Rock Mechanics and Tunneling
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Lecture 21
In-situ Testing Methods

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Hello everyone, I welcome all of you to the fifth lecture of our module 4. So, in module 4, we are discussing about the laboratory testing on rock sample and In-situ testing of rock mass. So, already in our previous four lectures we have discussed about the laboratories testings. Now, in our fifth lecture, we will discuss about the In-situ testing methods.

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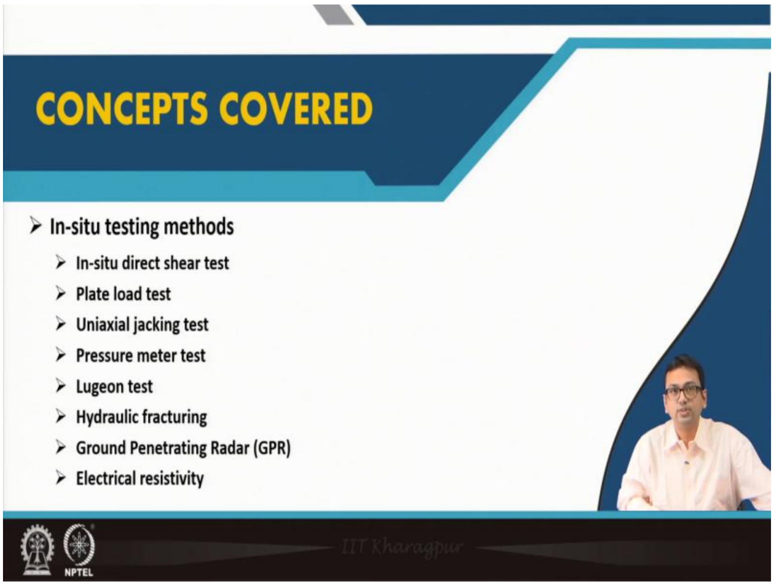

So here, under In-situ testing methods, we will try to briefly understand about different In-situ testing methods. So, among them first, we will discuss about the In-situ direct shear test, then plate load test, then uniaxial jacking test, after that pressure metre test, then Lugeon test or packer test. And after that hydraulic fracturing, then ground penetrating radar, and electrical resistivity test. So, these things we will try to cover in this part of our discussion.

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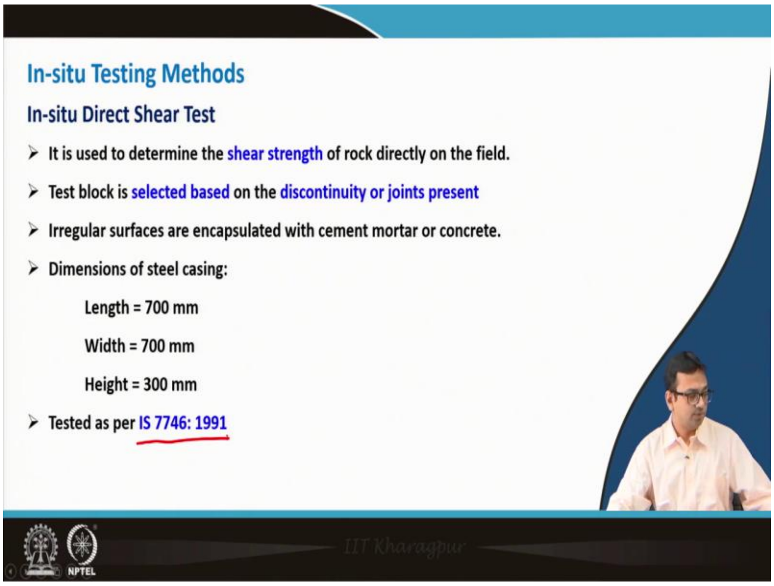

