Underground Space Technology
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Module No # 01
Lecture No # 01
Basics of Rock engineering: Introduction, Spherical representation, Physical properties of Intact Rocks

Hello everyone, let us start our discussion on this subject, that is underground space technology. So, this is the first lecture in which we will be discussing about some of the basics of rock engineering. So, what I will do is in the beginning, I will tell you what all are the topics that we are going to discuss in this subject followed by some of the reference material, and then we will have some discussion on the basics of rock engineering.

Including introduction, spherical representation, and physical properties of intact rocks so to start with let us discuss that what all are the topics which will be covered in this course.

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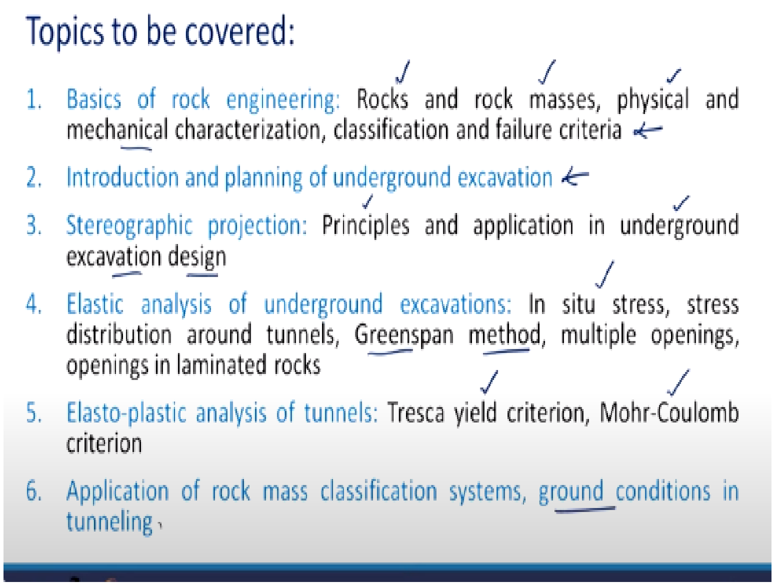

So, the first one is that we will take up basics of rock engineering this will include the description with respect to rocks and rock masses, their physical and mechanical characterization. Along with the classification and the failure criteria which are applicable to the materials like rocks and rock masses. Then we will discuss about the planning of underground excavation that what all are the criteria that one needs to keep in mind while going for planning of any kind of underground excavation whether it is tunnel cavern or things like that.

Then we will learn some aspects related to stereographic projection method, we will learn about its principle and the application in the underground excavation design. This will be followed by the elastic analysis of underground excavations, and in this one first we will learn about the in-situ stresses. Then we will also see that how the stress distribution around the tunnels can be obtained, this first we will start with the circular tunnels and then we will go to the different shapes of the tunnels.

For example, elliptical, oval, or say square shape tunnels, and in this context, we will learn this Greenspan method. Then we will move to the multiple openings because in many situations, you may have more than one opening. So, how to analyze that using the theory of elasticity that also we will learn and then in most of the cases, you may not have the uniform strata of the rock. So, in case, if you have laminated rocks, then how to go ahead with the elastic analysis of openings in laminated rocks that we will discuss.

Then, we will move to the elastoplastic analysis of tunnels, and in this one, we will take 2 types of yield criterion, one is Tresca yield criterion, and another is Mohr Coulomb yield criterion. And using these 2 criterions, we will see that how the elastoplastic analysis of tunnels can be carried out. Then, we will learn about the application of rock mass classification systems such as RMR system, Q-system Tarzagi's rock load theory, and also, we will learn about various ground conditions in tunneling.

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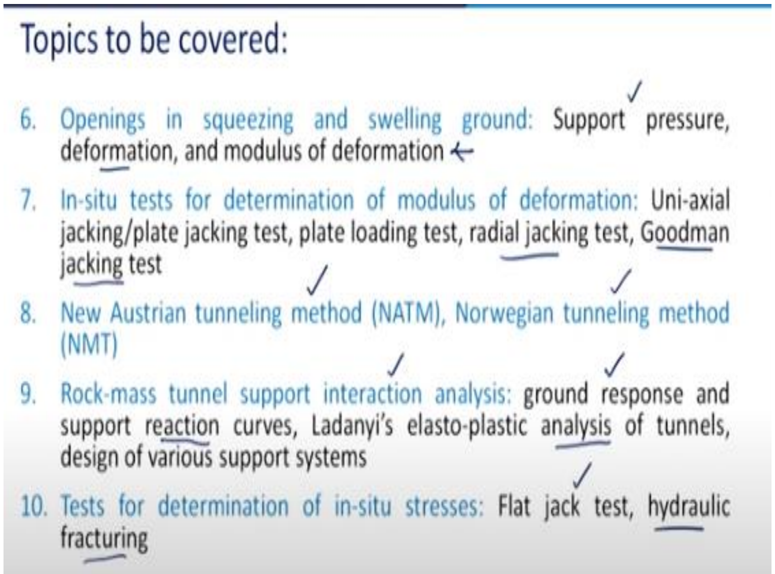

Then, we will go to the openings in squeezing and swelling ground conditions, and we will learn about the support pressures, deformations, and the modulus of deformation. This will be followed by various in-situ tests which are conducted in the field for determination of modulus of deformations. These include uniaxial jacking or plate jacking test, plate loading test, radial jacking test, and Goodman jacking tests. Then, we will discuss about the tunneling methods. Basically, these are not the methods but the philosophies.

