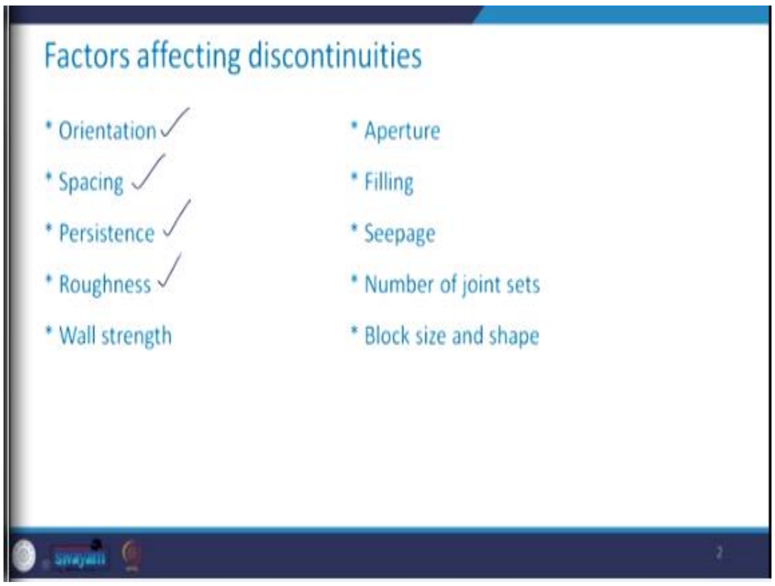
Rock Engineering
Prof. Priti Maheshwari
Department of Civil Engineering
Indian Institute of Technology-Roorkee

Lecture-20
Factors Affecting Discontinuities

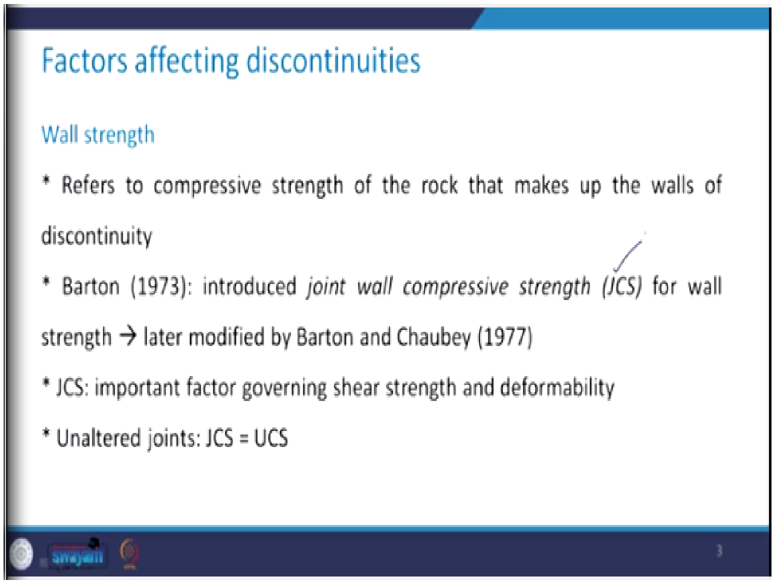
Hello everyone. In the previous class we discussed about factors affecting discontinuities. And in that series, we discussed about 3 to 4 factors. Let us continue that discussion today as well and see some of the other factors which influence the behavior of discontinuities.

(Refer Slide Time: 00:53)



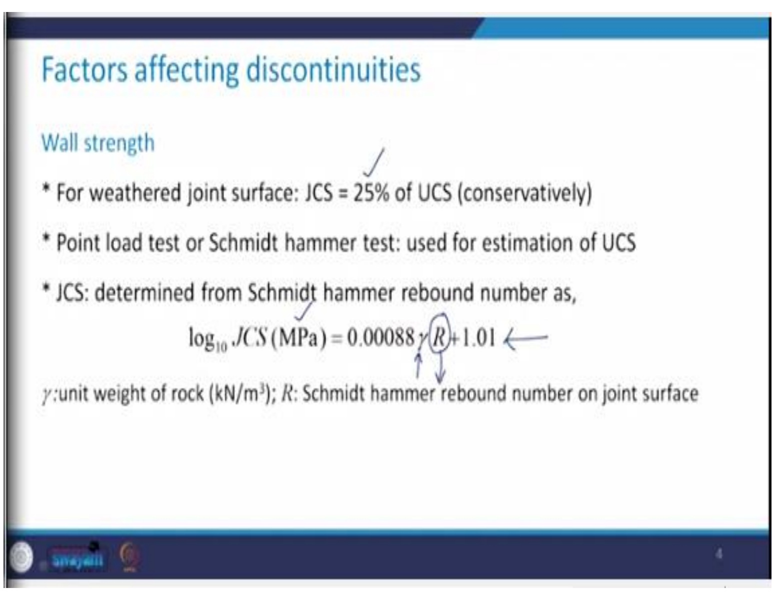
So, we discussed about the orientation, we discussed about spacing, persistence and roughness in the previous class. So, we will take up the remaining factors influencing the discontinuities today. First in that series is wall strength, very, very important in case if you have unfilled joints.

(Refer Slide Time: 01:25)



So, the wall strength refers to the compressive strength of the rock, that makes up the wall of the discontinuity. So, Barton in 1973 introduced a term called joint wall compressive strength to define the wall strength, and this term was later modified by him and his co authors in 1977. So, this joint wall compressive strength which is in short is called as JCS, it is a very important factor which govern the shear strength as well as the deformability of the jointed rock. In case if you have unaltered joints, then this JCS becomes approximately equal to unconfined compressive strength of the intact rock.

(Refer Slide Time: 02:27)



For weathered joint surfaces roughly JCS can be taken as 25% of the UCS. So, this is just an estimate and which has been found to work nicely for most of the cases. We use point load test or

Schmidt hammer test for the estimation of UCS. We have seen that in some of the earlier classes. JCS can also be determined from Schmidt hammer rebound number using this expression.

