

Unsaturated Soil Mechanics
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Week - 01
Lecture – 02
Phases of Unsaturated Soils-I

Hello everyone, we discussed prediction of phenomenon in the previous lectures, where we need to understand the physical laws, which govern the behavior of any material including soils. In that using this physical laws, we can derive the governing expressions for a given phenomena. And we provide additional constitutive relationships, which are purely related to the material.

These constitutive relationships are relationship between different state variables. Physical laws are also these mass conservation etcetera are also the dependent variables are state variables. So, we need to identify the state variables in a given phenomenon and we need to relate using constitutive relationships develop different constitutive relationships, so that we can predict the phenomenon well.

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FUNDAMENTAL PRINCIPLES

- Constitutive relationships
 - Constitutive equations express the interrelationships between different state variables. These equations for a given system are useful in the prediction of the physical phenomenon when qualitative understanding of the variables is available.
 - Ex.: Coulomb's law, c vs. σ' relation, Soil water characteristic curve, etc.
- State variables
 - The variables that represent the state of the system.
 - Ex.: void ratio, effective stress, water content, pore water pressure, pore air pressure, suction ($u_a - u_w$), etc.
- Material constants
 - These are the proportionality constants of the constitutive relationships. Material constants may vary from one state to another state and one material to another.
 - Ex.: Angle of internal friction, cohesion, coefficient of volume compressibility (m_v), viscosity of water, hydraulic conductivity, diffusion coefficient, air permeability, etc.

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Similarly, we can identify the material constants identification of material constant would help in understanding the phenomenon very well. And simulating the field conditions identification of material constants like coefficient of consolidation would

help in predicting the field consolidation settlements or field phenomenon using laboratory experiments.

So, as we understood the constitutive relationships express the interrelationship between different state variables, the constitutive relationships. Constitutive equations as we understood express the interrelationships between different state variables. These relationships for a given system are useful in the prediction of the physical phenomenon, when qualitative understanding of these variables is available. For example, Coulomb's law, compression relationship consolidation relationship, where void ratio versus effective stress is sort and soil water characteristic curve which will be introduced in due course of time, this relationship is for unsaturated soil and so on and so forth.

Similarly, the state variables they represent, the state of the system. For example, examples for state variables are void ratio, which defined the state of the soil effective stress water content. So, void ratio and effective stress define the state of soil in consolidation. Similarly, water content, pore water pressure, excess pore water pressure is a state variable in consolidation behavior, pore-air pressure and suction which is a $u_a - u_w$ - a difference between air pressure, pore-air pressure and pore water pressure, which is used unsaturated soil mechanics which we will discuss soon.

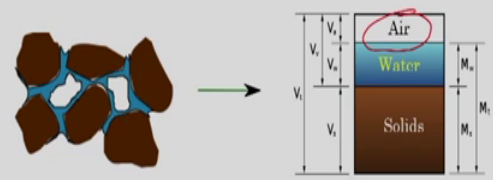
When it comes to the material constants, they are the proportionality constants of the constitutive relationships. Material constants may vary from one state to another state, and also one material to another material. Example the angle of internal friction and cohesion, these are the material constants in shear strength behavior of soils. Coefficients of volume compressibility are m_v suffix v , which is 1 over the bulk modulus of the soil which is also a material constant.

Viscosity of water, hydraulic conductivity, diffusion coefficient, air permeability etcetera, these are all the material constants. To understand the behavior of soils, these material constants are very helpful, and these information of these the knowledge of these material constants is required for predicting any phenomena.

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PHASES OF UNSATURATED SOILS

Multiphase System



- The air phase is generally bounded by the pore space not occupied by water.
- The matter within this pore space may be air, vapor, or combination of these two.

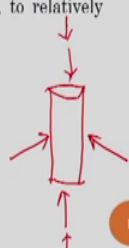
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If you consider unsaturated soils where we have three phase system pore-air, pore water and solids, the air phase is the phase, which is generally bounded by the pore space not occupied by water or liquid. The matter within this pore space maybe air, vapor or combination of these two.

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PHASES OF UNSATURATED SOILS...

- The liquid phase is generally bounded by the pore space not occupied by air.
- The matter within this pore space may be miscible/immiscible solutions (water, oil, non-aqueous phase liquids, etc.) or combination of two or more.
- The solid phase consists of the soil grains or particles and may range from relatively fine-grained materials such as silts and clays, to organic material, to relatively coarse-grained materials such as sand or gravel.
- However each of these phases is by no means pure.
 - Water vapor dissolves in pore air
 - Gases and solids dissolve in the pore water (e.g., dissolved air, dissolved salts)



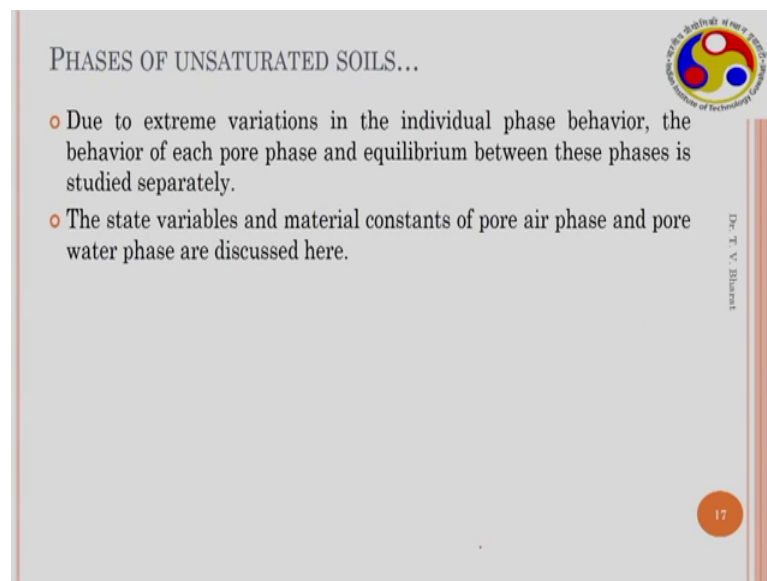
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Similarly, the liquid phase is generally bounded by the pore space not occupied by the air. The matter within this pore space may be miscible or immiscible solutions like water, oil, non-aqueous phase liquids etcetera or combination of two or more. The solid phase

consist of the soil grains are particles and may range from relatively fine grained materials such as silts and clays to organic material, to relatively coarse grained materials such as sand and gravel sand or gravel.

