Underground Space Technology
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Lecture – 55
Permeability and Groutability -02

Hello everyone, In the previous class we discussed about the aspects related to permeability and groutability, then, we started our discussion on various types of grouts where we saw that we have suspension grout, liquid grout, and some of the special type of grouts and, we were discussing about, these, special type of grouts. So, today let us continue with that discussion. So, first we will see few more properties related to grouts and then, we will see that when the grouting is successful or when should we stop that.

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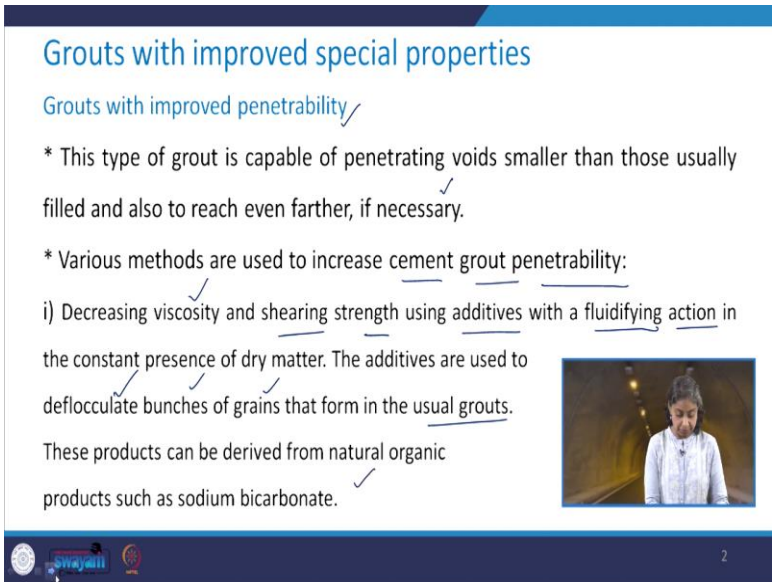

So, grouts with improved special properties. So, in this connection first we will discuss about the grouts with improved penetrability. So, this type of grout is capable of penetrating the voids which are smaller than those, which are usually filled, and also such type of grouts can reach even farther if required. There are various methods, which are used to increase the cement grout penetrability.

The first one is by reducing the viscosity and shearing strength, using the additives with a fluidifying action in the constant presence of the dry matter. So, in this case, what is done is the additives which are used to deflocculate bunches of grain that forms the usual grouts. So, such products can be derived from the natural organic products like sodium bicarbonate.

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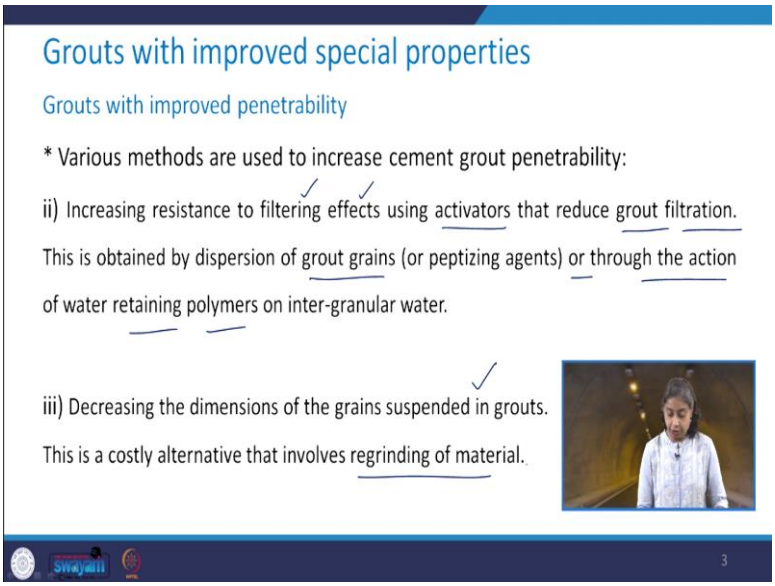

Further, various methods we have, the second type that is by increasing the resistance to filtering effects using activators which reduce the grout filtration. This is obtained by dispersion of grout grains or through the action of water-retaining polymers on intergranular water. Third way to increase the penetrability of the cement grout is by reducing the dimensions of the grains, which are suspended in grouts. This is the costly alternative, which involves the regrinding of material.

