A Laboratory Manual for

Foundation Engineering

(Program Elective)

(3160613)

B.E. Semester 6 (Civil)

Directorate of Technical Education
Gandhinagar, Gujarat

Shantilal Shah Engineering College, Bhavnagar
Certificate

This is to certify that Mr./Ms. ____ _________ Enrollment No. _________________ of B.E. Semester 6 Civil Engineering of this Institute (GTU Code: ______) has satisfactorily completed the Practical / Tutorial work for the subject Soil Mechanics (3160613) for the academic year 2023-24.

Place: ___________
Date: ___________

Name and Sign of Faculty member

Head of the Department

Preface

The basic aim of laboratory/practical/field work is to enhance the required skills as well as creating ability amongst students to solve real time problem by developing relevant competencies in psychomotor domain. By keeping this in view, GTU has designed competency focused outcome-based curriculum for engineering degree programs where sufficient focus is given to the practical work. It shows importance of enhancement of skills amongst the students and pays attention to utilize every second of time allotted for practical amongst students, instructors and faculty members to achieve relevant outcomes by performing the experiments rather than having merely study type experiments. It is must for effective implementation of competency focused outcome-based curriculum that every practical is keenly designed to serve as a tool to develop and enhance relevant competency required by the various industry among every student. These psychomotor skills are very difficult to develop through traditional chalk and board content delivery method in the classroom. Accordingly, this lab manual is designed to focus on the industry defined relevant outcomes, rather than old practice of conducting practical to prove concept and theory.

By using this lab manual students can go through the relevant theory and procedure in advance before the actual performance which creates interest and students can have basic idea prior to performance. This in turn enhances pre-determined outcomes amongst students. Each experiment in this manual begins with industry relevant skills, course outcomes as well as practical outcomes (objectives). The students will also achieve safety and necessary precautions to be taken while performing practical.

This manual also provides guidelines to faculty members to facilitate student centric lab activities through each experiment by arranging and managing necessary resources in order that the students follow the procedures with required safety and necessary precautions to achieve the outcomes. It also gives an idea that how students will be assessed by providing rubrics.

Foundation Engineering is the elective course which deals with the behavior of the various foundation due to different geotechnical properties of soil. It provides a platform for students to apply the basic principles of Foundation Engineering to solve real life problems for various ground conditions.

Utmost care has been taken while preparing this lab manual however always there are chances of improvement. Therefore, we welcome constructive suggestions and comments for improvement and removal of errors if any from those who use it.

Practical – Course Outcome matrix

Course Outcomes (COs):

CO.1: Select appropriate soil investigation/testing technique/method and get true sub soil parameters used for selection of type of foundation as per codal guidelines.

CO.2: Select and design appropriate (Shallow/ Deep) foundation system for different structures, that satisfy the allowable bearing capacity and settlement requirements based on soil properties.

CO.3: Design vertical piles and pile groups for various types of loading, soil conditions and settlement requirements.

CO.4: Design and analyze retaining walls, sheet piles and diaphragm walls under static loads.

CO.5: Explain engineering behavior of expansive soils and selection of suitable foundation type for such soils, suggest suitable type of geosynthetics for various foundation issues and its proper implications.

Sr. No.	Objective(s) of Experiment	CO1	CO2	CO3	CO 4	CO 5
1.	(a) To plan out the visit preferably for Standard Penetration Test and CPT test nearby area of the institute. (b) To understand and interpret the data collected during site investigation and compute bearing capacity of soil using results of SPT, CPT and other in-situ tests.	√	√	√		
2.	To compute settlement using consolidation test results.	√	√		√	
3.	Primary investigation to determine the swelling potential of the soil.	√				√
4.	Measurement of Swelling Pressure of Soils	√				√
5.	To determine California Bearing Ratio (CBR) of remolded soil specimen in soaked and unsoaked conditions.	√				

Industry Relevant Skills

The following industry relevant competencies are expected to be developed in the student by undertaking the practical work of this laboratory.

1. Collection of important data and specific information required to complete a construction project in a best way.
2. Analysis of the data and preparing reports about the geotechnical conditions of a location.

Guidelines for the Faculty members

1. Teacher should provide the guideline with demonstration of practical to the students with all features.
2. Teacher shall explain basic concepts/theory related to the experiment to the students before starting of each practical.
3. Involve all the students in performance of each experiment.
4. Teacher is expected to share the skills and competencies to be developed in the students and ensure that the respective skills and competencies are developed in the students after the completion of the experimentation.
5. Teachers should give opportunity to students for hands-on experience after the demonstration.
6. Teacher may provide additional knowledge and skills to the students even though not covered in the manual but are expected from the students by concerned industry.
7. Give practical assignment and assess the performance of students based on task assigned to check whether it is as per the instructions or not.
8. Teacher is expected to refer complete curriculum of the course and follow the guidelines for implementation.

Instructions for Students

1. Students are expected to carefully listen to all the theory classes delivered by the faculty members and understand the COs, content of the course, teaching and examination scheme, skill set to be developed etc.
2. Students shall organize the work in the group and make record of all observations.
3. Students shall develop maintenance skill as expected by industries.
4. Student shall attempt to develop related hand-on skills and build confidence.
5. Student shall develop the habits of evolving more ideas, innovations, skills etc. apart from those included in scope of manual.
6. Student shall refer technical magazines and data books.
7. Student should develop a habit of submitting the experimentation work as per the schedule and s/he should be well prepared for the same.

Common Safety Instructions

Follow the safety instructions displayed in the laboratory.

