Engineering geology
PROF. Debasis Roy
DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, Kharagpur

LECTURE - 19
Index properties of rock and rock masses

Hello everyone and welcome back. Today we are going to talk about index properties of rock and rock mass. Before we get on with the today's subject, we are going to consider the questions that I gave you in the last presentation.

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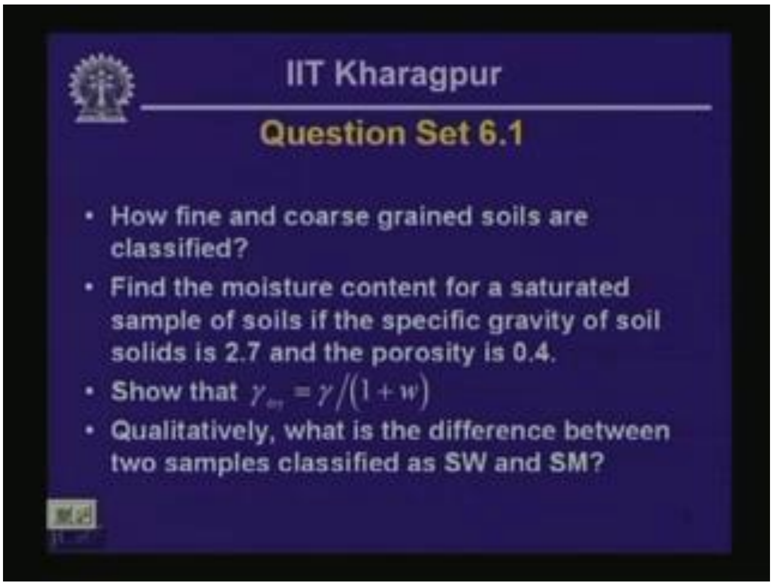

The first question that was asked was how find and coarse grained soils are classified? So basically, classification of fine grained soils and coarse grain soils have to consider the facts that these files, the behaviour of these files are primarily governed by plasticity and grain interlocking or grain size respectively. As a result, for classification, classification of fine grained soils, the main grain soils, the main consideration is the liquid limit and the plasticity index and we go into the Casagrande chart and the areas that is divided by this chart is sub divided again as I was explaining in the last presentation, let me repeat what I said.

So, let say this is the standard plot, what you brought here is a plot of liquid limit verses the plasticity index and you have got diagonal line, a sort of diagonal line that is called Casegrande's A line and this in turn I mean this zones are again subdivided by drawing vertical lines at liquid limits of 35 and 50 % this is actually according to the Indian standard classification system.

In case of the ASTN standard, the line at 50% is not there. So, what you got here is basically or one of these lines is not there in case of the ASTN standard. Now, what you do and also there is another sub zone near the bottom left of the particular plot which is reversed for a category called CL – ML.

Then what we got is basically, this one is O, this area is for, reserved for MH or OH type of soils and this one is for MI or OI then here we have got ML or OL, on the top left we have got CL and then we have got CI and finally on the top right we have got CH. So, this is the standard Indian classification chart for fine grained soil.

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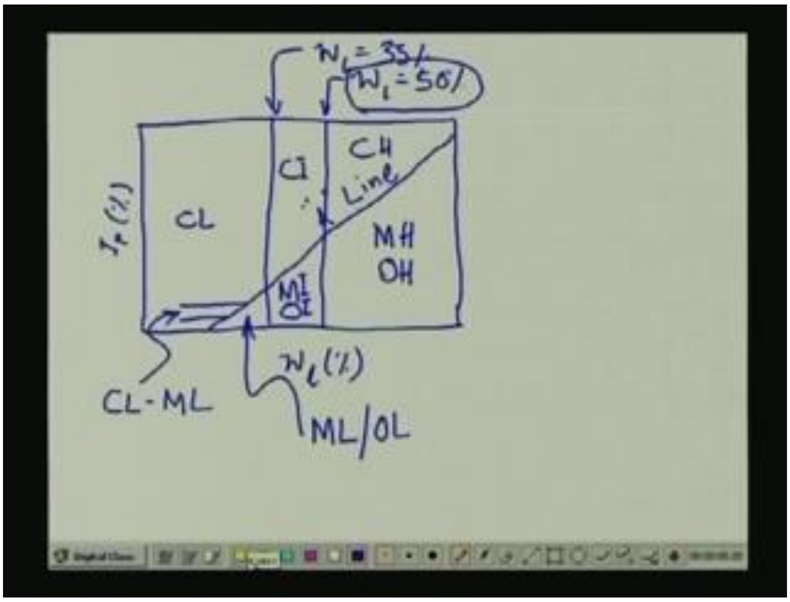

Now, let us get back; how did we classify coarse grain soils? In classification of coarse grain soils what we looked at is the grain size of these types of soils and we considered only those soils which have more than 50% of coarse grain particles that is particles that are courser than, sand size particles are courser that means the particles which are retained on sieve of opening size of 0.75 millimetre and then these types of soils, so 50% of the total weight of the soil will be composed of grain size of sand size or courser and then there were two sub categories of these types of soils.

In one of the sub categories more than 50% of the soil is composed of gavel size particles and as you recall from previous days lesson; gravel size particles are those particles which are retained on mesh or sieve size of opening of 4.75 millimetre and if more than 50% of the soil is composed of sand size particles, then they are called sands.

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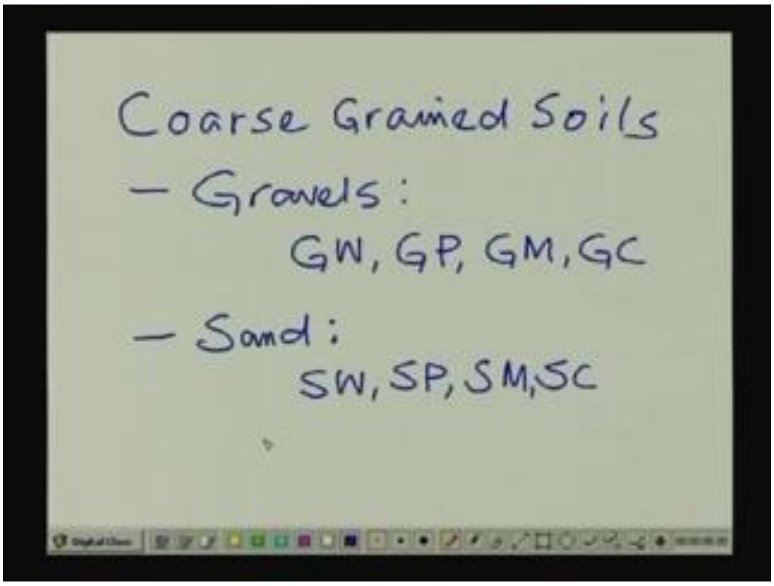

And so, what we got here is again this is for course grained soils, so we could have, we can have gravels and these types of soils have got several different classes like well graded gravel, poorly graded gravel, silty gravel or clayey gravel, then you have got sand. In case, the particles more than 50% by the weight of the soil particles are composed of sand size particles, then these things are also have got 4 sub categories; well graded sand, poorly graded sand, silty sand and clayey sand. So, that is in a nut shell the procedure used in the Indian standard classification system for classifying fined grained and course grained soils.