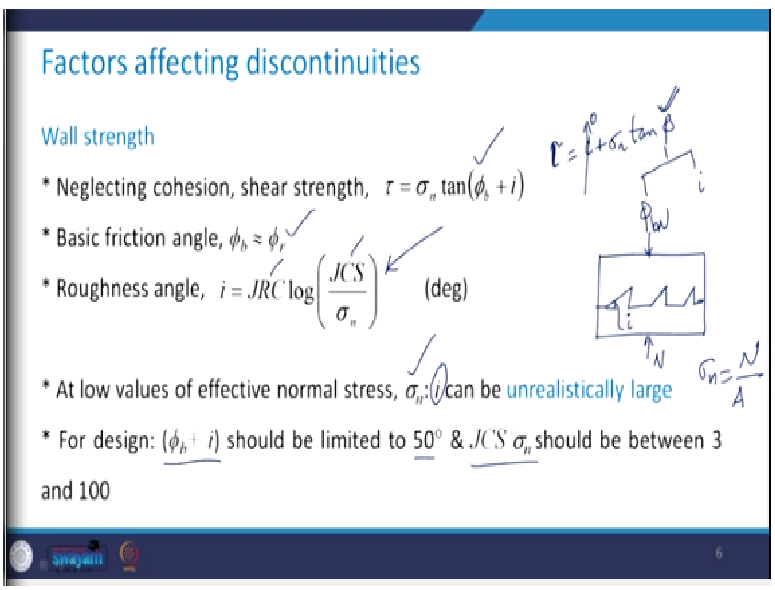
$$\log_{10} JCS\ (MPa) = 0.00088\gamma R + 1.01$$

γ =unit weight of rock (kN/m^3); R =Schimdt hammer rebound number on joint surface.

Once again, I am telling you that when we have this kind of empirical correlation, we have to be careful about the units, so again here this is another empirical correlation. So, whatever is the JCS value that you we will get from this expression that would be in MPa. And we need to substitute this unit weight of the rock in kilonewton per meter cube, and this R is the Schmidt hammer rebound number on the joint surface.

You can carry that hammer in the field, conduct the test and get the value of this parameter R, substitute it in this expression and you will be able to get the value of JCS. Now the peak friction angle of the unfilled joint usually it is in the range of 30 to 70°.

(Refer Slide Time: 04:15)



For un-weathered joint walls, it goes to the residual friction angle and that is in the range of 25 to 35°. For weathered joint walls, this residual friction angle gets as low as 15°, the friction angle of a rough discontinuity surface it has 2 components. The first one is basic friction angle of the rock material which is represented by ϕ_b. And the second one is the roughness angle due to interlocking of surface irregularities or asperities which we are representing by i.

If we neglect the cohesion, the shear strength can be given by this expression

$$\tau = \sigma_n tan\phi$$

You know that if a material follows the Mohr coulomb criteria, then the shear strength is given as

$$\tau = c + \sigma_n tan\phi$$

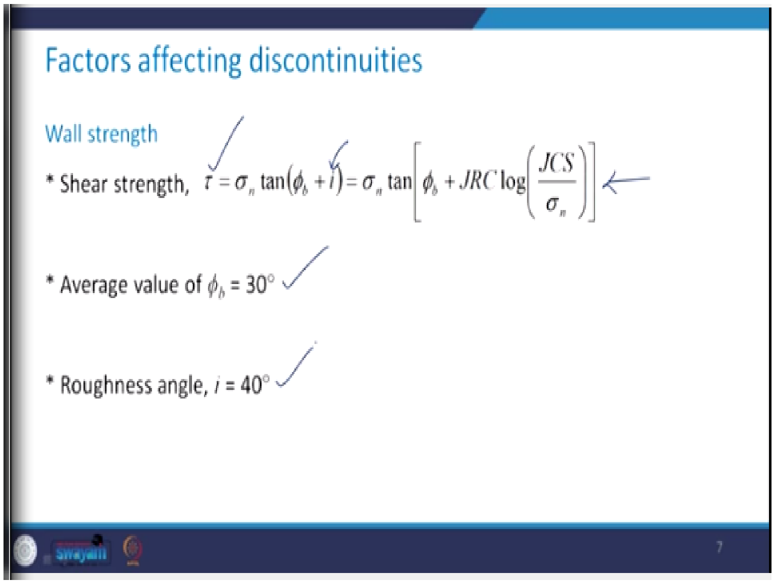
Now if you neglect the cohesion, this term will become equal to 0. And since here this characteristic has 2 parts, one is ϕ_b and another one is i, so therefore both are contributing towards the sheer strength, so we have this expression.

Now basic friction angle can be approximately taken as equal to the residual friction angle, and the roughness angle can be defined in degrees using this expression where this JRC and JCS, they represent the characteristic of the rock. At low values of effective normal stress, which is σ_n, this value of i it can be unrealistically very large. So, when you have let us say that you have this type of situation. Let us say that, you have these regular teeth.

So, when you have very small value of say here, it is a normal load, so σ_n =N/A. So, at a very small value of this σ_n this value of i, it can be unrealistically very large. So, we need to keep this in mind that for the design this quantity ϕ_b+i, it should be limited to 50°. Even if i is very large and this ϕ_b+i, works out to be let us say more than 50, we have to limit it to 50°.

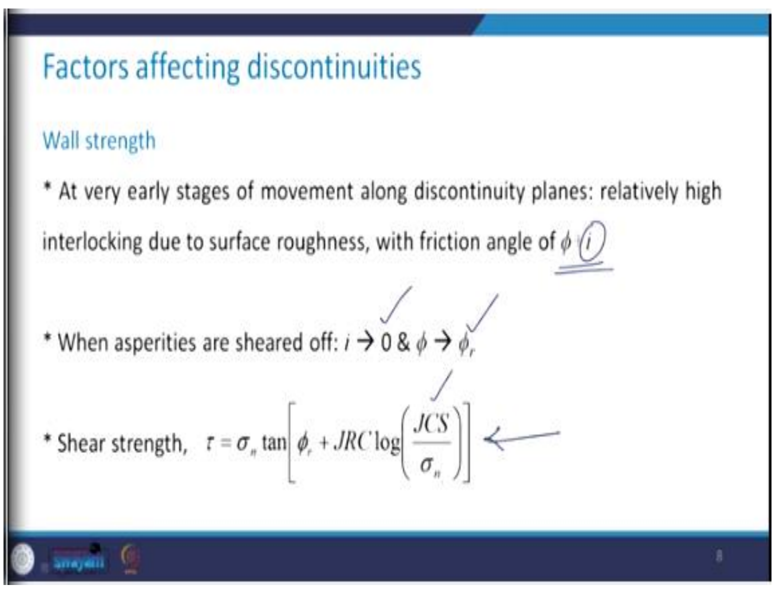
And this quantity JCS/σ_n it should be between 3 and 100, please remember these things that ϕ_b+i should be limited to 50°, and JCS/σ_n should be between 3 to 100 for the design purpose.

