PREFACE

Welcome to the Reference Handbook on Soil Mechanics and Foundation Engineering. This handbook is designed to serve as a comprehensive guide for engineers, researchers, students, and anyone interested in the fascinating field of geotechnical engineering. Soil mechanics and foundation engineering are pivotal disciplines within civil engineering, playing a crucial role in the design, construction, and maintenance of structures ranging from buildings and bridges to dams and highways.

In this handbook, we aim to provide a thorough understanding of the fundamental principles, advanced theories, practical applications, and emerging trends in soil mechanics and foundation engineering. Our goal is to equip readers with the knowledge and tools necessary to tackle real-world geotechnical challenges effectively.

Importance of Indian Standards:

The relevance of Indian standards in soil mechanics and foundation engineering cannot be overstated. India's diverse geological and environmental conditions present unique challenges and opportunities in the field of geotechnical engineering. Indian Standards (IS) formulated by the **Bureau of Indian Standards (BIS)** serve as essential guidelines and benchmarks for engineers and researchers working in this domain.

Indian Standards encompass a wide range of topics relevant to soil mechanics and foundation engineering, including soil classification, testing methods, design criteria for foundations, and construction practices. By adhering to these standards, engineers ensure the safety, reliability, and sustainability of infrastructure projects across the country.

Moreover, Indian Standards reflect the collective wisdom and experience of geotechnical experts, researchers, and practitioners in India. They incorporate indigenous knowledge, regional considerations, and lessons learned from past projects, making them particularly suited to the Indian context.

Holistic Approach:

Understanding soil mechanics and foundation engineering requires a holistic approach that integrates theoretical knowledge with practical insights and contextual understanding. By incorporating Indian Standards into our discussions and analyses, this handbook aims to provide readers with a comprehensive and holistic perspective on the subject.

We emphasize the importance of not only mastering theoretical concepts but also applying them effectively in real-world scenarios. Through case studies, examples, and practical exercises, readers will gain hands-on experience in solving geotechnical problems and making informed engineering decisions.

Furthermore, by aligning our discussions with Indian Standards, we ensure that readers are well-equipped to navigate the regulatory landscape and comply with relevant guidelines and specifications. This holistic approach fosters a deeper understanding of soil mechanics and foundation engineering, empowering engineers to address complex challenges with confidence and expertise.

In conclusion, this Reference Handbook on Soil Mechanics and Foundation Engineering aims to be a valuable resource for anyone seeking to deepen their understanding of geotechnical engineering. By integrating Indian Standards into our discussions, we strive to provide readers with a comprehensive, practical, and contextually relevant exploration of this vital discipline. We hope that this handbook will inspire curiosity, foster learning, and contribute to the advancement of Soil Mechanics and foundation engineering in India and beyond

Why Standards?

Indian Standards play a crucial role in soil mechanics and foundation engineering in India for several reasons:

Local Soil Conditions: India has diverse soil types ranging from sandy to clayey soils, which vary significantly across regions. Indian Standards are tailored to address the specific challenges posed by these diverse soil conditions, providing guidelines for soil testing, analysis, and foundation design that are relevant and effective in the Indian context.

Climate and Environmental Factors: Indian Standards take into account the climatic variations and environmental factors that influence soil behaviour and foundation performance. Guidelines for factors such as groundwater levels, seismic activity, and monsoon conditions are incorporated to ensure that foundations are designed to withstand local environmental stresses.

Structural Requirements: Indian Standards are aligned with the structural requirements and building codes prevalent in the country. They provide guidance on foundation design parameters, load considerations, and safety factors that are essential for ensuring the structural integrity and stability of buildings and infrastructure projects.

Regulatory Compliance: Adherence to Indian Standards is often mandated by regulatory authorities for construction projects in India. Engineers and developers are required to follow these standards to obtain necessary approvals, permits, and certifications, ensuring compliance with legal and regulatory requirements.

Historical Experience: Indian Standards draw upon the extensive experience and knowledge accumulated through decades of construction and infrastructure development in the country. They reflect the lessons learned from past successes and failures, incorporating best practices and recommendations based on practical experience and research.

Promotion of Best Practices: Indian Standards promote the adoption of best practices in soil mechanics and foundation engineering, encompassing aspects such as site investigation, soil testing, foundation types, construction techniques, and quality control measures. By following these standards, engineers can minimize risks, enhance project efficiency, and optimize resource utilization.

Capacity Building: Indian Standards contribute to capacity building efforts by providing guidance and training resources for engineers, geotechnical professionals, and construction stakeholders involved in soil mechanics and foundation engineering. They serve as educational tools that empower practitioners with the knowledge and skills necessary to tackle complex soil-structure interaction problems effectively.

In summary, Indian Standards are indispensable in soil mechanics and foundation engineering as they address the unique challenges posed by local soil conditions, environmental factors, structural requirements, regulatory compliance, historical experience, promotion of best practices, and capacity building efforts in India's construction industry.

Crucial Role played by Indian Standards in Ensuring Safety and Performance in the Field of Soil Mechanics and Foundation Engineering:

In the field of Soil Mechanics and Foundation Engineering, Indian standards play a crucial role in ensuring safety and performance on the following Key Factors:

1. **Design and Construction Safety**: Indian standards provide guidelines for the safe design and construction of foundations and soil-related structures. They address issues such as soil bearing capacity, settlement, and stability, which are critical for preventing structural failures and ensuring the safety of buildings and infrastructure.

2. **Quality Assurance**: Standards such as those outlined by the Bureau of Indian Standards (BIS) ensure that materials, construction practices, and testing methods meet established quality criteria. This helps in achieving reliable performance and durability of foundation systems and soil structures.

3. **Consistency in Testing**: Indian standards define standardized testing procedures for soil properties, including compaction, shear strength, and permeability. Consistent testing methods ensure that soil properties are accurately assessed, which is essential for designing safe and effective foundations.

4. **Regulatory Compliance**: Adhering to Indian standards is often a regulatory requirement for construction projects. Compliance helps in meeting legal and contractual obligations, thereby reducing risks associated with non-compliance and enhancing project credibility.

5. **Risk Mitigation**: By providing guidelines for various aspects of soil mechanics and foundation engineering, such as site investigation, foundation design, and construction techniques, Indian standards help in identifying and mitigating potential risks, such as soil instability or excessive settlement.

6. **Engineering Practice and Innovation**: Indian standards are periodically updated to incorporate advancements in engineering practices and technology. This ensures that engineering solutions remain current and effective, promoting innovation while maintaining safety and performance standards.

In summary, Indian standards are essential for guaranteeing safety and performance in Soil Mechanics and Foundation Engineering by providing clear guidelines for design, construction, testing, and quality assurance, thereby helping to prevent failures and ensure the reliability of structures.

Analysis and Illustrations of Few Specific Indian Standards:

In Soil Mechanics and Foundation Engineering, specific Indian Standards are pivotal for ensuring safety and performance. Here's an analysis of some significant and inevitable standards, detailing how they contribute to these aspects:

1. IS 6403:1981 - Code of Practice for Determination of Bearing Capacity of Shallow Foundations

Purpose and Scope:

- Provides methodologies for determining the bearing capacity of soil for shallow foundations.

- Covers various types of soil and foundation interactions.

Ensuring Safety and Performance:

- **Safety**: By accurately determining the load-bearing capacity of soil, this standard helps prevent overloading of foundations, which could lead to structural failures or unsafe conditions.
- **Performance**: Ensures that foundations are designed based on reliable soil data, enhancing the performance of structures by preventing excessive settlement or instability.

2. IS 1498:1970 - Classification and Identification of Soils for General Engineering Purposes

Purpose and Scope:

- Provides a system for classifying and identifying soils based on their physical and mechanical properties.
- Includes methods for soil testing and classification.

Ensuring Safety and Performance:

- **Safety**: Classification helps in selecting appropriate foundation types and construction methods based on soil characteristics, reducing risks of foundation failures.
- **Performance**: Accurate soil classification supports effective design, ensuring that foundations perform as expected under various loads and environmental conditions.

3. IS 2720 Series - Methods of Testing Soils

Purpose and Scope:

- Includes various parts detailing methods for testing soil properties (e.g., moisture content, shear strength, compaction).
- Covers essential soil properties needed for accurate analysis and design.

Ensuring Safety and Performance:

- **Safety**: By providing standardized testing methods, these standards ensure that soil properties are measured accurately, which is crucial for safe foundation design.
- **Performance**: Reliable soil data from these tests ensures that foundations and structures are designed to meet performance requirements, including stability and load-bearing capacity.

4. IS 3370 Part 2:2021 - Code of Practice for Concrete Structures for retaining Aqueous Liquids

Purpose and Scope:

- Focuses on the design and construction of concrete structures for storing liquids, with implications for foundations.

Ensuring Safety and Performance:

- **Safety**: Provides guidelines to ensure that storage tanks and their foundations can safely support the weight of stored liquids and withstand various stresses.
- **Performance**: Ensures that structures and foundations maintain their integrity and performance under the dynamic loads of stored liquids.

5. IS 2911 Part 4:2013 - Code of Practice for Design and Construction of Pile Foundations- Load test on Piles

This standard provides detailed guidelines for:

- **Pile Design**: Ensuring piles are designed to safely transfer loads from structures to the underlying soil or rock.
- **Construction Practices**: Outlining methods to ensure that pile foundations are constructed to meet safety and performance requirements.

6. IS 1080: 1985 - Code of Practice for Design and Construction of Shallow Foundations

Purpose and Scope:

- Offers guidelines for the design and construction of shallow foundations, including recommendations for various soil conditions and loading scenarios.

Ensuring Safety and Performance:

- **Safety**: Provides design criteria and construction practices that help prevent foundation issues such as excessive settlement or structural failure.
- **Performance**: Ensures that shallow foundations are designed to support intended loads effectively and maintain structural stability over time.

Summary

These Indian Standards are integral to Soil Mechanics and Foundation Engineering as they:

- **Ensure Safety**: By providing accurate methodologies for soil testing, classification, and foundation design, these standards help prevent foundation-related failures and safety hazards.
- **Enhance Performance**: By ensuring that foundations are designed and constructed based on reliable data and guidelines, these standards contribute to the effective performance and longevity of structures.

Incorporating these standards into engineering practices helps achieve safe, reliable, and high-performance foundations, crucial for the stability and safety of infrastructure projects.

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CHAPTER I

INTRODUCTION TO SOIL MECHANICS AND FOUNDATION ENGINEERING

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INTRODUCTION TO SOIL MECHANICS AND FOUNDATION ENGINEERING

Soil mechanics and foundation engineering are vital disciplines in civil engineering that deal with the behavior of soil and its interaction with structures. Here's a brief introduction to these fields and some emerging trends:

Soil Mechanics:

Soil mechanics is the branch of civil engineering that studies the properties of soil, its behavior under various loading conditions, and its suitability for construction projects. Key concepts include:

Soil Composition: Soil is composed of mineral particles, organic matter, water, and air. Understanding its composition is crucial for assessing its properties.

Soil Classification: Soils are classified based on grain size, mineral composition, plasticity, and other factors. Common classification systems include the Unified Soil Classification System (USCS) and the AASHTO Soil Classification System.

Soil Properties: Properties like density, porosity, permeability, compressibility, and shear strength determine soil behavior under different conditions.

Soil Testing: Various laboratory and in-situ tests are conducted to determine soil properties. Tests include the triaxial test, direct shear test, consolidation test, and Standard Penetration Test (SPT).

Foundation Engineering:

Foundation engineering focuses on designing safe and stable foundations for structures based on soil conditions. Key aspects include:

Types of Foundations: Foundations can be shallow (such as spread footings and mat foundations) or deep (such as piles and drilled piers), depending on soil conditions and structural requirements.

Soil-Structure Interaction: Understanding how soil interacts with the foundation and transferring loads from the structure to the soil is crucial for designing effective foundations.

Foundation Design: Designing foundations involves considering factors like soil bearing capacity, settlement, lateral stability, and potential hazards like earthquakes and expansive soils.

Foundation Construction: Construction methods must ensure that foundations are installed properly, considering soil conditions and design specifications.

Emerging Trends:

Several emerging trends are shaping the fields of soil mechanics and foundation engineering:

Advanced Geotechnical Modeling: Use of advanced computational techniques like finite element analysis (FEA) and computational fluid dynamics (CFD) for modeling soil-structure interaction and analyzing complex soil behavior.

Sustainable Foundations: Emphasis on environmentally friendly foundation solutions, such as using recycled materials, minimizing excavation, and designing foundations with low carbon footprints.

Geotechnical Instrumentation and Monitoring: Increasing use of sensors and monitoring systems to track soil behavior and foundation performance in real-time, allowing for early detection of issues and proactive maintenance.

Innovative Foundation Techniques: Exploration of innovative foundation solutions like geosynthetic-reinforced soil structures, soil improvement techniques, and the use of alternative materials for foundation construction.

Resilient Infrastructure: Designing foundations to withstand extreme weather events, sea-level rise, and other climate change-related challenges to ensure the resilience of critical infrastructure.

Data-Driven Approaches: Leveraging big data analytics and machine learning algorithms to analyze vast amounts of geotechnical data for more accurate predictions of soil behavior and optimized foundation designs.

As technology advances and sustainability becomes increasingly important, soil mechanics and foundation engineering will continue to evolve to meet the demands of modern infrastructure projects.

CHAPTER II

AN INSIGHT INTO SOIL PROPERTIES

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AN INSIGHT INTO SOIL PROPERTIES

Classification of soils (e.g., based on grain size, plasticity) & Indian Standards

Classification of soils is a fundamental aspect of soil mechanics and foundation engineering, and it plays a crucial role in various engineering applications. In India, the Bureau of Indian Standards (BIS) has developed specific standards for soil classification to ensure uniformity and consistency in soil characterization across the country. One of the key standards related to soil classification is Indian Standard IS 1498: 1970 "Classification and identification of soils for general engineering purposes."

Indian Standard IS 1498 provides guidelines for the classification and identification of soils based on their engineering properties, particularly their grain size distribution and plasticity. The standard divides soils into different groups and subgroups, each with its own characteristics and engineering significance. Here's a brief overview of the contents of IS 1498:

1. **Scope:** The standard defines the scope and purpose of soil classification for general engineering purposes.

2. **Terminology:** It establishes the terminology and definitions used in soil classification, ensuring consistency in communication within the engineering community.

3. **Sampling and Preparation of Soil Samples:** Guidelines for the collection, handling, and preparation of soil samples for testing are provided to ensure representative and reliable data.

4. **Identification of Soil Particles:** Methods for identifying soil particles based on their size, shape, and mineral composition are outlined.

5. **Classification of Soils:** The standard presents a systematic approach to classifying soils into various groups and subgroups based on their particle size distribution, plasticity, and other engineering properties.

6. **Particle Size Distribution:** Procedures for determining the particle size distribution of soils using sieve analysis and hydrometer analysis are described.

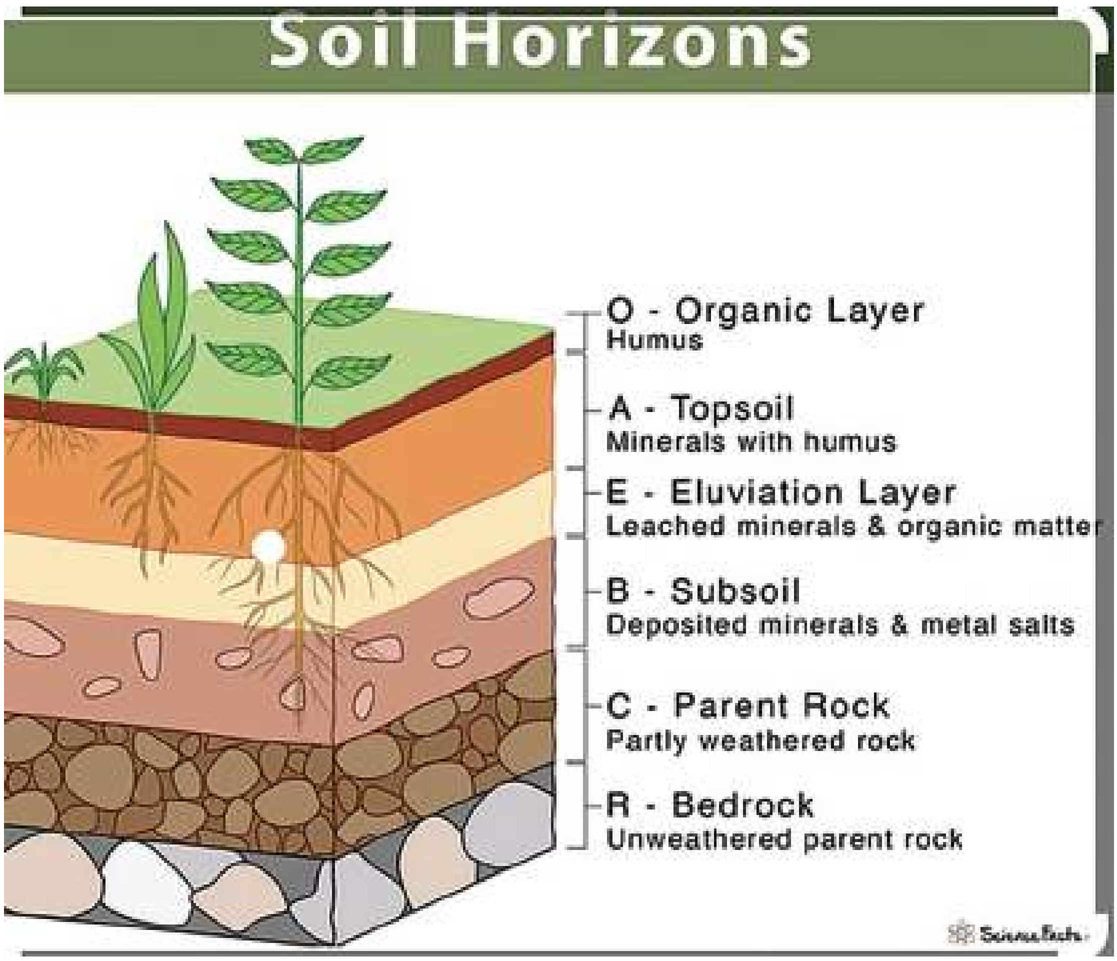
7. **Plasticity Characteristics:** Tests for determining the plasticity characteristics of fine-grained soils, such as liquid limit, plastic limit, and plasticity index, are specified.

8. **Unified Soil Classification System (USCS):** The standard discusses the adoption of the Unified Soil Classification System (USCS) for classifying soils into different groups based on their grain size and plasticity.

9. **Engineering Significance of Soil Classification:** The engineering significance of different soil groups and subgroups is elucidated, highlighting their behaviour and properties relevant to geotechnical engineering applications.

10. **Reporting of Classification Results:** Guidelines for reporting soil classification results in engineering reports and documents are provided to ensure clarity and consistency.

By adhering to Indian Standard IS 1498, engineers and geotechnical professionals in India can accurately classify soils and effectively communicate their engineering properties. This facilitates informed decision-making in various geotechnical applications, including foundation design, slope stability analysis, and earthwork construction, ultimately contributing to the safety, reliability, and sustainability of infrastructure projects across the country.



