MANUAL OF GEOTECHNICAL LABORATORY SOIL TESTING

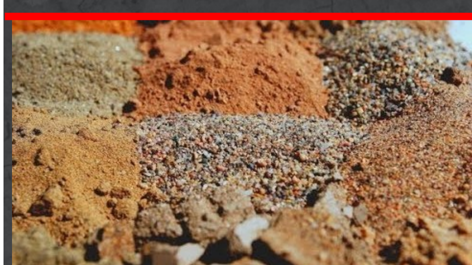
GEOTECHNICAL ENGINEERING (LABORATORY-I & II)

DEPTT. OF CIVIL ENGG.

NIT SRINAGAR, J&K

BY

BASHIR AHMED MIR



DEPARTMENT OF CIVIL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
HAZRATBAL, SRINAGAR-190 006, J&K (INDIA)

About National Institute of Technology (NIT) Srinagar

National Institute of Technology, Srinagar is one of the premier Educational Institutes in the Northern Regions of the country. It was established in 1960 and has been one of the eighteen Regional Engineering Colleges sponsored by the Govt. of India during the 2nd Plan. The Institute acquired the status of National Institute of Technology with deemed to be University status during August 2003 and attained full autonomy in its Academics.

The Institute is situated at the banks of world-famous Dal Lake, with the far-famed Hazratbal Shrine on another side of the campus. NIT Srinagar is a residential Institute with accommodation facility in Hostels and Staff-Quarters. There are four Boys and one Girls hostel which swallops about 1500 boys and 200 girls. Besides running the B. Tech. Programme the Institute also offers M. Tech programme in many streams. In addition to that, a large number of students are registered for M. Phil and Ph.D. Programmes.

The Institute has one of the best technical library in J&K State. It has a collection of over 60,000 books on Engineering Science and humanities and about 6,000 bound volumes/Journals, both foreign and Indian. The library remains open from 9.00 am to 10 pm. It has online repository of A.S.C.E, A.S.M.E.A.E.L, J.C.C.C etc in addition to journals through I.N.S.E.S, COMSORTIEM. It also has a collection of I.S.I codes, in the C.D-Rom format.

Vision of the Institution:

To establish a unique identity of a pioneer technical Institute by developing a high quality technical manpower and technological resources that aim at economic and social development of the nation as a whole and the region, in particular, keeping in view the global challenges.

Mission of the Institution:

M1. To create a strong and transformative technical educational environment in which fresh ideas, moral principles, research and excellence nurture with international standards.

M2. To prepare technically educated and broadly talented engineers, future innovators and entrepreneurs, graduates with understanding of the needs and problems of the industry, the society, the state and the nation.

M3. To inculcate the highest degree of confidence, professionalism, academic excellence and engineering ethics in budding engineers.

About the Department of Civil Engineering:

The department of Civil Engineering is the largest and one of the pioneering departments of National Institute of Technology, Srinagar. It was established at the inception of the Institute (then REC Srinagar) in 1960. Over the years, since then, the Department has progressed with a considerable development in its infrastructure, both in terms of its faculty and the other learning facilities. The Department has produced several eminent professionals who have made excellent contribution in the field of Civil Engineering, both at National and the International levels.

The Department offers a four-year course leading to the Bachelors Degree in Civil Engineering and two-year courses leading to Master's degree in four major specializations of civil engineering (viz., Water Resources Engineering, Structural Engineering Geotechnical Engineering, and Transportation Engineering & Planning). The Department, in addition to

Under-graduate and Post-Graduate programs is offering Doctoral Programs in all the specializations of Civil Engineering.

The Department is known for its reputed and well qualified faculty having experience in diverse fields. The faculty is supported by experienced technical staff and well-equipped laboratories. The faculty strives its level best in imparting the latest technical knowledge to the students and conducting the high quality of research. The faculty also offers technical advice on the live and challenging civil engineering problems to various Government, semi-government and the Private organizations.

The Vision, Mission and the Program Educational Objectives (PEOs) of the Department being presented below have been finalized in view of the ever-growing technical requirement and need in the field of Civil Engineering after considering the feedback from various Stakeholders, which include Students, Alumni,

Vision of Department:

To create a unique identity of the Department by achieving the excellent standards of quality technical education keeping a pace with the rapidly changing technologies and to produce Civil Engineers of global standards with the capability of accepting new challenges.

Mission of Department:

M1. To promote academic growth in the field of Civil Engineering by offering state-of the-art undergraduate and postgraduate programmes.

M2. To develop graduates to compete at the global level.

M3. To inculcate higher moral and ethical values among the students to become competent Civil Engineers with overall leadership qualities.

M4. To provide knowledge base and consultancy services in all areas of Civil Engineering for industry and societal needs.

Program Educational Objectives:

PEO1. To produce professionally competent Civil Engineers, capable of applying the knowledge of contemporary Science and Technology to meet the challenges in the field of Civil Engineering and to serve the Society.

PEO2. To impart the knowledge of analysis and design using the codes of practice and software packages.

PEO3. To inculcate in the students the sense of ethics, morality, creativity, leadership, professionalism, self confidence and independent thinking.

PEO4. To inculcate in the students the ability to take up the innovative research projects and to conduct investigations of complex civil engineering problems using research based methods, thus urging them for higher studies.

About the Geotechnical Engineering Laboratory Testing:

Geotechnical laboratory tests consist of number of tests for the properties of soil. Soil testing is an important function of geotechnical testing and civil engineering in the design of foundations, highway/road pavements, embankments and other earth structures. Geotechnical testing provides valuable information on soil mechanics and materials common to soils such as silt, clay, sand, gravel or rock.

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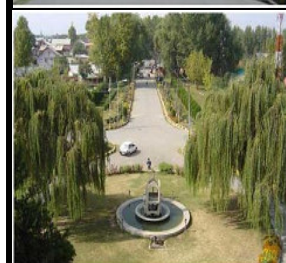
CE-502: GEOTECHNICAL ENGINEERING LAB-I

LABORATORY MANUAL



*Name*_________________________________

*Roll No*_______________________________

Group and Batch no. ___________________

Year _________________________________

*Soil sample*___________________________

OTHER ROLL NUMBERS IN THE GROUP

ROLL NO	NAME	ROLL NO	NAME
1.		5.	
2.		6.	
3.		7.	
4.		8.	

BY

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY

HAZRATBAL, SRINAGAR-190 006, J&K (INDIA)

ABOUT THE GEOTECHNICAL LABORATORY TESTING MANUAL

What is the role that Geotechnical laboratory soil testing should take in today's geotechnical practice? Laboratory measurements are used to obtain mechanical and physical properties of geotechnical materials for analysis and design. Laboratory tests are used to characterize site conditions, so engineers know what to design and contractors know what to bid and do. Lab testing provides a way to test ideas to improve the soils at a site before mobilizing expensive equipment. Using estimated or "conservative" parameters for design inherently increases the cost of construction. Realistic parameters obtained from appropriate laboratory testing can reduce the cost from such conservatism. Testing is used to determine whether a contractor is meeting the specifications. A significant amount of the geotechnical testing performed today is to screen the contractor's source materials and to check on the finished conditions of his work. Soil exist as a naturally occurring material in its undisturbed state, or as a compacted material and is, perhaps most common and probably the most complex construction material. Thus, it is mandatory that various soils properties (e. g., physical, index and engineering properties) may be evaluated carefully for the sustainable development.

Physical and Index properties of soils are those properties which are mainly used in the identification and classification of soils and help the geotechnical engineer in predicting the suitability of soils as foundation/construction material. Geotechnical laboratory tests consist of number of tests for the determination of different geotechnical properties of soils such as soil grading, moisture content, density, specific gravity, density index, and consistency limit tests. Soil testing is an important function of geotechnical testing and civil engineering in the design of foundations, highway/road pavements, embankments and other earth structures. Geotechnical testing provides valuable information on soil mechanics and materials common to soils such as silt, clay, sand, gravel or rock.

The main engineering properties of soils are compaction characteristics (Optimum moisture content and maximum dry unit weight), permeability (Coefficient of Hydraulic conductivity), compressibility characteristics (compression index and coefficient of compressibility, coefficient of consolidation, pre-consolidation pressure, swell/collapse potential etc) and shear strength (cohesion intercept and angle of internal friction), which can be used for quantifying the Engineering behavior of soils. In addition to these properties, the soils are classified and identified based on index properties. Laboratory tests serve mainly to illustrate the principles on which a judgment may be based or to set broad limits to the probable behavior of the soil.

Therefore, Geotechnical Laboratory Soil Testing Manual has been written to present the very basic essentials of the laboratory testing of **physical, index and Engineering properties of soils**, including methods of data collection, analysis, computations and the presentation of the test results along with well defined illustrations for the benefit of readers/research scholars. A step-by-step **procedure** for various tests based on relevant standards and some of the important references have been given for each laboratory test so as to avoid any cause of difficulty or misunderstanding by the students and readers. Further, this manual is based on my own experience and I have made every effort to explain and illustrate each test in a very lucid manner to present the state-of-the-practice information on the evaluation of physical, index and engineering properties of soils for geotechnical design applications. The Geotechnical Laboratory Soil Testing Manuals provide basic concepts, general understanding, appreciation of the geotechnical principles for determination of physical, index and engineering properties of soil materials and various empirical relationships between physical, index and engineering properties.

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No.: NIT/Civil/2012/BAM/R-203

Dated: ______________________

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REFERENCES

1. Bowles, J. E. (1979). Physical and Geotechnical properties of soils, McGraw Hill Publishers.
2. BS 1377: Methods of test for soils for civil engineering purposes
3. Head, K. H. (1982). "Manual of soil laboratory testing", Volume: I-II1. Pentech Press, London.
4. IS 2720 (various parts): Methods of test for soils, Bureau of Indian Standards

CE 502: GUIDELINES: LABORATORY RULES

1. Attendance is required for all students for all lab classes. Students who do not attend lab will not receive credit for their group's report.
2. Ensure that you are aware of the test and its procedure before each lab class.

- **You will NOT be allowed to attend the class if you are not prepared!**

3. Personal safety is top priority. Do not use equipment that is not assigned to you.
4. All accidents must be reported to your instructor or laboratory supervisor.
5. The surroundings near the equipment must be cleaned before leaving each lab class.
6. Ensure that the readings are checked by your TA for each lab period.