However, each of these phrases by no means pure. Because when you take soil sample in its partly saturated condition, when you apply pressure in triaxial setup; in triaxial setup if you have taken unsaturated sample and without saturation if you compress the sample, the pore-air which is available in the soil mass may get compressed, and the pore-air may get dissolved in pore water. Or, if due to the temperature changes fluctuations due to temperature fluctuations, even the pore water may get evaporated and pore water may exist as vapors in air. So, therefore, water vapor dissolves in pore-air; and gases and solids dissolve in pore waters. So, example dissolved air, dissolved salts.

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PHASES OF UNSATURATED SOILS...

- Due to extreme variations in the individual phase behavior, the behavior of each pore phase and equilibrium between these phases is studied separately.
- The state variables and material constants of pore air phase and pore water phase are discussed here.

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Due to extreme variations in individual phase behaviors, because the air phase if you consider, which is highly compressible; water phase, which is highly incompressible because for the geotechnical load applications, we consider the water pressure the compressibility of for geotechnical load applications, we consider water is incompressible. So, water is incompressible, air is highly compressible for the applied loads.

So, the behavior of the each pore phase and equilibrium between these phases is studied separately. Solids, soil solids are also relatively incompressible, but elastic compression

can be considered in the when load is applied on the soil. The state variables and material constants of pore-air phase and pore water phase separately are discussed here.

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PHASES OF UNSATURATED SOILS...

Air density

- It acts as a driving force for the pore-air flow and vapor phase transport in the soils
- It also plays an important role in the equilibrium between pore-air and free water or pore-water and the atmospheric air.
- Air density is defined as (from ideal gas law):

$$\rho_a = \frac{u_a M_a}{RT}$$

where u_a is the air pressure, M_a the molar mass, R the ideal gas constant, and T the temperature.

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Air density, density of air acts as a driving force for the pore-air floor and vapor phase transport in the soils. It also plays an important role in the equilibrium between pore-air and free water or pore water, and the atmosphere air. Air density, density is nothing but mass by volume, but then air density we cannot measure in this way. So, we use ideal gas law. And density of air is expressed as a u_a the atmospheric pressure times molar mass divided by $R T$. R is a gas constant and T is temperature in Kelvin.

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PHASES OF UNSATURATED SOILS...

o **Molar mass:**

- The molar mass of a substance is its mass divided by its amount of substance, which is a constant for any given substance and expressed in g/mol or $Kg/Kmol$.



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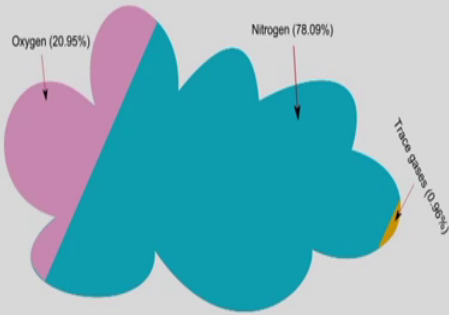
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So, molar mass is defined as the molar mass. The molar mass of a substance is its mass divided by its amount of substance, which is a constant for any given substance and expressed in gram per mol or kg per kilo mol.


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PHASES OF UNSATURATED SOILS...

Composition of Air



Gas	Percentage
Oxygen	20.95%
Nitrogen	78.09%
Trace gases	0.96%




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To compute the density of air, we need to understand the composition of air. When you consider the air, nitrogen is dominant, which is about 78 percent by volume and oxygen is 21 percent by volume, and trace gases there with less than 1 percent.

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PHASES OF UNSATURATED SOILS...



Components in Dry Air	Volume Ratio compared to Dry Air	Molar Mass - M (kg/kmol)	Molar Mass in Air (kg/kmol)
Oxygen	0.2095	32.00	6.704
Nitrogen	0.7809	28.02	21.88
Carbon Dioxide	0.0003	44.01	0.013
Hydrogen	0.0000005	2.02	0
Argon	0.00933	39.94	0.373
Neon	0.000018	20.18	0
Helium	0.000005	4.00	0
Krypton	0.000001	83.8	0
Xenon	0.09×10^{-6}	131.29	0
Total Molecular Mass of Air			28.97 kg/kmol

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So, individually if you see the oxygen the volume ratio compared to dry air is about 0.21 and nitrogen 0.781, carbon dioxide percentage is very very less 0.03, (Refer Time: 09:09), hydrogen very very less in significant amount, argon, neon, helium, krypton, xenon, all these different components available in dry air. If you consider molar mass of individual components of gas components, oxygen has 32, because it is O_2 16 times to there is 32 kg per kilo mol or gram per mol.

Nitrogen 28.02, carbon dioxide 44.01, likewise and if you consider the molar mass in air, this volume ratio is multiplied with molar mass, then you get molar mass in air, this is a volume fraction and this is a molar mass. So, this is a molar mass in air that is 6.704 contribution from oxygen, and 21.88 from nitrogen. And summation if 28.97 kg per kilo mol, this is the total molecular mass of air.