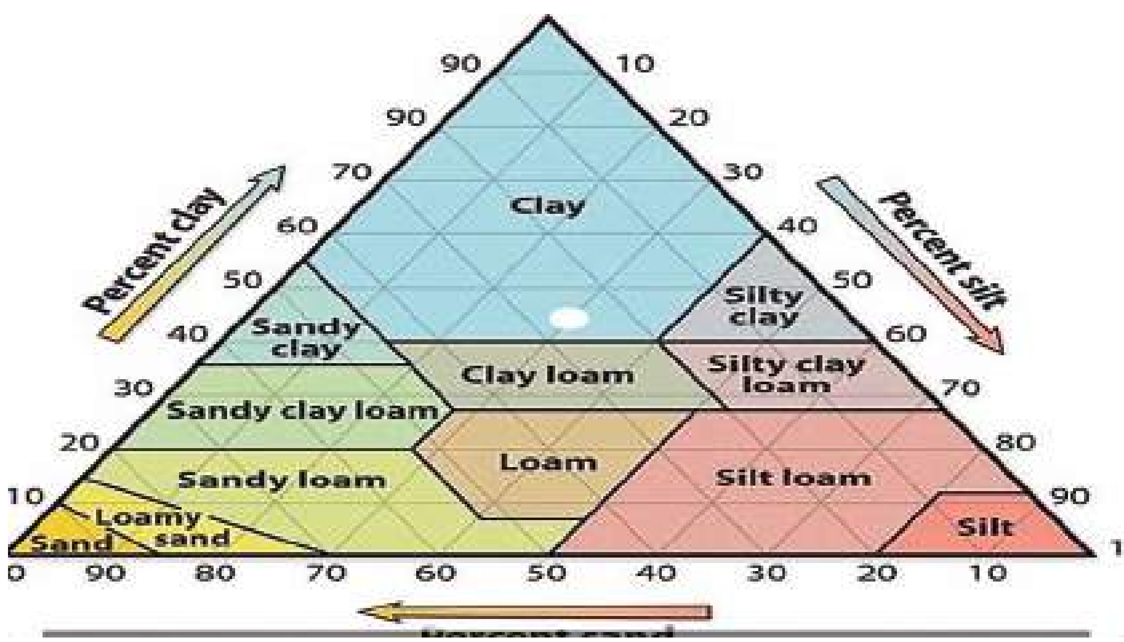
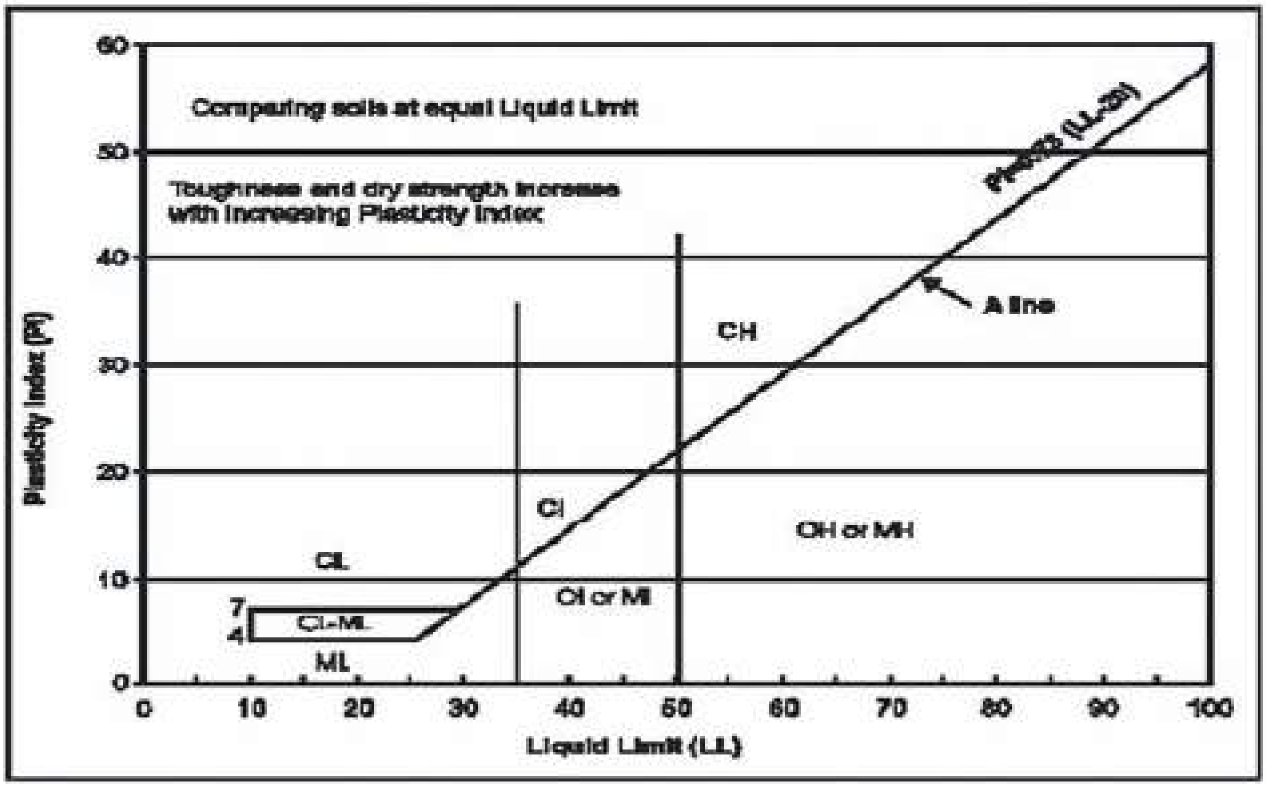
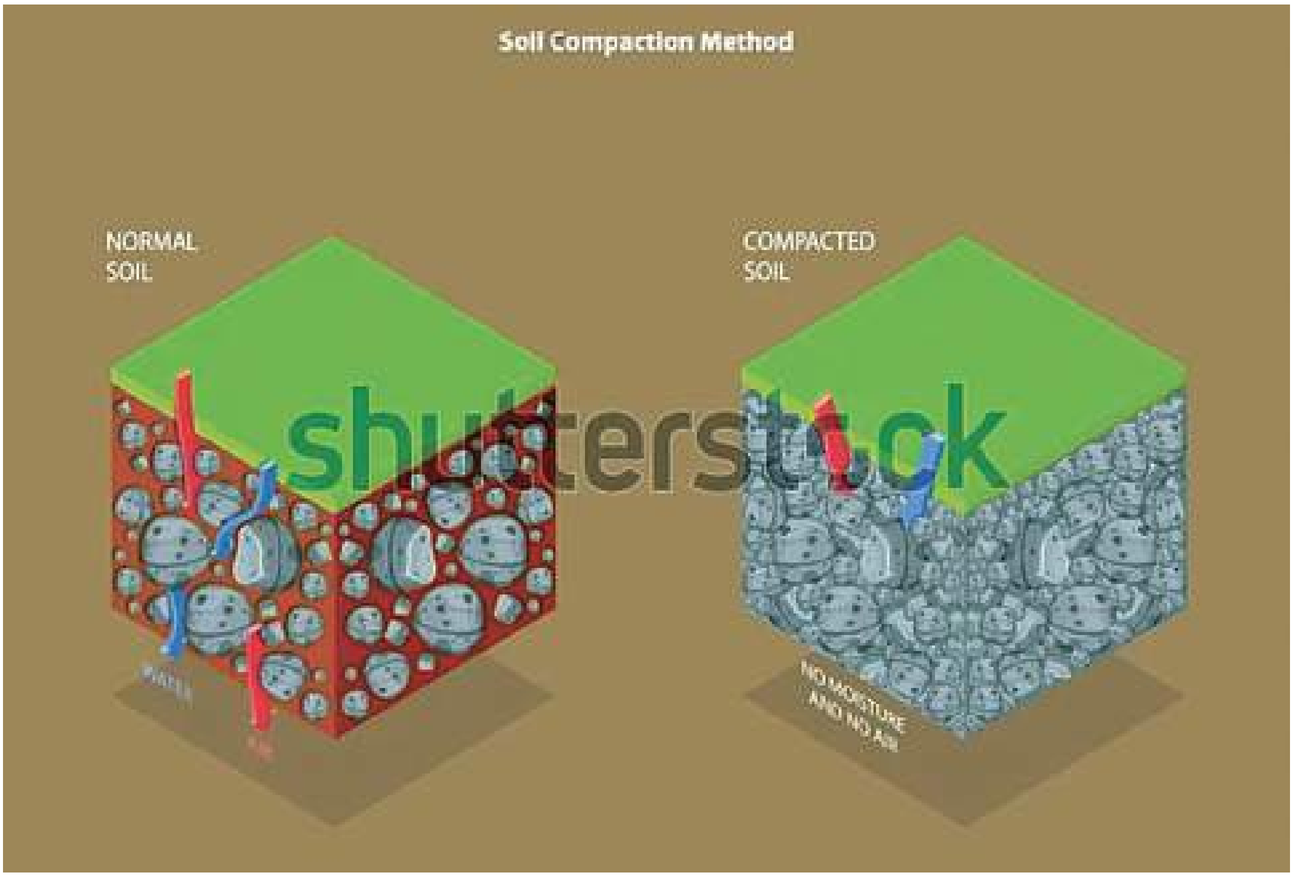


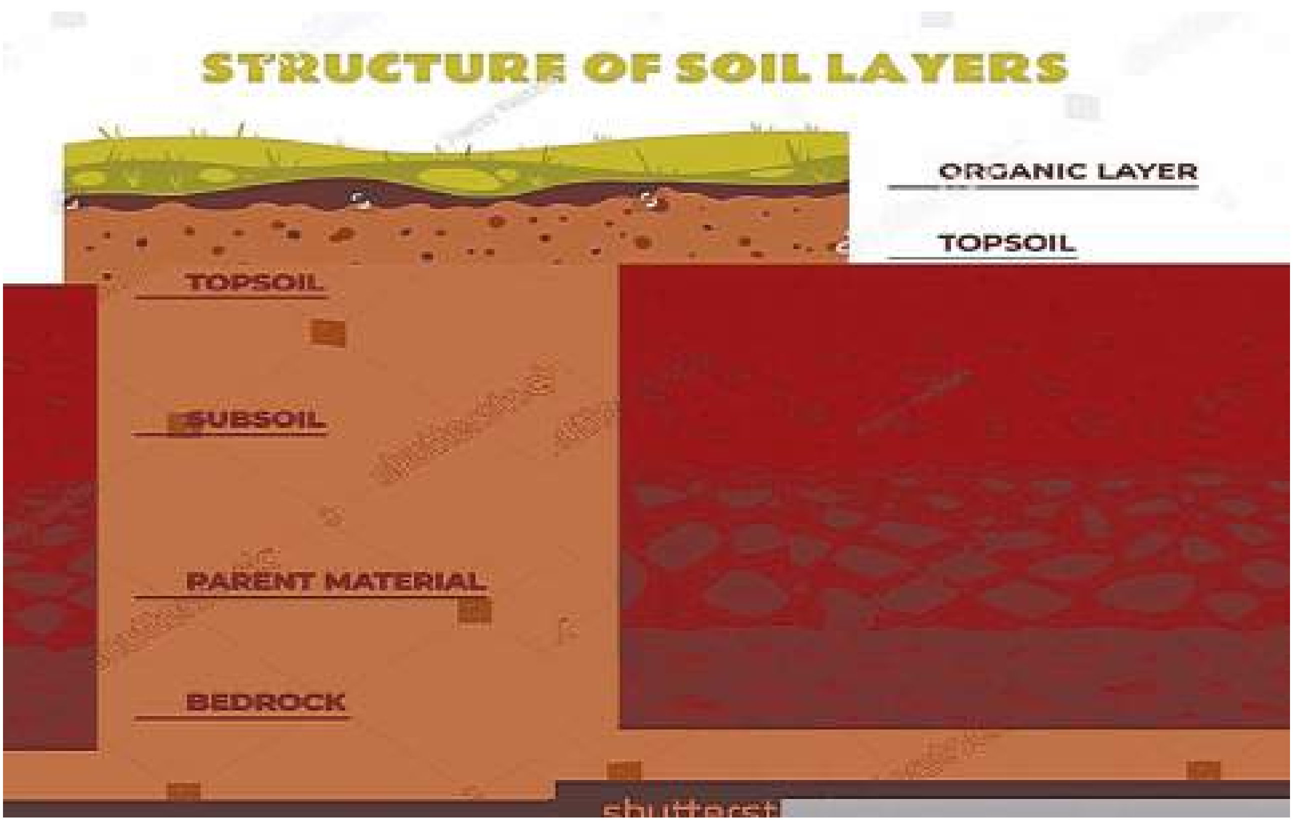
Table 1.4 Classification of Grain Size Boundaries (mm)

Clay	<0.002		
Silt			
Fine silt	0.002	—	0.006
Medium silt	0.006	—	0.02
Coarse silt	0.02	—	0.06
Sand			
Fine sand	0.06	—	0.2
Medium sand	0.2	—	0.6
Coarse sand	0.6	—	2.0
Gravel			
Fine gravel	2	—	6
Medium gravel	6	—	20
Coarse gravel	20	—	60
Cobbles	60	—	200
Boulders			>200



Soil Compaction and its Significance





Soil compaction is the process whereby soil particles are pressed together, reducing the pore space between them. This reduction in pore space leads to decreased water infiltration, increased runoff, and decreased air and water movement within the soil. Compacted soil can have detrimental effects on plant growth, soil fertility, and overall soil health.

Compaction can occur naturally through processes like rain, wind, and gravity, but it is often exacerbated by human activities such as construction, agriculture, and heavy machinery use. Common causes of soil compaction include vehicular traffic, heavy equipment operation, and excessive tillage.

The effects of soil compaction can vary depending on factors such as soil type, moisture content, and the intensity of the compaction. Compacted soils typically have reduced fertility, drainage, and aeration, leading to poor plant growth and decreased crop yields. They are also more prone to erosion and runoff, which can contribute to environmental degradation.

Mitigating soil compaction involves practices such as minimizing tillage, reducing heavy machinery traffic, incorporating organic matter into the soil, and practicing conservation tillage techniques. These practices help to improve soil structure, increase pore space, and enhance overall soil health. Additionally, using cover crops and implementing proper soil management strategies can help prevent and alleviate soil compaction issues.

Significance of Soil Compaction:

Structural Integrity: Compacted soil provides a stable foundation for buildings, roads, and other structures. It reduces the risk of settlement and structural failure.

Water Drainage: Compacted soil has reduced porosity, which helps in managing water drainage and preventing erosion.

Crop Growth: In agriculture, proper soil compaction facilitates root penetration, water retention, and nutrient uptake, thus enhancing crop growth.

Prevention of Soil Erosion: Compacted soil is less prone to erosion by wind and water, protecting agricultural land and infrastructure.

Trafficability: Compacted soil can withstand heavy loads and traffic, making it suitable for roads, highways, and airstrips.

Indian Standards Related to Soil Compaction:

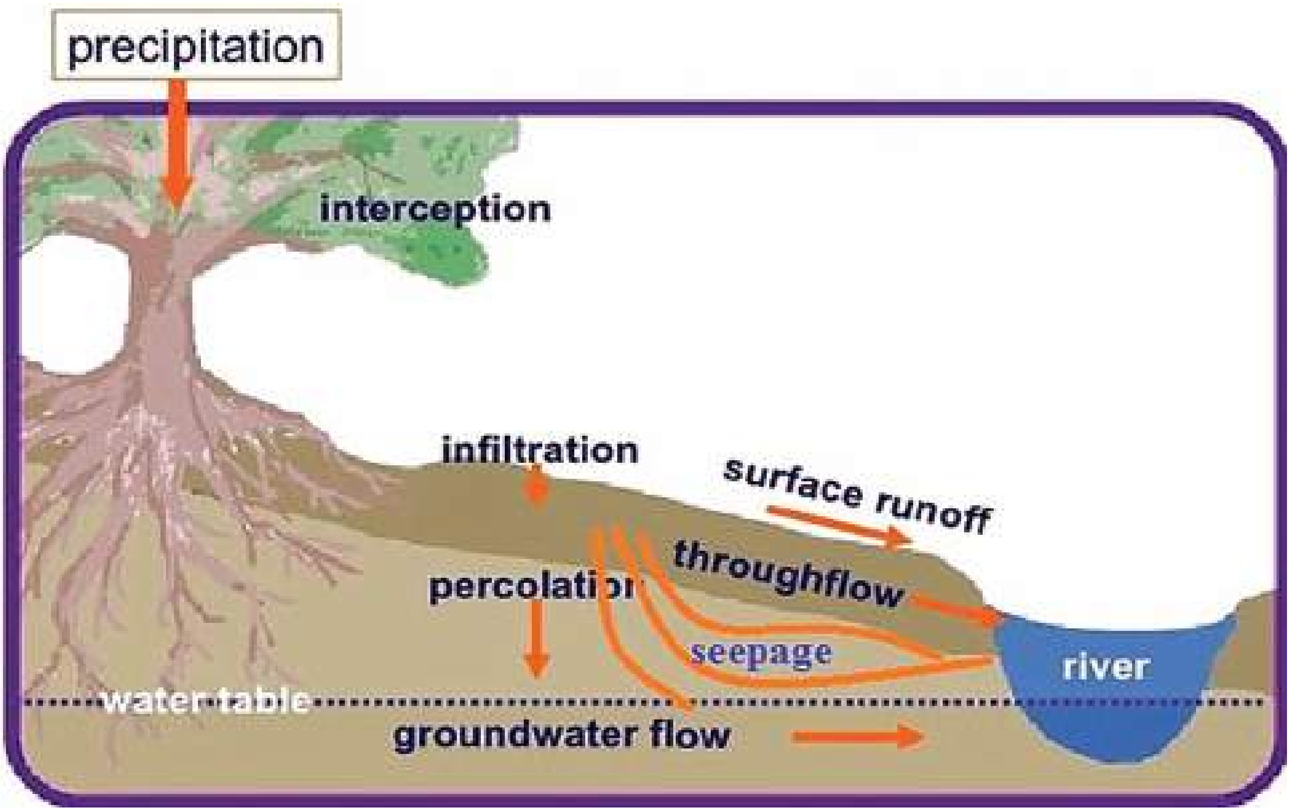
In India, soil compaction standards are established by the Bureau of Indian Standards (BIS). The primary standard related to soil compaction is:

- **IS 2720 (Part 8): 1983** - Methods of Test for Soils: Determination of Water Content-Dry Density Relation Using Heavy Compaction: This standard provides guidelines for determining the maximum dry density and optimum moisture content of soils using heavy compaction.
- **IS 2720 (Part 7): 1980** - Methods of Test for Soils: Determination of Water Content-Dry Density Relation Using Light Compaction-This standard outlines methods for determining the water content of soils, which is essential for compaction testing.

- **IS 9198: 1979**- Specification for compaction rammer for soil testing: This standard specifies requirements for various types of soil compaction equipment used in construction projects.
- **IS 9214: 1979** - Method of determination of modulus of subgrade reaction (K-value) of soils in field: This standard provides guidelines for determining the impact value of aggregates, which is relevant to soil compaction in road construction.

These standards ensure that soil compaction is carried out effectively and consistently across different projects, promoting safety, durability, and efficiency in construction and agricultural activities in India. Compliance with these standards helps in achieving desired engineering properties and performance of compacted soils.

Soil Permeability & Seepage



Soil permeability refers to the ability of soil to transmit fluids (such as water) through its pore spaces. It is a crucial property that influences groundwater flow, drainage, and the behaviour of structures founded on or within the soil. Permeability is typically expressed in terms of hydraulic conductivity, which represents the rate at which water can flow through a unit area of soil under a unit hydraulic gradient.

Factors Affecting Permeability

Particle Size and Distribution: Permeability is influenced by the size, shape, and arrangement of soil particles. Coarse-grained soils, such as sands and gravels, generally have higher permeability than fine-grained soils, such as clays.

Void Ratio: The void ratio, which represents the volume of voids to the volume of solids in a soil mass, affects permeability. Soils with higher void ratios typically have higher permeability due to increased interconnected pore spaces.

Soil Structure: Soil structure, including the arrangement of soil particles and the degree of compaction, can impact permeability. Well-graded and uniformly compacted soils tend to have higher permeability compared to poorly-graded or highly compacted soils.

Saturation: Permeability is greatly affected by the saturation level of the soil. In general, saturated soils exhibit lower permeability compared to partially saturated or unsaturated soils.

Seepage:

Seepage refers to the flow of water through soil under hydraulic gradients. It occurs when water infiltrates the soil surface or is introduced into the soil through precipitation, irrigation, or other sources. Seepage can have significant implications for the stability of slopes, embankments, dams, and other hydraulic structures.

Factors Affecting Seepage:

Hydraulic Gradient: Seepage occurs in response to hydraulic gradients, which represent the change in hydraulic head (water pressure) over a distance. Water flows from areas of higher hydraulic head to areas of lower hydraulic head, driving seepage flow through the soil.

Permeability: The permeability of the soil greatly influences the rate and extent of seepage. High-permeability soils allow for faster seepage rates compared to low-permeability soils.

Soil Layering: The presence of different soil layers with varying permeabilities can affect seepage patterns and flow paths. Interfaces between contrasting soil layers may promote seepage concentration or lateral flow.

Boundary Conditions: Seepage behaviour is influenced by boundary conditions, such as the presence of impermeable boundaries (e.g., bedrock) or the existence of drainage systems that intercept and control seepage flow.

Understanding soil permeability and seepage is essential for assessing groundwater flow, designing drainage systems, evaluating slope stability, and mitigating potential risks associated with water infiltration and pore pressure buildup in soil masses. Proper characterization of soil properties and hydraulic conditions is critical for effective engineering design and construction practices.

Indian Standards play a crucial role in the study of soil permeability and seepage, providing guidelines and methodologies for testing, analysis, and design in various engineering projects. Here's how Indian Standards are relevant in the study of soil permeability and seepage

Indian Standards Related to Soil Permeability:

IS 2720 (Part 17): 1986 - Methods of Test for Soils: Laboratory Determination of Permeability: This standard provides procedures for determining the permeability of soils in laboratory conditions. It outlines different methods such as constant head permeability test, falling head permeability test, and consolidation test with measurement of permeability.

IS 2720 (Part 16): 1987 - Methods of Test for Soils: Laboratory Determination of CBR: This standard is indirectly related to permeability as it provides guidelines for determining the California Bearing Ratio (CBR) of soils, which is influenced by permeability.

IS 1498: 1970 - Classification and identification of soils for general engineering purposes: This standard classifies soils based on their properties, including permeability, which is essential for engineering design and construction.

Standards Related to Seepage:

IS 6966 (Part 1): 1989 - Hydraulic design of barrages and weirs - Guidelines: Part 1 alluvial reaches-This standard provides guidelines for evaluating the hydraulic properties of alluvial formations, including seepage characteristics, which are crucial in various water resource projects and geotechnical engineering.

IS 7894: 1975 - Code of practice for stability analysis of earth dams: This standard provides recommendations and methodologies for calculating seepage through earth dams, ensuring the safety and stability of such structures.

IS 7113:2003 –Soil-Cement lining for canals-Code of practice: This standard is relevant to seepage control in irrigation canals, providing guidelines for designing linings using soil-cement, which helps in reducing seepage losses.

Importance of Indian Standards:

Quality Assurance: Indian Standards ensure that testing procedures for soil permeability and seepage are conducted accurately and consistently, leading to reliable results.

Safety and Stability: Compliance with Indian Standards in the design and construction of structures ensures safety against failures due to seepage-related issues such as piping and erosion.

Interoperability: Standardized testing methods and design guidelines facilitate communication and collaboration among engineers, researchers, and stakeholders involved in soil permeability and seepage-related projects.

In conclusion, Indian Standards provide a framework for the study, evaluation, and management of soil permeability and seepage, contributing to the safety, efficiency, and sustainability of engineering projects in India.