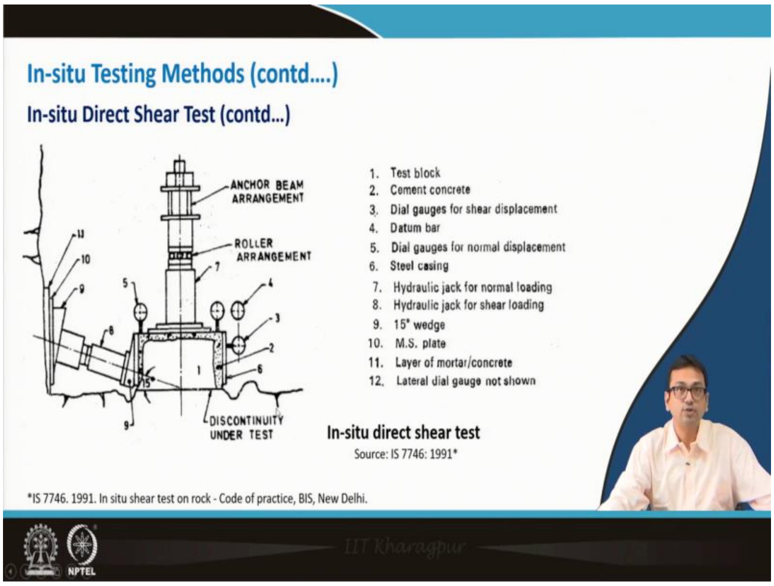

So, In-situ direct shear test very much similar to the direct shear test we conduct in our laboratory only the thing is here, the equipment is definitely quite big in size. And, let me show you that just the diagram, I think that will be first let me show you the diagram then I will come back over here. So, this is the pictorial representation of the direct shear test apparatus for conduct In-situ testing.

So, you see there we can see different components like this is the test block, then the blocks should be encased in this within this steel box. So, for that purpose, as you can see, the steel, your concrete, cement concrete is placed over here. So, that sample should be well within this and in proper position inside the steel casing as you can see the sixth one, then one component there are several components, let us try to see what are the main components like one is this eight, eight is what you can see hydraulic jack for shear loading.

On the other hand, the another one this seventh one is nothing but the hydraulic jack for normal loading. Then also you can see that different these two dial gauges are present to measure the normal displacement as well as these you see the dial gauge is also there to find out this dial gauge for the shear displacement.

Now, let us again go back to our previous slide. So, it is used to determine the shear strength of rock directly on the field. Now, along the as I have stated earlier that direct shear test is very much useful for finding out the joint strength also. So, not only the means In-situ strength when we are finding out then also, we keep in our mind that the as the joint strength is extremely important.

So, by conducting this test we can obtain the joint strength in the field then and there only, then the another important thing the test block is selected based on the discontinuity or joints present. So, the site you should select in such a way that they are maybe the discontinuity or joints are present and accordingly the test block you have to choose and irregular surfaces are encapsulated with the cement mortar or concrete as I have just shown you or told you here, this is a little bit irregular shaped blocks.

So, cement concrete or mortar is placed inside this steel casing to keep it in position at the time of testing and the dimension of the steel casing is generally this length by width 700 mm by 700 mm and height is 300 mm and for this test one should refer this IS 7746: 1991. So, if you follow this your test will be as per the Indian standard.

So, this already we have seen, now one thing what I want to discuss that is you see, why this In-situ test we need to do because as I have stated that the behaviour of intact rock and rock mass is quite different in field, different discontinuities are present and as a result of that the behaviour of rock mass is quite different from the behaviour of intact rock.

So, for that purpose you need to know or determine the shear strength properties very carefully and for that purpose this In-situ direct shear test becomes important not only this test, other In-situ tests are also very important to get the actual scenario.

Now, the problem is In-situ test are very much important we must perform some of the tests but since, the equipment's are quite big in size and since you need to carry those instrument in the site. So, maybe that may be, like hilly terrain, where maybe carrying this instrument can be quite difficult. So, and also huge equipment. So, for conducting the test you need a good amount of manpower.

So, ultimately the cost of conducting In-situ is much more higher than the laboratory test, laboratory test is simple it is with one or two person may conduct the test, but for conducting the suppose the direct shear test a good amount number of people are required and also the instruments are quite heavy, costly.

So, these are the issues, there is some issues like simulating the actual boundary condition that is rain under any condition that can be quite difficult understanding and also understanding the influence area of your test means, up to which means, what is the area over which we are testing is means up to each area you can consider that the test results are applicable for that area that you are finding out the influence zone or influence area is quite difficult.

So, however, it is very important to get the actual scenario and also it depends on the number of tests; how many In-situ test you will do that also depends on several things, number one it is costly. So, you have to judiciously decide how many tests you have to do. So, that depends on what type of structure you are constructing, how much important the structure is.