So, we will take up these two methods that is New Austrian tunneling method and Norwegian tunneling method that we call in short as NMT. After, we get the, this much of the foundation related to the underground space technology or the design of underground excavations. Then we will take up the topic which will deal with the rock mass tunnel support interaction analysis, and in this one, we will first discuss about the phenomena of this interaction. In this context, we will learn about the ground response and support reaction curves.

And then we will go ahead with the elastoplastic analysis of tunnels considering this interaction, and this is called as Ladanyi's elasto-plastic analysis. Then, we will discuss about the design of various support systems such as shortcrete, may be the steel sets, rock bolts, etc. Once we know this, then we will learn about various tests for the determination of in-situ stresses, these include flat jack test and hydraulic fracturing.

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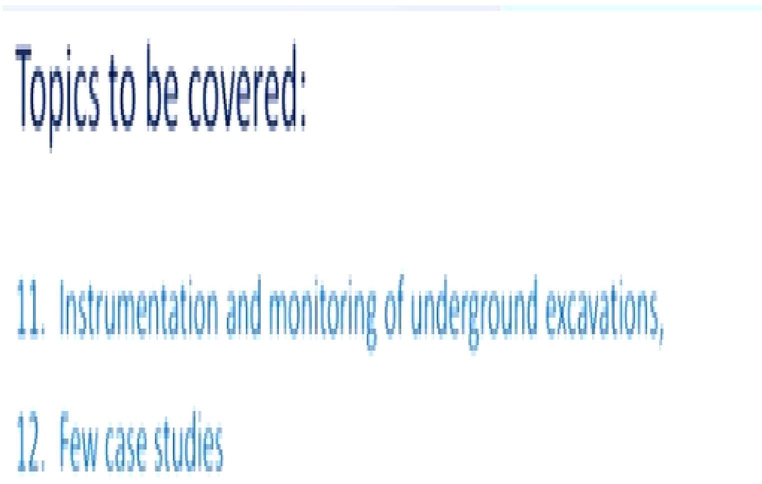

And then, we will go to the instrumentation and monitoring aspects of underground excavations, and this will be followed by finally some of the case studies. Which I will be discussing with you that how whatever knowledge that we gain throughout the journey of these 12 weeks. How these were applied to some of the case studies in solving some typical problems related to design of underground excavations.

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So, the source material is going to be the relevant chapters from various textbooks on underground excavations and rock engineering plus the relevant Indian standard quotes. Then, we will be referring to various documents which are available in public domain. And, of course many images through public domain research they are going to be used, and we highly acknowledge these sources.

Apart from these, I will be discussing with you time to time, if let us say, we discuss or we refer to any research paper with reference to any of these theories or topics that I will keep sharing you with time to time. Now, some of the books that I have mentioned here so first book is by Obert, L and Duvall here is the reference.

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Then this is the basics of the rock mechanics so by Goodman. Then very important reference by hook and brown and the title is underground excavations. Then one of the, basic book on the rock engineering and rock mechanics that is by Ramamurthy that is engineering in rocks for slopes, foundation, and tunnel. And then the book which deals with the engineering rock mass classification by Singh and Goel.

Now, once we know that what all things that we are going to discuss and what all are the references which we will be following let us first take a look about this material call rocks and that will be followed by rock masses. So, first we will discuss few aspects related to this please remember that this is a little bit advanced course. So, we will not be going into the details of the basics of rock mechanics and rock engineering. However, to have the completeness, we will be discussing some aspects, and then we will directly go to the elastic analysis of the circular tunnels.

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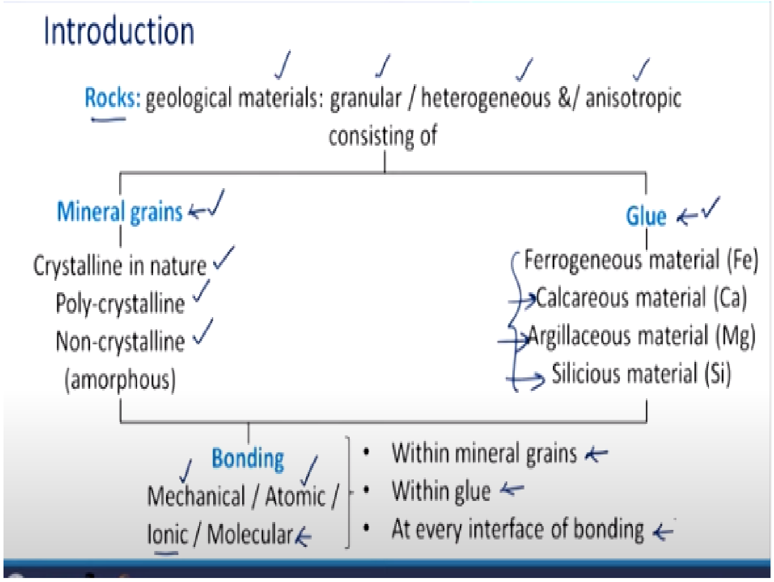

So, to start with these rocks are geological materials, and these are granular heterogeneous, and anisotropic. And these consist of 2 components, first one is the mineral grains and another one is glue. So, basically mineral grains they are crystalline in nature may be poly crystalline or can be non-crystalline. And the material which binds them together is under this category of glue material. These may have the properties like ferruginous material, calcareous, argillaceous, and siliceous material.

