Rock Mechanics and Tunneling
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Lecture 12
Topic - Introduction, physical properties

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Hello everyone, I welcome all of you to the first lecture of module 3. So, in this module, we will discuss the Physico-Mechanical Properties of Rock, so let us see what we will learn today.

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So, what are the different physico-mechanical properties, important properties that we should know that we will discuss, and then we will start in detail about the physical properties of rock?

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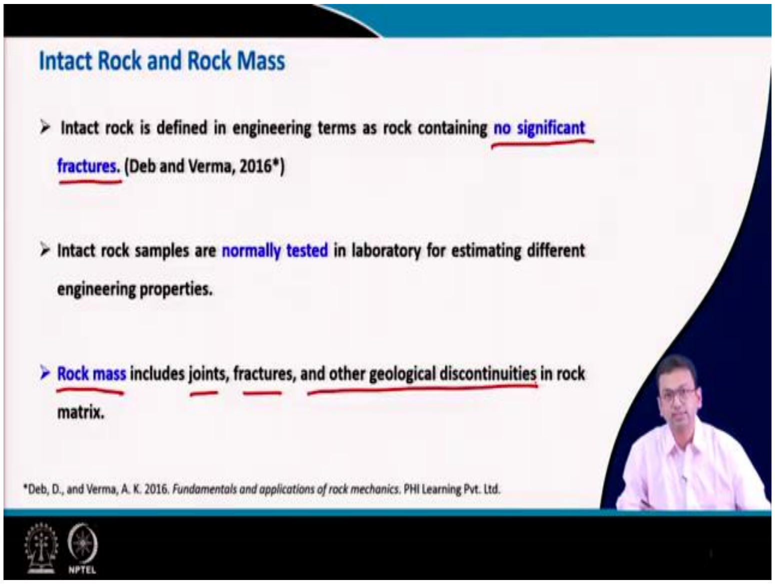

So, before discussing the physico-mechanical properties, I think let us become a little bit clear about these two terms, you must have noticed, or in the future, you will notice that we often tell these two terms, intact rock and rock mass. So, what is intact rock? Intact rock is defined in engineering terms as rock containing no significant fracture.

So, no significant fractures, that is very important. However, if we look at it on a small scale, then obviously in intact rock also is composed of small grains, but if we overall see, what we can say intact rock is defined in engineering terms as rock containing no significant fractures, so significant fracture that is important.

These intact rock samples are generally tested in the laboratory to estimate different engineering properties. So, for laboratory testing, we primarily use these intact rock samples. However, what is rock mass? That is very important. I told you earlier also, but it is written here in a better way.

So, rock mass includes joints, fractures, and other geological discontinuities in the rock matrix. So, when these joints, fractures, and other discontinuities, as we have seen earlier like bedding plane, fault, all these things will present in that matrix, then we call it the rock mass.

So, rock mass includes joints, fractures, and other geological discontinuities in the rock matrix. So, these two terms are important, intact rock and rock mass, because we will use these two terms in our future classes again and again.

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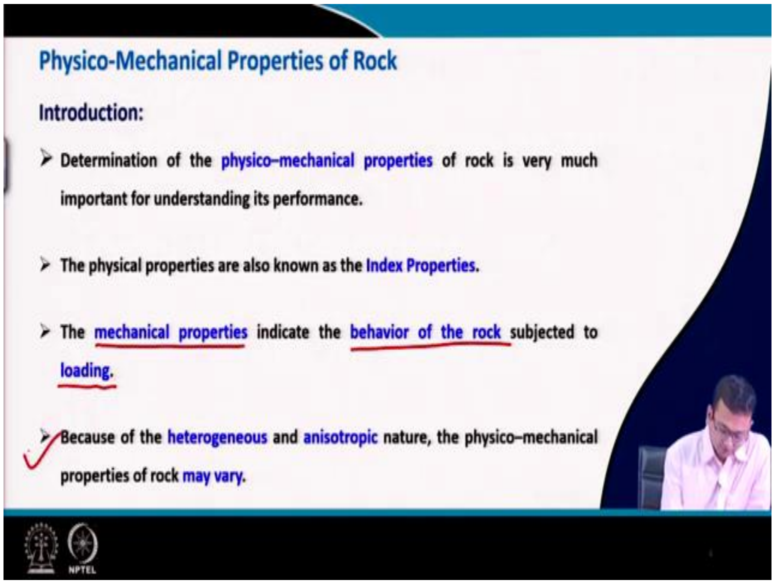

Now, again let us come back to the main topic of our discussion on the physico-mechanical properties of rock. Determining the physico-mechanical properties of rock is very important for understanding its performance. So, if we know about the physico-mechanical properties, we will be able to get some idea about how it will perform under different loading conditions.