Laboratory Report

1. General

- Each student has to submit the report for each experiment.
- The test results and graphs are to be written and drawn in the space provided in this manual only. The manual should be submitted to the TAs at the end of each lab class compulsorily.
- Please write your roll number, batch and group number along with the name of the soil sample given to your batch at the space provided on the first page of the manual.

2. Report Organization

- **Abstract**

This contains a brief summary of the experiment. You should explain what data you will gather, the procedure for gathering the data, and the reason for the same. The abstract should be very specific within the number of words as stipulated above the given box.

- **Measured Data**

Tabulate the measured and calculated test values, preferably in the format given in the lab manual. You should also show sample calculations. Attach reference figures and/ or tables used if any in the evaluation of the data.

- **Summary**

Tabulate the results/findings from the experiment. Towards the end of the semester, you should generate a detailed summary of soil properties in a table during the submission of the manual after the last experiment.

- **<u>Inference</u>**

Write briefly on your inference from test observations and analysis of results.

- **<u>Discussion</u>**

Discuss the possible sources of error, accuracy of the test method, and anything noteworthy you observed during the test. State the specific Indian Standard number for test procedure

======

<u>NOTE:</u>

- Your Report must be neat, well organised and make a professional impact. Label all axis and include proper units.
- Your reports should be submitted within 7 days and before the beginning of the lab class of the next batch.
- Your reports will be graded on a scale from 0 to 5 as follows:
  5 = Complete and excellent work
  4 = Satisfactory, but with some minor errors
  3 = Significant errors or omissions
  2 = Very little correct or useful work
  1 = Lab report handed in, but with minimal work
  0 = Missed lab
- Two points will be deducted for late submission. Anyone caught plagiarizing work in the laboratory report, from a current or past student's notebook, will receive 0 on the grading scale or XX grade in the course.
- **Anyone caught plagiarizing work in the laboratory report, from a current or past student's notebook, will receive 0 on the grading scale or XX grade in the course.**

==

<u>Declaration</u>

I have read and understood the above guidelines.

Signature: ____________________

Name: ______________________

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Dr. B A Mir (9419002500)

Faculty Incharge/Course Instructor

EXPERIMENT 1
Water content determination

Objective: To determine the water content of given soil by oven-drying method.

Theory: Water Content is defined as the ratio of the mass of water to the mass of solids. In oven drying method the soil is subjected to 105°-110°C for about 24 hours (For peat and soil containing organic matter a drying temperature of 60°C is to be preferred to avoid oxidation of the organic content). This method covers the determination of water content of the oven dry weight.

Apparatus

1. Thermostatically controlled oven (capable of maintaining a temperature of 105°-110°C, and adjustable to a lower temperature 60°C if necessary)
2. Weighing balance (with an accuracy of 0.01 g for fine-grained soils)
3. Desiccators (Use of desiccators can be avoided if cans with airtight lids are used)
4. Cans

Note: The soil specimen taken shall be representative of the soil mass. The size of the specimen selected depends upon the quantity required for good representation, which is influenced by the gradation and the maximum size of particles, and on the accuracy of weighing. The following quantities are recommended for general laboratory use.

Size of particles more than 90 per cent passing	**Minimum quantity of specimen to be taken for test (g)**
425µ IS Sieve	25
2 mm IS Sieve	50
4.75-mm IS Sieve	200
9.50-mm IS Sieve	300
19-mm IS Sieve	500
37.5-mm IS Sieve	1 000

Procedure

1. Note the can number and take the empty mass of moisture cans.
2. Take three samples of about 20-25 g of the soil in moisture can.
3. Find the mass of cans with the soil correct to 0.01g.
4. Keep the cans for drying in oven, with the temperature set at 105-110°C.
5. Find the mass of cans after 24 hours.
6. Enter the data in observation table and compute the water content of the given soil.

Record sheet for water content

Date of experiment: Sample:

Abstract (in about 200 words)

Can no.	Empty mass of can with lid M_1 g	Mass of can with lid + wet soil M_2 g	Mass of can with lid + dry soil M_3 g	Water content = $w = \frac{M_2 - M_3}{M_3 - M_1} \times 100$	Avg. water content (%)

Calculation

M_1 = empty mass of can with lid.
M_2 = mass of can with lid and wet soil.
M_3 = mass of can with lid and dry soil.

Water Content is given by $w = \frac{M_2 - M_3}{M_3 - M_1} \times 100$

Inference (in about 200 words)

Discussion

EXPERIMENT 2
Field density measurements

Objective: To determine the in-situ density by (1) sand replacement method and (2) core cutter method.

Theory: The in-situ density refers to the mass per unit volume of a soil in the undisturbed state or of a compacted soil in-place. During the construction of the compacted fills, it is standard practice to make in-situ determination of density of the soil after it is placed to ensure that the compaction effort has been adequate.

Sand Replacement Method

In sand replacement method a hole of specified diameter is excavated in the ground. The mass of the excavated soil is measured. The volume of the hole is determined by filling it with clean, uniform sand whose dry density is determined separately by calibration.

Apparatus

1. Sand pouring cylinder (3-liter capacity), mounted above the pouring cone and separately by shutter
2. Cylindrical calibrating container, with 10cm internal diameter and 15cm internal depth
3. Metal tray with central hole of a diameter equal to the diameter of the pouring cone.
4. Auger for excavating hole
5. Balance, cans for water content determination
6. Clean closely graded natural sand passing the 1mm IS sieve and retained on 600µm IS sieve

Procedure

(a) Calculation of the density of the sand:

1. Fill the clean closely graded sand in the sand-pouring cylinder up to a height 10mm below the top. Determine the total initial mass of the pouring cylinder plus sand (M_1). This total initial mass of the pouring cylinder should be maintained constant through out the test for which the calibration is used.
2. Determine the volume (V) of the calibrating container.
3. Place the sand pouring cylinder on the top of the calibrating container. Open the shutter and allow the sand to run out. Close the valve when no further movement of sand observed at the top. Remove the cylinder carefully and find its mass (M_2).
4. Place the sand pouring cylinder on the polythene sheet placed on the flat surface. Open the shutter and allow the sand to run out. Close the valve when no further movement of sand observed at the top. Weigh the pouring cylinder again, which gives (M_3).
5. Put the sand on the polythene sheet and the calibrating container back in to the sand pouring container.

(b) Determination of the in-situ density of the soil :

1. Clean and level the site at which the in-situ density is to be determined. Keep the tray on the leveled surface and excavate a circular hole 100 mm in diameter and approximately 150 mm in depth, and collect all the excavated soil in tray. Determine the mass (M) of the excavated soil.
2. Remove the tray and place the sand pouring cylinder. The cylinder should have its constant mass (M_1). Open the shutter and permit the sand to urn into the hole. Close the shutter when no further movement of sand is seen. Remove the cylinder and determine its mass (M_4).
3. Keep a representative sample of the excavated soil for water content determination.

Calculation

1. The mass of the sand filling the calibrating container (Mc) can be found by deducting the mass of sand filling the conical portion (Mc = M_2-M_3) from the mass of sand (M_4 = M_1-M_2) filling the container and the cone. Since the volume of the container (V) is known, the density of the sand (ρ) may be retained.
2. The mass of the sand occupying the test hole (M_s) is equal to M_5 minus the mass of sand occupying the conical portion (Mc). Where, M_5=M_1-M_4.
3. The volume of the hole dug in the field (V) can be obtained by dividing the mass M_s, by the density of sand.
4. The in-situ density of soil (ρ) is then obtained by dividing the mass of soil (M) by its volume (V). If the water content of the soil is determined, the dry density of the soil can be obtained as: $$\rho_d = \frac{\rho}{(1+w)}$$

Core Cutter Method

A cylindrical core cutter is a seamless steel tube. For determination of the dry density of the soil, the cutter is pushed into the soil mass to fill it with soil. The cutter is than removed. The mass of the soil in cutter is determined. The dry density is obtained as

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

Apparatus

1. Cylindrical core cutter of steel, approximately 100 mm in diameter and 450 mm in height
2. Steel dolly, 100 mm internal diameter, 25 mm high and 7.5 mm thick
3. Steel hammer
4. Palette knife, steel rule, straight edge, balance, oven etc.

Procedure

1. Measure the inside dimension of the core cutter and calculate its volume (V_c). Weigh the core cutter without dolly (M_c).
2. Clean and level the site at which the in-situ density is to be determined. Put the dolly on the top of the core cutter. Drive the assembly into the soil using the hammer.
3. Dig out the core cutter from the soil, and allow some soil to project from the lower end of cutter. With the help of straight edge, trim flat the ends of the cutter.
4. Weigh the cutter full of soil (M_1).
5. Keep some representative sample of the soil for water content determination.

Calculations:

1. The mass of the soil in core cutter is (M_1-M_c). The volume of the soil is the same as the volume of cutter (V_c).
2. The in-situ density of the soil (ρ) is given by W/V. If the water content of the soil is determined, the dry density of the soil can be obtained as,

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

a. void ratio of the soil = $e = \dfrac{G}{\rho_d} - 1$

b. Porosity $= n = \dfrac{e}{1+e}$

C. degree of saturation $= S = \dfrac{G_S.w}{e}$

Date of experiment: Sample:

Abstract (in about 200 words)

Record sheet for core cutter method

1.	Internal diameter of cutter	(cm)	
2.	Height of the cutter	(cm)	
3.	Volume of cutter	V_C (cm^3)	
4.	Mass of cutter	M_C (g)	
5.	Mass of soil and cutter	M_1 (g)	
6.	Mass of soil	$M = M_1 - M_C$ (g)	
7.	Wet density of soil	$\rho = M/V_C$ (g/cm^3)	
8.	Water content	w (%)	
9.	Dry density of soil	$\rho_d = \frac{\rho}{1+w} (g/cm^3)$	

Record sheet for sand replacement method

(a) To find the density of standard sand

1.	Weight of sand and pouring cylinder(initial)	M_1 (g)	
2.	Weight of sand and pouring cylinder after it is released to calibrating container	M_2 (g)	
3.	Weight of sand and pouring cylinder after releasing on flat surface	M_3 (g)	
4.	Weight of cone and container	$M_4 = M_1 - M_2$ (g)	
5.	Weight of sand in cone	$M_c = M_2 - M_3$ (g)	
6.	Weight of sand in calibrating container	$M_{cc} = M_4 - M_c$ (g)	
7.	Volume of calibrating container	V_{cc} (cm^3)	
8.	Density of sand	$\rho_s = \frac{Mcc}{Vcc}(g/cm^3)$	

(b) In-situ density of soil

1.	Weight of sand and pouring cylinder	M_1 (g)	
2.	Weight pouring cylinder (after the sand is released to pit)	M_4 (g)	
3.	Weight of sand in pit and cone	$M_5 = M_1 - M_4$ (g)	
4.	Weight of sand filling the cone	Mc (g)	
5.	Weight of sand filling the pit	$M_s = M_5 - Mc$ (g)	
6.	Weight of soil collected from pit	M	
7.	Density of sand	ρ_s (g/cm^3)	
8.	Volume of pit	$V_p = M_s/\rho_s$ (cm^3)	
9.	Density of soil	$\rho = M/V_p$ (g/cm^3)	
10.	Water content of soil	w (%)	
11.	Dry density of soil	$\rho_d = \frac{\rho}{1+w}(g/cm^3)$	

Inference (in about 200 words)

Discussion

EXPERIMENT 3
Sieve analysis

Objective: To determine the particle size distribution of a soil by mechanical sieving.

