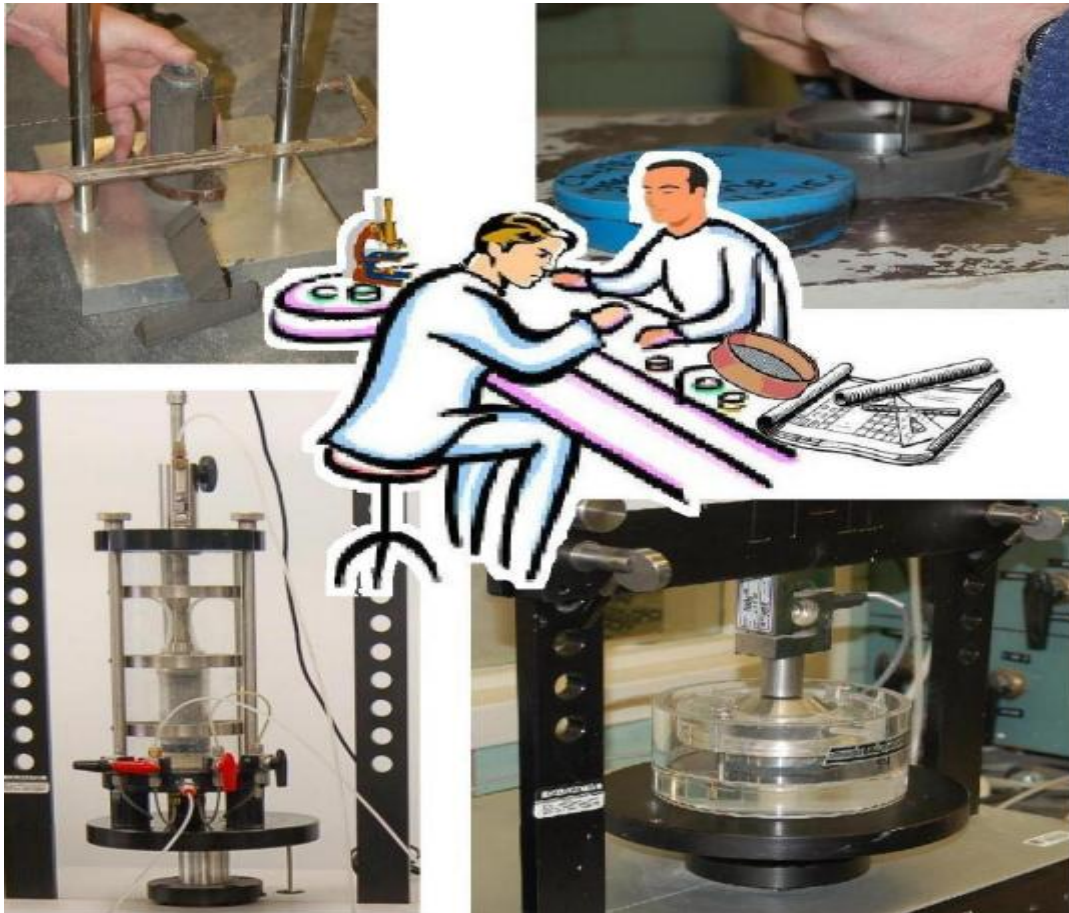




Komar University of Science and Technology (KUST)



Department of Civil Engineering
Laboratory Manual for Soil Mechanics

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Prepared By
Dr. Sabah Saadi Fayaed

PREFACE AND ACKNOWLEDGEMENT

The study of laboratory methods is a logical extension of all analytical subjects. The use of accurate and even elaborate methods of testing requires no justification in a research laboratory. The extent to which these methods should be adopted in routine testing depends largely on whether or not they reduce the margin of uncertainty in design sufficiently to justify their cost. The answer in many cases, particularly in soils and foundation engineering, is self-evident. The instruction volume is intended to serve as a helpful guide to civil engineering students performing experiments in a soils laboratory. A standard format of presentation, reference to IS codes, brief coverage of theory etc. are features which hopefully, would be welcomed. While the equipment may be made in a variety of forms the procedures outlined should still be broadly applicable in most cases. Short review questions to be answered by the student along with his report have been added to stimulate thinking and the instructor may add his own fund of knowledge.

This manual was completed with support of KUST administration, faculty, and staff members. Therefore, I am thankful for their efforts.

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INTRODUCTION

In this course we are seeking to understand soil properties through laboratory experiments. Usually the class is divided into groups. Each group will do a different experiment every week until all the required experiments are completed. Each instructor will indicate the experiments to be conducted and advise on the nature of the lab report and time of submission. However, a typical format for a lab report is included below. It is important that all the information necessary to complete the lab report is obtained before students leave the lab.

2. LAB REPORT REQUIREMENTS

2.1 GENERAL

The following suggestions should be helpful.