So, that is also very important, means very important structure which is very costly or maybe very sensitive. Suppose you are constructing a nuclear power plant. So, then you are obviously that is a very sensitive thing. So, important structure you may have to conduct the test in within means, with a number of tests can be quite high because you do not want to take any chance because rock mass is highly heterogeneous and isotropic.

And also, what are the different like boundary conditions, also the how the orientation of the joints and bedding planes all those things depending on all these issues. The engineer needs to decide how many tests he will do but we have to remember that the engineer must have to remember that to conduct test, conducting In-situ test is costly. So, he or she must take a judicious decision. So, anyway, let us continue our discussion with this, then the plate load test.

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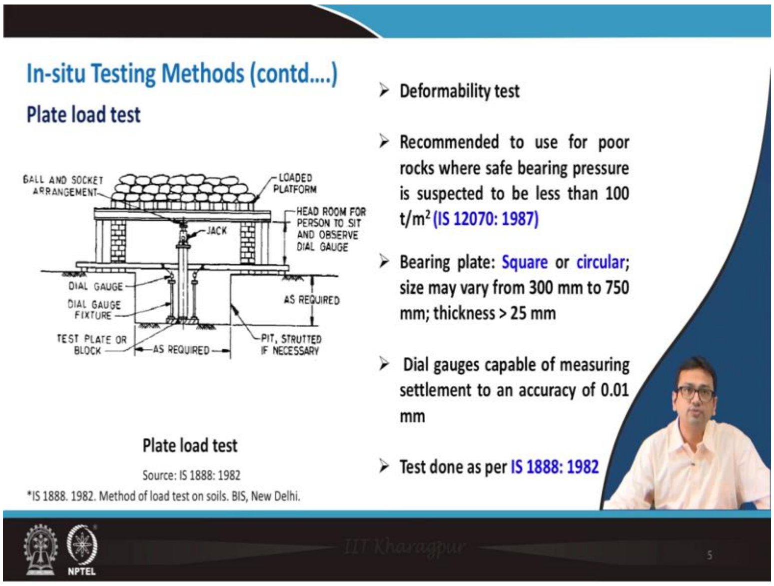

So, plate load test it is about this you have learnt in your soil mechanics. So, similar to that similar setup, as you can see over here that this is the test feed, if this is BP the size of your plate of which you are conducting that test. So, if it is BP then generally this dimension should be 5 BP because people will be there to conduct the test it should be, they should have enough space to do the activities freely.

And then hydraulic jack, this is the sandbags to apply the loads and this is the load platform, loading platform, steel girders. So, very much similar to what is done for the soil, so similar type of setup. If constructing a foundation at a particular location, we will be interested in doing the settlement characteristics. So, load settlement plot you want to get.

So, ultimately settlement is nothing but the deformability we want to find out. So, deformability of that particular type of rock mass, we want to find out. So, for that purpose this test is conducted and as per IS 12070: 1987 it says that the this test in case of rock is use means it recommends that recommend means when you should use this test only that situation where poor rock were saved bearing pressure is suspected to be less than 100 ton per metre square. So, it is as it is written recommended to use for poor rocks where safe bearing pressure is suspected to be less than 100 ton per metre square.

So, this is as per IS 12070: 1987. Now, the bearing plate as we can see over here, it may be square or circular and size may vary from 300 millimetres to 750 millimetre, means if the square plate then 300 millimetre by 300 millimetre or 700 or 600 millimetre by 600 millimetres, 750 millimetre by 750 millimetre or if it is a circular then this should be the diameter and the thickness of the plate should be greater than 25 millimetre and for the dial gauges should be capable of measuring the settlement to an accuracy of 0.01 millimetre. And if we are going to conduct this test then this IS code 1888: 1982 should be followed. So, this is our Indian standard for conducting the plate load test, I think that is fine.