Index
(Progressive Assessment Sheet)

Sr. No.	Objective(s) of Experiment	Page No.	Date of performance	Date of submission	Assessment Marks	Sign. of Teacher with date	Remarks
1.	(a) To plan out the visit preferably for Standard Penetration Test and CPT test nearby area of the institute. (b) To understand and interpret the data collected during site investigation and compute bearing capacity of soil using results of SPT, CPT and other in-situ tests						
2.	To compute settlement using consolidation test results.						
3.	Primary investigation to determine the swelling potential of the soil.						
4.	Measurement of Swelling Pressure of Soils						
5.	To determine California Bearing Ratio (CBR) of remolded soil specimen in soaked and unsoaked conditions.						
Total							

Experiment No: 1

Bearing Capacity Computation Using In-situ test Results

Date:

Relevant CO:

CO-1: Classify the soil, understand its behavior and will be able to compute/estimate index parameters.

CO-2: Select and design appropriate(shallow/Deep) foundation system for different structures, that satisfy the allowable bearing capacity and settlement requirements based on soil properties.

CO.3: Design vertical piles and pile groups for various types of loading, soil conditions and settlement requirements.

Objectives: (a) To plan out the visit preferably for Standard Penetration Test and CPT test nearby area of the institute.

(b) To understand and interpret the data collected during site investigation and compute bearing capacity of soil using results of SPT, CPT and other in-situ tests.

Equipment/Instruments: Standard Penetration Test and CPT test apparatus

Theory: Site investigation is the process by which geological, geotechnical, and other relevant information which might affect the construction or performance of a civil engineering or building project is acquired. The aim of the site exploration is to get maximum information that is useful in the design and construction of the project at a minimum cost. The knowledge about the site forms a vital role in the safe and economic development of a site. A thorough investigation of the site is very essential for the construction of any civil engineering works. Public building officials may require soil data together with the recommendations of the geotechnical consultant prior to issuance of a building permit. Elimination of the site exploration, which usually ranges from about 0.5 to1 percent of total construction costs, inadequate investigation can lead to very large construction cost. Based on the SPT "N" Value and qc cone resistance value from CPT test bearing capacity of soil can be calculated using empirical methods.

SPT Corrections

- Correction for Overburden Pressure

$N' = C_N * N$

N' = Corrected value of observed N

C_N = Correction factor for overburden pressure

- Correction for Dilatancy

If the stratum consists of fine sand and silt below water table, for N'> 15, the dilatancy correction is applied as

N" = 15 + 0.5 (N' – 15)   (When N' >15) as per IS: 2131-1981

If N' $\leq$ 15, N" = N'

Interpretations from SPT:

N"	Ø'	Dr (%)	consistency
0-4	25-30	0-15	very loose
4-10	27-32	15-35	loose
10-30	30-35	35-65	medium
30-50	35-40	65-85	dense
>50	38-43	85-100	very dense

Correlations with N values for Cohesive Soils

N-value	**Unconfined compressive strength(kg/cm2)**	**Consistency**
<2	<0.25	Very soft
2-4	0.25-0.50	Soft
4-8	0.50-1.00	Medium
8-16	1.00-2.00	Stiff
16-32	2.00-4.00	Very Stiff
>32	>4.00	Hard

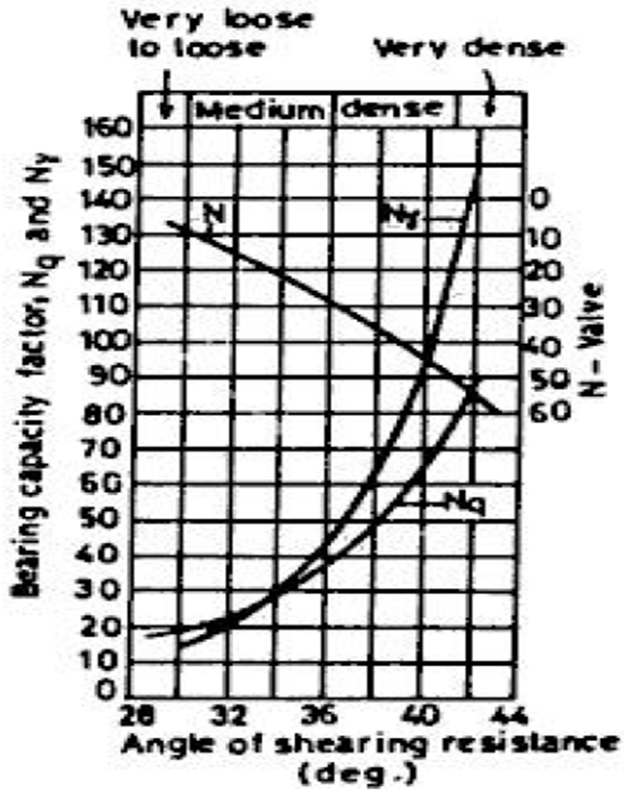


Fig: Relationship between N-values and ϕ', Nq and Nγ (after Peck, Hanson and Thornburn, 1974)

Teng (1962) has developed the following empirical equations for the net ultimate bearing capacity of footings on granular soils.

For continuous or continuous or strip footings:

$$q_{nu}= 1/6[3N^2\ BR'_w +5(100+N^2)\ D_f R_w]$$

For continuous or continuous or strip footings:

$$q_{nu}= 1/3[3N^2\ BR'_w +3(100+N^2)\ D_f R_w]$$

where:

q_{nu} = net ultimate bearing capacity in kN/m^2

N= Average N value corrected for overburden pressure and, if necessary, for dilatancy

B=depth of footing in m. If D_f>B, use D_f=B.

R'_w and R_w = correction factors for water table.

Interpretation with the results of CPT

The static cone resistance (qc) is used to determine the bearing capacity factor, Nγ from the correlation given by **Schmertmann(1975).**

$$N\gamma = qc/0.8\ (kg/cm^2)$$

From Nγ, ϕ and therefore Nq can be obtained **using IS:6403-1981**(Graph of bearing capacity determination from static cone resistance. This is used for estimating the net ultimate bearing capacity of shallow foundation).

Procedure:

Collecting data from the site where SPT, CPT and other insitu tests are performed. Using the collected data, prepare bore log report.