- Avoid personal pronouns.
- If you quote from a text, identify the text.
- View this report as though you were in industry and writing for your boss.

Hence sloppiness will not be accepted.

2.2 FORMAT

2.2.1 TITLE

There should be a Title Page with title, authors, group number, date, for whom report was written.

2.2.2 ABSTRACT

It should be approximately half a typed page in length. An abstract should tell: What was done briefly how experiment was conducted to satisfy objectives and what the major conclusions or representative results are.

2.2.3 TABLE OF CONTENTS

Must have page numbers of different sections in the report..

2.2.4 INTRODUCTION

- A. Establish general interest in the subject.
- B. Establish specific interest and justification for conducting this investigation leading to a statement of the specific objective(s).
- C. Introduce the report itself. That is, tell the reader how the report is organized and what to expect.

2.2.5 THEORY

- A. Present theoretical basis for the experiment or investigation.
- B. Present equations used with clear indication of which variables were measured and which is calculated.

2.2.6 EXPERIMENTAL APPARATUS

- A. Diagram of the test set-up illustrating the general relationships among the various components of the system and the locations at which the measurements were taken.
- B. Instrumentation (measurement systems) that was used should be stated and related to the measurement locations on the diagram (with a statement of the uncertainty associated with each measurement system).

2.2.7 RESULTS

Introduce results; that is, explain what is being presented. Don't just include the plots, charts, etc., without any explanation. Tables and figures must be self-contained. They must be numbered and with a caption. Thus the reader can tell what a table or figure means without having to look through the text.

2.2.8 DISCUSSION OF RESULTS

- A. Interpret and explain results
- B. Point out most important results, even if the results as presented seem obvious *to you*, you want *to* be sure your reader notices the most important features and trends, etc. State what you think the results show, prove, demonstrate or illustrate.

2.2.9 CONCLUSION

Summarize your findings; that is, itemize the most important things that you found out, measured, observed. Anything that could be preceded by "It was found that" or "It was discovered that" is a finding, not a conclusion. Remember conclusions are generalizations based on results of a specific investigation.

2.2.10 BIBLIOGRAPHY

Number your references in order.

2.2.11 APPENDICES

Extensive pages of data can go in Appendix.

3 SAFETY

1. Follow all safety instructions given in the class and in the laboratories.
2. Charpy machine can be lethal. Never leave the hammer in the up position until ready to break a specimen.
3. Furnaces. Be careful in touching and handling specimens. Use tongs for placing specimens in the furnace and removing them. Most specimens can be quenched in water after removal from furnace.
4. Use safety eye shield when grinding specimens.
5. Do not remove specimens from abrasive cut-off machine until the wheel has stopped.
6. NO eating or drinking in the lab.

3.1 SAFETY IN THE LABORATORY

All students must read and understand the information in this document with regard to laboratory safety and emergency procedures prior to the first laboratory session. **Your personal laboratory safety depends mostly on YOU.** Effort has been made to address situations that may pose a hazard in the lab but the information and instructions provided cannot be considered all-inclusive. Students must adhere to written and verbal safety instructions

throughout the academic term. Since additional instructions may be given at the beginning of laboratory sessions, it is important that all students arrive at each session on time. With good judgment, the chance of an accident in this course is very small. Nevertheless, research and teaching workplaces (labs, shops, etc.) are full of potential hazards that can cause serious injury and or damage to the equipment. Working alone and unsupervised in laboratories is forbidden if you are working with hazardous substances or equipment. With prior approval, at least two people should be present so that one can shut down equipment and call for help in the event of an emergency. Safety training and/or information should be provided by a faculty member, teaching assistant, lab safety contact, or staff member at the beginning of a new assignment or when a new hazard is introduced into the workplace.

3.2 EMERGENCY RESPONSE

1. It is your responsibility to read safety and fire alarm posters and follow the instructions during an emergency
2. Know the location of the fire extinguisher, eye wash, and safety shower in your lab and know how to use them.
3. Notify your instructor immediately after any injury, fire or explosion, or spill.
4. Know the building evacuation procedures.

3.2.1 Common Sense

Good common sense is needed for safety in a laboratory. It is expected that each student will work in a responsible manner and exercise good judgment and common sense. If at any time you are not sure how to handle a particular situation, ask your Teaching Assistant or Instructor for advice. **DO NOT TOUCH ANYTHING WITH WHICH YOU ARE NOT COMPLETELY FAMILIAR!!!** It is always better to ask questions than to risk harm to yourself or damage to the equipment.