These physical properties are also known as index properties, and in soil mechanics, you must have learned about the index properties, but here from the perspective of rock, we will also discuss this in detail. Then mechanical properties indicate the behavior of rock subjected to loading.

So, the behavior of the mechanical properties of rock indicates the behavior of rock subjected to loading. Due to the heterogeneous and anisotropic nature of the rock, these physico-mechanical properties of rock, even for the same geological formation, may vary significantly from point to point. So that is one of the crucial things that we have to keep in our mind, and that is why not only the laboratory test we must perform the field test to get a complete idea about the physico-mechanical properties of rock.

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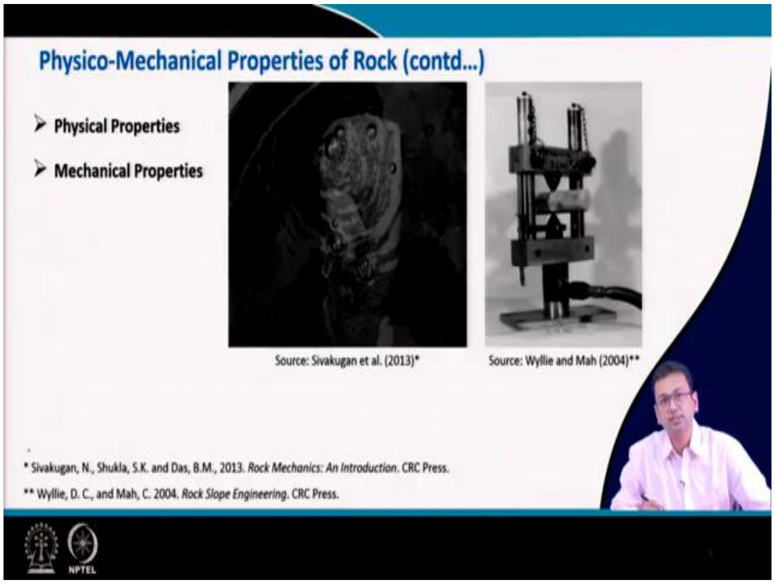

Now, we will discuss physical properties first and then the mechanical properties. So, let us see the different physical properties we should learn.

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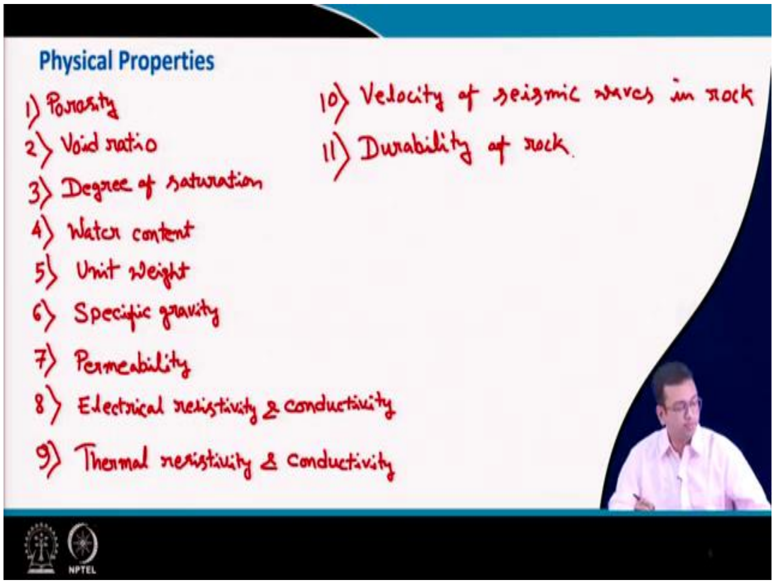

So, I can write down the name of some of the physical properties, such as porosity. We will discuss porosity. We will also discuss the void ratio, and then we will discuss the degree of saturation. Then we will also discuss the water content. We should discuss the different types of unit weights.

Then the specific gravity is also one of the important terms. Then we should learn about permeability also. Also, with the help of different electrical properties like electrical resistivity and electrical conductivity, we can get a good idea about the properties of the rock mass.

Similar to electrical resistivity and conductivity, thermal resistivity and conductivity are other things. These thermal properties are also very important based on that also we can get some good idea about the rock mask with which you have to deal.

We should also discuss another thing about which we have some idea: the velocity of seismic waves in rock. So, in our previous module, we have discussed geophysical testing, and from there, we could get the idea of the seismic waves. With the help of that, we can perform geophysical testing, which can be very helpful in exploring different useful information. So, that is why this is also one of the important physical properties.