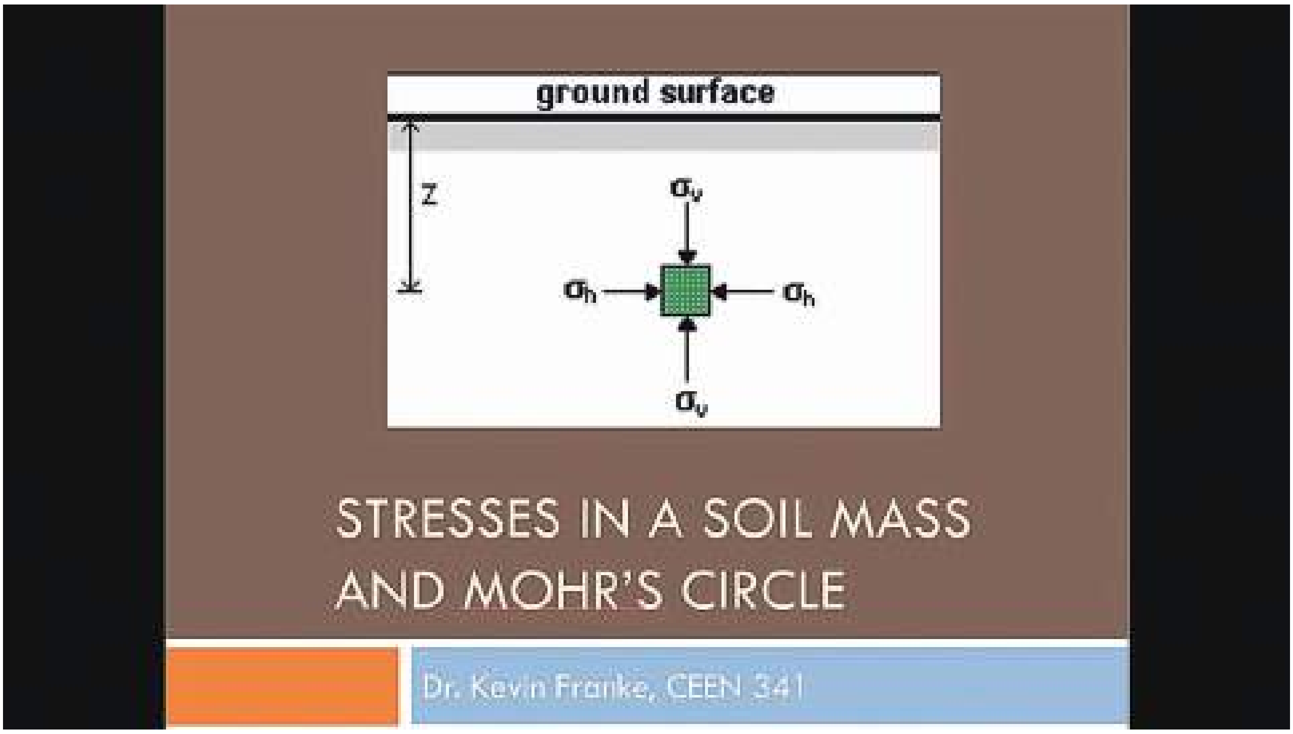
CHAPTER III

SOIL STRESS AND DEFORMATION:

Chapter III

Soil Stress and Deformation:

Stress in a soil mass refers to the distribution of forces within the soil caused by external loads, self-weight, and other factors. Understanding stress in soil is crucial in geotechnical engineering for assessing the stability and behaviour of foundations, retaining structures, slopes, and other earthworks. Here's a brief overview:



Total Stress and Effective Stress on Soil with Concepts and Formulas

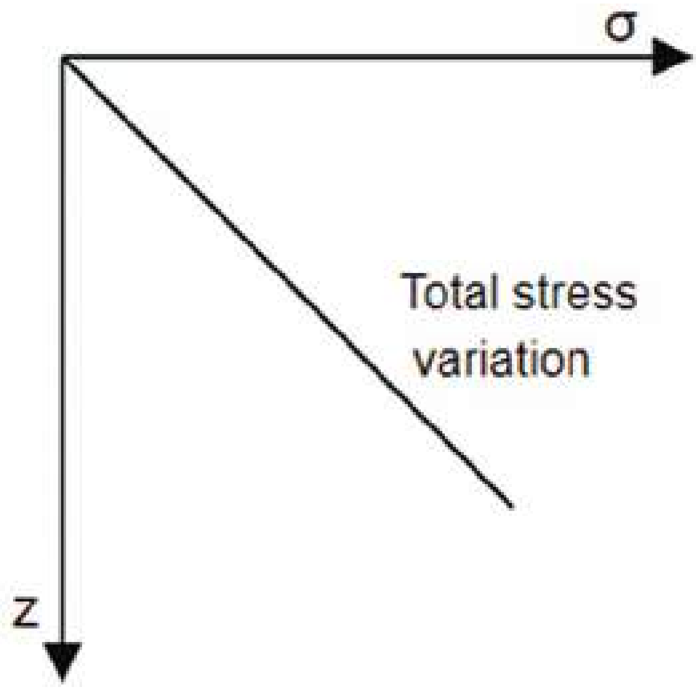
Total stress at a layer present at a certain depth below ground level is the **total weight of the soil** present above that layer **per unit surface area of the soil mass**. **Effective stress** is the **part of the total stress that is resisted by soil particles** by grain-to-grain interaction. The concept and methods of computing total and effective stress are discussed further.

Total Stress Concept

As said earlier, total stress at a layer is the **total weight of the soil present above that layer**, including self-weight of water present in soil pores or present above the ground level, **per unit surface area of the soil**. Total stress also includes the stresses de to externally applied loads, if any.

The pattern of stresses due to self-weight could be complicated except for one common case where the stresses are simple. One common case is when the **ground surface is horizontal** and the **nature of the soil does not vary significantly in the horizontal directions**. This is the most frequent case in any sedimentary deposit. Also, in this case, there can be no shear stresses upon vertical and horizontal planes within the soil mass.

Therefore, for the above-said case, total stress at a layer present at a certain depth can be computed as the product of the weight of the soil and depth below ground level at which total stress is required. Thus, the total stress varies linearly with depth.



Total stress distribution

Total Stress Formula

Total stress (óv) at a layer present at a depth of 'z' from the ground surface is given by,

$\sigma = \gamma * z$,

provided **unit weight (γ)** of the soil is **constant**.

where,

σ - total vertical stress (kN/m^2),

γ - the unit weight of soil (kN),

z - depth under consideration (m).

Pore Water Pressure Concept

As we all know, the soil is a three-phase system i.e., it contains solid, porewater and air voids. In the case of saturated soils, the pressure exerted by the pore water to its surrounding solid mass is called pore water pressure. Pore water pressure is also called **Neutral stress.**

Neutral stress can be defined as the **stress carried** (exerted) **by the pore water** and it is the same in all directions when there is static equilibrium.

Pore Water Pressure Formula

Pore water pressure(u) at a depth z can be calculated as the product of the unit weight of water and depth as given below.

u = γ w * z,

where,

γ w - the unit weight of the water (9.81 kN/m^3),

z - depth at which pore water pressure is required.

Pore water pressure can become negative in the case of capillary water. In such a case, pore water pressure (u) is calculated as,

u = -γ w * h,

where,

h - the height of the capillary rise above the ground level

Effective Stress Concept

The total stress (that was discussed earlier) at any point inside the soil is resisted by the soil grains and also by water present in the pores or void spaces (in the case of saturated soils). This portion of total stress that is resisted by soil grains is called effective stress. Effective stress is in macroscopic scale i.e., force/total area, and not in terms of contact stress at the grain-to-grain contacts as these will be very high.

In simple terms, imagine total stress as downward stress that is being resisted by effective stress by virtue of soil grains and pore water pressure by virtue of pore water, both acting in the upward direction.

Effective Stress Formula

Effective stress cannot be directly calculated but it can be calculated as the difference between total stress(ó) and pore water pressure(u). It is represented using ó'.

Effective stress, σ' = Total stress (σ) - Pore water pressure (u)

Types of Stress:

Effective Stress: Effective stress is the portion of total stress that is transmitted between soil particles and influences soil behaviour. It is the difference between the total stress and the pore water pressure within the soil mass. Effective stress governs soil strength, consolidation, and shear resistance.

Total Stress: Total stress represents the total force exerted on soil particles, including both the weight of the soil itself and any external loads applied to the soil mass. It is the sum of the effective stress and the pore water pressure.

Pore Water Pressure: Pore water pressure is the pressure exerted by the water present in the void spaces between soil particles. It counteracts the effective stress and affects soil stability, particularly in saturated or partially saturated soils.

Distribution of Stress:

Vertical Stress: Vertical stress, also known as overburden stress, is the stress acting vertically downward within the soil mass due to self-weight and external loads. It increases with depth and can vary depending on factors such as soil density, layering, and the magnitude of applied loads.

Horizontal Stress: Horizontal stress arises due to lateral confinement or external forces acting on the soil mass. It is significant in analysing the stability of retaining walls, tunnels, and other structures subjected to lateral loads.

Shear Stress: Shear stress occurs along potential failure surfaces within the soil mass and is critical in determining soil strength and stability against sliding and deformation. Shear stresses develop in response to applied loads, changes in pore water pressure, and other factors.

Factors Affecting Stress Distribution:

Soil Properties: Soil type, density, particle size distribution, and composition influence stress distribution within the soil mass. Cohesive soils, such as clays, tend to redistribute stresses more gradually compared to cohesionless soils, such as sands and gravels.

Loading Conditions: The magnitude, duration, and distribution of applied loads significantly affect stress distribution in soil. Different loading conditions, such as static loads, dynamic loads, and cyclic loads, can induce varying stress patterns and response mechanisms in the soil mass.

Boundary Conditions: Boundary conditions, including the presence of adjacent structures, support conditions, and geometric constraints, influence stress transmission and deformation behaviour at soil boundaries.

Understanding stress distribution in soil is fundamental for analysing soil behaviour, predicting settlement, evaluating bearing capacity, designing foundations, and ensuring the stability and performance of geotechnical structures. Advanced analytical techniques, such as finite element analysis and numerical modelling, are commonly used to simulate stress distribution in complex soil-structure interaction problems.

Indian Standards are highly relevant in the study of stress in soil mass, as they provide guidelines, methodologies, and specifications for testing, analysis, and design in geotechnical engineering. Here's how Indian Standards are pertinent to the study of stress in soil mass:

Standards Related to Stress in Soil Mass:

IS 6403: 1981 - Code of Practice for Determination of Bearing Capacity of Shallow Foundations: This standard provides guidelines for determining the bearing capacity of shallow foundations, which involves analysing the stress distribution in the soil mass beneath the foundation.

IS 1893 (Part 1): 2016 - Criteria for Earthquake Resistant Design of Structures: Part 1 - General Provisions and Buildings: Although not specifically focused on stress in soil mass, this standard provides criteria for earthquake-resistant design, considering the dynamic interaction between soil and structures under seismic loading.

IS 8009 (Part 1): 1976 (Reviewed in 2023) - Code of practice of calculation of settlement of foundations: Part 1shallow foundations subjected to symmetrical static vertical loads: This standard provides methods for calculating settlements of shallow foundations, which involves analysing the stress distribution and deformation characteristics of the underlying soil mass.

Importance of Indian Standards:

Safety Assurance: Indian Standards ensure that geotechnical investigations, analyses, and designs consider the stress distribution in soil mass to ensure the safety and stability of structures.

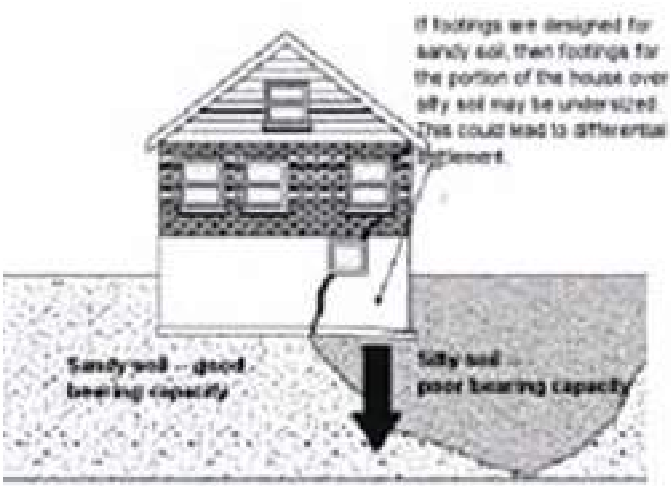
Performance Prediction: By providing standardized testing methods and calculation procedures, Indian Standards facilitate the prediction of stress distribution in soil mass, helping engineers assess the performance of foundations, retaining structures, and embankments.

Quality Control: Compliance with Indian Standards ensures that geotechnical investigations and analyses are conducted accurately and consistently, leading to reliable assessments of stress in soil mass and informed engineering decisions.

Risk Mitigation: By incorporating Indian Standards into geotechnical engineering practices, the risks associated with inadequate consideration of stress in soil mass, such as settlement, slope instability, and foundation failure, can be mitigated.

In summary, Indian Standards play a vital role in the study of stress in soil mass by providing guidance on testing, analysis, and design processes in geotechnical engineering. Compliance with these standards ensures the safety, reliability, and performance of civil infrastructure projects in India.

Settlement of Structures



Settlement of structures refers to the downward movement or compression experienced by buildings, bridges, and other engineered structures over time. Here's a brief overview:

Causes of Settlement:

Self-weight: The weight of the structure itself causes compression of the underlying soil.

Consolidation: Soil consolidation occurs when excess pore water is squeezed out of the soil, leading to compression

Moisture Changes: Fluctuations in moisture content can cause soil expansion or contraction, resulting in settlement.

Construction Activities: Excavation, soil compaction, and other construction processes can disturb the soil, leading to settlement.

Organic Decay: Decomposition of organic material within the soil can cause settlement over time.

Types of Settlement:

Immediate Settlement: Occurs immediately after the structure is loaded and is primarily due to the elastic deformation of soil.

Consolidation Settlement: Gradual settlement resulting from the expulsion of water from the soil under sustained loading.

Secondary Settlement: Continued settlement over time due to factors such as creep and ongoing consolidation.

Factors Influencing Settlement:

Soil Properties: Type, density, permeability, and compressibility of the soil.

Structural Load: Magnitude, distribution, and duration of applied loads.

Foundation Type: Shallow foundations, deep foundations, and pile foundations exhibit different settlement characteristics.

Groundwater Conditions: Presence and movement of groundwater can affect soil consolidation and settlement.

Construction Methods: Construction processes and sequencing can influence soil disturbance and settlement.

Effects of Settlement:

Structural Damage: Cracks, distortions, and other forms of damage to the building or infrastructure.

Serviceability Issues: Uneven floors, jammed doors, and other functional problems.

Safety Risks: Settlement can compromise the stability and safety of the structure, posing risks to occupants and users.

Financial Implications: Repair costs, downtime, and loss of property value.

Mitigation and Prevention:

Proper Foundation Design: Designing foundations based on thorough soil investigation and engineering analysis.

Soil Improvement Techniques: Compaction, grouting, and other methods to improve soil stability and reduce settlement.

Monitoring and Maintenance: Regular inspection and maintenance programs to detect and address settlement issues early.

Structural Modifications: Retrofitting and strengthening measures to mitigate settlement-related damage.

Settlement of structures is a complex phenomenon influenced by various factors, and its understanding is essential for ensuring the longevity, safety, and functionality of engineered infrastructure. Effective management of settlement involves careful design, construction practices, monitoring, and maintenance throughout the life cycle of the structure.

Indian Standards play a crucial role in the study of settlement of structures by providing guidelines, methodologies, and specifications for testing, analysis, and design in geotechnical engineering. Here's how Indian Standards are relevant and significant in this field:

Standards Related to Settlement of Structures:

IS 1893 (Part 1): 2016 - Criteria for Earthquake Resistant Design of Structures: Part 1 - General Provisions and Buildings: Although primarily focused on earthquake-resistant design, this standard indirectly addresses settlement by considering soil-structure interaction under seismic loading, which can lead to settlement of structures.

IS 8009 (Part 1): 1976 (Reviewed in 2023) - Code of practice of calculation of settlement of foundations: Part 1shallow foundations subjected to symmetrical static vertical loads: This standard provides methods for calculating settlements of shallow foundations, considering factors such as soil properties, foundation geometry, and loading conditions.

IS 2950 (Part 1): 1981- Code of Practice for Design and Construction of Raft Foundations:Part 1 Design- This standard provides guidelines for the design and construction of raft foundations, including recommendations for minimizing settlement through proper soil investigation, foundation design, and construction techniques.

IS 6403: 1981 - Code of Practice for Determination of Bearing Capacity of Shallow Foundations: Settlement is an integral part of the bearing capacity determination process, and this standard provides guidelines for assessing the bearing capacity of shallow foundations, considering settlement criteria.

Importance of Indian Standards:

Safety Assurance: Indian Standards ensure that geotechnical investigations, analyses, and designs consider settlement as a critical factor in the performance and safety of structures.

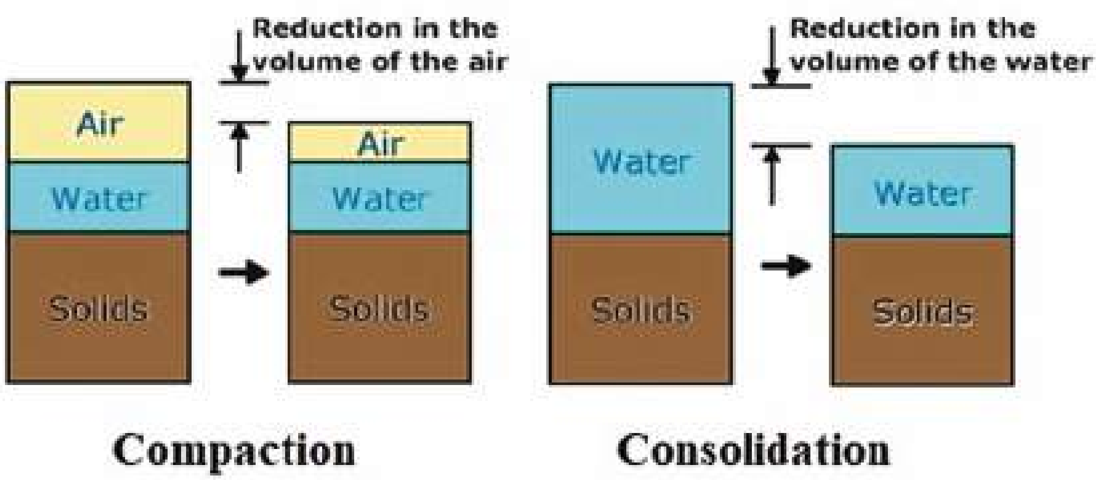
Quality Control: Compliance with Indian Standards ensures that settlement analyses and calculations are conducted using standardized methods, leading to reliable assessments of structure performance and informed engineering decisions.

Risk Mitigation: By incorporating Indian Standards into geotechnical engineering practices, the risks associated with settlement-related issues such as differential settlement, tilting, and structural damage can be effectively mitigated.

Performance Prediction: Indian Standards provide engineers with standardized procedures for predicting settlement, enabling them to assess the performance and serviceability of structures under various loading and environmental conditions.

In summary, Indian Standards are essential in the study of settlement of structures by providing guidance on testing, analysis, and design processes in geotechnical engineering. Compliance with these standards ensures the safety, reliability, and durability of civil infrastructure projects in India.

Consolidation of Soil and its Effects:



Consolidation of soil is a process in geotechnical engineering where soil particles are rearranged, and excess pore water is expelled under the influence of applied loads. Here's a brief overview:

Process of Consolidation:

When a load is applied to a saturated or partially saturated soil layer, the water within the soil pores experiences pressure.

Initially, the soil undergoes immediate settlement due to elastic deformation. This is followed by gradual consolidation as excess pore water is expelled from the soil mass.

The expelled water dissipates through drainage paths, such as vertical drains or the soil matrix itself, causing the soil particles to rearrange and compact over time.

Primary Consolidation:

Primary consolidation refers to the initial phase of settlement where most of the settlement occurs due to the expulsion of excess pore water.

During primary consolidation, the soil undergoes volume reduction as the pore water pressure decreases and the effective stress increases.

The rate of primary consolidation is governed by soil properties such as permeability, compressibility, and void ratio.

Secondary Consolidation:

Secondary consolidation, also known as creep or time-dependent settlement, occurs over an extended period after primary consolidation.

It involves further compression of the soil due to creep deformation and adjustment of soil particles under sustained loading.

Secondary consolidation can continue for years or even decades, depending on the soil type and loading conditions.

Effects of Consolidation:

Settlement of Structures: Consolidation leads to vertical settlement of buildings, foundations, embankments, and other structures founded on compressible soils.

Ground Movement: Consolidation can cause ground subsidence, uneven settlement, and differential settlement, leading to structural damage and serviceability issues.

Pore Water Pressure: During consolidation, pore water pressure decreases, which can affect the stability of slopes, embankments, and retaining structures.

Time-Dependent Behaviour: Secondary consolidation results in ongoing settlement over time, which may necessitate long-term monitoring and maintenance of structures.

Understanding consolidation of soil and its effects is crucial in geotechnical engineering for predicting settlement, designing foundations, and assessing the stability of earthworks. Proper soil investigation, analysis, and engineering measures are necessary to mitigate the potential risks associated with consolidation and ensure the safety and performance of infrastructure projects.

Indian Standards are integral to the study of consolidation of soil and its effects, as they provide guidelines, methodologies, and specifications for testing, analysis, and design in geotechnical engineering. Here's how Indian Standards are relevant in this field:

Standards Related to Consolidation of Soil:

IS 2720 (Part 15): 1965 - Methods of Test for Soils: Determination of consolidation properties- This standard provides procedures for consolidation properties of soils, which is crucial for understanding the drainage characteristics and consolidation behaviour of soil.

IS 2720 (Part 16): 1987 - Methods of Test for Soils: Laboratory Determination of CBR: California Bearing Ratio (CBR) is indirectly related to soil consolidation, as it reflects the strength and compressibility characteristics of soil, which influence consolidation behaviour.

IS 2720 (Part 5): 1985 - Methods of Test for Soils: Determination of Liquid and Plastic Limit: Liquid and plastic limits are essential parameters for assessing the compressibility and consolidation potential of cohesive soils, and this standard provides methods for their determination.

IS 6403: 1981 - Code of Practice for Determination of Bearing Capacity of Shallow Foundations: Settlement calculations, which are influenced by soil consolidation, are an integral part of bearing capacity determination, and this standard provides guidelines for assessing the bearing capacity of shallow foundations.

Importance of Indian Standards:

Safety Assurance: Indian Standards ensure that geotechnical investigations, analyses, and designs consider consolidation effects to ensure the safety and stability of structures built on or within the soil.

Quality Control: Compliance with Indian Standards ensures that consolidation tests and analyses are conducted using standardized methods, leading to reliable assessments of soil behaviour and informed engineering decisions.

Risk Mitigation: By incorporating Indian Standards into geotechnical engineering practices, the risks associated with soil consolidation-related issues such as settlement, differential settlement, and foundation failure can be effectively mitigated.

Performance Prediction: Indian Standards provide engineers with standardized procedures for predicting soil consolidation behaviour, enabling them to assess the performance and serviceability of structures under various loading and environmental conditions.

In summary, Indian Standards are crucial in the study of consolidation of soil and its effects by providing guidance on testing, analysis, and design processes in geotechnical engineering. Compliance with these standards ensures the safety, reliability, and durability of civil infrastructure projects in India.