Calculation:

Result: The net ultimate bearing capacity of soil using SPT N value is =

The net ultimate bearing capacity of soil using qc value is =

Conclusion:

Quiz:

1. What is safe bearing capacity of soil?

2. Name the type of sampler used in SPT test?

Suggested Reference:

- IS: 1892-1979 Code of practice for subsurface investigation for foundation
- IS 2131: 1981 (Reaffirmed 2002) Method for standard penetration test for soils
- IS: 4968(Part-3) Method for subsurface sounding of soil. Static cone penetration test.
- Soil Mechanics and Foundation Engineering, Dr. K.R. Arora, Standard Publishers Distributors, New Delhi, Year 2010.
- Soil Mechanics and Foundation Engineering, S.K. Garg, Khanna Publishers, New Delhi, Year-2005
- Soil Mechanics and Foundation Engineering, P. Purushothama Raj, Pearson India Education Services Pvt. Ltd., Noida, Year-2013
- Laboratory manual for soil testing, Dr. D.K. Maharaj, S.K. Kataria & sons, New Delhi, Year-2017

References used by the students:

Rubric wise marks obtained:

Rubrics	**1**	**2**	**3**	**4**	**5**	**Total**
Marks						

Experiment No: 2

Settlement computation using consolidation test results

Date:

Relevant CO:

CO-1: Select appropriate soil investigation/ testing, technique/method and get true sub soil parameters used for selection of type of foundation as per codal guidelines.

CO-2: Select and design appropriate(shallow/Deep) foundation system for different structures, that satisfy the allowable bearing capacity and settlement requirements based on soil properties.

CO.4: Design and analyze retaining walls, sheet piles and diaphragm walls under static loads.

Objectives: To compute settlement using consolidation test results.

Equipment/Instruments: Consolidometer test setup, bore log report

Theory: The vertical downward movement of the base of a structure is called settlement and its effect upon the structure depends on its magnitude, its uniformity, the length of the time over which it takes place and the nature of the structure itself.

Procedure: The soil sample collected by performing field tests (e.g SPT). Laboratory tests to be conducted on the collected soil samples. The test results of consolidation by performing using Consolidometer test setup. Computation of coefficient of consolidation **(refer IS 2720 Part-15 Reaffirmed 2002)**. Also, the available bore log report of the site. Settlement is to be computed using the data.

Observation:

Table: Data Sheet for Consolidation Test: Time-Displacement Relationship

Ring Dimensions: Diameter (cm): ____________ Area (cm^2): _____________ Height (cm): _____________

Initial Data: Specimen Ht (cm).___________ Specific Gravity of Soil: ___________

Volume of ring……. Specific Gravity of soil sample:…… Initial Setting Pressure:……….

Pressure Intensity (Kg/cm^2)								
Elapsed Time (min)	$\sqrt{t}$	Dial Gauge Reading						
0								
0.25								
1								
2								
4								
8								
15								
30								
1 hr								

2 hrs								
4 hrs								
8 hrs								
24 hrs								
Time (min)								

Description	Before test	After test
Wt. of ring+ wet soil		
Wt. of ring +wt. of dry soil		
Water content		
Wt. of dry soil(Wd)		
Degree of saturation, S=(wG/e)		
Height of Solids, Hs=(Wd/G.*A *γw)		

- **Height of Solids Method**

Applied Pressure(kg/cm^2)	Final Dial Gauge Reading	Change in thickness ΔH(mm)	Specimen height	Drainage Path d = ¼(H1+H)	Height of Solids H-Hs	Void Ratio e =(H-Hs)/Hs

- **Change in Void ratio method**

Applied Pressure(kg/cm^2)	Final Dial Gauge Reading	Change in thickness ΔH(mm)	Specimen height	Change in void ratio Δe =0.1219ΔH	Height of voids H-Hs	Void Ratio e =(H-Hs)/Hs

Calculations:

1. **Height of solids** (H_S) is calculated from the equation
   $H_s = W_s / (G_s.\gamma_w A)$
2. **Void ratio.** Voids ratio at the end of various pressures are calculated from equation
   $e = (H – H_s)/H_s$

3. Coefficient of consolidation. The Coefficient of consolidation at each pressure increment is calculated by using the following equations:

i. $C_v = 0.197\ d^2/t_{50}$ (Log fitting method)

ii. $C_v = 0.848\ d^2/t_{90}$ (Square fitting method)

In the log fitting method, a plot is made between dial readings and logarithmic of time, and the time corresponding to 50% consolidation is determined. In the square root fitting method, a plot is made between dial readings and square root of time, and the time corresponding to 90% consolidation is determined. The values of C_v are recorded in Table.

4. Compression Index. To determine the compression index, a plot of voids ratio (e) Vs log (t) is made. The virgin compression curve would be a straight line and the slope of this line would give the compression index C_c.

5. Coefficient of compressibility. It is calculated as follows
Change in void ratio/Change in vertical stress
6. Coefficient of permeability. It is calculated as follows
$k = C_v.a_v.\gamma_w/(1+e_o)$.

GRAPHS:
1. Dial reading Vs log of time
2. Dial reading Vs square root of time.
3. Voids ratio Vs pressure intensity.

