Underground Space Technology
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Module No # 01
Lecture No # 04
Basics of Rock Engineering: Classification of Intact Rocks, Concept of Rock Mass, RQD

Hello everyone, in the previous class we discussed about the determination of tensile strength of rock and also the shear strength characteristic using the tri-axial shear tests. So, today we will discuss few aspects related to classification of intact rocks. I will introduce you to the concept of rock mass and also the rock quality designation. As of now whatever test that we conducted those were on the intact rocks.

So first, we will learn about the rock mass concept, and then the concept of RQD I will be introducing to you. So, before that first we will have the difference between the rock material and the rock mask. Although I discussed this with you in the very first lecture but let us do that all over again because we will be doing this repeatedly many times throughout this course. So, when I say rock material this refers to the intact rock within the framework of discontinuities.

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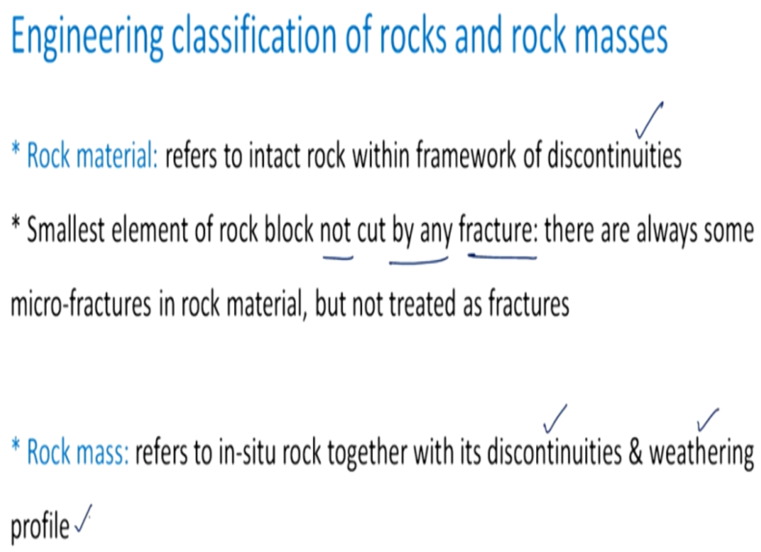

So, the smallest element of rock block which is not cut by any fracture although there is always going to be some micro fractures in the rock material. But these are not treated as fractures. So, the rock material is the smallest element of rock block which is not cut by any fracture although micro fractures or micro cracks may be present. Now coming to the concept of rock mass basically it refers to the in-situ rocks together with its discontinuity and weathering profile. So, when we have the intact rock plus the discontinuity this is called as the rock mass.

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Engineering classification of rocks and rock masses

(https://www.flickr.com/photos/jsjgeology/39608069664)

Take a look here on this picture this is a very nice picture and self explanatory say I get a sample only this portion of the rock. So, if I extract this specimen from there so it will not have any kind of discontinuity. So, that will be the intact rock but if I see this picture as a hole there are intact rocks as well as the discontinuities as you can see that these all are discontinuities various joint sets are there.

So, this as a whole we call as rock mass so this should be extremely and crystal clear to all of you that when I refer to rock or rock material that means intact rock and when I say rock mass that means the intact rock with discontinuities.

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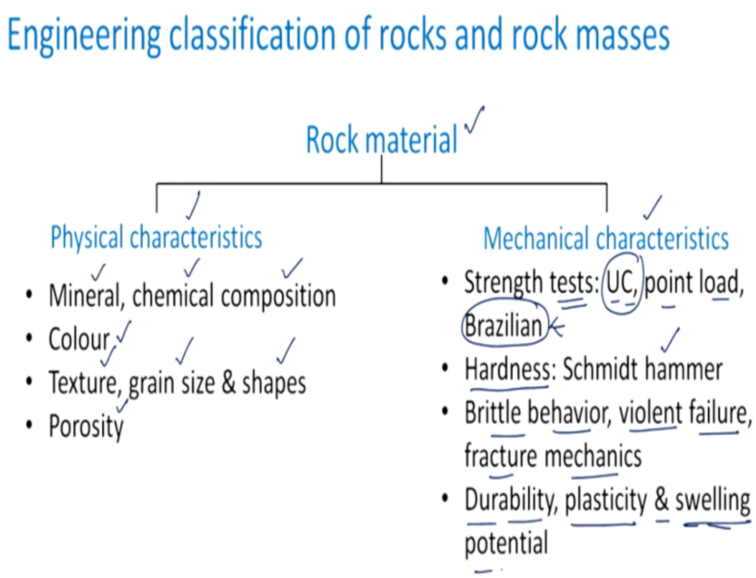

Now coming to the rock material so what is this? This is intact rock we saw that its physical characteristic and the mechanical characteristics so the physical characteristics included mineral and chemical composition its color, its texture grain size and shapes and porosity. However, when they talk about the mechanical characteristics so, here we have strength test. So, what all are the strength is unconfirmed compressive strength test then point load strength index test, Brazilian test.

