Rock Engineering

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Lecture-18
Engineering Classification of Intact Rocks, Concept of Rock Mass, RQD

Hello everyone. So, in the previous class we finished our discussion on the chapter on laboratory testing of rocks. So, today we will be starting a fresh chapter on engineering classification of rocks and rock masses. This is very interesting. So, today what we will see is first that what is the need for the classification of the rocks? You know about the classification of the soil. See in order to talk in the same language to represent any type of rock, we need to have a common language which everybody can understand. So, basically these classification systems they provide us that kind of common language to represent a rock.

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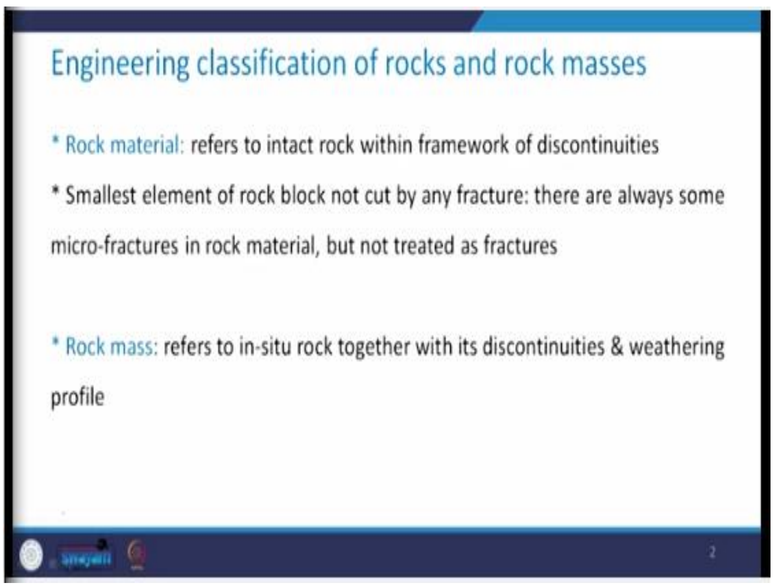

So, today we will learn about the engineering classification of intact rocks, then I will introduce you to the concept of rock mass and then we will have some discussion on RQD which is Rock Quality Designation. Rock material, when I say that it is rock material, it refers to the intact rock. So, whenever I say either rock or rock material or intact rock, it is one and the same thing. The smallest element of rock block, which is not cut by any kind of fracture that we call as the intact rock.

Obviously, there is going to be always the presence of the micro fractures in the rock material. But we have discussed this earlier also that these micro fractures, they are not treated as fractures or discontinuities or joints. So intact rock will not have any joint. Now what is rock mass? When the in situ rock it is together with the discontinuity and the weathering profile and the intact rock, as a whole we call that as rock mass.

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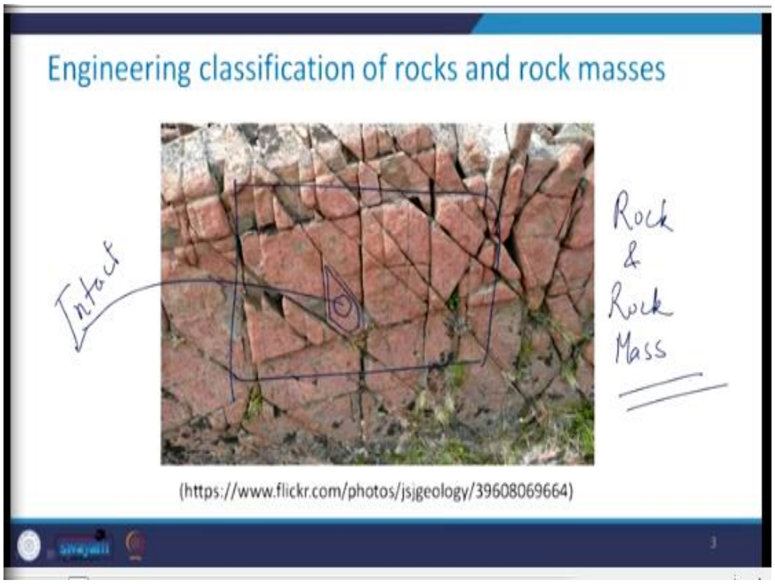

Take a look at this picture and this will give you the idea. Like let us see if I take only this much portion and I take a specimen out of it, this is what I am going to call as intact. Because in this portion there are no discontinuities, but if I take this big part, then this is what is called as rock mass. Because this is comprising of intact rock, this is comprising of discontinuities as well as the weathered surface, so that is the difference between rock and rock mass.

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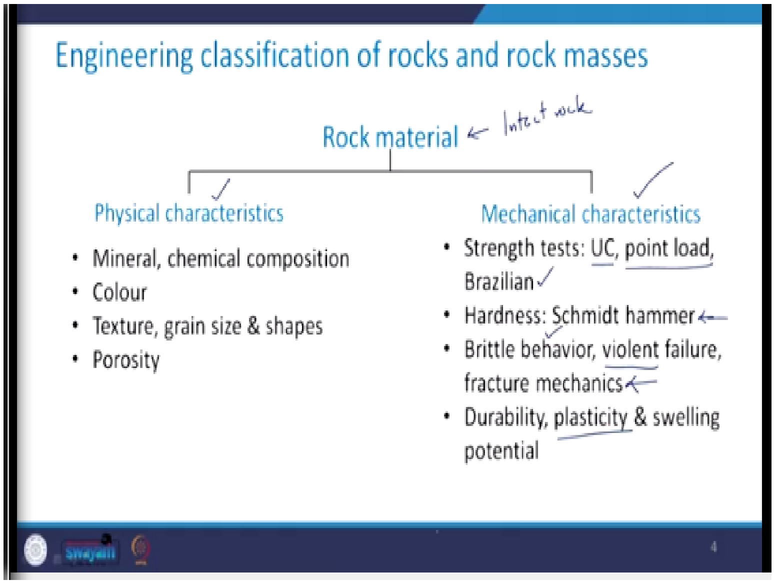

So, with this concept, let us proceed further, first we will take a look at the rock material itself. So, when I say rock material means I am talking about the intact rock. So, we have seen that it can have either the physical characteristic or and it will have the mechanical characteristic. In case of the physical characteristics what all things come into picture? Mineralogical and chemical composition, it is color, texture, grain size and shapes and the porosity.

