to 50% consolidation is equal to the deformation at 5/9 of the difference between 0 and 90 % consolidation.

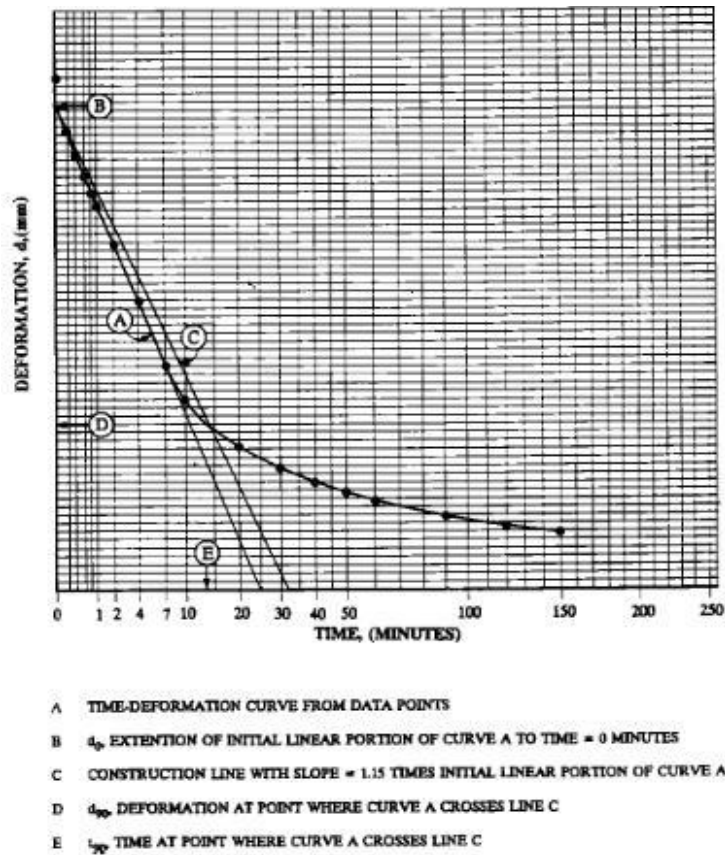


Figure 4. Time-Deformation Curve from Square Root of Time. *ASTM D2435-04*.



## Test Sheets

$M_{tf} =$		g	moist mass of the soil after the test
$w =$		%	water content of the sample after the test
$M_d =$		g	dry mass sample
$M_{t0} =$		g	moist mass of specimen before the test
$w_0 =$		%	initial water content
$w_f =$		%	final water content
$V_0 =$		cm <sup>3</sup>	initial volume of specimen
$\rho_d =$		g/cm <sup>3</sup>	dry density of specimen
$G =$		-	specific gravity
$\rho_w =$	1	g/cm <sup>3</sup>	density of water
$V_s =$		cm <sup>3</sup>	volume of solids
$A =$		cm <sup>2</sup>	area of the specimen
$H_s =$		cm	equivalent height of solids
$e_0 =$		-	initial void ratio
$e_f =$			final void ratio
$\gamma_d =$		kN/m <sup>3</sup>	dry unit weight

Dial Gauge Readings (mm)														
Time (min)	Applied Pressure (kPa)							UnLoading			Re-Loading			
	5	12	25	50	100	200	400	800	-400	-100	-50	100	200	400
0.1														
0.25														
0.5														
1														
2														
4														
8														
15														
30														
60														
120														
240														
480														
720														
1440														

H <sub>0</sub> =		mm			
H <sub>s</sub> =		mm			
Load Increments kPa	df	$\sum \Delta H$	H	e	$\epsilon$
	Readings		(H <sub>0</sub> - $\Delta H$ )	(H-H <sub>s</sub> )/H <sub>s</sub>	$\sum \Delta H/H_0$
	(mm)	(mm)	(mm)	-	(%)
Initial					
5					
12					
25					
50					
100					
200					
400					
800					
400					
100					
50					
100					
200					
400					

**Guide/Questions**

- 1) What problems did you encounter during the test?
- 2) What value did you get from the pre-consolidation curve?
- 3) Why is this number important?
- 4) Graph and analyze the other plot if you did not: void ratio and strain vs effective stress.
- 5) How does your results compare to the other groups?
- 6) Why is there a change in volume?
- 7) Why is consolidation important?
- 8) What is difference between compaction and consolidation?

## Laboratory No. 7: Unconfined Compressive Strength of Cohesive Soil (ASTM D2166-00)

### Objective

With this test, we will be able to determine the unconfined compressive strength of **fine grained** soils by means of applying an axial load.

### Scope of Experiment

The main purpose of the test is to estimate the unconfined compressive strength of a sample which will then give us the cohesion of the soil.