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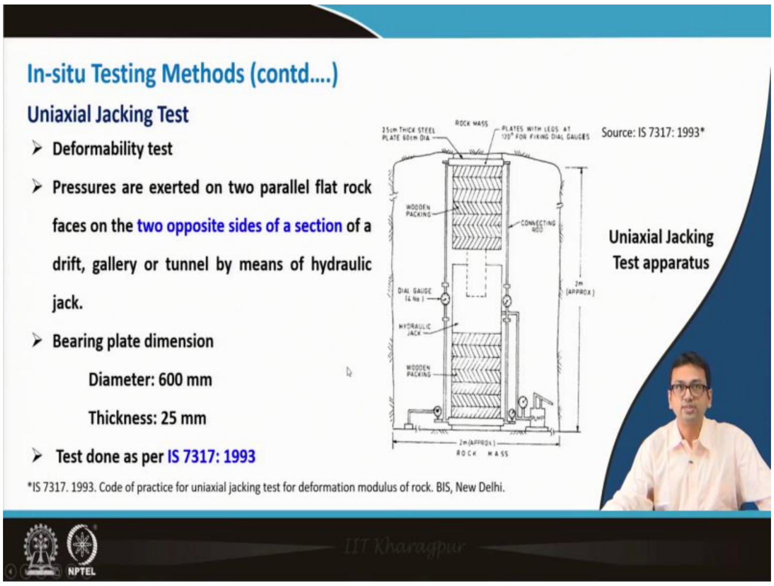

Now, uniaxial jacking test, this is also performed to find out the deformability. So, this is you can see this diagram and this is again taken from IS 7317: 9093. So, the test we need to perform as per IS 7317: 9093. So, this is again as I stated deformability test. Pressures are exerted on two parallel flat rock faces on the two opposite sides of a section of a drift gallery or tunnel by means of hydraulic jack, you see this one this face and this face they are parallel to each other and pressures are exerted on two parallel flat rock faces with the help of you see the hydraulic jack is over there.

So, the pressure applied on this face as well as this face, they are parallel to each other. Now, remember this test as you can see, vertically the test is performed as shown here but this test is also performed placing this equipment horizontally. In that case, the pressures are exerted on will be means if we rotate it by 90 degrees, what will happen the deformability of these two parallel faces also we will be able to determine and that can be very much important as it is stated that for like drift, gallery, or tunnels. So, as we know tunnels are very important, for for constructing tunnel and deformability of tunnel for determining that.

So, not only this, these parallel faces, these two parallel faces for that also the uniaxial jacking test should be conducted. And the bearing plate dimensions are like the diameter of 600 millimetre and thickness of 25 millimetre, as I have stated, IS 7317: 1993. This should be followed for conducting the uniaxial jacking test. So, that was a brief description.

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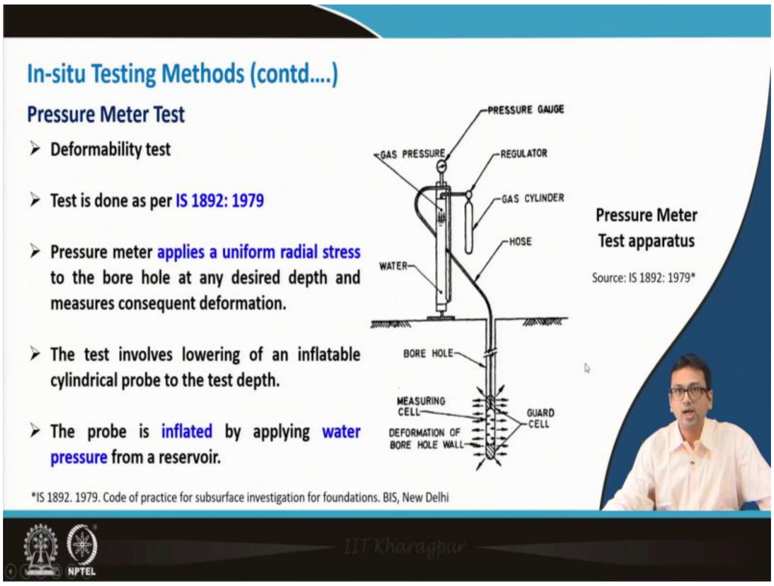

