Rock Engineering

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

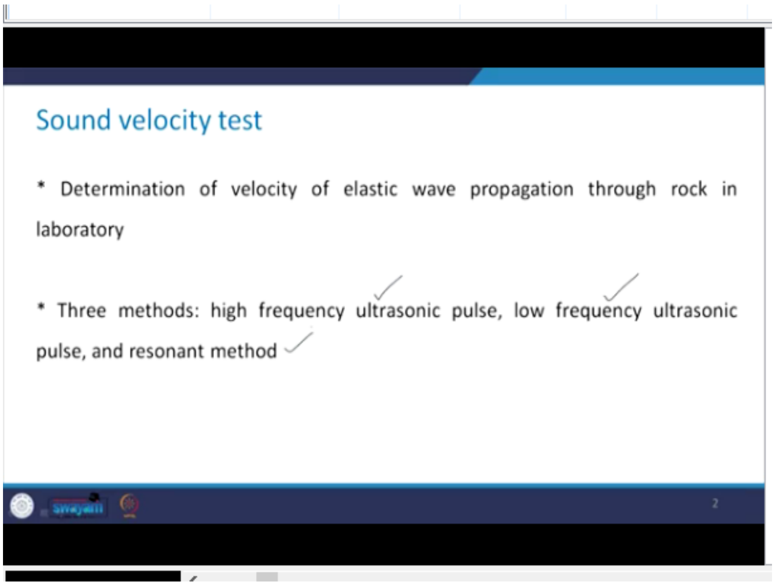
Lecture-15
Sound Velocity Test, Slake Durability Test, Swelling Pressure and Free Swell Test and Void Index Test

Hello everyone. In the previous class, we discussed about how to obtain the tensile strength of the rocks. And that was followed by the Schmidt rebound hammer test, I explained you that how the tests can be conducted and how the result of that test can be interpreted to obtain the unconfined compressive strength of rocks. So, today, we will continue our discussion with reference to laboratory testing of rocks.

And in that series, we will be discussing about sound velocity test, slake durability test, swelling pressure and free swell test and void index tests in today's lecture. We will start with this sound velocity tests. Why should we consider this and how we should carry out this test? So, basically, wherever the underground excavation they may be subjected to dynamic loading, we need to know the dynamic properties of the rock.

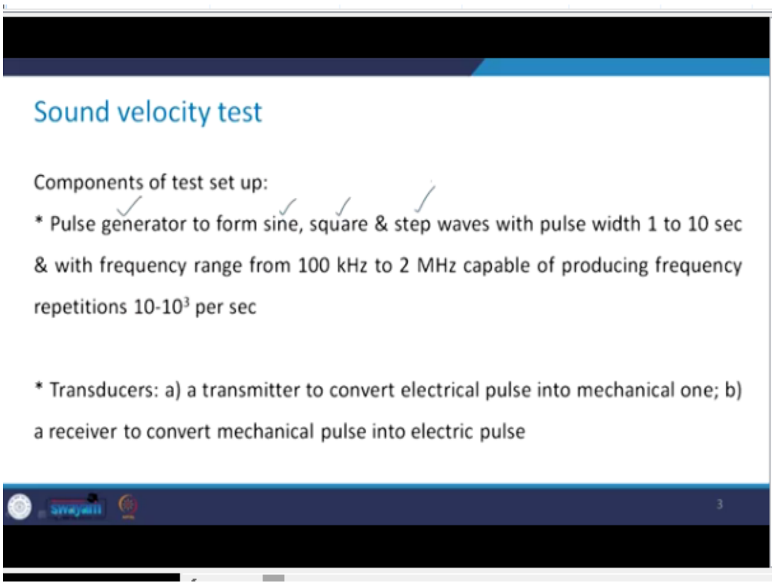
And therefore, we carry out these tests. The results of these tests, they are interpreted or analyzed in order to find out the dynamic elastic modulus and dynamic Poisson's ratio for the rocks. So, the basic philosophy as far as this test is concerned is that the wave is propagated through the specimen of rock and the velocity of elastic wave propagation through the rock is determined in the lab.

(Refer Slide Time: 02:40)



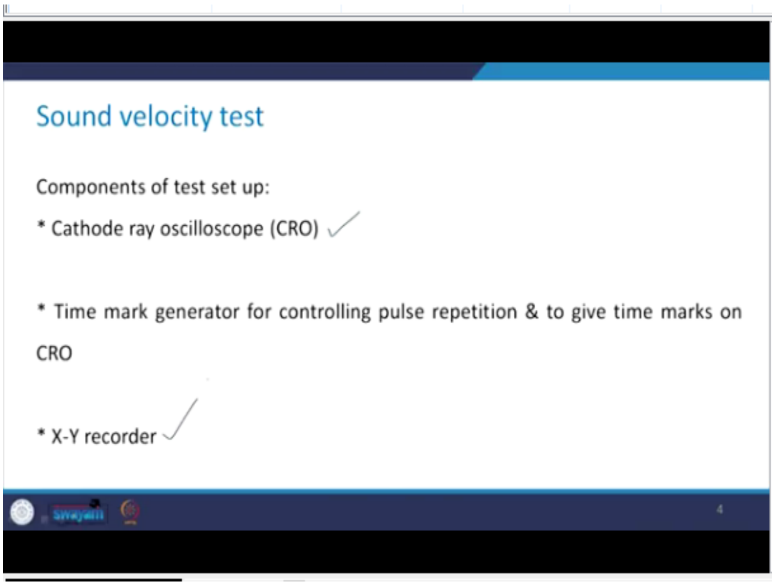
There are 3 methods to conduct this sound velocity test, which include high frequency ultrasonic pulse test, low frequency ultrasonic pulse test and the resonant method.