(Refer Slide Time: 08:13)



And if you substitute all these values of expression for i, here in this expression of τ, this is what is going to be the resulting expression which will give you the shear strength of the joint wall. And the average value of ϕ_b can be taken us 30° and roughness angle can be taken as 40°.

(Refer Slide Time: 08:43)



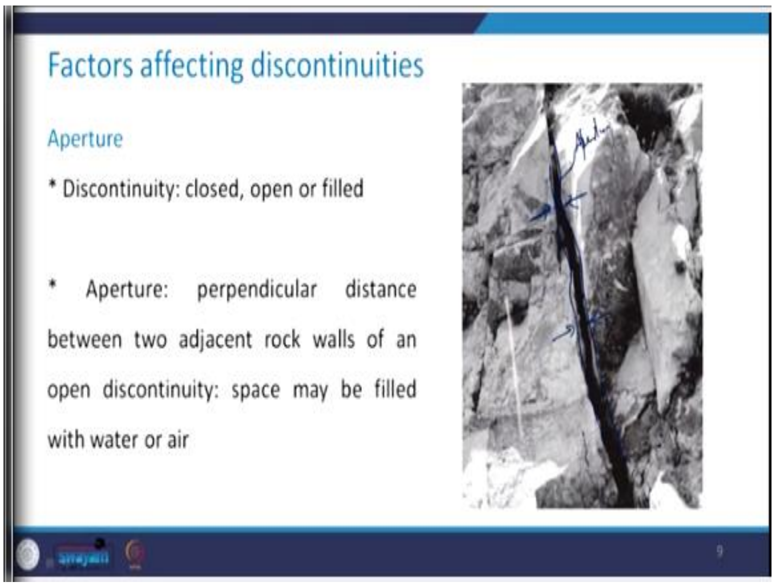
At the very early stages of movement along the discontinuity planes relatively high interlocking is there due to surface roughness just now I draw a figure and show that to you. So, therefore the friction angle is increased by this roughness angle i, that is this total is going to be $\phi+i$. Now when the asperities are sheared, let us say you are conducting a direct shear test and you keep on increasing the shear load, then what will happen?

Towards the end of the test all the asperities will be sheared off and the roughness angle which was i in the beginning that would become equal to 0, and this angle ϕ would be tending to the residual friction angle ϕ_r. And in that case your shear strength can be given by this expression,

$$\tau = \sigma_n tan\left[\phi_r + JRClog\left(\frac{JCS}{\sigma_n}\right)\right]$$

. When the asperities are sheared off this will become equal to 0 and ϕ will tend to ϕ_r, so therefore this term will get equal to 0.

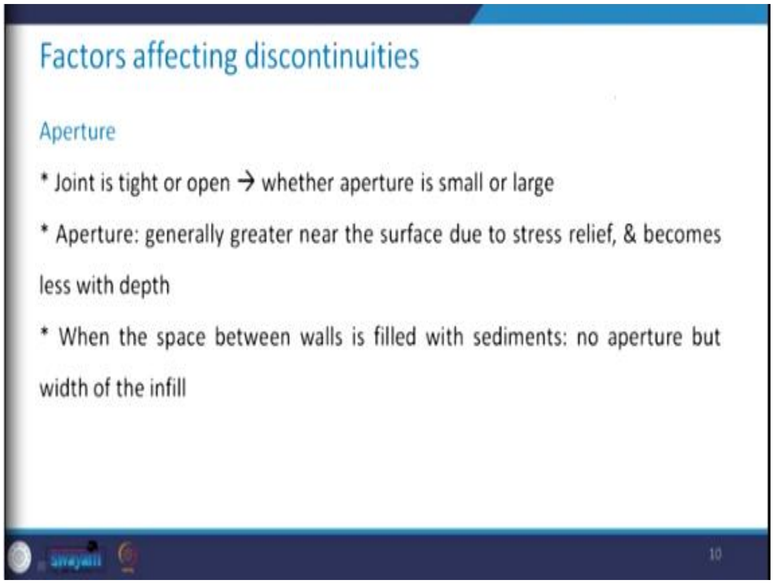
(Refer Slide Time: 10:11)



Next factor which influences the discontinuities is aperture. Now this discontinuity can be closed open or filled. I have shown you filled discontinuity earlier in the previous class. So, this is the picture which has the open discontinuities. Why we are seeing open discontinuity. Means, there is a gap between the 2 rock surfaces which are forming the surface of the joint, so you see here this is the one and this is the other one.

So, aperture is defined as the perpendicular distance between 2 adjacent rock walls of an open discontinuity. This space maybe filled with water or air. Like in this case here, right now there is no water it is only filled with air. So, what is the aperture here in this case? Just take the tape and measure this distance. This is what is going to be your aperture.

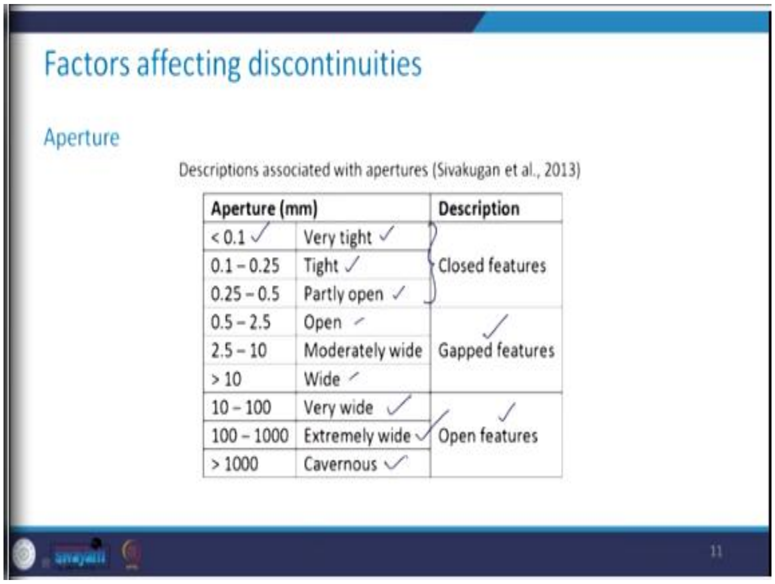
(Refer Slide Time: 11:30)



So, if the joint is tight or open, that will decide whether the aperture is small or large. Aperture is generally greater near the surface because near the surface the stresses are released and therefore the aperture is greater and it becomes lesser with the increase in the depth. With the space between walls is filled with the sediments, then there will not be any aperture but it will be called as width of the infill.