Now, what happens when there is a bonding between mineral grain and glue material, then we get the material rocks. Now which type of bonding should be there so it can be the mechanical bonding or atomic bonding, ionic or the molecular bonding. Now, these bonding should be within mineral grains, within glue, and at every interface of bonding. So, with the bonding of mineral grains and glue-type material the resulting material is rocks.

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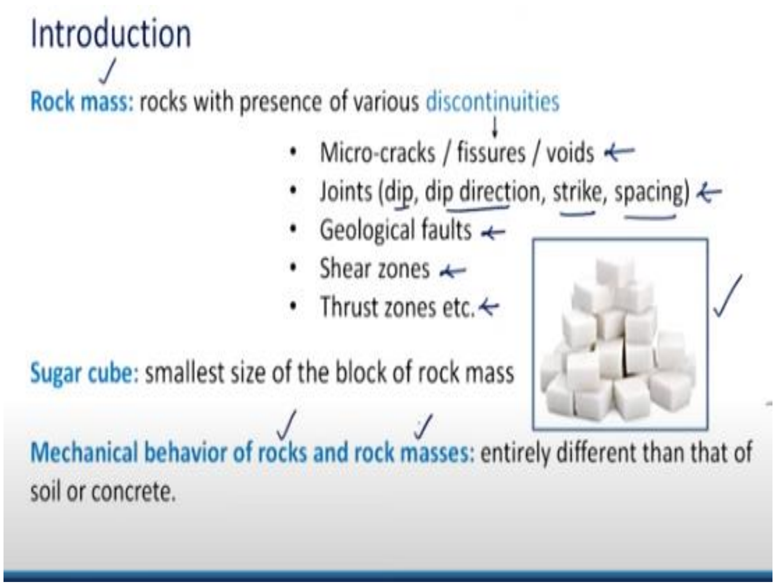

Now, coming to the rock mass so when these rocks they have various discontinuities then that material are called as rock mass. Now, what do we call that as discontinuities these can include micro cracks or fissures or voids. These can be called as joints of course these joints are defined by dip, dip direction, strike, their spacing. There can be geological faults, the discontinuities can be in the form of shear zones or thrust zones.

So here, I have added very interesting picture of sugar cubes, these are the smallest size of the block of rock mass. So, we see this thing on day-to-day basis but then we never realize that what it can be, so that is the most simple example of a rock mass that is a sugar cube. Now, the mechanical behavior of rocks and rock masses, they are entirely different than that of the soil or concrete. The reason is you have seen that it is the mineral grain and the glue material binding of these 2 at different levels that, results to this material rock.

And when there is a discontinuity that is present in the rock we get rock masses, however in case of soil it is altogether different, and concrete is a man-made material. So, the mechanical behavior of rock and rock masses, they are completely different. It is not that this engineering or this technology is very new, there are many structures which were constructed in rock masses.

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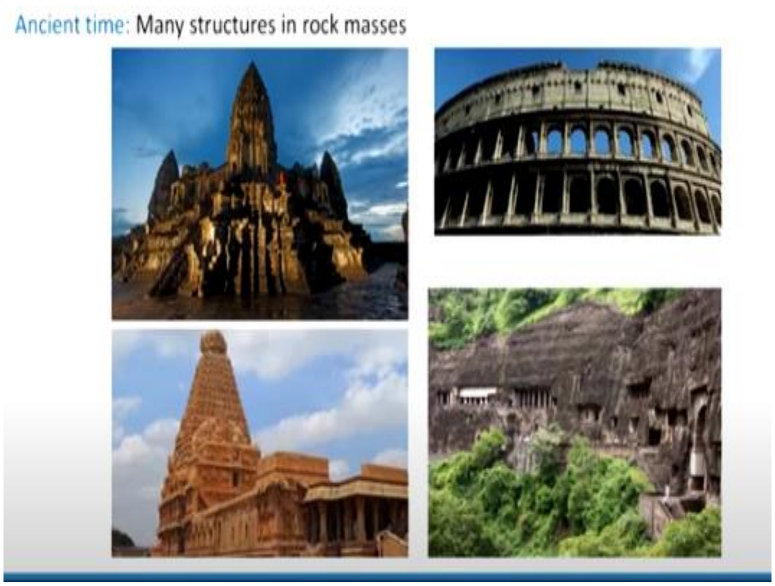

So here, some of the typical pictures that i have downloaded from Google just for your reference. So here, this one if you see this is the picture of the big temple in Tanjore okay. So, like that, all over the world you have many structures in rock masses, so it is not some engineering or the technology which is new.