(Refer Slide Time: 02:55)



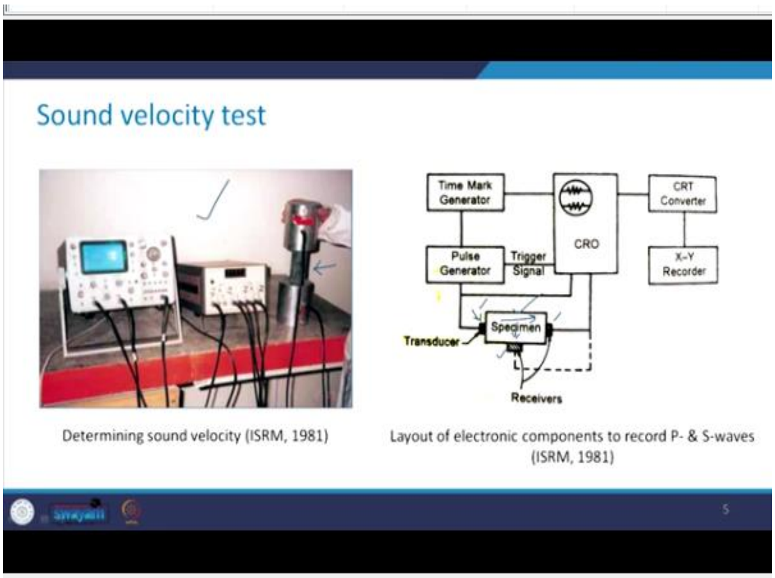
The components of the test setup they include pulse generator, this can form sine, square and step kind of wave with pulse width of 1 to 10 seconds and it has a frequency range from 100 kHz to 2 MHz and capable of producing frequency repetitions 10 -10^3 per second. Then, there are transducers. So, the first one is a transmitter which converts the electric pulse to the mechanical pulse. And the second one is receiver and this converts this mechanical pulse into the electrical pulse.

(Refer Slide Time: 03:57)



There are other components like cathode ray oscilloscope, then time mark generator for controlling the pulse repetition and to give time marks on this cathode ray oscilloscope and there is X-Y recorder. Let us see how the setup looks like.

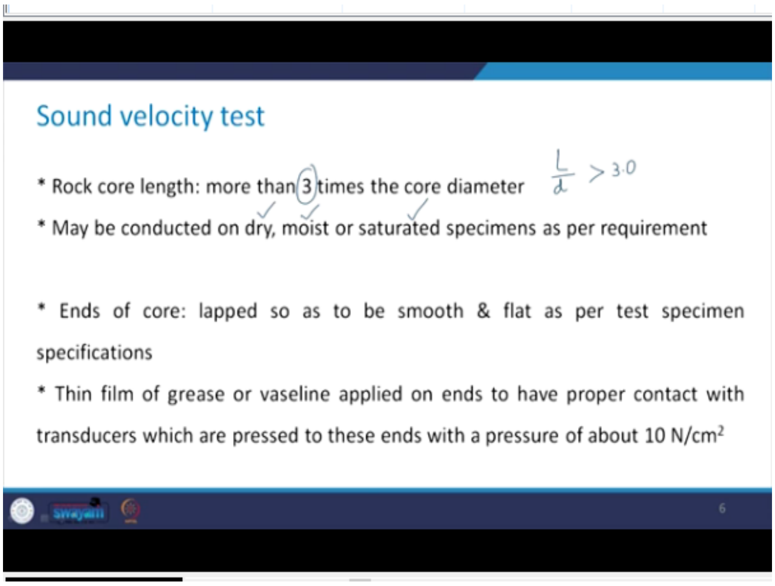
(Refer Slide Time: 04:18)



So, this is the layout of electronic components to record P and S waves and this is the picture of the setup which I have taken from ISRM 1981. So, you can see here that the specimen has been mounted between the 2 transducers, one is acting as a pulse generator. So, one is at where the pulse is hitting the specimen, then it travels through this specimen and which is received at the other end of the specimen.

If you take a look at the layout of electronic components, So, you see here is the specimen and here is one transducer through which the wave will pass from this point to this point and there are 2 receivers, one is here in this direction that means, one is in the direction, let us say the wave is travelling. So, one is exactly in this direction and another one is in this direction.

(Refer Slide Time: 05:41)



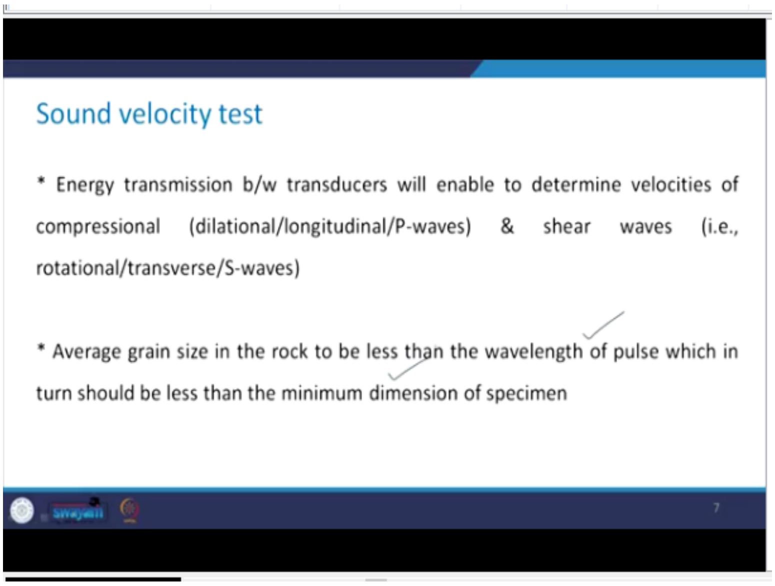
And what we get is that, how to obtain the velocity of P and S wave from this test and then these velocities they are correlated with the dynamic elastic constants of the rock. Now, as we had some special specimen preparation requirement in case of UCS test or in case of Brazilian tests, likewise, here in this case, we have some specific requirements for the specimen, these are listed here.