CHAPTER IV
SOIL STRENGTH

Chapter IV

SOIL STRENGTH

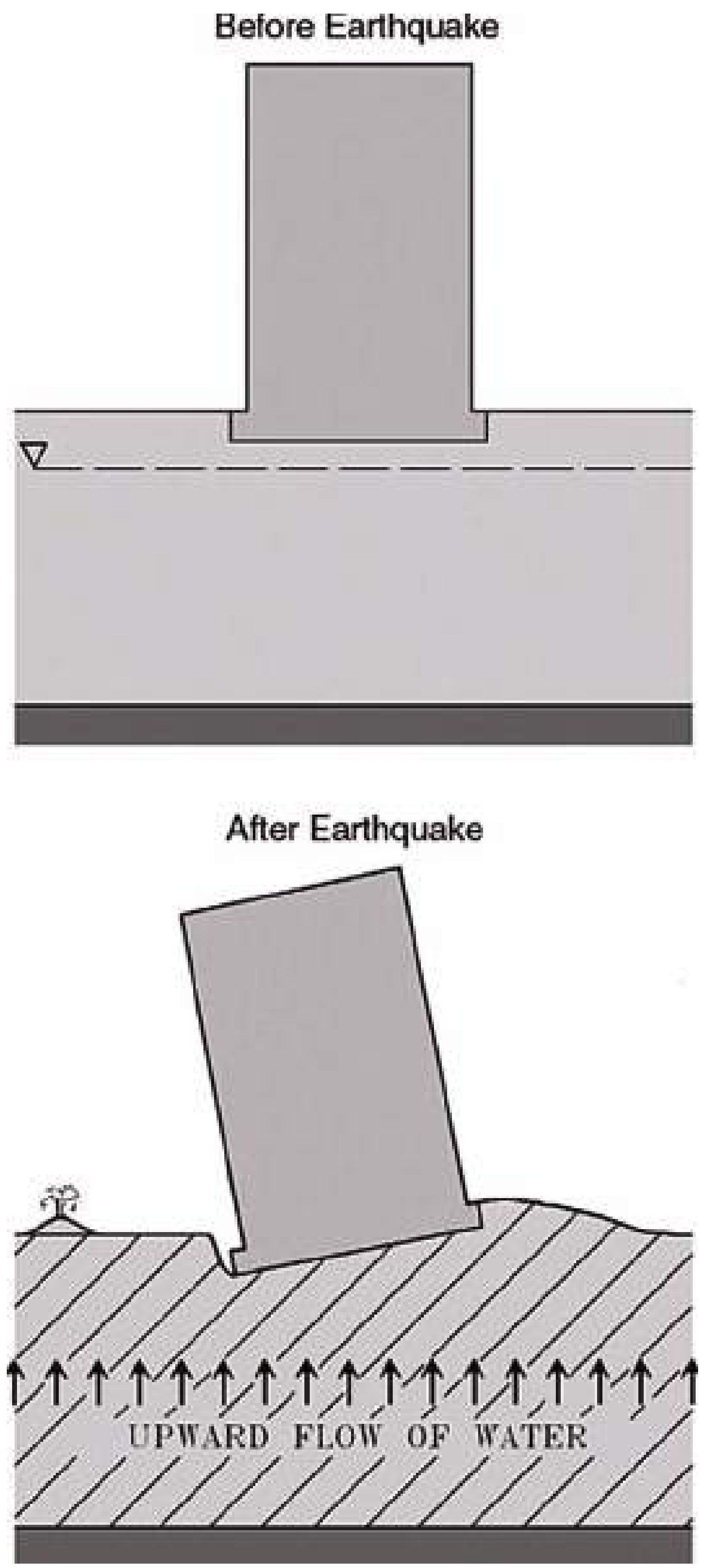
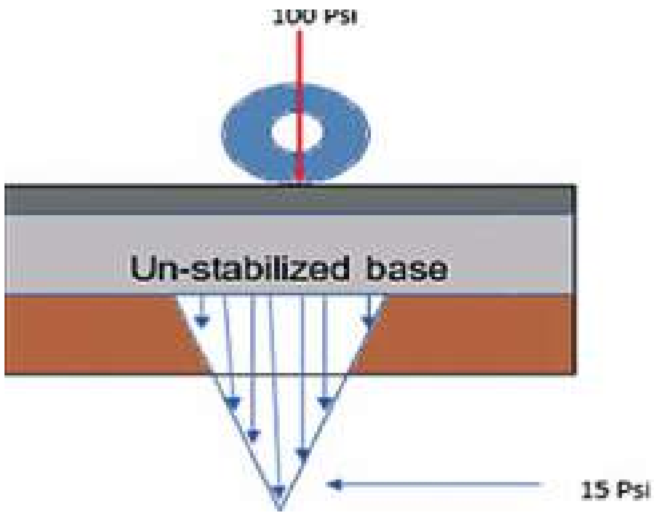


Diagram of bearing failure showing upward migration of pore water creating a liquefied or quick condition beneath structure.



Soil behaviour before and after stabilization.

Before stabilization (the picture on the left), when 100 psi of pressure is applied to the soil, there is a deflection of 15 psi, which is different than the stabilization where only 4 psi of deflection occurred. This means that the soil before stabilization contained voids and low strength and the stabilizer filled these voids and enhanced its compressive strength.

Soil strength is a fundamental property in geotechnical engineering that determines the ability of soil to withstand applied loads and resist deformation. Shear strength theories of soils are fundamental in geotechnical engineering for understanding the behaviour of soil under different loading conditions.Soil strength resists the stresses causing compaction, and tends to increase with compaction. However, at the same bulk-density and moisture content, a well-structured soil resists stresses better than a poorly structured soil under moist conditions, A wet soil is generally weaker than a dry soil. In periods with wet-weather conditions, compacted soils tend to become wetter than uncompacted soils due to limited infiltration capacity, smaller saturated hydraulic conductivity, and large micro porosity. Consequently, the strength and trafficability of compacted soils become lower than that of well-structured soils that drain more readily. After a wet period, a compacted soil will stay wet longer with limited workability. In a dry period, the strength of a compacted soil will increase considerably and result in high trafficability. Soil tillage then requires more powerful equipment and a higher energy input to loosen the soil and break up clods of soil into fragments that form a good seedbed.

Compaction increases the penetration resistance for roots, resulting in limited rooting depth and reduced crop growth. At penetration resistances (measured with a cone with a diameter of 12.7 mm and top angle of 30 degrees) of 1.5 MPa and 3.0 MPa, root growth rates of many crops are reduced to approximately 50% and 0%, respectively. However, in well-structured soils, roots can make use of continuous macropores to penetrate deeply into the soil. In drying soils, strength and penetration resistance increase.

Indian Standards provide guidelines, methodologies, and specifications for testing, analysis, and design, including those related to shear strength theories. Here's how shear strength theories relate to Indian Standards:

Shear Strength Theories:

Mohr-Coulomb Theory: This theory is one of the most widely used for analysing soil shear strength. It describes the shear strength of soil as a function of effective stress and provides a linear relationship between shear stress and normal stress on the failure plane. Indian Standards often adopt this theory in various geotechnical analyses.

Terzaghi's Shear Strength Theory: Proposed by Karl Terzaghi, this theory relates the shear strength of soil to effective stress and cohesion. It considers the influence of soil cohesion and friction angle on the shear strength of soil. Indian Standards may incorporate aspects of Terzaghi's theory in design methodologies.

Effective Stress Principle: This principle, commonly used in geotechnical engineering, states that the shear strength of soil is governed by the effective stress acting on the soil particles. Indian Standards often emphasize the consideration of effective stress in soil testing, analysis, and design.

Relation to Indian Standards:

IS 2720 (Part 7): 1980 - Methods of Test for Soils: Determination of Water Content: Dry density using light compaction. This standard provides methods for determining the water content of soils, which is essential for calculating effective stress and conducting shear strength tests.

IS 2720 (Part 10): 1991 - Methods of Test for Soils: Determination of unconfined compressive strength: This standard specifies methods for determining shear strength parameters such as cohesion and friction angle, which are crucial for applying shear strength theories in geotechnical analyses and design.

IS 6403: 1981 - Code of Practice for Determination of Bearing Capacity of Shallow Foundations: Shear strength theories are often employed in bearing capacity calculations for shallow foundations, and this standard provides guidelines for determining bearing capacity, considering shear strength parameters.

IS 1893: 1984 - Criteria for Earthquake Resistant Design of Structures -Shear strength theories play a significant role in the seismic design of foundations, and this standard provides criteria for designing foundations considering soil shear strength parameters and seismic loading.

Importance of Indian Standards:

Quality Assurance: Indian Standards ensure that shear strength tests and analyses are conducted using standardized methods, leading to reliable assessments of soil behaviour and informed engineering decisions.

Safety Assurance: Compliance with Indian Standards in geotechnical analyses and design helps ensure the safety and stability of structures built on or within the soil by considering shear strength parameters accurately.

Interoperability: Standardized testing methods and design guidelines provided by Indian Standards facilitate communication and collaboration among engineers, researchers, and stakeholders involved in geotechnical engineering projects.

In summary, shear strength theories of soils are closely related to Indian Standards, which provide guidance and specifications for testing, analysis, and design in geotechnical engineering, ensuring safety, reliability, and interoperability in civil infrastructure projects in India.

Indian Standards play a crucial role in determining the factors affecting soil strength by providing guidelines, methodologies, and specifications for testing, analysis, and design in geotechnical engineering. Here's how Indian Standards are relevant in this context:

Factors Affecting Soil Strength:

Particle Size and Shape: The particle size distribution and shape influence soil strength by affecting interparticle friction and cohesion. Indian Standards provide methods for particle size analysis (e.g., IS 2720 Part 4: 1985) and specifications for soil classification based on particle size (e.g., IS 1498: 1970).

Effective Stress: The effective stress principle states that soil strength depends on the effective stress acting on soil particles. Indian Standards (e.g., IS 2720 Part 12: 1981) provide methods for determining shear strength of soil from consolidated undrained triaxial compression test with measurement of pore water pressure.

Water Content: Soil strength is significantly affected by water content, with saturated soils typically exhibiting lower strength. Indian Standards (e.g., IS 2720 Part 7: 1980) provide methods for determining water content, essential for assessing soil strength characteristics.

Soil Structure and Fabric: Soil structure, including arrangement and orientation of soil particles, influences soil strength. Indian Standards (e.g., IS 2720 Part 29: 1975) specified method of testing in place dry density of soils for soil stability analysis for determining the degree of compaction of compacted soil etc.

Consolidation and Compression: Soil strength can change due to consolidation and compression processes. Indian Standards (e.g., IS 2720 Part 16: 1987) provide methods for determining the CBR aiding in understanding soil strength behaviour.

Role of Indian Standards:

Standardized Testing Methods: Indian Standards provide standardized methods for testing soil properties, such as particle size distribution, water content, and consolidation characteristics, essential for determining factors affecting soil strength.

Guidelines for Analysis: Indian Standards offer guidelines for analysing soil strength based on various factors, ensuring consistency and reliability in geotechnical engineering practice.

Design Specifications: Indian Standards provide design specifications based on soil strength parameters, enabling engineers to design structures considering factors affecting soil strength, such as bearing capacity and slope stability.

Safety and Reliability: Compliance with Indian Standards ensures that factors affecting soil strength are adequately considered in geotechnical investigations, analyses, and designs, leading to safer and more reliable civil engineering projects.

In summary, Indian Standards play a crucial role in determining factors affecting soil strength by providing guidelines, methodologies, and specifications for testing, analysis, and design in geotechnical engineering, ensuring safety, reliability, and consistency in civil infrastructure projects in India.

Bearing Capacity of Soil

Bearing capacity refers to the maximum load that soil can support without undergoing excessive settlement or failure. Vital for designing safe and stable foundations for buildings, bridges, roads, and other structures.

Factors Affecting Bearing Capacity:

- Soil properties: Composition, density, moisture content, and grain size.
- Loading conditions: Type, magnitude, and duration of the applied load.
- Foundation geometry: Shape, depth, and size of the foundation.

Methods for Determination:

- Empirical methods: Based on historical data and experience.
- Analytical methods: Utilize soil mechanics principles for calculation.
- Experimental methods: Conducting laboratory or field tests.

Safety Factors: Applied to calculated bearing capacity to ensure stability and reliability of foundation design.

Applications: Critical for preventing foundation failures and ensuring structural safety.

Considerations: Local building codes, soil conditions, and project requirements influence bearing capacity assessment.

Understanding bearing capacity is essential for constructing durable and safe structures atop various soil types.

Indian Standards play a vital role in the determination of bearing capacity of soil, which is a critical parameter in geotechnical engineering for designing foundations and ensuring structural stability. Here's how Indian Standards are relevant to bearing capacity determination:

Indian Standards Related to Bearing Capacity of Soil:

IS 6403: 1981 - Code of Practice for Determination of Bearing Capacity of Shallow Foundations: This standard provides guidelines for determining the bearing capacity of shallow foundations, including spread footings, isolated footings, and raft foundations. It outlines methods for calculating bearing capacity based on soil properties, such as cohesion, angle of internal friction, and size and shape of foundation.

IS 2911 (Part 1/Sec 1): 2010 - Design and Construction of Pile Foundations: Part 1/Section 1 - Concrete Piles: Driven cast in-situ concrete piles-This standard provides specifications for the design and construction of pile foundations, including guidelines for assessing the bearing capacity of piles based on soil properties and load test results.

IS 2911 (Part 1/Sec 2): 2010 - Design and Construction of Pile Foundations: Part 2 - Concrete Piles:Bored cast in-situ concrete piles-This standard provides additional specifications for the design and construction of concrete pile foundations, including guidelines for static load tests and dynamic load tests to determine bearing capacity.

Importance of Indian Standards in Bearing Capacity Determination:

Standardized Testing and Analysis Methods: Indian Standards provide standardized methods for testing soil properties and analyzing bearing capacity, ensuring consistency and reliability in engineering practice.

Safety and Stability: Compliance with Indian Standards in bearing capacity determination ensures that foundations are designed to withstand anticipated loads safely, reducing the risk of settlement, tilting, or failure.

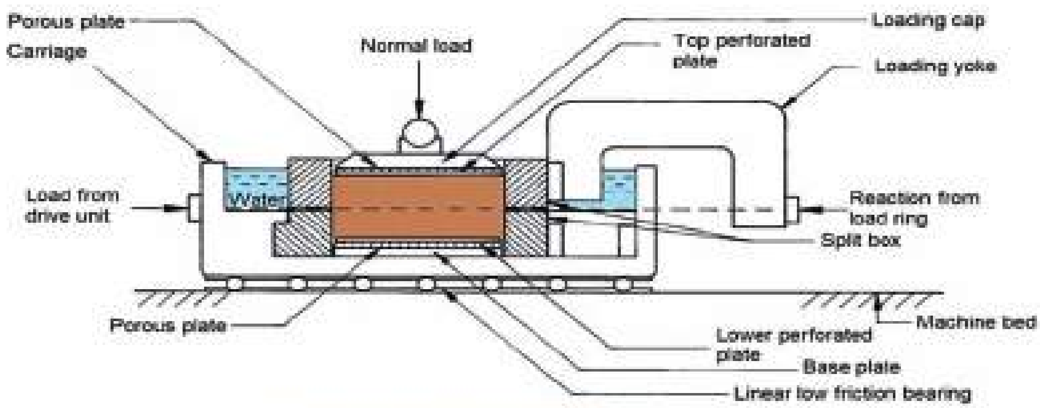
Efficient Design Process: Indian Standards provide engineers with guidelines and methodologies for efficiently determining bearing capacity, facilitating the design process and optimizing foundation designs.

Quality Assurance: By adhering to Indian Standards, engineers can ensure that bearing capacity calculations are performed accurately and that foundations are designed to meet regulatory requirements and project specifications.

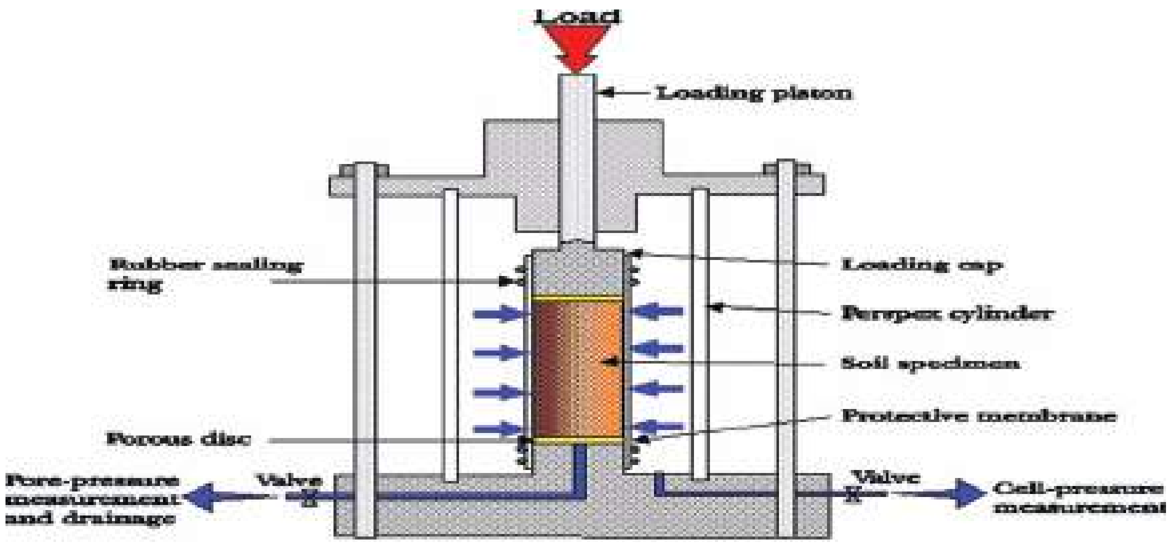
In summary, Indian Standards are integral to the determination of bearing capacity of soil, providing guidelines, methodologies, and specifications for testing, analysis, and design in geotechnical engineering. Compliance with these standards ensures safety, reliability, and efficiency in the design and construction of foundations for civil infrastructure projects in India.

Measurement of Soil Strength:

Laboratory Tests: Various laboratory tests, such as direct shear tests, triaxial compression tests, and unconfined compression tests, are conducted to determine soil strength parameters such as cohesion and friction angle.

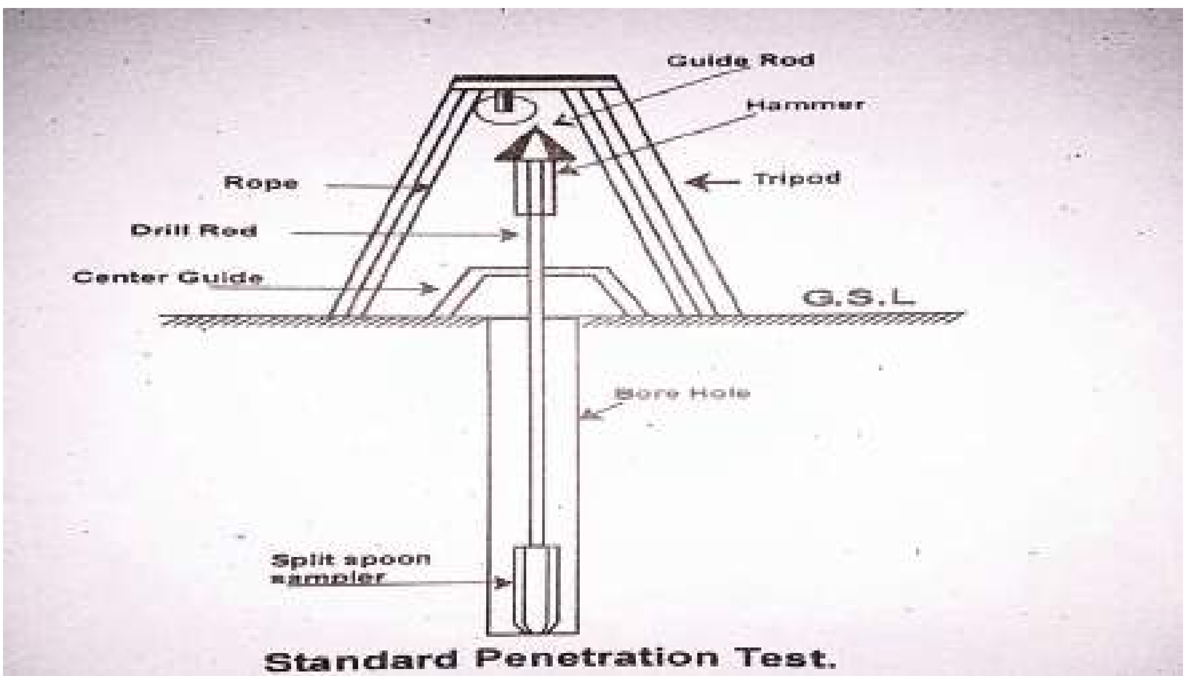


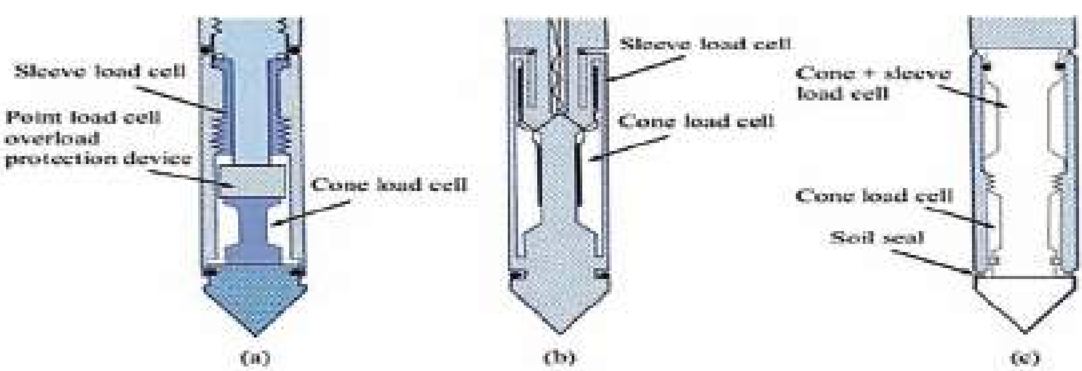
Typical setup for a direct shear test



Triaxial apparatus

Field Tests: In-situ tests, including standard penetration tests (SPT), cone penetration tests (CPT), and vane shear tests, provide valuable information about soil strength in the field.





Typical Cone Penetration test

CHAPTER V
FOUNDATION TYPES

Chapter V

FOUNDATION TYPES

In civil engineering, foundations are critical elements of any structure, serving as the base upon which buildings, bridges, dams, and other infrastructure are constructed. They transfer the weight of the structure to the underlying soil or rock in a manner that ensures stability, safety, and longevity.

Purpose of Foundations: Foundations distribute the load of the structure over a large area of soil to prevent settlement, tilting, or collapse. They also anchor the structure against horizontal forces like wind or earthquakes.

Indian Standards are of paramount importance in the study and practice of shallow foundations, deep foundations, and special foundations in geotechnical engineering. These standards provide guidelines, methodologies, and specifications that ensure safety, reliability, and efficiency in the design and construction of various types of foundations. Here's a breakdown of their importance in each category:

Shallow Foundations (e.g. Spread Footings, Mats):

Shallow foundations, also known as spread footings or footings, are structural elements that transfer building loads to the underlying soil near the surface.

Types:

- o **Isolated Footings**: Used to support individual columns or isolated loads.
- o **Combined Footings**: Support two or more columns when their footprints overlap.
- o **Mat or Raft Foundations**: Spread over the entire area beneath a structure to distribute loads evenly.

Design Considerations:

- **Soil Bearing Capacity**: Determined through soil tests to ensure it can support the proposed loads.
- **Foundation Size and Shape**: Designed based on the magnitude and distribution of loads, as well as soil properties.
- **Depth**: Typically, shallower than deep foundations, extending only to the depth where adequate bearing capacity is available.
- **Reinforcement**: Sometimes required to enhance the foundation's capacity or control settlement.

Construction Process:

- **Excavation**: Soil is excavated to the required depth, often using mechanical equipment.
- **Footings Placement**: Forms are constructed, and concrete is poured into them to create the footings.
- **Curing**: Concrete cures to attain its full strength before further construction proceeds.