So, the velocity of seismic waves in rock. Another important property is the durability of rock. These are very important properties listed here, which we should discuss. So, other than these physical properties, another thing is the mechanical properties.

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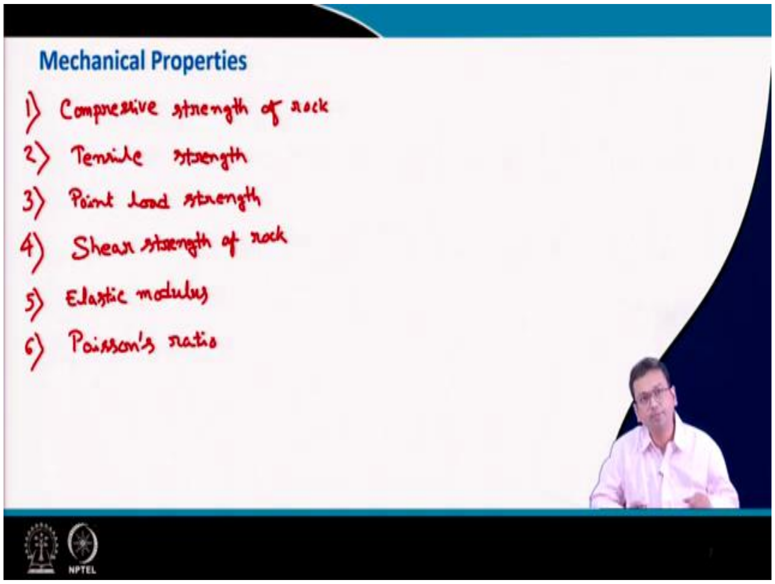

So, under mechanical properties, we will learn the compressive strength of rock. As we know, rock is good in taking compression but not good in tension. So, we should have a good idea about the compressive strength of rock. So, other than that, we should obviously learn about tensile strength.

Then we will learn the point load strength, and we should have a good idea about the shear strength properties of rock. So, we will learn the shear strength of the rock in detail. Other than that, we should have a good idea about the elastic modulus and Poisson's ratio of rock because they are also essential. So, elastic modulus and Poisson's ratio. So, these are some of the important mechanical properties we will definitely discuss in this module.

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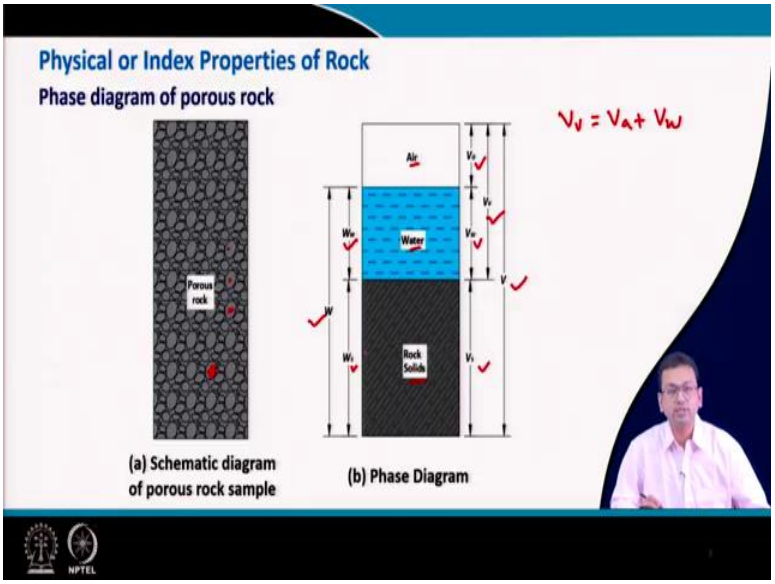

We will first discuss porosity, void ratio, all those things. So let us first discuss this phase diagram of porous rock. So, if we consider this is the porous rock. So, these are the solid rock particles. Voids are there in between these particles. In voids, water can be there, and air can be there.

Now, this schematic diagram of the porous rock sample can be represented with the help of a phase diagram. So, let us see this. So, we can see there are three phases, air, water, and rock solids. So, there are three phases, i.e., solid, liquid, and gas. Hence, it is known as the three-phase diagram.

Now, V is the total volume of the sample. V_a is the volume of air, then V_w is the volume of water. The volume of voids (V_v) = V_a + V_w. So, V_v is nothing but V_a + V_w, i.e., the volume of voids; likewise, V_s is the volume of rock solids.