Theory: Soil consists of an assemblage of discrete particles of various shapes and sizes. In this experiment the soil particles are grouped into separate size ranges and to determine the relative proportions of dry weight of each size range is determined.

Two separate procedures that is, sieving and sedimentation are used for grain size analysis to span the very wide range of particle sizes. Sieving is used for gravel and sand size particles, which can be separated into different size ranges with a series of sieves of standard aperture openings. Sieving can not be used for silt and clay size particles, wherein sedimentation procedure is used (e.g. hydrometer).

From the grain size distribution curve, particle sizes such as D_{10}, D_{30}, *and* D_{60} can be obtained. The D_{10} is called as the effective particle size of the soil.

Coefficient of Uniformity C_u: This is the indicator of the spread of the range of the particle sizes and defined as

$$C_U = D_{60} / D_{10} \quad (1)$$

Coefficient of Curvature C_c: This is the measure of the shape of curve between D_{60} and D_{10} grain sizes and defined as

$$C_C = \frac{(D_{30})^2}{(D_{10} \times D_{60})} \quad (2)$$

Apparatus

1. Set of fine sieves -2 mm, 1 mm, 600μm, 425μm, 212μm, 150μm and 75μm
2. Set of coarse sieves -100mm, 80mm, 40mm, 20mm, 10mm and 4.75mm
3. Weighing balance with an accuracy of 0.1 % mass of the sample
4. Trays, brushes etc

Procedure

(a) Processing of soil

1. Pound the soil with a wooden mallet and mix the pounded soil properly.
2. Weigh 1000g of soil separately in a tray. This is required for gravel analysis.
3. Pass the remaining soil through 4.75mm sieve.
4. Keep 5 to 7kg of soil (passing through 4.75mm sieve) in a packet supplied to you and keep it in box. This soil will be required for subsequent experiments.

(b) Gravel distribution

1. Soak 500g of deaired soil (from Step 3. above) in the tray.
2. Add a pinch of Na_2CO_3 to aid dispersion and mix the mixture thoroughly.
3. Keep the mixture for soaking for at least an hour.
4. Wash the mixture on 4.75 mm sieve under the current of water and collect the fraction retained on the sieve.
5. Transfer the fraction retained on the sieve to porcelain dish and keeps it for drying it in an oven for 24 hours.
6. Pass the dried soil through the set of sieves from 38mm to 4.75mm and record the weight of soil retained on each sieve in the record sheet.
7. Calculate the percent soil finer than the various sieve sizes.

(c) Sand distribution

1. Take 200g of soil (soil sieved from 4.75mm sieve)
2. Soak the sample for an hour in water.
3. Wash the soaked soil sample on 75 μm sieve.
4. Keep the soil retained on the 75 μm sieve in oven for 24 hours.
5. Sieve the dried soil through the set of sieves from 2.39mm to 75 μm and record the weight of the soil retained on each sieve in the record sheet.

Record sheet for sieve analysis

Date of experiment: Sample:

Abstract (in about 200 words)

Gravel Distribution

Weight of air dry soil taken = ...g
Water content = ...%
Weight of oven dry soil taken = ...g
Weight of gravel = ...g
Percent of gravel = ...%

Sieve opening mm	Weight of soil retained g	Percent retained	Cumulative percent retained (a)	Percent finer 100-a

Sand Distribution

Weight of air dry soil taken = ...g
Water content = ...%
Weight of oven dry soil taken = ...g

Sieve opening mm	Weight of soil retained g	Percent retained	Cumulative percent retained (a)	Percent finer N (100-a)	Corrected Percent finer N'

(Note: - The percentage finer (N) that we get is for fine sieve analysis is on the basis that we have taken 200g of soil sample. But to relate the data of fine sieve analysis to the gravel analysis we should correct the percentage finer of fine sieve analysis)

Inference (in about 200 words)

Discussion (mention point wise, in about 200 words)

EXPERIMENT 4
Sedimentation analysis

Objective: To determine the particle size distribution less than 75μm by hydrometer method.

Theory: Hydrometer analysis is a widely used method of obtaining an estimate of the distribution of particle sizes from the 0.075 mm to around 0.001 mm. It is generally used when material passing from 75 μ is more than 10 %.

It utilizes the relationship among the velocity (v, cm/s) of fall of sphere in liquid, the diameter (D, cm) of the sphere, specific weights of spheres and the fluid (γ_s and γ_w, g/cm^3) and the viscosity (η, g/cm-s) of the fluid as expressed by Stokes (1850) in the equation termed as Stoke's law:

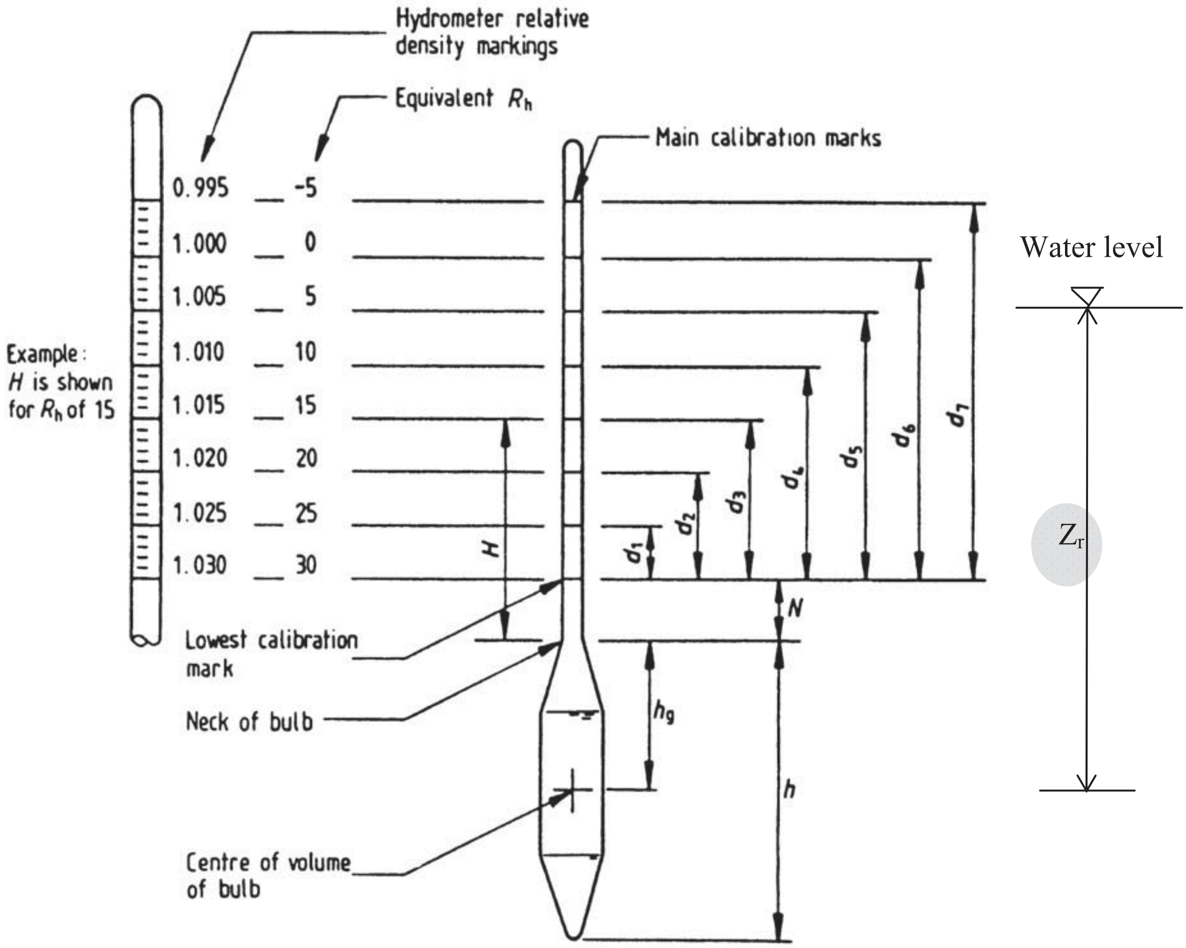
$$v = \frac{\gamma_s - \gamma_w}{18\eta} D^2 \qquad (1) \quad \text{or}$$

$$D = \left(\sqrt{\frac{18 \times \eta}{\gamma_s - \gamma_w}} \right) \sqrt{v} \qquad (2)$$

To obtain the velocity of fall of the particles, hydrometer is used. By mixing the given quantity of water with the soil and small amount of dispersing agent solution (33.0g Sodium-hexa-meta phosphate $(NaPO_3)_6$ and 7.0g Sodium carbonate (Na_2CO_3) to form a 1000ml of suspension) the charge on the smaller grains are neutralized.