Out of these, we have already seen unconfined compressive strengths and also the Brazilian test. Then hardness which is determined by Schmidt Hammer test it can have brittle behavior this also can be written as violent failure in this case and the fracture mechanics comes into picture. I showed you that how the same rock can behave as the brittle material also as a ductile material when it is subjected to the shear test under different confining pressures.

Then durability plasticity and swelling potential so all these comprise of the mechanical characteristic of the rock material that is intact rock.

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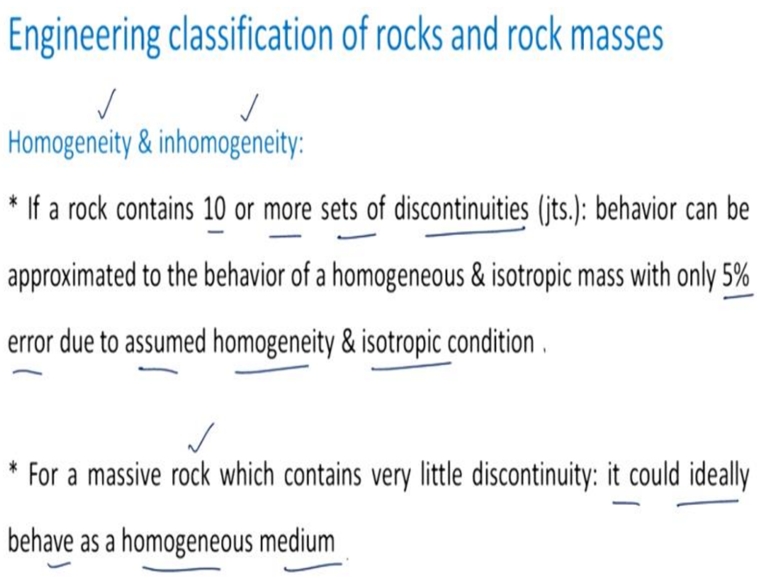

Now the concept of homogeneity and inhomogeneity let us say that if a rock contains 10 or more number of sets of discontinuities or joints its behavior can be approximated to the behavior of the homogeneous and isotropic mass with only 5% error due to assumed homogeneity and isotropic condition. For a massive rock which contains which contains very little discontinuity, it can also ideally behave as a homogenous medium.

So here we have the 2 extreme, on one side we have the massive rock which we are treating as a homogenous medium. And on the other side if the rock has 10 or more discontinuities, then also, we can consider it to be homogenous and isotropic medium because it is if we compare its behavior to a proper homogenous and isotropic mass there is going to be the error of to the tune of say 5% only.

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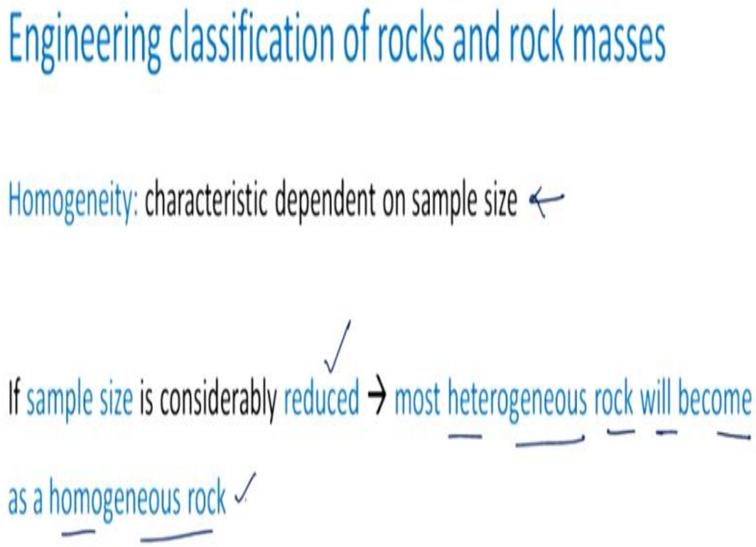

Homogeneity is the characteristic that depends on the sample size so if the same size is considerably reduced most heterogeneous rock will become as a homogenous rock. Please remember this with the help of the figure I will try to explain this.