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PHASES OF UNSATURATED SOILS...

The density of air at 25°C:

$$\rho_a = \frac{u_a M_a}{RT} = \frac{(101.325 \text{ kPa})(28.97 \text{ kg/kmol})}{(8.314 \text{ J/mol}\cdot\text{K})(298 \text{ K})} = 1.185 \text{ kg/m}^3$$

$K = ^\circ\text{C} + 273.5$

$$\frac{101.325 \frac{\text{K}\cdot\text{N}}{\text{m}^2} \times 28.97 \frac{\text{kg}}{\text{kmol}}}{8.314 \frac{\text{N}\cdot\text{m}}{\text{mol}\cdot\text{K}} \times 298 \text{ K}}$$

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So, if you know the total mass of total molecular mass of air, you can compute the density of air using this particular relationship, where you have if you consider the atmospheric air pressure as 101.325 kilo Pascal, and molecular mass we just obtain that is 28.97 kg per kilo mol, and gas constant is 8.314 joule per mole Kelvin and temperature is 298 Kelvin. So, here 101.325 kilo Pascal kilo Newton per metre square times 28.97 kg per kilo mol divided by 8.314 joule can be expressed as Newton meter per mol Kelvin into 298 Kelvin.

So, Kelvin get cancelled. The kilo, kilo gets cancelled; mol gets cancelled. And you have kilo here and Newton should cancelled here. And you have kilo gram kg per meter meter cube that is a density of water, density of the units of density of air. So, density of air is just this is 101.325 times 28.97 divide by 8.314 into 298 that is 1.185 kg per meter cube. So, here the conversion for temperature from degree of degree Celsius to Kelvin, this is the way one can express.

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PHASES OF UNSATURATED SOILS...

○ Sensitivity of air density :

$$\frac{\Delta \rho_a}{\rho_a} = \frac{\Delta u_a}{u_a} - \frac{\Delta T}{T} \checkmark$$

$$s_a = \frac{u_a M}{RT} \checkmark$$

$$\Delta s_a = \frac{\Delta u_a M}{RT} - \frac{u_a M \Delta T}{RT^2}$$

$$\checkmark \frac{\Delta s_a}{s} = \frac{\Delta u_a}{u_a} - \frac{\Delta T}{T}$$

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If you see the sensitivity of air density, the air density changes with temperature and pressure. So, the density of air, which is expressed as u_a times molecular mass by $R T$ change in density is equal to it depends on both air pressure and temperature. Therefore, Δu_a divided into M divided by $R T$ minus $u_a M$ by $R T^2$ into ΔT . So, using u by v principle, then $\Delta \rho_a$ by ρ_a is nothing but Δu_a by u_a minus ΔT by T . So, this is the expression for understanding the sensitivity of sensitivity of air density with pressure and temperature.

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PHASES OF UNSATURATED SOILS...

Sensitivity of air density with pressure:

Pressure, u_o (kPa)	Density of air, ρ_a (kg/m ³)	Relative change (%)
80	0.935	-21.1
90	1.052	-11.2
101.325	1.185	0
110	1.286	+8.6

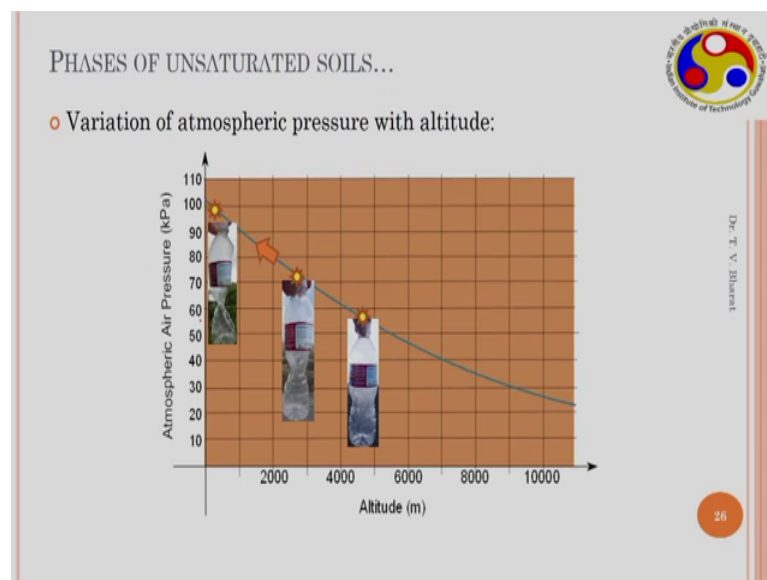
$$\frac{\Delta s_a}{s} = \frac{\Delta u_a}{u_a} = \frac{(80-101.325)}{101.325} \times 100$$

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This is the sensitivity of air density with pressure. When the pressure changes from standard value of 1.0, 1.0, 1.0, 101.325 kilo Pascal to different values, it may decrease or it may increase depending on the elevation from the mean sea level; when it decreases, the density of air decreases. So, the decrease can be directly estimated the delta rho a by rho can directly estimated by from this particular expression delta u by u a, where you do not need to estimate the rho a.

Here using this particle expression, directly the change can be understood. For example, this is change to 80 then 80 minus 101.325 divided by 101.325 times 100 should give you minus 21.1 percent. This is the relative change of density with change in the pressure.