Advantages:

- **Cost-Effective**: Generally, less expensive than deep foundations.
- **Ease of Construction**: Can be constructed using simple equipment and techniques.
- **Suitability for Light to Moderate Loads**: Ideal for structures with relatively low loads.

Limitations:

- **Limited Load Capacity**: Not suitable for structures with extremely heavy loads or poor soil conditions.
- **Risk of Differential Settlement**: Uneven settlement may occur if soil conditions vary beneath different parts of the foundation.

Applications:

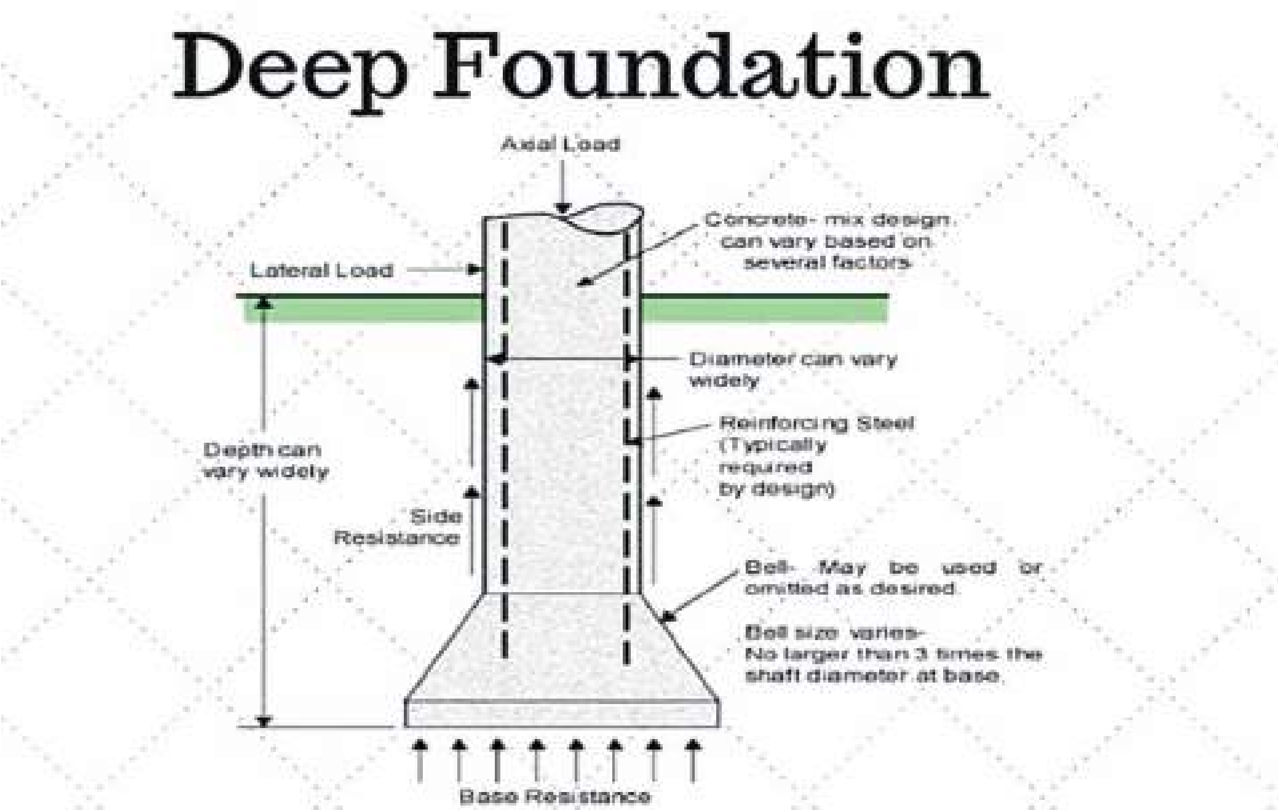
- **Residential Construction**: Commonly used for houses, small buildings, and low-rise structures.
- **Commercial Buildings**: Suitable for light to moderately loaded commercial structures.
- **Industrial Facilities**: Used in facilities with moderate loads and favourable soil conditions.

Shallow foundations offer a practical and cost-effective solution for many construction projects, provided soil conditions and loads are within their capacity limits. Some relevant Indian Standards are:

IS 6403: 1981 - Code of Practice for Determination of Bearing Capacity of Shallow Foundations: This standard provides guidelines for determining the bearing capacity of shallow foundations, such as spread footings and isolated footings. It outlines methods for calculating bearing capacity based on soil properties, ensuring safe and stable foundation designs.

IS 1904: 2021 - Code of Practice for Design and Construction of Foundations in Soils: This standard provides general guidelines for the design and construction of shallow foundations in various soil conditions. It covers aspects such as foundation geometry, soil investigation, and construction techniques, ensuring the reliability and durability of shallow foundations.

Deep Foundations (e.g. Piles, drill shafts):



Deep foundations are structural elements used to transfer loads from a building or structure through weak, compressible soil to stronger, more competent soil or rock at depth. They're essential when shallow foundations, such as footings, are not feasible due to inadequate bearing capacity or excessive settlement.

Types:

- **Pile Foundations**: Driven or cast-in-place columns of concrete, steel, or timber. Common types include driven piles, bored piles, and screw piles.
- **Drilled Shafts (or Caissons)**: Large-diameter, drilled deep into the ground and filled with concrete or reinforced with steel.
- **Piers**: Similar to drilled shafts but with smaller diameters, often used in bridge construction.

Function:

- Transfer structural loads from the superstructure to deeper, more competent soil or rock layers.
- Resist uplift, lateral, and overturning forces.
- Minimize settlement and prevent differential settlement.

Design Considerations:

- Soil properties: Including bearing capacity, shear strength, and settlement characteristics.
- Structural loads: Dead loads, live loads, wind loads, seismic loads, etc.
- Environmental factors: Water table level, corrosive conditions, etc.
- Construction constraints: Access, equipment, and space limitations.

Installation:

- Pile Driving: Uses impact or vibratory methods to drive piles into the ground.
- Drilled Shafts: Requires excavation using drilling equipment, then filling the hole with concrete or placing reinforcement before pouring concrete.
- Piers: Similar to drilled shafts but usually smaller in diameter and often used in bridges.

Advantages:

- Suitable for sites with poor soil conditions.
- Can be designed to withstand high loads and resist uplift and lateral forces.
- Minimal disturbance to surrounding areas during construction.

Disadvantages:

- Higher initial cost and longer construction time compared to shallow foundations.
- Requires specialized equipment and expertise for installation.
- Environmental concerns, especially with regards to noise and vibration during pile driving.

Applications:

- Skyscrapers and tall buildings.
- Bridges and highway overpasses.
- Industrial structures like power plants and refineries.
- Offshore structures such as oil platforms.
- Infrastructure projects like dams and retaining walls.

Deep foundations are crucial in ensuring the stability, safety, and longevity of structures, particularly in areas with challenging soil conditions or where high loads are expected. Proper design, construction, and maintenance are essential for their effectiveness and longevity. Some relevant Indian Standards are:

IS 2911 (Part 1/Sec 1): 2010 - Design and Construction of Pile Foundations-code of practice:Part 1Concrete piles:Sec2 driven cast in-situconcrete piles- This standard provides specifications for the design and construction of concrete pile foundations. It includes guidelines for pile load tests, pile spacing, and pile cap design, ensuring the structural integrity and stability of deep foundations.

IS 2911 (Part 1/Sec 2): 2010 - Design and Construction of Pile Foundations-code of practice:Part 1Concrete piles:Sec2 bored cast in-situconcrete piles-Similar to Part 1/Section 1, this standard provides specifications for the design and construction of timber pile foundations. It covers aspects such as pile materials, pile driving methods, and pile protection measures, ensuring the safety and durability of timber pile foundations.

Special Foundations (e.g. Underpinning, Caissons):

Special foundations are structural elements used in construction to support buildings and infrastructure in situations where conventional foundation methods are not suitable or efficient. These foundations are designed to transfer building loads to deeper, more stable soil layers or bedrock. Here's a brief overview:

Types of Special Foundations:

- **Pile Foundations**: Consist of long, slender members driven or drilled into the ground. Common types include driven piles (steel, concrete), bored piles, and screw piles.
- **Raft Foundations**: Spread the load of a structure over a large area, often used in areas with weak soil or where soil settlement is a concern.
- **Caisson Foundations**: Large-diameter, deep foundation elements often used in marine or bridge construction. They can be floated into place and then sunk into position or constructed in situ.

- **Diaphragm Walls**: Used for retaining soil and supporting loads, typically in deep excavations for basements or underground structures. They are constructed by excavating a trench and then filling it with reinforced concrete.
- **Micropiles**: Small-diameter piles used in situations where space is limited or ground conditions are challenging. They are often installed using drilling techniques.

Applications:

- Special foundations are used in a variety of applications, including high-rise buildings, bridges, dams, and infrastructure projects such as highways and railways.
- They are particularly important in urban environments where soil conditions may vary widely and where existing structures or utilities may limit the use of traditional foundation methods.

Design Considerations:

- Special foundations must be designed to withstand the loads imposed by the structure and to accommodate variations in soil conditions, groundwater levels, and other site-specific factors.
- Design considerations include the type and size of the foundation elements, their depth and spacing, and the method of installation.

Construction Techniques:

- Construction techniques for special foundations vary depending on the type of foundation and the site conditions. Common methods include driven piling, drilling and grouting, excavation and filling, and precast concrete installation.

Advantages and Challenges:

- Advantages of special foundations include their ability to support heavy loads, accommodate challenging soil conditions, and minimize settlement.
- Challenges include the high cost of construction, the need for specialized equipment and expertise, and the potential for unexpected site conditions or construction delays.

Overall, special foundations play a crucial role in modern construction, enabling the development of structures in challenging environments and ensuring their long-term stability and safety. Some relevant Indian Standards are:

IS 1080: 1985 - Code of Practice for Design and Construction of shallow Foundations in soil (other than raft,ring and shell)-This standard provides guidelines for the design and construction of special foundations, including friction piles, end-bearing piles, and composite piles. It covers various types of foundation systems and their applications, ensuring optimal performance and cost-effectiveness.

IS 2911 (Part 1/Sec 1): 2010 - Design and Construction of Pile Foundations-code of practice:Part 1Concrete piles:Sec2 driven cast in-situconcrete piles- This standard provides specifications for the design and construction of driven cast in-situ concrete piles, a type of special foundation commonly used in infrastructure projects. It covers aspects such as pile driving equipment, pile reinforcement, and pile integrity testing, ensuring quality and reliability in pile construction.

Importance of Indian Standards:

Safety Assurance: Indian Standards ensure that foundation designs and construction practices meet safety requirements, reducing the risk of foundation failure and structural instability.

Reliability: Compliance with Indian Standards ensures that foundation designs are based on sound engineering principles and methodologies, leading to reliable and durable foundation systems.

Efficiency: Indian Standards provide engineers with standardized methods and procedures, streamlining the design and construction process and optimizing resource utilization.

Regulatory Compliance: Adherence to Indian Standards ensures that foundation designs and construction practices comply with regulatory requirements, facilitating project approval and permitting processes.

In summary, Indian Standards are of utmost importance in the study and practice of shallow foundations, deep foundations, and special foundations, ensuring safety, reliability, and efficiency in foundation design and construction in India.

CHAPTER VI

FOUNDATION DESIGN

Chapter VI

FOUNDATION DESIGN

Design Principles of different types of Foundation

Indian Standards play a crucial role in establishing design principles, analysis and design methods, and considering factors affecting foundation design, such as soil properties and structural loads. Let's explore each aspect and the role of Indian standards:

Design Principles for Different Types of Foundations:

Shallow Foundations: Indian Standards like IS 6403:1981 provide design principles for determining the bearing capacity of shallow foundations. These standards outline methods for calculating bearing capacity based on soil properties, foundation geometry, and structural loads.

Deep Foundations: Standards such as IS 2911 (Part 1 Sec 1/2): 2010, IS 2911 Part 4:2013 covers design principles for various types of deep foundations, including pile foundations. They provide guidelines for analysing soil conditions, selecting appropriate pile types, and determining pile capacities based on load testing and soil properties.

Special Foundations: Indian Standards like IS 1904:2021 address general requirements for design and construction of Foundations in soils which involves design principles for special foundations, shallow foundations and deep Foundations. These standards offer guidance on selecting suitable foundation types, considering site-specific soil conditions and structural requirements.

Analysis and Design Methods:

Shallow Foundations: Indian Standards like IS 6403:1981 provide analysis and design methods for shallow foundations. They outline procedures for calculating bearing capacity using empirical formulas or advanced analytical methods based on soil properties and structural loads.

Deep Foundations: IS 2911 (Part 1 Sec 1/2): 2010, IS 2911 Part 4:2013, IS 2911 Part 3:2021 specifies analysis of design and construction methods for pile foundations. It includes provisions for pile load tests, dynamic analysis, and settlement prediction, considering factors like soil behaviour, pile material, and structural loading conditions.

Special Foundations: Indian Standards like IS 1904:2021 address general requirements for design and construction of Foundations in soils which involves design principles for special foundations, shallow foundations and deep Foundations. These standards offer guidance on selecting suitable foundation types, considering site-specific soil conditions and structural requirements.

Factors Affecting Foundation Design (e.g. Soil Properties, Structural Loads):

Soil Properties: Indian Standards consider soil properties such as bearing capacity, shear strength, settlement characteristics, and soil stratification in foundation design. Standards like IS 1904:2021 provide guidelines for design and construction of Foundation in Soil.

Structural Loads: Standards like IS 875 (Part 1): 1987 specify design loads for various structures, including dead loads, live loads, wind loads, and seismic loads. These standards help engineers determine the magnitude and distribution of loads acting on foundations.

Role of Indian Standards:

Safety and Reliability: Indian Standards ensure that foundation designs meet safety requirements and are reliable under anticipated loading conditions, minimizing the risk of failure and ensuring structural stability.

Standardization: These standards provide standardized methods, procedures, and design criteria, promoting consistency and uniformity in foundation design practices across projects and regions.

Guidance and Compliance: Indian Standards offer guidance based on established engineering principles and practices, aiding engineers in making informed decisions during foundation design. Adherence to these standards ensures compliance with regulatory requirements and industry best practices.

In summary, Indian Standards play a crucial role in establishing design principles, analysis and design methods, and considering factors affecting foundation design. They ensure safety, reliability, and compliance with regulatory requirements in foundation engineering practice in India.

CHAPTER VII

EARTH RETAINING STRUCTURES

Chapter VII

EARTH RETAINING STRUCTURES

Indian Standards play a significant role in the design of retaining walls by providing guidelines, methodologies, and specifications that ensure the safety, stability, and durability of these structures. Here's how Indian Standards contribute to the design of retaining walls:

Design Principles

IS 457: 1957 - Code of Practice for general construction for Plain and Reinforced Concrete for dams and other massive structures: This standard provides guidelines for the design of reinforced concrete structures, including retaining walls. It covers aspects such as material properties, structural analysis, and design considerations for concrete retaining walls.

Analysis and Design Methods:

IS 800: 2007 - General Construction in Steel - Code of Practice: For retaining walls made of steel, IS 800 offers guidelines for the design of steel structures, including structural analysis, material properties, and design considerations for steel retaining walls.

Factors Affecting Retaining Wall Design:

Soil Properties:

- o Indian Standards consider soil properties such as bearing capacity, cohesion, angle of internal friction, and lateral earth pressure coefficients in the design of retaining walls. Standards like IS 1892: 2021 provide subsurface investigation for foundations based on soil properties.

Structural Loads:

- o Standards like IS 875(Part 1,2 & 5): 1987, IS 875 (Part 3):2015, IS 875 (Part 4):2021 specify design loads for various structures, including retaining walls. They cover loads such as dead loads, live loads, wind loads, and seismic loads, imposed Loads which influence the design of retaining walls.

Role of Indian Standards:

Safety Assurance:

- o Indian Standards ensure that retaining walls are designed to withstand anticipated loads and environmental conditions, minimizing the risk of failure and ensuring the safety of adjacent structures and occupants.

Standardization:

- o These standards provide standardized methods, procedures, and design criteria for the design of retaining walls, promoting consistency and uniformity in engineering practice.

Guidance and Compliance:

- o Indian Standards offer guidance based on established engineering principles and practices, aiding engineers in making informed decisions during the design and construction of retaining walls. Adherence to these standards ensures compliance with regulatory requirements and industry best practices.

In summary, Indian Standards play a crucial role in the design of retaining walls by providing design principles, analysis and design methods, and considering factors affecting their design. They ensure safety, reliability, and compliance with regulatory requirements in retaining wall engineering practice in India.

Slope Stability Analysis:

Slope stability analysis is critical in the design and construction of earth retaining structures to ensure safety and durability. It involves assessing the stability of slopes, embankments, and retaining walls under various conditions such as soil type, groundwater levels, and external loads.

Indian standards, particularly those established by the Bureau of Indian Standards (BIS), play a crucial role in the analysis of slope stability. These standards provide guidelines, procedures, and design criteria specific to the geotechnical engineering practices in India. Some key aspects where Indian standards influence slope stability analysis of earth retaining structures include:

Soil Classification: Indian standards provide classification systems for soils based on their properties, such as the Indian Standard Soil Classification System (IS: 1498). Proper classification of soil is essential for accurate analysis of slope stability.

Geotechnical Investigations: BIS standards prescribe methods for conducting geotechnical investigations to assess soil properties, groundwater conditions, and other relevant parameters. This information is vital for input parameters in slope stability analysis.

Design Loads: Indian standards specify design loads and load combinations for various structures, including earth retaining structures. These loads are considered in slope stability analysis to determine the factor of safety against failure.

Methods of Analysis: BIS standards may recommend specific methods of slope stability analysis, such as limit equilibrium methods (e.g., Bishop's method, Fellenius method) or numerical modelling techniques. These methods consider factors like soil shear strength, pore water pressure, and slope geometry to evaluate stability.

Material Properties: Standards may provide guidelines for determining material properties such as soil shear strength parameters, which are crucial inputs for slope stability analysis.

Factor of Safety Criteria: Indian standards typically specify minimum factor of safety requirements for earth retaining structures. Factor of safety is a measure of how close the structure is to failure under given conditions, and it is a key parameter in slope stability analysis.

Construction Practices: BIS standards also cover construction practices related to earth retaining structures, ensuring that proper construction techniques are followed to enhance stability and longevity.

Bureau of Indian Standards (BIS) provides guidelines and standards for slope stability analysis of earth retaining structures. Some relevant standards include:

IS 14458:Part 1& 3:1998 - Guidelines for retaining wall for hill area: This standard provides guidelines for the design and construction of retaining walls in hill areas, where slope stability is a significant concern. It covers various types of retaining walls, including gravity walls, cantilever walls, and reinforced earth walls.

IS 457: 1957 - Code of practice for plain and reinforced concrete for dams and other massive structures: While not specifically focused on slope stability analysis, IS 457 provides guidance on the design of reinforced concrete structures, including retaining walls, which are commonly used for earth retaining purposes.

IS 1893 (Part 1):2016 - Criteria for earthquake resistant design of structures: This standard provides criteria for earthquake-resistant design of structures, including guidelines for assessing the seismic stability of earth retaining structures in seismic zones.

IS 3370 (Part 1-4):2021 - Code of practice for concrete structures for storage of aqueous liquids : Although primarily focused on concrete structures for liquid storage, Part 1-4 of IS 3370 provides valuable information on the design and construction of underground and earth-retaining structures.

IS 800:2007 - General construction in steel - Code of practice (third revision): This standard provides guidelines for the design of steel structures, including steel retaining walls and sheet pile walls commonly used in earth retaining applications.

While these standards may not specifically address slope stability analysis in their titles, they provide essential guidance on the design, construction, and assessment of earth retaining structures, which is integral to slope stability analysis. Additionally, BIS may periodically revise or update these standards to incorporate advancements in geotechnical engineering practices and address emerging challenges in slope stability analysis.

In summary, Indian standards provide comprehensive guidelines and criteria for conducting slope stability analysis of earth retaining structures. Adhering to these standards helps ensure that designs are safe, reliable, and suitable for the specific geological and environmental conditions prevalent in India.

Reinforced Soil Structures:

Reinforced soil structures are a type of earth retaining structure that utilizes the interaction between soil and reinforcement materials (such as geosynthetics, steel strips, or geogrids) to improve stability and performance. These structures are widely used in civil engineering for applications such as retaining walls, embankments, slope stabilization, and bridge abutments. Here's a brief outline of reinforced soil structures and their relevance to Indian Standards:

Background: Reinforced soil structures date back to the late 1960s and early 1970s when they were first developed as a cost-effective and efficient alternative to traditional concrete retaining walls. The concept involves inserting reinforcement elements into the soil mass to enhance its load-bearing capacity and resistance to various external forces, such as earth pressure, seismic loads, and settlement.

Components of Reinforced Soil Structures:

Reinforcement Elements: These can include geosynthetic materials like geogrids or geotextiles, metallic strips, or other types of geocomposites.

Fill Material: The soil mass that forms the body of the reinforced structure.

Facing Elements: Surface elements that provide aesthetic finishing and protect the reinforced soil mass from erosion.

Construction Process:

Preparation of Subgrade: Excavation and preparation of the foundation for the reinforced soil structure.

Placement of Reinforcement: Installation of reinforcement elements within the soil mass at specified intervals and depths.

Backfilling and Compaction: Filling the space between reinforcement layers with suitable fill material and compacting it to achieve desired density and stability.

Facing Installation: If required, installing facing elements such as concrete panels, blocks, or vegetative cover.

Relevance to Indian Standards: In India, the Bureau of Indian Standards (BIS) provides guidelines and standards relevant to reinforced soil structures. Some key points of relevance include:

Design Criteria: Indian standards specify design criteria for reinforced soil structures, including factors such as allowable bearing capacity, reinforcement spacing, facing stability, and seismic design considerations.

Material Specifications: Standards prescribe specifications for the materials used in reinforced soil structures, including geosynthetics, fill materials, and facing elements. These specifications ensure that materials meet the required quality and performance standards.

Construction Practices: BIS standards provide guidelines for the construction of reinforced soil structures, covering aspects such as excavation, reinforcement installation, compaction, and facing installation. Adhering to these guidelines helps ensure the structural integrity and stability of the constructed elements.

Quality Assurance: Standards may include provisions for quality control and assurance during the construction of reinforced soil structures, such as testing of materials, compaction monitoring, and inspection procedures.

Safety and Environmental Considerations: Indian standards address safety and environmental considerations related to reinforced soil structures, including guidelines for slope stabilization, erosion control, and mitigation of potential hazards during construction and operation.