3.3 PERSONAL AND GENERAL LABORATORY SAFETY

1. Never eat, drink, or smoke while working in the laboratory.
2. Read labels carefully.
3. Do not use any equipment unless you are trained and approved as a user by your supervisor.
4. Wear safety glasses or face shields when working with hazardous materials and/or equipment.
5. Wear gloves when using any hazardous or toxic agent.
6. Clothing: When handling dangerous substances, wear gloves, laboratory coats, and safety shield or glasses. Shorts and sandals should not be worn in the lab at any time. Shoes are required when working in the machine shops.
7. If you have long hair or loose clothes, make sure it is tied back or confined.
8. Keep the work area clear of all materials except those needed for your work. Coats should be hung in the hall or placed in a locker. Extra books, purses, etc. should be kept away from equipment, that requires air flow or ventilation to prevent overheating.
9. Disposal - Students are responsible for the proper disposal of used material if any in appropriate containers.
10. Equipment Failure - If a piece of equipment fails while being used, report it immediately to your lab assistant or tutor. Never try to fix the problem yourself because you could harm yourself and others.
11. If leaving a lab unattended, turn off all ignition sources and lock the doors.
12. Never pipette anything by mouth.
13. Clean up your work area before leaving.
14. Wash hands before leaving the lab and before eating.

3.4 ELECTRICAL SAFETY

1. Obtain permission before operating any high voltage equipment.
2. Maintain an unobstructed access to all electrical panels.
3. Wiring or other electrical modifications must be referred to the Electronics Shop or the Building Coordinator.
4. Avoid using extension cords whenever possible. If you must use one, obtain a heavy-duty one that is electrically grounded, with its own fuse, and install it safely. Extension cords should not go under doors, across aisles, be hung from the ceiling, or plugged into other extension cords.
5. Never, ever modify, attach or otherwise change any high voltage equipment.
6. Always make sure all capacitors are discharged (using a grounded cable with an insulating handle) before touching high voltage leads or the "inside" of any equipment even after it has been turned off. Capacitors can hold charge for many hours after the equipment has been turned off.
7. When you are adjusting any high voltage equipment or a laser which is powered with a high voltage supply, **USE ONLY ONE HAND**. Your other hand is best placed in a pocket or behind your back. This procedure eliminates the possibility of an accident where high voltage current flows up one arm, through your chest, and down the other arm.

3.5 MECHANICAL SAFETY

1. When using compressed air, use only approved nozzles and never direct the air towards any person.
2. Guards on machinery must be in place during operation.
3. Exercise care when working with or near hydraulically- or pneumatically driven equipment. Sudden or unexpected motion can inflict serious injury.

3.6 CHEMICAL SAFETY

1. Treat every chemical as if it were hazardous.
2. Make sure all chemicals are clearly and currently labeled with the substance name, concentration, date, and name of the individual responsible.
3. Never return chemicals to reagent bottles. (Try for the correct amount and share any excess.)
4. Comply with fire regulations concerning storage quantities, types of approved containers and cabinets, proper labeling, etc. If uncertain about regulations, contact the building coordinator.
5. Use volatile and flammable compounds only in a fume hood. Procedures that produce aerosols should be performed in a hood to prevent inhalation of hazardous material.
6. Never allow a solvent to come in contact with your skin. Always use gloves.
7. Never "smell" a solvent!! Read the label on the solvent bottle to identify its contents.
8. Dispose of waste and broken glassware in proper containers.
9. Clean up spills immediately.
10. Do not store food in laboratories.

3.7 LASERS SAFETY

1. NEVER, EVER LOOK INTO ANY LASER BEAM, no matter how low power or "eye safe" you may think it is.
2. Always wear safety goggles if instructed by your Instructor or Teaching Assistant.
3. The most common injury using lasers is an eye injury resulting from scattered laser light reflected off of mountings, sides of mirrors or from the "shiny" surface of an optical table. The best way to avoid these injuries is to always wear your goggles and NEVER LOWER YOUR HEAD TO THE LEVEL OF THE LASER BEAM! The laser beam should always be at or below chest level.

4. Always use "beam stops" to intercept laser beams. Never allow them to propagate into the laboratory. Never walk through a laser beam. Some laser beams of only a few watts can burn a hole through a shirt in only a few seconds.
5. If you suspect that you have suffered an eye injury, notify your instructor or teaching assistant IMMEDIATELY! Your ability to recover from an eye injury decreases the longer you wait for treatment.

3.8 ADDITIONAL SAFETY GUIDELINES

- ❖ Never do unauthorized experiments.
- ❖ Never work alone in laboratory.
- ❖ Keep your lab space clean and organized.
- ❖ Do not leave an on-going experiment unattended.
- ❖ Always inform your instructor if you break a thermometer. Do not clean mercury yourself!!
- ❖ Never taste anything. Never pipette by mouth; use a bulb.
- ❖ Never use open flames in laboratory unless instructed by TA.
- ❖ Check your glassware for cracks and chips each time you use it. Cracks could cause the glassware to fail during use and cause serious injury to you or lab mates.
- ❖ Maintain unobstructed access to all exits, fire extinguishers, electrical panels, emergency showers, and eye washes.
- ❖ Do not use corridors for storage or work areas.
- ❖ Do not store heavy items above table height. Any overhead storage of supplies on top of cabinets should be limited to lightweight items only. Also, remember that a 36" diameter area around all fire sprinkler heads must be kept clear at all times.
- ❖ Areas containing lasers, biohazards, radioisotopes, and carcinogens should be posted accordingly. However, do not post areas unnecessarily and be sure that the labels are removed when the hazards are no longer present.