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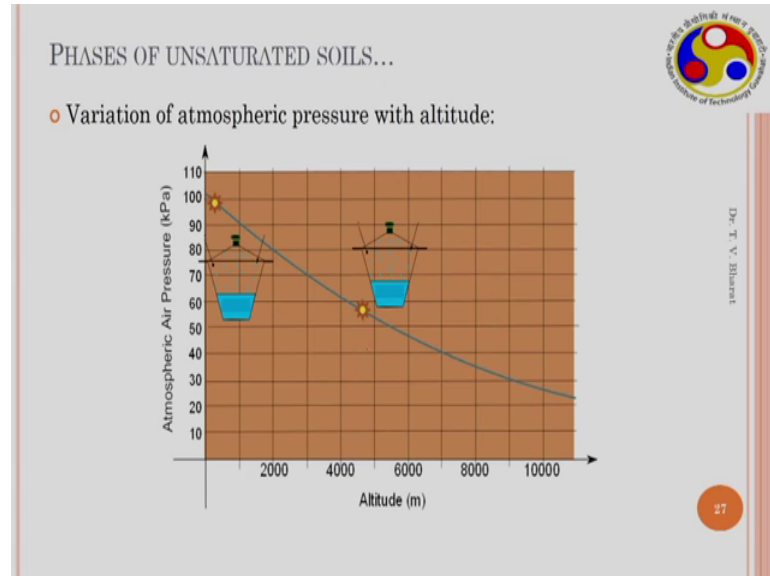


As all as we all know that the atmospheric pressure changes with altitude, when the altitude increases when you go up, when you go, when the altitude increases from the mean sea level the atmospheric pressure decreases. The decrease in the atmospheric pressure causes changes in the density of air as we observed from the earlier expression.

So, for example, if a if an empty water bottle, which is sealed well at an altitude of nearly 4500 meters above the mean sea level, where you have the pressure about 58 kilo Pascal, and brought to brought down to different elevations, altitudes, altitude of nearly about 2500 meters are nearly to the mean sea level, then the bottles get crushed, the empty bottle get crushed. Because the ambient pressure got increased relative to the pressure,

which is inside the bottle get crushed. This can be clearly witnessed, and due to change in the atmospheric pressure sorry this is change in the atmospheric pressure.

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Similarly, as the atmospheric pressure is smaller compared to the atmospheric pressure, atmospheric pressure at higher altitudes is smaller compared to the atmospheric pressure at mean sea level close to the sea levels. When you for cooking of lentils or any other grams, you require certain pressure to be maintained as the atmospheric pressure is lower, you require more gas consumption, you require more energy to cook the dal or lentils.

Because, the required pressure for lentils to be cooked is fixed. And therefore you need to give more energy to get the lentils cooked. So, the gas consumption at higher elevations is more compared to the lower elevations lower altitudes are close to the mean sea levels. So, therefore as the elevations change, as the atmospheric pressure change there is a change in the density of air, which can be seen. When you apply pressures on soils when there is a gradient of density that is experienced than there is flow of air that takes place.

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PHASES OF UNSATURATED SOILS...

Sensitivity of air density with temperature:

Temperature, T in °C	Temperature, T in K	Density of air, ρ_a (kg/m ³)	Relative change (%)
35	308.15	1.146	4.87
30	303.15	1.164	3.30
25	298.15	1.184	1.68
<u>20</u>	<u>293.15</u>	<u>1.204</u>	0.00
15	288.15	1.225	-1.74
10	283.15	1.247	-3.53
5	278.15	1.269	-5.39
0	273.15	1.292	-7.32
-5	268.15	1.316	-9.32
-10	263.15	1.341	-11.39
-15	258.15	1.367	-13.55
-20	253.15	1.394	-15.80

$$\frac{\Delta \rho_a}{\rho_a} = -\frac{\Delta T}{T}$$

$$= -\frac{(293.15 - 303.15)}{293.15} \times 100$$

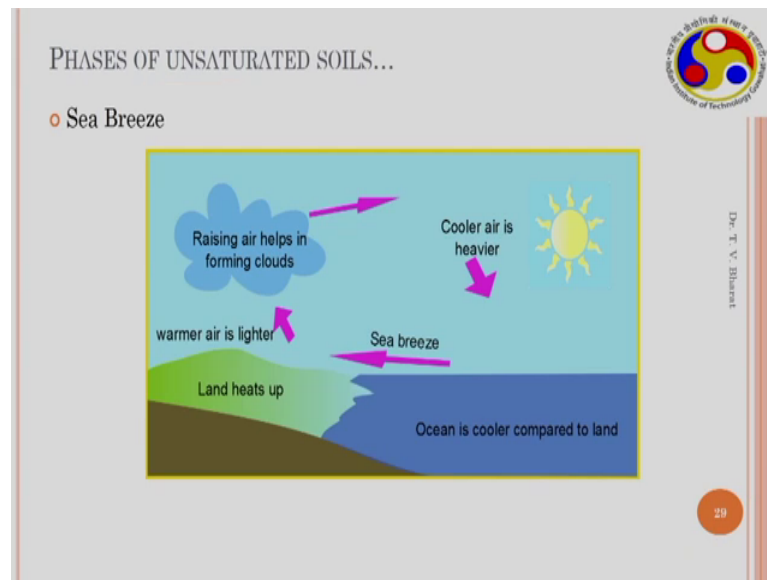
$$= +3.3\%$$

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Similarly, this is about sensitivity at sensitivity of air density with temperature. As we have seen the density of air changes with temperature in this particular manner, when air pressure is constant and the pressure is constant. So, the change in the temperature from at 20 degrees a standard temperature, the temperature is 293.15 Kelvin and the density of air is 1.204. And relative to this, when the temperature changes, how much relative change in density absorbed is seen in this particular column.