Total Settlement(S) = $S_i + S_c + S_s$

Where:
S_i = immediate elastic settlement
S_c= consolidation settlement
S_s= Settlement due to secondary consolidation of clay

$$S_i = qB\{1-\mu^2/Es\}I_w$$

Where
q = intensity of contact pressure
B= Least lateral dimension of footing
Es= Modulus of elasticity of soil
Iw= Influence factor (**use: IS 8009 Part-I 1976)**

Table: Correlations of E_s with N and qc (E in kN/m^2 for SPT)

Type of Soil	**SPT**	**CPT**
Sand (normally consolidated)	E= 500(N+15)	E=2 to 4 qc $E=2(1+D_r^2)qc$
Sand(saturated)	E= 250(N+15)	
Sand (over consolidated)		E= 6 to 30 qc
Gravelly sand	E=1200(N+6)	
Clayey sand	E=320(N+15)	E=3 to 6 qc
Silty Sand	E=300(N+6)	E= 1 to 2 qc
Soft clay		E= 5 to 8 qc

$$S_c = C_r \{H_o/1+e_o\} * \log\{\bar{\sigma_o}/\sigma_o) + C_c\{H_o/1+e_o\}*\log\{ (\bar{\sigma_o} + \Delta \bar{\sigma})/ \sigma_o\}$$

where:
C_r= recompression index
C_c=compression index
H_0= thickness
$\bar{\sigma_o}$ = effective stress
e= void ratio

$$S_s = \{H_0\ C_\alpha\ \Delta\log t\} / \{1+e_f\}$$

Where:
C_{α}= Secondary Compression index i.e equal to [Δe/ Δlog t]
e_f= void ratio at the end of primary consolidation (at U=100%)

Result:

Conclusions:

Suggested Reference:

- IS: 1892-1979 Code of practice for subsurface investigation for foundation
- IS 2131: 1981 (Reaffirmed 2002) Method for standard penetration test for soils
- IS: 4968(Part-3) Method for subsurface sounding of soil. Static cone penetration test.
- Soil Mechanics and Foundation Engineering, Dr. K.R. Arora, Standard Publishers Distributors, New Delhi, Year 2010.
- Soil Mechanics and Foundation Engineering, S.K. Garg, Khanna Publishers, New Delhi, Year-2005
- Soil Mechanics and Foundation Engineering, P. Purushothama Raj, Pearson India Education Services Pvt. Ltd., Noida, Year-2013
- Laboratory manual for soil testing, Dr. D.K. Maharaj, S.K. Kataria & sons, New Delhi, Year-2017

References used by the students:

Rubric wise marks obtained:

Rubrics	**1**	**2**	**3**	**4**	**5**	**Total**
Marks						

Experiment No: 3

Free swell index and swell potential

Date:

Relevant CO:

CO-1: Select appropriate soil investigation/ testing technique/method and get true sub soil parameters used for selection of type of foundation as per codal guidelines.

CO-5: Explain engineering behavior of expansive soils and selection of suitable foundation type for such soils, suggest suitable type of geosynthetics for various foundation issues and its proper implications

Objectives: Primary investigation to determine the swelling potential of the soil
.
Equipment/Instruments: Graduated glass cylinders of 100 ml capacity, Sieve - 425 pm IS sieve

Theory:

- To identify the expansive nature of the soil.
- Expansive soils are one of the problematic soils found in arid and semi-arid regions.
- Black cotton soils found in India which covers almost 20% of the total area.
- Expansive soils have tendency to expand or swell (increase in volume) in presence of water and shrink (decrease in volume) in dry conditions. This results in excessive differential settlement due to repetitive cycles of swelling and shrinkage resulting in significant damage to the foundation and adjoining super structure.

Degree of expansiveness	FSI (%)
Low	Less Than 20
Moderate	20 to 35
High	35 to 50
Very high	Greater than 50

Procedure:

1) Take three specimen of 10 g of oven dried soil passing through 425-micron IS Sieve.

2) Pour each soil specimen into a graduated glass cylinders of 100 ml capacity.

3) One cylinder shall then be filled with kerosene oil and the other two cylinders with distilled water up to the 100 ml.

4) Remove entrapped air by stirring well with the glass rod. Allow the soils in all three cylinders to settle.

5) Sufficient time (not less than 24 h) shall be allowed for the soil sample to attain equilibrium state without any further change in the volume of the soils.

6) The final volume of soils in each of the cylinders shall be read out.

NOTE**-** In the case of highly swelling nature of soils, the sample size may be 5 g or alternatively a cylinder of 250 ml capacity may be used.

Observations:

1) Vd= Volume of soil specimen read from the graduated cylinder containing distilled water = -----

2) Vk = Volume of soil specimen read from the graduated cylinder containing kerosene = ---------

Calculation:

$$\text{Free swell index (\%)} = ((V_d - V_k)/V_k) * 100$$

where,

Vd= Volume of soil specimen read from the graduated cylinder containing distilled water

Vk = Volume of soil specimen read from the graduated cylinder containing kerosene

Result:

Conclusion:

Suggested Reference:

- IS : 2720 (Part XL) – 1977, Reaffirmed 1997
- Soil Mechanics and Foundation Engineering, Dr. K.R. Arora, Standard Publishers Distributors, New Delhi, Year 2010.
- Soil Mechanics and Foundation Engineering, S.K.Garg, Khanna Publishers, New Delhi,

Year-2005

- Soil Mechanics and Foundation Engineering, P.Purushothama Raj, Pearson India Education Services Pvt. Ltd., Noida, Year-2013
- Laboratory manual for soil testing, Dr. D.K.Maharaj, S.K.Kataria & sons, New Delhi, Year-2017

References used by the students:

Rubric wise marks obtained:

Rubrics	**1**	**2**	**3**	**4**	**5**	**Total**
Marks						

Experiment No: 4

Swelling Pressure Test

Date:

Relevant CO:

CO-1: Select appropriate soil investigation/ testing technique/method and get true sub soil parameters used for selection of type of foundation as per codal guidelines**.**

CO-5: Explain engineering behavior of expansive soils and selection of suitable foundation type for such soils, suggest suitable type of geosynthetics for various foundation issues and its proper implications

Objectives: Measurement of Swelling Pressure of Soils

Equipment/Instruments: Consolidometer, Dial Gauge, Water Reservoir, Moisture Room, Soil Trimming Tools, Oven, Desiccator, Balance, Containers, Moisture Content Cans, Loading Unit of 5000 kg Capacity (Strain controlled type), High Sensitive Proving Ring of 200 kg Capacity

Theory:

The expansive clays increase in their volume when they come in contact with water owing to surface properties of these clay types. The pressure which the expansive soil exerts, if it is not allowed to swell or the volume change of the soil is arrested, is known as Swelling Pressure of Soil. The swelling pressure is dependent upon several factors (a) the type and amount of clay in the soil and the nature of the clay mineral, (b) the initial water content and dry density, (c) nature of pore fluid, (d) the stress history of the soil including the confining pressure and (e) drying and wetting cycles to which the soils have been subjected to.