The hydrometer displays the specific gravity of the soil-water dispersion at the center of the bulb. As time passes, soil grains larger than those still in suspension in the zone Z_r (i.e. distance between the center of the volume of the bulb and the water surface) fall below the center of volume, the constantly decreases the specific gravity of suspension at the center of volume of hydrometer. Since Z_r represents the distance of the particles fall in some time interval t, it is evident that the velocity of fall in equation (1) and (2) is given as:

$$v = \frac{Z_r}{t} \qquad (3)$$



For a symmetrical bulb, $h_g = h/2$

Correction to Hydrometer Readings:

a) **Meniscus correction C_m:** A hydrometer is calibrated to read correctly at the surface of the liquid in which it is immersed. Since soil suspension is not transparent enough to permit a reading to be taken at this level, the scale has to be read at the upper rim of meniscus. This correction is additive to the actual reading because density readings on the hydrometer stem increases downwards. It is constant for a given hydrometer and is determined by partly filling the measuring cylinder, inserting hydrometer and taking readings at the top and the bottom of meniscus. The difference between these two readings gives the meniscus correction.

b) Dispersing agent correction C_d: The addition of the dispersing agent results in the density of liquid in which sedimentation takes place, being greater than that of water. Generally 100ml Sodium-hexa-meta-phosphate solution is used as a dispersing agent in the form of its 4 % solution. To obtain the correction, 100ml of dispersing agent solution is taken in standard measuring cylinder and the volume is made equal to 1000ml by adding distilled water. Hydrometer is inserted and reading is taken. Similarly hydrometer is inserted in standard measuring jar filled with water and reading is taken. The difference between the two readings gives the dispersing agent correction and it is always subtracted from the hydrometer reading after it is corrected for meniscus.

c) Immersion correction: When the hydrometer is inserted into the suspension the surface of the suspension rises and therefore the immersion correction must be applied. The immersion correction is given below and must be applied to Z' value to obtain Z_r.

$$\text{Immersion Correction} = \frac{V_h}{2A_j} \qquad (4)$$

where, V_h is the volume of the hydrometer and

A_j is the cross-sectional area of measuring cylinder.

Hydrometer Calibration: In a liquid of variable specific gravity, hydrometer reads the specific gravity at approximately the depth in the liquid where the center of volume of the hydrometer floats. Since it is this depth that must be used in the computation of particle diameter it is desirable to have a curve which gives the depth from the surface of suspension to the center of volume of hydrometer for any hydrometer reading. Such a curve is known as calibration curve, is essentially a straight line for a symmetrical bulb hydrometer. To calibrate the hydrometer, first locate the mid length of the bulb, which is very close to the center of the volume. Next measure the distance from a graduation mark on each end of the stem to the center of the bulb, because the curve is essentially a straight line, only two such measurements are needed. Plot a curve of hydrometer reading against depth.

Apparatus

1. Soil hydrometer
2. Dispersing agent
3. Two graduated cylinders of 1000ml.
4. Distilled water
5. Thermometer
6. Stop-watch

Procedure

1. Take 50-55g deaired soil passing through 4.75mm sieve.
2. Determine the hygroscopic moisture content of the fraction passing through 4.75mm sieve.
3. Add about 150ml of hydrogen per oxide (H_2O_2) and stir the mixture gently with a glass rod.
4. Add enough water to soak the soil sample completely in a glass beaker and add 100ml Sodium-hexameta-phosphate. Warm the mixture gently for about 10 minutes.
5. Transfer the mixture to the top of the mechanical mixer using a jet of distilled water to wash all the traces of soil out of beaker.
6. Stir the soil suspension about 15 minutes.
7. Transfer the suspension on to 75 μm sieve placed on a receiver and wash the soil on the sieve using a jet of distilled water. Particular care should be taken to wash off all the traces of suspension adhering to the dispersion cup. Do not exceed a total volume of about 800ml.
8. Transfer the suspension to a measuring cylinder and make up the volume exactly to 1000ml with distilled water.
9. Start the stopwatch immediately after placing the measuring cylinder on the table and take the readings at the interval mentioned in record sheet. The reading shall correspond to the upper meniscus. Keep the hydrometer in the suspension for the first two minutes. Thereafter the hydrometer should be placed in separate cylinder filled with water and inserted in the suspension just before taking the reading.

Date of experiment: Sample:

Abstract (in about 200 words)

Measured data

Cylinder no ………………… …….. Hydrometer no……………………………

Area of cross-section, A………………….

Vol. of hydrometer……………………….

Meniscus correction C_m = ………………..

Dispersion agent correction C_d = ………...

Volume correction, $V_h/2A_j$ =………………

Room temperature = ……………………..

Viscosity of water at room temp. (η) = ……………………..

Sp. Gravity (G_s) = …………………………………………..

Hyd. Reading in clear water (R_w) = ………………………..

Volume of suspension Vs =1000 cm^3

Record sheet for Hydrometer Analysis

$$D = 10 \times \sqrt{\frac{18 \times \eta}{980 \times 60 \times (G_S - 1)}} \times \sqrt{\frac{h}{t}} \text{mm}$$

$$N = \frac{G_S}{(G_S - 1)} \times \frac{V_S}{W_S} \times (r - R_W) \times 100\%$$

Time (min)	Hydrometer reading in suspension r	r’= $r + C_m$	Zr (mm)	h = Zr- $(V_h/2A_j)$	V = h/t	r = r’ - C_d	$r - R_w$	D (mm)	Percent finer, N (%)	Corrected Percent finer, N (%)
0.5										
1										
2										
5										
15										
30										
60										
120										
1440										

Inference (in about 200 words)

Discussion (mention point wise, in about 200 words)

EXPERIMENT 5
Specific gravity test

Objective: To determine the specific gravity of given soil by Density Bottle Method.

Theory: Specific gravity of a soil (G_S) is the ratio of the mass density of solids to mass density of water. Specific gravity is usually reported at 20°C. Specific gravity is determined as

$$G_S = \frac{m_2 - m_1}{(m_2 - m_1) - (m_3 - m_4)}$$

Where, m_1 = mass of empty bottle,
m_2 = mass of bottle and dry soil,
m_3 = mass of bottle, soil and water, and
m_4 = mass of bottle filled with water only.

Apparatus:

(1). 50ml Specific gravity bottle, (2). Distilled water, (3). Hot plate, (4). Balance (with 0.01g sensitivity), (5). Oven, and (6). Vacuum desiccator

Procedure

1. Weigh a clean and dry density bottle empty (m_1).
2. Take about 15 g of oven dry soil in the bottle. Take the combined weight of soil and bottle (m_2).
3. Add deaired distilled water to cover soil (half full) and then boil it on the hot plate for about 30 minutes. Remove the stopper while boiling and avoid spurting.
4. Cool the bottle to room temperature, fill it completely with deaired distilled water and replace the stopper correctly. Wipe the surface of the bottle and weight the bottle (m_3).
5. Empty the contents and clean the density bottle thoroughly. Fill the bottle with distilled water and weight (m_4).
6. Fill the record sheet given and calculate the specific gravity.
7. If given the time, repeat the above steps 2 to 6 using a dry density bottle.

Date of experiment: Sample:

Abstract (in about 200 words)

Record sheet for specific gravity

Temperature: …………….   Type of soil: …………………

Sr. No.	Bottle No.	Empty mass of Sp. Gravity bottle m_1 g	Mass of Sp. Gravity bottle + soil m_2 g	Mass of Sp. Gravity bottle +soil +water m_3 g	Mass of Sp. Gravity bottle + water m_4 g	Mass of oven dry taken soil m_2-m_1 g	Sp. Gravity $G_S = \frac{m_2 - m_1}{(m_2 - m_1) - (m_3 - m_4)}$	Avg. value of Sp. Gravity
1								
2								
3								
4								
5								
6								
7								

Inference (in about 200 words)

Discussion (mention point wise, in about 200 words)

EXPERIMENT 6
Atterberg and shrinkage limits

Objective: To determine the range of water content which exhibits consistency of a given soil sample at liquid limit, plastic limit and shrinkage limit.

Theory: Liquid limit (LL): It is the water content at which a 2 mm wide groove in a soil pat will close for a distance of 12.5mm when dropped 25 times in a standard liquid limit device (casagrade apparatus).

Plastic limit (PL): It is the water content at which a thread of soil just begins to crack and crumble when rolled to a diameter of 3mm.

Shrinkage limit (SL): It is the maximum water content at which no change in volume of the soil mass occurs when the water content is further reduced.

Plasticity index (PI): The plasticity index (PI) is defined as;

$$PI = LL - PL$$

Liquidity index (LI): This index is defined as;

$$LI = (w - PL) / (LL - PL)$$

Apparatus

1. Liquid limit device and grooving tool
2. Shrinkage limit set consisting of shrinkage dish, glass plate with prongs, mercury and evaporating dish
3. Large glass plate for plastic limit
4. Distilled water
5. Oven
6. Balance of 0.01g accuracy
7. Dessicator
8. Water can
9. Spatula, cotton waste, duster and grease

Procedure

Liquid Limit

1. Take about 120g of dry soil passing 425μm IS sieve and mix it thoroughly with distilled water using spatula until the soil mass becomes homogenous paste.
2. Adjust the liquid limit device with the aid of the gauge on the grooving tool to obtain the fall of cup equal to 1cm above the base. Turn the handle and practice to obtain a speed of 2 blows per second.
3. Place the soil paste in the cup, level up to a depth of 1cm at the point, which comes in contact with the base. Divide this paste by drawing the grooving tool through the sample along the symmetrical axis of the cup, holding the tool perpendicular to the cup at the point of contact.
4. Turn the handle at the rate of two revolutions per seconds and count the blows necessary to close the groove in the soil for a distance of 12mm.
5. Take the sample of the soil paste from near the closed groove and keep in the water can to determine the water content.
6. Repeat the above process three or four times by adding some distilled water each time. Adjust the amount of water by visual judgment so that two readings are above 25 and two below 25 blows. However, the blows should not be lower than 15 nor greater than 35.
7. Preserve this soil for shrinkage limit test.
8. Draw the flow curve, and determine the liquid limit.

Plastic limit

1. Take about 20g of soil passing through the sieve of size 425μm and place it on a glass plate. Mix it thoroughly with distilled water until it is plastic enough to be rolled.
2. Roll the soil between the hand and the glass plate so as to form a thread of 3mm diameter.
3. Knead the soil together and roll again until a 3mm diameter thread shows sign of crumbling.
4. Take some of the crumbling material obtained in step 3 for water content determination. This defines the plastic limit.
5. Repeat steps 2 to 4 three times so as to obtain average plastic limit.