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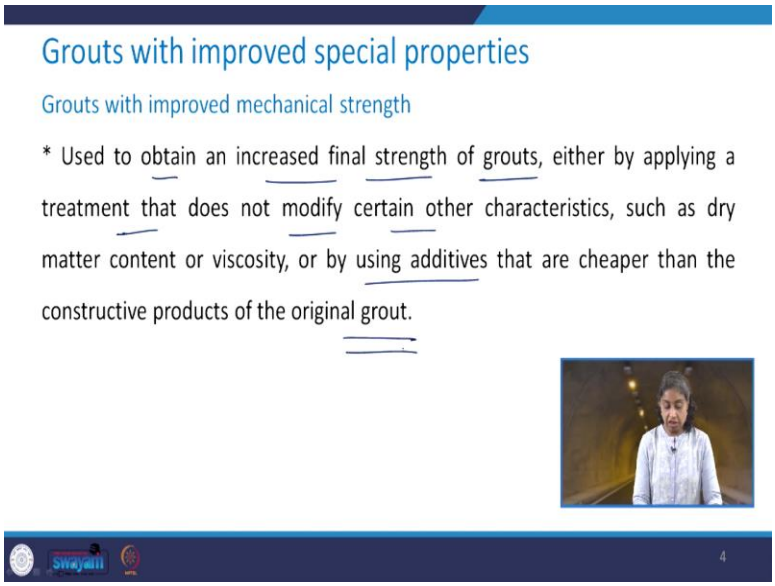

Then, we have the other type of these special property grout, which is the grout with improved mechanical strength. So, up till now we discussed that how we can increase the cement grout penetrability and make the special type of grout. Now, we focus on the grouts with improved mechanical strength. So, here these are used to obtain an increased final

strength of grouts, either by applying a treatment, which does not modify certain other characteristics such as maybe the dry matter content or viscosity, or by using the additives which are cheaper than the constructive products of the original grout.

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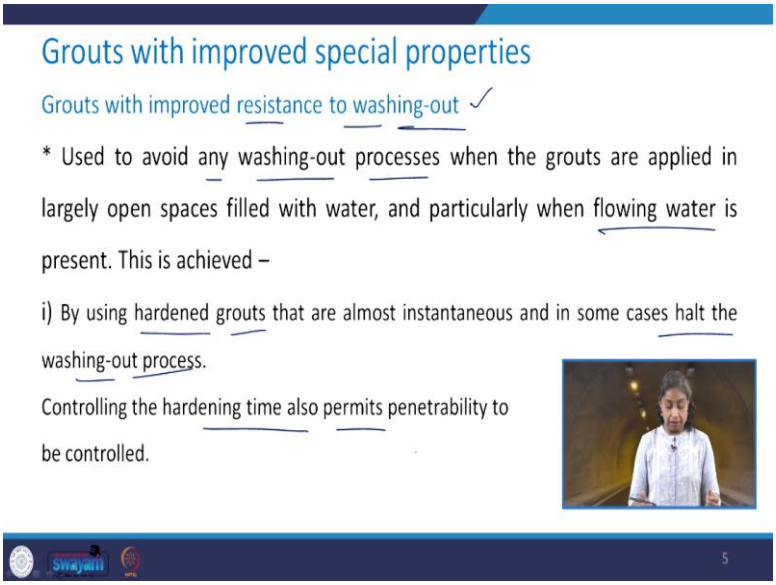

Then, the next type is the grout with improved resistance to washing out. See, wherever there is a large space and the flowing water is there, we need to use such type of grout which has the special property having resistance to washing out. So, these are used to avoid any washing out processes. When the grouts are applied in largely open spaces, which are filled with water and, especially when there is a presence of the flowing water.

So, this type of grout is achieved by using hardened grouts which are almost instantaneous and, in some cases, they halt the washing out process. So, controlling the hardening time also permits the control of the penetrability.

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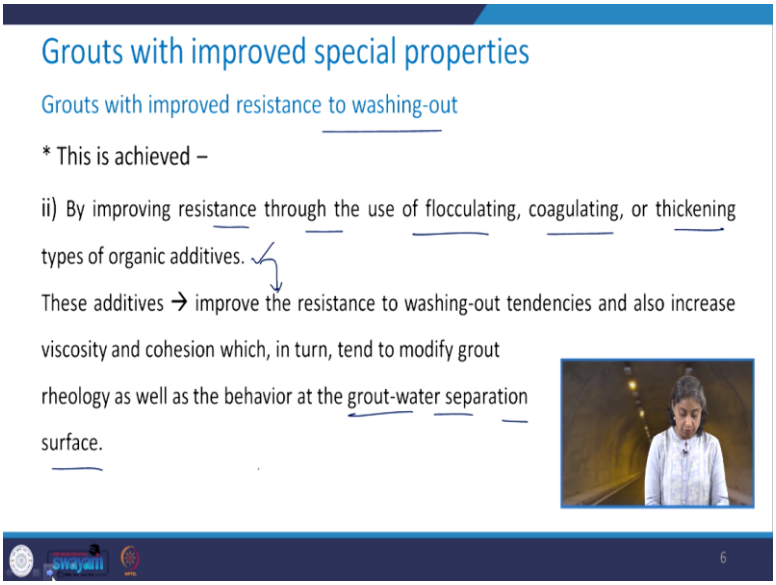