As per as mechanical characteristics are concerned, we have seen with the help of different strength tests, we can find out unconfined compressive strength, then we can carry out point load test, we can carry out Brazilian test in order to get the tensile strength. Then we can carry out the Schmidt hammer rebound test, which gives us the idea about the hardness of that drop. Then we saw that it can behave as a brittle material or it can be as a ductile material.

So, if it is acting as a brittle material, it is failure is going to be violent and there the fracture mechanics will come into picture, why? If it has ductile kind of behavior then you will have the plasticity which will come into picture. And obviously, the swelling potential, how to determine the swelling potential we have done that free swell test and swelling pressure test.

So, the testing which we discussed you can combine that discussion or you can get the idea from that discussion and related to the discussion which we are going to have in this chapter that is on engineering classification of rocks and rock masses. Now before I go further, let us first take a look at the concept of homogeneity and inhomogeneity in context of rocks, this is very interesting.

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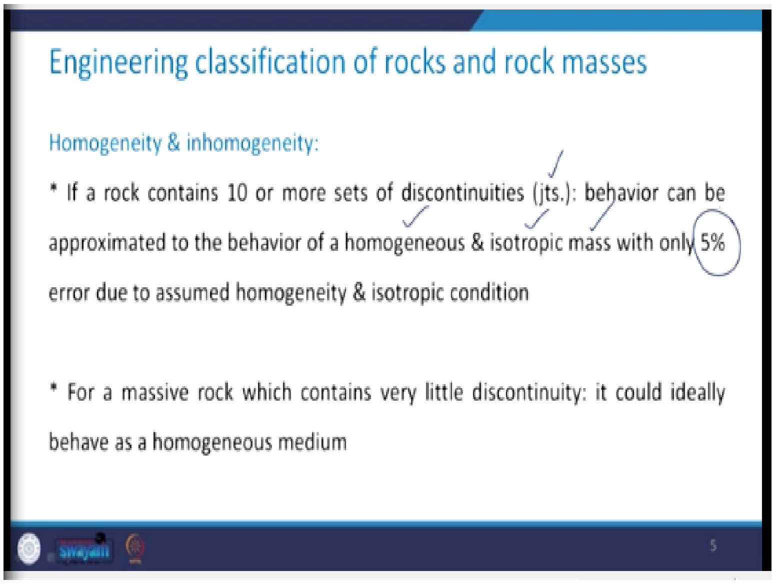

So, if rock contains 10 or more set of discontinuities or say joints, then it is behavior can be approximated to that of homogeneous and isotropic mass. And there is going to be error of only 5% because of this assumed homogeneity and isotropic condition. That means, if you have a greater number of discontinuities, the material can be considered as homogeneous and isotropic mass. And there is going to be not much error associated with this assumption marginally only for 5% error.

For a massive rock which contains very little discontinuity, so this could ideally behave as a homogeneous medium. So, you see we are talking on one hand about a massive rock which can be taken as a homogeneous medium. And on the other hand, we are saying that when we have more set of discontinuities like 10 or more set of discontinuity, that material will also behave as a homogeneous and isotropic mass. So, somewhere in between what exactly is happening, see.

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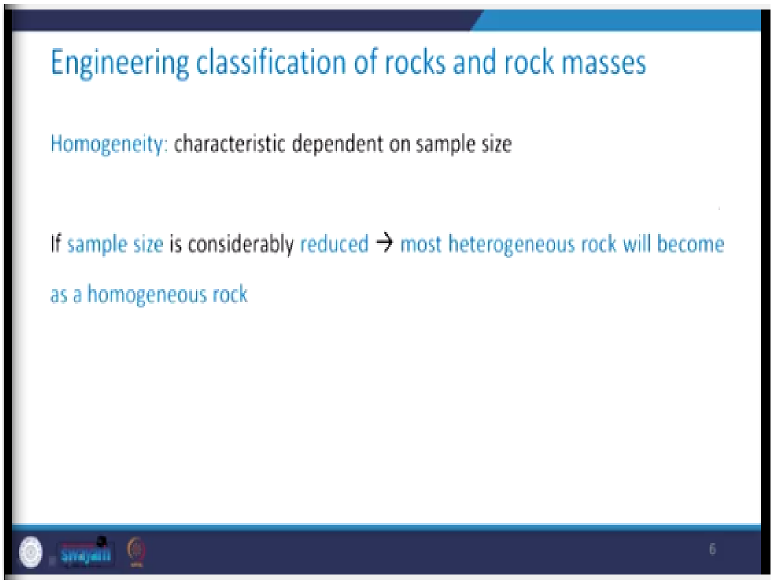

So, basically somewhere in between depending upon the sample size, you will have the definition of the material as homogeneous or heterogeneous. So, basically this homogeneity is a characteristic which is depending upon the sample size, this thing will become clearer when I show you one interesting picture, just in a short while. If the sample size is considerably reduced, what happens is that most heterogeneous rock will become a homogeneous rock.

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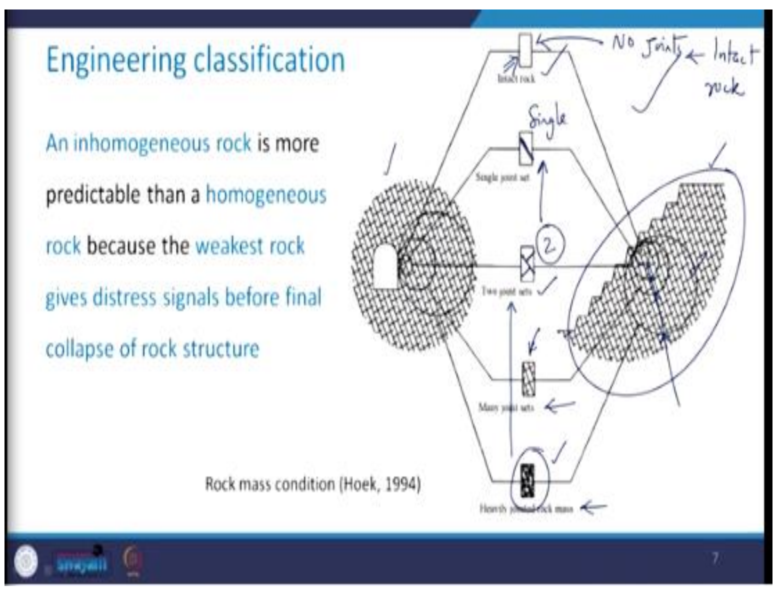

Look at this, this is really very interesting, focus on this figure. You see that here there is one panel which has been excavated in the rock mass and here there is a rock slope and both have rock mass. So, you can see that intact rock along with a set of discontinuities are there. Now I start with the bigger circle, you can see that there are many circles here in this figure, see this is one then second, third, fourth and so on, there are many circles.