Rock core length should be 3 times the core diameter, that means, *L/d* ratio must be equal to 3 in this case, these tests may be conducted on dry or moist or saturated specimens depending upon what is the condition that is relevant in the field. Accordingly, you take the specimen and carry out the test on such specimens. Ends of the core that is the raw core, which we are taking as a specimen that should be lapped.

So, as to be smooth and flat as per the test specimen specifications, this we have discussed like for ISRM. I mentioned to you that what all are those permissible limits for ends to be flat or ends to be perpendicular to the axis of the specimen. Then in order to have the ends of the specimen proper contact with these transducers, a thin layer of grease or vaseline is applied on the ends.

And then these transducers which are placed at the ends of this core they are pressed with a pressure of about 10 N/cm^2. And then the energy transmission between the transducers takes place and this enables to determine the velocities of compressional or dilatational, longitudinal or p waves and shear waves. Shear waves are also known as rotational transfers or s waves.

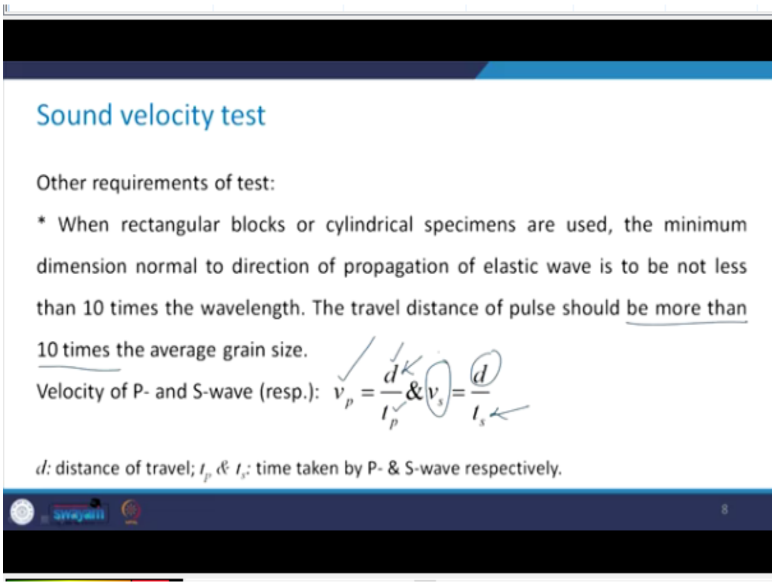
(Refer Slide Time: 08:38)



Another requirement which is there is that average grain size in the rock should be less than the wavelength of the pulse. That is the first thing plus this wavelength of the pulse should be less than this minimum dimension of the specimen. When I was discussing different types of rocks with you, I mentioned to you that same rock types depending upon its formation, they may have coarse or fine grains.

So, the information that we get at that stage can be useful here, when we conduct the test to make sure that this condition is satisfied. Now, the other requirement of the tests includes that if we are using rectangular blocks or the cylindrical specimen, the minimum direction normal to the direction of the propagation of the elastic wave should not be less than 10 times the wavelength.

(Refer Slide Time: 10:01)

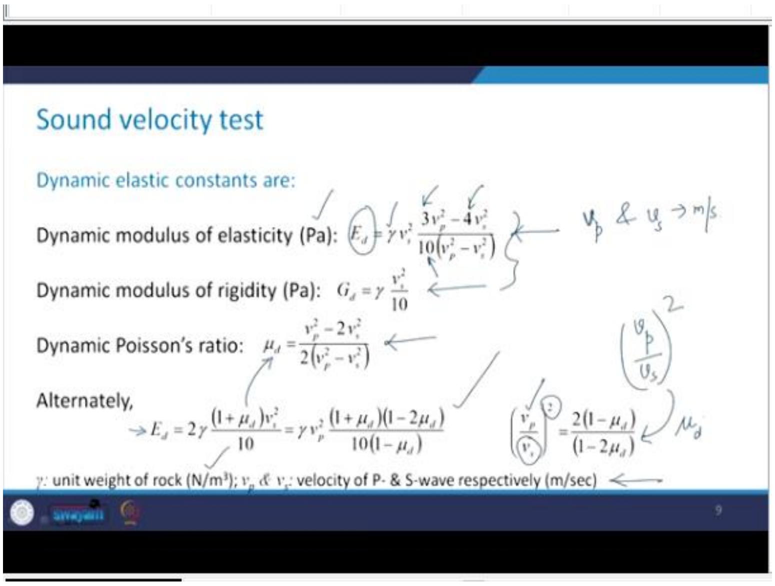


And the travel distance of the pulse should be more than 10 times the average grain size. So, apart from all those conditions that we discussed earlier, this is an additional condition which also should be satisfied. Now, we know wherever we have placed the transducer which is acting as a receiving end, we know its distance from the transducer through which the energy is being transmitted to the specimen.

So, we know this distance *d*, then this t_p and t_s, they will be known from the test result that is the moment the wave is received at that receiving end that time you will get from the result of these velocity tests. So, once we know the end, this is t_p that means, the time taken by the p wave to reach or to travel the distance *d*. Similarly, this t_s is the time taken by s wave to travel this distance *d*.

So, we divide this distance of travel by the corresponding values of time and we get the velocity of p wave, v_p and the velocity of s wave, v_s. Now, let us see that how these values can be used to obtain the dynamic elastic constants.