### Equipment Specifications:

- Compression Device capable of measuring the compressive stress
- Deformation Gauges
- Sample Extruder
- Balances
- Mixing Tools
- Timer

### Theoretical Fundament

During this test, the axial strain will be recorded as well as the axial stress applied.

Calculate the axial strain,  $\epsilon$ , for each load:

$$\epsilon_1 = \frac{\Delta L}{L_0}$$

Where:

$\Delta L$  = The change in length of the specimen read from the gauge, mm (in).

$L_0$  = initial length of the sample water content of the sample after the test

Then proceed to calculate the average cross-sectional area,  $A$ , of any load as follows:

$$A = \frac{A_0}{(1 - \epsilon_1)}$$

Where:

$A_0$  = initial average cross-sectional area of the sample, mm<sup>2</sup> (in<sup>2</sup>).

$L_0$  = initial length of the sample water content of the sample after the test

The next step is to calculate the compressive stress,  $\sigma_c$ , for each load:

$$\sigma_c = \frac{P}{A}$$

Where:

P= applied load, kPa (ton/ft<sup>2</sup>).

The undrained shear strength (cohesion, s or c) of the sample is half of the unconfined compressive strength:

$$s = \frac{q_u}{2}$$

### Preparation of Test Sample

The size of the sample should have a minimum diameter of 30mm (1.3 in). The largest particle size in the sample should be smaller than one tenth of the specimen diameter. The ratio between the height and diameter should be between 2 and 2.5. The height and diameter should be averaged by making three measurements at different locations.

Once the sample is extruded, proceed to removed and trim the uneven parts.



Figure 1. Compression Device.

## **Experimental Procedure**

1. Place the sample on the center of the loading device. Adjust the loading device just to touch the sample. Zero out all indicators and set the loading device to applied a load that produce an axial strain at a rate of  $\frac{1}{2}$  to 2%/min. The failure of the sample should occur no later than 15 min after the test start.
2. The test ends when a failure on the sample occurs or 15% of strain has occurred. A noticeable decrease on the load will occur. Record the value of the load applied and the change in strain.
3. Once completed, obtain the water content of the sample or from enough trimmings obtain previously.
4. Proceed to plot the relationship between the compressive stress and the axial strain and select the maximum value for the compressive strength. The undrained compressive strength can also be calculated.
5. Take a photo of the failure of the sample or make a drawing of it.



**Guide/Questions**

- 1) What problems did you encounter during the test?
- 2) Plot the graph of axial stress vs unconfined strength.
- 3) What value did you get from the compressive strength?
- 4) What value did you get from the undrained strength?
- 5) What does this number say about the soil?
- 6) Present the failure plane of the sample or photograph.



## Laboratory No. 8: Direct Shear Test Under Consolidated Drained Conditions (ASTM D3080-98)

### Objective

This test will permit us to calculate the consolidated drained shear strength of a sample in a direct shear box which will help us to estimate the cohesion and the friction angle of the sample.

### Scope of Experiment

The maximum shear strength,  $\tau$ , of a soil is the stress that the soil can resist without failing under a normal stress. The strength of the soil is measured by estimating the cohesion and the friction angle.

$$\tau = c + \sigma \tan \Phi$$

Where  $c$  is the cohesion,  $\sigma$  is the normal stress and  $\Phi$  is the friction angle.

This test is formed of two different phases. First, the sample has to be consolidated and the second part is to shear the sample. The sample will be sheared at a controlled strain rate. Generally, three or more samples are tested each at a different normal load.

This test is effective to determine, in a rapid manner, the consolidated shear strength of a soil. This test can be used for any type of soil. The sample on this test has to be saturated.

### Equipment Specifications:

- Shear Device where the sample will be held.
- Shear Box
- Porous Stones for drainage
- Loading Device
- Shear Force Measuring Device
- Balance
- Mixing Tools



Figure 1. Direct Shear Test Machine

### Theoretical Fundament

The shearing stress of sample will tell a lot of information about sample but mainly its strength. The strength of a soil sample depends on frictional capability of the individual particles and the cohesion with it's the force that makes the particles to stick together.

An appropriate shear rate has to be selected in order to make all the excess pore ware pressure to exit the sample. This is achieved by estimating the minimum time required from the beginning of the test to failure.

The total estimated time,  $t_f$ , is calculated with the following equation:

$$t_f = 50 * t_5$$

Where:

$t_5$ = This is the required time to achieve 50% consolidation. This is calculated as follows:

$$t_5 = \frac{t_9}{4.28}$$

Where:

$t_9$ = This is the required time to achieve 90% consolidation.

The next step is to estimate the displacement rate, mm/min or in/min,  $d_r$ :

$$d_r = \frac{d_f}{t_f}$$

Where:

$d_f$ = It is the estimated horizontal displacement at the moment of failure, mm or inch. Recommended values are between 5 to 12 mm (0.2 to 0.5 in).