Similarly, W is the total weight of the rock sample. Here we are neglecting W_a, which means the weight of air because that will be negligible compared to the weight of water and the rock solids. So, the weight of air is neglected. So, the total weight (W) = the weight of water (W_w) + the weight of rock solids (W_s). It is the three-phase diagram where air, water, and rock solids are present.

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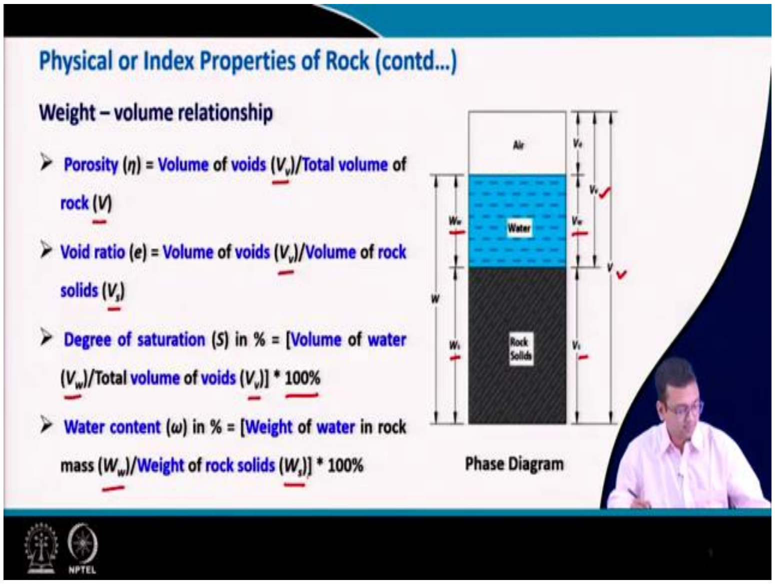

Now, with the help of this diagram, we can define different properties, such as porosity. Now, porosity (η) is defined as the ratio of the volume of voids (V_v) to the total volume of rock (V). So $\frac{V_v}{V}$ is the porosity of the rock.

Then related to this, another property is the void ratio. What is the void ratio? It is the ratio of the volume of voids (V_v) to the volume of rock solids (V_s), i.e., $\frac{V_v}{V_s}$. Then the degree of saturation is the ratio of the volume of water (V_w) to the total volume of voids (V_v). As we know, $V_v = V_a + V_w$. The degree of saturation is the volume of water (V_w)/the total volume of void (V_v), i.e., $\frac{V_w}{V_v}$. It is generally presented in %, so $\times 100\%$.

Next is water content. The water content (ω) is also a fundamental property. It is presented in terms of weight. It is the ratio of the weight of water (W_w) to the weight of the solids (W_s), i.e., $\frac{W_w}{W_s}$.

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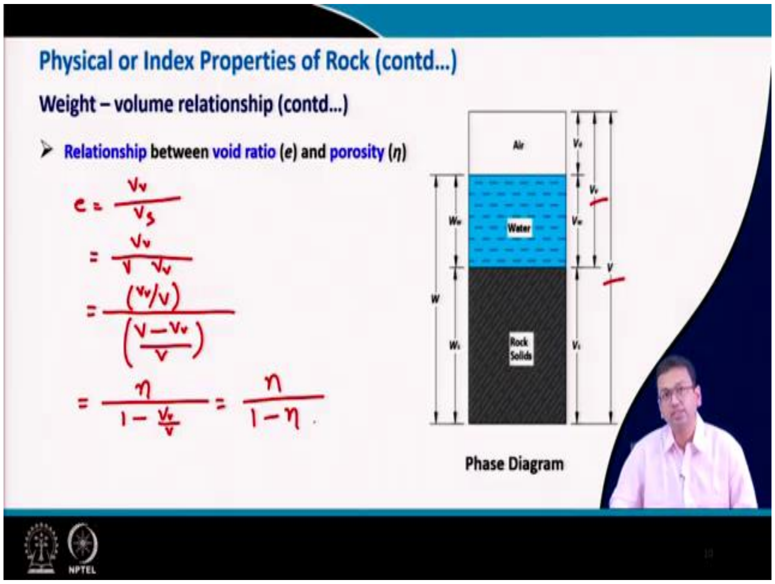

