

NPTEL
NATIONAL PROGRAMME ON
TECHNOLOGY ENHANCED LEARNING

CDEEP
IIT BOMBAY

ADVANCED GEOTECHNICAL
ENGINEERING

Prof. B.V.S. Viswanandhan

Department of Civil Engineering

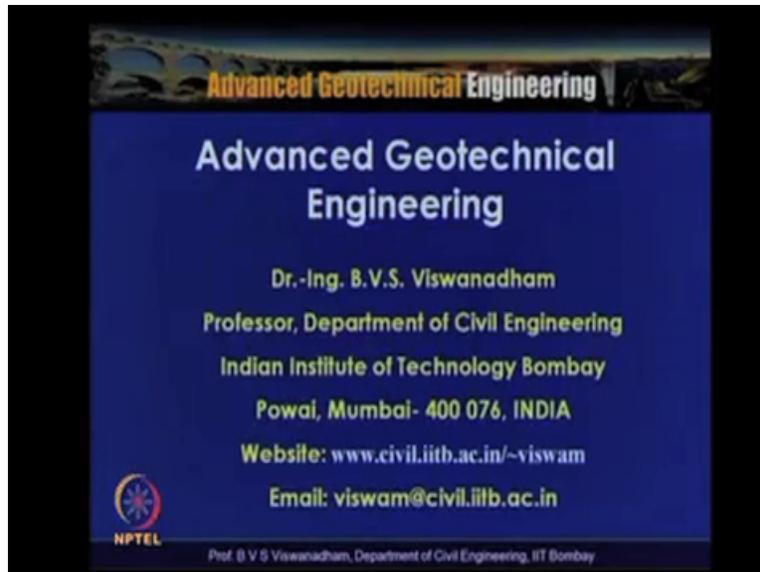
IIT Bombay
Lecture No. 01

Module-1

Introduction

Welcome to advanced geotechnical engineering course which is being offered under the program of NPTEL phase two being developed at IIT Bombay so as you all know the soil mechanics are part of Geo technology nearing place an important role in the behavior of civil engineering structures so this course is being offered for graduate students.

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As well as for practicing engineers who are actually you know going to use or working the area of geotechnical engineering myself previous viswanadham and professor at department of civil engineering with the geotechnical engineering a specialization my research areas include centrifuge modeling of geotechnical structures research in geotechnical engineering soil reinforcement geosynthetics and details of my work can be seen at website WW civil dot IA t p dot AC dot in backslash tilde Wishon my email id is given here this format.

The civil dot IA to be dot a c d a ting so this course we would like to cover in the following headfirst we will introduce ourselves to origin and nature of the soils as engineering materials as you all know soil.

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Advanced Geotechnical Engineering

Course Outline

- ☛ Origin and the nature of soils as engineering materials; Soil classification schemes; Clay mineralogy
- ☛ Soil compaction; Soil-water interaction; Permeability and Seepage
- ☛ Consolidation behaviour of the soil and Methods for accelerating consolidation of the soil.
- ☛ The stress-strain-strength response of soils,
- ☛ Earth retaining structures and stability analysis of slopes

Buried structures, and
Geotechnical physical modelling

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And rocks are the beige engineering materials which are used in civil engineering construction and then we will try to classify the soils and try to look into the claim a neurological aspects thereafter soil compaction soil water interaction term ability and seepage and effective stress will be covered after this consolidation behavior of this soil and methods for accelerating consolidation of the soil will be introduced having done.

This the stress-strain strength response of soils will be discussed in depth and as an application to this earth retaining structures and stability analysis of slopes will be covered this is followed by buried structures and their behavior and will be this course will be given a closure with geotechnical physical modeling.

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The slide features a title 'Advanced Geotechnical Engineering' at the top. Below it is a table with three columns: 'S.No.', 'Module', and 'Contents'. The first row contains the number '1', the module title 'Soil composition and soil structure', and a list of topics including soil formation, types of soils, particle characteristics, soil structure, clay mineralogy, soil-air-water interaction, consistency, soil compaction, and effective stress. At the bottom left is the NPTEL logo, and at the bottom center is the text 'Prof. B V S Viswanadham, Department of Civil Engineering, IIT Bombay'.

S.No.	Module	Contents
1.	Soil composition and soil structure	Soil formation; Types of soils and their characteristics; Particle sizes and shapes; their impact on engineering properties; Soil structure; Clay mineralogy; Soil-air-water interaction; Consistency; Soil compaction; Concept of effective stress.

This course is covered in eight modules in module 1 soil composition and the soil structure will be covered under. The soil composition and soil structure will be looking into soil formation types of soils and their characteristics particle sizes and shapes their impact on engineering properties soil structure clay mineralogy soil water interaction consistency soil compaction and concept of effective stress will be introduced here in this module and each module will be actually having problems and also self evolution and tutorial problems so that this will bring close to the subject what you learnt in the previous lectures.

Which are actually there in this module as a second module will be covering permeability and seepage permeability and the seepage force.

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Advanced Geotechnical Engineering

S.No.	Module	Contents
2.	Permeability and Seepage	Permeability; Seepage force and effective stress during seepage; Laplace equations of fluid flow for 1-D, 2-D and 3D seepage, Flow nets, Anisotropic and non-homogeneous medium, Confined and Unconfined seepage.

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And effective stress during seepage Laplace equations of flow particularly fluid flow in soil in one dimensional two-dimensional and three dimensional seepage flow rates and your strophic and non homogeneous medium confined and unconfined seepage and along with practical examples will be discussed in this module.

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Advanced Geotechnical Engineering

S.No.	Module	Contents
3.	Compressibility and Consolidation	Stresses in soil from surface loads; Terzaghi's 1-D consolidation theory; Application in different boundary conditions; Ramp loading; Determination of Coefficient of consolidation c_v ; Normally and Overconsolidated soils; Compression curves; Secondary consolidation; Radial consolidation; Settlement of compressible soil layers and Methods for accelerating consolidation settlements.

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In module 3 the compressibility and consolidation and under this the stresses in soil from surface loads terzaghi's one dimensional consolidation theory application indifferent boundary conditions ramp loading that is the loading which is actually carried out happens in the field determination of coefficient of consolidation CV for normally and or consolidated soils along with some practical examples compression curves secondary consolidation radial consolidation and settlement of compressible soil layers and methods for accelerating consolidation settlements will be discussed. In this module 3.

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Advanced Geotechnical Engineering

S.No.	Module	Contents
4.	Stress-strain relationship and Shear strength of soils	Stress state, Mohr's circle analysis and Pole, Principal stress space, Stress paths in p-q space; Mohr-coulomb failure criteria and its limitations, correlation with p-q space; Stress-strain behaviour: Isotropic compression and pressure dependency, confined compression, large stress compression, Definition of failure, Interlocking concept and its interpretations, Drainage conditions; Triaxial behaviour, stress state and analysis of UC, UU, CU, CD, and other special tests, Stress paths in triaxial and octahedral plane; Elastic modulus from triaxial tests.

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In module four stress-strain relationship and the shear strength of soils will be discussed in this module we will be discussing stress state Mohr circle analysis and Pole principal stress in the space and stress paths in PQ space Mohr-coulomb failure criteria and its limitations correlation with peak is PQ space and stress-strain behavior isotropic compression and pressure dependency confined compression large stress compression definition of failure interlocking concept.

And its interpretations drainage conditions and tri-axial behavior of stress state and analysis of unconfined unconsolidated-untrained consolidated and drain consolidated drain and other special test stress paths interracial and octahedral plain elastic modulus from the traction test will be introduced so in this at the end of this module what we will do is that we will try to seen number of problems and we will also try to have some tutorial problems.

So this will actually allow you to understand in a better manner in this module as module 5& 6 as an application.

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Advanced Geotechnical Engineering

S.No.	Module	Contents
5.	Earth retaining structures	Earth pressures; Stress changes in soil near retaining walls; Earth pressure theories- estimation of earth pressures-drained and undrained loading.
6.	Stability of Slopes	Stability analysis of a slope and finding critical slip surface; Sudden Draw down condition, effective stress and total stress analysis; Seismic displacements in marginally stable slopes; Reliability based design of slopes, Methods for enhancing stability of unstable slopes.

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Of shear strength what we learnt in module 4 what we do is that we will try to learn at retaining structures in this at pressures stress changes in soil near retaining walls at pressures and pressure estimation of the pressure under drained and untrained loading and stability of slopes particularly stability analysis of a slope and final critical slip surface sudden drawdown conditions and effective stress and total stress analysis seismic displacements and marginally stable slopes.

And we will be introducing briefly to reliability based design of slopes and methods for enhancing stability of unstable slopes there are many methods so that we can actually discuss some important methods so that how a stability of an unstable slope can be improved.