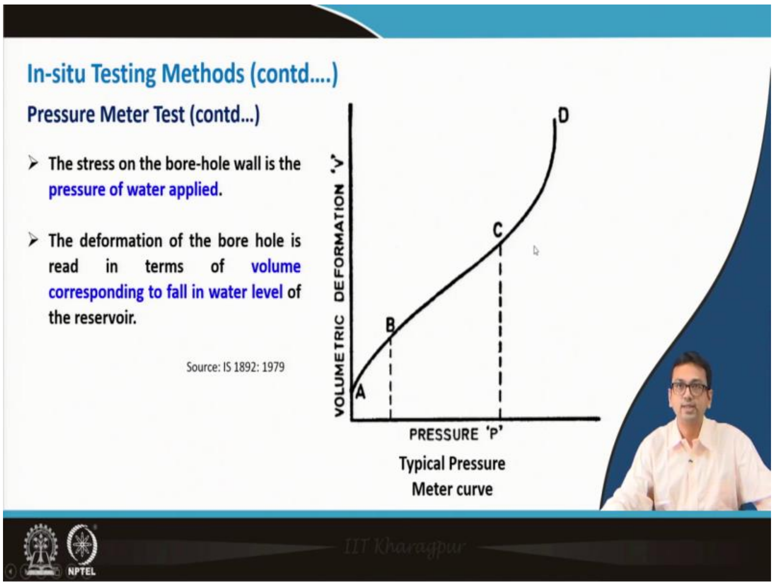

Now, next is pressure metre test. So, this is again for conducting pressure metre test, one should follow IS 1892: 1979. Now, what we can say this is also a deformability test, so deformability of rock mass can be found out by conducting this test and this is as per IS code as I have stated. Pressure metre applies a uniform radial stress to the borehole at any desired depth and measures consequent deformation.

So, you see, you see there is the pressure metre that probe is inserted inside this borehole at different depths this test can be conducted to find out the deformability at different depths and what is done pressure metre applies uniform radial stress to the borehole at any desired depth and measure the consequent deformation. As I have stated the test involves lowering and inflatable cylindrical probe to the test depth. So, this is a probe which is inflatable and the probe is inflated by applying water pressure from the reservoir. So, water is there and with the help of that it can be inflated.

And what we can get out of it, this type of ultimate plot volumetric deformation by pressure plot, as you can see the stress on the borehole wall is nothing but the pressure of water applied. As you can see, let us go back to the diagram once again the pressure is applied with the help of this inflating the this measuring cell and pressure up to uniform radial pressure is applied.

So, that is nothing but as you can see is the pressure on the borehole wall is the pressure of water applied and deformation of the borehole is read in terms of volume corresponding to fall in water level of the reservoir. So, obviously, as you can see as the falling water level in the reservoir with the help of that, the volume deformation of the probe of the borehole is read in terms of the volume corresponding to fall in water level of the reservoir.

So, ultimately a typical pressure metre curve like this you will obtain and that gives a lot of information that at which pressure how much volume change is happening that gives a lot of information regarding the deformability.

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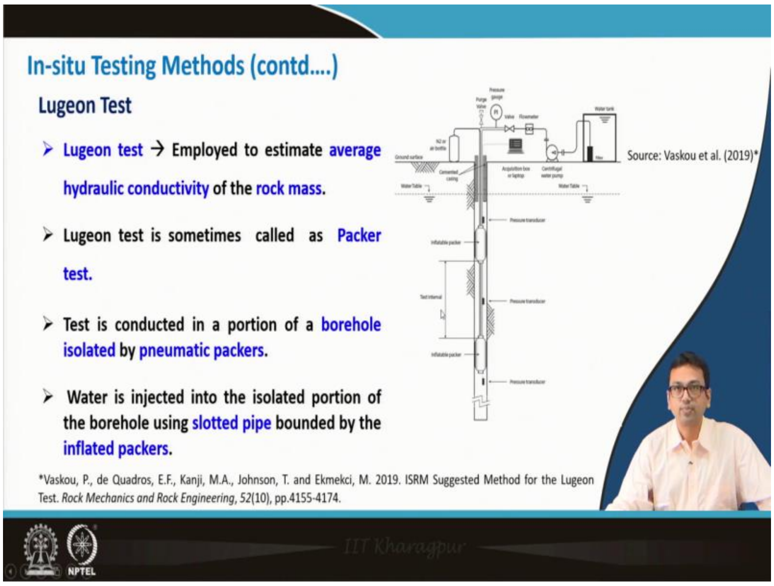