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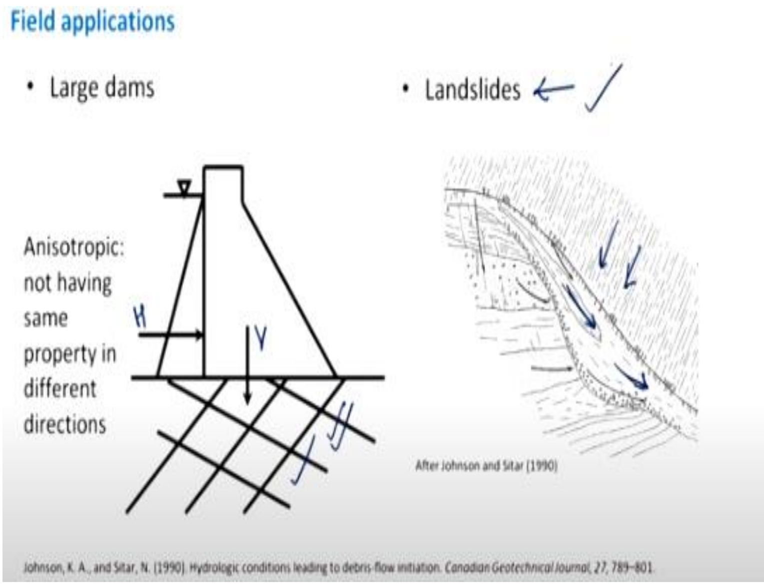

What are the field applications so right now we discuss with reference to rocks only so there can be various applications. For example, you have to you know go for the large dam construction which is founded on the rock masses. So, these may be an isotropic that is, they do not have the same property in different directions, and then you can see that there is going to be the presence of the vertical load as well as the horizontal load.

So, this is founded on rock masses, then you come across various landslides, so there is the rainfall and then it triggers the sliding of this material, you see in this particular direction. So here you may have soil bed or you may have rock bed so that is also one of the applications of this rock engineering.

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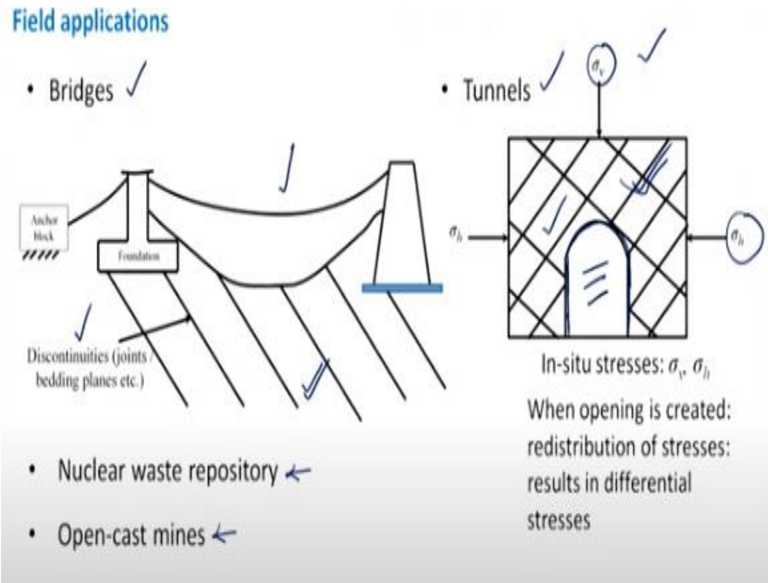

Then, you have the construction of bridges which may be founded on the rock masses having various discontinuities in the form of joints or bedding planes. So, this is another application area then we have the tunnels. So, you see that this area which is this one is the rock mass and we make an excavation which is this portion. So, when the excavation is made what happens to this boundary?

This boundary becomes stress-free the moment it becomes stress-free boundary there is going to be the redistribution of stresses, and this will result in the differential stresses. So, before the excavation, there were the presence of in-situ stresses say in the form of the vertical stress sigma v and horizontal stresses sigma h.

But the moment you create the opening you have a stress-free boundary and the stress redistribution has to take place, so that is another application with reference to rock engineering. Then we have the nuclear waste repository and the open cast mines also as one of the application of the rock engineering.