(Refer Slide Time: 12:01)



So, the first one which I have listed here is dynamic modulus of elasticity in Pascal's is this given by this expression, please be careful about the units because hear these terms like 3, 4 and 10 they are coming into picture. So, we need to be careful about the units. Here γ is the unit weight of rock that is in N/m^3 and this velocity of the wave v_p and v_s, these are in m/s**.**

And what you will get is the dynamic modulus of elasticity E_d that would be in Pascal's. Then, the dynamic modulus of rigidity, the next expression is given by $G_d = \gamma \frac{V_s^2}{10}$.

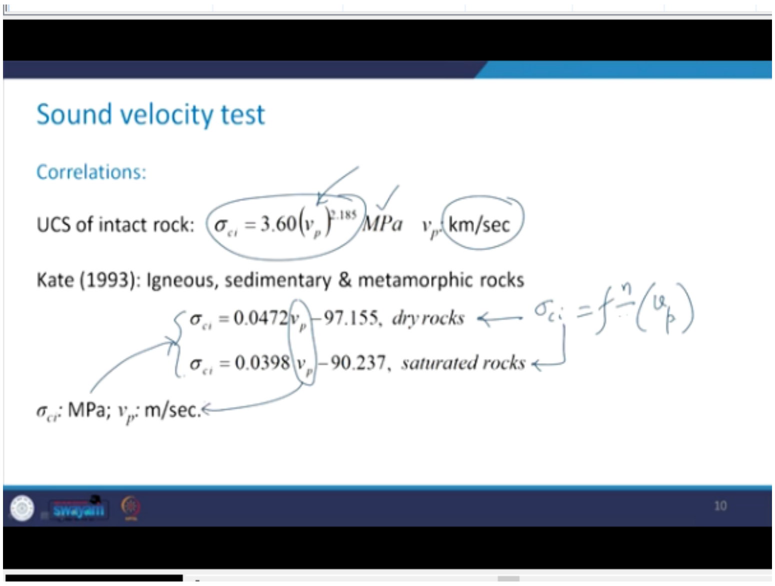
Again, we need to be careful about the units. Dynamic Poisson's ratio is defined in terms of velocities using this expression. Alternately, there are this expression that is this one,

$$E_d = 2\gamma \frac{(1+\mu_d)V_s^2}{10}$$

And this is like the same thing as this dynamic Poisson's ratio. So, you can use either this expression or this expression in order to obtain the dynamic modulus of elasticity. The ratio of the velocities of p and s waves and there square, that is, $\left(\frac{V_p}{V_s}\right)^2 = \frac{2(1-\mu_d)}{(1-2\mu_d)}$

which is a function of only the Poisson's ratio, that is dynamic Poisson's ratio. This is not the function of the dynamic modulus of elasticity.

(Refer Slide Time: 14:18)

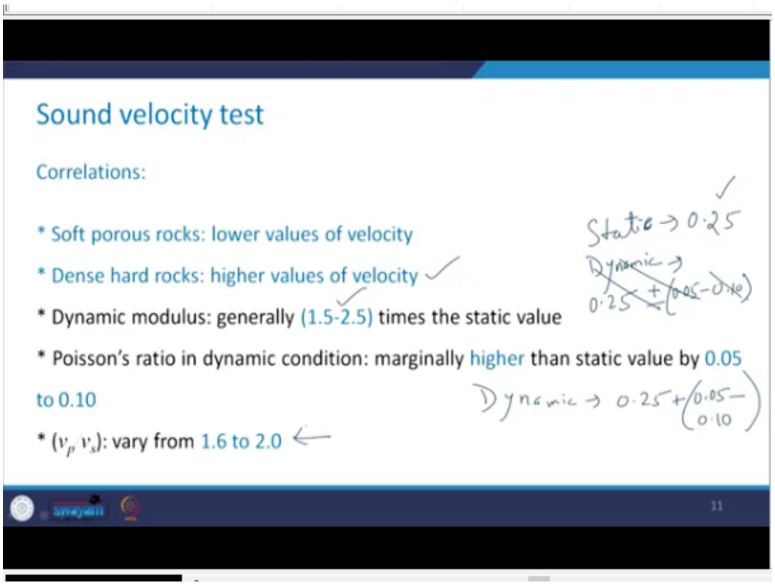


The UCS of the intact rock can also be obtained from the test result, we have the velocity of the p wave. So, that is to be given as an input in this expression in km/sec and you use this expression that is $\sigma_{ci} = 3.60(v_p)^{2.185}$ and you will get the UCS of intact rock in MPa. Please keep in mind that we need to be careful about these units because these expressions are generated in an empirical fashion that means lot many tests were conducted.

And then this equation was fitted to that data. Then Kate in 1993 gave the expression for UCS of the intact rock for igneous, sedimentary as well as metamorphic classes of the rocks. For dry rocks, it is the first expression. Again here, this σ_{ci} is only the function of velocity of the p wave. Here also the same thing. So, this is with respect to the saturated rocks and the first one is for dry rocks.

Here, the units for this σ_{ci} are MPa and for the velocities the units are m/s in this case. So, you see expressions, different and the units also different. One needs to be very, very careful about this aspect, while making use of empirical correlations which are obtained from the regression analysis of the experimental data. As obvious soft porous rocks will have lower values of velocity.