The second question what I gave you was to I asked you to find the moisture content for a saturated sample of soil if the specific gravity of the soil solids is 2.7 and the porosity is 0.4. Let us get back to the tablet. So, what is, we have to porosity to void ratio, so we know that that void ratio e is given by n over 1 minus n. So, n in this case is equal to 0.4, so what we got here is void ratio of 0.4 over 0.6 that is equal to 0.67.

Now you recall, see what we have to show here is an identity, actually what we have to calculate now is the moisture content. So you recall; in the last day's presentation, we used an identity given by this saturation ratio multiplied by void ratio is equal to the moisture content multiplied by specific gravity of solids.

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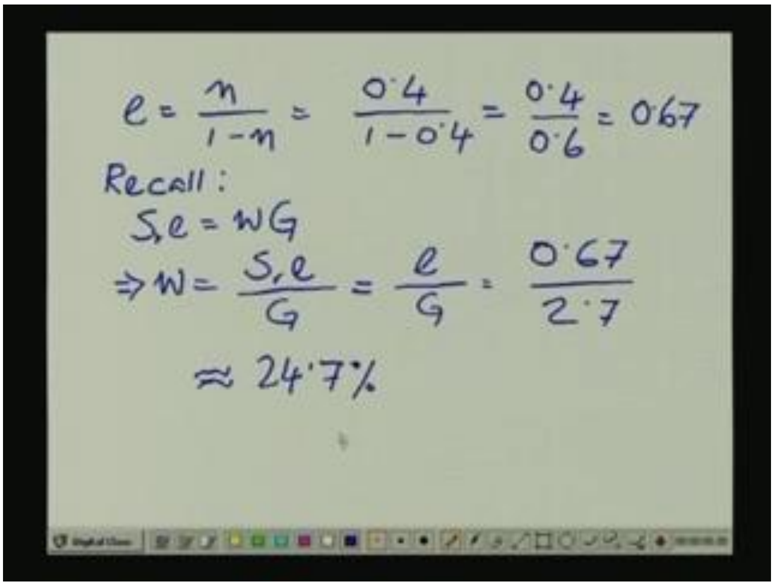

So, that gives us what W is equal to G divided by Sr sorry, W is going to be given by just the inverse of that really, so W is going to be given by saturation ratio multiplied by void ratio divided by the specific gravity of solids. We know in this case saturation ratio is 1 because the sample is completely saturated, so our moisture content will be given by void ratio divided by the specific gravity of solids that is 0.67 divided by 2.7 which is going to be approximately equal to 24.7%. We multiply it by 100 and we express the moisture content in this case in percentage. So, that is the second solution.

And, the third question that I asked you was to show, was to prove the identity that gamma dry is equal to gamma bulk over 1 plus w and let us look at the proof. You remember moisture content is given by rate of water divided by rate of solids, so that gives us 1 plus W is equal to Ww plus Ws divided by Ws that mean the total rate of the three face material divided Ws that is in turn going to be giving us Ws, this is big W, actually Ws is going to be equal to capital W that is the weight of the entire three face soil sample divided by 1 plus the moisture content.

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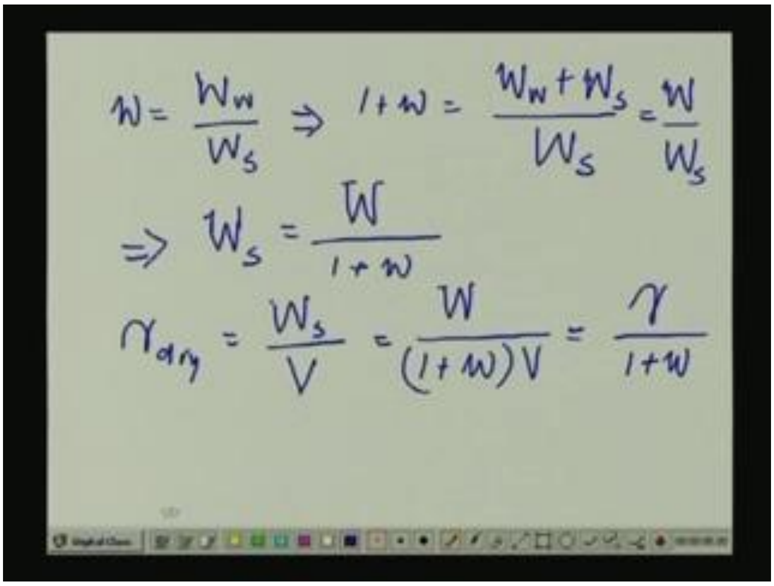

Now gamma dry is equal to weight of solids divided by the total volume of the three face material. So that, using the result that we just now derived is going to be W, capital W is the weight of the entire foil specimen divided by 1 plus the moisture content - small w multiplied by V and we know the capital W by capital V is equal to gamma that is the bulk unit rate that can be replaced by gamma and what we are left with the denominator is 1 plus W. So, that is the identity that I asked you to prove there, so in this case gamma dry is equal to the bulk unit rate divided by the divided by 1 plus the moisture content. Gamma dry in this case is the dry unit weight and all other terms used in this derivation is explained.

Then the fourth question that I asked was; qualitatively what is the difference between two samples classified as SW and SM. So, the matter in this case is both of these specimens they are going to have representations of a large range of grain sizes but the difference between SW and SM is essentially that SW well graded sand, it has got very minor amount of fines present, so it is basically a type of clean sand; whereas SM is the designation used to denote silty sand which has got quite a few tonnes or percents of silt size particles present within the matrix.

So, that takes care of the questions of the previous lesson. Now, we will move on to the subject matter of today's lesson. So, we begin with the objectives of this lesson; what we want to learn from this particular lesson. We are going to learn the fact, we are going to list, we should be able to list the factors, main factors that govern the engineering behaviour of intact rock specimens and rock masses, then we should be able to estimate some indices that govern these behaviours and using this insight, we should be able to classify rock masses. So, that actually is or those are the objectives of the particular lesson.