Then, the second way to achieve this is by improving the resistance through the use of flocculating or coagulating or thickening type of organic additives, what these additives, they do? They improve the resistance out to washing out tendency and also, increase the viscosity, and cohesion, and what happens, when the viscosity and the cohesion is increase, the result is that there is the modified grout rheology as well as its behavior at the grout water separation surface. So, therefore the complete result is going to be the improved resistance to washing out.

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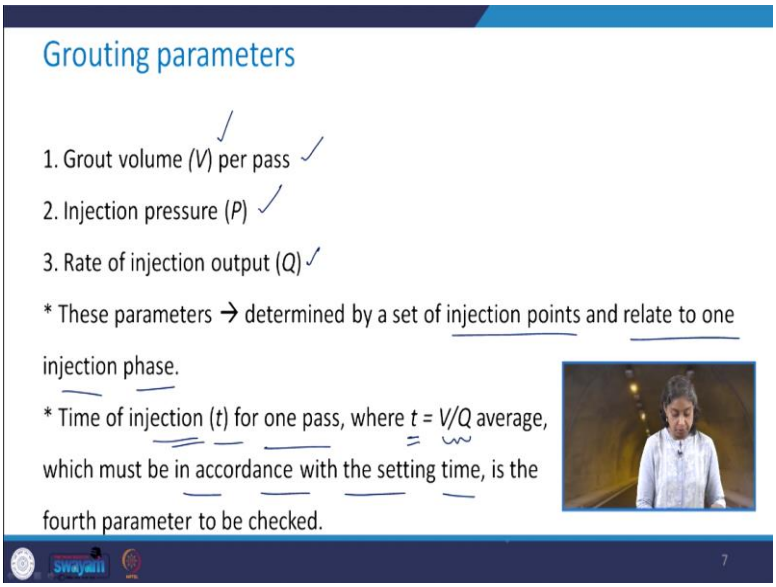

Some of the grouting parameters, that one should be aware of these include the first one is the grout volume V per pass then the injection pressure which is represented by capital P, and then the third one is rate of injection output which is Q. So, all these parameters these can be determined by the set of injection points and these relate to one injection phase. Another

aspect which one needs to keep in mind, or the fourth parameter which should be checked is the time of injection t for one pass where this, $t = V/Q_{average}$.

So, V is the grout volume per pass and Q be the rate of injection output. Now, this time of injection must be in accordance with the setting time and, therefore, this is the fourth parameter which should be checked.

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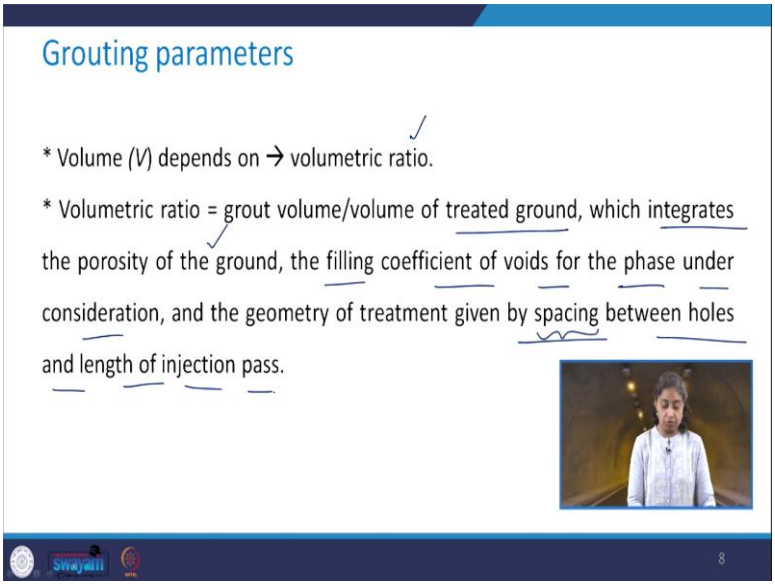

This volume V, it depends upon the volumetric ratio which is defined as the ratio of the volume of the grout to the volume of treated ground, which integrates the porosity of the ground. The filling coefficient of voids for the phase under consideration and, also the geometry of treatment which is given by spacing between holes and length of the injection pass.