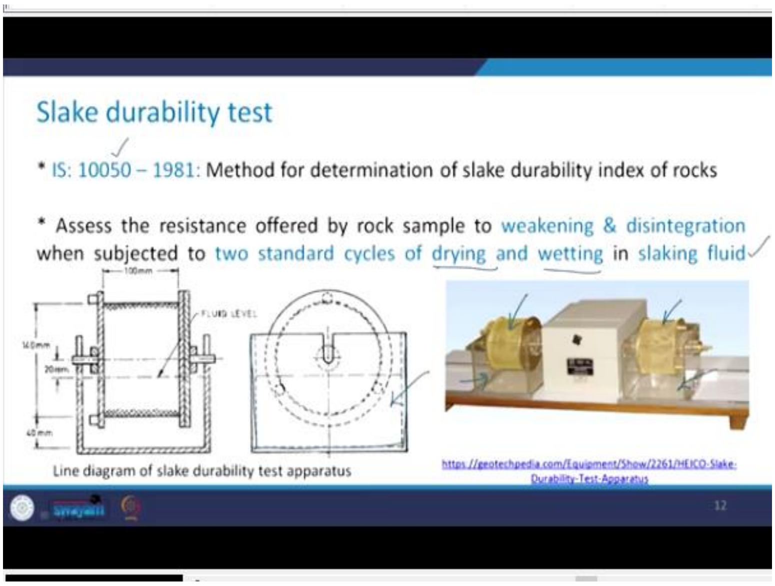
(Refer Slide Time: 16:49)



And dense hard rocks will have higher value of velocity. One needs to keep in mind that dynamic modulus is generally 1.5 to 2.5 times the static value. Poisson's ratio in dynamic condition is marginally higher than the static value, say by 0.05 to 0.10. So, let us say that in the static case, if this is 0.25, in the dynamic case, it will be 0.25 + (0.05-0.10). So, this is how the Poisson's ratio in dynamic condition can be estimated.

The ration of the velocities of p and s wave, these vary between 1.6 to 2.0. So, this was all about the sound velocity test. We have seen that, how this can be conducted and how the results of this test can be used to determine the UCS of the rocks and the dynamic elastic constants for the rocks. Now, coming to the next test, which is the slake durability tests.

(Refer Slide Time: 18:28)

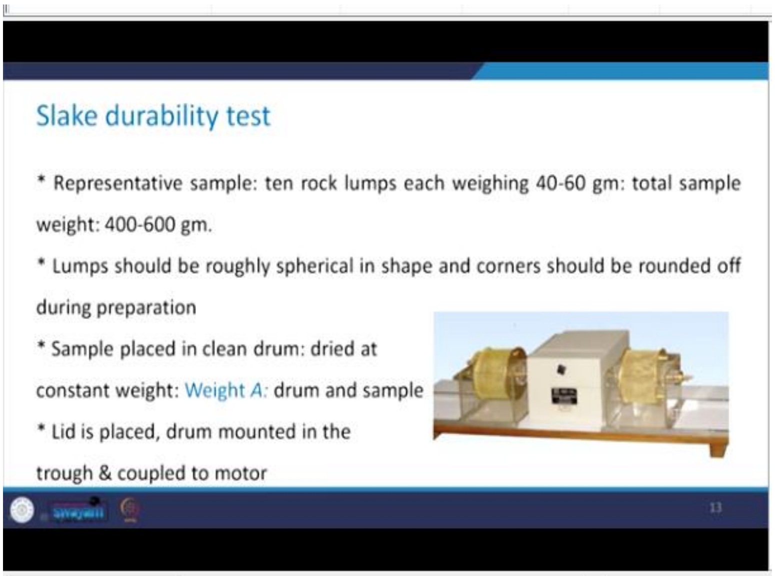


The relevant IS code for slake durability test is IS:10050 and it gives us the idea that how to determine the slake durability index of the rocks. So, first of all, let us understand that what do we get from this index? Why are we conducting this test? So, basically this test helps us in assessing the resistance offered by the rock sample to weathering and disintegration, when the rock is subjected to 2 standard cycles of drying and wetting in slaking fluid which is generally taken as water.

So, here is the line diagram of slake durability test operators. You can see that there is a drum here and then there is a trough this box. This drum is mounted on this trough and the water is filled or this slaking fluid is filled in this trough and then this drum is rotated about its axis. So, what will happen? The rock specimen which is in the form of some lumps they will interact with each other; they will hit each other.

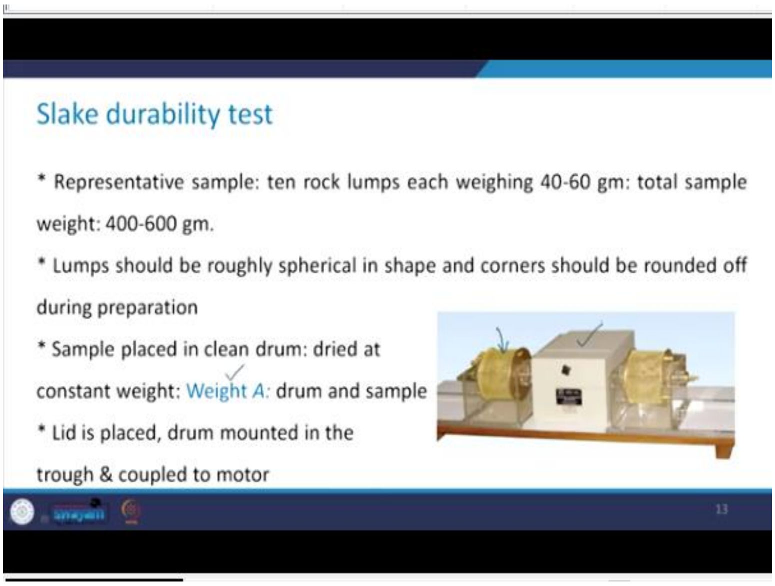
And what will happen because of that? That there will be some kind of weakening effect or the disintegration because of this action and that is how we are going to find out the slake durability index. Take a look at this picture. So, you can see that with the help of the perplex sheet, this trough has been made on both the sides and you have the drum here.