A soil with high swell pressure is considered “unsuitable” for use as embankment fill material and in case the sub-soil is having high swell pressure then suitable “ground improvement measures” may be needed before constructing embankment on such soil. One of the methods for constructing embankments on expansive soils is to lay a CNS (non-swelling clay) layer at the base of the embankment, to isolate the sub-soil from the moisture (mainly rain water) coming in vertically downwards direction. For any clay to be classified as “CNS (non-swelling clay)”, it should not have swell pressure more than the specified value (normally 0.5 kg/m^2).

In laboratory, one dimensional swelling pressure test is conducted using either fixed or the floating rings on both undisturbed and re-moulded soils in the partially saturated condition. Two methods are employed, namely, “Consolidometer method” in which the volume change of the soil is permitted and the corresponding pressure required to bring back the soil to its original volume is measured and "constant volume method" in which the volume change is prevented and the consequent pressure is measured.

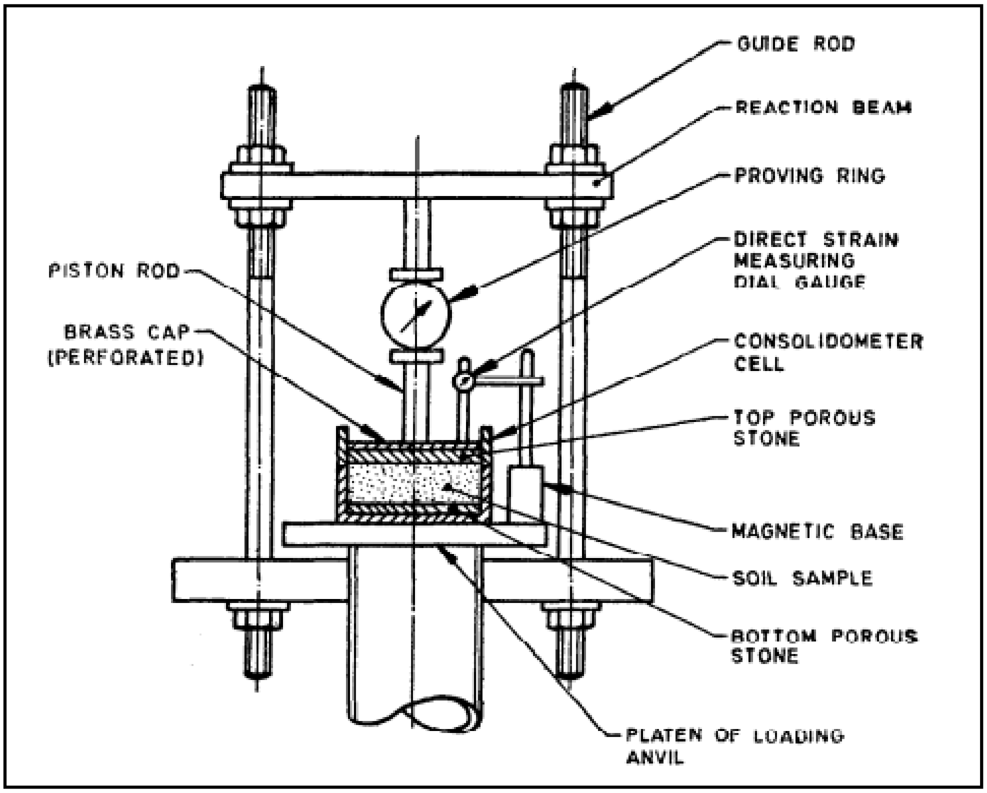


Fig. Set-Up for Measuring Swelling Pressure in Constant Volume Method
IS:2720 (Part XLI) - 1977

Procedure:

By Consolidometer Method:

1) Preparation of Specimen from Undisturbed Soil Samples: Clean and weigh the empty container. Cut-off the specimen either from undisturbed tube sample or from block sample, the latter generally being more representative of the field conditions. Remove about 30mm height from one end of the soil sample. Gradually insert the consolidation ring in the sample by pressing with hands and carefully removing the material around the ring. The soil specimen so cut shall project as far as 10mm on either side of the ring. Then trim the specimen smooth and flush with the top and bottom of the ring. Wipe the container ring clear of any soil sticking to the outside and weigh again with the soil. The whole process should be quick to ensure minimum loss of moisture and if possible, shall be carried out in the moisture room. The representative specimens from the soil trimming shall be taken in moisture content cans and their moisture content determined in accordance with IS:2720 (Part-XI).

2) Preparation of Specimen from Disturbed Soil Sample: The soil sample shall be compacted to the desired (field) density and water content in a standard compaction proctor mould. Samples suitable sizes are cut from it as given in Para (i) above.

NOTE-1: Since swelling pressure of the soil is very much influenced by its initial water content and dry density, it shall be ensured that in the case of undisturbed soil samples, the specimen shall be collected from the field for test during the driest season of the year, so that the swelling pressure recorded shall be maximum. In case of remoulded soil sample, the initial water content shall be at the shrinkage limit or field water content, so that the swelling pressure recorded shall be maximum.

NOTE-2: The desiccated soil obtained from the field coupled with smaller thickness consolidation ring make the undisturbed soil specimen always in danger of being disturbed during trimming; hence great care shall be taken to handle the specimen delicately with the least pressure applied to the soil.