Now what this infill can be? This infill can be clay type of material or let us say that there are some minerals which are getting deposited when they come in contact with say water and they fill that aperture, so that material is called as infill. Based upon the aperture, you can describe the discontinuity.

(Refer Slide Time: 12:59)

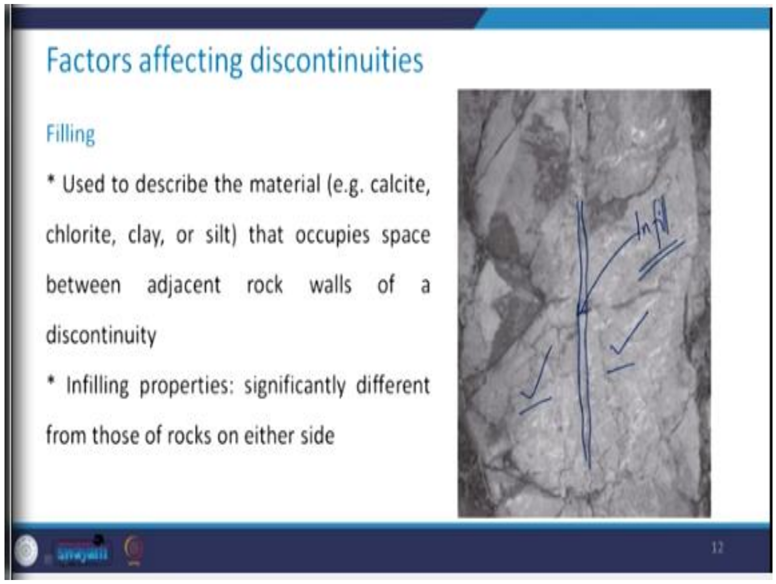


Aperture (mm)		Description
< 0.1	Very tight	Closed features
0.1 – 0.25	Tight	
0.25 – 0.5	Partly open	
0.5 – 2.5	Open	Gapped features
2.5 – 10	Moderately wide	
> 10	Wide	
10 – 100	Very wide	Open features
100 – 1000	Extremely wide	
> 1000	Cavernous	

If the aperture is less than 0.1 mm, it is called as very tight, and you see the first 3 categories that is very tight, tight and partly open, they fall under the category of closed features. So, that means that the aperture is varying from less than 0.1 to 0.5 mm. The next category is the gap feature, which has the description from open to wide with the aperture size changing from 0.5 to less than 10.

Then for open features it is more than 10 and you have very wide, extremely wide and cavernous kind of description depending upon what is the magnitude of aperture, so accordingly you can describe the joint. As I mentioned that these filling can be anything which can be clay, silt or calcite, chloride, so you can see in this figure, this joint is filled with the material called infill.

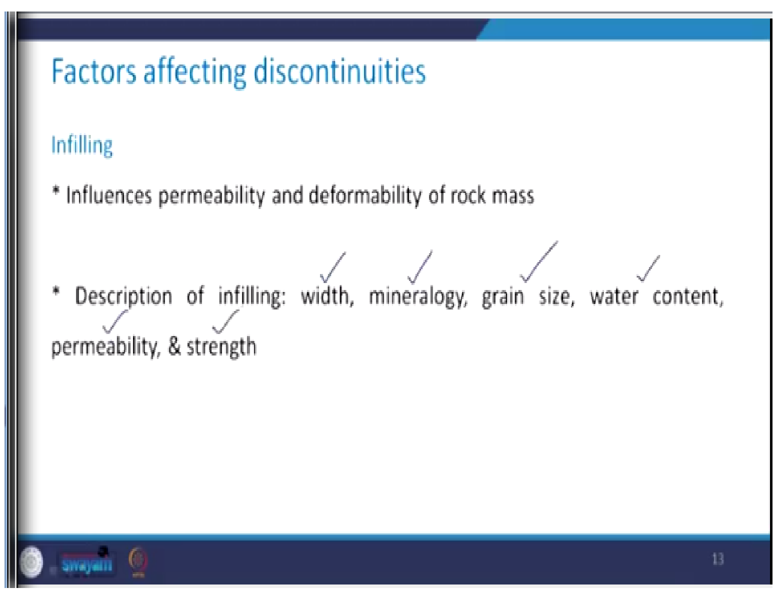
(Refer Slide Time: 14:21)



This is used to describe the material which occupies the space between the adjacent rock walls of a discontinuity. Now these infilling properties, they are significantly different than those of the rock which is on the either side. Like you see that here**,** this is the rock which are on the either side of this joint. So, the property of this infill material will be all together different than the property of these rocks.

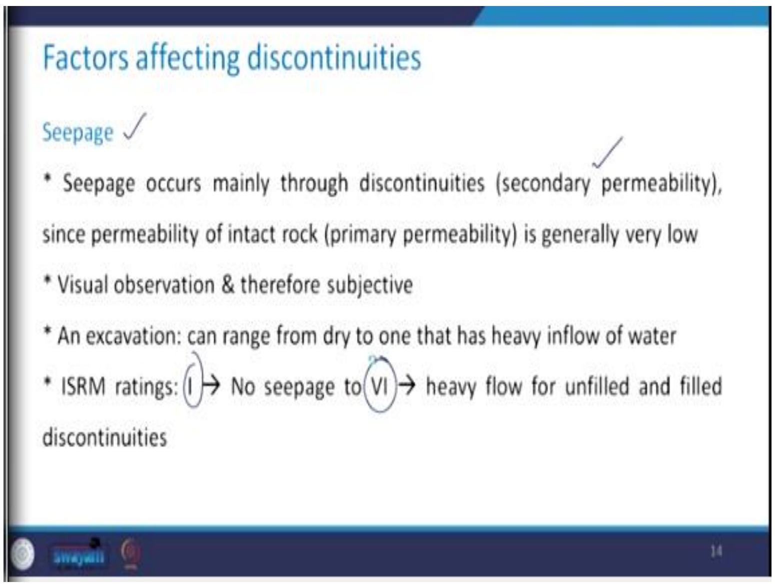
And when this joint is filled with such type of infill material, then it is the property of this infill material that starts governing the shear strength characteristic of these discontinuities and the jointed rock.

(Refer Slide Time: 15:22)



So, we need to study few things related to these infilling. These influence a permeability and deformability of the rock mass. How to describe these infilling? They can be described with the help of the width, mineralogy, grain size, water content, permeability and these strength characteristics. When I say strength characteristic, I mean you can take out the material and then maybe test it in the lab and find out it is strength parameters shear strength parameters. So, this is how the infilling is described with the help of width, it is mineralogy, grain size, water content, permeability and the strength.