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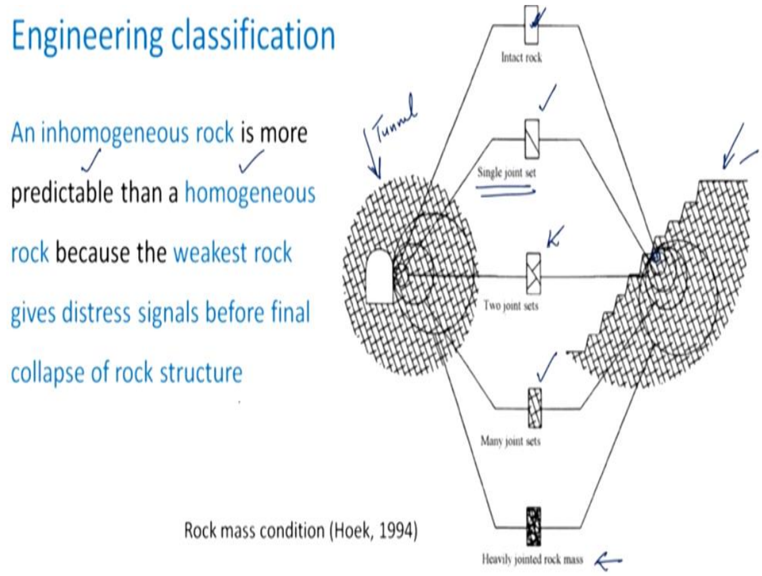

Once again, take a look here this is an example of the slope and this is an example of the underground excavation now see here as these circle is larger there are more number of discontinuities if the sample size is larger. If the sample size is small, you see here this is a small circle. So, if the sample size is small and if you take the specimen out of it, what you will get is the intact rock. So, whether, it is the slope material or whether it is the example of a slope or of the tunnel or any other excavation.

If you take out the sample size which is small very small then you may get the intact rock specimen from there. But let us take out some bigger specimen there you have single join that is coming into picture. So, you will have a single joint set you increase the size of the specimen you will have two joint set further increase many joint set further increase this will result into heavily jointed rock mass.

So, you see that how the sample size if we control this if we reduce this significantly how the most heterogeneous rock becomes as a homogeneous rock. Now an inhomogeneous rock is more predictable than the homogenous rock because the weakest rock will always give you the stress signal before the final collapse of the rock structure. However, in case if you have the solid rock mass and then it will not give you any stress signal and the failure is going to be sudden and catastrophic you will not get any time. You know to provide some kind of support measure to prevent that failure.

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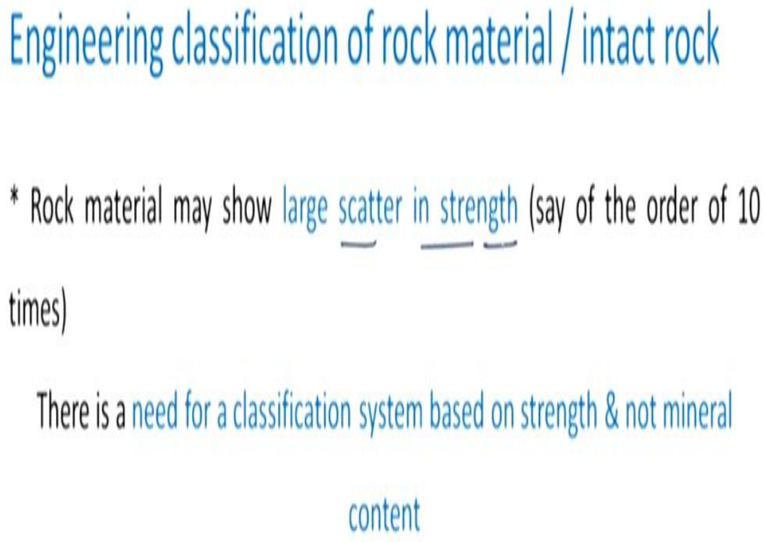

Now this rock material it may show large scatter in strength and this can be of the order of you know 10 times. So, there is always a need for the classification system based on the strength and not only on the mineral content. So, we will learn about some of the classification system first for the intact rock and then we will discuss about the classification system for the rock masses.

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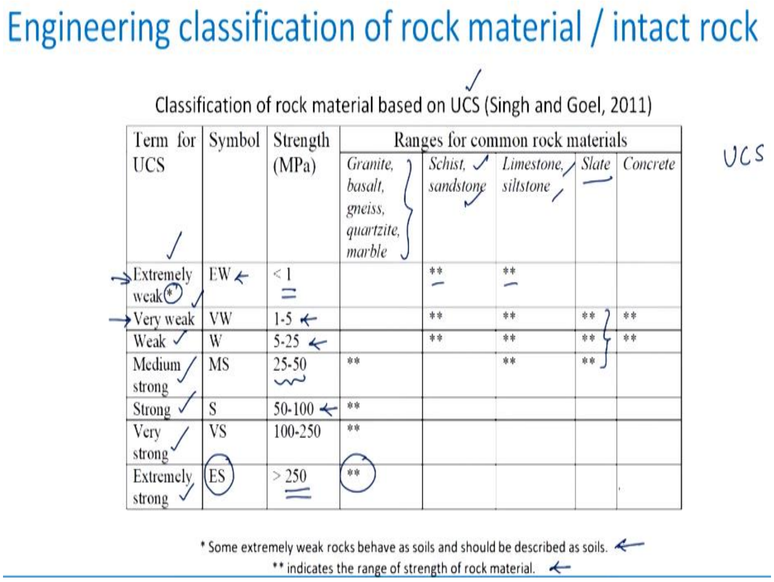