(Refer Slide Time: 20:38)



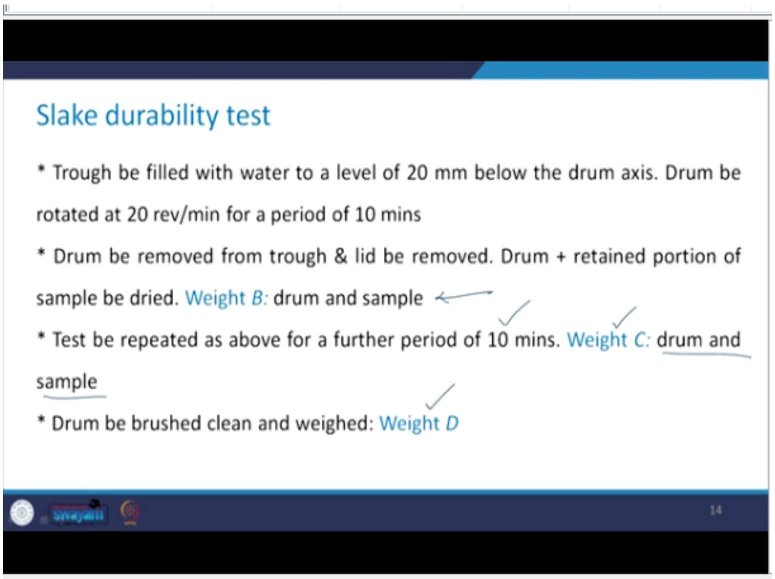
Now, see how the sample is prepared. So, in this, 10 rock lumps each weighing about 60 to 40 grams, they are taken. So, if there are 10 lumps, the total sample weight is going to be 400 to 600 grams. If you have the irregular sample, then these lumps should be made roughly spherical in shape and the corners should be rounded off again by the light hammer blows during the preparation. So that, the disintegration because of these sharper corners should not occur.

(Refer Slide Time: 21:31)



Then, the sample is placed in the clean drum which is dried and at the constant rate, say, it is the weight A. So, before the conduct of the test when the sample is placed in the drum, you take the weight of it, that is, I am calling as weight A, then the lid is placed, that is the lid which is there when you open the lid you can place the sample inside the drum. You place the lid and then mount these drum in the trough like it has been shown here, which is coupled to the motor. So, here is the motor.

(Refer Slide Time: 22:15)



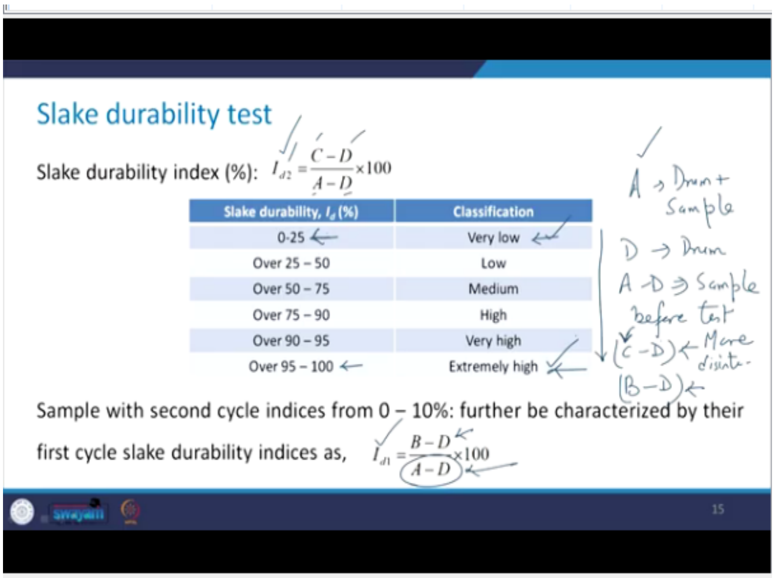
Then, this trough is filled with water to a level of 20 millimeter below the drum axis and drum is rotated at 20 revolutions per minute for a period of 10 minutes. So, what will happen because of this action? Those 10 rock lumps which are there as a part of the sample, they will hit each other during this motion and because of this action, whatever is the disintegration that is taking place.

That those particles will be there in the water they will get deposited in the water. Now, that drum is removed from the trough and lid also is removed. So, the drum plus the retain portion of the sample is dried. So, that is going to give me another weight that is weight B. So, you see that if the rock is prone to disintegration what will happen is that there will be a lot of difference between the weights A and B.

Because with the action of this revolution and the sample inside that the disintegration will be more and those fine particles because of that disintegration, they will get deposited in the water, come out of the drum and get deposited in the water and the remaining weight will be much less than the weight A. Then the test is repeated as it was done in the previous step for further period of 10 minutes.

So basically, that was the first cycle of wetting and drying. So again, we will have the next cycle and we take the weight C. This means that we have weight of the drum and the sample after the second cycle. Then we take the weight of only the drum which is clean and vague. That means there is no particle from the rock sticking to the drum. So, this is weight D is only the weight of the drum.

(Refer Slide Time: 24:58)



Then this is how we find out the slake durability index after the end of the second cycle.

$$I_{d2} = \frac{C-D}{A-D} \times 100.$$

This is represented in %. Now, if the slake durability index I_d is low that is between 0 to 25, the rock is case classified as very low. If it is over 95 to 100% it is the index or the classification is extremely high, what does this mean?