Now, let us try to understand what is that we mean in the engineering sense by the term rock. Now, if you recall from our earlier lessons that rock, there is a fossil line that separates rock from soil in the sense that some soils could be stronger in fact than some weaker varieties of rock. So, there is really a fossil line that separates rocks from soil. So, what we tried to do earlier in order to differentiate the notions of rock and soil is that we said soils are in sense assemblage of mineral or organic materials, decomposed organic material just like just like rock but the difference between the rock and soil is in the fact that individual particles that compose soil samples, they can be relatively easily separated from each other.

So for example, if we take a sample of soil and if we take it, if we mix it up with a little bit of water and we try to put it in a blender and stir it vigorously and what we are going to end up with is that all the individual soil particles they are going to get separated from each other. But that is not going to happen if we do the same thing with the small piece of rock. So, the essential difference than is that rock mineral particles, mineral particles that compose a mass of rock they are stuck together by a much stronger bonds in comparison with individual soil particles. So, it is the individual rock particles, they are much difficult to separate from each other. So, that is the essential difference.

Now, it is a qualitative statement really and there is sacrosanct line or quantifiable line that separates the material what could be termed as rock from what could be termed as soil and this actually gives rise to lot of dispute, construction dispute if the construction contract is not probably rewarded.

Now anyway, so we then know that what is rock and rock is essentially a natural aggregation of mineral and this aggregation is usually cemented and as I explained that the bond of cementation is much stronger in this case, in comparison with most of the soils, then the aggregation is more compact than the soil that means the porosity of a rock mass is much smaller in comparison with that you would expect in case of the soil sample. Then rock mass also I mean, if you consider a relatively large volume of rock, then you are likely to see some discontinuities within the rock mass and rock is expected to occur in various states of weathering. So, this is actually a very qualitative description of the notion that is eluded by the term rock.

Then, what is the second bullet? The second bullet follows essentially from the first bullet. In that the rock mass response is controlled by the characteristics of both the mineral aggregation as well as the properties of discontinuities. So, in order to or if we want to see the engineering behaviour of rock, then we have to look at the engineering characteristic of the intact specimen of rock that is bounded by the discontinuities as well as the properties or the characteristics of the discontinuities themselves.

So, this is going to be a rather challenging job in comparison with soils because you remember that in case of soils we actually we were describing the properties of the three phase material considering the soil to be a continuum; unlike in this case where the mass is actually cress crossed by discontinuities. So, that is the basic difference that we will face when we are trying to look at engineering characteristic of rock.

First of all, we have to look at the strength. The first step in trying to characterise the rock I mean the engineering behaviour of rock mass, we are going to characterise the properties of intact rock specimens. The first thing that comes to mind is how you are going to characterise this strength of an intact rock specimen.

So, what we do typically is the easiest option is to conduct the uniaxial test; uniaxial compression test in which we have got a core sample with a cylindrical sample of rock really that is subjected to an axial compression. So, the sample of rock in this case, in this cartoon is shown with a brown rectangle on the left side of this particular slide and then what we are going to do is we are going to keep track of the deformation of the particular sample and the corresponding values of the axial force or axial stress and we are going to express the result as it plot between axial stress and axial strain.

You all know that axial stress in this case is going to be the axial force divided by the cross sectional area of the specimen and axial strain in this case is going to be the deformation in the actual direction divided by the undeformed length, undeformed axial length of the specimen. So let us say, let’s begin the test.

So first of all, we apply small load, small axial load, compressive load on the specimen and as a result the length of the specimen is going to shortened little bit and we are going to plot that particular value, corresponding value of the axial stress verses the axial strain and you look at the plot to your right and you are going to see the stress strain curve is going to gradually develop as we apply larger and larger amount of deformation on the sample.

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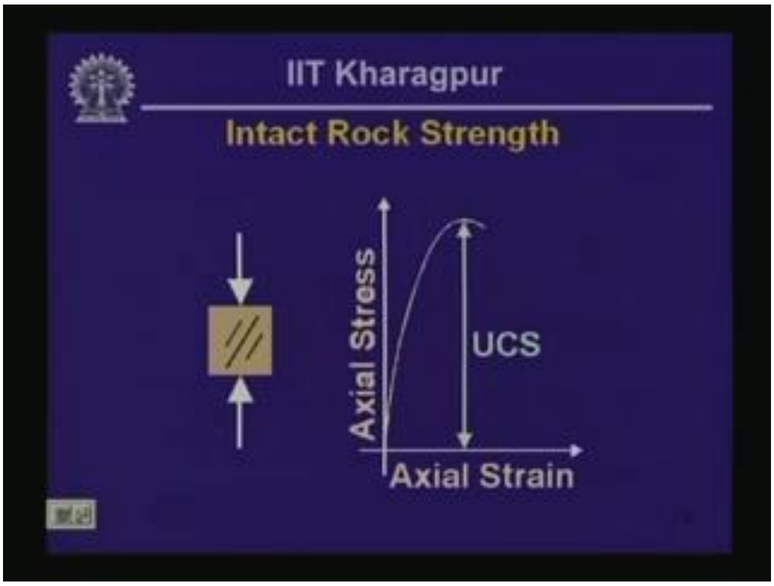

So, we increase the axial load and what we get is the further shorting of the sample and as a result we get a longer plot of the axial stress verses axial strain. Continue the test, the sample shortens further and it shortens further, the stress increases more, the stress goes up even further and you can see that the stress strain curve is trying to bend over to your right.

So, this is the nominal stress strain response we are looking at in this case and then what we are going to get is the stress strain curve is going to bend further over and it is going to become almost horizontal with no further increase in the stress possible and this particular situation is actually, it corresponds to development of damage within the sample because the sample is going to get damaged as the formation increases, cracks are lightly to develop in the sample as a result we might get a reduction in the strength as you are going to see in the next little bit.

So, if we try to deform the sample further, what you will see is that the stress doesn't go up anymore because the sample starts to crack up as it is shown by the dark lines going across the shortened specimen on your left and if we try to strain the sample even further, then these cracks they are going to actually propagate further and the sample, the strength of the sample is going to decrease even further and ultimately what is going to happen is the sample is going to split up and that is going to be an ultimate failure step of this particular specimen.

So, that is how the unconfined compression test is carried out and the strength that we obtain in this particular test is called the unconfined compressive strength or the UCS. If you look at the slide there, the UCS for this particular specimen is marked on the plot to the right of the slide there. So then, let us move on, let us try to see the sequence once again.