Term for UCS	Symbol	Strength (MPa)	Ranges for common rock materials				
			Granite, basalt, gneiss, quartzite, marble	Schist, sandstone	Limestone, siltstone	Slate	Concrete
Extremely weak*	EW	< 1		**	**		
Very weak	VW	1-5		**	**	**	**
Weak	W	5-25		**	**	**	**
Medium strong	MS	25-50	**		**	**	
Strong	S	50-100	**				
Very strong	VS	100-250	**				
Extremely strong	ES	> 250	**				

* Some extremely weak rocks behave as soils and should be described as soils.
** indicates the range of strength of rock material.

So, based upon the unconfined compressive strength the classification of the rock material when I say rock material it is intact rock the classification of the rock material is given here. So, you can see that if the strength is less than 1 mega Pascal so when I say strength means I am talking about the UCS that is unconfined compressive strength here with reference to this particular cable.

So, if the UCS value is less than 1 MPa the term that would be used for the rock would be extremely week and the symbol that it will be represented as it will be EW. So here some of the range of the common rock materials which fall under this category is mentioned here. So, the rocks like Schist sandstone, Limestone and siltstone they fall under this category. So, you see this double star it indicates the range of the strength of the rock material.

Now here this 1 star is there so some extremely week rocks they may behave like a soil and these should be particularly described as soils and not as rock. So, we need to be careful now the second category is when you have the UCS value lying between 1 to 5 MPa it will be categorized in very weak category that is VW as the unconfined compressive strength increases you will have the better rock material as far as the strength is concerned.

So therefore, from the extremely week there will be very weak and then weak then medium strong, strong very strong and extremely strong and you can take a look at these values that how this UCS value is increasing from 5 to 25 here in this category. Then 25 to 5200 and so on and for extremely strong category the UCS value comes out to be more than 250 MPa and this represented as ES.

So, basically the first category that is Granite Basalt nice, Quartize and marble they fall under this category. So various types of rocks a range of typical rocks they are given and then you can get the idea from this table that let us say if I say it is a slate type of rock. So, you can get the idea that ok slate so slate is here. So, it will fall it may fall under these categories so it is not that you take slate from 3 different location and they will have the exact value of UCS.

No these are all natural occurring materials so they differ from one place to other based on their mineral content. So, accordingly you will always have a range in case of rock mechanics and rock engineering rather than having a very specific value.

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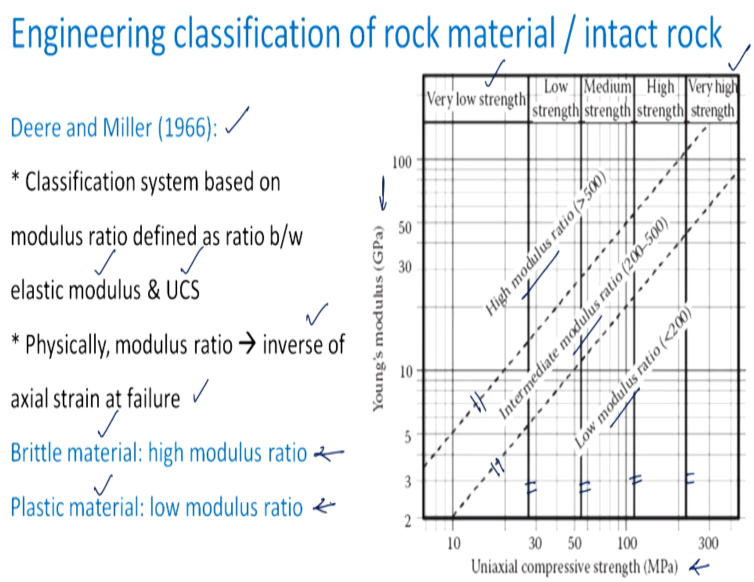

So, here is the other classification system that is Deere and Miller classification system which was given in 1966 and this figure is the self explanatory which is plot between the uni-axial compressive strength or unconfined compressive strength in mega Pascal and the modulus of elasticity in Giga Pascal. So, some ranges are given you can see that some thick vertical lines are there which divide this whole space into 5 columns where it starts from very lowest strength and it goes up to very high strength.