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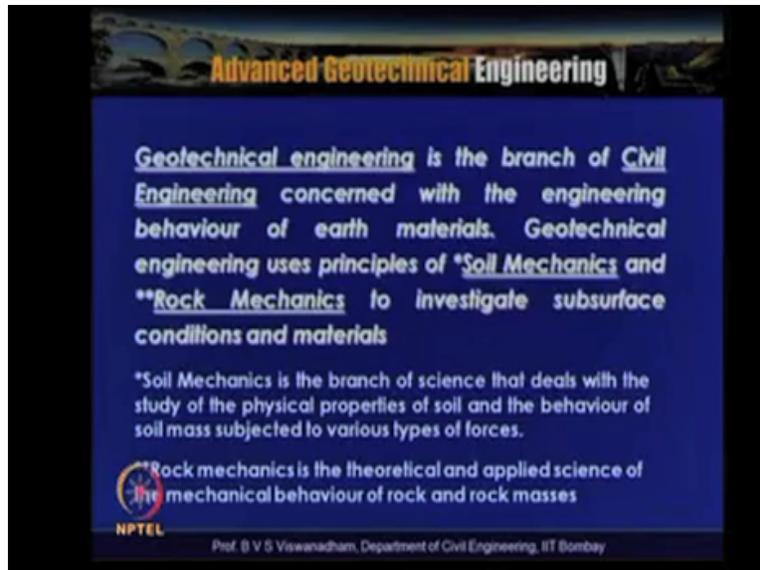
The slide features a title 'Advanced Geotechnical Engineering' at the top. Below it is a table with three columns: 'S.No.', 'Module', and 'Contents'. The table lists two modules: Module 7, 'Buried Structures', and Module 8, 'Geotechnical Physical Modeling'. At the bottom left is the NPTEL logo, and at the bottom center is the text 'Prof. B V S Viswanadham, Department of Civil Engineering, IIT Bombay'.

S.No.	Module	Contents
7.	Buried Structures	Load on Pipes, Marston's load theory for rigid and flexible pipes, Trench and Projection conditions, minimum cover, Pipe flotation and Liquefaction.
8.	Geotechnical Physical Modeling	Physical modeling methods; Application of centrifuge modeling and its relevance to geotechnical engineering; Centrifuge modeling of geotechnical structures.

In module 7 we will try to understand about the Buried structures these are very prominent or important nowadays with urban constructions the load on pipes mustang's load theory for rigid and flexible pipes trench and projection conditions and minimum cover pipe flotation. And liquefaction so these are you know some of the critical conditions like liquefaction and then behavior of the pipes subjected to flotation and Don will be discussed finally under eight module will be discussing geotechnical physical modeling .

The physical modeling methods applications of centrifuge modeling and it is relevance to geotechnical engineering centrifuge modeling of geotechnical structures with practical examples will be discussed.

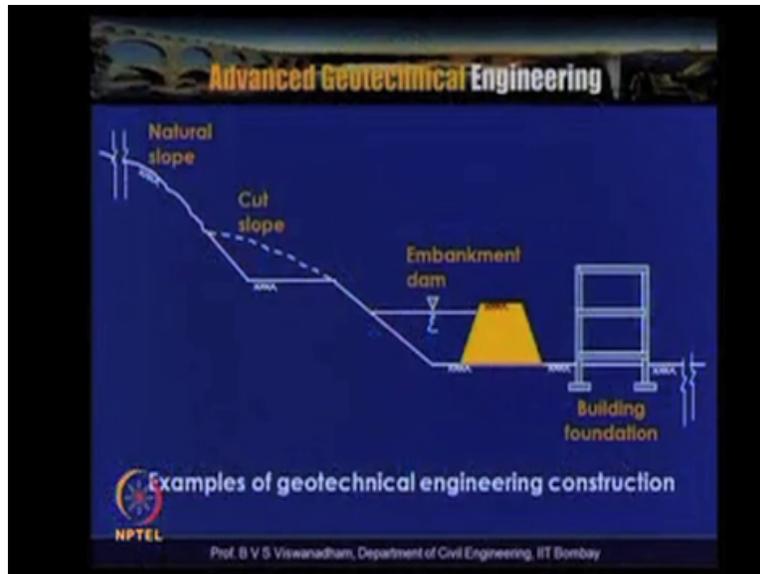
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So if you look into this the geotechnical engineering is the branch of civil engineering concerned with the engineering behavior of at materials geotechnical engineering uses principles of soil mechanics and the rock mechanics so here the soil mechanics and rock mechanics to investigate subsurface conditions and materials which is very important so if you look the soil mechanics is the branch of science that deals with the study of physical properties of soil and the behavior of soil mass subjected to various types of forces.

Whereas the rock mechanics is the theoretical and applied science of the mechanical behavior of rock and rock masses so soil mechanics is the branch of science that deals with the study of the properties of the physical properties of soil and the behavior of soil mass subjected to various types of forces the forces can be gravity forces or seepage forces or external loading etcetera the rock mechanics is the theoretical and applied science in of the mechanical behavior of rock and rock masses so in this slide a series of geotechnical engineering the construction activities.

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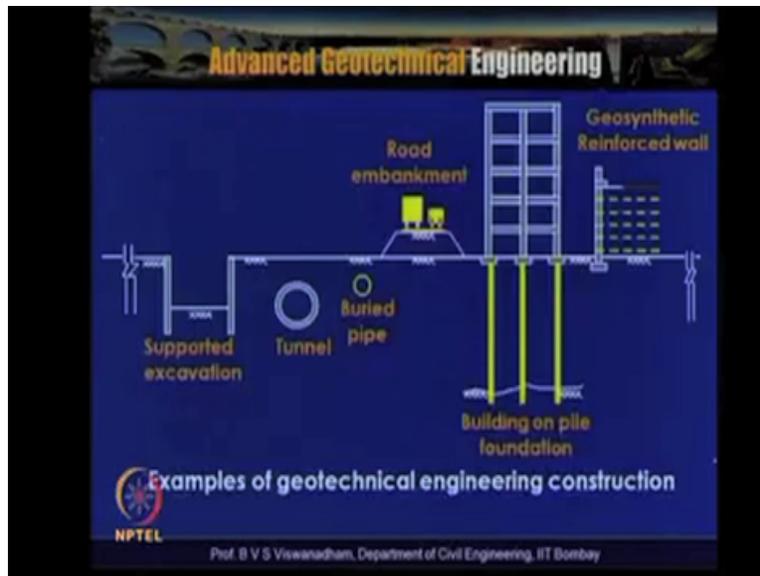


Which are actually formed with soil is shown a natural Slope or natural slope which is the inner structure which is a geotechnical structure which is actually formed either because of the erosion or because of the gravity loading so this natural slope which is actually shown and then in order to allow the urban construction sometimes along the hilly terrains the cutting fill method is adopted the slopes would be cut and then the load for the slopes to the roads to construct.

So this infrastructure development makes some of the existing natural slopes unstable so hence there is a need for understanding about the behavior of these slopes under the natural conditions are subjected to some adverse effects here whenever if there is a requirement of storage of water then this is particular structure is called a magma dam and which is required to prevent the leakage of the water through the dam so this particular structure which is actually called as an embankment dam.

So if you see here this particular structure is a building foundation for a one or two storey building so here the foundation transmits the loads to the subsoil and the it should be such that the settlement should be minimum.

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In this slide when the slope is steeper and if it is required then there is a need for the supporting so if this is called a supported excavation or this is called if you are using a braces for this it is called braced excavation or supported excavation and in this case the next structure which is actually shown is a tunnel and which is required nowadays because of the urban constructions so for the metros another applications you need to have the underground constructions.

So this allows this particular cross section shows tunnel which is embedded in soil or it can be in the rock so this is you know lining of the tunnel material and herein this particular figure part of the figure of this slide it shows a buried pipe and which we will be discussing in the subsequent lectures so this is buried pipe at a certain depth below the ground level and here in this particular figure it shows a road embankment above the existing ground level.

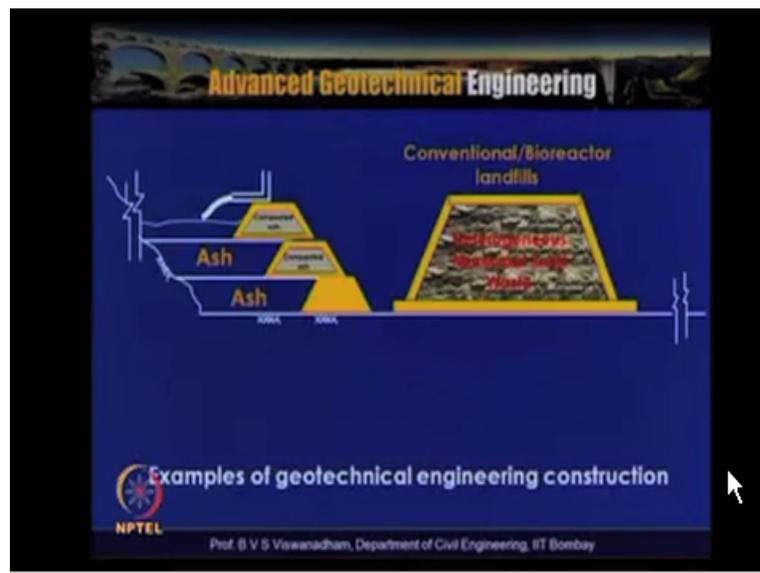
So this is atypical structure which is very common as far as civil engineering construction for highway and railway applications is concerned in particularly if you have got a soft soil and if there is a requirement of the large loads to be transferred to the deeper strata's then it is required to construct foundations such that the loads are actually transferred to the harder strata which are actually there below so here this is cross section.

Which actually shows the building on the pile foundation so these yellow members which are actually shown are the piles and here this particular surrounding soil which may be can offer a frictional resistance or sometimes if it is in the form of a clay it derives the strength only from

the bearing so in this particular cross section what you see is geosynthetic reinforced soil walls which are actually very popular in urban construction.

Nowadays because of the requirement of the construction of the steep walls in urban areas and where you can actually have different sleep road and highway intersections in the congested areas so this is possible to construct with the economical construction so that this can lead to you know large economics in the civil engineering construction.