- ❖ Be careful when lifting heavy objects. Only shop staff may operate forklifts or cranes.
- ❖ Clean your lab bench and equipment, and lock the door before you leave the laboratory.

4. Laboratory Experiments

4.1 Experiment No.1: Water Content Determination

Purpose:

This test is performed to determine the water (moisture) content of soils. The water content is the ratio, expressed as a percentage, of the mass of “pore” or “free” water in a given mass of soil to the mass of the dry soil solids.

Standard Reference:

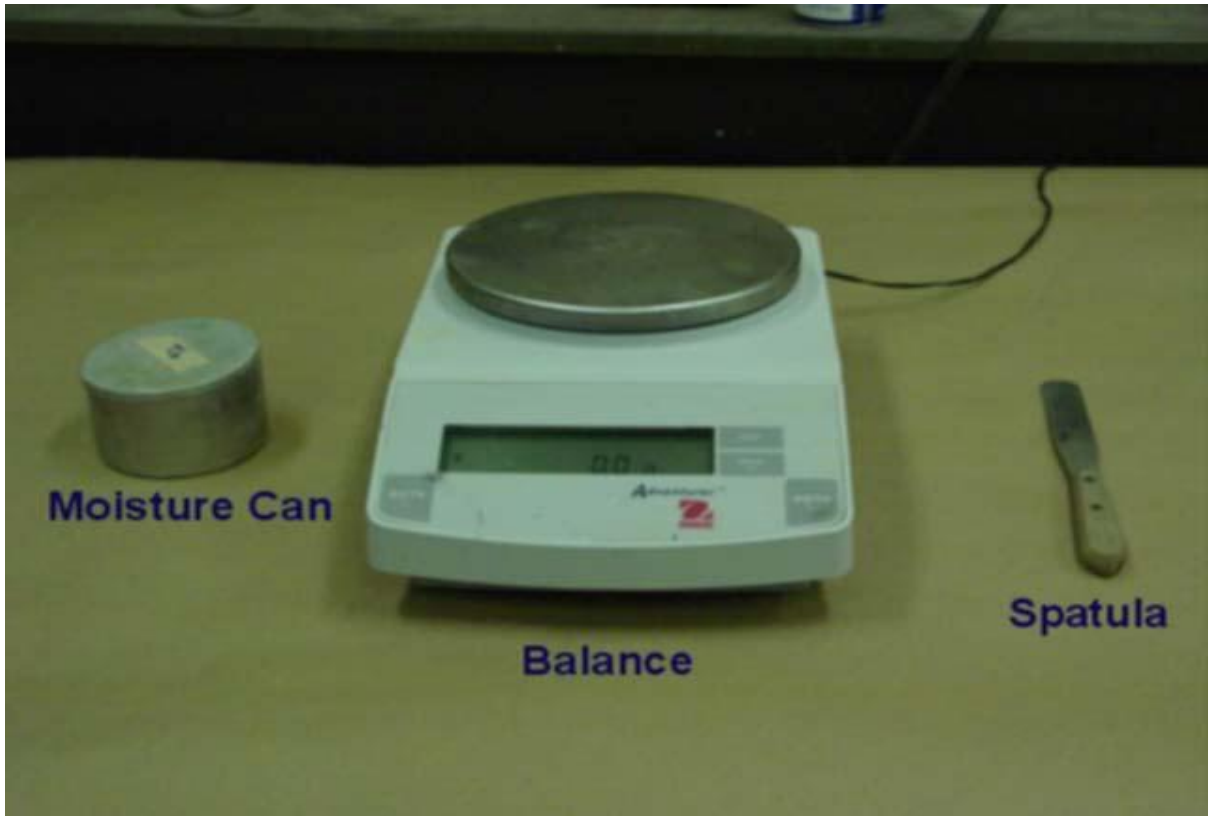
ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures.

Significance:

For many soils, the water content may be an extremely important index used for establishing the relationship between the way a soil behaves and its properties. The consistency of a fine-grained soil largely depends on its water content. The water content is also used in expressing the phase relationships of air, water, and solids in a given volume of soil.

Equipment:

Drying oven, Balance, Moisture can, Gloves, Spatula.