That as the slake durability index increases, the classification changes from very low to extremely high. If this I_{d2} works out to be between 0 to 10% this can further be classified by the first cycle. So, you see that in that case you will have

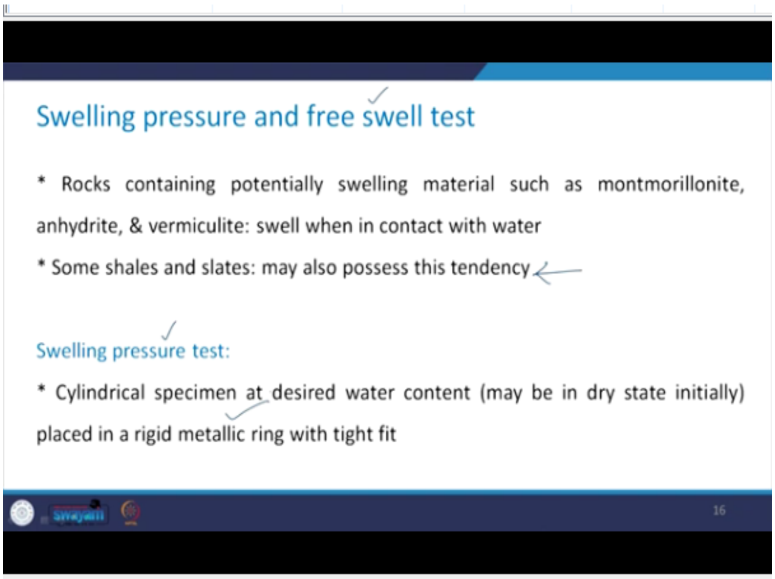
$$I_{d2} = \frac{B-D}{A-D} \times 100.$$

Take a note here, what is this A – D? See, D is the weight of the drum and A was the initial weight of the drum plus the sample before this conduct of the test. D is the weight of the drum.

So, A-D is going to give me the weight of only the sample before the test right. Now, either you take a look at C - D or B – D. What does this represent? C - D means what this is the C is the weight after the second cycle and D is the weight of the drum. That means, this C will always be less than or equal to A, it can never be more than A. So, lesser will be the value of C means more disintegration.

Because, when the more disintegration has taken place, so, more particles have gone out from that lump and therefore, when it is low it is, I mean then it is 0 to 25%, it is very low and if it is 95 to 100, it is extremely high. So, this is how the slake durability index can be used to classify the rock.

(Refer Slide Time: 28:03)

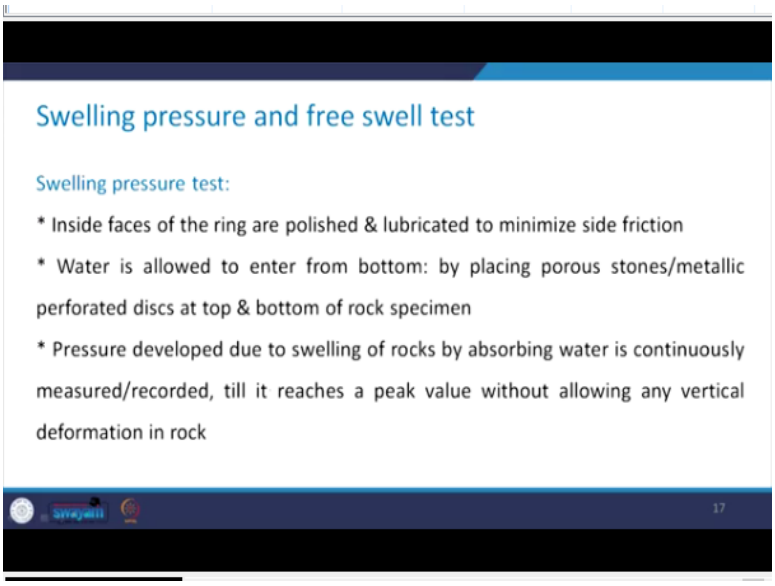


Then coming to the next test, that is swelling pressure and free swell tests. So, rocks which contain potential swelling materials such as montmorillonite, anhydride or vermiculite then they swell when they come in contact with water. Some shells and slate they also may possess this tendency of swelling. There are 2 tests, one is the swelling pressure and another is the free swell test.

As the name suggests, in case of the swelling pressure test, we are going to measure some kind of pressure. I will tell you what it is. And in case of the free swell test, we are going to allow the specimen to swell freely. That means, if any object is allowed to swell freely that means what it will not create any pressure because whatever is the pressure that is being developed, it is getting transformed into that deformation.

So, let us first focus on the first test, that is, swelling pressure test. So, in this case a cylindrical specimen at desired water content or maybe at the dry state initially, it is placed in a rigid metallic ring with a tight fit. When I say that it is placed in the rigid metallic ring with the tight fit means I will not allow the specimen to deform, it is constrained.

(Refer Slide Time: 29:47)

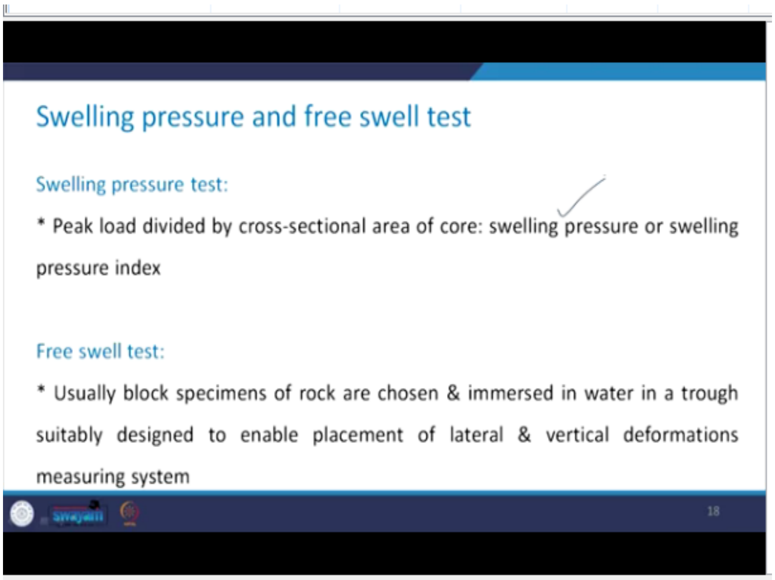


So, what will happen? Because it is constrained it is not able to deform. So, it will exert the pressure. So, that pressure is measured. Now when we place the specimen inside the face of the rings, which are polished and they should be lubricated to minimize the side friction. Then the water is allowed to enter from the bottom and how this can be done by placing the porous stone or metallic perforated disc at top and bottom of the rock specimen.