3) Saturate the porous stones by boiling in distilled water for at least 15 minutes and moisten at surfaces of the Consolidometer which are to be enclosed. Assemble the Consolidometer with the soil specimen (in the ring) and porous stones at top and bottom of the specimen, providing wet filter paper between the soil specimen and the porous stone. Then position the loading block centrally on the top porous stone.

4) Mount this assembly on the loading frame such that load applied is transmitted to the so specimen through the loading cap.

5) In the case of the lever loading system, the apparatus shall be properly counter-balanced. If jack with load measurements by platform scales is used as the loading systems the tare weight with the empty consolidation apparatus, excluding those parts which will be on top of the specimen, which rest on the platform shall be determined before filling the ring with the soil and this tare weight shall be added to the computed scale loads required to give the desire pressures at the time of loading the soil specimen.

6) Screw the holder with the dial gauge to record the progressive vertical heave of the specimen under no load.

7) Place initial setting load of 50 gf/cm2 (this includes weight of the porous stone and the loading pad) on the loading hanger and note initial reading of the dial gauge.

8) Connect the system to a water reservoir with the level of water in the reservoir being at about the same level as the soil specimen and allow water to flow in the sample. Then allow the soil to swell.

9) Record the free swell readings shown by the dial gauge under the seating load at different time intervals. The dial gauge readings shall be taken till equilibrium is reached. This is ensured by making a plot of swelling dial reading versus time in hours, which plot becomes asymptotic with abscissa (time scale). The equilibrium swelling is normally reached over a period of 6 to 7 day in general for all expansive soils.

10) Then subject the swollen sample to consolidation under different pressures. Record the compression dial readings till the dial readings attain a steady state for each load applied over the specimen. The consolidation loads shall be applied till the specimen attains its origin volume.

By Constant Volume Method:

1) Preparation of Specimen from Undisturbed Soil Samples as well as Preparation of Specimen from Disturbed Soil Sample: Same as for "Consolidometer Method".

2) Keep the consolidation specimen ring with the specimen between two porous stones saturated in boiling water providing a filter paper between the soil specimen and the porous stone. The loading block shall then be positioned centrally on the top of the porous stone.

3) Then place this assembly on the platen of the loading unit. The load measuring proving ring to be attached to the load frame shall be placed in contact with the consolidation cell without an eccentricity. A direct strain measuring dial gauge shall be fitted to the cell. Inundate the specimen with distilled water and allow it to swell.

4) Note down the initial reading of the proving ring. The swelling of the specimen with increasing volume shall be obtained in the strain measuring load gauge. To keep the specimen at constant volume, the platen shall be so adjusted that the dial gauge always shows the original reading. This adjustment shall be done at every 1 mm of swell or earlier. The duration of test shall conform to the requirements given in "Consolidometer method". Then dismantle the assembly and extract the soil specimen from the consolidation ring to determine final moisture content accordance with IS: 2720 (Part-IX).

Observations:

Table 1: Details of soil specimen (By Consolidometer Method/ Constant Volume Method)

Natural Density			**Moisture Content**		
Description	**Test- 1**	**Test-2**	**Description**	**Before Test**	**After Test**
Weight of container ring+ wet specimen			Weight of container + wet soil		
Weight of container			Weight of container + dry soil		
Diameter of container			Weight of container		
Initial thickness of soil sample			Weight of water		
Wet density in g/ml			Weight of dry soil		
Dry density in			Moisture		

g/ml			content in %		

Table 2: Data Sheet for Swell - Compression Test (By Consolidometer Method)

Elapsed Time in Hours	**Swelling dial reading**	**Elapsed Time in Hours**	**Swelling dial reading**
0		36	
0.5		48	
1		60	
2		72	
4		96	
8		120	
12		144	
24			

Table 3: Data Sheet for Swell - Compression Test (By Consolidometer Method)

Pressure Increment (kgf/cm^2)	Pressure Increment (kN/m^2)	Compression	Change in Thickness of Expanded Specimen
0.0-0.05	0-5		
0.05-0.10	5-10		
0.10-0.25	10-25		
0.25-0.50	25-50		
0.50-1.00	50-100		
1.00-2.00	100-200		
2.00-4.00	200-400		
4.00-8.00	400-800		
8.00-16.00	800-1600		

Calculation:

By Consolidometer Method:

The observed swelling dial reading recorded in Table 1 shall be plotted with elapsed time as abscissa and swelling dial reading as ordinates on natural scale. A smooth curve shall be drawn joining these points. If the curve so drawn becomes asymptotic with the abscissa, the swelling has reached its maximum and swelling phase shall be stopped, and the consolidation phase shall be started. The compression readings shall be tabulated as in Table 3 and a plot of change in thickness of expanded specimen as ordinates and consolidation pressure applied as abscissa in semi-logarithmic scale shall be made. The swelling pressure exerted by the soil specimen under zero swelling condition shall be obtained by interpolation and expressed in kN/m^2 (kgf/cm^2).

By Constant Volume Method:

The difference between the final and initial dial readings of the proving ring gives total load in terms of division which when multiplied by the calibration factor gives the total load. This when divided by the cross-sectional area of the soil specimen gives the swell pressure expressed in kN/m^2 (kgf/cm^2).

Table 4: Swell Pressure Data (By Constant Volume Method)

Date	Time	Strain Dial Gauge Reading Before Adjustment	Proving Ring Reading	Differences	Load in kg	Swell Pressure in kg/cm^2	Remarks

Result:

Conclusion:

Suggested Reference:

- IS 2720(Part 41):1977 Reaffirmed - December 2016.
- Soil Mechanics and Foundation Engineering, Dr. K.R. Arora, Standard Publishers Distributors, New Delhi, Year 2010.
- Soil Mechanics and Foundation Engineering, S.K. Garg, Khanna Publishers, New Delhi, Year-2005
- Soil Mechanics and Foundation Engineering, P. Purushothama Raj, Pearson India Education Services Pvt. Ltd., Noida, Year-2013

- Laboratory manual for soil testing, Dr. D.K. Maharaj, S.K. Kataria & sons, New Delhi, Year-2017

References used by the students: IS 2720 (Part 41):1977 Methods of test for soils: Measurement of swelling pressure of soils. Reaffirmed - December 2016.