The shear stress is estimated by using the following equation:

$$\tau = \frac{F}{A}$$

Where:

$\tau$ = This is the shear stress, kPa or psi.

F= shear force, N or lbf.

A= initial area of the sample, mm<sup>2</sup> o in<sup>2</sup>.

### **Preparation of Test Sample**

For the test, there should be enough material to run at least three tests. Write down the wet mass of the sample in order to estimate water content and unit weight values.

The size of the sample should have a minimum diameter of 50 mm (2.0 in) and not less than 10 times the largest particle size. The minimum thickness should be 12 mm (0.5 inch). The ratio between the height and diameter should be 2 to 1. Write down all the dimensions of the specimen.

The sample has to be prepared in a controlled temperature space to avoid changes in water contents. Once the sample is extruded, proceed to removed and trim the uneven parts.

### **Experimental Procedure**

1. Take the shear box and place all parts at the correct places and the sample. Place one porous stone on the bottom of the sample to allow the free travel of water.
2. Place and adjust all knots and tight them. Make sure to not over tighten to avoid exerting pressure on the sample.
3. Place all measuring devices at their respect places and make sure that they are zero out. After that, place the top porous stone and top plate on the sample.
4. Align the system use to apply the normal force. Apply a small normal load to check that the system is functioning well and parts are seated. Record this value. The approximate value to apply should be near 7 kPa (1 psi).
5. Fill the shear box with water. Place the vertical displacement measurement device and write down the initial reading for the vertical measurement device and for the horizontal displacement.

6. Compute and record the normal force required to reach the desired normal stress. This is done by adding mass to the force system.
7. Once the force is calculated, proceed to apply the load. Start recording the normal deformation of the sample. Allow the sample to consolidate for 24 hours.
8. Once the consolidation is completed, remove the vertical screws, and allow a gap of approximately 0.64 mm (0.025 in) between the two shear box section.
9. Proceed to shear the specimen.
10. Use the equation on the theoretical section to estimate the displacement rate.
11. Write the initial time, vertical and horizontal displacement and the normal and shear forces.
12. Once all data is collected, start the shear apparatus and start taking the displacement and forces readings. It is recommended to take reading at displacement intervals equal to 2% of the specimen diameter or width. More readings are recommended to take to help identify the peak values of the curves.
13. Once failure has occurred, this is when the shear force readings stop, stop the device. The displacement may range between 10% to 20% of the specimen diameter or length.
14. Remove the normal forces from the loading machine. Separate the shear box in a sliding motion to not disturbed the sample. DO NOT pull the part perpendicularity.
15. Take a photo of the failure of the sample or make a drawing of it and describe the surface.
16. Take the sample and calculate the water content.
17. Proceed with the calculation of the shear stress.



**Guide/Questions**

- 1) Plot of shear stress vs percent lateral deformation.
- 2) Plot the graph of shear strength vs normal stress for all samples and estimate the cohesion and friction angle of the sample.
- 3) What is the importance of the shear strength value on the soil?
- 4) Does your result correspond to the soil type sampled? What does this number say about the soil?
- 5) What are the advantages and disadvantages of this test?
- 6) Present the failure plane of the sample or photograph.

## Laboratory No. 9: Standard/Modified Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (ASTM D698-00 ASTM D1557-00)

### Objective

With this test, we will be able to determine the relationship between water content and dry unit weight of soils by means of compaction and removal of air voids.

### Scope of Experiment

There are occasions where the soil on the surface is not suitable for supporting the structure that was designed to be built. If we are talking about a granular fill, it might be in a loose state. In most of the cases, this weak layer has to be removed and replaced by a selected and tested material which is later compacted to optimum values.

Before placing any fill, the soil has to be tested to obtain these optimum values. The Proctor tests are applied to the soil to obtain the values.

Small amounts of water are added to the soil in order to increase its unit weight. The water works as a lubricant between the soil particles that help them to make a better arrangement between them. However, if a lot of water is added, then the water will push the particles and reduce the unit weight.

The test consists of placing soil in a mold at a selected molding water content. This material is placed in three different lifts or five (for modified). Each layer is compacted by 25 or 56 blows of the hammer dropped from a distance of 305mm (12") or 457mm (18") for modified. The rammer will cause a compactive effort of 600 kN-m/m<sup>3</sup> (12,400 ft-lbf/ft<sup>3</sup>) for the standard and 2,700 kN-m/m<sup>3</sup> (56,000 ft-lbf/ft<sup>3</sup>).

Then, the unit weight is calculated. The same process is later repeated at different water contents in order to form the relationship curve between water content and dry density.