So, you see when we need to go for the grouting, I mentioned to you that first we need to make a drill hole and then the grout is placed in that drill hole with pressure. So, basically, it becomes important to decide upon the spacing of these drill holes and the length of the injection pass as well.

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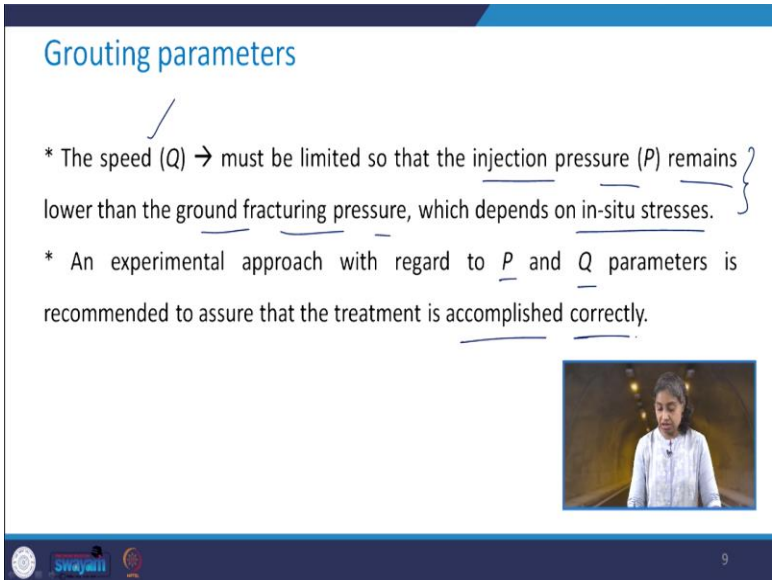

The parameters Q, which is the speed this must be limited so that the injection pressure remains lower than the ground fracturing pressure, which depends upon the in-situ stress and if this is not satisfied, if this condition is not satisfied then, it is very obvious that what it is going to be. If the injection pressure is more than the ground fracturing pressure, what will happen is that this grouting process may generate more number of cracks in the rock mass.

Then, an experimental approach with regard to P and Q parameters is recommended to assure that the treatment is accomplished correctly.

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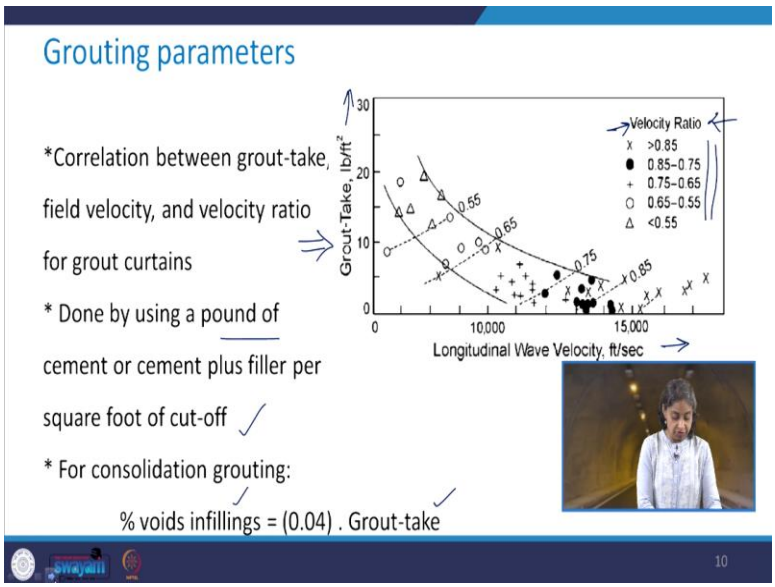

There is the correlation, between grout take field velocity and the velocity ratio for the grout curtains which is given here. So, you can see that on x-axis, we have the longitudinal wave velocity and on y-axis, grout take has been plotted and, here you see that there is a term

velocity ratio. So, corresponding to different values of velocity ratio the points were observed, and then this correlation was established.

So, this was done by using a pound of cement plus filler per square foot of the cut-off. As far as the consolidation grouting is concerned

% void in fillings = (0.04). grout take

The question comes here that, what is the meaning of this term velocity ratio?