So in this case, I am just going to run the animation. You just try to observe the shortening of this particular sample that we are trying to test here and how the cracks develop within the sample and the sample goes to the ultimate state of failure. So, that is how the UCS is conducted. Here, why this particular test is called unconfined is because we just apply axial stress in this case or axial deformation in this case and we do not make any attempt in this case to confine the sample in the lateral direction or we do not have any confining pressure that actually keeps the sample from bulging in the lateral direction. So, that is how the un confined compression test is conducted.

Now, there is a simpler method for finding out the unconfined compressive strength of a specimen of intact rock and that particular procedure is called point load test. So, what is done in this case? We are going to take a core sample, you remember that a rock core sample is going to be approximately cylindrical and we are going to only choose those samples which have a length of at least 1.5 times its diameter and then we are going to apply a point load diametrically across the specimen and then we are going to calculate a term called the point load index and that point load index is going to be converted into the unconfined compressive strength of the specimen by the equation that is known near the bottom of this particular slide.

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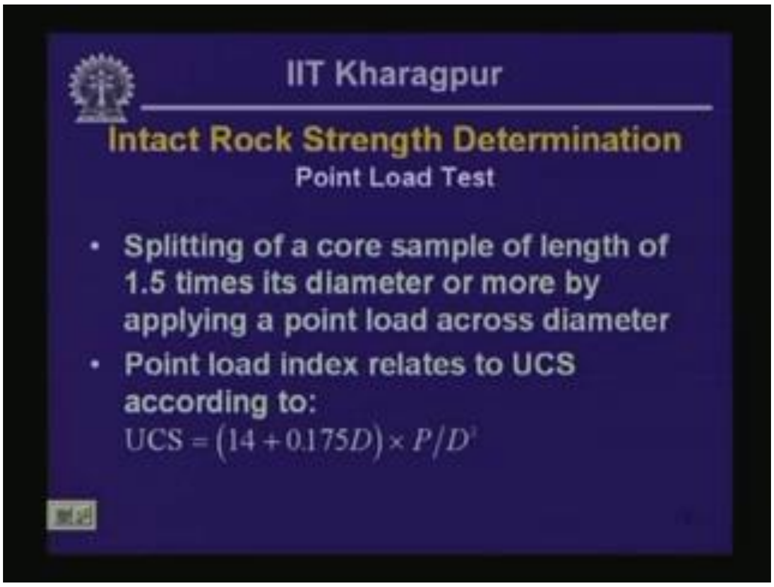

Now, here the point load index is this term, is the term on the right there. So, P here, the upper case P here is used to denote the load, the point load that splits the core sample, that splits the sample and D here is the diameter of the core sample, D is the diameter of the core sample. In the other words, the point load index is given by P over square of D. Now, this particular equation, for using this particular equation, you have use D in millimetre and if you do that and if you take P in Newton, then you are going to compute the UCS value MPa or in Newton per square millimetre.

So, you have to remember that you can only use this particular equation if you have D, the diameter of the core specimen in millimetre and the force that splits the sample is in newton. So, the equation then is UCS is equal 14 plus 0.75D multiplied by point load index and point load index is given by P over D square.

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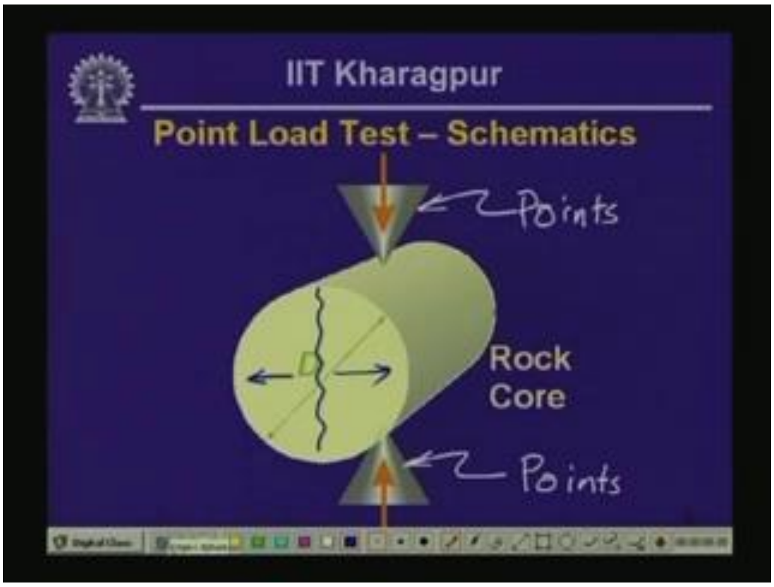

So, schematic of this particular test, the schematic of this particular test, point load index, point load test is shown here. So, what do you see here are basically the rock core that is noted there and then point load is applying using two sharp points. So, these are the points across which these core sample is mounted and these two points are actually brought near to each other, they are brought near to each other and in that process the rock sample, it tries to squeeze the rock sample and a tension develops across the sample and that ends up splitting the sample in the lateral direction. So, that how this particular test is conducted. That is the schematic details of point load testing.

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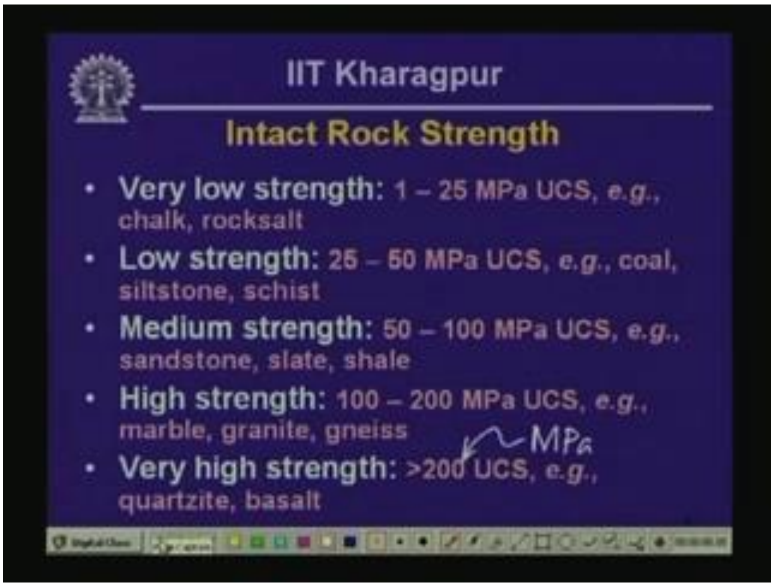

Now, we want to classify rock samples, intact rock samples depending on their unconfined compressive strength. If you have got an unconfined compressive strength of between 1 and 25 mega Pascal, then you are going to call that particular rock or classify that particular rock as very low strength rock. Examples of this particular category are chalks and rock salt.