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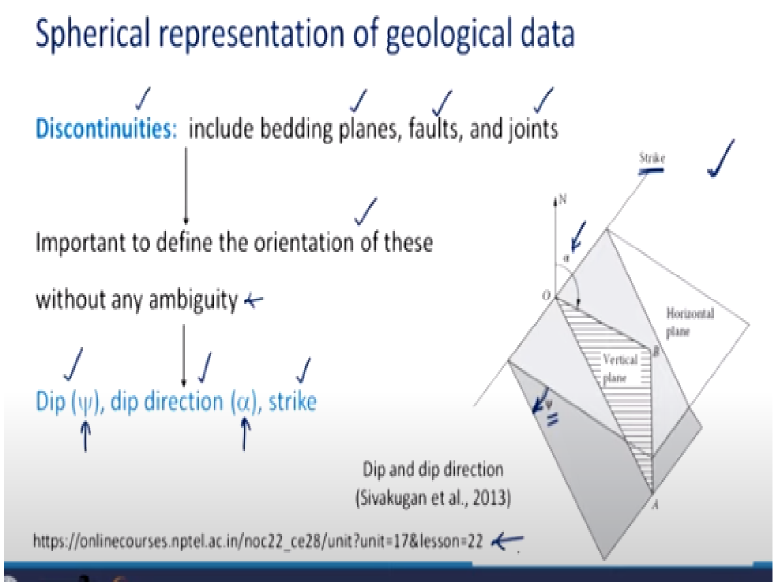

So, we have seen that discontinuities are important and when the rocks they have these discontinuities it becomes the rock mass. So, the question comes that how to represent these discontinuities or any geological data that is present may be in the form of shear zone, thrust zone like that. So let us see that how these can be represented spherically, so we have the discontinuities these include bedding planes, faults, and joints.

And, it is important to define the orientation of these without any ambiguity so the terms which are used include dip which is usually denoted by the angle psi then dip direction denoted by alpha and strike. Now this figure is self-explanatory to define you the various terms which have been mentioned here that is dip, dip direction, and strike. So, you can see that the plane has the dip with reference to this strike line, and hence this is the angle that is psi which is given by or which represent the dip this angle or this dip direction is shown here.

So, in case if you want to learn in detail about these terms and how these can be determined you can refer to this link where the details have been discussed.

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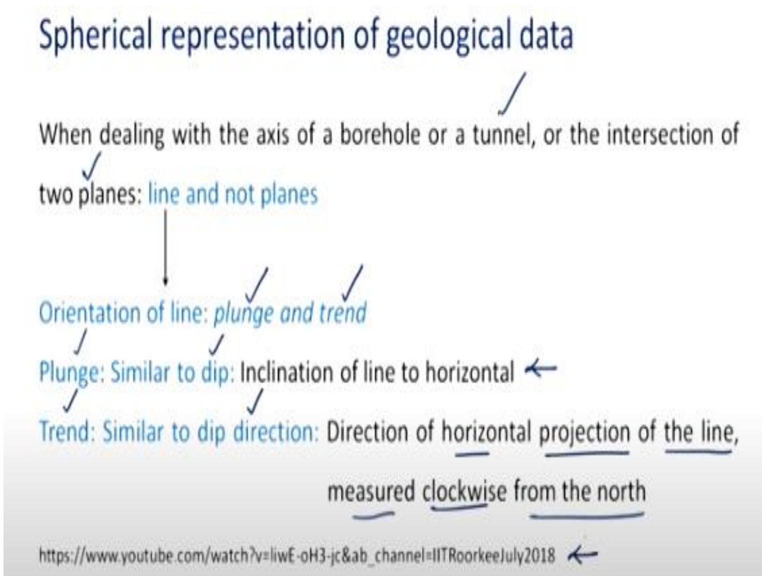

Now, when we deal with the access of a borehole or a tunnel or the intersection of 2 planes these are lines and not the planes. So, the orientation of a line is denoted by plunge and trend rather, than dip and dip direction which was there in case of planes. So, plunge is basically a term which is similar to dip this is the inclination of line to the horizontal and trend is the term that is similar to dip direction.

Which is the direction of horizontal projection of the line that is measured clockwise from the north for more details you can refer to this link then coming to the various laboratory testing of rocks.

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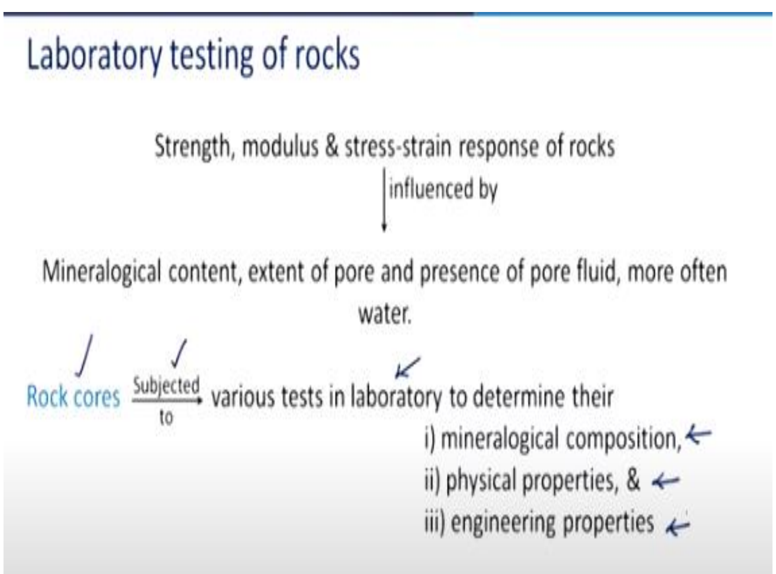

So, basically strength, modulus, and stress strain relationship of rocks these are influenced by their mineralogical content the extent of pore, and presence of the pore fluid which is more often water. So, based upon these conditions- the question is how to determine the strength and the mechanical characteristic? So, for this we take the sample from the field bring it to the lab and then we carry out various tests.