Test Procedure:

- (1) Record the moisture can and lid number. Determine and record the mass of an empty, clean, and dry moisture can with its lid (M_C)
- (2) Place the moist soil in the moisture can and secure the lid. Determine and record the mass of the moisture can (now containing the moist soil) with the lid (M_{CMS}).
- (3) Remove the lid and place the moisture can (containing the moist soil) in the drying oven that is set at 105 °C. Leave it in the oven overnight.
- (4) Remove the moisture can. Carefully but securely, replace the lid on the moisture can using gloves, and allow it to cool to room temperature. Determine and record the mass of the moisture can and lid (containing the dry soil) (M_{CDS}).
- (5) Empty the moisture can and clean the can and lid.

Data Analysis:

- (1) Determine the mass of soil solids.

$$M_S = M_{CDS} - M_{SC}$$

- (2) Determine the mass of pore water.

$$M_W = M_{CMS} - M_{CDS}$$

- (3) Determine the water content.

$$w = \frac{M_W}{M_S} \times 100$$

**WATER CONTENT DETERMINATION
DATA SHEET**

Specimen number	1	2
Moisture can and lid number	12	15
M_C = Mass of empty, clean can + lid (grams)	7.78	7.83
M_{CMS} = Mass of can, lid, and moist soil (grams)	16.39	13.43
M_{CDS} = Mass of can, lid, and dry soil (grams)	15.28	12.69
M_S = Mass of soil solids (grams)	7.5	4.86
M_W = Mass of pore water (grams)	1.11	0.74
w = Water content, w%	14.8	15.2

Example Calculation: $M_C = 7.78g$, $M_{CMS} = 16.39g$, $M_{CDS} = 15.28g$

$$M_S = 15.28 - 7.78 = 7.5g$$

$$M_W = 16.39 - 15.28 = 1.11g$$

$$w = \frac{1.11}{7.5} \times 100 = 14.8\%$$

4.2 Experiment No.2: Density (Unit Weight) Determination

Purpose:

This lab is performed to determine the in-place density of undisturbed soil obtained by pushing or drilling a thin-walled cylinder. The bulk density is the ratio of mass of moist soil to the volume of the soil sample, and the dry density is the ratio of the mass of the dry soil to the volume the soil sample.

Standard Reference:

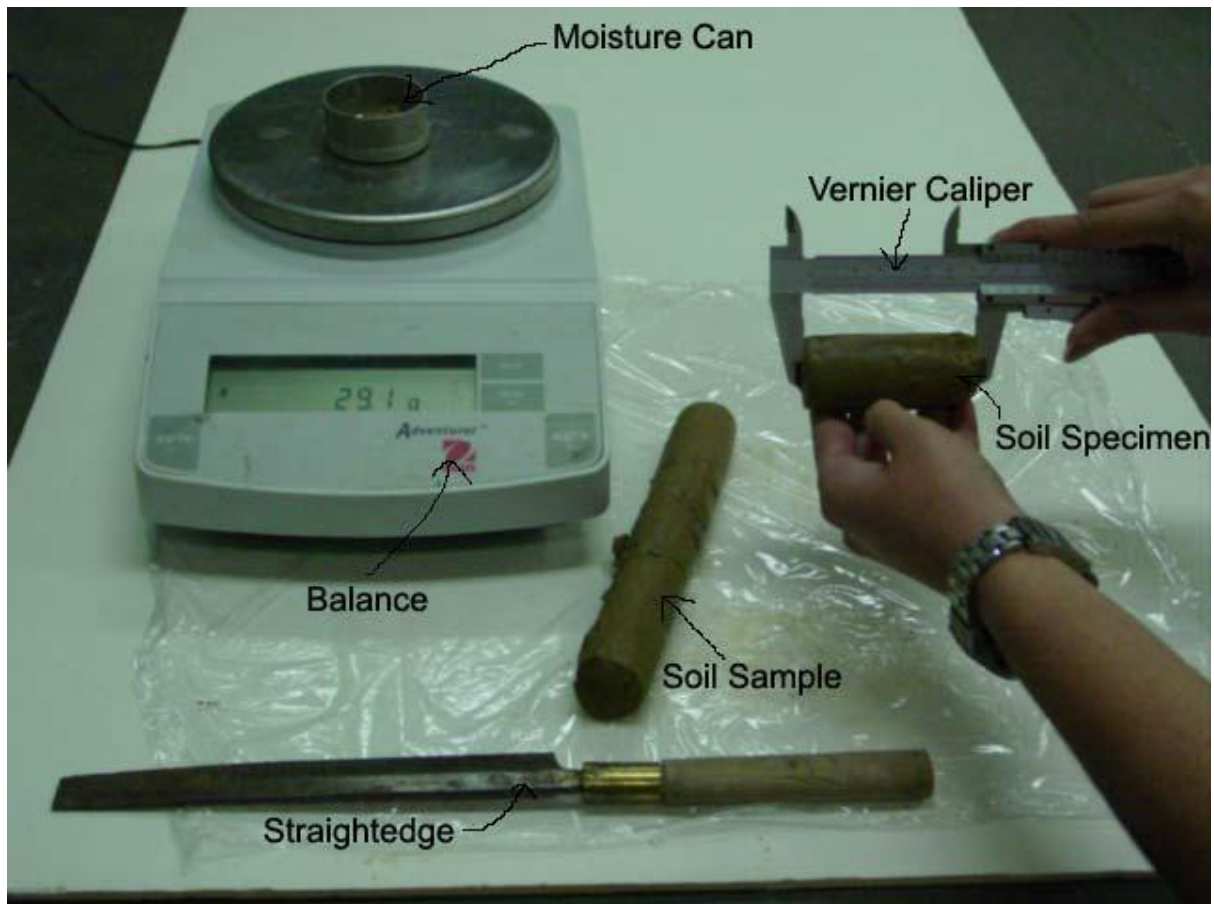
ASTM D 2937-00 – Standard Test for Density of Soil in Place by the Drive-Cylinder Method.