Then, you could have low strength rock with USC between 25 to 50 mega Pascal. Examples include coal, siltstone and schist. Medium strength rock if you have got unconfined compressive strength between 50 and 100 MPa of an intact specimen. Examples are stone, slate and shale.

You could have high strength rock if the unconfined compressive strength goes between 100 and 100 MPa, examples being marble, granite gneiss and finally very high strength rock if you have got unconfined compressive strength of more than 200 MPa, this one is in MPa just like before, examples are quartzite and basalt. That is how you are going to classify intact specimen of rock based on their unconfined compressive strength

Now, we know that characterisation of intact specimen is only about half of the total problem because we have to now categorize or characterise the discontinuities in terms of their behaviour and strength. So, what we mean by discontinuities; they are, they could be of different types and all of them or many of them have already been discussed when we were talking about different types of rocks.

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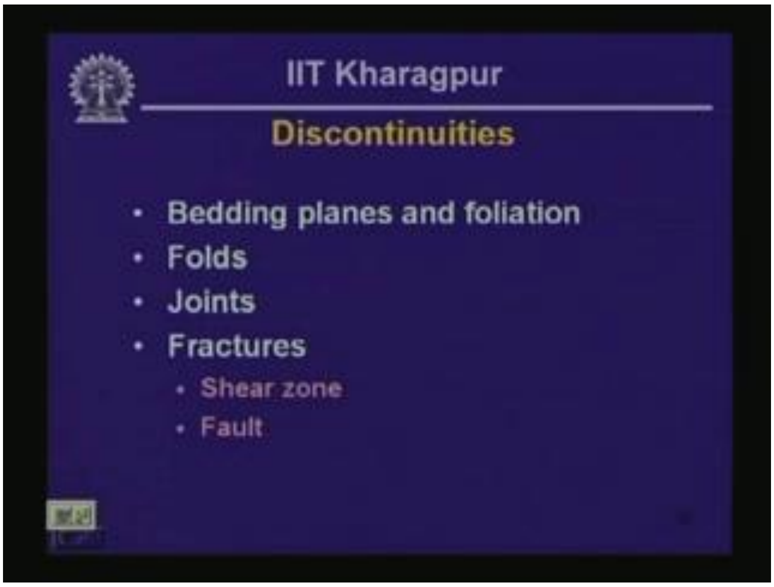

The first type of discontinuity belongs to the category of bedding planes and foliation. So, you remember in case of gneiss or schist what we had is basically relatively thin lamination of alternate layers of different minerals. So, this kind of stacking is called foliation and you can have bedding plans in case of sedimentary rocks and we discussed the details or the details of the geometry of these characteristics.

And then, we have folds. So, what we mean by folds is basically let us say you have got a rock mass which has got which has got horizontal bedding like that and this particular rock mass is subjected to a compressive load in the lateral direction.

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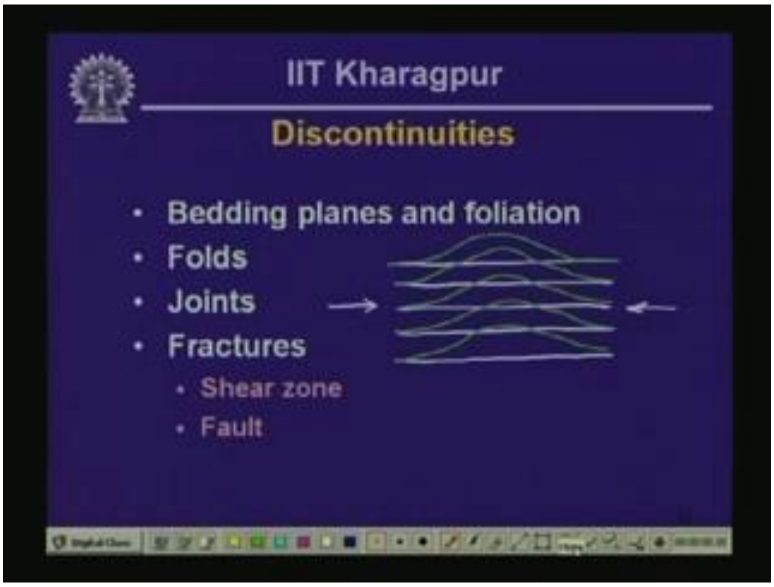

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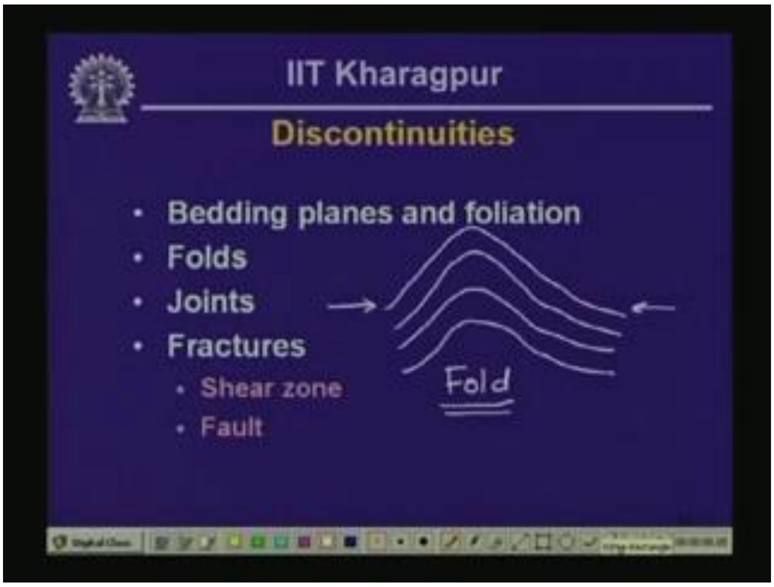

Then what is going to happen is that the bedding, they are going to bulge up in this manner and finally what you could get is a rock mass that has got bedding planes of this type and we discussed these features in details, in in greater detail when we were talking about different types of faults and folds in one of the earlier lessons. So, that is what is fold.

Then you could have joints. So, what are joints? Joints are basically static discontinuities, joints are basically static discontinuities that means let us a rock, a volcanic rock is being formed and when the magma cools, then different parts of magma solidifies at different rates and as a result the magma could shrink and that leads to the development of joints within the mass of cooling magma and these joints they remain within the body of rock and this particular type of discontinuity is given the name joints. So, joint are essentially static discontinuities in the sense that basically they are not because of relative movement of different parts of the rock mass.