(Refer Slide Time: 16:16)

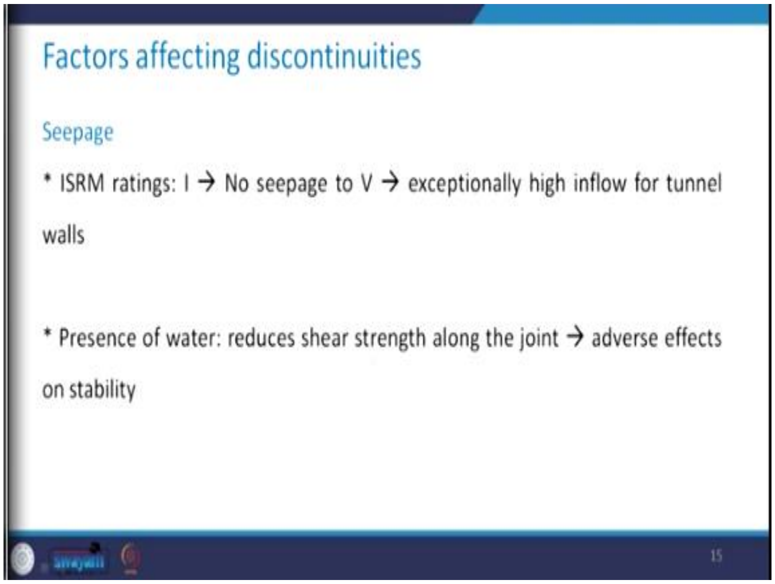


Next factor which influences the discontinuity is seepage, very, very important. You know that wherever this water comes into picture, the property of this natural occurring material. For example, soils and rocks greatly influence by this water and seepage is one of the phenomena which occurs mainly through the discontinuities. So, that let us say we call that as secondary permeability while the primary permeability is associated with the permeability of the intact rock.

So, usually this seepage which takes place through the discontinuities, the permeability of this through the discontinuity is very large as compared to the permeability of the intact rock. And this seepage can be only visually observed and therefore it is very much subjective in nature. Like there are 2 persons, both are observing the same thing that is seepage through the rock mass, one can say that it is very heavy inflow of the water, second one would say it is heavy inflow of the water, so it is really very subjective.

So, an excavation it can range from completely dry to one that has heavy inflow of water. ISRM rating has been given, the first, that is rating I is to the no seepage condition to rating VI to the heavy flow for unfilled and filled discontinuities.

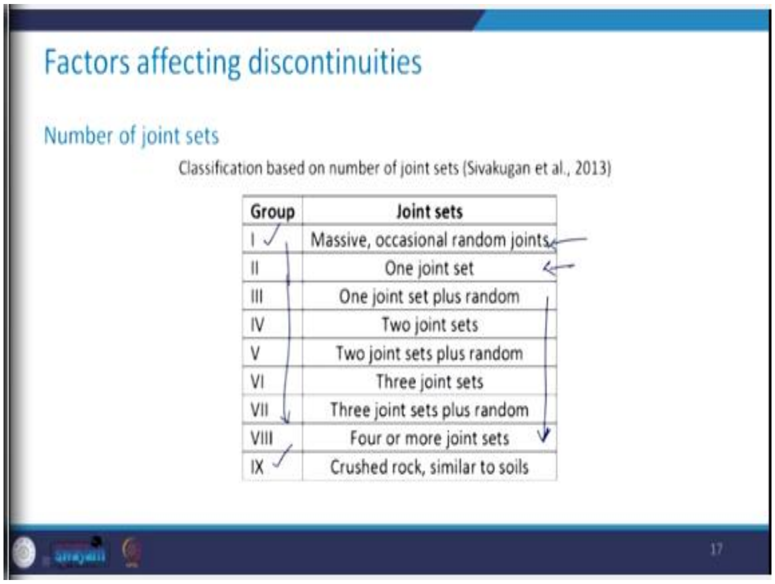
(Refer Slide Time: 18:27)



In case of the tunnels, this ISRM rating is one for no seepage, and ϕ for exceptionally high inflow for tunnel walls. What this presence of water does? It reduces the shear strength along the joint and therefore it has an adverse effect on the stability of any structure, tunnel, slope or the foundations. Coming to the next one, which is the number of joint sets? So, this is one of the factors which will be used for the classification of the rock mass in various classification systems.

Number of joint sets, it determines the ability of rock mass to deform without undergoing any failure within the intact rock. What happens when the number of joint sets they are increased? In the previous class I showed you it with the help of some pictures. So, when you have a greater number of joints sets, individual block sizes will reduce and their degrees of freedom for their movement will increase. So, based upon the number of joint sets, the classification is done and the rock mass is divided into few groups.

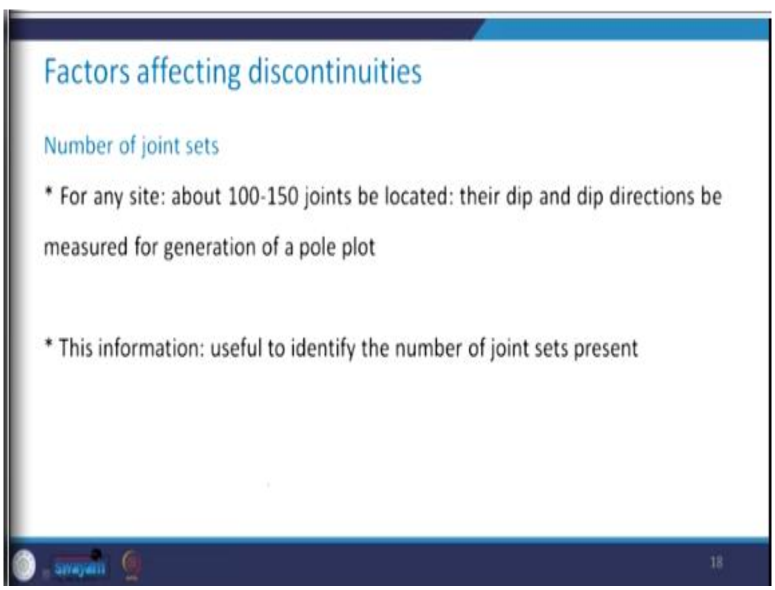
(Refer Slide Time: 20:19)



Group	Joint sets
I	Massive, occasional random joints
II	One joint set
III	One joint set plus random
IV	Two joint sets
V	Two joint sets plus random
VI	Three joint sets
VII	Three joint sets plus random
VIII	Four or more joint sets
IX	Crushed rock, similar to soils

Starting from group I to group IX, you can see that if you have massive or occasional random joints, then it falls under the category or under the group of I. One joint set, second group likewise number of joint sets are increasing and therefore it will keep changing the group from second to or from first to group IX, the description has been given here.