So, basically what we do is we get rock cores from the field, and these are subjected to various tests in the lab. In order to determine their mineralogical composition, physical properties, and engineering properties let us try to take a look.

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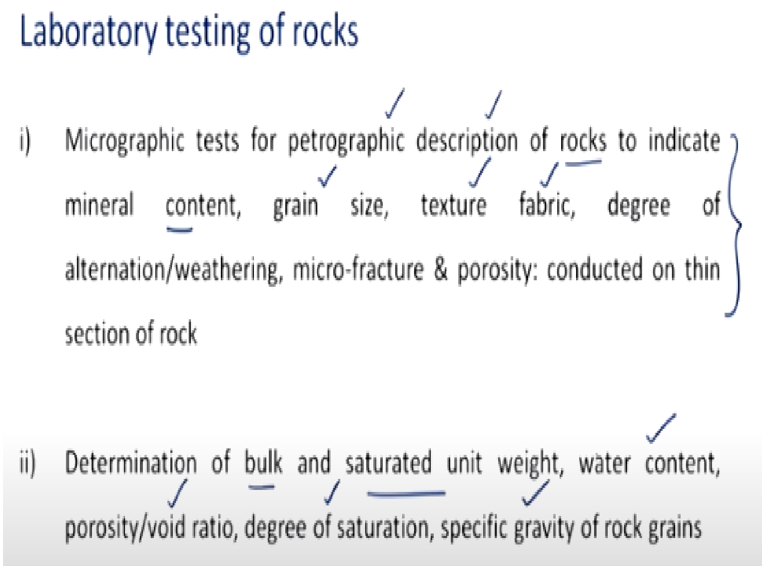

So, for the mineralogical studies we carry out the micrographic tests for petrographic description of rocks to indicate it mineral content, grain size, texture, fabric, degree of weathering and porosity. So, what we do is we make a thin section of rock, and then we carry out this test so as far as civil engineers are concerned yes, we conduct these. But many times, we rely on to the experts from earth science stream because they have the better insight about this mineralogical content as far as rocks are concerned.

Coming to the second category of tests, that is determination of bulk and saturated unit weight, water content, porosity and void ratio degree of saturation, and specific gravity of rock grains. You have studied these terms with reference to soil mechanics, so the definition remains the same so we will see in short that how we define these once I discuss about the third category which include the engineering properties.

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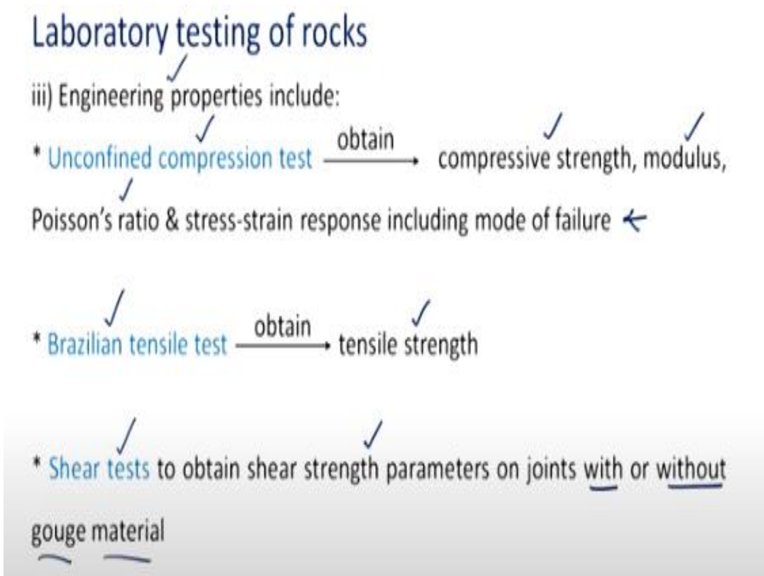

So, under this category the first test that we conduct is the unconfined compression test, and this is conducted to obtain the compressive strength, elastic modulus Poisson's ratio, and also the complete stress-strain response including various modes of failure. Then the second category is the determination of the tensile strength using Brazilian tensile tests. This is an indirect test where the specimen is subjected to the compressive load but what we get is the tensile strength.

Then, the third category is shear test in which we obtain the shear strength parameters on joints with or without gauge material. Now what is this see in the field you have the rock with joints that is you have the rock mass now if by some way or other if these joints get open. And, if they are there for longer period of time what happens is this gauge material which may be of let us say clay type of material it gets deposited in that joint so those joints they are called as joints with gauge material.