So, look at the biggest circle first, the moment you consider this biggest circle and if you just zoom it, it will look like something like this which can be considered as the heavily jointed rock mass. Because the sample size is big and lot many discontinuities sets, they are coming in that size of the specimen. So, therefore that rock mass is being called as heavily jointed rock mass. Now you reduce the size of the circle, so what exactly will happen?

The number of discontinuities which are there inside that circle, they are going to be lesser than the previous one. So, although there are going to be many joint sets, but as compared to this case, it is going to be a smaller number of joints in this case. So, we are calling this as many joints sets are there in this specimen. You further reduce the size of the circle, in such a manner that there lie only 2 joint sets.

So, you can see that this is the one joint and this is another joint set, so there are only 2 joint sets in this case. So, you see it is the same rock mass, but I am reducing the sample size in this direction. And therefore because of that the number of discontinuities which are occurring in the specimen, they are also reducing. You further reduce the size of the circle, what will happen? And you choose it in such a manner that there is only single joint set, that means here it is only single joint set.

So, you see that we have been discussing about this direct shear test along jointed specimen. So, it was this situation only where you have only one joint set, same rock but specimen size is reducing in this direction. You further reduce the size of the specimen and you take in such a manner that small specimen that there are no discontinuities in this case, no joints. So, this is going to be your intact rock.

So, this is what that I wanted to tell you, that see as a whole, this is the heterogeneous rock. The moment you start reducing the size of the specimen the same heterogeneous rock became intact rock without any discontinuity. So, remember that an inhomogeneous rock is more predictable than a homogeneous rock because more the discontinuity, weaker it is and before the final failure those discontinuities will give you enough signal, distress signal before the final collapse of the rock structure.

So, 2 things here we need to keep in mind. First is, when we reduce the specimen size or the sample size, same heterogeneous rock can be converted or can be taken as the intact rock it depends upon the specimen size. Second thing is inhomogeneous rock behavior is more predictable than a homogeneous rock, because the weakest rock will give you the enough distress signal before the final collapse of the rock structure.

It will not fail suddenly, there is going to be say some kind of sliding or other type of signals they are going to be there. So, you will be knowing beforehand that**,** now that this distress is there and it can fail anytime. So, you will have sufficient time to let us evacuate that place or things like that. Now this rock material that is, intact rock it may show larger scatter in the strength characteristic.

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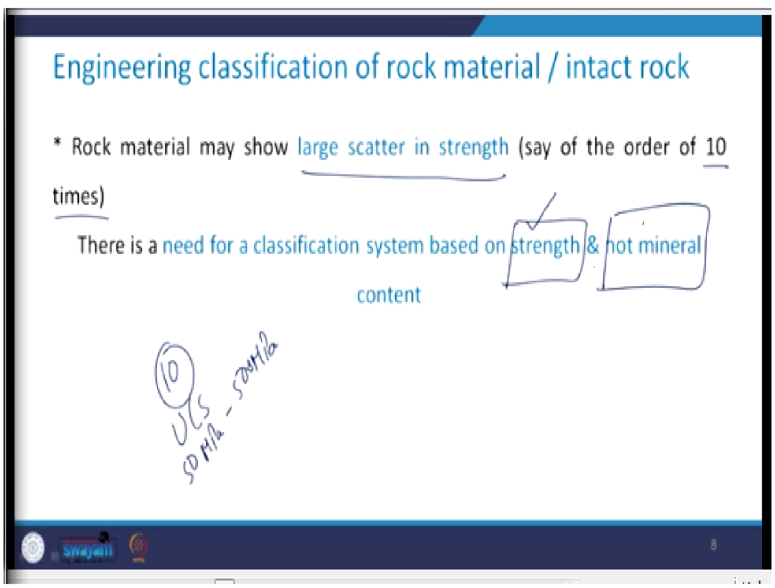

Say I conduct 10 UCS test and there can be large scatter in the UCS values, again these tests are conducted on the same rocks. And it can be to the order of ten times like it can vary from 50 MPa to 500 MPa, that can happen in case of the rock. And therefore, it is required that we classify the rock on the basis of it is strength and not on the basis of it is mineral content. Till now I have been telling you that one rock is different from the other rock based upon it is mineralogical composition.

But as far as engineering classification is concerned, this mineralogical composition cannot form a basis of the engineering classification of rocks or rock masses because there is a large scatter in the strength characteristic of the rock material. So, one needs to devise different classification system based on the strength and not on the mineral content.

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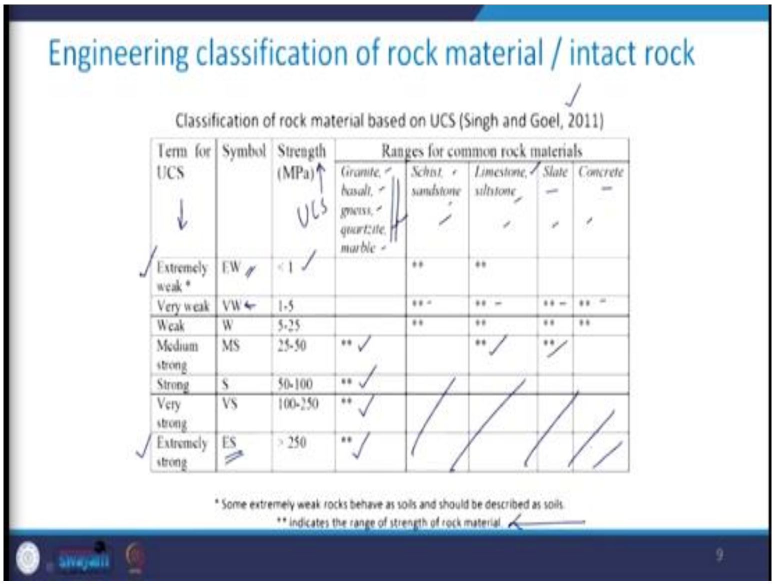

So, you see, here this table has been taken from this reference it gives you the idea about the classification of the intact rock based upon only the UCS value. So, here first column deals with the terms for the UCS, so it varies from extremely weak to extremely strong. And the symbol which is given us EW stands for extremely weak, VW very weak, W is weak and likewise you have extremely strong which is ES.