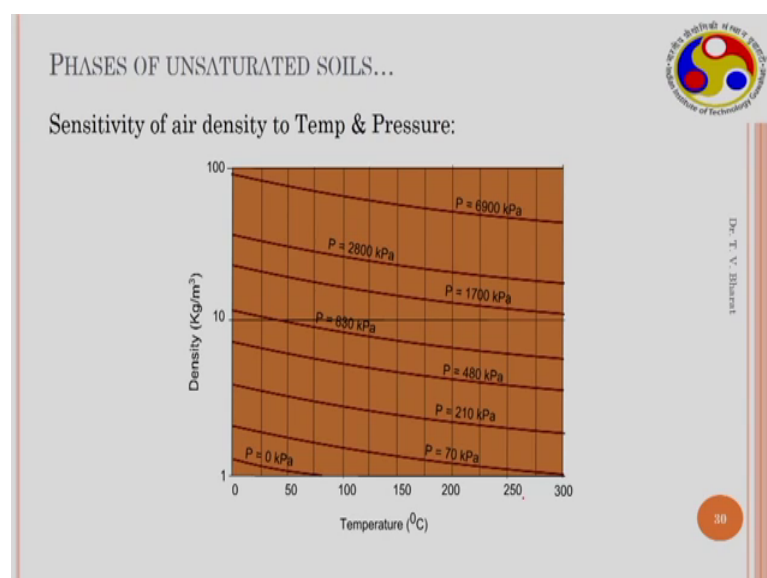
Here, the temperature should be substituted in Kelvin. So, if there is a change in temperature of temperature from 20 to 30, when there is a change in temperature from 293.15 to 303.15 standard temperature is this so which is plus 3.3 in percentage, this need to be multiplied with 100 to get in percentage. So, this is the change in density of air is a percentage change in density out of density of air due to temperature.

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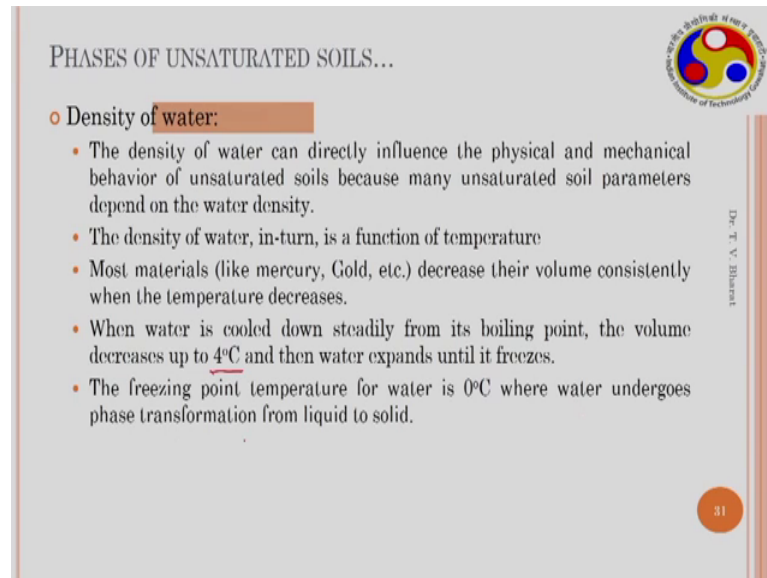
This is implication of sea breeze, which we often see on the seashore as the ocean is cooler compared to land. Because, water is a heat sink, therefore water is cooler compared to land. So, therefore there is a breeze the, when the air comes on to the land, which gets heated up quickly and density of air decreases which is lighter. So, therefore it raises and raising air helps in forming clouds, and this cooler air as this produces cooler air, and this cooler air is heavier, and then again it deposits. So, this is the cycle that follows, and you get a cooler air, when you are near the sea shore or water body in summer.

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So, this is in summary the density of air density with temperature and pressure. Here the pressure is represented as a gauge pressure. So, this is not absolute pressure this is a gauge pressure, so for a given pressure with change in the temperature this is how the density changes. And for very high pressures also it is mentioned here that may not be important in geotechnical practice.

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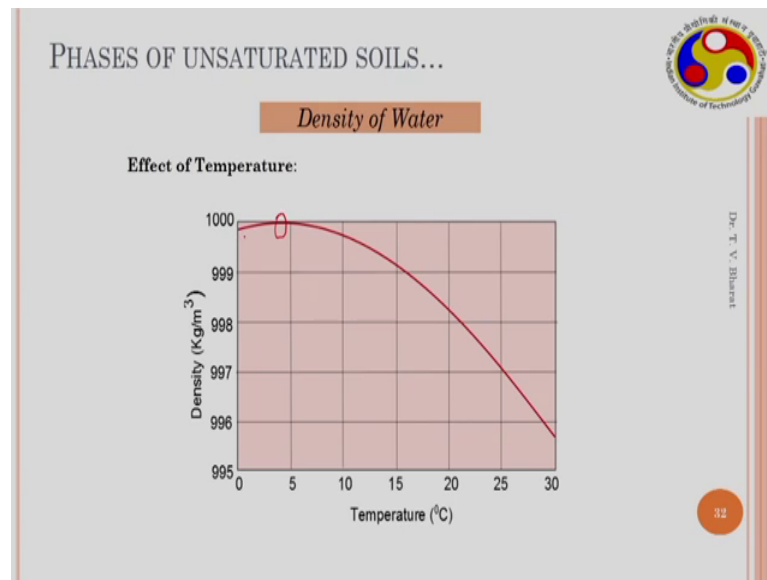
PHASES OF UNSATURATED SOILS...