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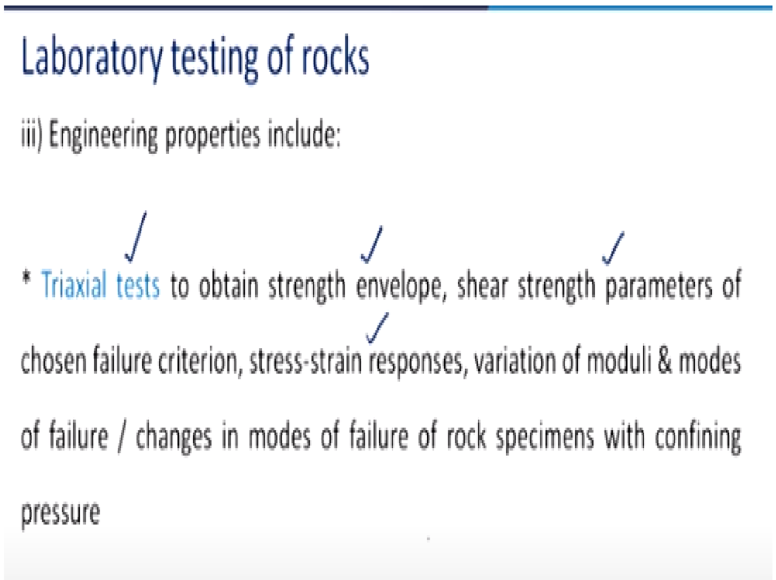

Then, we have another type of shear tests which are tri-axial tests which help us to obtain these, strength envelope. Then shear strength parameters of chosen failure criterion, stress strain response. How the modulus is varying what is the change in the modes of failure when we increase the confining pressure you all know that the tri-axial test they are conducted at different values of the confining pressure.

So, what happens if we increase the confining pressure there may be the change in the mode of the failure. So, by conducting this tri-axial test we will be able to get all these information.

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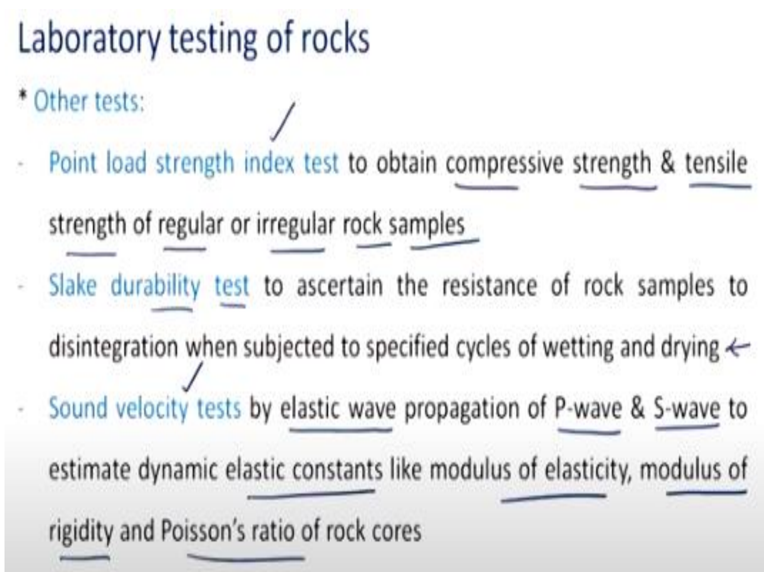

There are various other tests apart from these which also help us in getting some of the engineering properties of the rocks. So, one such test include point load strength indexes this helps us to obtain compressive strength and the tensile strength of regular as well as irregular rock samples. Then the second one is the slate durability test it helps us to find out the resistance of the rock samples to disintegration when these are subjected to specified cycles of wetting and drying.

Then, we have the sound velocity test which we conduct by the propagation of elastic wave, these can be P-wave or S-wave and this helps us to find out the dynamic elastic constants such as modulus of elasticity, modulus of rigidity and Poisson's ratio of rock coarse.

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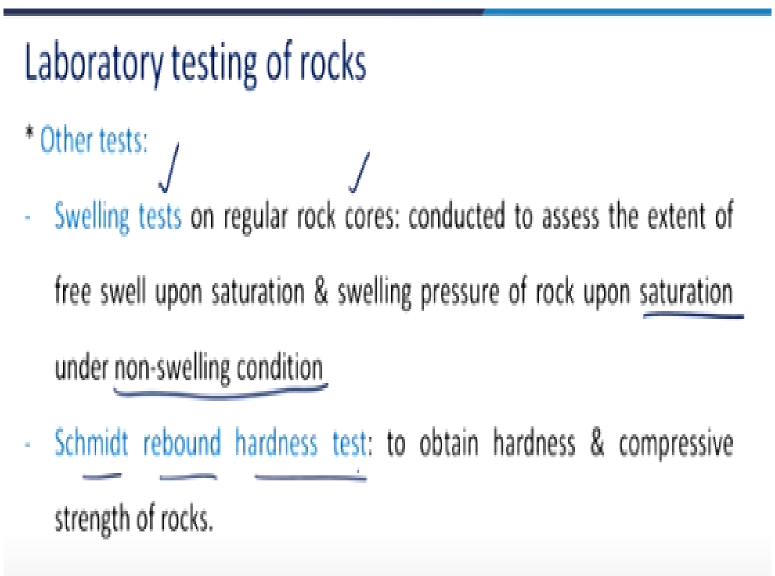

Then, we conduct swelling tests on regular rock cores these are conducted to assess the extent of free swell upon saturation and also the swelling pressure of rock upon saturation under non swelling condition. Then, the last tests in this category special test that is Schmidt rebound hardness test this helps us to find hardness and also the compressive strength of the rocks. Now coming to some of the physical properties as I mentioned to you that, you are aware of these with reference to soil mechanics.