Overall, adherence to Indian Standards is essential for the proper design, construction, and performance of reinforced soil structures in India, ensuring safety, durability, and sustainability in civil engineering projects. Bureau of Indian Standards (BIS) had not issued a specific standard solely dedicated to reinforced soil structures. However, reinforced soil structures are governed by a combination of relevant BIS standards and guidelines that cover aspects such as design, materials, construction practices, and quality assurance. Here are some of the key Indian standards that are relevant to reinforced soil structures:

IS 2720 (Part 1-41) - Methods of Test for Soils: This series of standards provides methods for testing various properties of soils, including those used in reinforced soil structures. These tests help in determining soil characteristics such as compaction, strength, and permeability.

IS 3764:1992 – Excavation Work – Code of Safety: This standard specifies requirements for carrying out safely the excavation work such as trenches, test pits, cellars, borrow pits, cuttings for rail, canals and road formations and all excavations on which the sides of excavations are not trimmed simultaneously to a stable slope.

IS 11532: 1995 - Guidelines for River embankment construction and Maintenance: Although not specific to reinforced soil structures, this standard provides guidelines for the construction of river embankments on soft ground, which may be relevant to the construction of reinforced soil embankments.

IS 18591:2024 – Geosynthetic reinforced soil structures-code of practice: This standard provides guidelines for the design and construction of reinforced soil walls, which are a common type of reinforced soil structure.

IS 16380: 2020 - Geosynthetic reinforcement – Method of Test for Measuring Pull out Resistance of geosynthetics in Soil: This standard specifies test methods to determine the performance related property of a geosynthetic and other geosynthetic products(geogrid, geostrips, geotextiles etc) in terms of resistance to pullout force occurring due to the shearing, buried under compacted soil using a laboratory pull out box.

While these standards do not comprehensively cover all aspects of reinforced soil structures, they provide essential guidance on materials, design principles, and construction practices relevant to such structures. Additionally, BIS may periodically update or revise these standards to reflect advancements in technology and changes in industry practices. Therefore, it's essential to consult the latest versions of relevant standards and guidelines when designing and constructing reinforced soil structures in India.

CHAPTER VIII

GEOTECHNICAL INVESTIGATIONS

CHAPTER VIII

GEOTECHNICAL INVESTIGATIONS

Site Exploration Technique:

Site exploration techniques are essential in geotechnical engineering to gather information about subsurface conditions at a construction site. This information is crucial for designing safe and cost-effective foundations, earthworks, and other geotechnical structures. Here's a brief outline of site exploration techniques and the role played by Indian standards:

Site Exploration Techniques:

Desk Study: This involves gathering existing data from maps, geological surveys, previous reports, and other sources to understand the geological and environmental context of the site.

Geophysical Surveys: Techniques such as seismic surveys, electrical resistivity tomography (ERT), ground-penetrating radar (GPR), and others are used to detect subsurface features and anomalies without excavation.

Drilling: Drilling methods such as auger drilling, rotary drilling, and percussion drilling are used to collect soil and rock samples from various depths for laboratory testing and analysis.

Sampling: Soil and rock samples obtained through drilling are collected and preserved for laboratory testing to determine properties such as grain size, moisture content, shear strength, permeability, and compressibility.

In-Situ Testing: In-situ tests such as standard penetration tests (SPT), cone penetration tests (CPT), pressure meter tests, and vane shear tests are performed to directly measure soil properties and assess subsurface conditions.

Borehole Logging: Geologists and engineers analyse borehole logs to identify soil and rock types, stratigraphy, groundwater levels, and other relevant information.

Field Testing: Field tests such as plate load tests, field vane shear tests, and pressure bulb tests are conducted to assess the load-bearing capacity and deformation characteristics of soil in its natural state.

Role of Indian Standards:

Indian standards play a crucial role in site exploration by providing guidelines and specifications for conducting various exploration activities. Some key areas where Indian standards are relevant include:

Site Investigation Methods: Indian standards prescribe methods and procedures for conducting site investigations, including desk studies, geophysical surveys, drilling, sampling, and testing. For example, IS 1892 provides guidelines for the subsurface investigation of soil and rock using rotary drilling methods.

Sampling and Testing Standards: Standards such as IS 10108, IS 2132 and IS 4332: Part 1 specify procedures for sampling soils and rocks during exploration activities. IS 2720 series provides methods for testing soil samples in the laboratory to determine their engineering properties.

In-Situ Testing Standards: Standards like IS 5529 (Part 1&2), IS 7746, IS 2720 cover in-situ testing methods such as SPT, CPT, and pressure meter tests, including specifications for equipment, procedures, and interpretation of test results.

Safety Guidelines: Indian standards also include safety guidelines for site exploration activities to ensure the well-being of personnel and the integrity of equipment used during exploration.

Quality Assurance and Reporting: Standards may include provisions for quality assurance and quality control measures to be implemented during site exploration, as well as requirements for preparing comprehensive investigation reports.

Overall, adherence to Indian standards ensures that site exploration activities are conducted systematically, safely, and in accordance with established best practices, ultimately contributing to the reliable assessment of subsurface conditions and the successful design and construction of geotechnical structures.

In India, site exploration techniques are governed by a set of standards provided by the Bureau of Indian Standards (BIS). These standards outline the procedures, methods, and guidelines for conducting various site exploration activities. Here are some of the key Indian standards related to site exploration techniques:

IS 10042: 1981- Code of Practice for Site Investigations for foundation in gravel-boulder deposit: This standard provides guidelines for conducting site investigations, including desk studies, geophysical surveys, drilling, sampling, and testing of soil and rock. Each part of IS 1892 focuses on specific aspects of site investigation techniques.

IS 2131: 1981 - Methods of Standard Penetration Test: This standard specifies the procedures and equipment requirements for conducting the Standard Penetration Test (SPT), which is commonly used to determine the relative density of soils and assess their engineering properties.

IS 1892: 2021 - Guidelines for sub-surface investigations for foundation: This standard provides guidelines for conducting sub-surface investigations specifically for foundation design in land reclamation projects. It covers methods for drilling, sampling, and testing of soil and rock in reclaimed land areas.

IS 14243 (Part 1):1995 – Selection and development of site for building in hill areas-Guidelines: Part 1-Microzonation of urban centres – This standard provides guidelines for microzonation maps for the urban centres or multi-purpose project sites which are based on several factors including nature of sufficient soil and rock strata. While not directly related to site exploration techniques, this standard provides guidelines for seismic microzonation studies, which involve site-specific assessments of seismic hazards and soil conditions in urban areas.

IS 2720 (Part 1-41)- Methods of Test for Soils: This series of standards provides methods for testing various properties of soils, including those obtained through site exploration techniques. It covers tests for properties such as grain size distribution, moisture content, density, shear strength, and permeability.

These standards ensure that site exploration activities are conducted systematically, safely, and in accordance with established best practices. They help in the reliable assessment of subsurface conditions, which is essential for the successful design and construction of various civil engineering projects. It's important for engineers and geotechnical professionals to adhere to these standards to ensure the quality and accuracy of site investigation data.

Soil Sampling and Testing Methods:

Soil sampling and testing methods are fundamental in geotechnical engineering for assessing soil properties, characteristics, and behaviour. These methods involve collecting soil samples from the subsurface and subjecting them to various laboratory tests to determine their engineering properties. Here's a brief outline of soil sampling and testing methods, their significance, and the crucial role played by Indian standards:

Soil Sampling Methods:

Hand Auger Sampling: This method involves manually drilling a borehole using a hand auger and extracting soil samples from different depths. It's suitable for relatively shallow depths and cohesive soils.

Rotary Drilling: Rotary drilling employs a rotary drill rig to bore into the ground and extract soil samples using a hollow drill bit. It's suitable for both cohesive and non-cohesive soils and can reach greater depths than hand auger sampling.

Percussion Drilling: Percussion drilling uses a hammering action to penetrate the ground and collect soil samples. It's suitable for dense or rocky soils and can be used at varying depths.

Cone Penetration Testing (CPT): CPT involves pushing a cone-shaped penetrometer into the ground at a constant rate and measuring the resistance encountered. It provides continuous data on soil resistance and can be used for rapid, in-situ soil characterization.

Soil Testing Methods:

Grain Size Analysis: This test determines the distribution of particle sizes in a soil sample using sieves or sedimentation methods. It provides information on soil texture and classification.

Atterberg Limits Test: Atterberg limits tests determine the moisture content at which a soil transitions between solid, plastic, and liquid states. These limits include the liquid limit, plastic limit, and shrinkage limit, which are essential for soil classification and engineering design.

Shear Strength Tests: Shear strength tests, such as direct shear tests and triaxial compression tests, assess the soil's resistance to deformation and failure under applied stress. They provide crucial information for slope stability analysis, foundation design, and retaining structure design.

Compaction Tests: Compaction tests, including the Proctor compaction test and modified compaction test, evaluate the soil's compaction characteristics and optimum moisture content for achieving maximum density. This information is vital for earthwork and embankment construction.

Significance and Role of Indian Standards:

Indian standards, provided by the Bureau of Indian Standards (BIS), play a crucial role in soil sampling and testing by providing guidelines, specifications, and procedures to ensure the quality and accuracy of soil investigation data. These standards cover:

Sampling Procedures: Indian standards specify procedures for collecting representative soil samples using different sampling methods, ensuring that samples accurately reflect subsurface conditions.

Testing Methods: BIS standards provide standardized methods for conducting laboratory tests on soil samples, including grain size analysis, Atterberg limits tests, shear strength tests, and compaction tests. These methods ensure consistency and reliability in soil testing results.

Quality Control and Assurance: Indian standards include provisions for quality control and assurance measures during soil sampling and testing, ensuring that equipment is calibrated, procedures are followed correctly, and test results are interpreted accurately.

Reporting Requirements: BIS standards may specify requirements for documenting and reporting soil sampling and testing results, including formats for test reports and interpretations.

Overall, adherence to Indian standards is essential for ensuring the quality, reliability, and consistency of soil sampling and testing methods in geotechnical engineering practice. These standards help engineers and geotechnical professionals make informed decisions in the design and construction of various civil engineering projects.

Soil sampling and testing methods are governed by a set of standards provided by the Bureau of Indian Standards (BIS). These standards outline the procedures, methods, and guidelines for collecting soil samples from the subsurface and subjecting them to various laboratory tests to determine their engineering properties. Here are some of the key Indian standards related to soil sampling and testing methods:

IS 2131: 1981- Methods of Standard Penetration Test: This standard specifies the procedures and equipment requirements for conducting the Standard Penetration Test (SPT), which is commonly used to determine the relative density of soils and assess their engineering properties.

IS 2132: 1986 - Code of practice for thin-walled tube sampling of soils: This standard provides guidelines for collecting undisturbed soil samples using thin-walled tube sampling methods. It covers procedures for sampling cohesive and non-cohesive soils and ensures that samples retain their natural structure and moisture content.

IS 2720 (Part 1-41) - Methods of Test for Soils : This series of standards provides methods for testing various properties of soils obtained through soil sampling techniques. It covers tests for properties such as grain size distribution, moisture content, density, shear strength, and permeability.

IS 2720 (Part 4): 1985 - Methods of test for soils: Grain size analysis: This part of IS 2720 specifies the procedure for determining the grain size distribution of soils using sieve analysis or sedimentation methods. It provides guidelines for preparing soil samples, conducting the test, and interpreting the results.

IS 2720 (Part 5): 1985 - Methods of test for soils: Determination of liquid and plastic limit: This part of IS 2720 outlines the procedure for determining the liquid limit and plastic limit of soils using the Casagrande method. It provides guidelines for preparing soil specimens, conducting the test, and calculating the Atterberg limits.

IS 2720 (Part 7): 1980 - Methods of test for soils: Determination of water content-dry density relation using light compaction: This part of IS 2720 specifies the procedure for determining the moisture-density relationship of soils using light compaction methods such as the Proctor test. It provides guidelines for preparing soil specimens, compacting the soil, and determining the dry density.

IS 2720 (Part 16): 1987 - Methods of test for soils: Laboratory determination of CBR: This part of IS 2720 describes the procedure for determining the California Bearing Ratio (CBR) of soils in the laboratory. It provides guidelines for preparing soil specimens, conducting the test, and calculating the CBR value.

These standards ensure that soil sampling and testing activities are conducted systematically, safely, and in accordance with established best practices. They help in the reliable assessment of soil properties, which is essential for the successful design and construction of various civil engineering projects. It's important for engineers and geotechnical professionals to adhere to these standards to ensure the quality and accuracy of soil investigation data.

Interpretation of geotechnical data:

Geotechnical data refers to information obtained from the investigation of subsurface soil and rock conditions at a construction site. This data is crucial for engineers and geotechnical professionals in the design and construction of various civil engineering projects. Here's a brief outline of geotechnical data and its significance, along with the importance of adherence to Indian Standards:

Outline of Geotechnical Data:

Soil and Rock Properties: Geotechnical data includes information on soil and rock properties such as grain size distribution, moisture content, density, shear strength, compressibility, permeability, and geological characteristics. These properties influence the behaviour of soil and rock masses under different loading conditions.

Groundwater Conditions: Geotechnical investigations provide data on groundwater levels, flow rates, and hydrogeological properties. Understanding groundwater conditions is essential for designing foundations, excavations, and drainage systems.

Subsurface Stratigraphy: Geotechnical data reveals the stratigraphy of subsurface layers, including soil and rock formations, bedrock depth, and geological discontinuities. This information helps in understanding the stability and bearing capacity of the ground.

Engineering Properties: Geotechnical tests yield data on engineering properties such as soil classification, Atterberg limits, compaction characteristics, consolidation behavior, and shear strength parameters. These properties are used for foundation design, slope stability analysis, earthwork design, and other geotechnical analyses.

Geotechnical Hazards: Data on geotechnical hazards such as landslides, subsidence, liquefaction, and seismic hazards provide crucial information for assessing risks and implementing mitigation measures in construction projects.

Significance of Geotechnical Data:

Foundation Design: Geotechnical data is fundamental for designing foundations that can safely support the loads from structures and transfer them to the underlying soil or rock strata.

Slope Stability Analysis: Understanding soil and rock properties, groundwater conditions, and subsurface stratigraphy is essential for evaluating slope stability and designing measures to mitigate risks of slope failures.

Earthworks and Excavation Design: Geotechnical data informs earthwork and excavation designs by providing information on soil compaction, bearing capacity, and excavation support requirements.

Risk Assessment and Management: Geotechnical data allows engineers to assess geological and geotechnical risks associated with construction projects and implement appropriate risk management measures.

Adherence to Indian Standards:

Adherence to Indian Standards, provided by the Bureau of Indian Standards (BIS), is essential for ensuring the quality, reliability, and consistency of geotechnical data. Indian Standards provide guidelines, specifications, and procedures for conducting geotechnical investigations, sampling, testing, and reporting. Adhering to these standards ensures that geotechnical data is collected systematically, safely, and in accordance with established best practices. It also facilitates communication and collaboration among engineers, geologists, contractors, and other stakeholders involved in construction projects.

In summary, geotechnical data is crucial for informed decision-making and successful execution of civil engineering projects. Adherence to Indian Standards in collecting, analysing, and interpreting geotechnical data is essential for ensuring the safety, reliability, and durability of infrastructure projects in India.

In India, geotechnical data collection, testing, and reporting are guided by a set of standards provided by the Bureau of Indian Standards (BIS). These standards outline the procedures, methods, and guidelines for conducting geotechnical investigations and ensuring the quality and accuracy of geotechnical data. Here are some of the key Indian standards related to geotechnical data:

IS 1892 : 2021 - Code of Practice for subsurface investigation for foundations: This standard provides guidelines for conducting site investigations, including desk studies, geophysical surveys, drilling, sampling, and testing of soil and rock. Each part of IS 1892 focuses on specific aspects of site investigation techniques.

IS 2131: 1981 - Methods of Standard Penetration Test: This standard specifies the procedures and equipment requirements for conducting the Standard Penetration Test (SPT), which is commonly used to determine the relative density of soils and assess their engineering properties.

IS 2720 (Part 1-41) - Methods of Test for Soils (Part 1-31): This series of standards provides methods for testing various properties of soils obtained through soil sampling techniques. It covers tests for properties such as grain size distribution, moisture content, density, shear strength, and permeability.

IS 2132: 1986 - Code of Practice for Thin-Walled Tube Sampling of Soils: This standard provides guidelines for collecting undisturbed soil samples using thin-walled tube sampling methods. It covers procedures for sampling cohesive and non-cohesive soils and ensures that samples retain their natural structure and moisture content.

IS 2720 (Part 5): 1985 - Methods of Test for Soils (Part 5): This part of IS 2720 outlines the procedure for determining the liquid limit and plastic limit of soils using the Casagrande method. It provides guidelines for preparing soil specimens, conducting the test, and calculating the Atterberg limits.

IS 2720 (Part 7): 1980 - Methods of Test for Soils (Part 7): This part of IS 2720 specifies the procedure for determining the moisture-density relationship of soils using light compaction methods such as the Proctor test. It provides guidelines for preparing soil specimens, compacting the soil, and determining the dry density.

These standards ensure that geotechnical investigations and testing activities are conducted systematically, safely, and in accordance with established best practices. Adhering to these standards helps ensure the quality, reliability, and consistency of geotechnical data, which is essential for the successful design and construction of various civil engineering projects.

CHAPTER IX
CONSTRUCTION ASPECTS

Chapter IX

CONSTRUCTION ASPECTS

Construction techniques for foundation and Retaining Structures:

The construction techniques of foundations and retaining structures are critical aspects of civil engineering, ensuring the stability, durability, and safety of structures in various construction projects. Foundations provide the base upon which structures are built, while retaining structures help to stabilize soil and accommodate changes in ground elevation. Indian Standards, established by the Bureau of Indian Standards (BIS), play a crucial role in guiding these construction techniques, ensuring adherence to best practices and safety standards.

Foundations Construction Techniques:

Shallow Foundations: Shallow foundations, such as spread footings and mat foundations, are constructed near the ground surface and distribute building loads to a broader area of soil. Construction techniques involve excavation, preparation of the foundation bed, placing reinforcement if needed, and pouring concrete to form the foundation.

Deep Foundations: Deep foundations, including pile foundations and drilled shafts, are used when the soil near the surface is unable to support the building loads effectively. Construction techniques for deep foundations involve drilling boreholes, installing piles or shafts, and filling them with concrete or grout to transfer loads to deeper, more competent soil or rock strata.

Retaining Structures Construction Techniques:

Gravity Retaining Walls: Gravity retaining walls rely on their mass to resist soil pressure and retain earth masses. Construction techniques involve placing large, heavy blocks or poured concrete to form the wall structure. Proper compaction of backfill material behind the wall is essential to prevent settlement and instability.

Reinforced Soil Structures: Reinforced soil structures utilize the interaction between soil and reinforcement materials to enhance stability. Construction techniques involve layering soil and reinforcement elements, such as geogrids or geotextiles, and compacting each layer to form a stable structure. Facing elements may be installed for aesthetic and protective purposes.

Significance of Indian Standards:

Guidance on Design and Construction: Indian Standards provide comprehensive guidelines and specifications for the design and construction of foundations and retaining structures. They ensure that construction techniques meet safety, durability, and performance requirements.

Quality Assurance: Indian Standards include provisions for quality control and assurance during construction, ensuring that materials, techniques, and workmanship adhere to specified standards. This helps minimize risks of structural failures and ensures the longevity of constructed elements.

Safety Compliance: Adherence to Indian Standards ensures compliance with safety regulations and codes, protecting workers, occupants, and the public from potential hazards associated with foundation and retaining structure construction.

Innovation and Best Practices: Indian Standards evolve to incorporate advancements in construction techniques, materials, and technologies. They encourage innovation while upholding best practices in foundation and retaining structure construction.

In India, construction techniques for foundations and retaining structures are guided by a set of standards provided by the Bureau of Indian Standards (BIS). These standards outline the procedures, methods, and guidelines for designing and constructing foundations and retaining structures to ensure safety, stability, and durability. Here are some of the key Indian standards related to construction techniques of foundations and retaining structures:

Foundations:

IS 456:2000 - Code of practice for plain and reinforced concrete (Fourth Revision): While not specifically focused on foundations, IS 456 provides guidelines for the design and construction of reinforced concrete structures, including foundations. It covers aspects such as materials, design principles, construction practices, and quality control.

IS 2974 (Part 1-5) - Code of practice for design and construction of machine foundations (Part 1-3): This standard provides guidelines for designing and constructing foundations for machinery. It covers aspects such as dynamic analysis, soil investigation, foundation design, and construction practices.

IS 1080: 1985- Code of practice for design and construction of shallow foundations in soils (other than raft, ring and shell): This standard provides guidelines for the design and construction of shallow foundations, including spread footings and isolated footings, in various soil conditions.

IS 2911 (Part 1 Sec 1 &2):2010, IS 2911 (Part - 4): 2013 - Design and construction of pile foundations: This series of standards provides guidelines for the design and construction of pile foundations, including driven piles, bored cast-in-situ piles, and driven cast-in-situ piles, in different soil and site conditions including load test on piles.

Retaining Structures:

IS 1080: 1985- Code of practice for design and construction of shallow foundations in soils (other than raft, ring and shell): While primarily focused on shallow foundations, this standard also provides guidance on the design and construction of small retaining walls, such as those used for garden walls or minor earth retaining structures.

**IS 14458:Part 1:1998 - Guidelines for retaining wall for hill area (First

Revision): This standard provides guidelines for the design and construction of retaining walls in hilly terrain. It covers various types of retaining walls, including gravity walls, cantilever walls, and reinforced earth walls.

IS 10379:1982 - Code of practice for field control of moisture and compaction of soils for embankment and subgrade: The earthwork involved in embankments and subgrades has to be controlled so that the average properties of the soil are equal in quality as adopted in design and a number of control methods have been evolved for that. This standard covers such methods and also gives guidance for use in various situations.

IS 3370 (Part 1-4): 2021 - Code of practice for concrete structures for storage of aqueous liquids (Fourth Revision): Although primarily focused on concrete structures for liquid storage, Part 1-4 of IS 3370 provides valuable information on the design and construction of underground and earth-retaining structures, which may be relevant to retaining wall construction.

These standards ensure that construction techniques for foundations and retaining structures are carried out systematically, safely, and in accordance with established best practices. Adhering to these standards helps ensure the quality, reliability, and longevity of constructed elements, ultimately contributing to the safety and performance of civil engineering projects.

In summary, Indian Standards play a crucial role in guiding the construction techniques of foundations and retaining structures, ensuring safety, reliability, and compliance with established norms and regulations. Adherence to these standards is essential for the successful execution of construction projects and the long-term performance of built infrastructure.

Soil Improvement Methods:

Soil improvement methods are techniques used to enhance the engineering properties of soils for construction purposes. These methods are crucial in geotechnical engineering to address challenges such as poor bearing capacity, high compressibility, excessive settlement, and low shear strength of natural soils. Indian Standards, provided by the Bureau of Indian Standards (BIS), play a significant role in guiding soil improvement methods, ensuring their effectiveness, safety, and sustainability.