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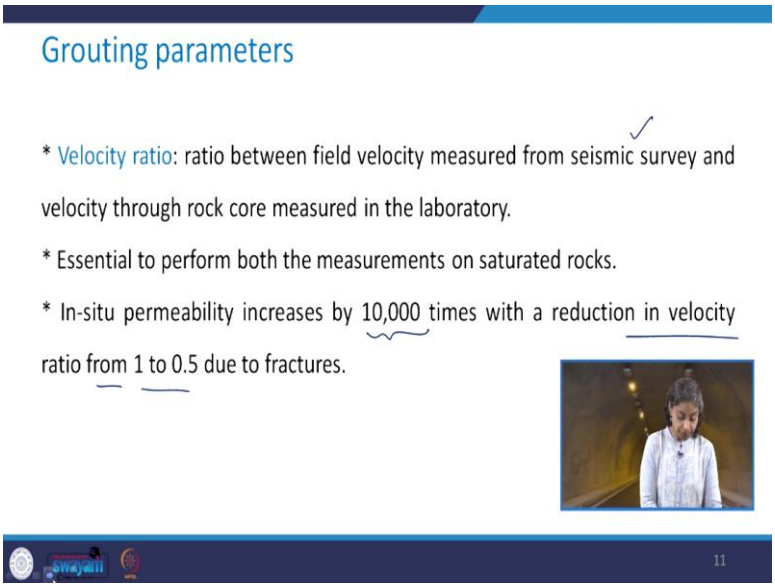

So, this is the ratio between the field velocity, which we measure from the seismic survey, and the velocity through the rock core which is measured in the lab. It is essential to perform both the measurements on the saturated rocks. We know that, the in-situ permeability increases with the reduction in velocity ratio, but then this increase can be of the order of 10,000 times with a reduction in velocity ratio from 1 to 0.5 because of the fractures.

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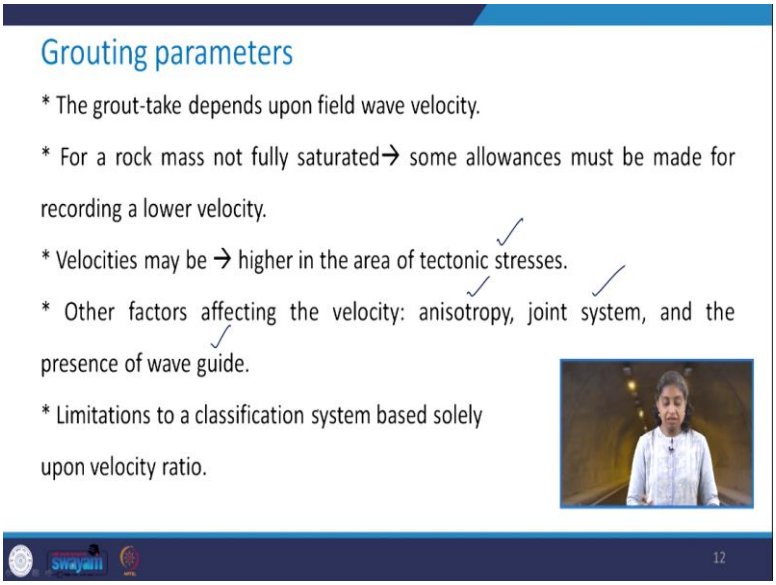

The grout take depends upon the field wave velocity, which is very obvious and for a rock mass, which is not fully saturated, some allowance must be made for recording a lower velocity. Further, there can be the record of higher velocities, especially in the area of tectonics stresses, then, there are other factors which influence the velocity, such as anisotropy joint system, and the presence of waveguide.

So, if there is a classification system, which is solely based upon the velocity ratio this can be one of the major limitation of that particular classification system, in view of these parameters which influence the velocity.

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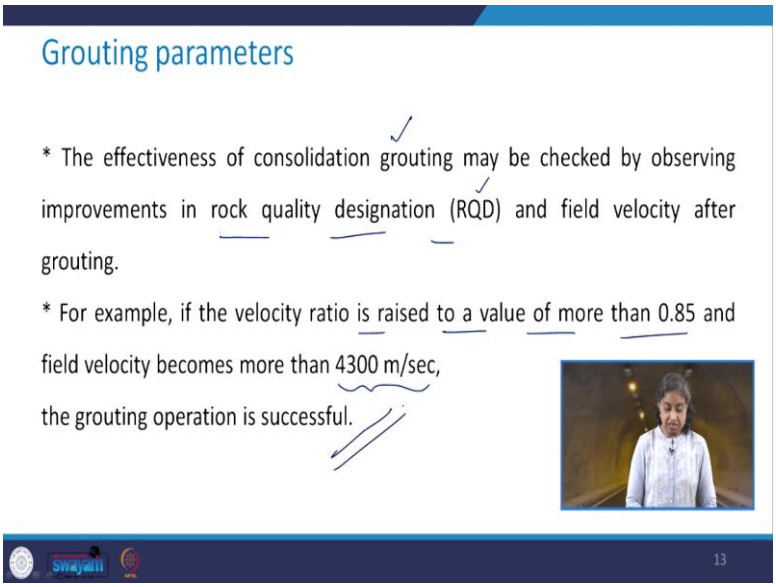

The effectiveness of the consolidation grouting maybe checked by observing the improvements in the rock quality designation, which we represent by RQD and the field

velocity after grouting. So, for example, if the velocity ratio is raised to a value more than 0.85 and the field velocity becomes more than 4,300 meters per second, we can say that the grouting operation is successful.