(Refer Slide Time: 20:58)

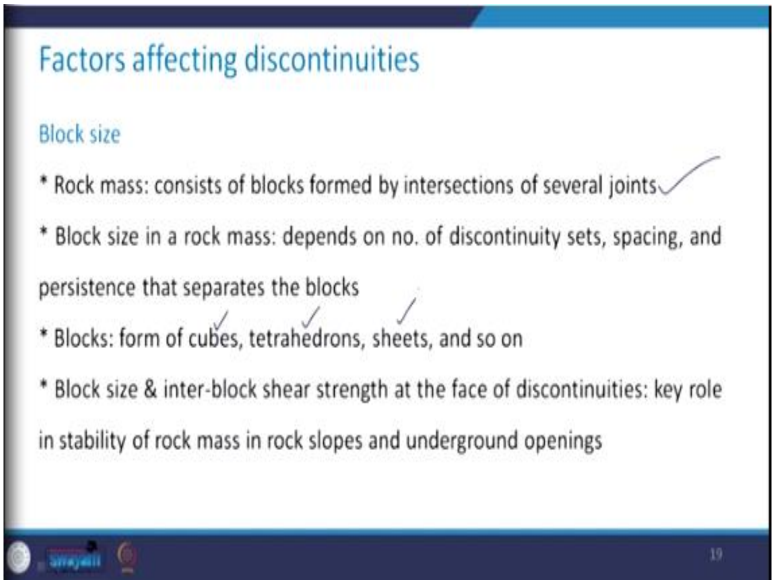


At any site, how should we find out that what all are the number of joint sets which are present at the site? If you recall our discussion on the application part of graphical representation of the geological data, there I showed you with the help of a pole plot that how the information which is plotted using the equal area net can be useful in deciding the some of the key parameters in the stability analysis of slopes, tunnels or the foundations.

So, at any site when we go, we take about 100 to 150 joints, we locate it at the site, we measure their dip and dip direction and then we generate a pole plot. Looking at that pole plot or looking at the graphical representation of all that geological data pertaining to these 100 to 150 joints, we can identify the number of joint sets which are present at the site. So, it is not that just for the academic purpose, we learned about the graphical representation of the geological data.

In almost every chapter, it will have it is application. So, as far as the classification is concerned, whenever we need to know the number of joint sets, we need to look at that graphical representation of the geological data. And from there, we need to identify the number of joint sets which are present at the site.

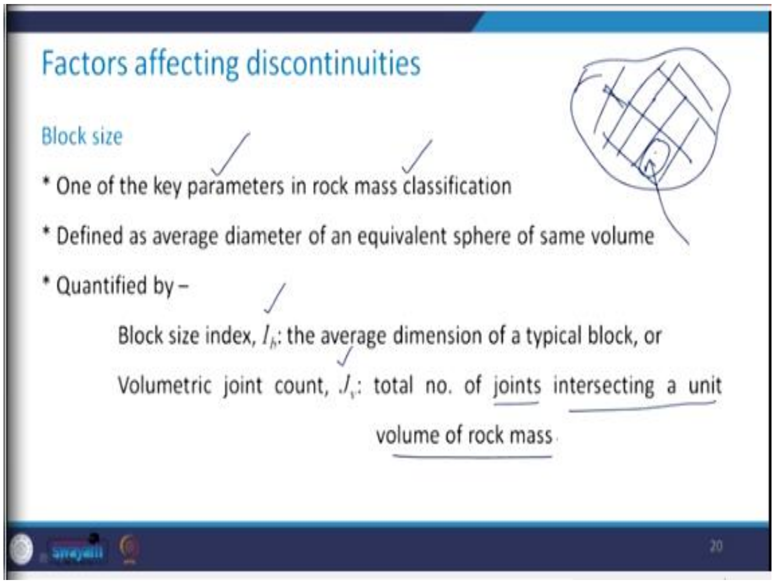
(Refer Slide Time: 23:16)



Next factor that is block size. Rock mass consists of blocks which are formed by the intersection of several joints. Block size in a rock mass, it depends on how many numbers of discontinuities sets are there, what are their spacings and the persistence that separates these blocks. These blocks can be in the form of cubes, tetrahedrons, sheets and there can be n number of shape and sizes of these blocks.

Block size and inter block shear strength at the face of the discontinuities, they play a key role in the stability of rock mass specially in case of rock slopes and underground openings, so one needs to be careful about it. So, one of the key parameters in rock mass classification as well, this is defined as the average diameter of an equivalent sphere of the same volume.

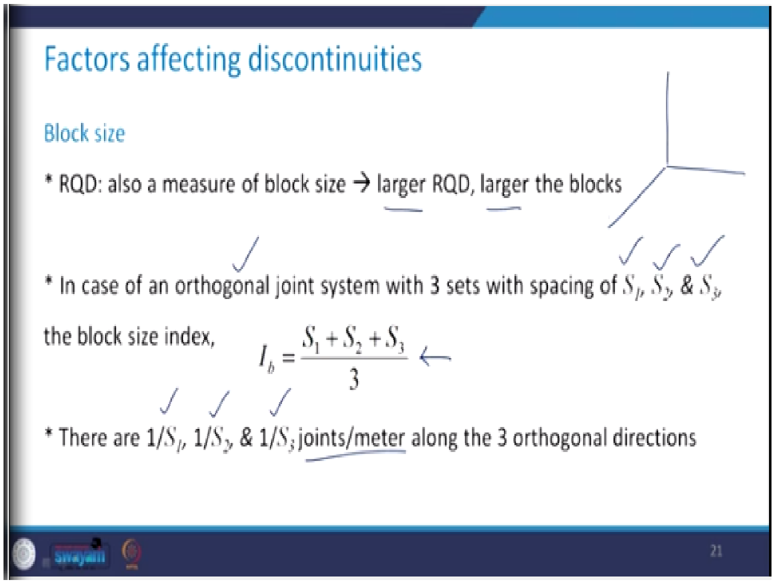
(Refer Slide Time: 24:23)



So, let us say that here you have the rock mass and you have, say, some joint sets, few joint sets, let us see here I am showing only 2 joint sets, so let us see it is there. So, now I can find out that what exactly is the block size? It is of this order. And I need to find out the equivalent sphere of the same volume as that of this block. So, the average diameter meter of that equivalent sphere is going to give me the block size for this block.