### Equipment Specifications:

- Molds
- Hammer
- Balances
- Drying Oven
- Straight/Steel/Ruler larger than 10"
- Sieves ¾ 3/8 and #4
- Mixing Tools



**Figure 1. Compaction Test Equipment. Controls Group.**

### **Theoretical Fundament**

Proceed to calculate the molding water content, the moist and dry density, and dry unit weight of all specimen processed.

The molding water content shall be calculated according to the ASTM D2216 – Water Content.

Proceed to calculate the moist density:

$$\rho_m = K * \frac{M_t - M_m}{V}$$

Where:

$P_m$  = moist density of compacted sample to four significant figures, g/cm<sup>3</sup> or kg/m<sup>3</sup>.

$M_t$  = mass of moist soil in mold and mold, g.

$M_{md}$  = mass of compaction mold, cm<sup>3</sup> or m<sup>3</sup>.

$V$  = volume of compaction mold, cm<sup>3</sup> or m<sup>3</sup>.

$K$  = Conversion factor for density and volume unit.

Use 1 g/cm<sup>3</sup> and volume in cm<sup>3</sup>

Use 1000 for g/cm<sup>3</sup> and volume in m<sup>3</sup>

Use 0.001 for kg/cm<sup>3</sup> and volume in m<sup>3</sup>

Use 1000 for kg/m<sup>3</sup> and volume in cm<sup>3</sup>

Let's now calculate the dry density:



$$\rho_d = \frac{\rho_m}{1 + \frac{W}{100}}$$

$\rho_d$  = dry density of compaction samples, g/cm<sup>3</sup> or kg/m<sup>3</sup>

W = water content of compaction sample

Now proceed to determine the dry unit weight:

$$\gamma_d = K * \rho_d \text{ in } \frac{\text{lb}}{\text{ft}^3} \text{ or } \frac{\text{kN}}{\text{m}^3}$$

$\gamma_d$  = dry unit weight, in lbf/ft<sup>3</sup> or kN/m<sup>3</sup>

The next step is to draw the compaction curve. This curve is composed of the compaction points previously calculated for the unit weight and water contents.

### Test Procedure

- 1) Check all of your equipment and make sure that the set is complete.
- 2) Do not use material that has been previously compacted. This material might yield off results.
- 3) Take about 20kg of sample and process it through the  $\frac{3}{4}$  sieve. We will work with the material passing this sieve.
- 4) First, we will estimate a water content of 4%. Using 2000 g, and assuming a 4%, we need to add 80g of water.
- 5) Once the water is added, mix the material thoroughly.
- 6) Determine and record the mass of the mold with the base (not with the collar). Also record the volume of the mold by measuring the diameter at three different distances as well as the height.

- 7) Now, place some material on the mold to up to  $\frac{1}{5}$  the height of the mold. Place the mold on the concrete floor and proceed to compact the soil with the rammer by applying 25 **evenly distributed** blows.
- 8) Place the second layer of soil and proceed to compact. Place soil close to the end of the mold.
- 9) Add the third and final up to passing the collar about 1.5" and proceed to compact.
- 10) Remove the top collar and remove the soil passing the mold with a straightedge.
- 11) Take the weight of the mold with the sample.
- 12) Now, take measure the mass of two empty containers for water content measurements. Take a sample from the top and one from the bottom.
- 13) Now, proceed to prepare four more samples with a higher water content. No more than 2% in increased is recommended.
- 14) Proceed to perform the test with the new samples.
- 15) Proceed to plot the mold water content and dry unit weight.

## Test Sheets – Proctor Test

MOLD

NUMBER		
DIAMETER		cm.
HEIGHT		cm.
VOLUMEN		cm <sup>3</sup> .
WEIGHT		gr.

Blows/Layer	
N° of Layer	

Test N°	Proctor Test				
THEORETHICAL MOISTURE CONTENT, %					
Test N°					
MOLD WEIGHT+SAMPLE, g					
MOLD WEIGHT, g					
MASS OF COMPACTED SOIL, g					
MOIST DENSITY, g/cm <sup>3</sup>					
MOLD NUMBER					
WET SAMPLE + CONTAINER MASS, g					
DRY SAMPLED + CONTAINER MASS, g					
WATER WEIGHT					
CONTAINER MASS, g					
DRY SAMPLE WEIGHT, g					
MOISTURE CONTENT, W%					
DRY DENSITY, g/cm <sup>3</sup>					

### Guide/Questions

- 1) Plot the compaction curve: dry density vs moisture content graph and estimate the optimum density and moisture content of the sample.
- 2) What source of mistake can happen during the test?
- 3) What are the main differences between the standard and modified proctor?
- 4) How can we use the results of this test?
- 5) How do large particles change the results?
- 6) How do your results compare to others?