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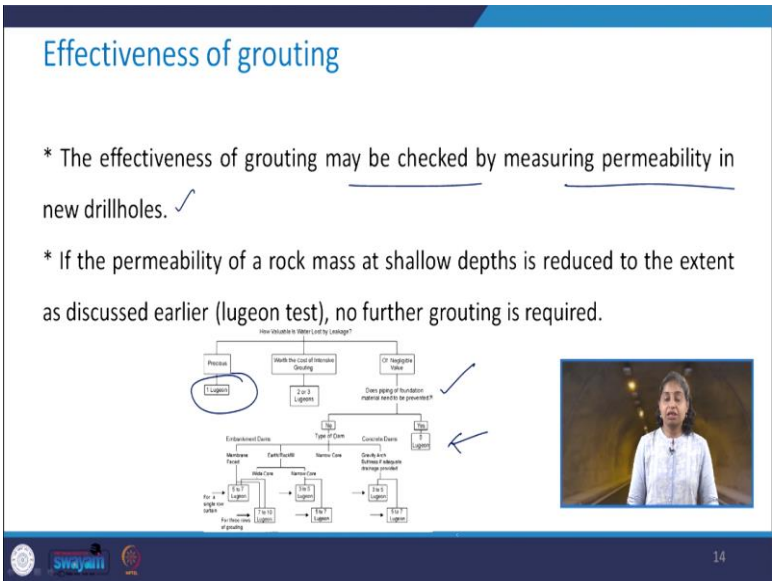

Now, coming to the effectiveness of grouting, how we can check whether whatever that we have done in the field is effective because, this grouting process is kind of a blind process, because, what we are doing we cannot really see. So, we need to check the effectiveness of grouting after we are done with it. So, this may be checked by measuring the permeability in new drill holes.

Now, if the permeability of the rock mass at shallow depths reduce to the extent, which we discussed earlier you remember this particular figure in connection with the lugeon test. So, in case, if we have the permeability, let us say about one lugeon or then, we can say that no further grouting is required or then maybe we can follow this tree to decide based upon the lugeon test, whether the grouting is further required or not.

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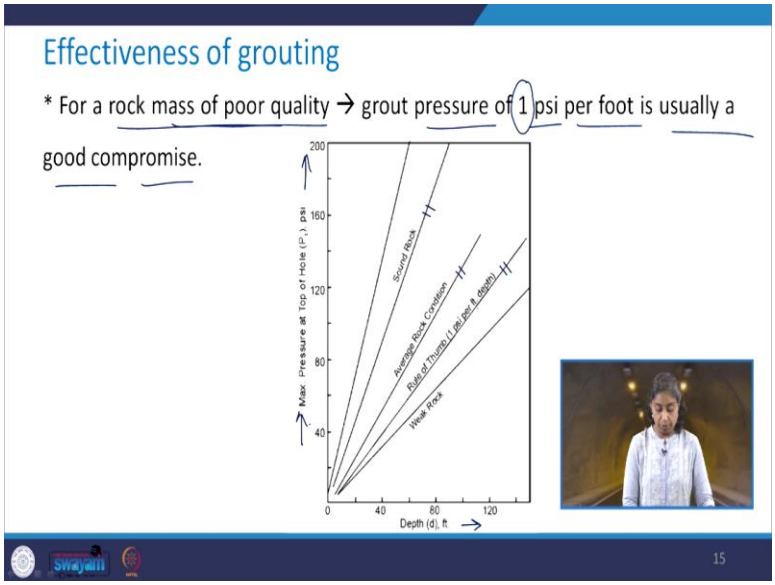

Then, for a rock mass of poor quality, so, please keep in mind that what we are discussing is the rock mass with respect to the poor quality. The grout pressure of one psi per foot is usually a good compromise. So, you see that it was plotted which is the depth in feet on x-axis and maximum pressure at the top of the hole in psi. So, here this is what is the rule of thumb which is one psi per feet of depth.

So, for this weak rock or the rock mass of the poor-quality grout pressure of one psi per foot is usually a good compromise, but then you have the average rock condition here and this one is for the sound rock. So, based upon this we can take a call that what is going to be the maximum pressure at the top of the drill hole.