Common Soil Improvement Methods:

Compaction: Compaction is the process of increasing the density of soil by mechanically applying force to reduce voids and improve load-bearing capacity. Standard compaction methods include static compaction (using rollers), vibratory compaction, and dynamic compaction.

Grouting: Grouting involves injecting cementitious or chemical grouts into the soil to fill voids, improve cohesion, and increase soil strength. Different types of grouting techniques include permeation grouting, compaction grouting, and jet grouting.

Soil Stabilization: Soil stabilization techniques aim to increase the stability and strength of soil particles by adding stabilizers such as lime, cement, fly ash, or chemical additives. Stabilization methods include mechanical stabilization, chemical stabilization, and thermal stabilization.

Vibro-Compaction: Vibro-compaction, also known as vibro-flotation, involves the use of vibratory probes to densify loose granular soils. Vibrations reduce the soil's void ratio and improve its load-bearing capacity, making it suitable for supporting structures.

Deep Soil Mixing: Deep soil mixing involves mechanically mixing cementitious or lime-based materials into the soil using specialized equipment. This method improves soil strength, reduces compressibility, and enhances drainage properties.

Significance of Indian Standards:

Guidance on Material Selection: Indian Standards provide specifications for selecting appropriate materials, such as cement, lime, fly ash, and chemical additives, for soil improvement works. These standards ensure that materials meet quality requirements and perform effectively in enhancing soil properties.

Design Guidelines: BIS standards offer design guidelines and methodologies for implementing soil improvement techniques. They provide criteria for determining the optimal depth, spacing, and dosage of soil stabilizers or additives to achieve the desired engineering properties.

Quality Assurance: Indian Standards include provisions for quality control and assurance during soil improvement works. They specify testing procedures, sampling methods, and acceptance criteria to ensure that soil improvement measures meet specified standards and performance requirements.

Safety Compliance: Adherence to Indian Standards ensures compliance with safety regulations and codes during soil improvement activities. Standards address safety considerations related to equipment operation, handling of materials, and environmental protection measures.

Monitoring and Evaluation: BIS standards may include guidelines for monitoring and evaluating the effectiveness of soil improvement methods. They provide procedures for conducting field tests, collecting data, and assessing the performance of treated soils over time.

Overall, adherence to Indian Standards is essential for ensuring the quality, reliability, and sustainability of soil improvement methods in construction projects. These standards promote best practices, enhance safety, and contribute to the long-term performance of engineered soil systems in diverse geotechnical conditions prevalent in India.

Soil improvement methods and their implementation are guided by a set of standards provided by the Bureau of Indian Standards (BIS). These standards outline the procedures, methods, and specifications for various soil improvement techniques to ensure their effectiveness, safety, and sustainability. Here are some of the key Indian standards related to soil improvement methods and their implementation:

IS 2720 (Part 16): 1987 - Methods of Test for Soils: Laboratory determination of CBR (Part 16): This standard specifies the laboratory test method for determining the California Bearing Ratio (CBR) of soils. CBR values are crucial for evaluating the effectiveness of soil improvement techniques, especially in pavement design and construction.

IS 15284 (Part 1): 2003 - Guidelines for ground improvement by use of stone columns: This standard provides guidelines for ground improvement using stone columns. It covers design considerations, construction methods, quality control, and performance evaluation of stone column installations.

IS 15284 (Part 2): 2004 - Guidelines for ground improvement by preconsolidation using vertical drains: This standard provides guidelines for ground improvement using vertical drains or wick drains. It covers design considerations, installation methods, monitoring, and performance evaluation of vertical drain systems.

IS 13094:2021 – Selection of ground improvement techniques for foundation in weak soils-Guidelines: This standard provides guidelines for selection of ground improvement techniques like soil densification, pre-consolidation, injection and grouting, soil reinforcement etc.

These standards ensure that soil improvement methods are implemented systematically, safely, and in accordance with established best practices. Adhering to these standards helps ensure the quality, reliability, and long-term performance of soil improvement measures in construction projects across various geotechnical conditions prevalent in India. Additionally, BIS periodically updates and revises these standards to incorporate advancements in technology, materials, and construction practices, ensuring their relevance and effectiveness in addressing evolving challenges in soil improvement.

Quality Control and assurance in geotechnical construction:

Indian standards play a crucial role in ensuring quality control and assurance of geotechnical construction projects in India. They provide guidelines, specifications, and procedures that help maintain consistency, reliability, and safety throughout various stages of construction. Here's how Indian standards contribute to quality control and assurance in geotechnical construction:

Material Specifications: Indian standards specify the quality requirements for various construction materials used in geotechnical projects, such as aggregates, cement, lime, and geosynthetics. By adhering to these specifications, contractors can ensure that the materials used meet the necessary standards for strength, durability, and compatibility with the surrounding soil or rock.

Construction Procedures: Indian standards outline the recommended construction procedures and techniques for different geotechnical applications, including foundation construction, soil stabilization, retaining wall installation, and ground improvement. By following these procedures, construction teams can ensure that work is carried out in a systematic and controlled manner, minimizing errors and deviations from the intended design.

Quality Control Testing: Indian standards provide guidance on conducting quality control tests to assess the properties and performance of construction materials and completed geotechnical structures. Standards specify testing methods, sampling procedures, and acceptance criteria for various tests, such as soil compaction tests, concrete strength tests, and geosynthetic testing. These tests help verify that construction materials meet the required specifications and that constructed elements meet design requirements.

Safety Standards: Indian standards include provisions for safety measures and practices to be followed during geotechnical construction activities. They address aspects such as excavation safety, equipment operation, hazard mitigation, and worker protection. By adhering to these safety standards, construction teams can minimize the risk of accidents, injuries, and damage to property.

Quality Assurance Plans: Indian standards may require the development and implementation of quality assurance plans for geotechnical construction projects. These plans outline the procedures, responsibilities, and controls to be implemented throughout the project lifecycle to ensure that quality standards are met. They may include provisions for regular inspections, audits, and documentation of construction activities and test results.

Compliance and Certification: Indian standards serve as a benchmark for compliance with regulatory requirements and contractual obligations in geotechnical construction projects. Compliance with relevant standards may be a prerequisite for obtaining regulatory approvals, permits, and certifications. It also helps demonstrate adherence to industry best practices and quality management systems.

Overall, Indian standards provide a framework for ensuring the quality, reliability, and safety of geotechnical construction projects. Adhering to these standards helps mitigate risks, minimize defects and failures, and ultimately, deliver successful and durable infrastructure that meets the needs of society.

Quality control and assurance in geotechnical construction are governed by a set of standards provided by the Bureau of Indian Standards (BIS). These standards outline the procedures, methods, and guidelines for ensuring the quality, reliability, and safety of geotechnical construction projects. Here are some of the key Indian standards related to quality control and assurance in geotechnical construction:

IS 1893 (Part 1-6)- Criteria for Earthquake Resistant Design of Structures: While not specifically focused on quality control and assurance, this standard provides guidelines for earthquake-resistant design of structures, including geotechnical considerations. It covers aspects such as site investigation, soil dynamics, foundation design, and construction practices to ensure seismic safety.

IS 1892: 2021 - Code of Practice for subsurface investigation for foundations: This standard provides guidelines for conducting site investigations, including geotechnical investigations, soil testing, and sampling. It outlines procedures for quality control and assurance during site investigation activities to ensure the accuracy and reliability of geotechnical data.

IS 2131: 1981 - Methods of Standard Penetration Test: This standard specifies the procedures and equipment requirements for conducting the Standard Penetration Test (SPT), a common test used in geotechnical investigations. It includes provisions for quality control and assurance to ensure the consistency and accuracy of test results.

IS 2720 (Part 1-41) - Methods of Test for Soils: This series of standards provides methods for testing various properties of soils obtained through geotechnical investigations. It includes provisions for quality control and assurance during soil testing to ensure that test procedures are followed correctly, equipment is calibrated, and test results are reliable.

IS 4985: 2021 - Unplasticized PVC Pipes for Potable Water Supplies: While focused on PVC pipes, this standard includes provisions for quality control and assurance during the manufacturing and installation of pipes used in geotechnical applications such as drainage, subsoil drainage, and ground improvement.

IS 4923: 2017 - Hollow Steel Sections for Structural Use - Specification: This standard provides specifications for hollow steel sections used in various geotechnical applications, including foundation piles, retaining walls, and ground support systems. It includes provisions for quality control and assurance during manufacturing, fabrication, and installation of steel sections.

These standards ensure that quality control and assurance measures are implemented throughout the lifecycle of geotechnical construction projects, from site investigation and material testing to construction and installation of geotechnical elements. Adhering to these standards helps mitigate risks, ensure compliance with regulatory requirements, and deliver geotechnical infrastructure that meets the required quality, safety, and performance standards.

CHAPTER X

CASE STUDIES & EXAMPLES

Chapter X

CASE STUDIES & EXAMPLES

Real-world examples demonstrating the implementation of soil mechanics principles and Foundation Engineering &the use of Indian standards:

Foundation Design for High-Rise Buildings: In the construction of high-rise buildings, soil mechanics principles are crucial for designing foundations that can support the structure's weight and withstand various loads, including wind and seismic forces. Indian Standards such as IS 456 (Code of Practice for Plain and Reinforced Concrete) and IS 1892 (Code of Practice for subsurface Investigation for foundations) provide guidelines for conducting geotechnical investigations and designing foundations based on soil properties. For example, in the construction of the World One Tower in Mumbai, extensive soil investigations were conducted to analyse soil properties and seismic conditions. Based on this data and adherence to Indian standards, a raft foundation design was implemented to distribute the building loads efficiently and ensure stability.

Road Construction and Pavement Design: Soil mechanics principles play a significant role in road construction and pavement design, where soil properties influence the performance and durability of road infrastructure. Indian Standards such as IS 2720 (Methods of Test for Soils) provide testing procedures for evaluating soil properties relevant to pavement design, including California Bearing Ratio (CBR) tests. For instance, in the construction of highways like the Golden Quadrilateral project, soil mechanics principles were used to assess soil strength, compaction characteristics, and drainage properties. Adherence to Indian standards ensured that appropriate materials and construction techniques were used to achieve the desired pavement quality and longevity.

Slope Stability Analysis for Infrastructure Projects: Soil mechanics principles are essential for assessing slope stability and mitigating risks of landslides and slope failures in infrastructure projects. Indian Standards such as IS 14458 (Guidelines for Retaining Walls in Hill Areas) provide guidance on slope stability analysis and design considerations for retaining structures in hilly terrain. For example, in the construction of roads and railways through mountainous regions like the Western Ghats, soil mechanics principles are used to analyze slope stability, evaluate geological hazards, and design appropriate retaining structures. Adherence to Indian standards ensures that slope stabilization measures are implemented effectively, minimizing risks to infrastructure and ensuring safety.

These examples demonstrate how soil mechanics principles and Indian standards are applied in real-world construction projects to ensure the stability, durability, and safety of infrastructure. By incorporating geotechnical engineering principles and adhering to relevant standards, engineers can mitigate risks, optimize design solutions, and deliver successful projects that meet quality and performance requirements.

CHAPTER XI

SUCCESSFUL FOUNDATION DESIGN

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SUCCESSFUL FOUNDATION DESIGN

Burj Khalifa, Dubai, UAE:

- o The Burj Khalifa, the tallest building in the world, stands at over 828 meters tall. Its foundation design is a crucial aspect of its structural integrity.
- o The foundation system consists of a reinforced concrete raft supported by bored reinforced concrete piles. The piles extend to a depth of over 50 meters into the bedrock.
- o Extensive geotechnical investigations were conducted to assess soil conditions and seismic considerations.
- o The foundation design effectively distributes the building loads and accommodates lateral forces, ensuring the stability and safety of the structure.

Failed Foundation Design:

Millennium Tower, San Francisco, USA:

- o The Millennium Tower is a residential skyscraper in San Francisco known for its significant tilt and sinking issues.
- o The tower's foundation consists of concrete friction piles driven into dense sand and mud. However, it does not extend to bedrock.
- o Subsequent monitoring revealed that the tower has sunk more than expected and tilted significantly.
- o Investigations indicated that the building's excessive settlement and tilt were due to the differential settlement of the foundation piles, possibly exacerbated by nearby construction activities and inadequate foundation design.

- o Remedial measures, such as underpinning and strengthening the foundation, have been proposed to stabilize the building.

These case studies highlight the importance of thorough geotechnical investigations, proper foundation design, and adherence to engineering standards in ensuring the success and safety of construction projects. In successful projects like the Burj Khalifa, meticulous attention to geotechnical conditions and robust foundation design contributed to the stability and longevity of the structure. Conversely, in cases like the Millennium Tower, inadequate foundation design and oversight led to significant structural issues and costly remediation efforts.

Case Study 1: Sabarmati Riverfront Development, Ahmedabad, India

Background: The Sabarmati Riverfront Development project aimed to transform the Sabarmati riverfront in Ahmedabad into a vibrant urban space with recreational areas, parks, promenades, and commercial zones.

Implementation of Soil Mechanics and Foundation Engineering Techniques:

Geotechnical Investigation: Extensive geotechnical investigations were conducted to assess soil conditions along the riverfront. This included soil sampling, laboratory testing, and analysis of soil properties such as bearing capacity, permeability, and compressibility.

Foundation Design: Based on the geotechnical investigation findings, foundation designs were developed for various structures along the riverfront, including bridges, promenades, and recreational facilities. Indian Standards such as IS 1892 (Code of Practice for subsurfaceinvestigation for foundations) and IS 456 (Code of Practice for Plain and Reinforced Concrete) were followed for foundation design and construction.

Pile Foundations: In areas with poor soil conditions, pile foundations were used to support structures. Bored cast-in-situ piles were driven to the required depth, ensuring adequate load-bearing capacity and stability. IS 2911 (Design and Construction of Pile Foundations) provided guidelines for pile foundation design and construction.

Retaining Structures: Retaining walls and embankments were constructed along the riverfront to prevent soil erosion and provide stability. Indian Standards such as IS 14458 (Guidelines for Retaining Walls) were followed for the design and construction of these structures.

Outcome: The implementation of soil mechanics and foundation engineering techniques, in accordance with Indian Standards, ensured the stability, safety, and durability of structures along the Sabarmati riverfront. The project transformed the riverfront into a vibrant urban space, enhancing the city's aesthetics and providing recreational opportunities for residents.

Case Study 2: Metro Rail Construction, Delhi, India

Background: The construction of the Delhi Metro Rail involved extensive underground excavation and tunnelling through varying soil and rock conditions.

Implementation of Soil Mechanics and Foundation Engineering Techniques:

Soil Investigation: Geotechnical investigations were conducted along the metro rail alignment to assess soil and rock properties. IS 1892 (Code of Practice for subsurfaceinvestigation for foundations) provided guidelines for conducting soil investigations and sampling techniques.

Tunnelling: Tunnel boring machines (TBMs) were used for underground excavation, minimizing disruption to surface structures. Indian Standards such as IS 15026 (Tunnelling in Rocks) provided guidelines for tunnelling methods and safety measures.

Foundation Design for Stations: Foundation designs for metro stations were developed based on soil investigation data and Indian Standards such as IS 456 (Code of Practice for Plain and Reinforced Concrete). Raft foundations and bored pile foundations were used to support station structures.

Ground Improvement: Ground improvement techniques, such as soil stabilization and grouting, were employed in areas with weak or collapsible soils. Indian Standards such as IS 14343 (Choice of grouting, materials for alluvial grouting) and IS 15284(Part 1&2)(Guidelines for Ground Improvement – stone columns & preconsolidated vertical drains) provided guidance for these techniques.

Outcome: The implementation of soil mechanics and foundation engineering techniques ensured the safe and efficient construction of the Delhi Metro Rail network. The project has significantly improved urban mobility in the National Capital Region, reducing traffic congestion and air pollution.

These case studies demonstrate how soil mechanics and foundation engineering techniques, in accordance with Indian Standards, are applied in real-world construction projects to ensure the stability, safety, and durability of infrastructure. Adhering to these standards helps mitigate risks, optimize design solutions, and deliver successful projects that meet quality and performance requirements.

case study of Construction of Metro Rail project under River Ganga in Kolkata using the technique and principles of Soil Mechanics and Foundation Engineering with relevance to use of Indian Standards

Case Study: Construction of Metro Rail Project under River Ganga in Kolkata, India

Background: The construction of the Metro Rail project under the River Ganga in Kolkata aimed to enhance urban transportation infrastructure by connecting the two banks of the river with an underground metro line.

Implementation of Soil Mechanics and Foundation Engineering Techniques:

Geotechnical Investigation: Before the construction began, extensive geotechnical investigations were conducted along the proposed alignment, including the riverbed and the banks of the River Ganga. These investigations aimed to understand soil and rock conditions, groundwater levels, and potential geotechnical hazards. Indian Standards such as IS 1892 (Code of Practice for subsurfaceinvestigation for foundations) were followed for conducting soil investigations.

Foundation Design: Based on the geotechnical investigation findings, foundation designs were developed for the underground metro stations and tunnels. Indian Standards such as IS 456 (Code of Practice for Plain and Reinforced Concrete) were followed for foundation design and construction. Given the complex geology and the presence of soft alluvial deposits, deep foundation techniques such as bored cast-in-situ piles were used to support station structures and tunnel portals.

Tunnelling Techniques: Tunnelling under the River Ganga required the use of specialized tunnel boring machines (TBMs) equipped with slurry shields to navigate through soft soils and groundwater. Indian Standards such as IS 15026 (Tunnelling in Rocks) provided guidelines for tunnelling methods and safety measures.

Waterproofing Measures: Given the proximity to the river and the high groundwater table, waterproofing measures were crucial to prevent water ingress into the tunnels. Indian Standards such as IS 2645 (Specification for Integral Waterproofing Compounds for Cement Mortar and Concrete) provided guidelines for selecting and applying waterproofing materials to the tunnel lining.

Monitoring and Quality Control: Throughout the construction process, continuous monitoring of ground settlement, groundwater levels, and structural performance was conducted to ensure the safety and stability of the tunnelling operations. Indian Standards for instrumentation and monitoring provided guidelines for installing and interpreting monitoring data.

Outcome: The implementation of soil mechanics and foundation engineering principles, in accordance with Indian Standards, ensured the successful construction of the Metro Rail project under the River Ganga in Kolkata. The project enhanced urban connectivity, reduced traffic congestion, and provided a sustainable transportation solution for the city.

Significance of Indian Standards: Adherence to Indian Standards played a crucial role in ensuring the quality, safety, and durability of the Metro Rail project under the River Ganga. These standards provided comprehensive guidelines for conducting geotechnical investigations, designing foundations, selecting construction materials, and monitoring construction activities. By following Indian Standards, engineers and contractors were able to optimize design solutions, mitigate risks, and deliver a resilient infrastructure project that meets the needs of the community while adhering to the highest standards of engineering excellence.

Case Study: Bullet Train Project from Ahmedabad to Mumbai, India

Background: The proposed high-speed bullet train project connecting Ahmedabad to Mumbai is one of the most ambitious infrastructure projects in India. This project aims to revolutionize transportation in the country by providing a fast and efficient mode of travel between two major economic hubs.

Implementation of Soil Mechanics Techniques and Foundation Engineering:

Geotechnical Investigation: Before the commencement of construction activities, extensive geotechnical investigations were conducted along the proposed alignment of the bullet train route. These investigations aimed to assess the soil and rock conditions, groundwater levels, seismic hazards, and other geotechnical parameters. Indian Standards such as IS 1892 (Code of Practice for subsurfaceinvestigation for foundations) were followed for conducting soil investigations.

Foundation Design: Based on the geotechnical investigation findings, foundation designs were developed for various structures along the bullet train route, including bridges, viaducts, and station buildings. Indian Standards such as IS 456 (Code of Practice for Plain and Reinforced Concrete) and IS 2911 (Design and Construction of Pile Foundations) were followed for foundation design and construction. The foundation designs incorporated considerations for soil bearing capacity, settlement analysis, and seismic design parameters.

Bridge Construction: The bullet train route includes numerous river crossings and bridges. Soil mechanics techniques were employed to assess the soil-structure interaction and design the bridge foundations accordingly. Deep foundation techniques such as bored cast-in-situ piles and pile caps were used to support the bridge piers. Indian Standards such as IS 3370 (Code of Practice for Concrete Structures for Storage of Aqueous Liquids) were followed for bridge foundation design and construction.

Tunnelling: The bullet train route includes several sections of tunnelling through varied geological formations. Soil mechanics principles were used to analyse soil stability, groundwater conditions, and tunnel support requirements. Tunnel boring machines (TBMs) equipped with appropriate soil conditioning and support systems were used for tunnel excavation. Indian Standards such as IS 15026 (Tunnelling in Rocks) provided guidelines for tunnelling methods and safety measures.

Quality Control and Assurance: Throughout the construction process, strict quality control and assurance measures were implemented to ensure the safety and reliability of the bullet train infrastructure. Indian Standards for material testing, construction methods, and quality assurance procedures were followed to maintain the highest standards of construction quality.

Outcome: The implementation of soil mechanics techniques and foundation engineering principles, in accordance with Indian Standards, ensured the successful construction of the bullet train project from Ahmedabad to Mumbai. Once completed, the bullet train will provide a safe, efficient, and sustainable mode of transportation, reducing travel time and boosting economic growth in the region.

Significance of Indian Standards: Adherence to Indian Standards played a crucial role in ensuring the quality, safety, and durability of the bullet train project. These standards provided comprehensive guidelines for conducting geotechnical investigations, designing foundations, selecting construction materials, and implementing quality control measures. By following Indian Standards, engineers and contractors were able to optimize design solutions, mitigate risks, and deliver a world-class transportation infrastructure project that meets the highest standards of engineering excellence.

CHAPTER XII

EXTRACTS OF FEW INDIAN STANDARDS

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EXTRACTS OF FEW INDIAN STANDARDS

IS 2720 (Part 8) : 1983

IS : 2720 (Part 8)-1983

(Reaffirmed 2006)

Indian Standard

METHODS OF TEST FOR SOILS

PART 8 DETERMINATION OF WATER CONTENT—DRY DENSITY RELATION USING HEAVY COMPACTION

(Second Revision)

Second Reprint SEPTEMBER 1994

UDC 624·131·431·3:624·131·431·5

BUREAU OF INDIAN STANDARDS
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NEW DELHI 110002

Gr 3 *February* 1984

expressing the result of a test or analysis, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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1. SCOPE

1.1 This standard (Part 8) lays down the method for the determination of the relation between the water content and the dry density of soils using heavy compaction.