Now this block size is quantified by block size index I_b, which is the average dimension of a typical block or it can also be quantified with the help of volumetric joint count, which is J_v which is defined as the total number of joints intersecting a unit volume of the rock mass. So, you take one unit volume of the rock mass and see how many numbers of joints they are intersecting it. So, that would be your volumetric joint count and, in a sense, it would give you the idea about the block size.

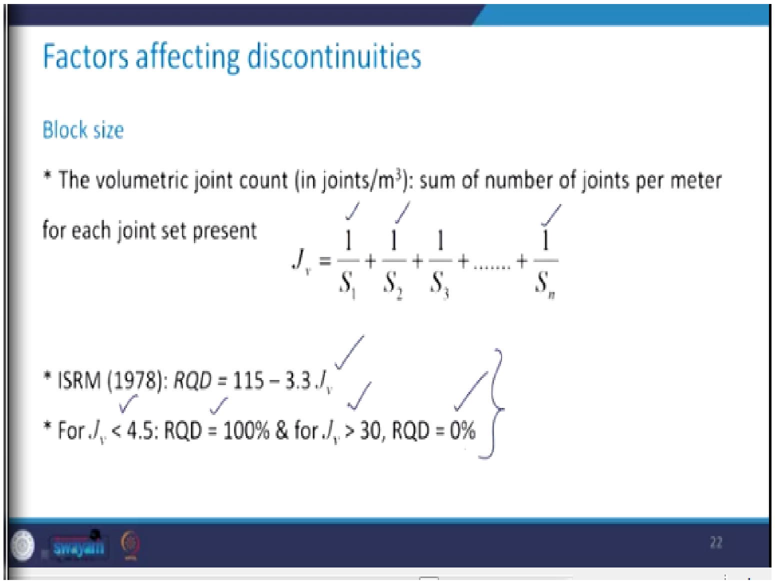
(Refer Slide Time: 26:02)



Apart from these RQD is also a measure of block size, you know how to determine the RQD. Whatever pieces of the core which have the length more than 10 cm, you add all of them divided by the total core run length multiplied by 100 and that is going to give you the RQD. So, larger the value of RQD and larger will be the block size. In case of an orthogonal joint system say with 3 sets, so when I say orthogonal joint system means.

These 3 joints they are perpendicular to each other and say they have the spacing of S_1, S_2 and S_3, we can obtain the block size index as the average of these 3. Again, this is a particular case where we can obtain the block size index using this expression, condition being that it is the orthogonal joint system with 3 sets. There are $1/S_1$,$1/S_2$ and $1/S_3$ joints/meter along the 3 orthogonal directions. So, you see that we have x, y, z direction and the joints have been assumed along these orthogonal directions only.

(Refer Slide Time: 27:29)



So, the volumetric joint count whose unit is in joints/m^3, it is the sum of number of joints per meter for each joint set which is present. And that is defined as

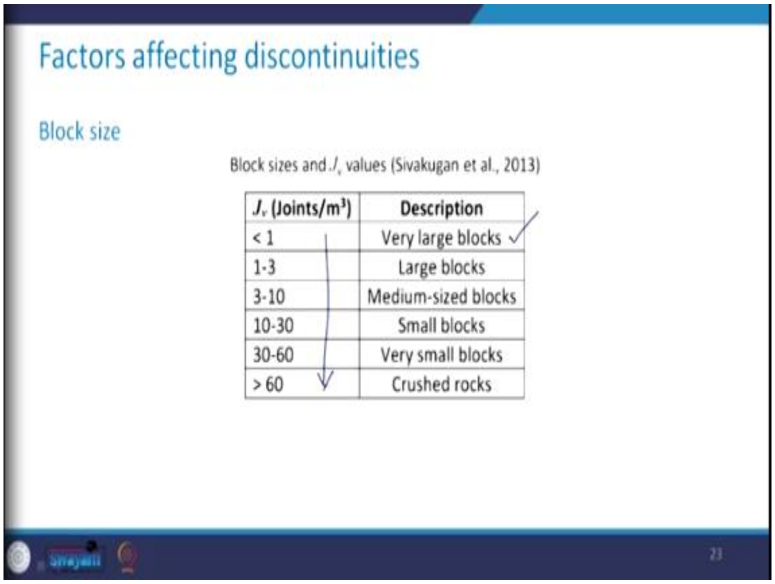
$$J_v = \frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3} + \cdots + \frac{1}{S_n}$$

Where n is the number of joints.

ISRM has also given a relationship between RQD and J_v, this we have seen earlier also. So, it is the same expression $RQD = 115 - 3.3\ J_v$.

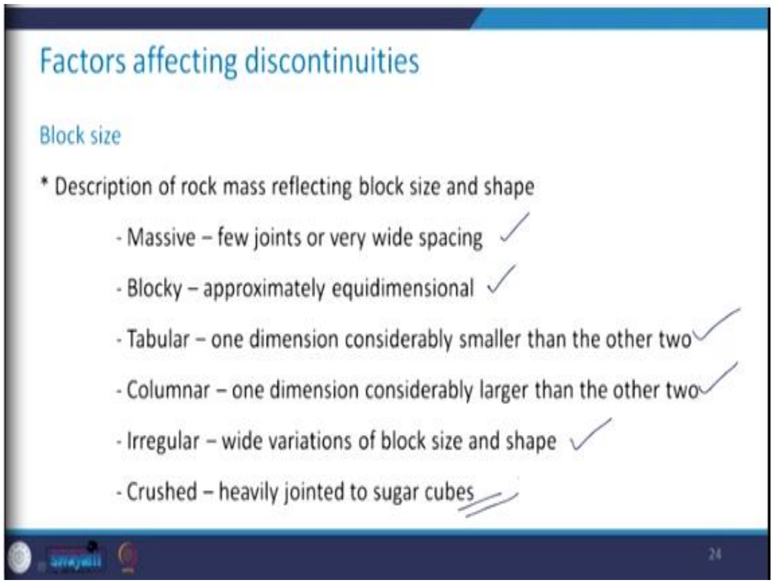
So, when you have $J_v < 4.5$, RQD =100% and $J_v > 30$, RQD =0%, so this is what you must remember.