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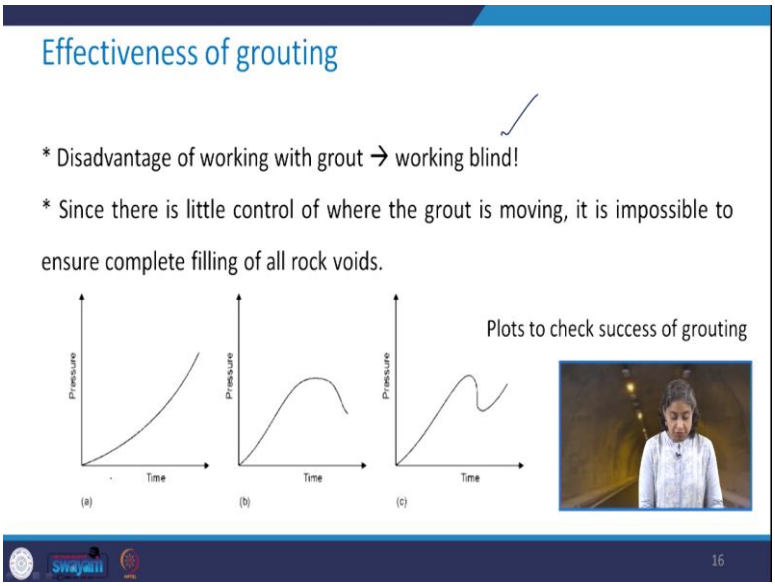

There are some disadvantages associated with the working with grout because, the working is extremely blind as I mentioned to you. We really do not know what exactly is happening and, because, there is very little control of where the grout is moving. It is almost impossible to ensure whether the complete filling of all the rock voids has taken place or not. So, therefore we need to have some kind of check the success of the grouting.

So, if we plot the pressure versus time curve then these three plots give us the idea whether the grouting is successful or not. Let us try to interpret them one by one. So, first we take the, a part of these plots.

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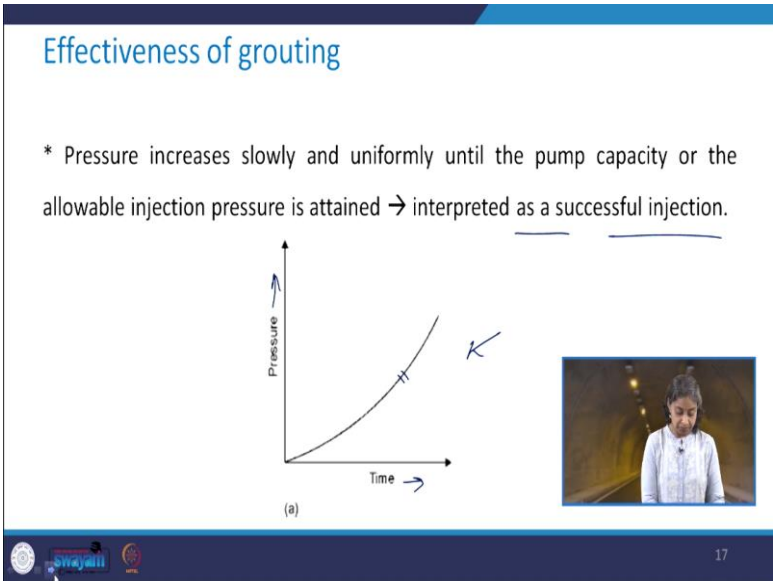

So that, I have zoomed, and pasted it here. On x-axis we have time and, on y-axis we have pressure. So, in this case, what happens is that the pressure increases slowly and uniformly until the pump capacity or the allowable injection pressure is attained. So, you see that it is continuously increasing, and therefore, it can be interpreted as successful injection.

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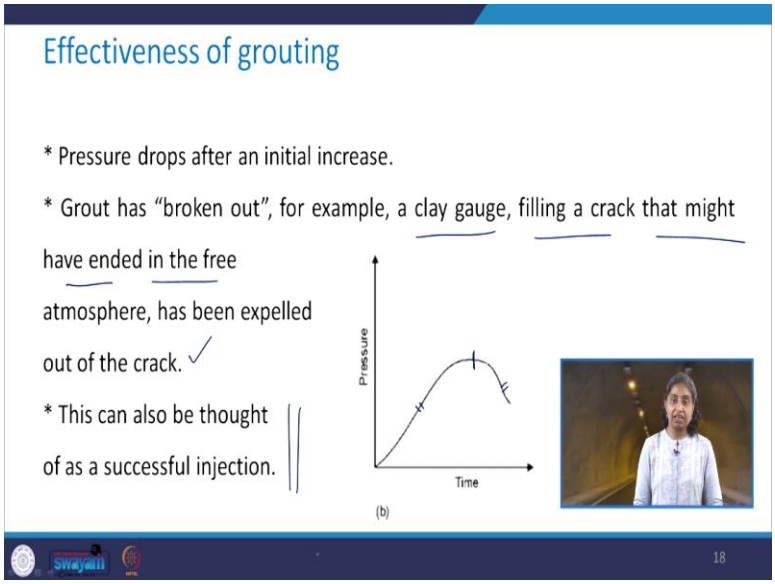