Shrinkage Limit

1. Place about 30g of the soil fraction passing 425μm IS sieve in a porcelain dish and thoroughly mix it with distilled water. The water should be added to make the soil slightly flowing.

   Note: The amount of required water could be about the liquid limit in low plastic (friable) soils; otherwise it could be about 1.1 to 1.2 times the liquid limit in medium to high plastic soils.
2. Apply a thin coat of grease to the inside of the shrinkage dish and measure its empty weight.
3. Place the soil paste in the shrinkage dish, simultaneously tapping it so that it fills completely the dish without entrapping any air bubbles. Weigh the dish with soil paste inside.
4. Keep the dish in the oven set at 105 to 110^{0}C for 24 hours. Take the dry weight of the soil pat.
5. Determine the volume of the dry soil pat by mercury displacement method *
6. Determine the volume of the dish by filling it with mercury.
7. Enter the observation in the record sheet and compute the shrinkage limit.

* **Important:** Every precaution should be taken while handling mercury (e.g. your finger nails should be trimmed). For detailed safety requirements, you are advised to refer to the web page http://www.ilpi.com/safety/mercury.html

References:

IS 2720 (Part 5): Determination of liquid and plastic limit

IS 2720(Part 6): Determination of shrinkage factors

Date of experiment: Sample:

Abstract (in about 200 words)

Record sheet for Atterberg limit

Sample no……………… Date …………………

Sr. No.	Test	No. of blows	Can no.	Wet mass of soil + can g	Dry mass of soil + can g	Empty mass of can g	Water content %	Result
1	Liquid Limit Tests							Liquid Limit (LL) = ……… Plastic Limit (PL) = ……… Plasticity Index (PI) =……….. Flow Index = ……………….
2								
3								
4								
1	Plastic Limit Test							
2								

Record sheet for shrinkage limit

Sample details: ………..   Date: ..….............

Observations	I	II	III	IV
Dish Number				
Empty wt. of dish, W_1 g				
Volume of dish, V_1 cm^3				
Weight of dish + wet soil,W_2 g				
Weight of dish + dry pat, W_3 g				
Weight of wet soil (W_2-W_1) G				
Weight of dry soil (W_3-W_1) g				
Volume of dry soil pat, V_2 cm^3				
Shrinkage Limit = $\frac{(W_2 - W_3) - (V_1 - V_2)}{(W_3 - W_1)} 100$				

Average Shrinkage Limit =................

RESULT SUMMARY

Liquid Limit	Plastic Limit	Shrinkage Limit	Plasticity Index	Flow Index

Calculation

1. Liquid limit: A graph is drawn between the Number of blows (on log scale) that are required to close the 2mm wide groove in soil for a distance of 12.5mm and the corresponding moisture content of the soil (on linear scale). The relationship is linear and referred to as flow curve. From this, the water content corresponding to the 25 blows is noted and reported as the liquid limit.

2. Plastic limit: Water content of the soil when it is crumbled when 3mm threads were rolled.

3. Alternatively, shrinkage limit (SL) can also be calculated using the following formula:

$$SL = \left[\frac{V_2}{(W_3 - W_1)} - \frac{1}{G_s} \right] 100$$

where G_s is the specific gravity of the soil fraction passing 425μm used in this test.

INFERENCE (in about 200 words)

DISCUSSIONS

EXPERIMENT 7
IS light compaction test

Objective: To determine the compaction characteristics of a soil sample using IS light compaction test.

Theory: Compaction is the process of packing soil particles closely together by mechanical means to increase its dry density.

There is an optimum amount of mixing water for a given soil and compaction process, which will give a maximum weight of soil per unit volume. This corresponds to the maximum dry density of the soil.

Apparatus

1. Standard Proctor mould with base plate and collar (should conform to IS 10074:1982).
2. Standard Proctor hammer
3. G.I. trays (600×500×80mm deep)
4. Weighing balance of 1g accuracy to weigh up to 10kg
5. Weighing balance of 0.01g accuracy to weigh moisture cans
6. Trowels
7. Measuring cylinder
8. Moisture cans
9. Extractor jack
10. Scraper (straight edge)
11. Grease or oil

Procedure

1. Note the dimensions of mould, collar and the base plate.
2. Apply a thin film of grease on inside of the mould.
3. Take the empty weight of the mould (without collar and base plate).
4. Fix the mould to the base plate with the help of wing nuts, place collar on the mould.
5. Take about 3000g of deaired soil passing through sieve size 4.75 mm in tray.

6. Add about 4 % water (approximately 120ml) to the soil and mix thoroughly with trowel and cover it with moist cloth.
7. To determine the Proctor density, place the soil in the mould in 3 layers of 50 mm thick, each in a loose state and give 25 blows to each layer using standard hammer. Scrap the top surface of the compacted layer before placing the next layer of a soil. Ensure that after compaction of the third layer, the level of compacted soil slightly above the top of the mould (usually within 5mm).
8. Remove the collar trim the soil with a straight edge, disconnect the mould from base plate and weigh it.
9. Take two samples from top and bottom respectively of the mould for water content determination.
10. Extrude the compacted soil from the mould and break it in to original size. Add another 3-4% of water and repeat step 7 to 9.
11. Continue the operations until a decrease in the weight of a soil is observed for at least two successive readings.
12. Draw a plot of water content v/s. dry density. Determine the maximum dry density and optimum moisture content corresponding to the standard proctor compaction.
13. On the same graph (in step 12), plot constant degree of saturation lines for 100%, 90%, 80% degrees of saturation. Calculate the degree of saturation corresponding to the maximum dry density.

Date of experiment: Sample:

Abstract (in about 200 words)

Sample no. : ……………… Date: …………………

Proctor cylinder details

Diameter: ……………… cm

Height: ………………… cm

Volume: ………………. cm^3

Empty wt. of Proctor Mould (Bare Cylinder): ……………..g

Proctor hammer details

Rammer wt.: 2.6 kg

Drop height: 31 cm

Record sheet for standard Proctor test

Trial No.	Wet mass. of soil + Cylinder g	Wet mass of soil g	Wet Density g/cm^3	Water content determination							Average water Content %	Dry density g/cm^3	Degree of Saturation
				Can no.	Wet soil +can g	Dry soil + can g	Mass of can g	Moisture Lost	Mass of dry soil g	water Content %			
1													
2													
3													
4													
5													
6													

Inference (in about 200 words)

Discussion (mention point wise, in about 200 words)

EXPERIMENT 8
Permeability test

Objective: To determine the permeability of a soil by (1) Constant head test and (2) Falling head test.

Theory: The ability of a soil to permit water to flow through its pores or voids is termed as permeability. As per Darcy's law $q = kiA$ or $k = \frac{q}{iA}$

where k= coefficient of the permeability, i= hydraulic gradient, A= area of cross-section, and q= discharge through soil sample.

Constant head test is used to measure permeability of soils that have relatively high permeability such as sands, gravel and coarse silts. For fine grained soils we use falling head permeability test. The principal difference between the two tests is that the hydraulic gradient is always changing in the falling head method, while it is constant for constant head method.

Constant Head Method: The coefficient of permeability is determined by $k = \frac{q}{Ai} = \frac{q}{A} \times \frac{L}{H}$ where k= coefficient of permeability, q= discharge through soil sample, A= area of cross-section, H= water head and L= length of the mould.

Falling Head Method: The coefficient of permeability is determined by

$$k = \frac{2.303.a.L}{A(t_1 - t_0)} \log_{10} \frac{H_0}{H_1}$$

where a= area of cross section of stand pipe, A = area of cross-section, L= length of the mould and, H_0 and H_1= water head at time t_0 and t_1 respectively.

Temperature correction: The reference temperature for this test is 20˚C. If the room temperature is different at the time of taking observations than apply the following correction:

$k_{20} = k_T \times \frac{\mu_T}{\mu_{20}}$, where μ_T and μ_{20} are the viscosity values at temperature T and 20˚, respectively.

Date of experiment: Sample:

Abstract (in about 200 words)

Measured data

(1) Constant Head Method

Diameter of mould………………………

Length of mould…………………………

Area of cross section…………………….

(2) Falling Head Method

Area of cross section of stand pipe………………………..

Diameter of mould……………………….

Length of mould…………………………

Area of cross section…………………….

Record sheet for constant head method

S.No.	Constant head (H) mm	Quantity of water (q) cm^3/s	Time s	k m/s
1				
2				
3				
4				
5				

Record sheet for Falling Head Method

S.No.	Initial head (H_1) Mm	Final head (H_2) mm	Elapsed time $(t_1 - t_0)$	$\log_{10} \frac{H_0}{H_1}$	k m/s
1					
2					
3					
4					
5					

Inference (in about 200 words)

Discussion (mention point wise, in about 200 words)

NOTES

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CE-602: GEOTECHNICAL ENGINEERING LAB-II

LABORATORY MANUAL





*Name*_______________________________

*Roll No*_______________________________

Group and Batch no. _______________________________

Year _______________________________

*Soil sample*_______________________________

OTHER ROLL NUMBERS IN THE GROUP

ROLL NO	NAME	ROLL NO	NAME
1.		5.	
2.		6.	
3.		7.	
4.		8.	

BY

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY

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No.: NIT/Civil/2012/BAM/R-203

Dated: ______________________

PREFACE

This laboratory manual has been prepared by Dr. B A Mir. In this update, the current practices in the NIT Geotechnical Engineering Laboratory and feedback from the previous years' undergraduate students has been taken into account. Your valuable suggestion to improve this edition would greatly be appreciated. Kindly input any suggestion through e-mail to:

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Dated: ________________________

INDEX

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2. BS 1377: Methods of test for soils for civil engineering purposes
3. Head, K. H. (1982). “Manual of soil laboratory testing”, Volume: I-II1. Pentech Press, London.
4. IS 2720 (various parts): Methods of test for soils, Bureau of Indian Standards

CE 602: GUIDELINES: LABORATORY RULES

1. Attendance is required for all students for all lab classes. Students who do not attend lab will not receive credit for their group's report.
2. Ensure that you are aware of the test and its procedure before each lab class.