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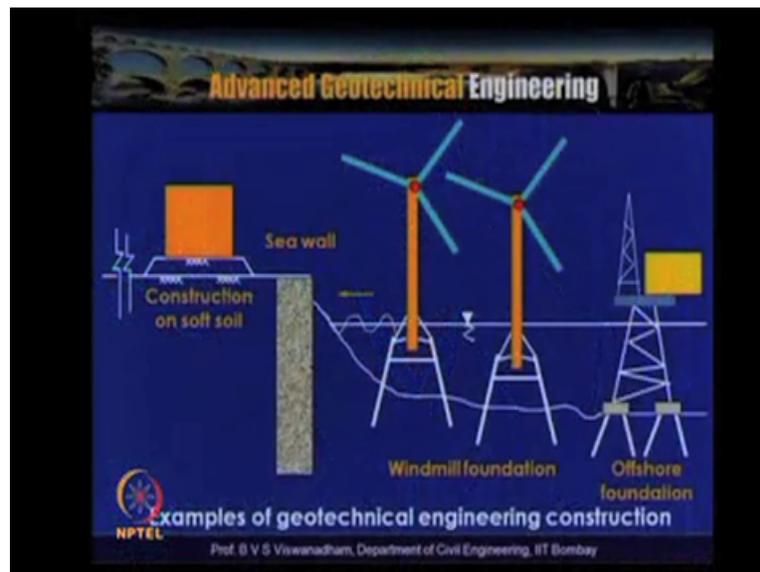


In this particular slide the left curve section of the figure which actually shows Ash pond Dam so this is actually a started dike where the ash is actually deposited once the ash this portion is filled then the second like is constructed above this started like and to have economics the compacted ash is actually used as a filler and then it is surrounded by soil so that this can actually have less prone for erosion adheres so like this you know it can actually go up to three to five levels so the total height of the structure can go up to 2025 meters.

So this requires you know the understanding about the stability of this type of ash dams in and also in retaining these ash safely and because of the advent because of the development and generation of the municipal solid waste there is a requirement for multiple solid waste landfills that means that the waste which is actually incinerated or generated has to be finally dumped safely in the ground or above the ground.

And this construction or this type of a geotechnical structure is called landfill if the leachate which is actually generated is recirculated and from periodically so that this can actually avoid the periodic treatment of the this can avoid intermittent treatment of the leachate so this is actually if that is the case then it is called bioreactor landfill the least recirculation of leachate allows the landfill to undergo decomposition rapidly and this can actually lead to the you know this particular areas can release for the future so in this slide a typical structure of construction.

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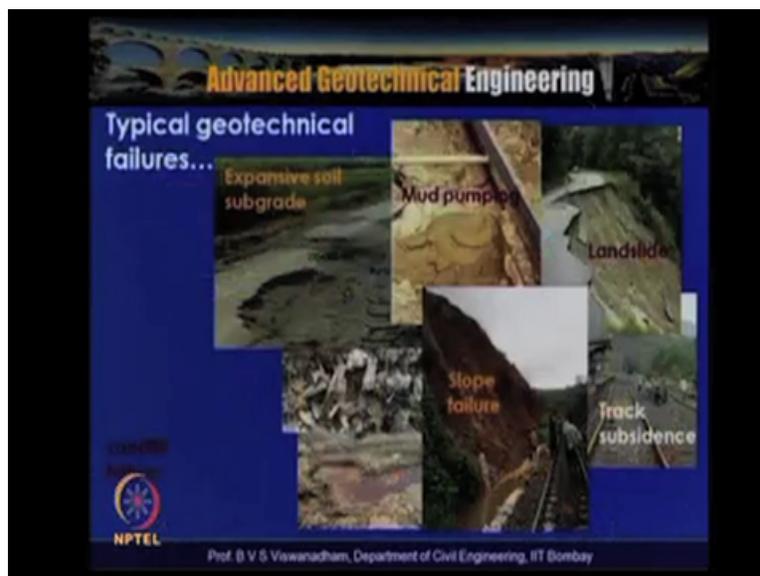


On soft soil is shown so this is a typical oil storage tank which is actually constructed on soft soil and wherever it is close to the coastal belt there is a requirement there is possibility that you have got soft soil so in order to allow the construction that soft soil has to be consolidated so that that the settlements are minimum so here in this it involves construction on the soft soil particularly different techniques for accelerating the construction of the soft soil.

Then this type of constructions can be made possible to have a better performance so here this particular cross section it shows a sea wall which actually protects the land from the waves which are actually arise because of the because of sea waves which are arising because of the water which is actually there so this is actually seabed which also requires to understand about the stability that is the from the stability point of view and these are windmill foundations which are actually.

These windmill foundations are nowadays used for production of the wind energy from the wind so these are sometimes when they are located in the sea they are called they are located in offshore and sometimes they are also located on the on the onshore so you have if you have got a windmill foundation which is therein the see the typical foundation with rocker piles would look like this and this is a typical I will store a oil oilrig for a offshore foundation which is actually shown here on Drecker pipe so we have seen the different types of geotechnical structures.

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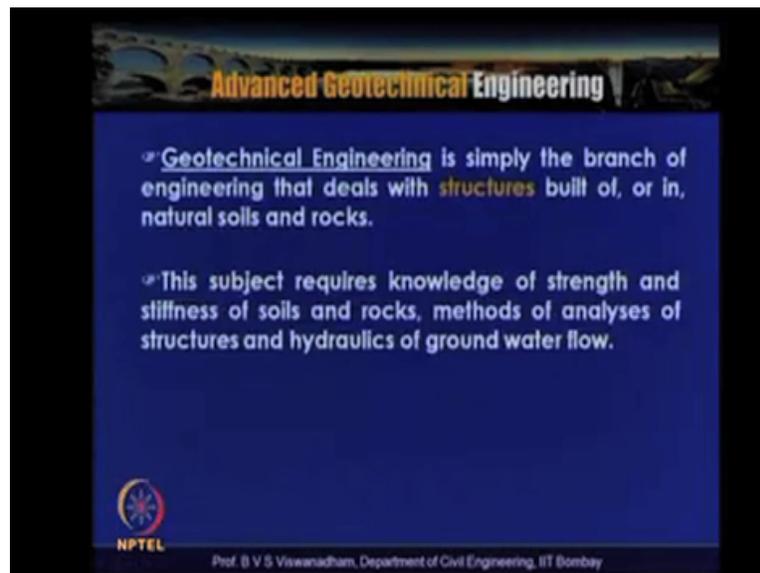
And all these structures are subjected to typical failures for example if you have got a road which is on the soil which actually have inadequate drainage that can lead to you know expansive if it is on the expansive soil the sub grade can undergo failure like this and if you have got a railway track on the soft soil formation there is a possibility of the mud fumed pumping

like this and if you have got some instability because which is because of the sea page or because of some landslides.

Then this are earthquake this type of instabilities can cause and if you have got a landfill and if the stability is not ensured either because of some mining work or some other problem then this type of land landfill failure can cause and this is a close view of municipal solid waste which is in particular generated in Mumbai and which shown and this is the typical leach ate which is actually shown here so the degree of contamination levels are very high and so if you want to see the impact.

On the engineering properties of the soil and all is required to be understood very clearly so here the typical slope which is actually shown along the railway track and these type of failures are very common because of the C page which actually takes place during the monsoon and here a typical railway track which is actually subjected to a track subsidence is shown.

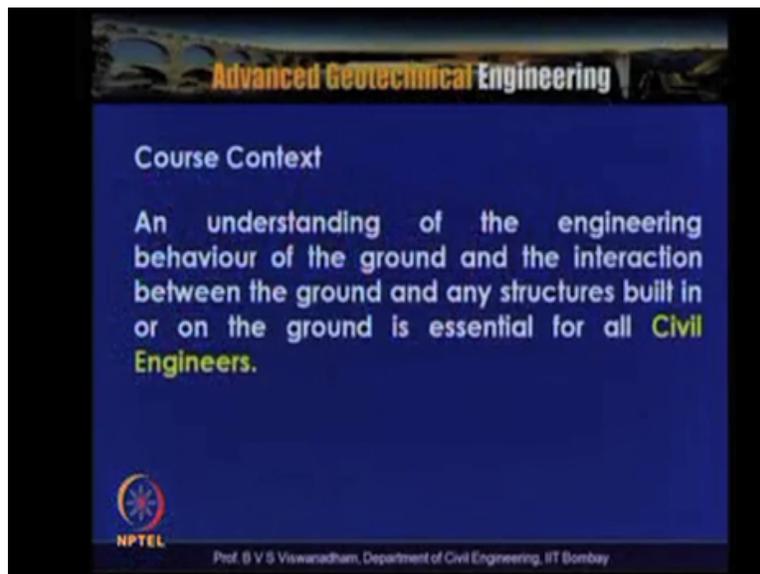
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So geotechnical engineering if you look into the definition it is simply the branch of engineering that deals with structures built off or in natural soils and rocks this subject requires knowledge of strength and stiffness of soil soils and rocks and methods of analysis of structures and hydraulics of groundwater flow so you are required to understand the structures which are actually built off are in natural soils and rocks so this subject requires knowledge of the strength and stiffness of soils and rocks methods of analysis of structures and hydraulics of groundwater flow.