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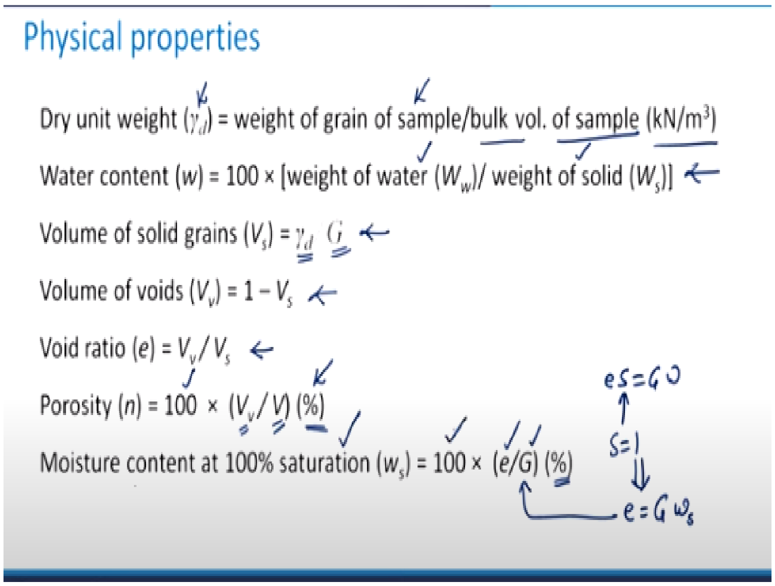

So, the definition remains the same for example when we say that dry unit weight, so it is represented by γ_d. That is weight of grain of the sample/bulk volume of the sample and its unit is KN/m^3. Then the next one is the water content, W= 100 × (w_w/w_s). Then the third term is volume of the solid grains, $V_s = \gamma_d/G$.

That is, G then volume of voids is, V_v = 1-V_s, then void ratio, e = V_v/V_s. porosity, n = (V_v/V) × 100. Then we have the moisture content at 100% saturation, So that is you remember we have e×s = G×w.

So, when we have the 100% saturation so this s=1 so, this will result into e = G×w. So, if we want to find out the moisture content at 100% saturation, it is w_s. So that is how you are getting this expression that is w_s = (e/G) × 100 (%).

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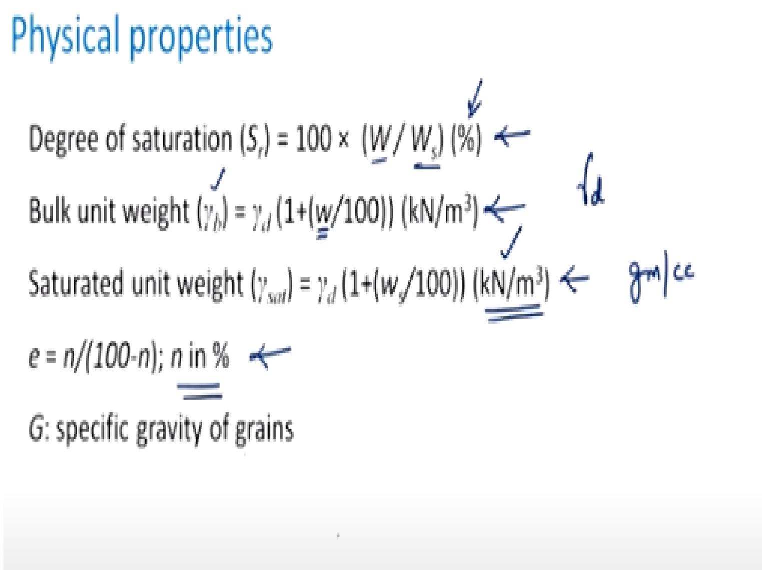

Coming to the next definition, which is the degree of saturation, S_r= (W/Ws) ×100 (%). once we know the dry unit weight γ_d, we can find out the bulk unit weight, γ_b = γ_d/(1+(w/100)). And then we can also find out the saturated unit weight, please remember that here we are finding out the unit weight and therefore the unit is KN/m^3.

The unit for density is not KN/m^3 but may be the g/cc or kg/m^3. So that is a difference between density and the unit weight density is mass per unit volume and unit weight is weight per unit volume then there is a relationship between the void ratio and the porosity which is given by this where n is the porosity and is represented in %. So, G as I mentioned to you is the specific gravity of grains.

So here we learnt about the introduction related to the material called rocks and rock masses what all are the various tests to determine the physical and the mechanical properties of the rocks in the lab? So, in the next class we will learn some aspects about preparation of specimen and the conduct of unconfined compressive strength tests in the lab, thank you very much.