Look at the strength. What is this strength this is UCS? That is unconfined compressive strength. You know now how to evaluate or how to obtain the strength for a rock in the lab. If the strength is this UCS is less than 1 MPa, it is in this category. And you can see that here some of these columns, they give you the idea that what type of rock will fall under which type of category. So, the first column in this case is granite, basalt, gneiss, quartzite and marble.

The second has schist and sandstone, third has limestone and siltstone followed by slate and then finally the concrete. So, in the category of extreme weak, generally schist sandstone, limestone and siltstone there UCS is in such a range that they will fall under this extremely weak category. So, wherever these 2 stars have been given that indicate the range of strength of the rock material.

So, likewise, let us see, if I take medium strong, so some variety of granite, basalt gneiss, quartzite or marble, they lie in this category. And then limestone, siltstone and slate also, they lie in the that category. These rocks in general they belong to the stronger categories, and therefore you will see that here for strong, very strong, and extremely strong category, they are present in all these three categories however these rocks there is nothing in this case.

So, this gives you an overall picture about the common rock types, common rock material or common intact rock and their classification on the basis of their UCS value. Better manner, this was given by Deere and Miller, the classification system in 1966. This classification system was based upon quantity, that is modulus ratio which is defined as a ratio between the elastic modulus and UCS.

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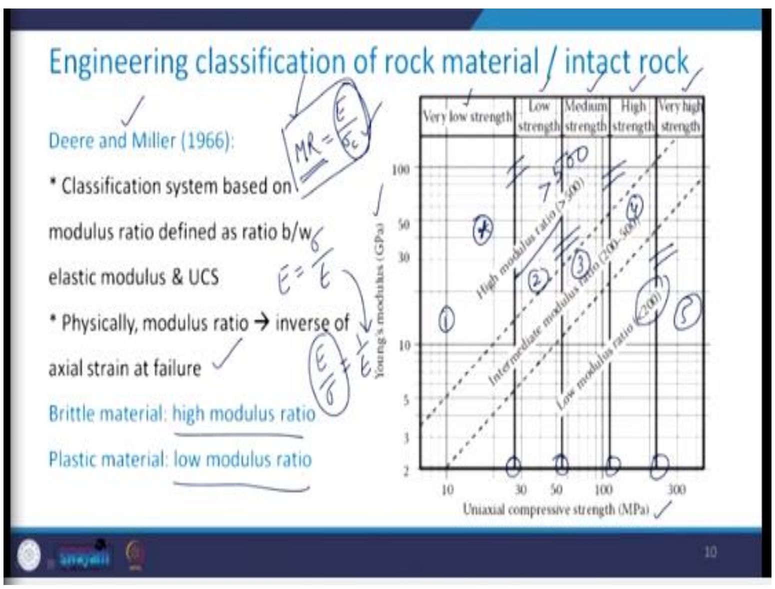

So, if I just write this modulus ratio was defined as $MR= E/\sigma_c$, you know that this is how that we represent the UCS, σ_c. So, you can see here a plot has been given where on the x axis you have the UCS in MPa and on y axis you have the modulus in GPa. It has been divided into three zones based upon the value of the modulus ratio. See, how the modulus ratio is defined is E/σ_o, this means what?

If we draw a line, the slope of this line is going to give me this modulus ratio as per it is definition. So, you see here that three ratios they have been taken, the first one is this first or these 2 lines they have been taken. The ratio of this line is, that this below this you have the low modulus ratio which is 200. That means, the slope of this line is 200:1.

Similarly, the second one has that is if you have in this zone, then it is the high modulus ratio and numerically it is being defined as that here it is greater than 500 that means the modulus ratio is greater than 500. So, if the modulus ratio is less than 200, it falls under the category of low modulus ratio. If it is beyond 500 then it falls in the category of high modulus ratio and somewhere between 200 and 100 it is called as intermediate modulus ratio.

So, that is one way of differentiating with respect to the modulus ratio. Now you see on this scale that is along the x axis, you can see that some of these vertical lines, solid vertical lines, this one then this one this, this they divide this chart into 1, 2, 3, 4 and 5 parts get these four lines they defined. So, these signify very low strength, when I say very low strength means what? Here we are doing it with respect to UCS.

So, you see the UCS is in between somewhere because it is all this log scale is there, so you see that it is somewhere just below 30 here and then this is between 50 and little above 50 then 100 and then so on you have these vertical separations. So, there you have very low strength, low strength, medium strength, high strength and very high strength. Conduct the test in the field, find out what is it is UCS, find out it is modulus of elasticity.

You know how to find out all these things, just plot it on this space and say if the point let us say, lie on this space, so what will be the classification of this? It will have the low very low strength with high modulus ratio. So, that is how the intact rock is going to be classified on the basis of this classification system, which is called as Deere and Miller classification system. So, basically you see take a look at the definition of this modulus ratio.

Generally, this modulus ratio, here is defined as modulus of elasticity and the UCS**.** It is kind of a stress. We know that modulus of elasticity in general definition is σ/ε that is stress upon strain. Now if I just take E/σ that is going to give me $1/\varepsilon$ from here, so physically compare this quantity with this modulus ratio. So, it is one and the same thing, modulus of elasticity divided by the stress.

So, physically this is representing the inverse of the axial strain at the failure this. Brittle material will always have high modulus ratio and the plastic material or the ductile material will have low modulus ratio. Point to be noted here.

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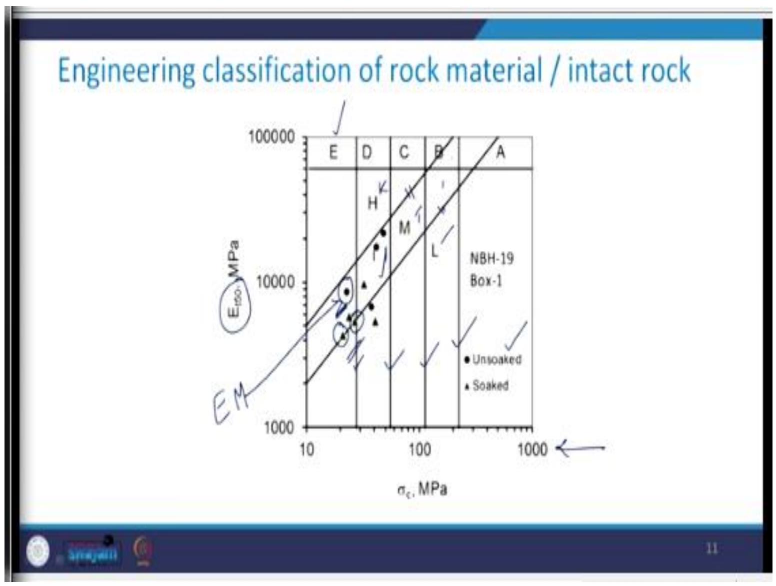

Now as I mentioned how to classify? So, this was like we had few samples at a particular site. So, that plot I just thought that it will make these things clearer to you. So, this was at a particular site. So, the round points they are for the unsoaked samples and the triangular one they are for the soaked. That means we soak that in water before carrying out the UCS test.