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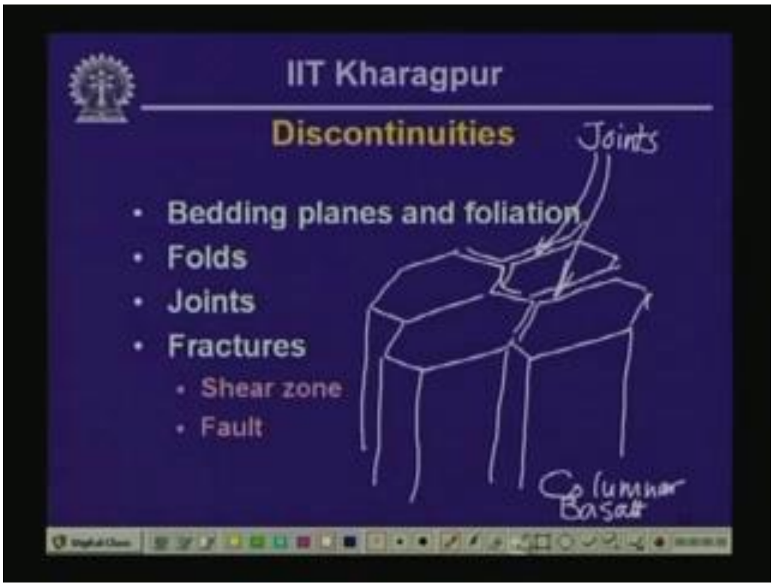

So, we talked about different joint sets because in our earlier lesson we talked about columnar basalts and ((…)) basalts. So, you could have basalt columns developing in this manner, developing in this manner because of differential cooling within different portions of the magma. So, in this case, these features are called joints, so these are joints and this is an example of joints for a type of rock called columnar basalt.

Then, finally we have got fractures. We can have fractures, these are also discontinuities but in this case unlike joints, some dynamic trigger is involved in developing, in the development of these discontinuities and fractures developed because of relative movement of different parts of the rock mass and there are two sub categories of fractures; one is called shear zone and the another one is called fault. Shear zone - when the movement is relatively of small magnitude, permanent slip between different portions of the rock mass is of smaller magnitude then the discontinuities is the result from that kind of movement is called shear zone.

And, if the movement is much larger, then we could have or that leads to the development of faults and we looked at various different categories of faults in our earlier lessons.

So now, the question comes how we are going to characterise discontinuities. So, discontinuities could be continues or discontinues that means the discontinuities themselves can go a larger distance or they could be confined within a relatively small volume of the rock and the walls of the discontinuity could be rough or smooth, they could be fresh or weathered or in other words the wall themselves could be hard or they could be soft because of the weathering action. Then discontinuities could be welded or they could be cleaned or in filled.

What we mean by welded is that within these discontinuities, chemical or other minerals, they get deposited and these deposits they act as a welding agent connecting the two blocks that are on either side of the discontinuity. So, welded discontinuity is going to be much stronger in comparison with discontinuities that are not welded.

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Then, discontinuities could be cleaned or they could be in filled with weathering material or other types of deposits unlithified deposits or deposits that are not, that are yet to turn into rock. Then, the composition of the in filled could be they are most of the time they are composed of different types of clays because if you recall from the discussion that we had earlier on chemical weathering of rock, rock minerals; they get weathered that leads to the formation of clay minerals, different types of clay minerals and these clay minerals actually fill the discontinuity because the weathering action is also going to be more pronounced at the discontinuities themselves because of water entry and entry of air and so on and so forth.

So, these discontinuities sometimes get filled by clay type minerals and these clay minerals could be the swelling type clay or just like smog type or they could be inactive clay minerals such as kaolinite or the discontinuity could be filled with rock flour, they are basically particles, non clay particles. Their fragment ground up from the relative movements of the two parts of the rock across the discontinuity itself and that also could be another type of in filled material within the discontinuity. So, we have to consider all these aspects when we try to look at the behaviour of discontinuity.

Now, we will try to look at index of discontinuity spacing. So, two indices we are going to look at in this case. One is the recovery ratio and the other one is called the RQD or the rock quality designation. How do you define RQD? RQD is the ratio of the length of core pieces or the pieces of core individual length of which is equal to or more than 100 millimetre and that is divided by the length of the core run.

Once again, RQD is given by the length of pieces of a core specimen which are more than 4 inches long, 100 millimetre long and we are going to divide that the cumulative length of those pieces which are more than 100 millimetre long by the length of the entire core run. Now, RQD is typically expressed only for cores that are more than or equal to 54.7 millimetre diameter with double tube core barrel. Then recovery ratio, the second index is given by the length of the core recovered divided by the length of the core run.

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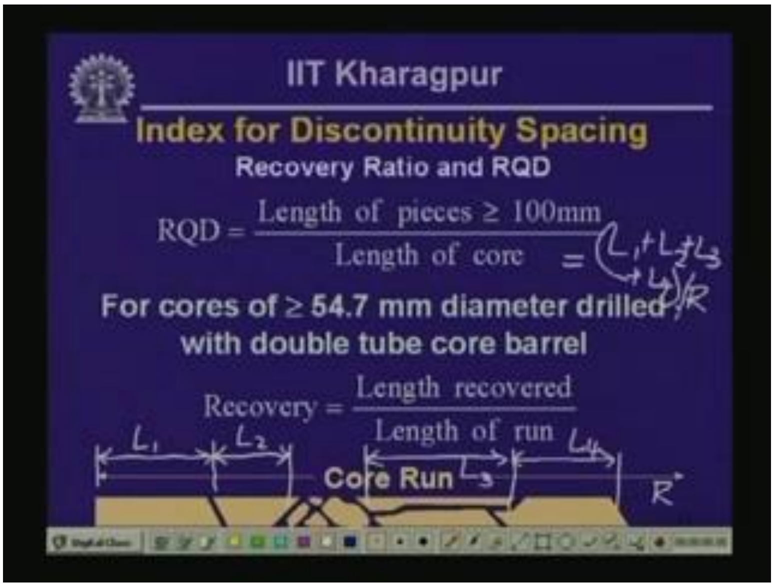

In this case, let us consider the core sample near the bottom of this particular slide. So here, let us say we have got more than, I mean this particular core piece is more than 100 millimetre long, then let us say this particular core piece or piece of core sample is also more than 100 millimetre long, then there is another long core piece that is this much out here and we have got another one which is out here.