- Density of water:
 - The density of water can directly influence the physical and mechanical behavior of unsaturated soils because many unsaturated soil parameters depend on the water density.
 - The density of water, in-turn, is a function of temperature
 - Most materials (like mercury, Gold, etc.) decrease their volume consistently when the temperature decreases.
 - When water is cooled down steadily from its boiling point, the volume decreases up to 4°C and then water expands until it freezes.
 - The freezing point temperature for water is 0°C where water undergoes phase transformation from liquid to solid.

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The next one is density of water. Water density can directly influence the physical and mechanical behavior of unsaturated soils because many unsaturated soil parameters depend on the water density. The density of water in turn is a function of temperature. Most materials like mercury, gold, etcetera decrease their volume consistently on the temperature decreases. When water is cool down steadily from its boiling point, the volume decreases up to 4 degrees 4 degree Celsius and then water expands until it freezes. The freezing point temperature of water is 0 degrees, where water undergoes phase transformation from liquid to solid.

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So, if you plot the density versus temperature, density of water versus temperature. As the temperature decreases the density increases, because volume decreases up to 4 degrees, but beyond that the density drops. So, here at 4 degrees, you see that the density is maximum for water. So, because of which here it is maximum, and of beyond that it decreases again. So, therefore when it when water changes its phase from when phase transformation occurs for water from water to solids that is ice, ice has lower density lesser density compared to the water. So, ice can float in water.

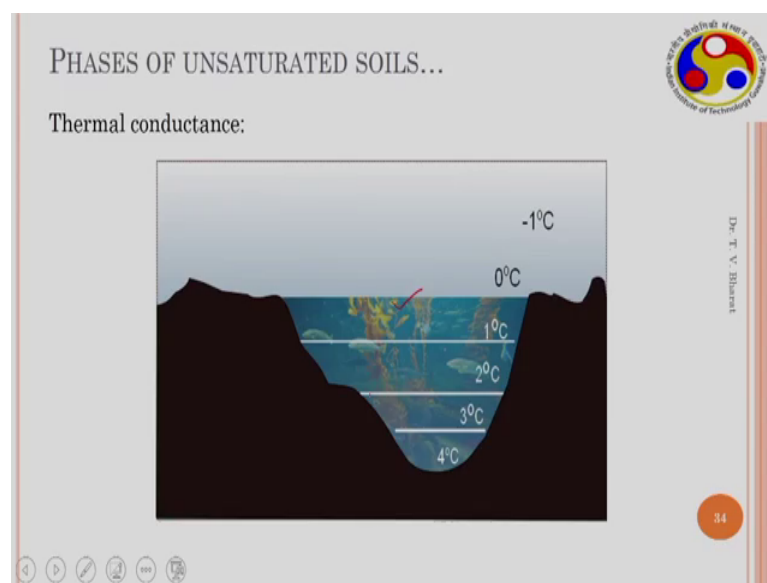
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- PHASES OF UNSATURATED SOILS...
- As ice starts to melt upon heating, some of the hydrogen bonds break, and water molecules can slide closer together when compared to its solid state, i.e. ice. The ice is about 10% less denser than cold water at 4°C.
 - The volume expansion of water below 4°C temperature is called *anomalous expansion of water*.
 - Such expansion causes bursting of frozen pipes and frostbites on human skin in the cold countries.
 - The ice (< 4°C) can float on water due to these consequences. The ice displaces more water volume than its weight.
 - Moreover, the conduction of heat is dependent on the density of the substance. A lighter material (i.e., less dense) conducts less heat than the heavier material/substance.
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As ice starts to melt upon heating; a reverse phenomena, if you are going from here to here; As ice starts to melt upon heating some of the hydrogen bonds break, and water molecules can slide closer close to closer together, when compared to its solid state it is ice. The ice is about 10 percent less denser than cold water at 4 degrees Celsius. So, the volume expansion of water below 4 degrees temperature is called anomalous expansion of water.

We all know this. Such expansion causes bursting of frozen pipes and frostbites on human skin in the cold countries. So, the ice, which is less than 4 degree Celsius, can float on water due to these consequences. The ice can displace more water volume than its weight. Moreover, the conduction of heat is dependent on the density of the substance a lighter material, which is a less dense, conducts less heat compared to the heavier material or substance that is dense substance.

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Because of which the aquatic life survives, because in cold countries, when cold places in cold places, when the waters freeze. It acts as a barrier thermal barrier, and it conducts thermal. It is a poor conductor it is a poor thermal conductor, because of which the waters inside maintain warmer temperatures, because of which the aquatic life survives. This is also has implications on geotechnical practice in cold countries, where thermal expansion of water etcetera cause bursting of pipes, and changes in the pore structure,

freezing of the volume expansion of pore water due to dropping of temperatures may affect the soil behavior.

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PHASES OF UNSATURATED SOILS...