So, we find out UCS which is on the log scale on x axis and then we found out E_{t50}, you know how to obtain that, that is also on the log scale. And then these four lines, vertical lines as have been given in the Deere Miller classification system, that have been superimposed here, along with these lines with having slope 200:1 and 500:1. So, you see that it has been divided into L means low modulus ratio, M is intermediate modulus ratio, H is high modulus ratio.

So, let us say, I take this sample. What will be it is classifications system? It is going to be EM. What does that mean? It has very low strength with intermediate modulus ratio. So, likewise depending upon where the point is lying in this space you can classify the rock. Now there can be few cases where these are exactly on the boundary line and just to show you that I pasted this picture here to give you the idea.

You see here this one and this one, they are lying exactly on the boundary line. So, there you have to use your judgment that whether you would like to put it here in this zone or in this zone. So, slowly there, let us say, you have conducted ten tests on the same rock, 2 our lying here rest eight are lying let us say above this line. So, then maybe you can say that, more or less it is strength is going to be somewhat in between this region.

So, accordingly you can decide that what is the classification for the intact rock using this Deere and Miller classification system.

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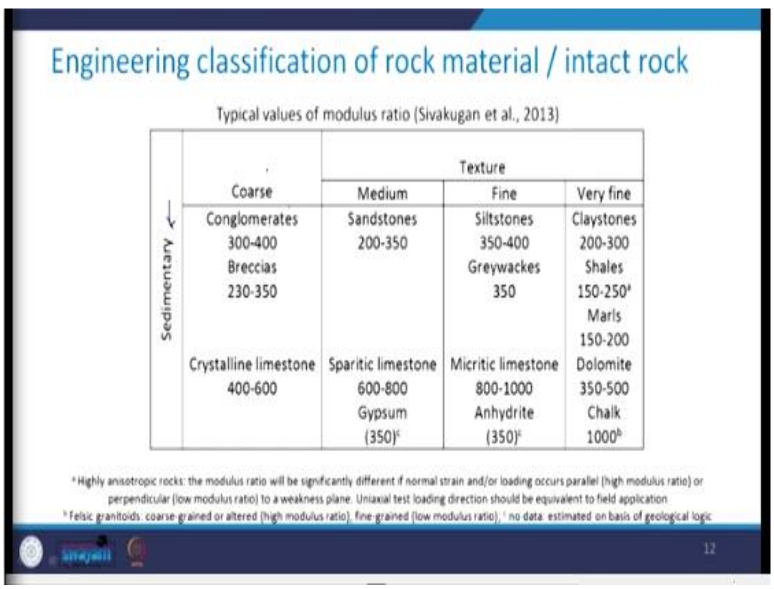

	Coarse	Texture: Medium	Fine	Very fine
Sedimentary	Conglomerates 300-400 Breccias 230-350	Sandstones 200-350	Siltstones 350-400 Greywackes 350	Claystones 200-300 Shales 150-250[a] Marls 150-200
	Crystalline limestone 400-600	Sparitic limestone 600-800 Gypsum (350)[c]	Micritic limestone 800-1000 Anhydrite (350)[c]	Dolomite 350-500 Chalk 1000[b]

[a] Highly anisotropic rocks: the modulus ratio will be significantly different if normal strain and/or loading occurs parallel (high modulus ratio) or perpendicular (low modulus ratio) to a weakness plane. Uniaxial test loading direction should be equivalent to field application
[b] Felsic granitoids: coarse-grained or altered (high modulus ratio), fine-grained (low modulus ratio); [c] no data: estimated on basis of geological logic

Some of the typical values of the modulus ratio they have been given in this table. So, here different types of rocks are there, so first I have taken the sedimentary type of rocks, we have discussed these types of rocks. And then you can see that based upon it is texture, coarse, medium, fine or very fine, you have different type of rocks and their range of modulus ratio have been given in this table. So, this is for the sedimentary rock.

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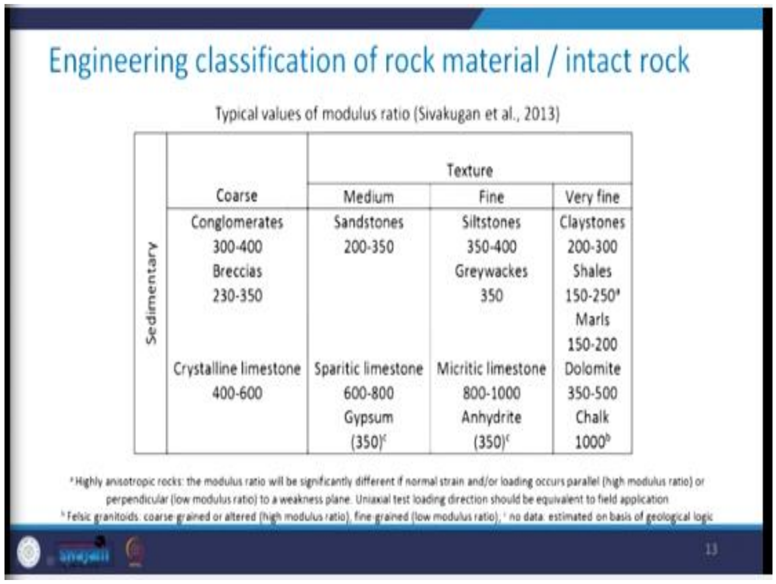

Again, for the sedimentary rock, other rocks.