2. TERMINOLOGY

2.1 For the purpose of this standard, the definitions given in IS : 2809-1972† shall apply.

3. APPARATUS

3.1 Cylindrical Metal Mould — It shall be either of 100 mm diameter and 1 000 cm^3 volume or 150 mm diameter, and 2 250 cm^3 volume and shall conform to IS : 10074-1982‡.

3.2 Sample Extruder (Optional) — It consists of a jack, lever frame or other device adopted for the purpose of extruding compacted specimens from the mould.

3.3 Balances — One of 10 kg capacity sensitive to 1 g, and other of 200 g capacity and sensitive to 0·01 g.

3.4 Oven — Thermostatically controlled, with interior of non-corroding material to maintain temperature between 105°C and 110°C.

3.5 Container — Any suitable non-corrodible airtight container to determine the water content for tests conducted in the laboratory.

3.6 Steel Straightedge — A steel straightedge about 30 cm in length and having one bevelled edge.

3.7 Sieve — 4·75-mm, 19-mm and 37·5 mm IS sieves conforming to IS : 460 (Part I)-1978§.

*Rules for rounding off numerical values (*revised*).

†Glossary of terms and symbols relating to soil engineering (*first revision*).

‡Specification for compaction mould assembly for light and heavy compaction of soils.

§Specification for test sieves: Part 1 Wire cloth test sieves (*second revision*).

6. CALCULATIONS

6.1 Bulk Density — Bulk density, γ_m, in g/cm³ of each compacted specimen shall be calculated from the equation:

$$\gamma_m = \frac{m_2 - m_1}{V_m}$$

where

m_1 = mass in g of mould and base;

m_2 = mass in g of mould, base and soil; and

V_m = volume in cm³ of mould.

6.2 Dry Density — The dry density, γ_d, in g/cm³, shall be calculated from the equation :

$$\gamma_d = \frac{100\ \gamma_m}{100 + w}$$

where

w = moisture content of soil in percent.

6.3 The dry densities, γ_d obtained in a series of determinations shall be plotted against the corresponding moisture contents w. A smooth curve shall be drawn through the resulting points and the position of the maximum on this curve shall be determined.

7. REPORTING OF RESULTS

7.1 The experimental points and the smooth curve drawn through them showing the relationship between moisture content and dry density shall be reported.

7.2 The dry density in g/cm³ corresponding to the maximum point on the moisture content/dry density curve shall be reported as the maximum dry density to the nearest 0·01.

7.3 The percentage moisture content corresponding to the maximum dry density on the moisture content/dry density curve shall be reported as the optimum moisture content and quoted to the nearst 0·2 for values below 5 percent to the nearest 0·5 for values from 5 to 10 percent, and to the nearest whole number for value exceeding 10 percent (*see* Note under **7.5**).

7.4 The amount of stone retained on the 19-mm IS sieve shall be reported to the nearest 1 percent.

7.5 The method of obtaining the result shall be stated, (4·9-kg rammer method). The procedure used shall also be stated that is single sample or separate sample and the size of the mould used.

NOTE — For some highly permeable soils such as clean gravels, uniformly graded and coarse cleen sands the results of the laboratory compaction test (4·9-rammer method) may provide only a poor guide for specifications on field compaction. The laboratory test often indicates higher values of optimum moisture content than would be desirable for field compaction and the maximum dry density is often much lower than the state of compaction, that can readily be obtained in the field.

IS: 9214 -1979
(Reaffirmed 2011)

Indian Standard

METHOD OF DETERMINATION OF MODULUS OF SUBGRADE REACTION (*K*-VALUE) OF SOILS IN FIELD

First Reprint AUGUST 1997

(Incorporating Amendment No 1)

UDC 624.131.522

BUREAU OF INDIAN STANDARDS
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NEW DELHI 110002

Gr 6

May 1980

2. TERMINOLOGY

2.0 For the purpose of this standard, the definitions given in IS : 2809-1972* and the following shall apply.

2.1 Modulus of Subgrade Reaction — Ratio of load per unit area (applied through a centrally loaded rigid body) of horizontal surface of a mass of soil to corresponding settlement of the surface. It is determined as the slope of the secant drawn between the point corresponding to zero settlement and the point of 1·25 mm settlement, of a load-settlement curve obtained from a plate load test on a soil using a 75 cm diameter or smaller loading plate with corrections for size of plate used.

2.2 Deflection — The amount of downward vertical movement of a horizontal surface due to the application of a load to the surface.

2.3 *K*-value — If the assumption that the reaction of the subgrade is proportional to the deflection is entirely correct, the curve in Fig. 1 should be straight line and the slope of this line should give the modulus of subgrade reaction measured in MPa/cm ($kgf/cm^2/cm$). The results, however, usually give a curve which is convex upwards and which has no straight portion even initially, *K*-value is, therefore, taken as the slope of the line passing through the origin and the point on the curve corresponding to 1·25 mm settlement (*see* Fig. 1):

$$K = \frac{p}{0{\cdot}125}\ \text{MPa/cm} = \frac{10p}{0{\cdot}125}\ \text{kgf/cm}^2\text{/cm}$$

where

p = load intensity corresponding to settlement of plate of 1·25 mm.

Alternatively, the *K*-value may be defined as a pressure of 0·07 MPa (0·70 kgf/cm^2) divided by the corresponding settlement. That is when a standard 75 cm diameter steel bearing plate is subjected to a load of 3 100 kgf, say $K = \frac{0{\cdot}07}{d}$ MPa/cm

$$\left[K = \frac{0{\cdot}70}{d}\ \text{kgf/cm}^2\text{/cm} \right]$$

where

d = settlement in cm.

2.4 Stiffening Plates — Nest of plates stacked on the bearing test plate for stiffening it.

*Glossary of terms and symbols relating to soil engineering (*first revision*).

IS : 8009 (Part I) - 1976
(Reaffirmed 2003)

Indian Standard

CODE OF PRACTICE FOR CALCULATION OF SETTLEMENTS OF FOUNDATIONS

PART I SHALLOW FOUNDATIONS SUBJECTED TO SYMMETRICAL STATIC VERTICAL LOADS

(Fifth Reprint MARCH 1999)

UDC 624·151·5·042·13

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Gr 9 *August* 1976

0.4 A settlement calculation involves many simplifying assumptions as detailed in **4.1**. In the present state of knowledge, the settlement computations at best estimate the most probable magnitude of settlement.

0.5 In the formulation of this standard due weightage has been given to international co-ordination among the standards and practices prevailing in different countries in addition to relating it to the practices in the field in this country.

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1. SCOPE

1.1 This standard (Part I) provides simple methods for the estimation of immediate and primary consolidation settlements of shallow foundations under symmetrical static vertical loads. Procedures for computing time rate of settlement are also given.

1.2 This standard does not deal with catastrophic settlement as the foundations are expected to be loaded only up to the safe bearing capacity. Analytical methods for the estimation of settlements due to deterioration of foundations, mining and other causes are not available and, therefore, are not dealt with. Satisfactory theoretical methods are not available for the estimation of secondary compression. However, it is known that in organic clays and plastic silts, the secondary compression may be important and, therefore, should be taken into account. In such situations, any method considered suitable for the type of soil met with may be adopted by the designer.

2. TERMINOLOGY

2.0 For the purpose of this standard, tne following definitions shall apply.

2.1 Coefficient of Compressibility — The secant slope, for a given pressure increment, of the effective pressure-void ratio curve.

2.2 Coefficient of Consolidation (c_v)— A coefficient utilized in the theory of consolidation, containing the physical constants of a soil affecting its rate of volume change:

$$c_v = \frac{k(1+e)}{a_v \gamma_w}$$

where

k = coefficient of permeability,

e = void ratio,

a_v = coefficient of compressibility, and

γ_w = unit weight of water.

IS : 2131 - 1981
Reaffirmed 2011

Indian Standard

METHOD FOR STANDARD PENETRATION TEST FOR SOILS

(*First Revision*)

Third Reprint MARCH 1997

UDC 624.131.381

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 3 *February* 1982

2. EQUIPMENT

2.1 Drilling Equipment

2.1.1 The equipment used shall provide a clean borehole, 100 to 150 mm in diameter, for insertion of the sampler to ensure that the penetration test is performed on undisturbed soil and shall permit driving of the split spoon sampler to obtain penetration record and the sample in accordance with the procedure specified in **3**.

NOTE — The stiffness of the drill rod used for testing influences the *N* value obtained by means of the test. A light rod 'whips' under the blows of the hammer. The drill rod shall preferably have a stiffness equal to A-rod (41·3 mm outer diameter). For depths of exploration more than 10 m, special precautions shall be taken to keep the rod vertical by using centering spacers and/or by using stiffer rods to minimize the whipping effect. Spacers may be provided at every 10 m, or more frequently, if necessary.

2.1.2 *Casing or Drilling Mud* — It shall be used when drilling in sand, soft clay or other soils in which the sides of borehole are likely to cave in. In sandy and other non-cohesive soils, below water table it is often preferable to use drilling mud rather than a casing. If drilling mud alone is not successful, casing may be used along with the drilling mud.

2.2 Split-Spoon Sampler — The split spoon sampler shall conform to IS : 9640-1980*.

2.3 Drive Weight Assembly

2.3.1 The drive weight assembly shall consist of a driving head and a 63·5 kg weight with 75 cm free fall. It shall be ensured that the energy of the falling weight is not reduced by friction between the drive weight and the guides or between rope and winch drum.

2.3.2 The rods to which the sampler is attached for driving should be straight, tightly coupled and straight in alignment. For driving the casing, a hammer heavier than 63·5 kg may be used.

2.4 Lifting Bail, Tongs, Rope, Screw Jack etc

3. PROCEDURE

3.1 Driving the Casing — Where casing is used, it shall not be driven below the level at which the test is made or soil sample is taken. In the case of cohesionless soils which cannot stand without casing, the advancement of the casing pipe should be such that it does not disturb the soil to be tested or sampled; the casing shall preferably be advanced by

*Specification for split spoon sampler.

IS : 12175 - 1987

Indian Standard

SPECIFICATION FOR RAPID MOISTURE METER FOR RAPID DETERMINATION OF WATER CONTENT FOR SOIL

UDC 543·812·08 : 624·131·431·3

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 3

January 1988

2. DIMENSIONS

2.1 Dimensions of the equipment with different component parts of the equipment shall be as detailed in Fig. 1 to 5. Except where tolerances are specifically mentioned against the dimensions, all dimensions shall be taken as nominal dimensions and tolerances shall be as given in IS : 2102 (Part 1)-1980* for medium class.

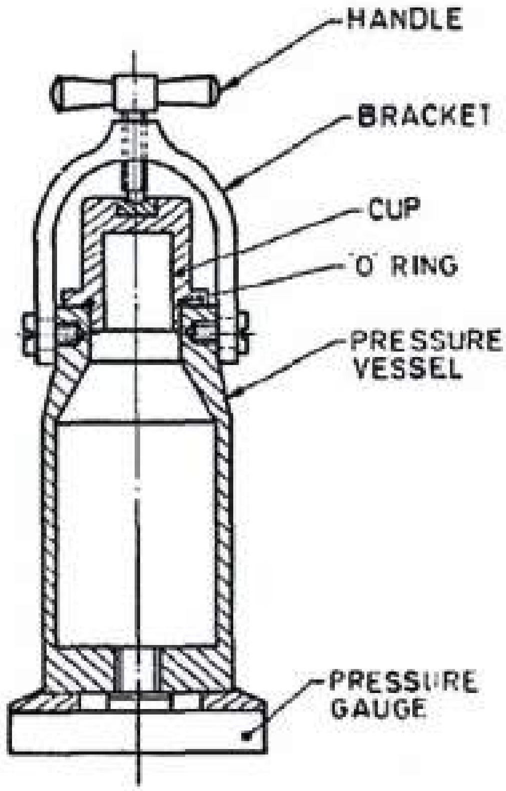

FIG. 1 ASSEMBLY

3. MATERIAL

3.1 The materials of construction of various component parts of the equipment shall be as given in Table 1.

4. CONSTRUCTION

4.1 The mating parts of the pressure vessel and the cup shall be machined properly to ensure a proper and leak-proof seating when assembled with ring fitted in its position.

*General tolerances for dimensions and form and position: Part 1 General tolerances for linear and angular dimensions (*second revision*).

IS 7113 : 2003

भारतीय मानक

नहरों के मिट्टी-सीमेंट अस्तर — रीति संहिता

(पहला पुनरीक्षण)

Indian Standard

SOIL-CEMENT LINING FOR CANALS — CODE OF PRACTICE

(First Revision)

ICS 93.160

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

January 2003

Price Group 3

than 1.8 g/cm^2 and the subsoil water is near the subgrade, the compaction shall be done by under cutting the bed by 75 mm and then ploughing up to 150 mm below the subgrade level. The loosened soil shall then be recompacted with sheep foot rollers or other suitable devices. Where the subsoil water is low, requiring no dewatering and the dry bulk density of the natural soil is less than 1.8 g/cm^3, consolidation shall be done by digging the canal up to subgrade level and after that loosening the earth below subgrade up to 150 mm by disc harrows, or ploughing and compacting the same to a layer of 110 mm. After that, the second layer of 150 mm of earth shall be laid over the compacted layer by taking earth from lip cutting and compacting this to depth of 110 mm. The compacted layer of 70 mm above the subgrade level shall be removed and the subgrade brought to design profile before laying the lining.

7.4.5.3 *Sides*

Compaction on sides shall be done by manual labour or suitable compactors to a depth of 300 mm to obtain a minimum dry bulk density of not less than 90 percent of the density at optimum moisture content obtained in accordance with IS 2720 (Part 7).

8 CONSTRUCTION

8.1 Pulverizing the Soil

The soil shall be pulverized manually or mechanically to make sure that there are no clods and the soil conforms to **5.2**.

8.2 Mixing Soil and Cement

The required quantity of cement shall be thoroughly mixed with the dry soil either mechanically or by hand-mixing through manual labour. The mixing shall be continued till the soil-cement mix acquires uniform colouration which can be examined under a magnifying glass. The required quantity of water will be added and mixing continued to ensure uniform distribution of the moisture throughout the soil-cement mass.

8.2.1 Batching of the materials shall be by weight. The appropriate quantities of soil and cement required for one batch shall be measured out after making due allowance for the moisture present in the soil. The correct amount of water to bring the moisture content of the mix to the optimum giving due allowance for evaporation shall be then added.

8.3 Placing

The mixed material shall be discharged uniformly on to the prepared subgrade and distributed to a uniform loose layer by means of shovels and rakes. Care shall be taken to obtain uniformity in depth. Sufficient depth of loose material to give the required thickness after compaction shall be spread in one operation. The thickness of the soil-cement lining should be 100 to 150 cm. Generally, it is necessary to process 130 to 150 mm of loose soil to obtain a compacted thickness of 100 mm.

8.4 Compaction of the Soil-Cement Mix

Compaction shall be carried out continously as the mixed material is spread, but the equipment shall be kept sufficiently far back from the free edges of the layer to prevent lateral movement of the mixed material. The compaction shall be effected by means of a smooth wheeled roller, vibratory roller, tampers or any other type of equipment capable of achieving the desired degree of compaction.

8.4.1 The time between preparation of the soil-cement mixture and the commencement of the compaction shall be as short as possible, and in no case shall exceed 30 min. Compaction of any portion of the layer to required density shall be completed within 1½ h after the material has been spread.

8.5 Curing

After final compaction and finishing, the surface shall be allowed to harden and soon after it shall be kept continuously damp for at least 14 days. This may be done by any suitable method, such as fog-spraying with water or covering the surface with damp hessian, straw or sand maintained moist throughout the period of curing.

8.6 Jointing

A straight transverse construction joint shall be formed wherever there is a break of work (of even a few hours). Such joints shall be sealed leak tight with sealing compound conforming to the requirements given IS 5256 after the expiry of the curing period. As an alternative, the edge surface of the previous lining may be roughened with 1 : 3 cement sand grout not more than 12 mm thickness applied and the lining operation continued.

9 FIELD CONTROL

The following factors shall be checked for controlling field operations during the progress of the work:

a) *Subgrade Condition* — Prior to placing of the soil-cement the conditions of the subgrade shall be checked to ensure that it is well compacted (to a density not less than 95 percent of the standard maximum for the soil) clean and the surface moist.

CHAPTER XIII
ANNEXURE

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ANNEXURE

List of BIS standards pertaining to Soil Mechanics and Foundation Engineering:

Sl. No.	IS Code	Title
1	IS 10379 : 1982	Code of practice for field control of moisture and compaction of soils for embankment and subgrade
2	IS 12175 : 1987	Specification for rapid moisture meter for rapid determination of water content for soil
3	IS 13468 : 1992	Apparatus for Determination of Dry Density of Soil by Core Cutter Method
4	IS 14684 : 1999	Determination of nitrogen and nitrogenous compounds in soils
5	IS 14685 : 1999	Determination of total sulphur and sulphur compounds in soils
6	IS 14765 : 2000	Determination of water retention capacity in soils - Method of test
7	IS 2131 : 1981	Method for Standard Penetration Test for Soils (First Revision)
8	IS 4332 (Part 1-Part 10)	Methods of test for stabilized soils
9	IS 11196:1985	Specification for equipment for determination of liquid limit of soils cone penetration met – Hod
10	IS 11209 : 1985	Specification for mould assembly for determination of permeability of soils
11	IS 12175 : 1987	Specification for rapid moisture meter for rapid determination of water content for soil
12	IS 2810: 1979	Glossary of terms relating to soil dynamics
13	IS 2809 : 1972	Glossary of terms and symbols relating to soil engineering (First Revision)
14	IS 2720 (Part 1-Part 41)	Various methods of test for soils
15	IS 13468 : 1992	Apparatus for Determination of Dry Density of Soil by Core Cutter Method-
16	IS 1498 : 1970	Classification and identification of soils for general engineering purposes
17	IS 1888 : 1982	Method of load test on soils

18	IS 2110 : 1980	Code of practice for in situ construction of walls in buildings with soil – Cement
19	IS 5249 : 1992	Determination of dynamic properties of soil - Method of test (Second Revision)
20	IS 5510 : 1969	Guide for soil surveys for river valley projects
21	IS 10074 : 1982	Specification for compaction mould assembly for light and heavy compaction test for soils
22	IS 10108 : 1982	Code of practice for sampling of soils by thin wall sampler with stationary piston
23	IS 10589 : 1983	Specification for equipment for subsurface sounding of soils
24	IS 1080 : 1985	Code of practice for design and construction of shallow foundations in soils (Other Than Raft, Ring And Shell) (Second Revision)
25	IS 4410 : Part 14 : Sec 1 : 1977	Glossary of terms relating to river valley projects: Part 14 soil conservation and reclamation: Sec 1 soil conservation
26	IS 4410 : Part 14 : Sec 2 : 1977	Glossary of terms relating to river valley projects: Part 14 soil conservation and reclamation: Sec 2 reclamation
27	IS 4434 : 1978	Code Of Practice For In-situ Vane Shear Test For Soils
28	IS 4880 : Part 5 : 1972	Code of practice for design of tunnels conveying water: Part 5 structural design of concrete lining lIu soft strata and soils
29	IS 4968 : Part 1 : 1976	Method for subsurface sounding for soils: Part 1 dynamic method using 50 mm cone without bentonite slurry
30	IS 4968 : Part 2 : 1976	Method for subsurface sounding for soils: Part 2 dynamic method using cone and bentonite slurry
31	IS 4968 : Part 3 : 1976	Method for subsurface sounding for soils: Part 3 Static cone penetration test
32	IS 4999 : 1991	Recommendations for grouting of pervious soils
33	IS 5249 : 1992	Determination of dynamic properties of soil - Method of test
34	IS 5499:1969	Code of practice for construction of underground air - Raid shelters in natural soil

***Note- Standards can be downloaded from BIS website(www.bis.gov.in) free of cost under ‘know your standards’ link on homepage.**

35	IS 6748 : Part 1 : 1973	Recommendations for watershed management relating to soil conservation: Part 1 agronomic aspects
36	IS 7112 : 2002	Criteria for design of cross -: Sec for unlined canals in alluvial soil
37	IS 7113 : 2003	Soil - Cement lining for canals - Code of practice
38	IS 9198 : 1979	Specification for compaction rammer for soil testing
39	IS 9214 : 1979	Method of determination of modulus of subgrade reaction (K - Value) of soils in field
40	IS 9259 : 1979	Specification for liquid limit apparatus for soils

CHAPTER XIV

REFERENCES AND FURTHER READING

CHAPTER XIV

REFERENCES AND FURTHER READING

Textbooks and References:

"Principles of Geotechnical Engineering" by Dr.Braja M. Das and Dr. Khaled Sobhan.

"Soil Mechanics and Foundation Engineering" by Dr. V. N. S. Murthy.

"Foundation Engineering" by Dr. P. C. Varghese.

"Advanced Foundation Engineering: Geotechnical Engineering Series" by Dr. V. N. S. Murthy.

"Principles and Practices of Soil Mechanics and Foundation Engineering" by Dr. B. V. S. Viswanathan.

"Geotechnical Engineering: Principles & Practices" by Donald P. Coduto, Man-Chu Ronald Yeung, and William A. Kitch.

"Soil Mechanics: Concepts and Applications" by William Powrie.

Research Papers and Journals:

"Journal of the Indian Geotechnical Society" (JIGS) - The official journal of the Indian Geotechnical Society, featuring research articles, case studies, and technical notes on various aspects of geotechnical engineering, including soil mechanics and foundation engineering.

"Geotechnical Engineering" by Dr. C. Venkatramaiah - A comprehensive textbook covering various aspects of geotechnical engineering, including soil mechanics, foundation engineering, and ground improvement techniques.

"Soil Mechanics and Foundation Engineering" by Dr. K. R. Arora - A widely used textbook in Indian engineering universities, covering fundamental principles of soil mechanics and foundation engineering, with a focus on practical applications.

"International Journal of Geotechnical Engineering" (IJGE) - Publishes research articles, review papers, and case studies on geotechnical engineering topics, including soil mechanics, foundation engineering, slope stability analysis, and ground improvement techniques.

"Indian Geotechnical Journal" (IGJ) - Publishes original research articles, technical notes, and case studies related to geotechnical engineering, soil mechanics, and foundation engineering, with contributions from Indian authors and researchers.

Geotechnique (published by ICE Publishing)

Journal of Geotechnical and Geo environmental Engineering (published by ASCE)

Terzaghi, K. (1943). Theoretical Soil Mechanics.

Peck, R. B., & Bazaraa, A. (1977). Foundation Engineering for Difficult Subsoil Conditions.

International Standards:

ASTM D2487 - Standard Practice for Classification of Soils for Engineering Purposes.

ASTM D1586 - Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils.

ASTM D854 - Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer.

ASTM D1556 - Standard Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method.

ASTM D422 - Standard Test Method for Particle-Size Analysis of Soils.