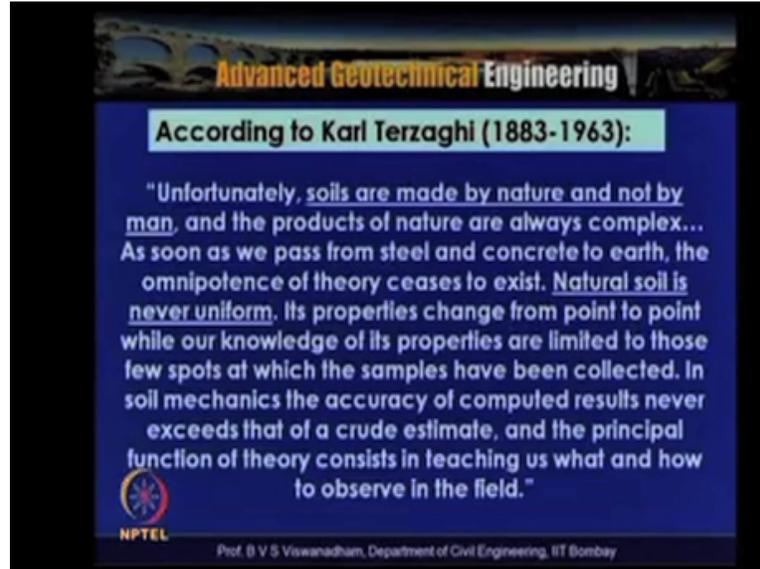
So in this course we will be concentrating mostly on the soil behavior and soil stiffness and the methods of the analysis of structures resting on the soil predominantly as course context I like to introduce here an understanding of the engineering behavior of the ground the interaction between the grounds.

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And any structures built or in the ground is essential for civil engineers or engineers so that means that this particular understanding about this subject which involves the engineering behavior of the ground and the interaction between the ground and any structure like retaining wall interacting with the soil built on or on the ground is essential for civil engineers.

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Before introducing and giving references of this particular course I will be giving the quote which is actually given by Karl Terzaghi's 1883 to 1963 who is known as the father of soil mechanics here it says is like this unfortunately soils are made by nature not by man many times in soil mechanics what will happen is that engineer requires to use the soils which are actually available in the nature and the products of nature are always complex.

As soon as we pass from the steel and concrete to earth the Oh many patents of the theory ceases to exist natural soil is never uniform we are what we are going to see that there are different types of soils and its properties change from point to point while our knowledge of its properties are limited.

To those few spots at which the samples have been collected and tested in soil mechanics the accuracy of computed results never exceeds that of crude estimate and the principal function of theory consists in teaching us what and how to observe in the field.

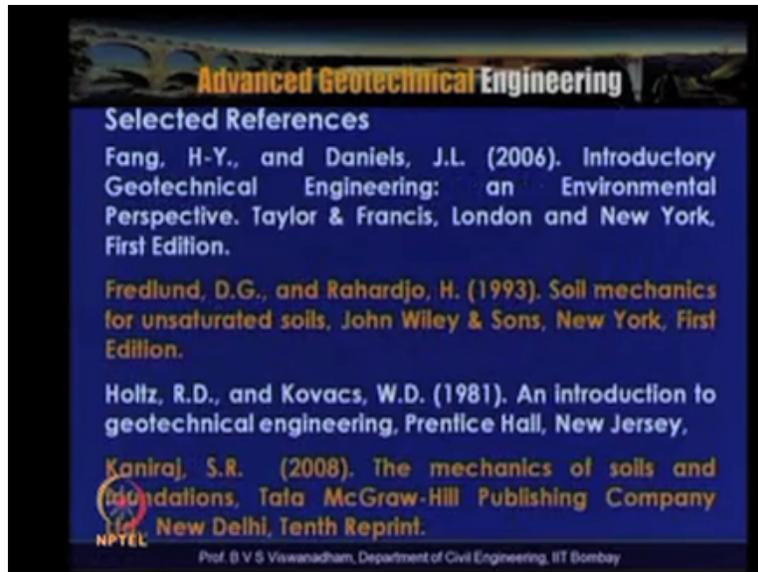
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So here some selected differences are listed in these are these references are listed in the alphabetical manner Atkinson 2007 which will be following for majority of the portions of this course the mechanics of soils and foundations and which is published by Taylor and Francis in 2007 and this is the secondary edition which I included here Ayden a 2005 soil mechanics the basic concepts and engineering applications Taylor & Francis London and which is published.

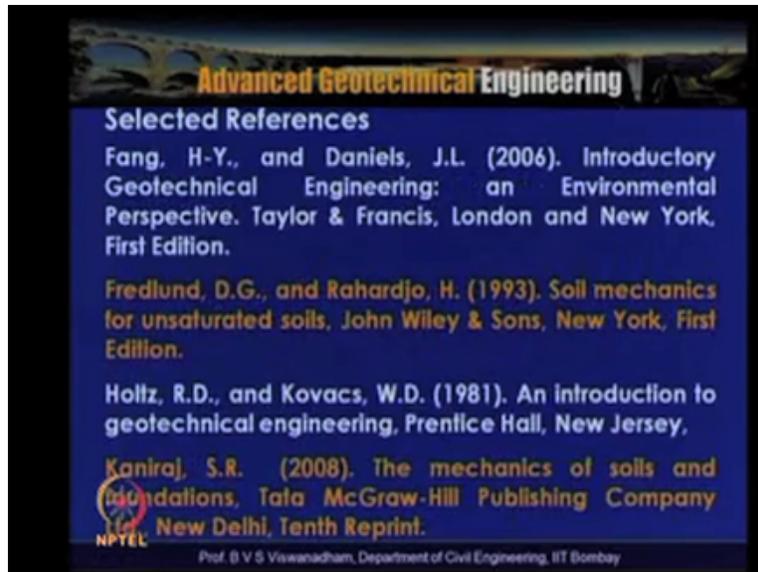
I think in the first edition and Craig.R.F 2004 this is the title of this book is Craig soil mechanics spawn fresh trailer in France's londonand new York 7th edition thus BM 2008 advanced soil mechanic Saylor and Francis London and you our third show.

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Fang and Daniels 2006 introductory geotechnical engineering and environmental perspective Taylor & Francis London and New York first edition
Fredlund and Rahardjo 1993 soil mechanics for unsaturated soils John Wiley & Sons New York first edition
Holtz and Kovacs 1981 introduction to geotechnical engineering Prentice Hall New Jersey
Kaniraj 2008 the mechanics of soils and foundations Tata McGraw-hill Publishing Company New Delhi 10th preprint.

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McCarthy2007 essentials of soil mechanics and foundations basic geo techniques prentice on new jersey 7th edition parry R.H.G 2004 more circles stress paths and Joe techniques so here we will be discussing mostly about the stress paths and then the failure criteria which are actually involved with the stress stiffness response of soils the spawn trust Taylor & Francis and London and New York 2nd edition wood DM geotechnical modeling basically here we will be covering the geotechnical physical modeling involved which is in the module 8 of this course.

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Advanced Geotechnical Engineering

Rock: The source of soils

- ☐ Most of the nonorganic materials that are identified as soil originated from rock as the parent material.
- The rocks that form the earth's surface are classified as to origin as:
 - - Igneous
 - - Sedimentary
 - - Metamorphic

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So as a source of the soil first let us look into the origin of the rock and origin of the soils so the rock the source of the soils most of the non-organic materials that are identified as soil originated from the rock as the parent material as you all know that the rocks that form the Earth's surface are classified as 2as igneous sedimentary and metamorphic rocks.

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Advanced Geotechnical Engineering

Igneous Rocks

- are those formed directly from the molten state of magma.
- ◇ The molten magma that cooled rapidly at or near earths surface are called extrusive or volcanic type rocks. Eg. *Basalts, Rhyolites* and *Andesites*.
- ◇ If the molten rock cools very slowly, the different materials segregate into large crystals forming a coarse-grained or granular structure (Trapped at deeper depths)
 - Intrusive or plutonic type, Eg. *Granite* (which consists of quartz and feldspar), *Syerites*, and *Gabbros*
- ◇ Because of high silica content these rocks are classified as ACIDIC → Decomposes to predominantly sandy or gravel with little clay. (Good construction materials)
- ◇ Rocks whose minerals contain Fe, Mg, Ca or Na but little silica such as the *Gabbros, Diabases, Basalts* are classified as BASIC

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Igneous rocks sedimentary rocks are metamorphic rocks these igneous rocks are formed directly from the molten state of magma the molten magma that cools rapidly at or near Earth's surface are called extrusive or volcanic type rocks examples for this are vessels rewrites and Anne decides if the molten rock cools very slowly the different materials segregate into large crystals forming a coarse-grained or granular structure that trapped in deep at deeper depths intrusive or platononic type examples for this type of rock.

Which is actually formed when the molten rock cools very slowly that is granite which consists of quartz and feldspar sides and gabbros because of the I silica content these rocks are called as HD clocks they decompose to predominantly sandy or gravelly with little clay so you see here when these rocks with high silica content when they decompose they form a predominantly sandy or gravelly with little clay.

This is this is actually used as good construction material rocks whose minerals contain iron magnesium calcium or sodium but little silica such as the gabbros databases results are called as base across the rocks whose minerals contain iron magnesium or calcium or sodium but little amount of silica these rocks are called as basic rocks examples are gabbros deserts.
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Advanced Geotechnical Engineering

Igneous Rocks

- ↳ When the solution of magma is cooled very very rapidly the minerals do not separate into crystals but solidify as amorphous vitreous rock.
- Such as, Volcanic Scoria, Pumice, and Obsidian**
- ↳ Rock types that are intermediate between acidic and basic include the *Trachytes, Diorites, and Andesites*.
- Easily break down into the fine-textured soils due to their mineral components.
- ↳ The clay portion of fine-textured soil is the result of primary rock minerals decomposing to form secondary minerals.
- ↳ Not small fragments of the parent rock minerals
- ↳ The properties and behaviour of clay soils are different from those of gravel, sand, and silt soils.