And then you can see that there are 2 dotted lines which divide this further into 3 areas these represent low modulus ratio, intermediate modulus ratio and high modulus ratio. So, basically let us first understand that what do we, mean by the modulus ratio so this defined as a ratio between the elastic modulus and the UCS value. So, physically this modulus ratio is basically the inverse of the axial strain at failure.

As far as the brittle materials are concerned you have the high modulus ratio in case of the plastic material, they posses low modulus ratio.

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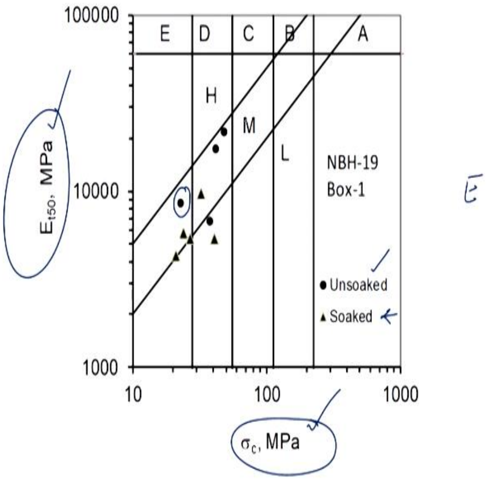
Engineering classification of rock material / intact rock



So, in the next slide I have pasted a figure which is giving you an idea this is a typical figure from a site where we tested the sample and then try to get the elastic modulus as well as the UCS of those samples and then have put all the data on the one space. Let us take a look so these dark circles they represent the un-soaked samples and the triangles they represent soaked samples.

So, you find out UCS and E_{t50}, how to find out E_{t50}? That we have already discussed in some of the earlier lectures so we can locate the particular point based upon the value of UCS and E_{t50} and then wherever this is lying. So, let us focus on this so what will be the classification for this sample this will be C E and this is lying here so EM or maybe you can call this as the specimen of intermediate modulus ratio and very low strength.

So, this is how the classification system which was given by Deere and Miller is used to classify the rock material or intact rock. I am repeating again that this is the classification system for the intact rock.

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Engineering classification of rock material / intact rock

Typical values of modulus ratio (Sivakugan et al., 2013)

		Texture		
	Coarse	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

Now the typical values of the modulus ratio they are given for different types of rocks here. So, the first table gives you the various types of rock which fall under the category of sedimentary rock so you can see that typical range is there so here you have the texture based upon that you have 3 category medium, fine and very fine. So, you can refer this table and get the typical idea about the values of modulus ratio based upon what type of rock that you are dealing with.

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Engineering classification of rock material / intact rock

Typical values of modulus ratio (Sivakugan et al., 2013)

		Texture		
	Coarse	Medium	Fine	Very fine
Igneous	Gabbro 400-500 Norite 35-400	Dolerite 300-400		
	Porphyries (400)[c]		Diabase 300-500	Peridotite 250-300
		Rhyolite 300-500 Andesite 300-500	Dacite 350-450 Basalt 250-450	
	Agglomerate 400-600	Volcanic breccia (500)[c]	Tuff 200-400	

[c] no data: estimated on basis of geological logic

Similarly, here in case of the metamorphic rock you have marble granite may be Meta sandstone, Quazite, mica schist, slates. So, you can get the idea about the typical values of the modulus ratio and this is the table for igneous types of rocks. So here it has say basalt may be Gabbro, Norite and many like that. So, in case most of the time we conduct the test in the lab we find out the UCS value and E value and then try to find out from the result of UCS test we try to find out what is the modulus ratio.

But let us say in case if you are not able to get it so these are some of the reference values which where you can get some idea that what will be the typical value of the modulus ratio.

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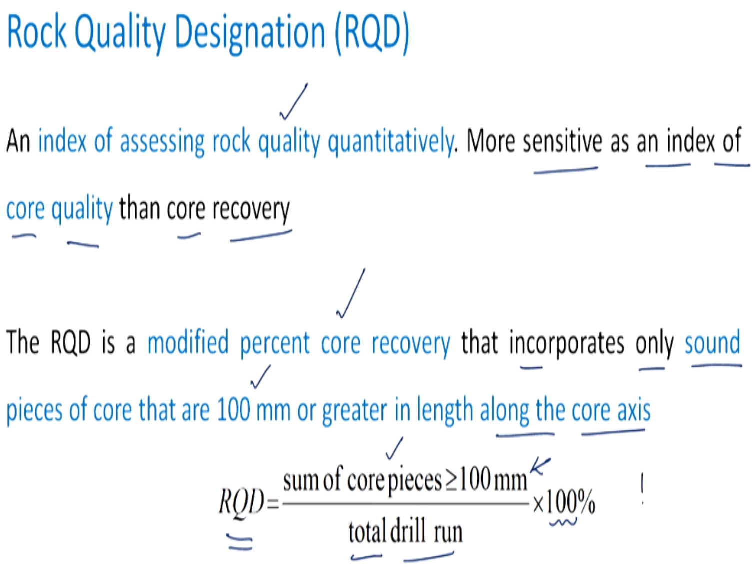

So, these measures large scatter in strength and therefore it is important to have the classification system based on the strength and not on the material content. So, in this context before we go ahead with the classification system of the rock mass let us first understand this particular term which is rock quality designation in short we call it as RQD which is extremely important with reference to the rock mass.