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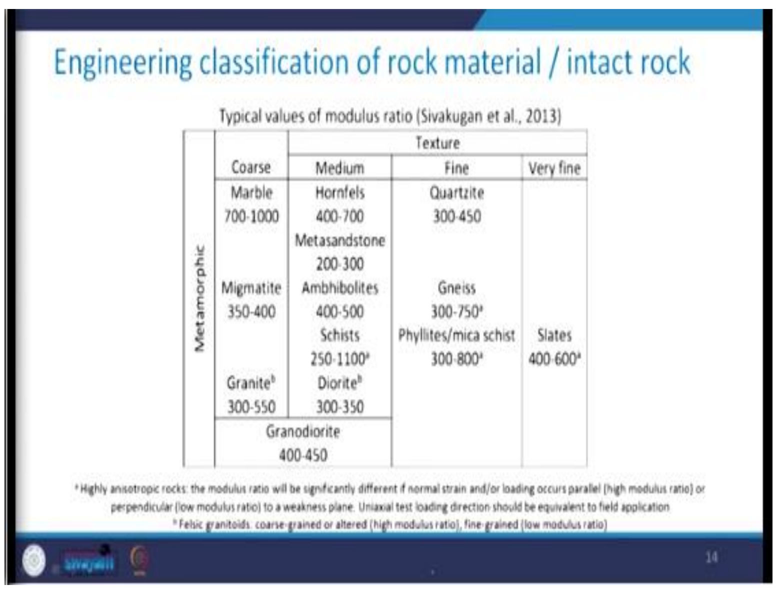

Then you have for the metamorphic rock, you have marble, migmatite, granite and then for depending upon what is the texture, medium, fine or very fine accordingly you have different rocks. So, basically this table gives you an idea the typical range of the modulus ratio.

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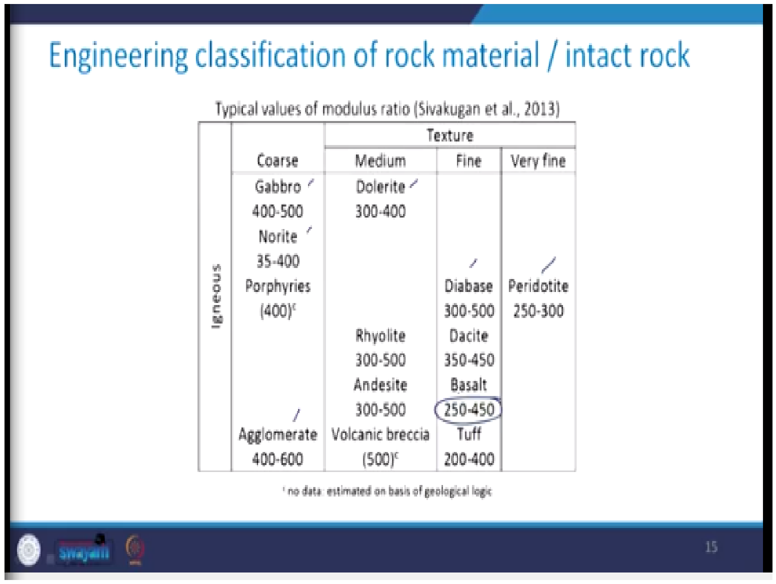

Likewise, here we have for the igneous rock or like gabbro, norite, agglomerate and then here you have dolerite, diabase, peridotite and like that, you have a basalt. So, you see that the modulus ratio is varying. See that range is there, so this gives you the idea.

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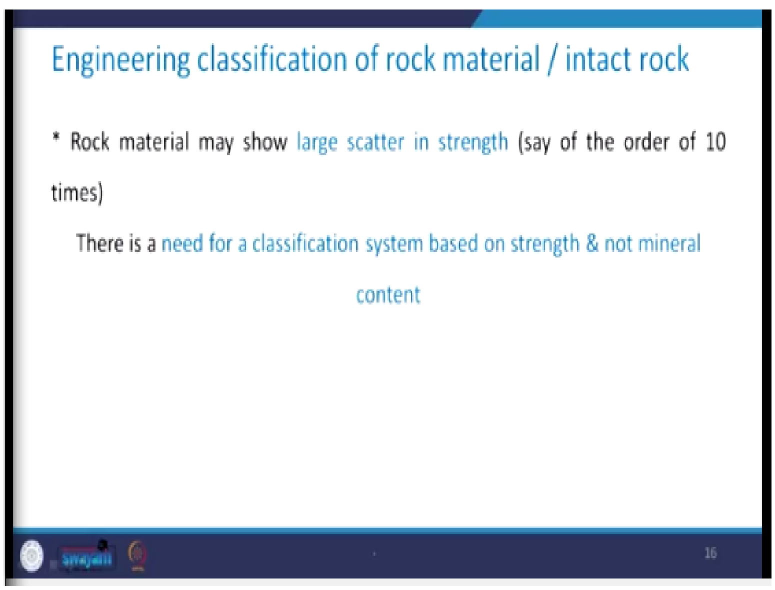

So, once again why do we need? So, when you see that this modular ratio, that also is showing, large scatter in the strength. And therefore, there is a need for the classification based on the strength and not on the mineralogical content or mineralogical composition. So, one needs to go for the engineering classification of rocks as well as rock masses. So, before we study about the classification of the rock mass. We need to understand the concept of Rock Quality Designation which we will be using pretty often in almost all the rock mass classification systems, in short it is called as RQD.

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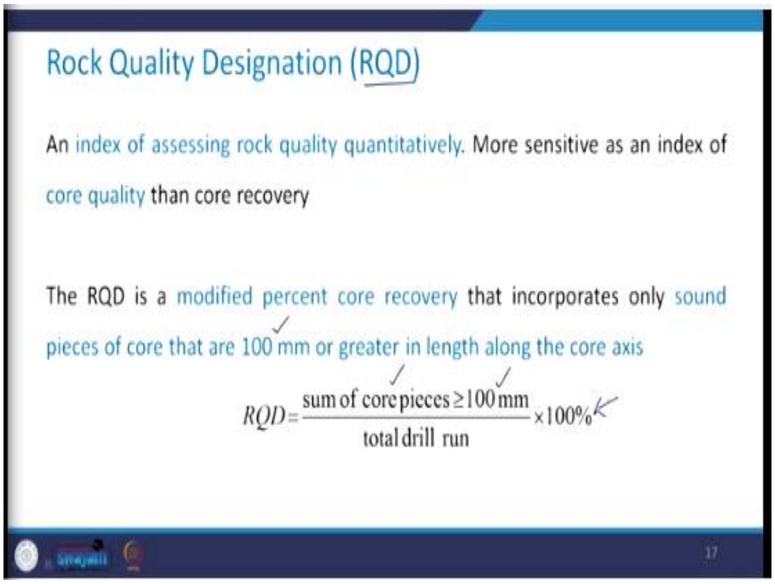

It is an index of assessing the rock quality in the quantitative manner, this is more sensitive as an index of core quality than the core recovery. So, there are going to be 2 terms: rock core recovery and another one is Rock Quality Designation. There is a difference between the 2, what is it? We will see it now. So, first of all let us learn about this RQD, so this RQD is defined as a modified percent core recovery which incorporates only the sound pieces of core that are 100 mm or greater in length along the core axis.