(Refer Slide Time: 28:35)



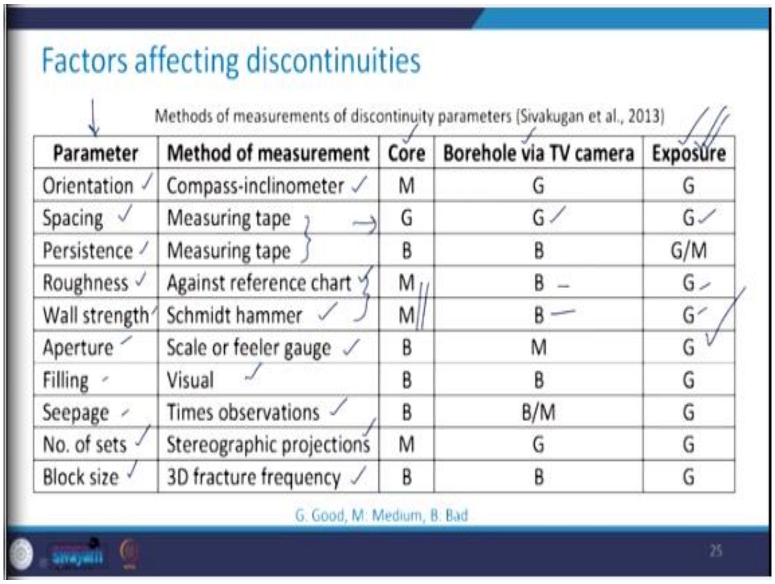
Based upon the value of J_v that is joint per meter cube, you can describe the block size. So, if there is less than one joint per meter cube, you have very large blocks. And as the value of J_v increases, you have lesser size of the blocks, and ultimately when J_v becomes more than 60 then it gets into the category of crushed rocks. The description of the rock mass reflecting block size and the shape is given here.

(Refer Slide Time: 29:25)



You can have massive with few joints or very wide spacing. Blocky, which is approximately equidimensional. Tabular, one dimension is considerably smaller than the other 2. Columnar, one dimensional considerably larger than the other 2. Irregular means all sorts of variation of the block size and shape is there. Crushed means heavily jointed rocks to sugar cubes.

(Refer Slide Time: 30:05)



Some of the methods for the measurement of various discontinuity parameters have been summarized here in this table. So, the first column gives you the idea about the parameters, which are orientation, spacing, persistence, roughness, wall strength, aperture, filling, seepage, number of sets and block size. Then what is the method of measurement? Like orientation can be measured using a compass inclinometer.

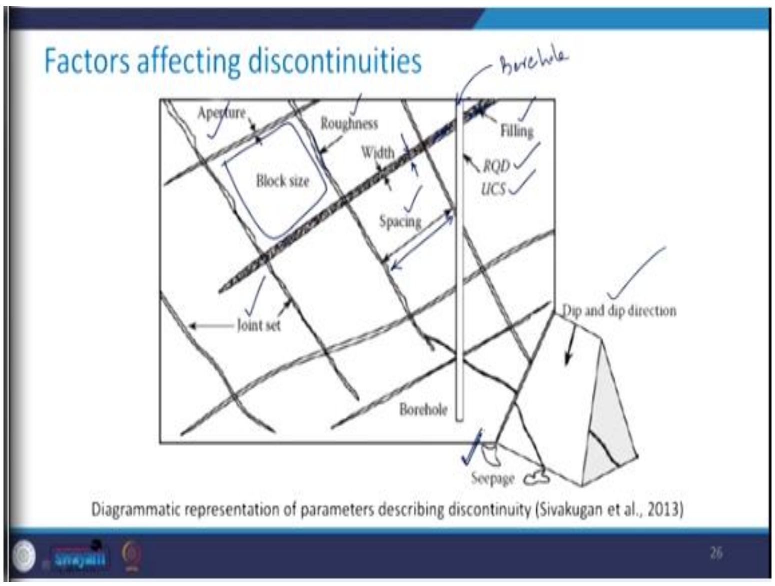
Spacing and persistence, you have to use measuring tape to measure these. Roughness, you have some reference charts, so you have to take the help of those reference charts in order to decide the roughness. Wall strength, we have seen how to determine this using Schmidt hammer rebound test. Then aperture either you use scale or feeler gauge, filling visual, seepage you have to have the visual observation with respect to time.

Number of sets, stereographic projection comes into picture, block size we have 3D fracture frequency. Now here these measurements can be taken in a core or through borehole via TV camera or from the exposed surface. Now depending upon from where you have taken this measurement, you can get the quality of the data. So, here G stands for good quality, M stands for medium and B stands for bad quality of the data.

So, likewise here if you just see that as per as spacing is concerned, you take either core or borehole via TV camera or the exposure. It is always you can measure it with the very good quality with quite a lot of precision that you can find out this spacing. However, you can see that in this matrix somewhere for let us say for roughness and wall strength. If you, do it using the core data is the medium kind of accuracy that you will get.

If you use borehole via TV camera, it is bad quality but if you take the observation from the expose surface, then it is good. So, you observe one thing that when we take the measurement mostly from the exposed surface or let us say we create some kind of a drift small tunnel just to take that these observations, then most of the time we get good quality data from this method as compared to core and borehole via TV camera.

(Refer Slide Time: 33:27)



Now to summarize all these factors, here is a figure which has been given showing diagrammatic representation of the parameters which are describing the discontinuity. So, start one by one, you can see how the spacing is defined between the 2 joints spacing. If it is infill, then you measure this and find out what is the width, find out it is roughness profile at the joint wall surface.

That will give you roughness, this portion between the joints, the block size, you can find out the aperture like this, this way you can find out what are the joint sets. You have a borehole and from here you extract the specimen sample from there you will be able to obtain RQD tested in the lab and you will be able to get UCS. As for as filling and it is property is concerned, you have to take out the material from this spot and you will be able to get the filling.

As far as dependent direction is concern, you can see that this is how that you can determine. And for seepage you see whatever is the water you just need to see, take the observation at this location in order to measure the seepage. So, basically this figure gives you the overall idea about all the factors which influence the discontinuity. So, we learnt about various factors which influence the discontinuities.

So, in the next class we will start our discussion on the engineering classification of the rock mass. And in that series, we will take up the first classification system, which is the rock mass rating system, that in short is called as RMR system. So, we will discuss that in the next class. Thank you very much.