Then, the second category is as you see, that pressure first increases and then it goes up to the maximum and then there is a drop. So, this represent the broken out grout. For example, a clay gauge filling a crack that might have ended in the free atmosphere, which has been expelled out of the crack. Now, this can also be thought of as a successful injection.

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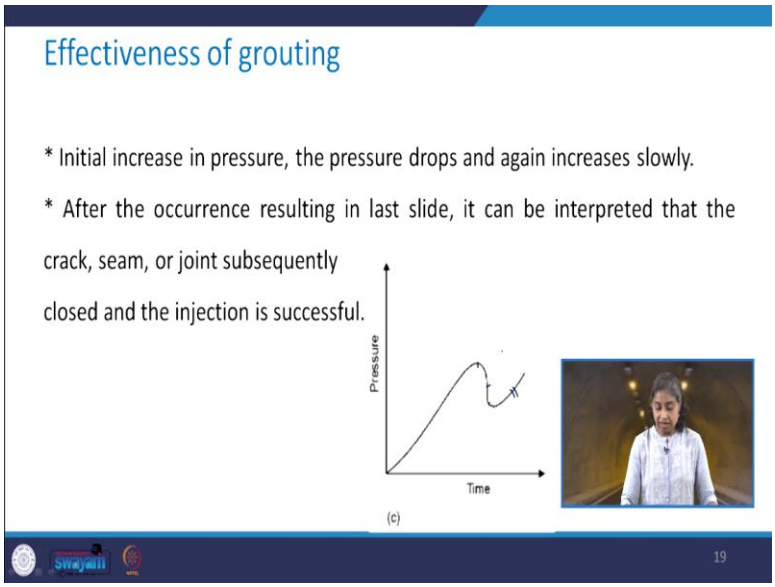

The third case is it first rises and then there is a drop and further, it rises again or further it increases again. So, after the occurrence which was there in the previous slide that we discussed that the increase and, then the drop it can be interpreted that the crack or seam or the joint subsequently got closed and then we can say that the injection is successful.

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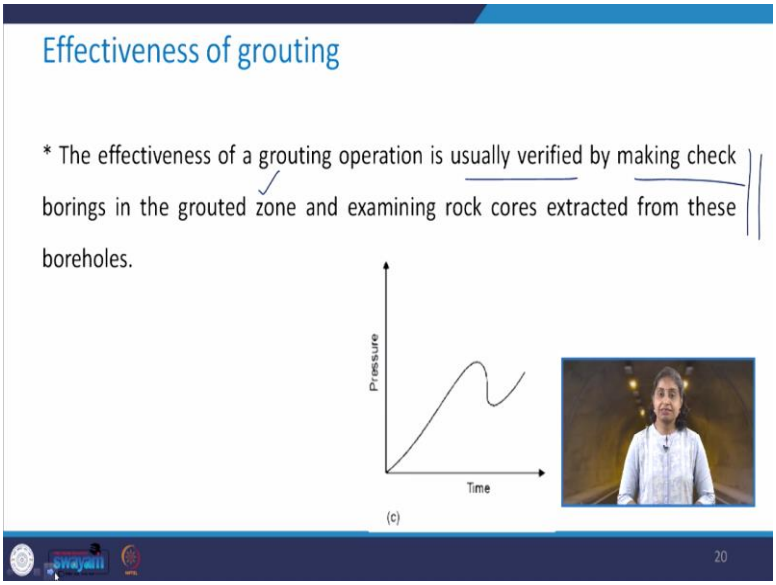

Further, this effectiveness of grouting operation can be usually verified by making the check borings in the grouted zone and examining rock core extracts from these boreholes. This is done exactly on the similar lines, when, we do the rock exploration we drill and then we collect the rock cores and keep arranging them, in the order to get the idea about the geology. So, this was all about the grouting through rocks.

So, we discussed about the various support systems including shotcrete then steel sets, rock bolts, and grouting through rocks. Now, in the next class, we will start the new topic which is the determination of the in situ stresses, which are there in the field and we have few in-situ test, which we perform in the field and, we try to obtain the state of stress, in-situ in the rock mass. So, we take a one such test, that is flat jack test in the next class. Thank you very much.