And therefore, the RQD is defined as

$$RQD = \frac{sum\ of\ core\ pieces \geq 100mm}{total\ drill\ run} \times 100\%$$

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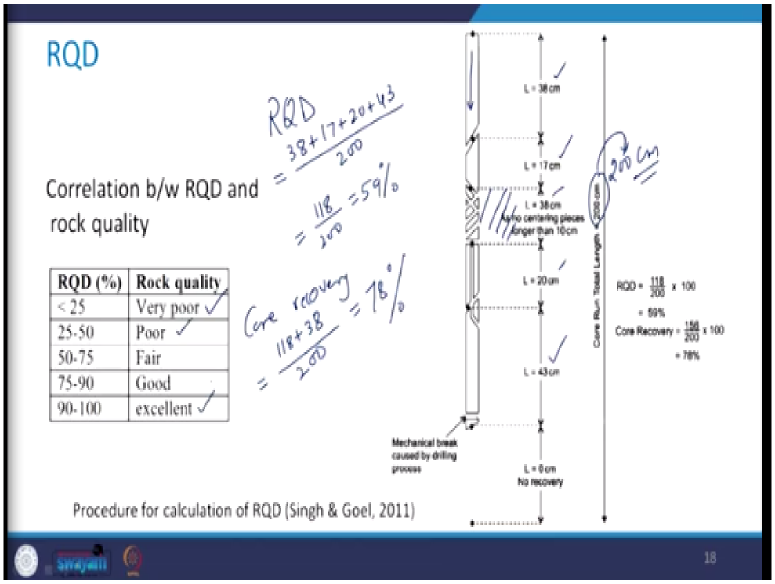

We take a look at this picture and it will become clearer. So, you see here that this is the axis of the coring, that the axis of the coring, total core run length is 200 cm in this case. Now the cores which have been recovered, they are having the length 43 cm, 20 cm and then here in between you have 38-centimeter length where no centering piece longer than 10 cm was obtained, and here you have 17 cm and 38 cm.

So, RQD is going to be what? See this RQD is going to be sum of all the pieces which are more than 10 cm long. So, we will start from the top that is 38 + 17 + because here in this zone, there is nothing which is more than or longer than 10 cm so we are not going to take that + 20 + 43. So, this divided by the total core run length which is 200, so you see this will work out to be 118 divided by 200 which is equal to 59%, so this is what is RQD.

Now what is core recovery? So, in core recovery, we will add all the pieces, so the core recovery is going to be, in this case, sum all these pieces. So, this 118 is there which were there more than 10 cm, so you add + 38 divided by 200 and when you solve it you will get 78%. Remember, that RQD can never be more than core recovery. Core recovery will always be more than RQD or at the maximum RQD can become equal to core recovery, which is in the ideal case.

That means all the pieces that have been recovered from the core along it is axis, they have length more than 10 cm. Now based upon the value of RQD, one can classify the rock quality. So, when you have RQD < 25, it is very poor, between 25 to 50 poor and so on, if it is between 90 to 100 it is excellent.

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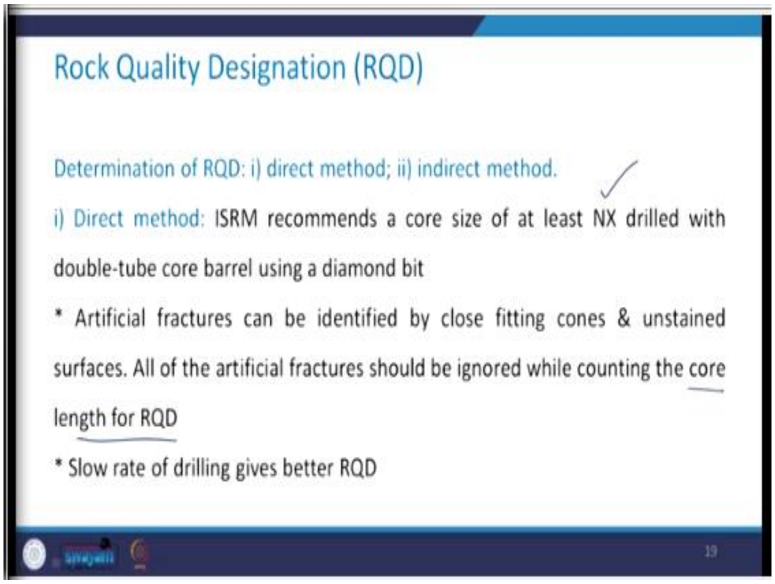

Now, how to determine this RQD? We have different methods. So, the first one is direct method and the second one is indirect method. As far as direct methods are concerned, I just explained it to you that we need to go for a coring using the double tube core barrel with the help of a diamond drill bit. And at least NX sized drilled core should be there.

Then we need to see that artificial fractures with close fitting cones and unstained surfaces, that should not be considered while taking the core length for RQD. So, it should be, I mean, you can ignore all these things when you calculate this RQD. The slow rate of drilling obviously will give the better value of RQD.

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So, you see these pictures you have seen earlier also. So, you can see that there are few pieces where you have the length of the core more than 10 cm. So, depending upon see this the length of this core was to the tune of I think it was 40 m. So, 40 m was the total core run length and this has been arranged in that order the way it has been recovered from the ground.

So, you measure whichever piece has a length more than 10 cm, keep on summing up, adding up their length. Like for example, you can see here this and especially in this box, you see this they all have the length more than 10 cm, similarly you have here like this here. So, you add some of these and then directly you will be able to get RQD.