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When the solution of the magma is cooled very rapidly the minerals do not separate into crystals but solidify as amorphous vitreous rocks such as examples volcanic scoria Pumas and obsidian the rock types that are intermediate between acidic and basic include track hides die writes and add the size they are easily break down into the fine textured soils due to their mineral components so the rocks that are intermediate between acidic and basic rock.

The examples include track eights diorite sand and asides they easily break down into the fine textured soils due to their mineral components the clay portion of the fine textured soil is the result of the primary rock minerals composite to form secondary minerals not small fragments of the parent rock minerals the properties and we have the clothes clay soils are different from those of gravel sand and city soils so the clay portion of the fine textured soil is the result of the primary rock minerals decomposing to form secondary minerals.

So the properties and behavior of clay soils are different from those of gravel and sand and salty soils that this is one of the results for different behavior of the properties of the clay.

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Advanced Geotechnical Engineering

Sedimentary Rocks

◇ are formed from accumulated deposits of soil particles or remains of certain organisms that have become hardened by pressure or cemented by minerals.

Cementing materials such as silica, Calcium Carbonate, iron oxides are abundant

For E.g., *Limestones, *Dolomites, Sandstone, Shale, Conglomerate and Breccia*

*Dolomite is referred to both the rock forming mineral $\text{CaMg}(\text{CO}_3)_2$ and sedimentary rock (present name is Dolostone)

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Then comes to sedimentary rocks these are actually formed from the accumulated deposits of soil particles or remains of certain organisms that become hardened by pressure are cemented by minerals cementing materials such as silica calcium carbonate iron oxides are abundant in this type of rocks example lime stones Dolomites the present proposal new name is dollars tone and sandstone are shale or conglomerate and Brescia these are the examples of the sedimentary rocks.

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Advanced Geotechnical Engineering

Sedimentary rocks

- ◇ Shales are predominantly formed from deposited clay and silt particles.
 - The degree of hardness = f (the type of minerals, the bonding that developed, and the presence of foreign materials).
 - The hardness is mainly due to external pressures and particle bonds, not due to cementing minerals.
 - When exposed to environment (water or air), shales tend to expand or delaminate (the layers separate)
 - Break down of shale → fragments of varying sizes → Clay particle sizes

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The shells are predominantly formed from the deposited clay. And silt particles the degree of the hardness of this shale depends upon the type of minerals the bonding that developed and in the presence of foreign materials the hardness is mainly due to the external pressures and particle bonds not due to the cementing materials that is this is mainly due to the external pressure which has been subjected and the particle bonds not due to the cementing material which is actually due to any cementing materials.

When expressed in environment our ale shells tend to expand and Dominate this is one of the problem in some parts where the shale soils are available and then they have planar types of failures and the slopes with very small inclination or mild incarnations can be subjected to plan our failures and breakdown of the shale the fragments of various sizes and varying sizes and clay particle sizes so if the shale actually breaks and it gets fragmented into clay particle size.

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Advanced Geotechnical Engineering

Sedimentary rocks

- ◇ Limestone is predominantly crystalline CaCO_3 (Calcite) formed under water.
- ◇ Limestone-Dolomite is referenced as Karst or Karstic terrain.
- ◇ Sinkholes/cavities can result due to solvable nature with ingredients present in ground water. →
- ◇ Weathering of limestones predominantly finer size particles.



Formation of sinkholes

(Modified after: <http://geoservicesbd.com/limestone/sinkholes.html>)

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Limestone is predominantly crystalline calcium carbonate that is calcite formed underwater so limestone dolomite is referenced as a karst or karstic terrain and here in this particular photograph a typical formation of a sinkhole which is actually shown and here this is due to the cavity which is formed because of the soluble nature of the ingredients present in the groundwater so these types of formations cause problem to the infrastructure particularly pipes.

Which are actually pipes which are located on this type of structures or any structures which are actually resting on this type of formation can be subjected to discuss so weathering of limestones predominantly fine sized particles where will be reduced so what we are seeing is that we have seen igneous rocks and we have seen sedimentary rocks now let us look into the third type of the rock which is called metamorphic rock.

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- **Metamorphic Rocks [Source: IR or SR]**
 - results when any type of existing rock is subject to metamorphism, the change brought about by combinations of heat, pressure and plastic flow so that the original rock structure and mineral composition are changed.
 - [→ Plastic flow - slow viscous movement and rearrangement within the rock mass due to external forces]

Limestone →→ MARBLE; Shale →→ SLATE or PHYLLITE;
Granite → → GNEISS; Sandstone →→ QUARTZITE

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The source of this metamorphic rocks either igneous or sedimentary rocks the results when any type of existing Rock is subjected to metamorphism the change brought about the combinations of heat pressure and plastic flow so that the original rock structure and mineral compositions are changed so here the plastic flow means the slow viscous movement and rearrangement within the rock mass due to external forces.

So limestone after subjecting to metamorphism converts into marble shale to slate and the slate or flight grenade to grace and sandstone to quartzite so if metamorphism of limestone yields to marble metamorphism of shale yields to slate or flight metamorphism of granite yields to Ignacio and metamorphism of sandstone yields to quartzite.

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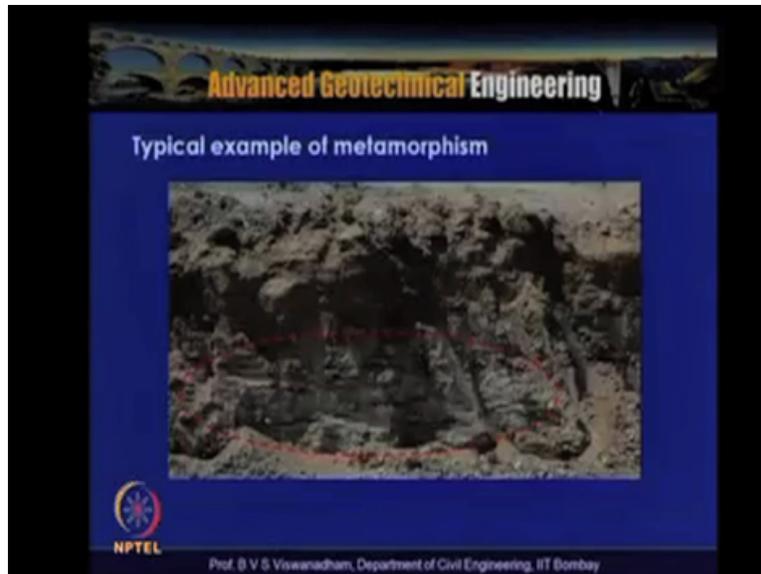
Metamorphic Rocks

- ◇ Gneiss is a foliated rock with distinctive banding that results from the metamorphosis of granite.
- ◇ Distinction between Gneisses and Schists is not always clear
- ◇ Upon weathering Gneiss and Schist decompose to form silt-sand mixtures with mica.
- ◇ Soils from phyllites are more clayey and decomposition of quartzite produces sands and gravels.

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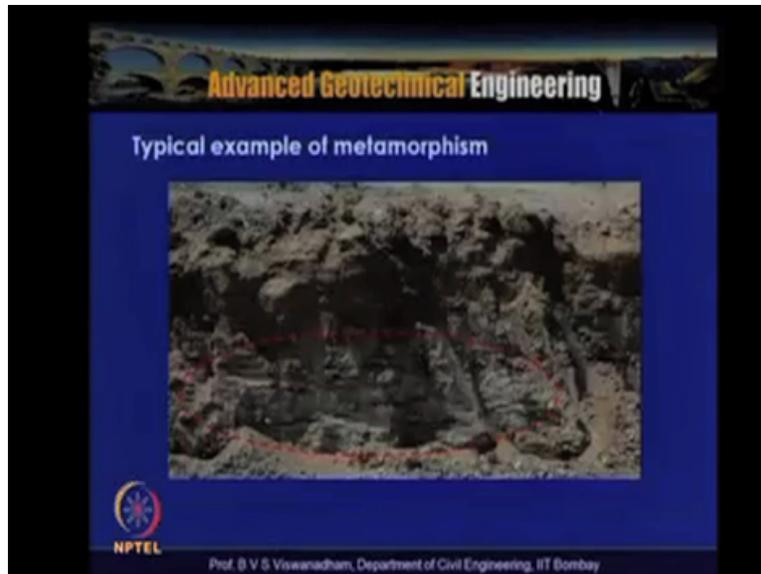
The gneiss is a foliated rock with the distinct and distinctive banding that results from the metamorphism of granite. Distinction between Gneisses and Schists is not always clear. Upon weathering Gneiss and Schist decompose to form silts and mixtures with the mica content. Soils from phyllites are more clayey and decomposition of quartzite produces sands and gravels. The composition of fillings produce clay material.