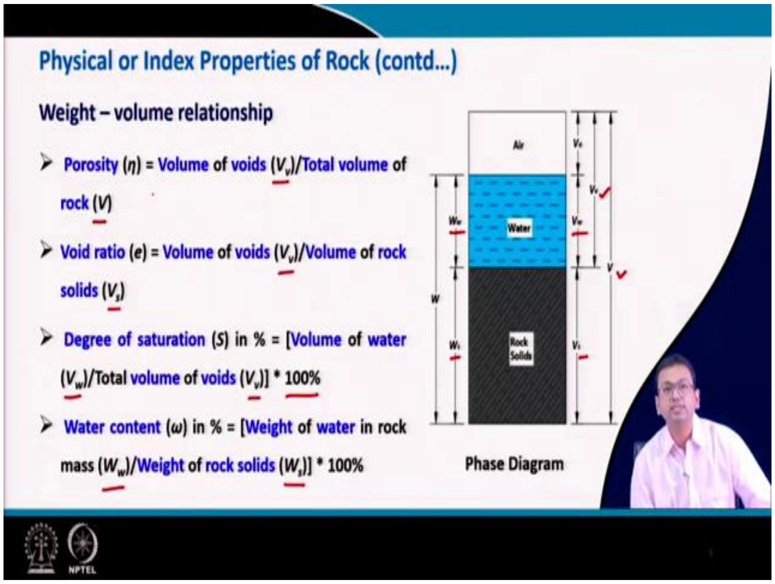

Now, we will see a few more important things also. However, let us see the relationship between void ratio and porosity. If one parameter is known, the other one can be easily evaluated. So, let us see what the relationship between void ratio and porosity is.

So, let us keep this diagram beside and try to derive an expression between void ratio (e) and porosity (η). So, we know void ratio (e) is $\frac{V_v}{V_s}$. Now, our objective is to find a relationship between void ratio and porosity.

So, the void ratio (e) can be written as $\frac{V_v}{V_s}$. Now, V_s can be written as total volume (V) – Volume of voids (V_v). Now, what will you get if we divide both the numerator and denominator with the total volume (V)? So, $\frac{\frac{V_V}{V}}{\frac{V - V_v}{V}}$. Now, what is this $\frac{V_v}{V}$?

So, $\frac{V_v}{V}$ is equal to the porosity, and if we simplify this one, it will give $\left(1 - \frac{V_v}{V}\right)$. Again, $\frac{V_v}{V}$ is the porosity. So, this is (1 – porosity). Hence, $e = \frac{\eta}{1-\eta}$. So, this is the relationship between void ratio and porosity. Similarly, we can have another relationship between porosity and void ratio. Here, we have represented the void ratio in terms of porosity. Now, we can also present porosity in terms of void ratio.

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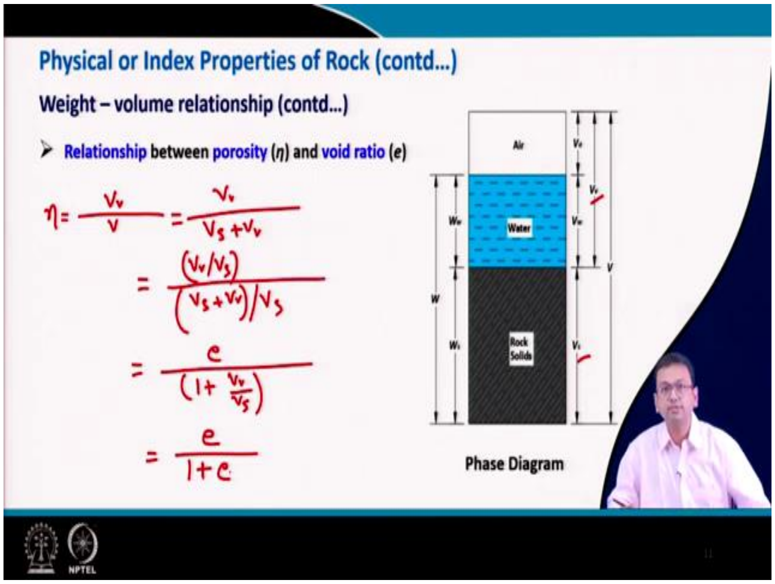

As we already know that $\eta = \frac{V_v}{V}$. The total volume (V) can be represented as $V_s + V_v$. So, $V = V_s + V_v$. Now, if we divide both the numerator and denominator with V_s, what we should get let us see.

So, in the numerator, it is $\frac{V_v}{V_s}$, and in the denominator, it is $\frac{V_v + V_s}{V_v}$. If we simplify, $\frac{V_v}{V_s}$ will represent the void ratio (e). So we can write it as a void ratio, and in the denominator, it is $1+\frac{V_v}{V_s}$. $\frac{V_v}{V_s}$ is the void ratio. So, the porosity (η) = $\frac{e}{1+e}$. Thus, if we know the void ratio (e), we can simply evaluate the porosity (η).