So, it is an index of assessing rock quality in a quantitative manner it is so sensitive as an index of core quality rather than core recovery. Now what do we mean by this core quality core and core recovery you will learn in a while bur first let me tell you that how this RQD is defined. So, this is a modified percent core recovery that incorporates only sound pieces of core which are 100mm or greater in length along the core axis.

So, RQD = (sum of core pieces ≥100mm / total drill run) × 100 %

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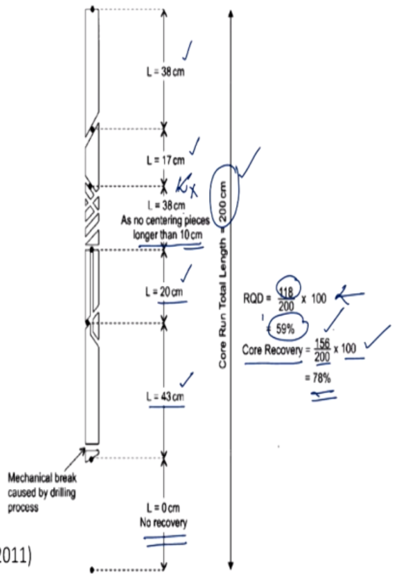
RQD

Correlation b/w RQD and rock quality

RQD (%)	Rock quality
< 25	Very poor
25-50	Poor
50-75	Fair
75-90	Good
90-100	excellent



Procedure for calculation of RQD (Singh & Goel, 2011)

Take a look at this figure so you see that the total core run total length is 200 centimeter in this case. And this is how that you have obtained say the core all along the depth of this drill hole. So, up to this there was no recovery then you get a piece of L as 43 centimeters followed by 20 centimeters and then here it is L = 38 centimeter but no centering piece which is longer than 10 centimeters.

So, basically you see that RQD will be what? That, whatever are the pieces that you have recovered which have the length more than 10 centimeter or equal to 10 centimeter. So take a look what all we will consider? We will consider 43 we will consider 20 but here there is no piece which is longer than 10 centimeter. So, we will not consider this we will consider 17 and we will consider 38. If you sum all these you will get 118 and this divided by the total core run length which is 200 centimeters.

So, the RQD value is going to be 59% in this case come to the core recovery. Now in core recovery whatever is the length of the core or the pieces that you have got after the drilling everything you will add it up. So, here in this case you have to add this 38 as well so here this is going to this core recovery will be 156 by 200 multiplied by 100 that will be equal to 78%. So, please remember there is a difference between RQD and core recovery in core recovery we take all the pieces that have been recovered over the total core run length.

And we find out in this particular manner but in case of the RQD we will include only those pieces which have length greater than or equal to 100 mm and that how is how we find out RQD in this particular manner. Now there is a correlation between RQD and rock quality and that has been shown in this table. So, in case if RQD works out to be less than 25 the rock quality is said to be very poor if it is 25 to 50 it is poor 50 to 75 it is fair if it is 75 to 90 good quality rock 90 to 100 it is the excellent quality of rock.

So, this RQD becomes very important and that is used in many of the rock mass classification system. So, right now at this stage it is very important for you to understand the concept related to rock RQD in a most clear manner.

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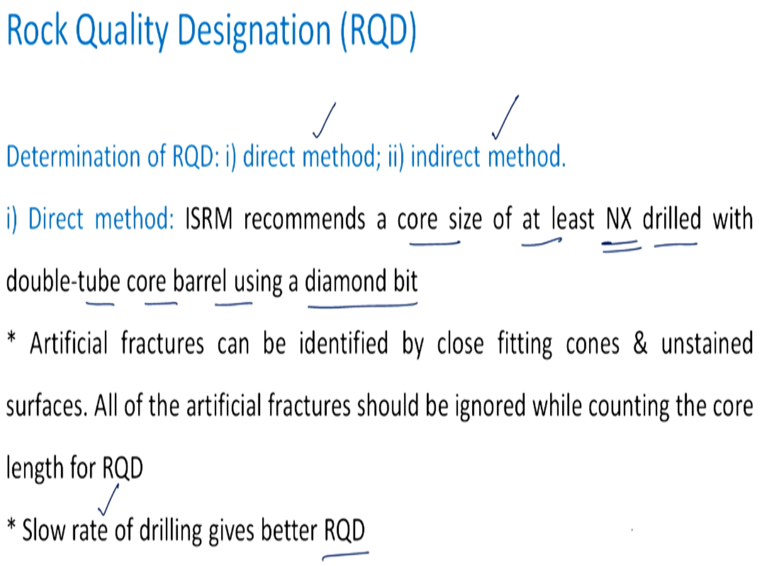