- **You will NOT be allowed to attend the class if you are not prepared!**

3. Personal safety is top priority. Do not use equipment that is not assigned to you.
4. All accidents must be reported to your instructor or laboratory supervisor.
5. The surroundings near the equipment must be cleaned before leaving each lab class.
6. Ensure that the readings are checked by your TA for each lab period.

Laboratory Report

1. General

- Each student has to submit the report for each experiment.
- The test results and graphs are to be written and drawn in the space provided in this manual only. The manual should be submitted to the TAs at the end of each lab class compulsorily.
- Please write your roll number, batch and group number along with the name of the soil sample given to your batch at the space provided on the first page of the manual.

2. Report Organization

- **Abstract**

This contains a brief summary of the experiment. You should explain what data you will gather, the procedure for gathering the data, and the reason for the same. The abstract should be very specific within the number of words as stipulated above the given box.

- **Measured Data**

Tabulate the measured and calculated test values, preferably in the format given in the lab manual. You should also show sample calculations. Attach reference figures and/ or tables used if any in the evaluation of the data.

- **Summary**

Tabulate the results/findings from the experiment. Towards the end of the semester, you should generate a detailed summary of soil properties in a table during the submission of the manual after the last experiment.

- **Inference**

Write briefly on your inference from test observations and analysis of results.

- **Discussion**

Discuss the possible sources of error, accuracy of the test method, and anything noteworthy you observed during the test. State the specific Indian Standard number for test procedure

======

NOTE:

- Your Report must be neat, well organised and make a professional impact. Label all axis and include proper units.
- Your reports should be submitted within 7 days and before the beginning of the lab class of the next batch.
- Your reports will be graded on a scale from 0 to 5 as follows:
  5 = Complete and excellent work
  4 = Satisfactory, but with some minor errors
  3 = Significant errors or omissions
  2 = Very little correct or useful work
  1 = Lab report handed in, but with minimal work
  0 = Missed lab
- Two points will be deducted for late submission. Anyone caught plagiarizing work in the laboratory report, from a current or past student's notebook, will receive 0 on the grading scale or XX grade in the course.
- **Anyone caught plagiarizing work in the laboratory report, from a current or past student's notebook, will receive 0 on the grading scale or XX grade in the course.**

===

Declaration

I have read and understood the above guidelines.

Signature: ____________________

Name: ________________________

===

Dr. B A Mir (9419002500)

Faculty Incharge/Course Instructor

EXPERIMENT 1

Consolidation test

Objective: To determine the following consolidation properties of a given soil sample:

1. Coefficient of compressibility a_v
2. Coefficient of volume change m_v
3. Coefficient of consolidation c_v
4. Compression index c_c
5. Precompression pressure p_c
6. Coefficient of permeability k

Theory: When a saturated soil mass is loaded, the volume of voids decrease while the volume of solids and pore water remain unchanged. The decrease in voids results in escape of pore water present in them. This process is called consolidation.

This test is conducted over a period of a few days to obtain the properties of saturated clays. The samples are loaded to a stage until about 90% consolidation on each of them is achieved.

The following definitions are applicable in the theory of consolidation:

1. Coefficient of compressibility a_v

It is the change in void ratio per unit load increment. Both the void ration and applied loads are expressed on the arithmetic scales.

$$a_v = -(\Delta e/\Delta\sigma')$$

where Δe =change in void ratio, for a particular load increment, $\Delta\sigma'$ = incremental load

2. Coefficient of volume change m_v

It is also called the modulus of volume change. It is defined as the change in volume per unit volume, per unit load increment.

$$m_v = -\frac{\Delta e}{(1+e_0)\Delta\sigma'}$$, where e_0 = initial void ratio.

For a laterally confined soil (i.e. K_0 constant), change in volume is proportional to the change in thickness ΔH and initial volume is proportional to the initial thickness H_0. Therefore the above equation can be rewritten as,

$$m_v = \frac{\Delta H}{H_0 . \Delta\sigma'}$$

3. Coefficient of Consolidation c_v

It is the parameter which relates the change in excess pore water pressure to time. It is defined as the amount of water drained out of the voids of a clay prismatic element in unit time, due to consolidation.

$$c_v = \frac{T_v.H^2}{t_{90}}, \text{ where} \qquad T_v = \text{time factor (dimensionless)}$$

= 0.848 for 90% consolidation

The value of t_{90} is determined by Taylor's square root of time fitting method.

4. Compression Index c_c

It is the slope of the linear portion of e-logσ' curve. It is dimensionless.

$$c_c = \frac{e_0 - e_1}{\log(\frac{\sigma_1'}{\sigma_0'})}$$

5. Precompression pressure σ_0'

It is the maximum load to which an over-consolidated clay was ever subjected.

It is determined by Casagrande's method of empirical construction on the pressure-voids curve plotted on a semi-log graph.

6. Coefficient of Permeability k

It is the flow which takes place through a porous media per unit area perpendicular to flow, under unit hydraulic gradient.

It is given by the following relation:

$$k = \frac{c_v.a_v.\gamma_w}{1+e_0}, \text{ where} \qquad \gamma_w = \text{unit weight of water}$$

e_0 = initial void ratio

Apparatus

1) Preparation of the Test Specimens
   a) Flat glass plate, such as is used for liquid limit tests
   b) Cutting tools and a straight edge for specimen trimming
   c) Jig for holding the consolidation ring in place while jacking out the sample from a U-tube.
   d) Watch glass (100 mm diameter), or metal tray to hold the consolidation ring.
   e) Balance and vernier calipers, for weighing and measuring the dimensions of the specimen, and ring
   f) Apparatus for determining water content.

2) Consolidation Test

Oedometer cell, consisting of

1) Consolidation ring (cutting ring), 75mm internal diameter and 20mm high, of stainless steel or plated brass, rigid, with polished internal surface and a cutting edge.
2) Cell body and base (watertight)
3) Consolidation ring retainer and fixing screws or nuts
4) Loading Cap (pressure pad)
5) Two porous discs capable of withstanding maximum vertical load applied to the specimen.

c) Measurements

Dial gauge, Stop watch

d) Loading Frame, including the rigid stand

1. Rigid beam supported in suitable bearings
2. Adjustable counterbalance weights on beam
3. Loading yoke assembly, to apply vertical force to the specimen loading cap through a spherical ball on the oedometer cell.
4. Calibrated masses within accuracy of 1%

   2 nos. 200g, 1 no. 300g, 1 no. 500g, 5 nos. 1kg, 1 no. 2 kg

Procedure

1. Prepare and check apparatus.
2. Weigh and measure dimensions of consolidation ring
3. Cut and trim specimen into the ring
4. Determine water content and specific gravity from trimmings.
5. Weigh specimen into the ring
6. Assemble specimen into the consolidation ring
7. Fit cell in load frame
8. Set up loading yoke
9. Saturate the specimen.
10. Set dial gauge and note its least count.
11. Apply seating load (10 kN/m^2) to hanger.
12. Adjust beam to horizontal
13. Apply load increment to specimen (as given in the loading table).
14. Record settlement readings in dial gauge at time intervals given in the table 1.
15. Plot readings
16. Apply next load increment after 25-36 mins or until 90% consolidation has reached.
17. Repeat steps 12-16.
18. Remove specimen and take the entire specimen for water content measurements.
19. Calculate the consolidation parameters from graph and/ or calculations.

Date of experiment: Sample:

Abstract: (in about 150 words)

Measured data:

Specific Gravity: ____________________Diameter of the Sample: ___________________

Height of the Sample: _______________________ Area of C/S: __________________

Empty wt. of the ring: ________________________
Wt. of Ring + Wet wt. of the sample: ________________________
Dry wt. of the sample: ________________________

Initial Reading of the Dial Gauge at seating load: ____________________________
Least Count of Dial Gauge: _____________________________

Initial γ_{wet}: __________________________ γ_{dry}: __________________________
Water Content: _______________________
Initial Void Ratio (e_0): _______________________

Loading table

a) Consolidation

Elapsed Time t (in mins)	√t	Load Increments in kN/m^2						
		10 to 20	20 to 50	50 to 100	100 to 200	200 to 100	100 to 200	200 to 400
		Compression Dial Readings						
0	0							
0.25	0.5							
1	1							
2.25	1.5							
4	2							
6.25	2.5							
9	3							
12.25	3.5							
16	4							

b) Calculation of void ratio

Specific Gravity (G): ____________________ Area of Sample (A): __________________

Height of Sample: ____________________ Volume of Sample (V): ________________

Wt. of Sample: (W) ____________________ Dry Wt. (W_d): _______________________

Ht. of Solids (h_s) = W_d/GA = ____________________________________

Initial height of voids (h_v) = ($H-h_s$) = ______________________________

Load Applied (kN/m^2)	Dial Gauge (mm)	Compression (d) (mm)	Height of Voids (h_v - d)	Void Ratio e = h_v/h_s
0				
10				
20				
50				
100				
200				
400				

Inference (in about 150 words)

Discussions (mention point wise, in about 150 words)

EXPERIMENT NO. 2

Direct shear test

Objective: To determine the drained shear strength parameters (c', ϕ') of a sandy soil specimen by direct shear test.

Theory: In Direct Shear Test, a normal load N is applied to the soil which produces a vertical stress σ_n, where $\sigma_n = N/L^2$, L being the side of square box. A steady increasing displacement, which causes an increasing shearing force F, is applied to one-half of the sample in horizontal direction, while the other half is restricted by the load measuring device. The shear stress = F/L^2. The peak of the curve plotted, of this stress with displacement gives shear strength of the soil under that normal load. The test is carried for three different normal loads, to obtain corresponding 3 maximum shear stresses. A straight line is fitted between these points plotted between normal stress (σ) and shear stress (τ). The intercept on τ axis gives cohesion (c), while slope gives angle of friction (ϕ).

Apparatus

1. Shearbox carriage, watertight, running on ball or roller bearings

1) 2. Shearbox
   a) Shearbox body, in two halves, upper half fitted with a yoke for applying shear force. The point of application of shear force on the yoke should be in line with the plane of separation of the two halves of the box.
      The two halves are temporarily fixed by two clamping screws. Two lifting screws enable the upper half of the box to be lifted slightly.
   b) Base plate
   c) Load pad (with spherical seating and ball bearing)
   d) Upper and lower porous plates.
   e) Upper and lower grid plates (perforated). The grid plates enable the shearing forces to be transmitted uniformly along the length of the sample.