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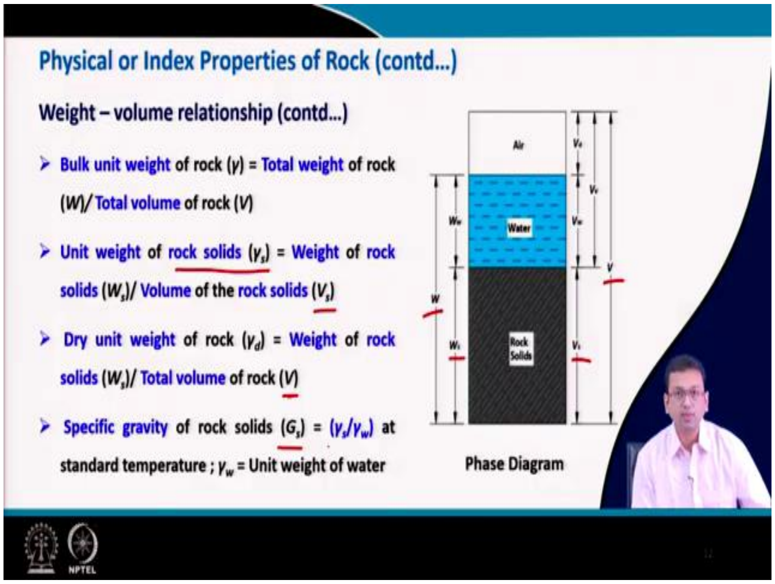

Now, let us proceed further. Let us see a few more important relationships like the weight volume relationship. and some of the important definitions of different other properties like the bulk unit weight of the rock (γ), so what is that? That is the total weight of rock (W) divided by the total volume of rock (V). The bulk unit weight of the rock, $\gamma = \frac{W}{V}$.

Now, we will see another essential term, i.e., unit weight of rock solids (γ_s). So, in that case, what do we have to consider? The weight of rock solids (W_s) is divided by the volume of rock solids (V_s). So, both weight and volume are with respect to the rock solids. The unit weight of rock solids, $\gamma_s = \frac{W_s}{V_s}$.

Another important term is the dry unit weight of the rock (γ_d). It is different from the unit weight of the rock solids (γ_s). So, what is the difference? The dry unit weight of rock (γ_d) is equal to the weight of rock solids (W_s) divided by the total volume of rock (V). In the case of dry unit weight (γ_d), the denominator is the total volume (V), whereas, for the unit of rock weight of rock solids (γ_s), the denominator is the volume of rock solids (V_s). For the dry unit weight of the rock, it is the total volume (V). So, the dry unit weight of the rock, $\gamma_d = \frac{W_s}{V}$.

We all know about specific gravity. The specific gravity of rock solids can be presented with G_s. It is the ratio of the unit weight of rock solids (γ_s) to the unit weight of water (γ_w). It is at a standard temperature. We know that specific gravity is always presented at a particular temperature. So, the specific gravity of rock solids (G_s) = $\frac{\gamma_s}{\gamma_w}$.

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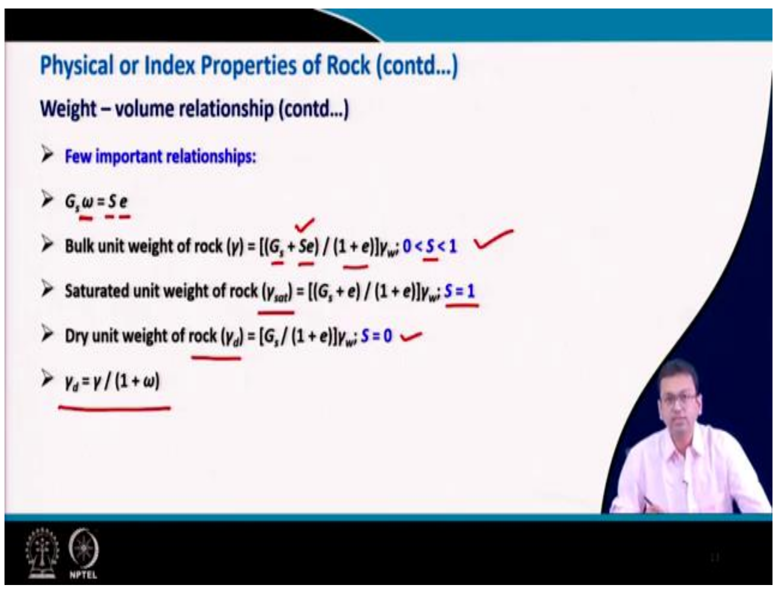

Now, let us see a few other important weight-volume relationships like, $G_s \omega = Se$. Here, ω represents the moisture content. So, the specific gravity of rock solids (G_s) $\times$ the moisture content (ω) = the degree of saturation (S) $\times$ the void ratio (e).