Now how to determine RQD one method I have already discussed let us see what all things are available to us. First is the direct method and then you have the indirect method in the direct method that is what we discussed that ISRM that is international society of rock mechanics recommends a core size of a least NX which is drilled with double tube core barrel using a diamond bit.

In this, artificial-fractures can be identified by close-fitting cones and unstained surfaces. So, all the artificial fracture should be ignored while counting the core length for RQD. Another point which is to be noted is if you go for the drilling that will give better value of RQD. Because if you go ahead with a drilling at a very faster rate it will generate more heat and with that higher rate of drilling there will be more deterioration in the surrounding rock mass and, it will introduce more number of cracks, or joints fresh cracks in the rock course that you will retrieve.

And in that process you will get lesser number of course which will be having length maybe more than or equal to 100 mm. So, the faster rate of drilling will not give you better value of RQD but the slower rate of drilling gives you the better picture.

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So, you see that as I mentioned that when you are taking out the course from the drill hole this picture you have seen earlier as well. So, we keep arranging these so let us say that the total drill run was maybe let us say few meter. So over that much you just count that how many number of or what exactly was the total length of the core pieces which had the length individual length greater than or equal to 100 mm.

So, you see that here so what we need to do is? We measure this so whatever has not this one sorry. So, whatever has the length greater than or equal to 100 mm we will keep on adding those and that divided by the total drill run length multiplied by 100 is going to give us the RQD at that side for that particular rock. Now coming to the indirect method so there are indirect methods which are available.

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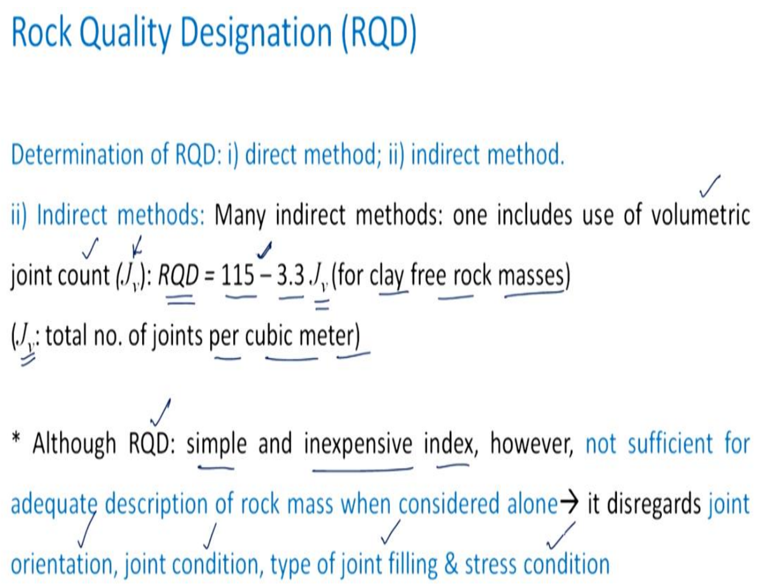

So, one of those includes the use of volumetric joint count which is represented by J_v and the expression for RQD =115 – 3.3J_v. Now you have to careful that this expression is valid for clay free rock masses that means all the joints there is no gorge material or there is deposition of the clay type of material in those joints. So, this J_v is the total number of joint per cubic meter and this you have to find out manually when you go to the field.

So, although this RQD is very simple and inexpensive index however when it is considered alone it is sufficient for the adequate description of the rock mass. So, the reason why it is not adequate because we are only considering the quality of the rock course that have been extracted from the drill holes. So, we are only considering the length that is what so ever has the length more than or equal to 10 centimeter we are considering that to calculate RQD.

We are not considering what is the joint orientation or the condition of the joint or the type of the join filling or the stress condition while calculating or determining this rock quality designation. So, these parameters such as joint orientation, joint condition type of join filling and stress condition. When I say stress condition means that whether it is the hydrostatic state of stress if it is uni-axial or it is bi-axial or many other such type of situation.

What are the in-situ stresses which are there in the field all, those thing play an important role towards the behaviour of the rock mass. So, we really cannot close our eyes and forget about these parameters and blindly follow the classification or the quality that is solely depending on the value of this quality designation. So, we have to consider these other methods to go ahead with the classification of rock mass.