3. Loading yoke and weight hanger, for applying normal pressure to the specimen.

4. Lever-arm loading system, for extending the range of normal pressures. Beam ratio used is 5:1

5. Slotted weights for the loading hangar

6. Proving ring for measuring horizontal force, with calibration constant. Dial gauges to measure vertical and horizontal deflections of the shear box.

7. Electric motor and multi-speed drive unit, to provide a strain rate of 1.25 mm/min (typical for a drained test).

Procedure

1. Preparation of test specimen

Sand
Sand is placed in the Shearbox in 3 layers, each subjected to a controlled amount of tamping with a hand tamper. The mid-height of the middle layer should be about level with the plane of shear.

Note: Direct Shear Tests on cohesive soils are seldom conducted and at a lower strain rate. For these soils the following procedure is usually adapted for sample preparation.

a) Cohesive soils – Undisturbed
   Undisturbed specimens of cohesive soil are prepared by using square specimen cutter, form a U-100 tube or a block sample. The specimen is transferred to the Shearbox using a wood pusher.

b) Cohesive soils – Remoulded or Recompacted
   A specimen may be Recompacted or remoulded directly into the Shearbox at the appropriate moisture content. It is better to first compact the soil into a mould and then use the square specimen cutter as for an undisturbed sample.

2. Test

1. Prepare and check apparatus
2. Prepare test specimen
3. Assemble the apparatus
4. Fit load hangar
5. Set vertical Dial Gauge
6. Add water in the water bath (for the submerged test). Avoid this for dry test.
7. Apply normal stress
8. Lift top half of the box using lifting screws
9. Shear through the given mechanism
10. Remove load at the end of the test
11. Drain box
12. Remove shearbox
13. Remove specimen
14. Measure water content
15. Repeat stages 2-15 using at least two other specimens at different normal loads.
16. Calculate
17. Analyze data and report results – plot curves of shear stress vs. axial and horizontal strains.
18. Plot Mohr's Circle and evaluate the major and minor principal stress for the test conditions only.
19. Obtain data from other groups and plot the Mohr-Coulomb failure envelope to obtain c' and ϕ' for both the test conditions.

Date of experiment: Sample:

Abstract (in about 150 words)

Measured data:

Type of Test: ____

Size of the box: _________________________ Area of the box: ___________________

Thickness of the specimen: ________________Volume of the specimen: ___________

Mass of the box + base plate + porous stone + grid plate = _______________________
Mass of the box + base plate + porous stone + grid plate + Soil specimen =

____
Mass of the specimen = _________________________________

Bulk Density: ______________________ Water content: ______________________
Dry Density: _______________________

Proving Ring Constant: _______________________
Least count of dial gauge measuring vertical deflection: _________________________
Least count of dial gauge measuring horizontal deflection: _______________________

Data table

Strain Reading	Strain (%)	Normal Stress = kN/m^2		
		PR Dial Reading	Shear Stress (kN/m^2)	Vertical Dial Reading
0				
30				
60				
90				
120				
150				
180				
210				
240				
270				
300				
330				
360				
390				
420				
450				
480				
510				

Measured data:

Type of Test: ____

Size of the box: _________________________ Area of the box: ___________________

Thickness of the specimen: ________________Volume of the specimen: ____________

Mass of the box + base plate + porous stone + grid plate = _______________________

Mass of the box + base plate + porous stone + grid plate + Soil specimen =

____

Mass of the specimen = ________________________________

Bulk Density: ______________________ Water content: ______________________

Dry Density: _______________________

Proving Ring Constant: _______________________

Least count of dial gauge measuring vertical deflection: _________________________

Least count of dial gauge measuring horizontal deflection: _______________________

Data table

Strain Reading	Strain (%)	Normal Stress = kN/m^2		
		PR Dial Reading	Shear Stress (kN/m^2)	Vertical Dial Reading
0				
30				
60				
90				
120				
150				
180				
210				
240				
270				
300				
330				
360				
390				
420				
450				
480				
510				

Inference (in about 150 words)

Discussions (mention point wise, in about 150 words)

EXPERIMENT NO. 3

Unconfined compression test

Objective: To determine the unconfined compressive strength of a clayey soil.

Theory: The unconfined compressive strength (q_u) is the load per unit area at which the cylindrical soil specimen fails in compression. Typically, it is twice the cohesive strength or undrained shear strength for saturated clay ($\phi_u = 0$).

$q_u = \frac{P}{A}$, where P = axial load at failure

A = Corrected Area = $A_c = \frac{A_0}{1-\varepsilon}$,

A_0 = Initial Area of the specimen.

$\varepsilon = \frac{\Delta L}{L_0}$ = Axial Strain,

L_0 = Initial Length of the specimen

Apparatus

1. Machine driven mechanical load frame, capable of providing platen speeds in the range of 0.5-4 mm/min.
2. Proving ring, of capacity 1kN, and accuracy of 1N.
3. Platen with axial strain dial gauge mounting designed for unconfined compression testing. The assembly consists of a) Lower platen, fitting on to the load frame
   b) Post and bracket for dial gauge
   c) Upper platen fitting on to the proving ring.

Usually specimens up to 76 mm diameter can be accommodated. However, we shall use specimens of diameter 38 mm in this experiment.
(Alternatively, a triaxial test apparatus can be used without the cell fluid).

4. Dial Gauge of least count 0.01mm
5. Lever assembly fitting to the dial gauge.
6. Apparatus for extruding and trimming undisturbed soil specimens.
7. Vernier calipers
8. Balance, reading to 0.1gm
9. Drying oven, and other standard moisture content apparatus.

Procedure

1. Proving Ring Adjustment:
    a) Attach the proving ring to the cross head of the frame.
    b) Fit any necessary extension pieces, and the upper platen, securely to the lower end of the ring.
    c) Secure the dial gauge and check that the end of its stem makes contact with adjustable stop on the ring.

2. Adjust lower platen to provide space to insert the specimen.
3. Set the strain rate to 1.5 mm/min, on the loading machine.
4. Prepare the test specimen from the U-100 tube or the U-38 tube.
5. Measure specimen. It should have a diameter of 38mm and length of 76mm.
6. Set up specimen
7. Record zero readings
8. Apply compressive load
9. Take readings till the proving ring pointer moves in opposite direction.
10. Unload
11. Sketch mode of failure from the sample
12. Remove specimen
13. Remould and re-test two more samples
14. Measure water content
15. Plot graphs
16. Calculate
17. Report results

Date of experiment: Sample:

Abstract (in about 150 words)

Measured data:

Initial Length L_0 of the specimen: ___________________________
Initial Diameter D_0 of the specimen: _________________________
Initial Area A_0 of the specimen: _____________________________
Initial Volume V_0 of the specimen: ___________________________

Strain Rate: ___________________________

Mass of the specimen: ______________________________
Bulk Density of the specimen: ________________________

Water content: _________________________ (average of at least two values)
Dry Density of the specimen: _________________________

Specific Gravity G of the soil: __________________________

Void ratio e: _____________________________
Degree of saturation S: _____________________

Data table

S. No	Strain Div.	Load (kN)	Deformation (mm)	Strain (%) (ϵ_a)	Corrected Area A_c (m^2)	Axial Stress (kN/m^2)
1	0					
2	30					
3	60					
4	90					
5	120					
6	150					
7	180					
8	210					
9	240					
10	270					
11	300					
12	330					
13	360					
14	390					
15	420					
16	450					
17	480					
18	510					
19	540					
20	570					
21	600					

From Graph, q_u = ______________________

Undrained Shear Strength of saturated cohesive soil (ϕ=0) = $q_u/2$ = _________________

Inference (in about 150 words)

Discussions (mention point wise, in about 150 words)

EXPERIMENT NO. 4

Unconsolidated undrained triaxial test

Objective: To determine the undrained shear strength parameters of undisturbed or remoulded specimens by unconsolidated undrained triaxial test.

Theory: The triaxial test simulates the field conditions most, amongst the other tests for determining the shear parameters (cohesion, c and angle of friction, ϕ) in the laboratory, as it considers the confining pressure to which a soil is subjected, along with the vertical stresses. Generally, for stability of foundations, dams and slopes, we require to conduct undrained tests, whether consolidated or unconsolidated. For obtaining long term stability parameters, drained tests are done.

From the triaxial shear test results, Mohr's circles are drawn for different confining pressures, on which is drawn a common tangent called the Mohr-Coulomb Envelope. The intercept and slope of this line gives the required shear strength parameters c and ϕ.

Apparatus

Preparation and measurement of test specimen:
1. Extruder for vertical extrusion of samples from U-100 tubes.
2. Adaptor for holding 3 nos. 38 mm diameter sample tubes.
3. Sample tubes 38 mm internal diameter and about 230 mm long, with sharp cutting edges.
4. Extruder for 38 mm diameter tubes.
5. Split mould for forming 38 mm diameter specimen, 76 mm long.
6. Trimming knife, wire saw, spatula.
7. Straight edge.
8. Steel rule, Vernier Calipers.
9. Balance reading to 0.1 gm.
10. Oven and cans for obtaining water content.

Setting up and testing
1. Load frame, 10kN capacity or larger, preferably motorized. For 38 mm diameter specimens, a strain rate of 1.5mm/min is required.
2. Electronic LVDT (Linear Variable Displacement Transducer) for measuring displacement, and a load cell for measuring load.
3. Triaxial cell, capable of sustaining internal water pressure of up to 1000 kN/m^2, with Perspex body and fitted with a base, including the specimen pedestal.
4. Constant pressure system for maintaining cell pressure up to 1000 kN/m^2, at a constant level to within 10 kN/m^2.
5. Nylon tubing and couplings for connecting pressure system to the cell.
6. Pressure gauge covering the range 0-1000 kN/m^2, reading to at least 20 kN/m^2.
7. Mounting bracket for attaching strain dial gauge to the lower end of proving ring.
8. Upper and lower solid specimen end caps, 38mm diameter, of non-corrodible metal or plastic. The upper cap has a spherical seating for a ball bearing.

9. 3 latex rubber membranes, 38mm diameter and about 150mm long, 0.25mm thick, in the form of an open tube.
10. Rubber O-rings to fit tightly on the end caps.
11. Suction membrane stretcher for 38mm diameter specimens, fitted with a short length of rubber tube and pinch clip.
12. Sponges and wiping cloths.