So, the following important expression or the weight-volume relationship is bulk unit weight of rock (γ) can be represented as $\left(\frac{G_s + Se}{1 + e}\right) \times \gamma_w$. Here, the degree of saturation varies from 0 to 1, i.e., 0% to 100%. S is represented not in percent in the expression, so it is presented in decimal. It varies from 0 to 1.

When S = 1, it represents 100% saturation. Thus, we will get the saturated unit weight of rock (γ_{sat}). So, in this equation $\gamma = \left(\frac{G_s + Se}{1+e}\right) \times \gamma_w$, if we place S = 1, then γ will become the γ_{sat}. The expression for saturated unit weight will be $\gamma_{sat} = \left(\frac{G_s + e}{1+e}\right) \times \gamma_w$

What do we have to do for the dry unit weight (γ_d)? We have to consider no saturation for dry unit weight, i.e., S = 0. So, if we make S = 0 in the equation $\gamma = \left(\frac{G_s + Se}{1+e}\right) \times \gamma_w$, the Se term vanishes. The dry unit weight of rock (γ_d) = $\frac{G_s \times \gamma_w}{1+e}$.

Now, this one is the essential expression, i.e., the dry unit weight of the rock (γ_d) = bulk unit weight of rock (γ_d) divided by [1 + moisture content (ω)]. So, now let us try to derive this expression from the three-phase diagram.

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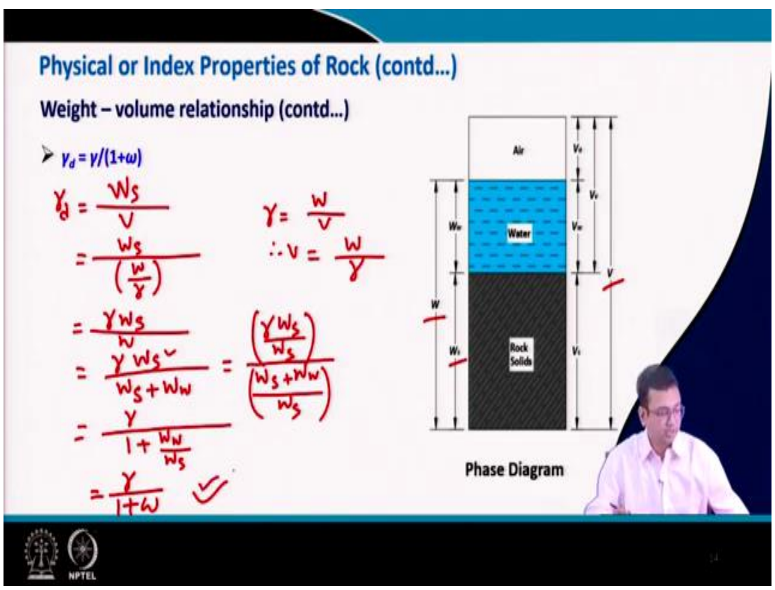

As we know that γ_d is equal the dry unit weight of the rock, i.e., $\frac{W_s}{V}$. Now, the V can be represented as $\frac{W}{\gamma}$. Since the bulk unit weight, $\gamma = \frac{W}{V}$, therefore, $V = \frac{W}{\gamma}$.

So, we will write it over here $\frac{W}{\gamma}$. Now, let us take this γ at the numerator. Then we will get $\gamma_d = \frac{\gamma W_s}{W}$. Now, what is W? It is the summation of W_w and W_s. So, we can write $\gamma_d = \frac{\gamma W_s}{W_s + W_w}$. In the denominator, it is the weight of rock solids (W_s) plus the weight of water (W_w) as we are neglecting the weight of air.

If we divide both numerator and denominator by Ws, we will get $\gamma_d = \frac{\frac{\gamma W_s}{W_s}}{\frac{W_s + W_w}{W_s}}$. W_s will get canceled in the numerator, and in the denominator, it will be $1 + \frac{W_w}{W_s}$. Now, $\frac{W_w}{W_s}$ is the moisture content (ω). Thus, the dry unit of the rock can be expressed as $\gamma_d = \frac{\gamma}{1+\omega}$.