Significance:

This test is used to determine the in-place density of soils. This test can also be used to determine density of compacted soils used in the construction of structural fills, highway embankments, or earth dams. This method is not recommended for organic or friable soils.

Equipment:

Straightedge, Balance, Moisture can, Drying oven, Vernier caliper



Test Procedure:

- (1) Extrude the soil sample from the cylinder using the extruder.
 - (2) Cut a representative soil specimen from the extruded sample.
 - (3) Determine and record the length (L), diameter (D) and mass (M_t) of the soil specimen.
 - (4) Determine and record the moisture content of the soil (w).
- (See Experiment 1)

(Note: If the soil is sandy or loose, weigh the cylinder and soil sample together. Measure dimensions of the soil sample within the cylinder. Extrude and weigh the soil sample and determine moisture content)

Data Analysis:

(1) Determine the moisture content as in Experiment 1

(2) Determine the volume of the soil sample

$$V = \frac{\pi D^2 L}{4} \text{ cm}^3$$

(3) Calculate bulk density (ρ_t) of soil

$$\rho_t = \frac{M_t}{V} \frac{\text{g}}{\text{cm}^3}$$

or unit weight $\gamma_t = \rho_t g$

(4) Calculate dry density (ρ_d) of soil

$$\rho_d = \frac{\rho_t}{1+w} \frac{\text{g}}{\text{cm}^3}$$

or dry unit weight $\gamma_d = \rho_d g$

**DENSITY (UNIT WEIGHT) DETERMINATION
DATA SHEET**

Specimen number	1
Moisture can and lid number	15
M_C = Mass of empty, clean can + lid (grams)	7.83
M_{CMS} = Mass of can, lid, and moist soil (grams)	13.43
M_{CDS} = Mass of can, lid, and dry soil (grams)	12.69
M_S = Mass of soil solids (grams)	4.86
M_W = Mass of pore water (grams)	0.74
w = Water content, w%	15.2

Example calculations: $w=15.2\%$, $M_t=125.2g$, $L=7.26cm$, $D=3.41cm$

$$V = \frac{\pi(3.41)^2(7.26)}{4} = 66.28 \text{ cm}^3$$

$$\rho_t = \frac{125.20}{66.28} = 1.89 \frac{g}{\text{cm}^3} \text{ or } \gamma_t = 1.89 \times 62.4 = 118 \frac{\text{lb}}{\text{ft}^3}$$

$$\rho_d = \frac{1.89}{1 + \left(\frac{15.20}{100}\right)} = 1.64 \frac{g}{\text{cm}^3} \text{ or } \gamma_d = 1.64 \times 62.4 = 102.3 \frac{\text{lb}}{\text{ft}^3}$$

(Note: 62.4 is the conversion factor to convert density in g/cm^3 to unit weight in lb/ft^3)

4.3 Experiment No.3: Specific Gravity Determination

Purpose:

This lab is performed to determine the specific gravity of soil by using a pycnometer. Specific gravity is the ratio of the mass of unit volume of soil at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature.