Although I say that when, this rock quality designation or RQD is considered alone it is not sufficient but still it has lot of application. So, let us see what are all those applications are? So, it is one of the most widely used parameters in almost all the engineering classification of rock mass.

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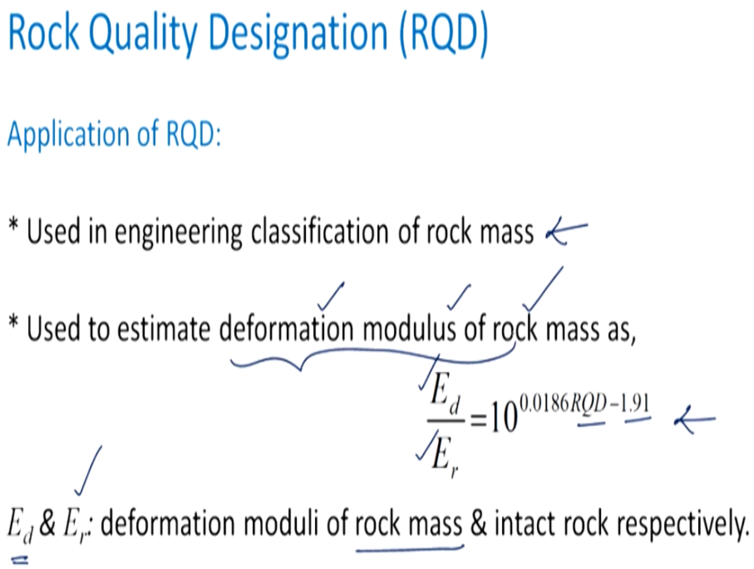

It is used to determine the deformation modulus of the rock mass that is given in this particular manner that is $E_d / E_r = 10^{0.018\ RQD\ -1.91}$. So, this is an empirical correlation which was developed after conducting the test on different types of rock and rock masses. So, E_d represents the deformation modulus of rock mass and E_r represents the modulus of the intact rock.

Now there is new term which is coming here deformation modulus so here at this stage it is extremely important for us to understand this particular term deformation modulus.

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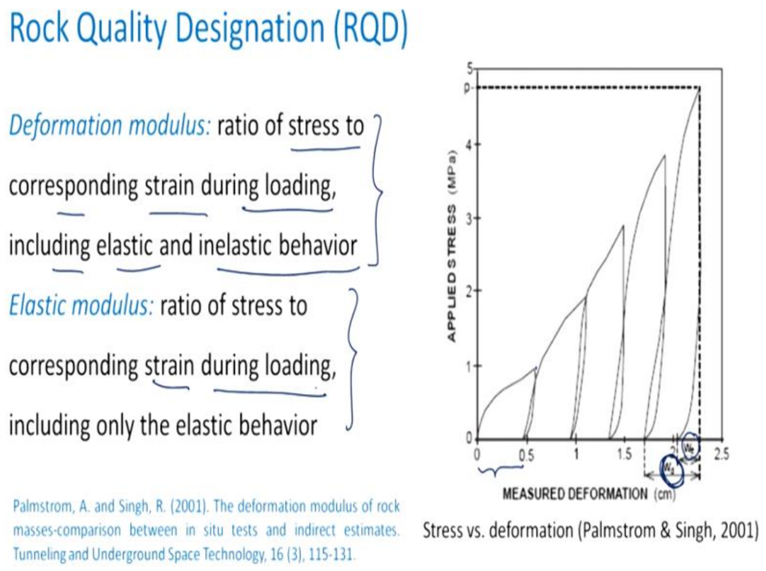

So, this picture is self-explanatory the difference between the deformation modulus and the elastic modulus has been explained here. See we conduct test in the field in the cyclic manner we load it first cycle here. Then we unload it what happens when the unloading takes place elastic part of the deformation is recovered. And you have some residual part which is the plastic deformation.

So, for every cycle you will get elastic deformation that is the WE and you have the total deformation that is WD. So, the deformation modulus is the defined as the ratio of the stress to corresponding strain during loading including elastic as well as the inelastic behavior. That means when you are finding out the deformation modulus you will use this total deformation. However, in case of the elastic modulus it is the ratio of a stress to the corresponding strain during loading including only the elastic behavior.

So that is a main difference between the deformation modulus and elastic modulus let me tell you here is that with reference to rocks and rock masses it is more often deformation modulus is used with reference to rock mass. So, with this background what we learnt is that, what is the concept of the rock mass how do we define between the intact rock and the rock mass. And then we learnt the concept of the RQD and, also, we saw the difference between the deformation modulus and elastic modulus.

So, with this background now we are ready to take up the classification of the rock mass there are various classification systems. So, we will discuss these in brief in some of the subsequent lectures, thank you very much.