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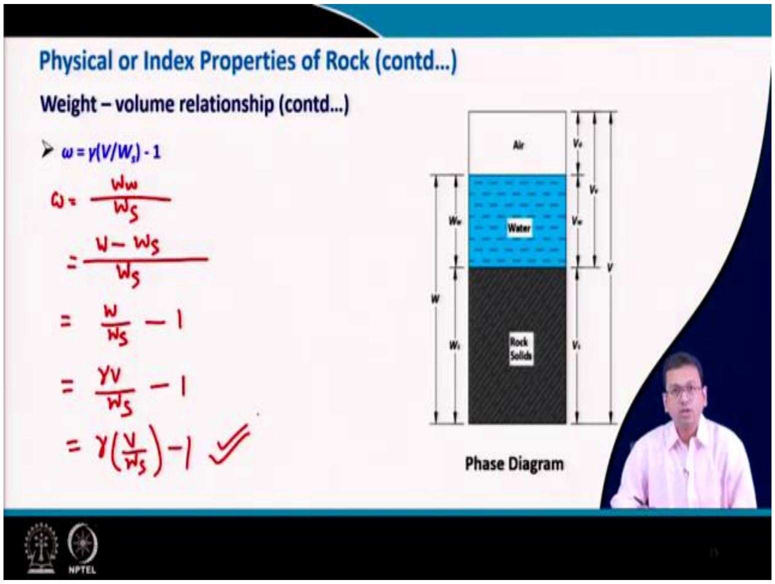

Similarly, we can derive another expression. The moisture content, $\omega = \gamma \frac{V}{W_s} - 1$. So, how to do that? We will again look at the three-phase diagram. So, we know that moisture content (ω) = $\frac{W_w}{W_s}$. Now, W_w can be written as $W - W_s$, and it is W_s in the denominator. Now, what can we do?

We can simplify it. So, $\omega = \frac{W}{W_s} - 1$. Now, W is equal to $\gamma \times V$. So, we can write $\omega = \frac{\gamma \times V}{W_s} - 1$ or, $\omega = \gamma\left(\frac{V}{W_s}\right) - 1$. So, this is proved.

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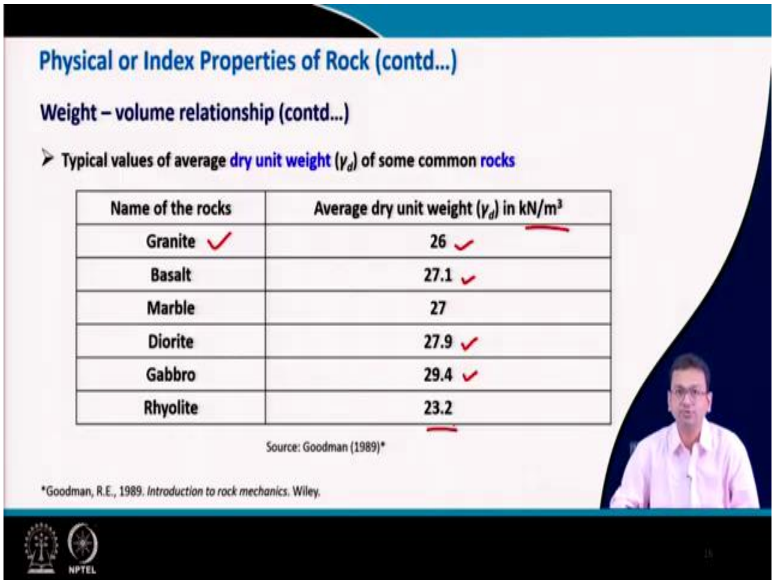

Now, we will look into some of the typical average dry unit weight (γ_d) values of some of the common rocks from this table. So, these all are in kN/m^3. The average dry unit weight of the Granite sample is around 26 kN/m^3. It is a typical value. The average dry unit weight may differ depending on the mineralogical composition, how closely they are packed, grain size, and grain shape. However, the typical value is around 26 kN/m^3.

So, we will generally not get a Granite rock sample having a dry unit weight of 20 kN/m^3. It will be around 26 kN/m^3. Similarly, Basalt has a slightly higher unit weight, i.e., 27.1. Now, we can see that the average dry unit weight of the Marble and Basalt are almost similar, i.e., 27. However, we can see that Diorite has a relatively little higher average dry unit weight, i.e., 27.9.

Nevertheless, what we can notice over here is that the dry unit of Gabbro is 29.4. It is relatively high compared to others, whereas the dry unit weight of Rhyolite is quite less (23.2 kN/m3) than Granite or Gabbro. So, these are just some of the representative values.

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So, thank you. So, today we have learned mainly the physical properties of rock. We will continue with the same physical properties of rock in our next lecture. Thank you.