So, what is going to be the RQD in this case? Let us call his one L1, this one L2, then the third piece as L3 and the fourth piece is L4 and the core run in this case let us express that by the symbol R. So, what we are going to get in this case is RQD is going to be equal to L1 plus L2 plus L3 plus L4 and this entire thing is going to be divided by R and this particular ratio is often times expressed as a percentage.

Then let us consider for this sample itself, how we are going to express the recovery. So, recovery in this case is going to be given by the length of the core recovered that in this case is this much and that is going to be divided by the length of the core run. So, recovery here is going to be given by L over R and this in turn is going to be expressed by percentage. So, if we are going to multiply L by R by 100 and express core recovery by percentage.

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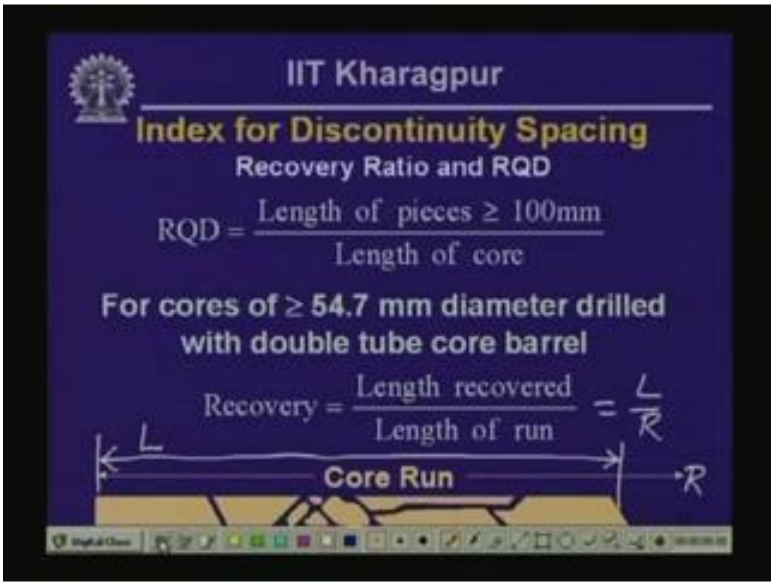

So, both RQD and recovery if you recall when we discussed the logging activity of sub surface investigating, both RQD and recovery are details that need to be included in the log that describes the drilling process and they are evaluated at the time of the drilling itself.

Now, we will try to get into the geomechanics classification of rock mass. So, first of all we are going to consider the UCS - unconfined compressible strength of the rock mass and we are going to assign a score R1 depending on what is the value of unconfined compressive strength of intact specimen of rock. So, if it is for instance more than 200 MPa, then we are going to have an R1 of 15; if we have let us say UCS between 50 and 100 MPa, then R1 reduces to 7.

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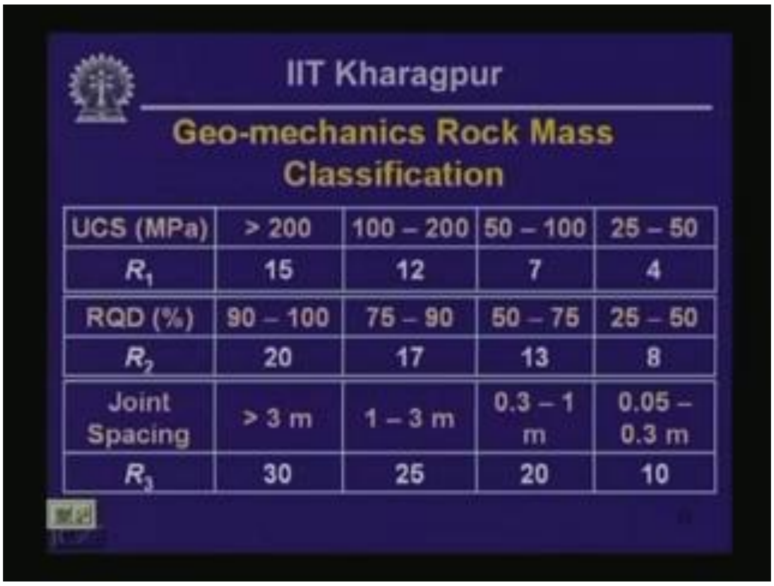

UCS (MPa)	> 200	100 – 200	50 – 100	25 – 50
R_1	15	12	7	4
RQD (%)	90 – 100	75 – 90	50 – 75	25 – 50
R_2	20	17	13	8
Joint Spacing	> 3 m	1 – 3 m	0.3 – 1 m	0.05 – 0.3 m
R_3	30	25	20	10

Second R square to consider is the RQD of the course sample and we are going to assign a score of R2 depending on the RQD. For instance, if RQD is between 90 and 100, then score R2 is going to be 20 whereas if RQD goes between 25 and 50 percent, then R2 becomes equal to 8.

Third aspect to consider is the joint spacing and the core for this particular aspect is R3 and here if the joint spacing in more than 3 metres that the joints are very widely apart then R3 is going to be equal to 30 whereas when the joints are between 50 millimetre and 0.3 of a meter, then R3 will be equal to 10.

There are further aspects to consider; joint condition and the score that are going to be assigned to characterize joint condition is going to be R4. In this case, if we have got very rough joint with hard wall that are discontinues and there is no separation of the rock blocks across the joint mass that the separation is less than say 1 millimetre, then R4 is going to be equal to 25.

If the joint on the other hand is filled with soft clay like gouge, gouge is the term used for joint infill and the joints are continues and there is more than 5 millilitre separation of the rock body, of the rock parts across the joints, then R4 is going to be equal to 0.

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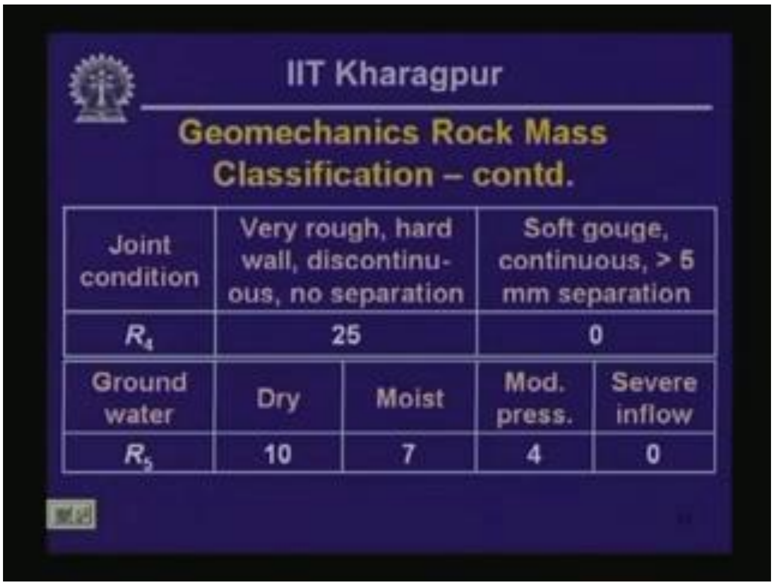

Then, the fifth aspect that we are going to consider is ground water. If the rock mass is dry, then R5, the score that characterise the ground water condition is going to be 10; if the rock mass is moist, then R5 is going to be equal to 7; if there is moderate pressure in the ground water within the rock mass, then R5 is going to be equal to 4 and in case of severe inflow of ground water, R5 is going to be equal to 0.