Standard Reference:

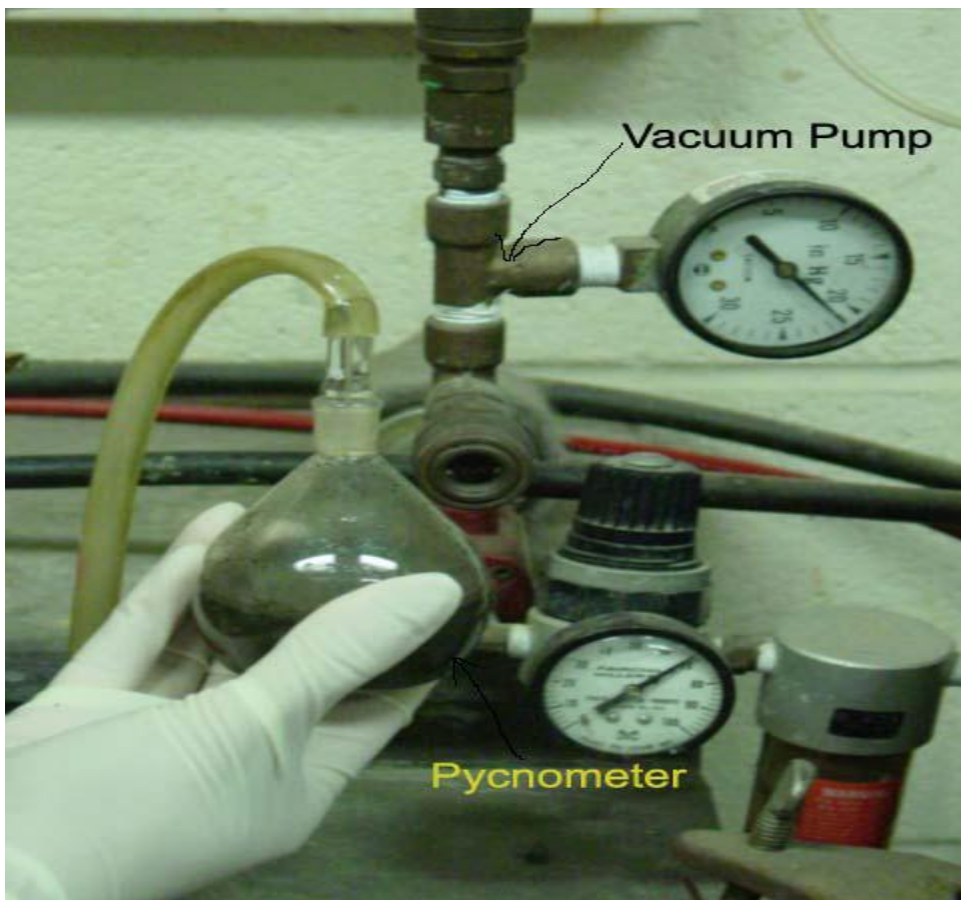
ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids by Water Pycnometer.

Significance:

The specific gravity of a soil is used in the phase relationship of air, water, and solids in a given volume of the soil.

Equipment:

Pycnometer, Balance, Vacuum pump, Funnel, Spoon.



Test Procedure:

- (1) Determine and record the weight of the empty clean and dry pycnometer, W_P .
- (2) Place 10g of a dry soil sample (passed through the sieve No. 10) in the pycnometer. Determine and record the weight of the pycnometer containing the dry soil, W_{PS} .
- (3) Add distilled water to fill about half to three-fourth of the pycnometer. Soak the sample for 10 minutes.
- (4) Apply a partial vacuum to the contents for 10 minutes, to remove the entrapped air.
- (5) Stop the vacuum and carefully remove the vacuum line from pycnometer.
- (6) Fill the pycnometer with distilled (water to the mark), clean the exterior surface of the pycnometer with a clean, dry cloth. Determine the weight of the pycnometer and contents, W_B .
- (7) Empty the pycnometer and clean it. Then fill it with distilled water only (to the mark). Clean the exterior surface of the pycnometer with a clean, dry cloth. Determine the weight of the pycnometer and distilled water, W_A .
- (8) Empty the pycnometer and clean it.

Data Analysis:

Calculate the specific gravity of the soil solids using the following formula:

$$\text{Specific Gravity, } G_s = \frac{W_0}{W_0 + (W_A - W_B)}$$

Where:

W_0 = weight of sample of oven-dry soil, $g = W_{PS} - W_P$

W_A = weight of pycnometer filled with water

W_B = weight of pycnometer filled with water and soil

**SPECIFIC GRAVITY DETERMINATION
DATA SHEET**

Specimen number	1	2
Pycnometer bottle number	96	37
W_P = Mass of empty, clean pycnometer (grams)	37.40	54.51
W_{PS} = Mass of empty pycnometer + dry soil (grams)	63.49	74.07
W_B = Mass of pycnometer + dry soil + water (grams)	153.61	165.76
W_A = Mass of pycnometer + water (grams)	137.37	153.70
Specific gravity (G_S)	2.65	2.61

Example Calculation: $W_P = 37.40$ g, $W_{PS} = 63.49$ g, $W_B = 153.61$ g,

$$W_A = 137.37 \text{ g}$$

$$W_0 = 63.49 - 37.40 = 26.09 \text{ g}$$

$$G_S = \frac{26.09}{26.09 + (137.37 - 153.61)} = 2.65$$

4.4 Experiment No.4: Direct Shear Test

Purpose:

This test is performed to determine the consolidated-drained shear strength of a sandy to silty soil. The shear strength is one of the most important engineering properties of a soil, because it is required whenever a structure is dependent on the soil's shearing resistance. The shear strength is needed for engineering situations such as determining the stability of slopes or cuts, finding the bearing capacity for foundations, and calculating the pressure exerted by a soil on a retaining wall.