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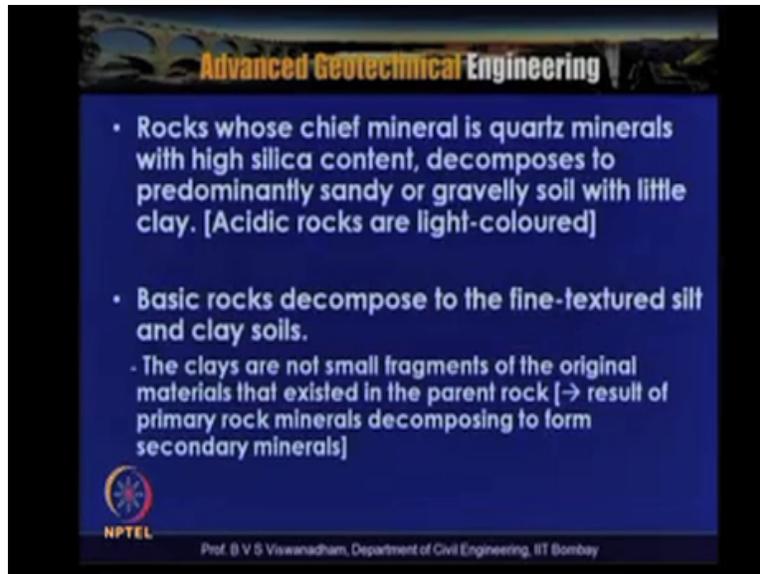
So this is a typical example of metamorphism which is actually shown in the site.

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So if you look into this slide the rocks are subdivided into igneous sedimentary and metamorphic and when they are subjected to weathering either due to physical or chemical means and they get divided into transported or sometimes when the weathering takes place when the soils deposit and their location then that is also called a residual so when the transported soils and the soil is now broadly classified as boulders gravel sand silt and clay so this particular gravel sand silt and clay if you see the size of the particle keeps on decreasing as we traverse from gravel sand silt and clay.

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The slide features a dark blue background with a landscape image at the top. The title 'Advanced Geotechnical Engineering' is written in orange and white. The main content consists of three bullet points in white text. At the bottom left is the NPTEL logo, and at the bottom center is the text 'Prof. B V S Viswanadham, Department of Civil Engineering, IIT Bombay'.

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- Rocks whose chief mineral is quartz minerals with high silica content, decomposes to predominantly sandy or gravelly soil with little clay. [Acidic rocks are light-coloured]
- Basic rocks decompose to the fine-textured silt and clay soils.
 - The clays are not small fragments of the original materials that existed in the parent rock [→ result of primary rock minerals decomposing to form secondary minerals]

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So rock whose chief mineral is quartz minerals with high silica content become poses to predominantly sandy and gravelly soil with little clay so these are acid rocks and they are light-colored in nature basics rocks decompose to the final textured silt and clay soils the Clay's are not small fragments of the original materials that exist in the parent rock this we have discussed earlier this results the primary rock minerals decomposing to form secondary minerals.

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Major soil types based on particle size

- ◇ The major engineering categories of soil are gravel, sand, silt and clay
- ◇ Gravel and sands are considered coarse-grained soils (with large bulk particle sizes)
- ◇ Silt (very fine particles of disintegrated rock) and clay particles are considered fine-grained soils because of their small particle sizes.
 - Clay soil is plastic (if it can be remolded without cracking/breaking) over a range of water content and silt soil possesses little or no plasticity.

Particles larger than gravel are called cobbles or boulders

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So if you look into this the major soil types based on the practical size if you look if you are classifying just now we discussed that in the in the type of formation ,we said that the gravel sand silt and clay they originated from the different types of rocks the gravel and sands are considered to be coarse-grained soils with large particle sizes and silt with very tiny particles of disintegrated rocks and clay particles are considered as fine-grained soils because of their small particle size sand clay soil is plastic over certain range of water content.

And still silt soil possess little or no plasticity so clay soil is plastic in nature it if it can be removed it without cracking and breaking we can say that the clay soil is plastic and wall range of water content so practices larger than gravel are called Coble's are boulders.

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- Soils can be grouped into two broad categories (depending on the method of deposition):
 - Residual – Formed from weathering of rock and remain at the location of their origin.
[a material which may possess little mineralogical resemblance to the parent rock]
 - Transported – those materials that have been moved from their place of origin
- by agencies like, gravity, water, glaciers, or man- either singularly or in combination

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So soils can be grouped into two broad categories as we see the based on the deposition based on the sizes we have actually divided into different types like gravel sand silt and clay based on the method of deposition residual which is actually called or formed when weathering of the rock and the remaining at the lower and weathering of the rocks takes place and their soils remain at the location of their origin itself this is because a material which possesses little mineralogical resemblance to the parent rock.

So the soil which actually resembles which remains there at the at it is origin at the origin itself and it resembles the parent rock characteristics predominantly and there is another type which is called transported these transported soils are called as those materials that have been moved from their place of origin like by agencies like gravity wattle glaciers are and either a singularity or in combination.

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- Characteristics of Residual soils are dependent on:
 - Climatic conditions - humidity, temp., rainfall)
 - Natural drainage pattern
 - Form and extent of vegetation cover

[A warm and humid climate is favourable to the formation of residual soils and nature of residual soil differs markedly at different depths below ground surface and constantly changes with time]

Soil deposits in Deccan Plateau

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So characteristics of the residual soils depend upon the climate conditions humidity temperature rainfalls some islands actually have the residual soils where the soil gets originated and then deposited at its place of origin so the characteristics of these residual soils are predominantly depending upon the humidity temperature and rainfall and the natural drainage part pattern and form and extent of the vegetation cover so these are the prime factors on which the characteristics of the residual soils are depend on the depend.

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- Transported Soils are classified according to the transporting agency and method of deposition:
 - Alluvial – transported in running water [rivers]
 - Lacustrine – deposited in quiet lakes
 - Marine – deposited in sea water
 - Aeolin – transported by wind
 - Glacial – by ice [Glaciation – massive moving sheets of ice]
 - Colluvial – deposited through action of landslide and slope wash

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Now the transported soils. We said that there is an agency which actually transports if it is transported by a running water then it is called alluvial deposits and if they are deposited in quiet lakes they are called lacustrine deposits if they are deposited in seawater and they are called as marine deposits if they have been transported by wind or a then it is called Aeolian deposits and if there is a glaciation which actually takes place because of the large movements of the sheets of ice then they are called glacial deposits these are actually predominant in hilly areas.

And colluvial that is deposited through action of the landslide and aslope slope wash where this particular types of deposits are possible so according to the transporting agency and method of deposition we subdivide this transported soils into alluvial colluvial marine Aeolian glacial where the glaciation is predominant and colluvial deposits.

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Examples of Transported soils:

- **LOESS** – Wind blown deposit with very uniform fine silt particles (possesses slight cementation properties)
 - Formed in Arid and Semi-Arid regions with yellowish light brown colour
- **Tuff** – Fine-grained slightly cemented volcanic ash [by wind/water]
- **Glacial fill** – Heterogeneous mixture of boulders, gravel, sand, silt and clay [Hilly regions]

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Examples of the transported soils are layers this is basically a windblown deposit with very uniform fine silt particle and possesses slight cementation so this is the reason why if suppose if there are some unsupported vertical cuts they stand vertical because of the cementation which is present in the particular soil which is transported by so this format in arid and semi-arid regions and with yellowish light brown color tough which is a fine grain slightly cemented volcanic ash and which is deposited by wind or water so tough is an example of transported soil glacial.

Till is a pros ingenious mixture of boulders gravel sand silt and clay which is predominantly in hilly region and where the glaciations is predominant and the war wood clay which is an example of transported soil which is nothing but which is formed by alternating layers of silt and clay deposited in freshwater with glacial lakes one band of silt and clay deposited each year so each layer is approximately 10 mm thick or so this particular transported soil is called a war wood clay marl very fine-grained soil of marine origin impermeable.

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Examples of Transported soils:

- **Varved Clay** – Alternate layers of silt and clay deposited in fresh water glacial lakes.
 - One band of silt and clay deposited each year [each layer is approx. 10 mm thk.]
- **Marl** – Very fine grained soil of marine origin [impermeable, greenish colour]
- **Peat** – A highly organic soil consisting almost entirely of vegetable matter in varying stages of decomposition, fibrous, brown to black in colour and highly compressible

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And which is highly compressible and greenish in color peat which is a highly organic soil consisting almost entirely of vegetable matter in varying stages of decomposition so it is a basically fibrous type of material and is the fibrous in nature and brown to black in color and highly compressible deposits so these PT soil deposits are also called as marshy lands where the construction needs to be done with care.

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Major soil deposits:
f (Ambience, Geography and Topography)

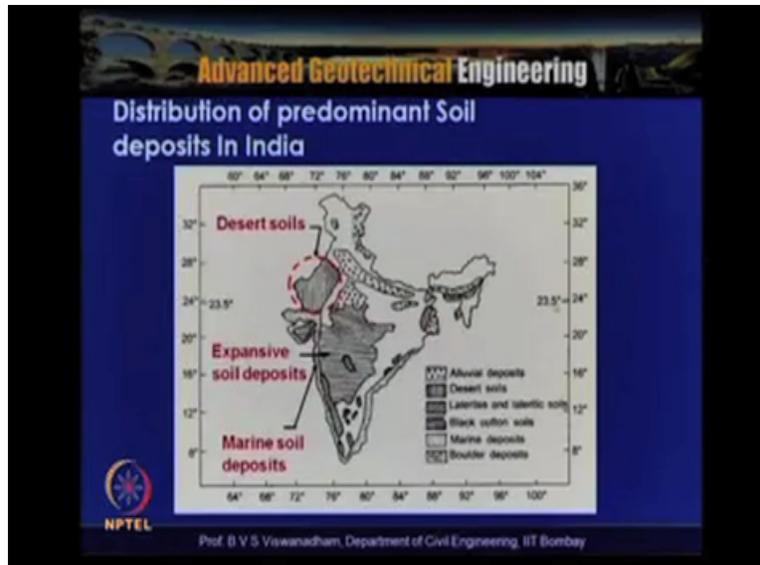
- > **Expansive** – High shrink-swell characteristics (attributed to the mineral)
Colour- Black (presence of Fe, Mg and Ti)
- > **Marine** – Very soft and may contain organic matter
- > **Laterite** – Red in colour due to Fe_2O_3 (Laterization- Leaching of Silica – due to intense chemical weathering)
- > **Alluvial** – Alternate layers of Sand, Silt and Clay
- > **Desert** – Wind blown, Uniformly graded
- > **Glacial** – Boulder clay (all ranges of particle sizes)

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So major soil deposits a base on the ambience geography and topography they are called as expansive these expensive soils also how high shrinkage swell characteristics attributed to the winter which is actually present in these expansive soils and the basic color is black this is due to the presence of iron magnesium and titanium moraine deposit very soft and may contain organic matter and electorate soil red in color due to fe_2o_3 and the loss of silica which is a due to the intense chemical weathering.