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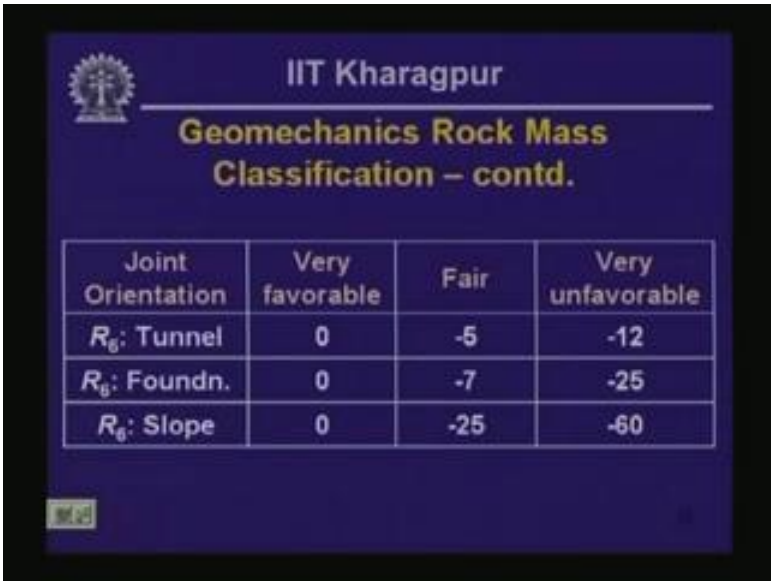

And finally, we have to consider joint orientation with respect to the project, these are the projects we are handling and these core that we are going to consider to account for this aspect is R6 and it is going to be different if we are looking at the tunnel construction or if we are looking at the construction of the foundation or construction of a slope. If the joint orientation is very favourable, then R6 is going to be 0 in all cases. If the joint orientation is very unfavourable in case of tunnels, we are going to have a negative 12 for R6. In case of foundation, we are going to have negative 25 and in case of slopes, we are going to have negative 60.

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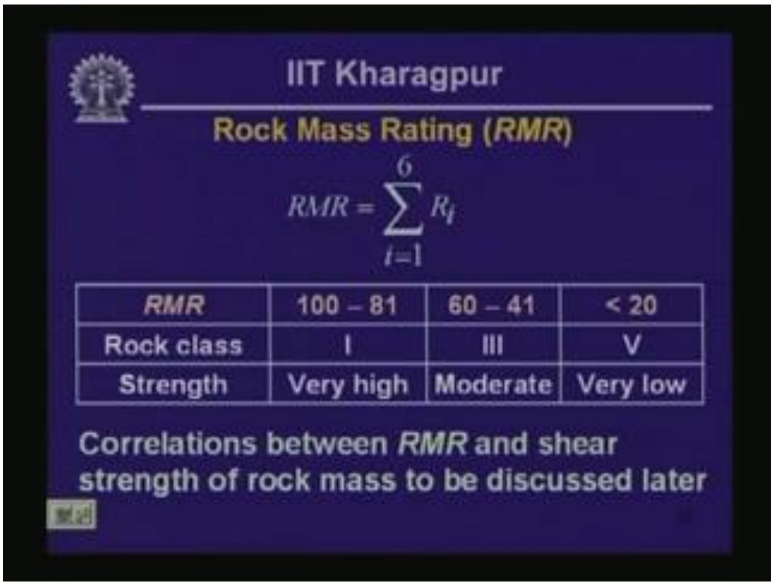

Then what we do is we will sum up all the R values, all the ratings or all the scores R1 to R6 and the sum is given the name as rock mass rating. If the rock mass or RMR; rock mass rating or RMR. So, if RMR is between 100 and 81, then the rock class is 1; if the RMR goes between 41 and 60, then rock class is 3; if on the other hand RMR is less than 20, then rock class is 5 and you can easily see that the strength of rock mass is going to be very high if you have got an RMR between 100 and 81; if you have got a class 3 rock the strength is going to be moderate intermediate and if you have got class 5 rock, then the strength of the rock mass is going to be very low.

At this time, we are not going to consider the correlations between RMR and design strength of rock but you should be aware that those kinds of correlations are available and we are going to consider those correlations connecting the rock mass rating and the shear strength of the rock later on in one of the future presentations.

What we learnt in this particular lesson? We looked at the fundamental factors that affect the engineering behaviour of intact rock and rock mass, we considered indices of engineering behaviour of intact rock and rock mass - for example we looked at RQD, we looked at the UCS, we looked at the recovery ratio, they were the indices that we considered in order to describe the, in order to describe the behaviour, engineering behaviour of the intact specimen as well as the jointed rock mass and we also looked at some of the procedures that were used for estimating these incidences.

In order to wrap up this particular lesson, I am going to leave you with a number of questions. First of all you try to answer these questions at your leisure and I am going to give you my answers when we meet again in the next lesson. The first question is what are the differences between joint and fractures? Second question - is a sand stone core sample of 55 millimetre diameter failed in a point load test at 17,000 mega Newton force and you are asked to estimate the unconfined compressive strength of that core sample of the intact rock.

The third question is classify the following granite rock mass for a tunnel construction and the given parameters are UCS equal to 150 MPa, RQD is equal to 70%, joints are with rough surfaces, joints have got rough surfaces and hard wall and the spacing between the individual joints is 0.5 metres and the separation of the blocks of rock across the joints is less than 1 millimetre. Now, this particular rock mass contains ground water under moderate pressure and the joint orientation is fair with respect to the tunnel alignment.

So, you try to answer these questions following the procedure that has been described in this lesson and when we meet again, we will take up these questions and consider the answers. So, thank you very much and bye for now.