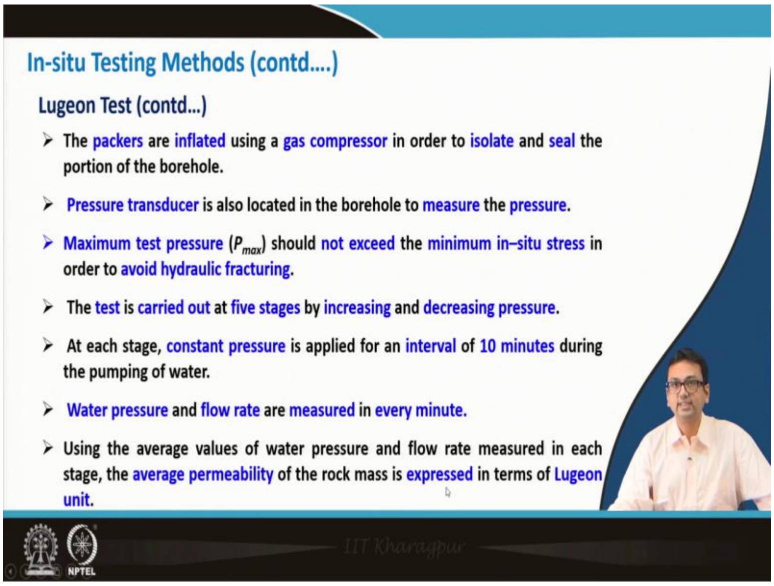

Now, remember when we have discussed about the permeability of rock mass then we have discussed that there are different tests for obtaining the coefficient of permeability hydraulic conductivity of rock, means intact rock in the laboratory or the rock mass in the field among them. One of the very important tests is Lugeon test and which is also called as the packer test. So, here you can see the schematic diagram.

So, Lugeon test, why it is done? It is employed to estimate the average hydraulic conductivity of the rock mass. The Lugeon test is sometimes called as the packer test as I have stated. Test is conducted in a portion of a borehole isolated by pneumatic packers. So, this is these in this diagram you see this is a borehole and with the help of these two packers this portion is isolated, so test is conducted in a portion of borehole isolated by pneumatic packers.

Now what is done, water is injected into the isolated portion of the borehole using slotted pipe bounded by the inflated packers. So, you see, this portion is bounded by this inflated this packers isolated. And now, water is injected into the isolated portion of the borehole using slotted pipe. So, this is a slotted pipe, now water is injected you see water tank water is injected and to the slotted pipe there the water is injected. Now, if water is injected, then what will happen the pressure will develop.

Now, the packers are inflated using gas compressor in order to isolate this and isolate and seal the portion of the borehole, as I already have mentioned. Pressure transducers are used means as we can see this just let us go back here. So, the pressure transducers are also used here, why? To measure obviously the pressure developing. So, let us see. So, pressure transducer is also located in the borehole to measure the pressure.

Now, the maximum test pressure, P max this is the condition the maximum test pressure P max should not exceed the minimum In-situ stress in order to avoid hydraulic fracturing. Now, you see, let me read it, the maximum test pressure P max should not exceed the minimum In-situ stress in order to avoid hydraulic fracturing. Now, you see what may happen if we apply too much water pressure then what may happen this rock mass may get fractured.

So, maybe in In-situ situation though there are these fractures are not the maybe the cracks are not that much wide enough or no fracture is maybe present there. Now, if we apply more water pressure, what may happen the fractures may develop or open. So, because of that you are obviously hydraulic conductivity can increase. So, that we do not want to learn to find out the in-situ condition.

So, maximum test pressure should not exceed the minimum in-situ stress in order to avoid hydraulic fracturing. The test is carried out at five stages by increasing and decreasing the pressure. So, pressure increased and again gradually decreased. So, it is done in five stages. At each stage constant pressure is applied for an interval of 10 minutes during the pumping of water. So, the 10 minutes that is important.

And the water pressure and flow rate are measured at every minute. Using the average value of water pressure and flow rate measured in each stage, the average permeability of the rock mass is expressed in terms of Lugeon unit, so Lugeon unit with the help of that the average permeability is presented.