And this particular loss of silica due to the intense chemical weathering is called lateral and this causes a lot of problems in late rites oil deposits alluvial is alternate layers of sand silt and clay and desert is nothing but a windblown deposit and which is uniformly graded in nature glacial which is Boulder clay and which consists of all ranges of particle sizes here the distribution of the predominant of soil predominant soil deposits in India are shown here in this particular slide.

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Where in this portion where the desert soils which are actually transported by wind are shown here basically here the Aeolian deposits are there and along the coastal belt the Indian coastal Peninsula is about 6,500 kilometers and majority of the Indian coastal peninsula has marine soil deposits and in this portion, which is actually here shows the expansive soil deposits so the construction in these areas which is difficult and you in this particular portion here it is shown here the late rite soils.

So if you look into north to south and west to east there are the different ranges of soils which makes engineering difficult and where this there is a relevance of the subject as far as Indian context is concerned.

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Constituents of the soil mass

- Formation of soils from the weathering of the parent rock
- Wide range of sizes of soil solids

➤ Behaviour of soil mass under stress is a function of material properties, such as:

(i) size and shape of grains, (ii) gradation, (iii) mineralogical composition, (iv) arrangement of grain, (v) Inter-particle forces, etc.)

➤ Material properties $\rightarrow f(\text{constituents of the soil mass})$

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So if you looked at consistence of the soil mass the formation of soils from the weathering of the parent rock and the wide range of the soil solids are possible so behavior of the soil mass under stress is a function of the material properties such as size and shape of the grains so if you wanted to see understand about the material properties and its behavior the size and shape of the grains gradation like what type of particles and how the combination is there whether it has actually has got fine-grained portion or coarse grain portion and mineralogical composition.

The type of mineral which is actually present in the particular soil arrangement of the grains and inter-particle forces so the behavior of the soil mass under stress is a function of the material properties such as size and shape of grains gradation mineralogical composition arrangement of the grain antiparticle forces so material properties are now if you look into this is a function of the consistence of the soil mass.

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Constituents of the soil mass

- Soil is a particulate material,

which means that a soil mass consists of accumulation of individual particles that are bonded together by mechanical or attractive means, *though not strongly as for rock.*

- Spaces in between solid particles → Voids or pore space

- In soil (In most rock), voids exist between particles, and voids may be filled with a liquid, usually water or gas, usually air.

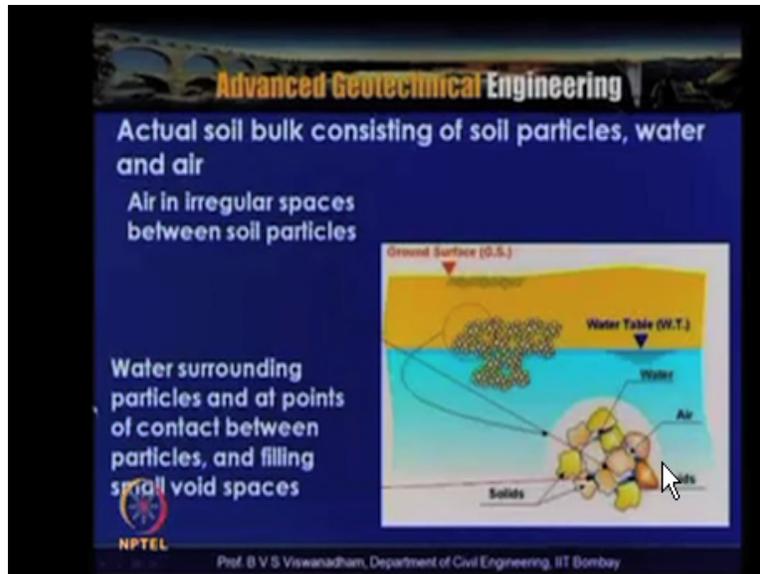
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The soil is a particulate material which means that the soil mass consists of accumulation of individual particles that are bonded together by mechanical or attractive means though not strongly as by rock in the rock there are the materials which are actually with permanent bonding the spaces between solid particles are referred here as whites or pore spaces the spaces between solid particles are referred here as whites or pore space sand, if the these voids are filled with water then it is called pore water and they exert pressure.

On the whites it is called as the pore water pressure in soil in most Rock the voids exist between particles and whites may be filled with a liquid usually water gas are usually air so in soil if the whites majority of the rocks or so they do have whites so why is existing between particles and whites may be filled with the a then in that case it actually is divided into a if it is only predominantly air then it is called as a two-phase system which will be introduced in the next slide and if it is filled with the water .

Only it is again also called as a two-phase system but here it is called water saturated all the voids are actually filled with the water and there is also possibility that partially saturated soil where you have got air water and solids so actual soil bulk consists of soil particles water and a air in the air is actually.

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Occupied here in the in the space which is actually shown here and here is actually portion which is actually shown as with water so this type of soil deposits which are actually above the groundwater table and this particular zone from here to here is called as a water zone and here this is this zone is called unsaturated soil and the soil mass which is actually there below the solids which are actually filled with water is called saturated soil here and here it is called partially saturated soil.

If there is no water here then there is only air and solids and if they here below water table the soil mass is actually completely filled with soil voids are completely filled with water the water surrounding particles at points of contact with water particles in the filling in the small solid spaces.

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Constituents of the soil mass

- Soil is inherently multiphase material (Generally consists of three phases)
 - Solid phase
 - Liquid phase
 - Gaseous phase

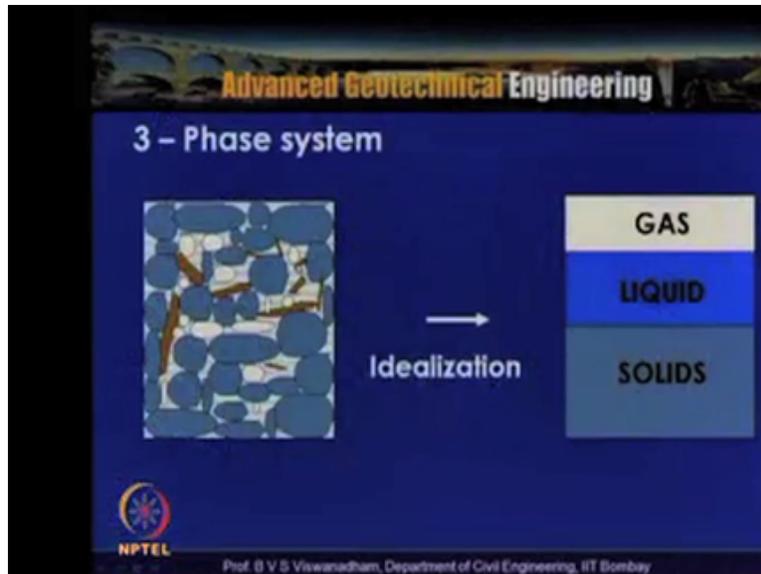
It can also be TWO PHASE material:

- With solid + Gaseous (DRY STATE)
- With solid + Liquid (SATURATED STATE)

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So the consistence of the soil mass we what we are saying is that there is a solid phase liquid phase and gaseous phase and if we have solid and gaseous or predominantly a which is called as dry state when the solid and liquid which is their predominantly then there is this phase is called as saturated state so here a typical three phase system is shown where soil solids.

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And you have got a and then water which is filled with the remaining portions so idealization if you idealize this three phase system then it is called gas or a liquid and solids.