Rubric wise marks obtained:

Rubrics	1	2	3	4	5	Total
Marks						

Experiment No: 5

California Bearing Ratio Test

Date:

Relevant CO:

CO-1: Select appropriate soil investigation/testing technique/method and get true sub soil parameters used for selection of foundation as per codal provisions.

Objectives: To determine California Bearing Ratio (CBR) of remolded soil specimen in soaked and unsoaked conditions

Equipment/Instruments: CBR mould with detachable perforated base plate ,Spacer disc with a removable handle (to be placed inside the mould),Collar of 50mm high, Penetration plunger of 50 mm diameter, One annular and a few slotted surcharge masses 2.5 kg each, Rammer (2.6 kg with 310mm drop for standard proctor results) and (4.89 kg with 450mm drop for modified results), Straight cutting edge, Loading machine of 50 kN capacity fitted with a calibrated proving ring to which plunger has to be attached, Penetration measuring dial gauge of 0.01mm accuracy, Soaking tank, Swelling gauge consisting of perforated plate with adjustable extension stem

Theory: The California Bearing Ratio (CBR) test was developed by the California division of Highway as a method of classifying and evaluating soil-subgrade and base course material for flexible pavements and in designing base course for airfield pavements. The California Bearing Ratio (CBR) is defined as the ratio of load corresponding to the chosen penetration to the standard load for same penetration expressed in percentage.

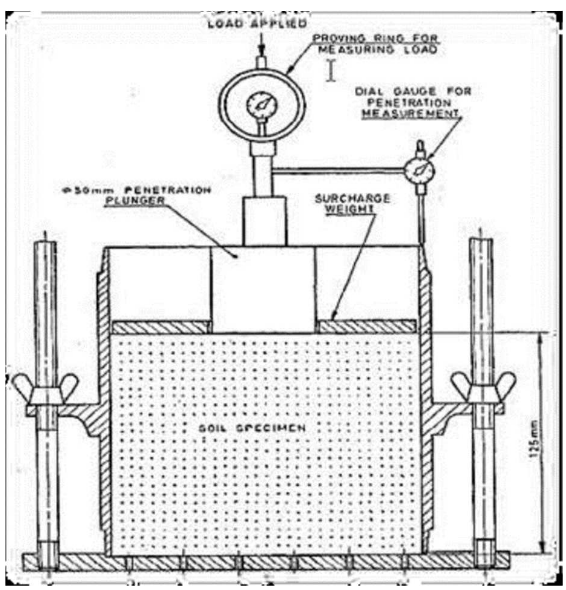


Fig. California Bearing Ratio Test Setup

Mould Specification:

Diameter of the mould = 150mm

Height of the mould = 175mm

Height of the CBR soil specimen = 125mm

Soil specification:

Particle size = should pass through 19mm sieve

Soil particles of size greater than 19mm should be replaced by particles of size between 4.75mm and 19mm

Procedure:

1. Take the weight of empty mould
2. Keep the spacer disc on the base plate and a filter paper on the disc and fix the mould to the base plate with the disc inside the mould and the attach the collar over the mould.
3. Add water to the specimen and compact it in accordance to Standard proctor test or modified proctor test.
4. After compaction, remove the collar and level the surface using cutting edge.
5. Detach the base pate and remove the spacer disc.
6. Take the weight of mould + compacted specimen and determine the bulk density of the specimen
7. Take sample for moisture content determination and hence find the dry density
8. Place filter paper on the perforated base plate.
9. Fix the mould upside down to the base plate so that surface of the specimen which was downwards in contact with spacer disc during compaction is now turned upwards on which the penetration test is to be performed (for unsoaked condition).
10. For soaked condition, Fix adjustable stem and perforated plate on the compacted soil specimen in the mould along with 2.5kg surcharge load
11. Place the above set up in the soaking tank for four days (ignore this step in case of unsoaked CBR).
12. After four days, measure the swell reading and find % swell with the help of dial gauge reading
13. Remove the mould from the tank and allow water to drain
14. Then place the specimen under the penetration piston and place total surcharge load of 4kg (2.5kg during soaking + 1.5 kg during testing)
15. The load and deformation gauges shall then be set to zero
16. Load shall be applied to the plunger into the soil at the rate of 1.25 mm per minute.
17. Reading of the load shall be taken at penetrations of 0.5, 1.0, 1.5, 2.0, 2.5, 4.0, 5.0, 7.5, 10.0 and 12.5 mm
18. Remove the plunger and determine the water content of the soil.
19. Plot load versus deformation curve.

CALCULATIONS:
Expansion ratio:

$$\text{Expansion ratio} = \frac{d_f - d_s}{h} \times 100$$

where,
d_f=final dial gauge reading in mm(after 96 hrs),
d_s=initial dial gauge reading in mm, and
h=initial height of the specimen in mm

California bearing Ratio (CBR):

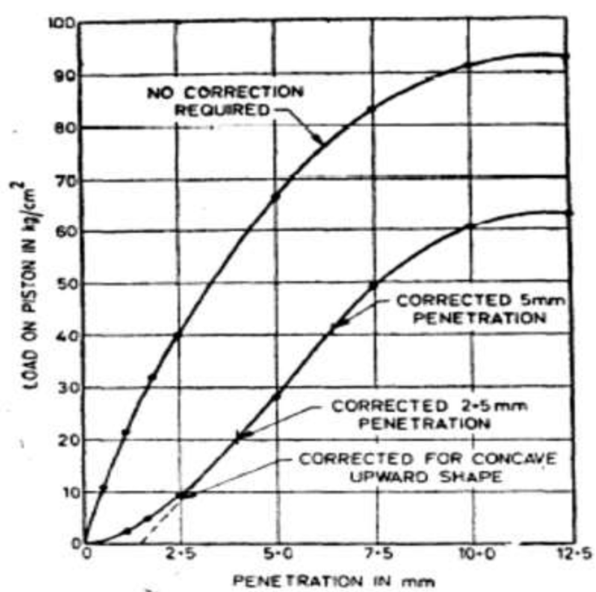
$$\text{California Bearing Ratio} = \frac{P_T}{P_S} \times 100$$

where,
P_T = corrected unit (or total) test load corresponding to the chosen penetration from the load penetration curve
P_S = unit (or total) standard load for the same depth of penetration as for *PT* taken from the table given below.