Standard Reference:

ASTM D 3080 - Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions.

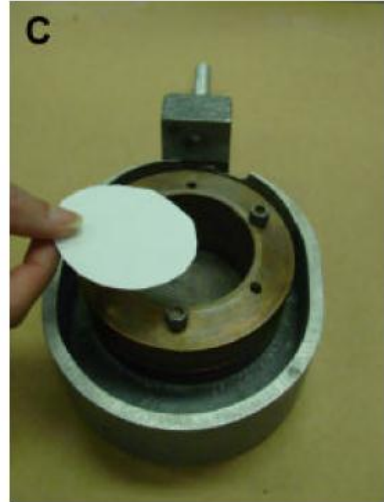
Significance:

The direct shear test is one of the oldest strength tests for soils. In this laboratory, a direct shear device will be used to determine the shear strength of a cohesionless soil (i.e. angle of internal friction (f)). From the plot of the shear stress versus the horizontal displacement, the maximum shear stress is obtained for a specific vertical confining stress. After the experiment is run several times for various vertical-confining stresses, a plot of the maximum shear stresses versus the vertical (normal) confining stresses for each of the tests is produced. From the plot, a straight-line approximation of the Mohr-Coulomb failure envelope curve can be drawn, f may be determined, and, for cohesionless soils ($c = 0$), the shear strength can be computed from the following equation:

$$s = s \tan f$$

Equipment:

Direct shear device, Load and deformation dial gauges, Balance.





Test Procedure:

- (1) Weigh the initial mass of soil in the pan.
- (2) Measure the diameter and height of the shear box. Compute 15% of the diameter in millimeters.
- (3) Carefully assemble the shear box and place it in the direct shear device. Then place a porous stone and a filter paper in the shear box.
- (4) Place the sand into the shear box and level off the top. Place a filter paper, a porous stone, and a top plate (with ball) on top of the sand
- (5) Remove the large alignment screws from the shear box! Open the gap between the shear box halves to approximately 0.025 in. using the gap screws, and then back out the gap screws.
- (6) Weigh the pan of soil again and compute the mass of soil used.
- (7) Complete the assembly of the direct shear device and initialize the three gauges (Horizontal displacement gage, vertical displacement gage and shear load gage) to zero.

- (8) Set the vertical load (or pressure) to a predetermined value, and then close bleeder valve and apply the load to the soil specimen by raising the toggle switch.
- (9) Start the motor with selected speed so that the rate of shearing is at a selected constant rate, and take the horizontal displacement gauge, vertical displacement gage and shear load gage readings. Record the readings on the data sheet. (Note: Record the vertical displacement gage readings, if needed).
- (10) Continue taking readings until the horizontal shear load peaks and then falls, or the horizontal displacement reaches 15% of the diameter.

Analysis:

- (1) Calculate the density of the soil sample from the mass of soil and volume of the shear box.
- (2) Convert the dial readings to the appropriate length and load units and enter the values on the data sheet in the correct locations. Compute the sample area A , and the vertical (Normal) stress s_v .

$$s_v = \frac{N_v}{A}$$

Where: N_v = normal vertical force, and s_v = normal vertical stress

- (3) Calculate shear stress (τ) using $t = \frac{F_h}{A}$

Where F_h = shear stress (measured with shear load gage)

- (4) Plot the horizontal shear stress (τ) versus horizontal (lateral) displacement δH .
- (5) Calculate the maximum shear stress for each test.

(6) Plot the value of the maximum shear stress versus the corresponding vertical stress for each test, and determine the angle of internal friction (ϕ) from the slope of the approximated Mohr-Coulomb failure envelope.

5. REFERENCES

1. K. H. Head. Manual of Soil Laboratory Testing. Pp. 616-628.
2. B.S. 1377: Part 7. Pp. 22-25.
3. R. F. Craig. Soil Mechanics. Pp. 107-112.1- American Society for Testing and Materials (1997). Annual Book of ASTM Standards, Vol. 04.08, Conshohocken, Pa.
- 4- Khanna, S.K. and C.E.G Justo, Highway Materials Testing Laboratory Manual, Nem Chand Bros. Roorkee.
- 5- Sood H., Mittal L.N and Kulkarni P.D., "Laboratory Manual on Concrete Technology", CBS Publishers & Distributors Pvt. Ltd