Effect of pressure on water density:

- Water is incompressible
- Pressure influence is negligible
- Effect of electrochemical properties of clays

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SSA = 800 m²/g
CEC = 110 meq/100g

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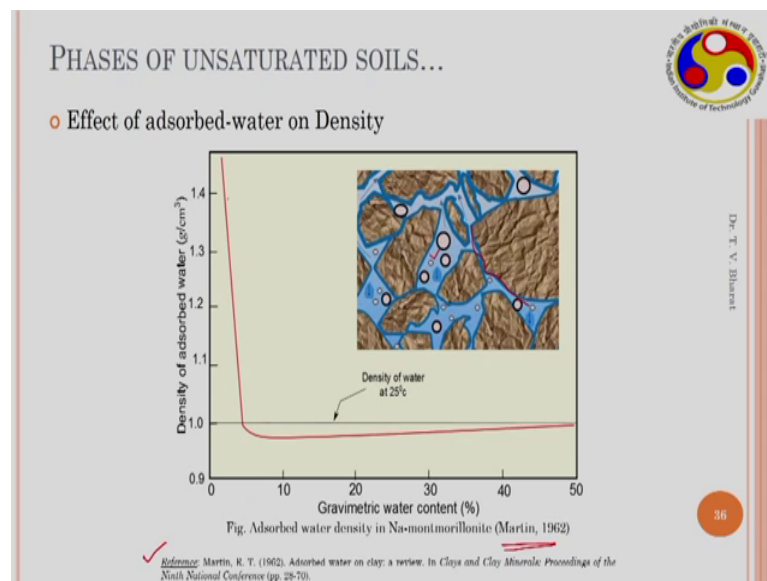
Here the effect of pressure on water density, if we consider as we have already discussed that water is relatively incompressible for the geotechnical loads we encounter. However, due to electro chemical properties of clays the density of water changes with saturation. As we have discussed earlier clay particles carry negative charge on its surface due to isomorphous substitution, because of which positive ions are exchangeable positive ions or exchangeable cations are held on the surface strongly exchangeable cations are held on the surface. When water is available due to when water is available due to the concentration gradient the ions this positive ions should diffuse away from the surface.

However, due to the strong electrical forces or due to the strong affinity towards the positive ions the clay surface try to hold ions at the surface. So, at equilibrium you have a distribution of these ions distribution of ions and forming diffuse double layer around a clay particle. This we have seen earlier. So, when the therefore if you consider expansive soils like bentonites bentonites, and black cotton soils, where you have high percentage of mod morganite mineral content, they have very high surface area. And they essentially have very high surface charge density that can be estimated from its surface area, and cation exchange capacity.

So, pure mod morganite may have a surface area of about 800 meter square per gram. And it can have a CEC of 110 mille equal and per 100 gram due to such a high value of surface area, and cation exchange capacity the surface charge density has a surface charge density is very high. It can have very high values of specific surface area and cation exchange capacity, because of which in air dry state self soil sample is left outside.

It can absorb water from the atmosphere, and can hold it around the particle surface. And forms a thin film around the particle surface, so which is the diffuse double layer atmospheric conditions the hygroscopic moisture content can be as high as 15 percent in highly expensive mod morganite rich clays and clay soils. So, it also depends on the ambient conditions, where at high humid conditions, it can absorb more water compared to dry conditions, and temperature also plays a role.

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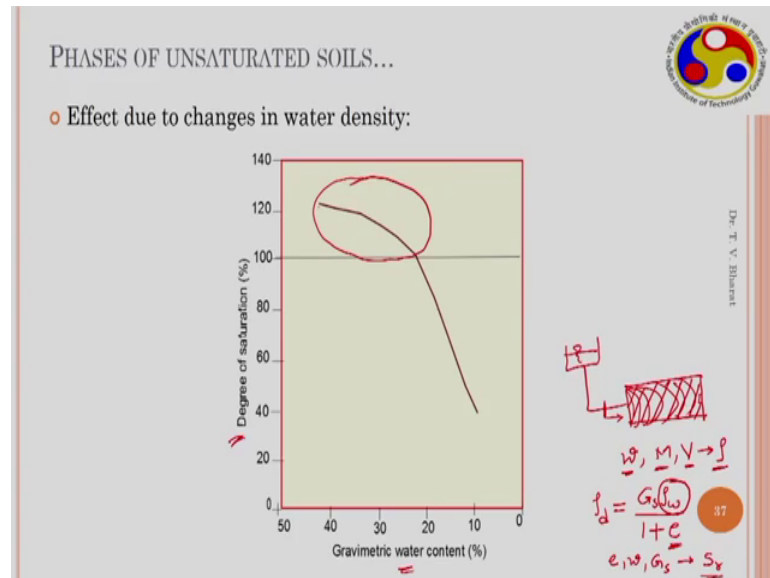


Therefore, in clays because of the strong bond due to because in clays, if you observe in clays, the thick layer here; thick line here; around the clay particles is a diffuse double layer, which is very strong strongly held around the particles. And this is free water light blue colour is light blue colour is free water; and thick blue is absorbed water; and which is due to formation of diffuse double layer. This white colour is air pockets.

Since, an unsaturated soil where you have three phase system, it is observed that from physical observations using X-ray diffraction techniques etcetera that as a gravimetric water content decreases. The density of water decreases slightly from one gram per

centimeter cube, but then when gravimetric water content is decreased beyond 10 percent. It is observed that the density increases even 7 to 1.4 gram percent meter cube, so that means the density of adsorbed water is very high, which can be as high as 1.4 gram per centimeter cube. This is from a review paper by Martin, the full reference is given here Adsorbed Water and Clay review in Clays and Clay minerals.

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This has strong implications on soil behavior this has some strong implications in soils, because when you estimate the degree of saturation for at different gravimetric water contents are in unsaturated states, you often see that the degree of saturation crosses 100 percent; So, this anomalies because the density of water is not considered into account.

For example, if you take column, compacted with soil, maybe at air dry straight, and then after that you connect to a reservoir, water reservoir. And allow the water to flow into you should have air went, so that air can escape when water goes in. So, then water when it diffuses into the soil, at after sometime you do not allow the water to go are let it completely get saturated. You can measure its weight with time, and then when the sample gets completely saturated, you can extrude the sample from the column, and measure its water content.