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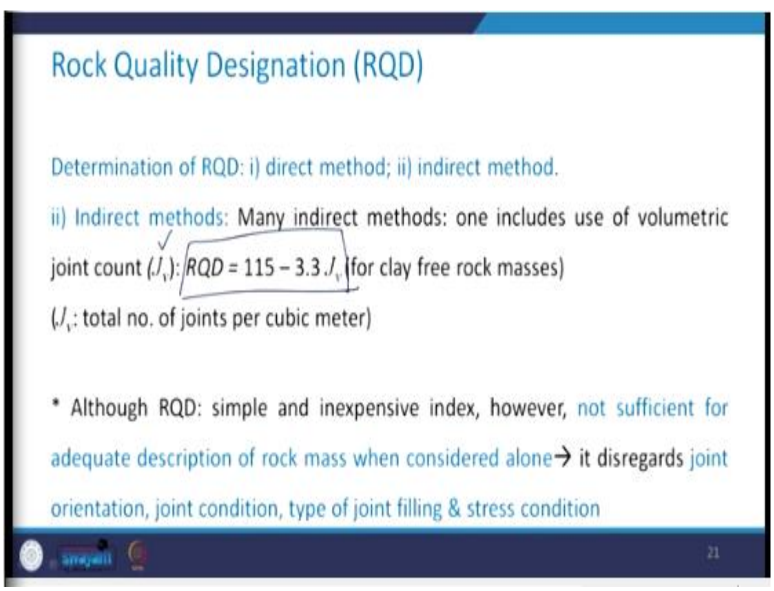

Now in case, we do not have this core boxes with us, there are many indirect methods. So, one of the indirect methods it makes use of the volumetric joint count which is represented as J_v. And the RQD is connected with this J_v in this form with this expression which is $RQD=115 - 3.3\ J_v$, and this is for clay free rock masses. Although this RQD is a very simple and inexpensive index. However, it is not sufficient to completely classify the rock mass when it is considered alone.

Because it is not taking into account the joint orientation, joint condition or the type of joint filling and stress condition. However, it is very important but it is not the complete thing in it is own. So, we need to take a look at different aspects related to the joints. The application of this RQD is first and foremost.

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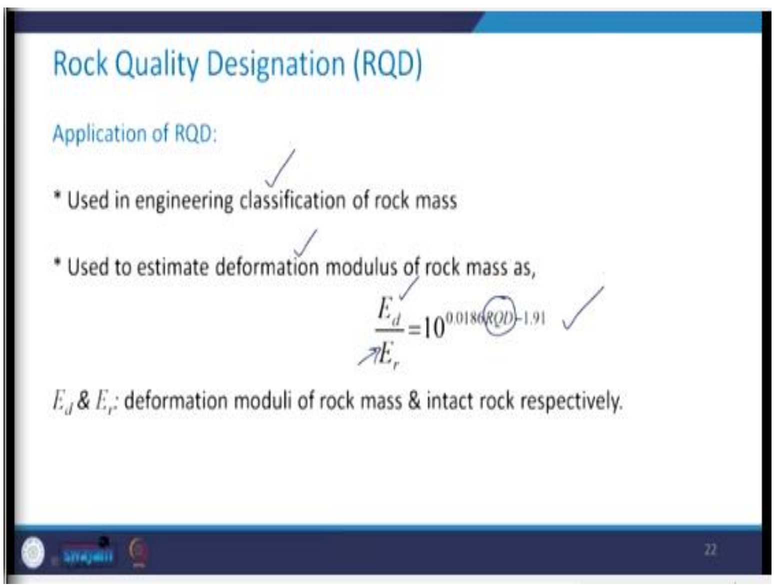

That is what that we are going to discuss in the engineering classification of the rock mass. Then it is used to estimate the deformation modulus of the rock mass, you can see here E_d is the deformation modulus, E_r is the modulus of the intact rock and here this RQD is coming into picture. So, using this expression one can obtain the deformation modulus of the rock mass. Now till now, we have learned about the elastic modulus, what is this deformation modulus?

Because I will be using this pretty often throughout this course. So, right at this point of time it is important for you to understand this term deformation modulus.

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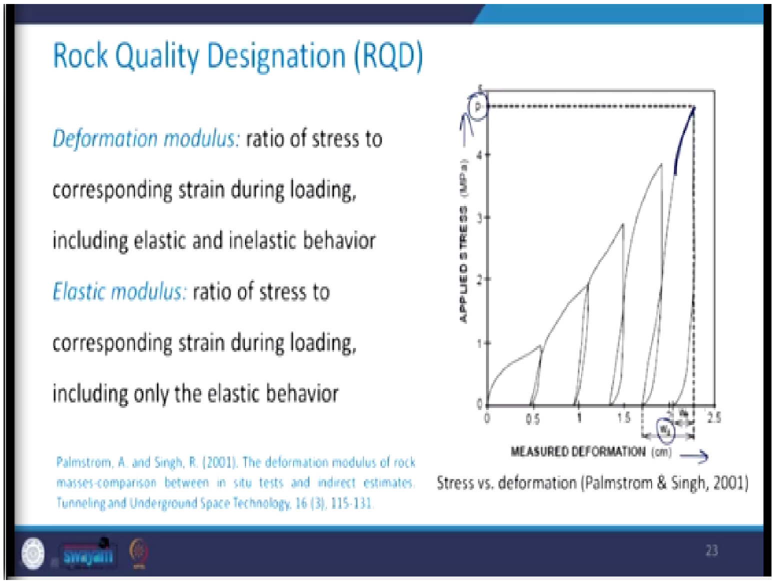

Take a look, here on the x axis you have the measured deformation and here you have the applied stress. So, the difference between deformation modulus and elastic modulus has been given here. As for as deformation modulus is concerned, it is the ratio of a stress to the corresponding strain during loading including elastic as well as inelastic behavior. However, in case of the elastic modulus, you do not consider inelastic behavior**,** you consider only the elastic behavior.

That means, whatever is the slope of that elastic part of the stress strain curve, we find out the elastic modulus from that. But here you see that elastic as well as this inelastic portion is also there. So, we consider the whole thing, that is here you see the total deformation is there, w_d. So, when we take the whole thing that is this is the applied stress and here you have the corresponding deformation from here, you will find out the deformation modulus.

So, the difference between deformation modulus and the elastic modulus is in case of the deformation modulus you have to consider elastic as well as inelastic behavior during the loading cycle. But in case of the elastic modulus, you consider only the elastic behavior. So, this is what that I wanted to discuss with you today. So, we discussed with you that why there is a need for the engineering classification of the rock mass and intact rocks.

Then we saw the classification for the intact rock, that uses the modulus ratio, we learnt about the concept of rock mass, then Rock Quality Designation. And lastly, I told you the difference between deformation modulus and the elastic modulus. So, in the next class, we will start our discussion on different engineering classification system for rock masses. And there first we will discuss about the various factors which influence the characteristic of the rock mass. And then we will proceed with the different classification systems. Thank you very much.