Procedure

Preparation of sample
a) Undisturbed specimen:
1. Extrude the sample with the help of sample extruder.
2. Trim the ends of the specimen flat and normal to the axis.
3. Measure specimen dimensions.
4. Place the specimen on top of the lower end cap.
5. Take a (waste) portion for determining water content.

b) Remoulded specimen:
1. Compact the soil at the required water content in the mould.
2. Measure specimen dimensions.
3. Place the specimen on the lower end cap.

Testing
1. Prepare the test apparatus.
2. Put specimen on the lower end cap.
3. Fit membrane end caps.
4. Set up in triaxial cell.
5. Assemble cell.
6. Pressurize cell at 50 kN/m^2 (or at a cell pressure assigned for your group).
7. Select machine strain rate to 1.5mm/min.
8. Measure load and displacement from the electronic device by selecting appropriate switches.
9. Compress specimen by applying load, and continue till the load cell reading decreases.
10. When sample has failed, unload the system.
11. Drain out water from the cell.
12. Dismantle cell.
13. Remove specimen.
14. Sketch mode of failure.
15. Measure water content.
16. Clean equipment.
17. Repeat stages 6-17 for higher cell pressures.
18. Plot graphs and Mohr circles.
19. Calculate and report results.

Date of experiment: Sample:

Abstract (in about 150 words)

Measured data:

Type of Test: ____________________________________

Diameter of specimen: _____________________ Height of specimen: _______________

Volume of specimen: ______________________

Density of specimen: ______________________

Rate of Strain: ____________________________

Initial Area A_0: ___________________________

Data sheet for UU test

Strain Div.	Strain	Corrected Area	$\sigma_3 =$ kN/m^2			$\sigma_3 =$ kN/m^2			$\sigma_3 =$ kN/m^2		
	ε (%)	$A_c = A_0/(1-\varepsilon)$ (m^2)	Load (kN)	Stress (kN/m^2)	u (kN/m^2)	Load (kN)	Stress (kN/m^2)	u (kN/m^2)	Load (kN)	Stress (kN/m^2)	u (kN/m^2)
0											
30											
60											
90											
120											
150											
180											
210											
240											
270											
300											
330											
360											
390											
420											
450											
480											
510											
540											
570											
600											

Inference (in about 150 words)

Discussions (mention point wise, in about 150 words)

EXPERIMENT NO. 5

Vane shear test

Objective: To determine the undrained shear strength of clays using laboratory vane shear test apparatus.

Theory: Shear strengths of soft clay deposits is difficult to obtain accurately in laboratory by conventional triaxial tests as getting undisturbed samples is very difficult. In such situations, the shear strength can be obtained by conducting vane shear test in the field. The vane is pushed into the soil up to the desired depth and a torque is then applied at the upper end. The torque is measured by noting the angle of twist. Shear failure occurs over a cylindrical surface (periphery and ends) having a diameter d equal to that of the vane.

For the situation when the vane is completely buried into the specimen, the shear strength c_u is given by

$$c_u = \frac{T}{\pi(\frac{d^2h}{2} + \frac{d^3}{6})}$$

, where h = length of the vane blades of the vane shear apparatus.

T is given by

$$T = \frac{(\theta_{initial} - \theta_{final}).k.\pi}{180},$$

k = spring constant,

$\theta_{initial}$ = Initial angle of twist
θ_{final} = Final angle of twist

Sensitivity of clay

The term sensitivity is defined as the ratio of undisturbed to remoulded strength of clay. Sensitive clays are those having the value of sensitivity between 4 and 8. Higher the value, more sensitive is the clay.

Apparatus

1. Laboratory vane shear test apparatus (self contained), having essentially the following:
   - a) Frame and stand.
   - b) Vane mounting assembly.
   - c) Handle for raising and lowering the vane assembly by means of the square-thread lead screw.
   - d) Vane, with 4 blades, 12 mm wide and 24 mm long.
   - e) Handle for rotating vane head.
   - f) Graduated scales, marked in degrees, one on the fixed vane head, another rotating with the vanes.
   - g) Rotation pointer.
   - h) Vertical shaft attached to the knob fitted with pointer carrier on friction sleeve.
   - i) Set of springs (usually 4) of different stiffness, to allow for a range of soil strengths.
   - j) Calibration chart for the springs.

2. A means of supporting and clamping a 38 diameter sampling tube close to the edge.
3. Drying oven and cans for obtaining water content.
4. Spatulas, trimming knives, steel rule.
5. Stop-cock or timer.

Procedure

A. Preparation of test specimen

1) Clamp the sample tube securely.
2) Keep its axis vertical and with the end to be rested uppermost.
3) Remove any end cap, wax seal or packing material.
4) Trim the sample above tube so that its upper end is flat and perpendicular to the tube axis.

B. Vane shear test

1. Clamp the tube in position.
2. Select spring.
3. Prepare apparatus.
4. Adjust scales.
5. Measure initial angle of twist.
6. Insert vane.
7. Measure final angle of twist.
8. Measure shear strength.
9. Remould.
10. Repeat steps 4-8 to obtain remoulded shear strength.
11. Remove vane.
12. Measure water content and density.
13. Repeat the above steps on a fresh sample at least once.
14. Calculate and report results.

Date of experiment: Sample:

Abstract (in about 150 words)

Measured data:

		Position 1	Position 2	Position 3	Position 4
1	Initial angle				
2	Final angle				
3	Height of Vane H (cm)				
4	Diameter of Vane D (cm)				
5	Spring Constant (N/cm)				
6	Water Content				
7	Dry Density (kg/m^3)				
8	Torque (kNm)				
9	Shear Strength c_u (kN/m^2)				

Inference (in about 150 words)

Discussions (mention point wise, in about 150 words)

EXPERIMENT NO. 6

Consolidated undrained triaxial test (Demonstration)

Objective: To determine the undrained shear strength parameters of undisturbed or remoulded specimens by consolidated undrained triaxial test.

Theory: The triaxial test simulates the field conditions most, amongst the other tests for determining the shear parameters (cohesion, c and angle of friction, ϕ) in the laboratory, as it considers the confining pressure to which a soil is subjected, along with the vertical stresses. Generally, for stability of foundations, dams and slopes, we require to conduct undrained tests, whether consolidated or unconsolidated. For obtaining long term stability parameters, drained tests are done.

From the triaxial shear test results, Mohr's circles can be drawn for different effective confining pressures, on which is drawn a common tangent called the Mohr-Coulomb Envelope. The intercept and slope of this line gives the required shear strength parameters c' and ϕ'.

Apparatus

Preparation and measurement of test specimen:

1. Extruder for vertical extrusion of samples from U-100 tubes.
2. Adaptor for holding 3 nos. 38 mm diameter sample tubes.
3. Sample tubes 38 mm internal diameter and about 230 mm long, with sharp cutting edges.
4. Extruder for 38 mm diameter tubes.
5. Split mould for forming 38 mm diameter specimen, 76 mm long.
6. Trimming knife, wire saw, spatula.
7. Straight edge.
8. Steel rule, Vernier Calipers.
9. Balance reading to 0.1 gm.
10. Oven and cans for obtaining water content.

Setting up and testing

1. Load frame, 10kN capacity or larger, preferably motorized. For 38 mm diameter specimens, a strain rate of 1.5mm/min is required.
2. Electronic LVDT (Linear Variable Displacement Transducer) for measuring displacement, and a load cell for measuring load.
3. Triaxial cell, capable of sustaining internal water pressure of up to 1000 kN/m^2, with Perspex body and fitted with a base, including the specimen pedestal.
4. Constant pressure system for maintaining cell pressure up to 1000 kN/m^2, at a constant level to within 1 kN/m^2.
5. Nylon tubing and couplings for connecting pressure system to the cell.
6. Pressure gauge covering the range 0-1000 kN/m^2, reading to at least 1 kN/m^2.
7. Mounting bracket for attaching strain dial gauge to the lower end of proving ring.

8. Upper and lower solid specimen end caps, 38mm diameter, of non-corrodible metal or plastic. The upper cap has a spherical seating for a ball bearing.
9. Three latex rubber membranes, 38mm diameter and about 150mm long, 0.25mm thick, in the form of an open tube.
10. Rubber O-rings to fit tightly on the end caps.
11. Suction membrane stretcher for 38mm diameter specimens, fitted with a short length of rubber tube and pinch clip.
12. Sponges and wiping cloths.

Procedure

Preparation of sample
a) Undisturbed specimen:
1. Extrude the sample with the help of sample extruder.
2. Trim the ends of the specimen flat and normal to the axis.
3. Measure specimen dimensions.
4. Place the specimen on top of the lower end cap.
5. Take a (waste) portion for determining water content.

b) Remoulded specimen:
1. Compact the soil at the required water content in the mould.
2. Measure specimen dimensions.
3. Place the specimen on the lower end cap.

Testing
The entire testing procedure can be summarized into three main steps:

Saturation
The term 'saturation' as a stage of the test refers to ways by which the pore water pressure in the sample is increased so that air as a separate phase in the void spaces is eliminated. This enables reliable readings of pore pressure changes to be obtained during subsequent testing stages for the determination of the effective stress. The pore water pressure is increased in a controlled manner usually by the application of back pressure, so that the air in the voids is forced into the solution.

Consolidation
In the consolidation stage the sample is consolidated isotropically under a confining pressure by allowing water to drain out into the back pressure system so that the pore water pressure gradually falls until it virtually equals the back pressure. Drainage of water results in a decrease in volume and an increase in the effective stress, which after consolidation is equal to the difference between the confining pressure and the mean pore pressure remaining in the sample. If 100% consolidation is achieved, the pore pressure equals the back pressure.

Compression

In the compression stage the axial load is gradually increased while the total confining pressure remains constant, until failure occurs due to the maximum available shear strength of the sample being overcome. Compression can be extended to reach an 'ultimate' condition.

This process may also be referred to as the 'loading' stage, or 'shearing' stage, or 'shearing to failure'. Drainage conditions differ for the two types of the test, CD and CU. In the CU test, no drainage is permitted, but measurements are made of pore water pressure changes.

Usually three identical specimens are prepared from one soil sample for a set of tests, each specimen being isotropically consolidated to a different effective stress for the compression stage.

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