So, water will enter because the mineral is such that that it has a tendency to swell, then what will happen? The moment the water goes inside the rock specimen, it will start swelling, it will start increasing its volume and I am not allowing it to deform because of the constraint. So, therefore, the pressure is developed by absorbing the water by the rock and that is continuously measured till it reaches a peak value without allowing any vertical deformation in the rock.

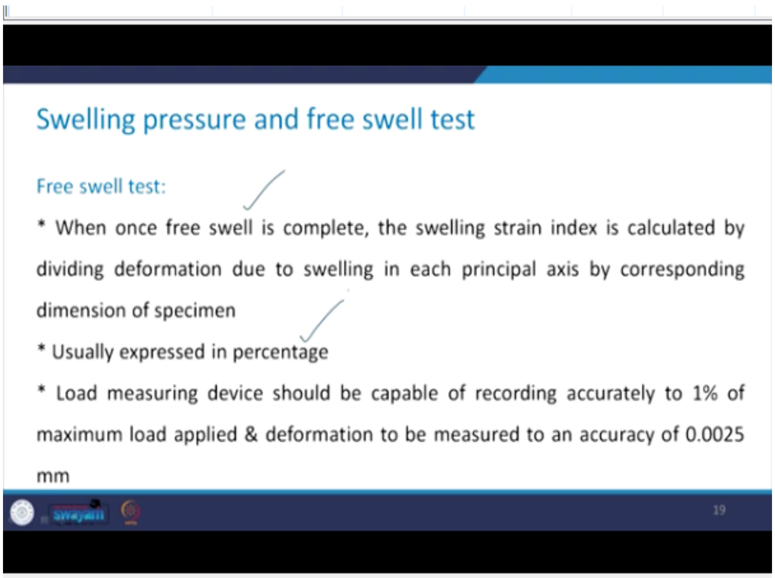
This gives us the idea or it helps that whether the specimen or that particular rock has any kind of swelling mineral or any kind of mineral which may cause swelling in the presence of the water. If there is no pressure that is being generated, that means, that rock is free from the mineral which is causing any kind of swelling. Then the peak load which is divided by the cross-sectional area of the core that will give you the swelling pressure or swelling pressure index.

(Refer Slide Time: 31:46)



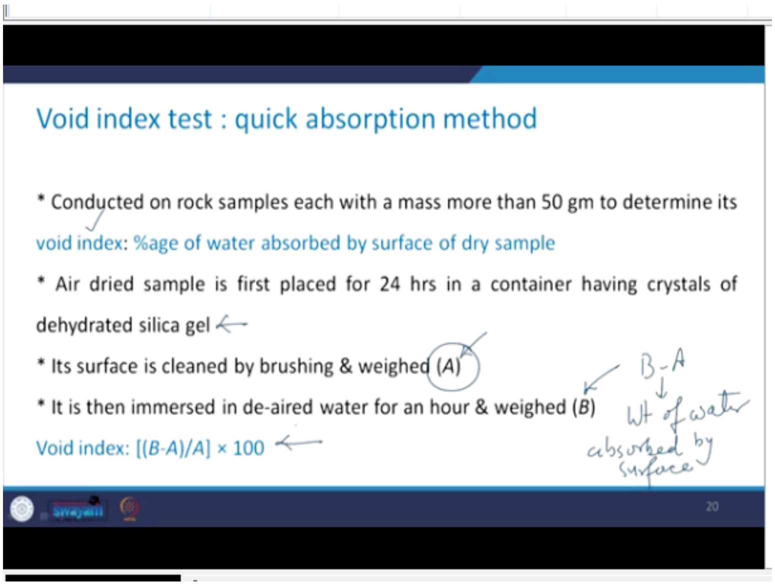
The second test is free swell index. In this case usually block specimens of rock they are chosen. They are immersed in water which is suitably designed to enable the placement of lateral as well as the vertical deformation measuring system. So, I just put the specimen in the water and I because it is allowed to swell that is free swell, I can measure the lateral and the vertical deformation.

(Refer Slide Time: 32:23)



So, when once the free swell is completed, the swelling strain index can be calculated by dividing the deformation due to swelling in each of the principal axis by the corresponding dimension of the specimen. This is usually represented in percentage. One needs to be careful about the load measuring device. This should be capable of recording accurately to 1% of the maximum load applied and deformation to be measured to an accuracy of 0.0025 mm. So, you have to be careful about this load measuring device.

(Refer Slide Time: 33:17)



Now, the last in this series is void index test, which is the quick absorption test. It gives us the idea about the percentage of water that is absorbed by surface of the dry sample. And it is conducted on the rock samples each with a mass more than 50 gram to determine its void index. So, what is done? This is very simple. So, air dried sample we first place it in a container having the crystals of dehydrated silica gel.

What these silica gel does is? That it soaks all the water that is there at the surface, then you clean the surface of the specimen by brushing and then take the weight of it. Let us say the weight is A. And then you immerse that in de-aired water for about an hour and then you take the weight of that again say that is B. So, B - A is going to give you the weight of the water that is absorbed by the surface of the specimen. And that if you divide by the weight of the sample, that is going to give you the void index. So, this is how the void index is defined that is $Void\ Index = \frac{B-A}{A} \times 100$.

So, today we learnt about the sound velocity test, slake durability test and free swell index and swelling pressure and the void index test. You could get the idea that how these tests are helpful in determining some of the properties related to the rocks. Now, in the next class, we will go to the next category of the tests which are the shear tests. So, that we will discuss in the next class. Thank you very much.