Penetration Depth	*Unit Standard Load*	*Total Standard Load*
(1)	(2)	(3)
mm	kg/cm²	kgf
2·5	70	1 370
5·0	105	2 055

Generally, the CBR value at 2.5 mm penetration will be greater than that at 5 mm penetration and in such a case, the former shall be taken as the CBR value for design purposes. If the CBR value corresponding to a penetration of 5 mm exceeds that for 2.5 mm, the test shall be repeated. If identical results follow, the CBR corresponding to 5 mm penetration shall be taken for design.

Corrections in load vs. deformation curve:
The curve plotted may be convex upwards although the initial portion of the curve may be concave upwards due to surface irregularities. A correction shall then be applied by joining the tangent to the curve at the point of maximum slope. The corrected curve shall be taken to be this tangent, together with the convex portion of the original curve, within the origin of strains shifted to the point where the tangent cuts the horizontal axis for penetration.



IRC-37 SPECIFICATIONS:

SUBGRADE:
The CBR values for sub grade should range from 2% to 10%. Preferably it should be greater than 2%. If the CBR value is less than 2%, a soil capping layer of 150mm thickness, having CBR value greater than or equal to 10% should be provided between sub grade and sub-base. The sub grade should be compacted to 97% of maximum dry density achieved with heavy (modified proctor) compaction as well as the dry density obtained should not be less than 1.75gm/cc for

Expressways, National Highways, State Highways, Major District Roads and other heavily trafficked roads. In other cases the subgrade should be compacted to at least 97% of the standard proctor density.

SUB-BASE:
The sub base soil should have liquid limit less than 25% and plasticity index less than 6%. For cumulative traffic up to 2 msa (million standard axles), the CBR value should not be less than 20%. For cumulative traffic greater than 2 msa (million standard axles), the CBR value should not be less than 30%.

Note:
CBR test is performed for both soaked and unsoaked soil specimen. Usually, the unsoaked CBR value will be greater than the CBR value for soaked condition. The CBR values for unsoaked specimen are suitable for (i) arid regions, (ii) where comparatively thick bituminous surfacing of an impermeable nature is provided in top and where the water table is very deep. For other cases, soaked CBR results are preferred.

Observations:

Maximum dry density of the specimen to be prepared		g/cc
Optimum moisture content to be taken		%
Weight of the empty mould		g
Weight of the soil specimen and mould before soaking		g
Volume of the soil specimen		cm3
Bulk density of the specimen		g/cc
Water content of the specimen		%
Dry density of the specimen		g/cc
Diameter of plunger		cm
Area of plunger		sq.cm
Deformation rate		mm/minute
Proving ring constant		kN/division
Standard pressure for 2.5mm penetration		kg/cm^2
Standard pressure for 5mm penetration		kg/cm^2

Unsoaked condition:

Dial gauge reading in divisions	**Penetration in mm**	**Load in division**	**Load in kN**	**Pressure in kg/cm^2**	**CBR (after correction)**
0					
50					
100					
150					
200					
250					
400					
500					
750					

1000					
1250					

Soaked condition:

Maximum dry density of the specimen to be prepared		g/cc
Optimum moisture content to be taken		%
Weight of the empty mould		g
Weight of the soil specimen and mould before soaking		g
Volume of the soil specimen		cm^3
Bulk density of the specimen		g/cc
Water content of the specimen		%
Dry density of the specimen		g/cc
Weight of the soil specimen and mould after soaking for 96 hours		g
Weight gain due to absorption of water		g
Diameter of plunger		cm
Area of plunger		sq.cm
Deformation rate		mm/minute
Proving ring constant		kN/division
Standard pressure for 2.5mm penetration		kg/cm^2
Standard pressure for 5mm penetration		kg/cm^2

Dial gauge reading in divisions	**Penetration in mm**	**Load in division**	**Load in kN**	**Pressure in kg/cm^2**	**CBR (after correction)**
0					
50					
100					
150					
200					
250					
400					
500					
750					
1000					
1250					

Result: The CBR value is ……….

Conclusion:

Quiz:

1.Enlist the significance of CBR value in various geotechnical engineering applications.

2.If CBR value for 5.0mm penetration is greater than CBR value at 2.5mm penetration then what should be done?

Suggested Reference:

- IS: 2720 (Part 16) – 1987 (Re-affirmed 2002) Code of practice for Laboratory determination of CBR.
- **(**II) Soil Mechanics and Foundation Engineering, Dr. K.R. Arora, Standard Publishers Distributors, New Delhi, Year 2010.
- (III) Soil Mechanics and Foundation Engineering, S. K. Garg, Khanna Publishers, New Delhi, Year-2005.
- (IV) Soil Mechanics and Foundation Engineering, P. Purushothama Raj, Pearson India Education Services Pvt. Ltd., Noida, Year-2013.
- (V) Laboratory manual for soil testing, Dr. D. K. Maharaj, S. K. Kataria & sons, New Delhi, Year-2017

References used by the students:

Rubric wise marks obtained:

Rubrics	**1**	**2**	**3**	**4**	**5**	**Total**
Marks						