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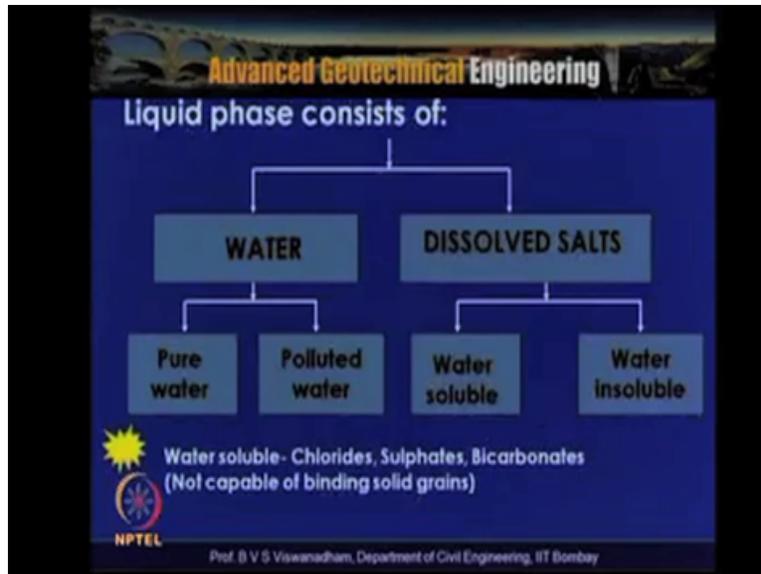
Solid phase consists of:

- Primary rock forming minerals (Size > 2 μ m, Poor Reactivity, Prone to disintegration)
- Clay minerals (Basic materials that form the soil mass, Size < 2 μ m, High Reactivity)
- Cementing material (Carbonates)
- Organic matter (High water absorption, Compressible, unstable)

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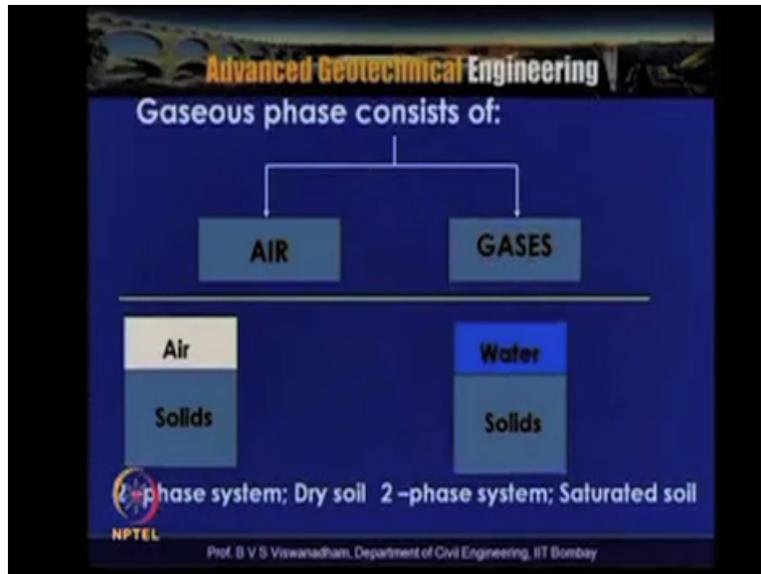
The solid phase consists of primary rock forming minerals such as greater than two micrometers and pore reactivity prone to disintegration so this is a basically a solid phase and clay minerals the basic material that form the soil mass size less than two micron micrometers and high reactivity and a cementing material this is the basically carbonates an organic matter high water absorption compressible and unstable in nature so solid phase which is actually there in the part of a phase system which is introduced in the previous slide this can be primary rock forming minerals and clay minerals cementing material and organic matter.

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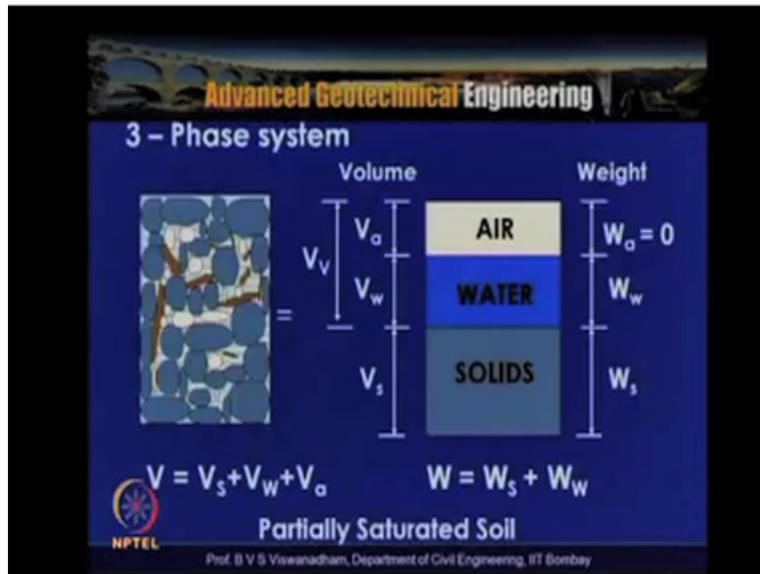
Liquid phase basically it consists of water are dissolved it is where we have pure water or polluted water and this is polluted water because of the levels of contamination which is actually introduced in the previous slides and the dissolved salts sometimes you have got water soluble and water insoluble and water soluble salts which are press were predominantly chloride sulfates and bicarbonates not capable of binding solid grains.

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And gaseous phase predominantly consists of air and gases and if only you have got air and solids which is called as a two-phase system dry soil and if you have got a two-phase system again with water and solids it is also it is called as a saturated soil so we have a dry soil saturated soil and partially saturated that is referred as three-phase soil system.

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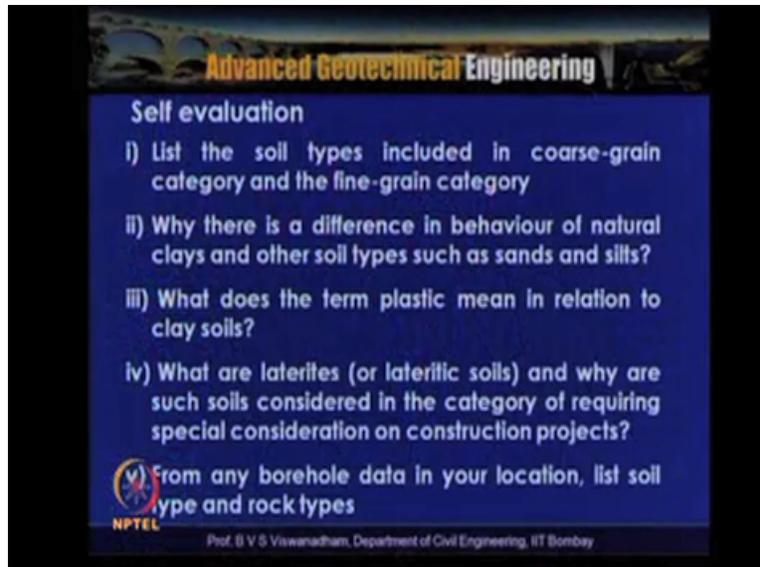


In the three-phase soil system in order to reduce relationship between volumetric ratios and weight ratios the soil which is actually here is idealized it has the three phase system is idealized as water and solids air water and solids on the left-hand side the volume is given here and the right-hand side weight is actually shown here so here W suffix sis called the weight of solids and here W is the weight of water and weight of a as zero but it actually has got volume.

Which is called as volume of the air volume of water volume of water plus volume of air is called volume of whites that means that in the three phase soil we have got volume of whites which is actually both air and water will be there if you have got a dry soil then you have got volume of air only if it is a saturated soil you have got volume of water only so here this solid reapportion volume is referred here as volume of solids so if you look into this w is nothing but weight of solids plus weight of water if suppose the weight of water zero.

In case of a dry soil then you have got weight of solids only and volume of this total volume of the soil bars is nothing but the volume of these solids and volume of the water and volume of the air so what total volume is nothing but volume of soil solids plus volume of whites so this is the case for the partially saturated soil so as a part of self evolution in this so in this lecture what we have tried to understand is that we have introduced ourselves to the different modules.

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Self evaluation

- i) List the soil types included in coarse-grain category and the fine-grain category
- ii) Why there is a difference in behaviour of natural clays and other soil types such as sands and silts?
- iii) What does the term plastic mean in relation to clay soils?
- iv) What are laterites (or lateritic soils) and why are such soils considered in the category of requiring special consideration on construction projects?

From any borehole data in your location, list soil type and rock types

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Which are actually going to be there in this particular advanced geotechnical engineering course and we also have discussed about the different ranges of geotechnical structures which are actually possible like we said that natural slopes or slopes embankment dams or foundations particularly building foundations on shallow foundations or deep foundations or Road embankments or some windmill foundations and offshore foundations like we have ranges of geotechnical structures all structures.

Which are actually they are predominantly the resting in or on the soil and the soil is actually is a major predominant material and if you if you see a typical foundation the foundation should transmit the loads the settlement should be minimum so that the safety can be ensured so all these geotechnical structures which are actually there should be understood such a way that they should not fail and ensure performance during their lifetime of the design so in this particular lecture you know.

What we have done is that we have actually discussed about the origin of the soil the origin of soil is predominantly basically from the rocks predominantly that rocks are igneous sedimentary metamorphic rocks and these rocks are basically when you are actually how different states of either metamorphism can takes place because the either source from igneous or sedimentary rocks.

And we also discussed that some types of sedimentary locks which are actually how some ingredients which are soluble within the which are present in the groundwater can actually

dissolve the rock and form sinkholes and which these are very popular in United Kingdom called as plastic stone sarcastic formations so as a self evolution in this I would like you to listen to the soil types included in coarse-grained category and fine grained category so if you if you come across any soil type kindly look into the type of soil and list the soil type whether it is a coarse-grained type or fine-grained type and why there is difference in behavior of natural place.

And other soil types such as sands and silts at this primitive stage if you can able to understand why there is difference in behavior of the natural place and other soil types every name can be if you can relate to what we discussed in this lecture and this answer will be able to answer and what does the term plastic means in relation to clay soils and what are late rites are late rite soils and why are such soils are considered in the category of required special consideration on construction projects and for any soil investigation project.

Any genetically engineering project or any projects engineering project you require to understand about the extent of the soil horizontally as well as vertically in such situation we do at a number of selected locations the both holes so any particular periphery many borehole data tested in your location are if you have come across any borehole data list the soil types and rock types so this will you know converse allow you to converse with the subject which we are going to cover in advance George Engle engineering course you.

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