So, you know its mass, total mass and total volume, because volume of the column is known. So, inside diameter and then the length of the sample is known, so that you can estimate the volume, mass is known, and water content is known. From mass and

volume, you can estimate the density. And known the knowing the density and water content you can estimate the dry density from $\rho_d = \rho / (1 + w)$. Knowing the dry density, you can estimate void ratio using this expression, you can estimate void ratio.

And knowing the void ratio, and water content and G_s specific gravity, you can estimate degree of saturation. When you estimate in this process in when you estimate the degree of saturation in this process, when you plot degree of saturation versus gravimetric water content, nearly is saturated state you see that the degree of saturation estimated is more than 100 percent in highly expensive clays line bentonites. So, this is because unless until you adjust the ρ_w to higher values, you will not get degree of saturation to 100 percent. So, this can be clearly seen when you experimentally estimate a degree of when you experimentally measure the water content, and estimate the degree of saturation.

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PHASES OF UNSATURATED SOILS...

Viscosity of Air and Water

- Viscosity is defined as the ability of fluid to deform under shear stresses
- Viscosity of soil pore air and pore water have a direct bearing on the hydraulic conductivity
- An important material constant for analyzing flow problems

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So, after discussing the state variable such as the density of water and density of air, let us discuss some material constant such as viscosity of air and viscosity of water. Viscosity is defined as the ability of fluid to deform under shear stresses; Viscosity of soil pore-air and pore water have a direct bearing on the hydraulic conductivity. And important viscosity is an important material constant for analyzing the flow problems.

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PHASES OF UNSATURATED SOILS...

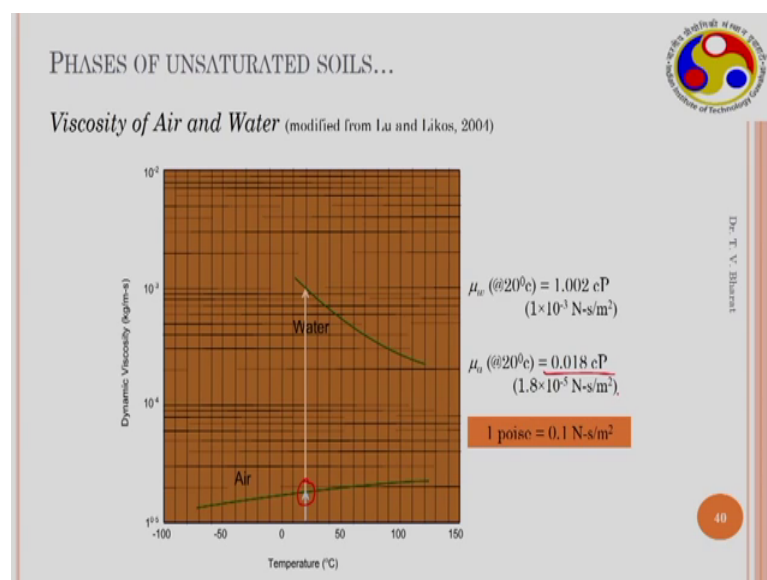
- Viscosity definitions in fluid mechanics:
 - dynamic viscosity (μ)
 - kinematic viscosity (ν)
- Dynamic or absolute viscosity ($\text{N}\cdot\text{s}/\text{m}^2$ or centi-Poise) expresses resistance to shearing flows of the fluid.
- Kinematic viscosity is expressed as the ratio of dynamic viscosity to the density of the fluid, which is used in analyzing Reynolds number.

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Viscosity definitions in fluid mechanics, you see that there is one dynamic viscosity and kinematic. So, dynamic or absolute viscosity, which has units of Newton's second per meter square or centi-Poise expresses resistance to shearing flows of the fluid. Kinematic viscosity is expressed as the ratio of dynamic viscosity to the density of fluid, which is used in analyzing the Reynolds number.

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So, if you plot the dynamic viscosity of both air and water with temperature, an interesting observation is that the water, viscosity decreases with increase in temperature.

But, air viscosity increases with increase in temperature. At standard temperature 20 degrees, the air viscosity is 0.018 centi-Poise or 1.8×10^{-5} Newton second per meter square. Because 1 poise is equal to 0.1 Newton second per meter square there is a conversion. So, the at the same temperature, the viscosity of water dynamic viscosity of water is 1 nearly 1 centi-Poise are 1×10^{-3} Newton second per meter square.

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PHASES OF UNSATURATED SOILS...

- It is interesting to note that the dynamic viscosity of air increases with temperature contrary to the water where the viscosity decreases.
- Increase in air temperature increases the air viscosity because the gas molecules get additional energy and collide more often. This increases the momentum transfer between stationary and moving molecules which is what causes the air viscosity.
- Water viscosity, in contrast, decreases with the temperature.
- Warm water is useful for washing clothes as the low viscous water will have more ability to penetrate into the smaller pores of the cloth and remove the dirt. The use of detergents would enhance the dirt removal process.
- The flow characteristics of water through the soils will also be improved with the low viscosity as the conductivity of the water increases. Therefore, the viscosity has a direct bearing on the flow behavior.

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It is interesting to note that the dynamic viscosity of air increases with temperature contrary to the water where the viscosity decreases. Increase in air temperature, increases the air viscosity because the gas molecules get additional energy and collide more often. This increases the momentum transfer between stationary and moving molecules which is what causes the air viscosity. Water viscosity in contrast decreases with temperature.

Warm water is useful, therefore for washing clothes has the lowest viscous water will have more ability to penetrate into the small pores of the cloth and remove the dirt. The use of detergents would enhance the dirt removal process. The flow characteristics of water through the soils will also be improved with the low viscosity as the conductivity of the water increases. Therefore, the viscosity has a direct bearing on the flow behavior.

Thank you.