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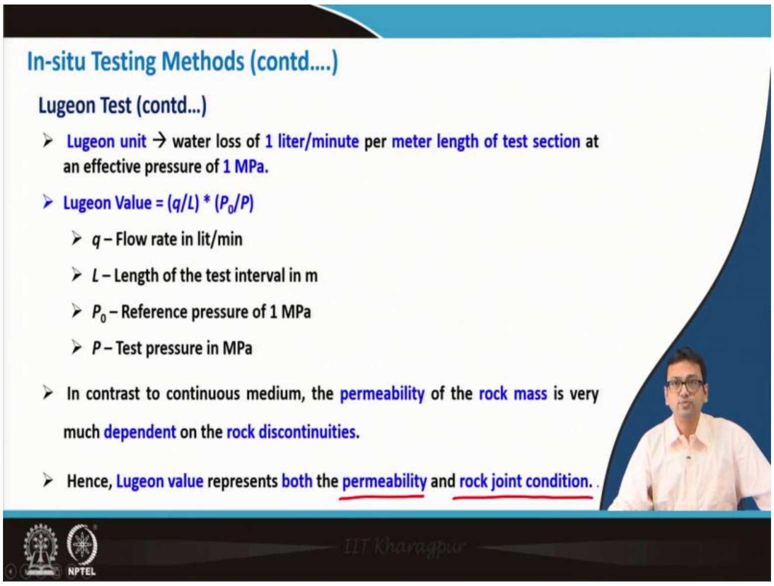

Now, Lugeon unit what is this, water loss of 1 litre per minute per metre length of test section at an effective pressure of 1 megapascal. Water loss, let me read it once again, water loss of 1 litre per minute per metre length of test section at an effective pressure of 1 megapascal. So, the Lugeon value is often like (q/L) (P_0/P). Here, q is the flow rate in litre per minute, L is length of the test interval in metre, P_0 is the reference pressure of 1 megapascal and P is the test pressure in megapascal.

In contrast to the discontinuous medium as we know the permeability of rock mass is very much dependent on the rock discontinuities. So, that is why as we have seen that the means, by applying extra pressure if the hydraulic fracturing happens that will, that may mislead means give the erroneous permeability in situ permeability of the rock muscle that is important.

So, hence the Lugeon value represent both the permeability and rock joint condition. So, as if the rock there are naturally formed if there are too many rock joints, so obviously the permeability will be higher if it is not so it will be lesser. So, this Lugeon value represent both the permeability and join rock joint conditions. So, this test means, two types of information we can get.

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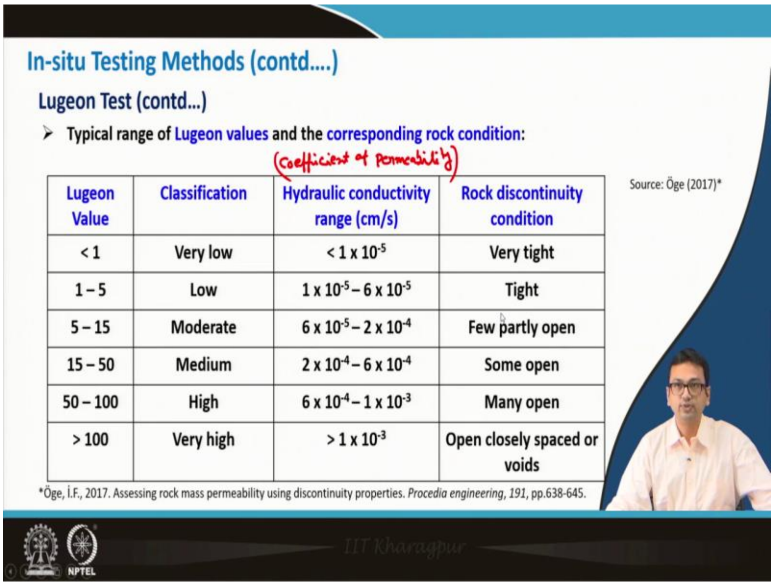

Now, this is a nice useful table gives a lot of information you see. Typical range of Lugeon values and the corresponding rock condition. So, you see Lugeon value if it is less than 1, then it may be classified as very low and corresponding hydraulic conductivity range is provided in centimetre, hydraulic conductivity or coefficient of permeability whatever you say, coefficient of permeability or the hydraulic conductivity if for less than 1 generally the it is classified at very low and the conductivity is less than $1{\times}10^{-5}$.

And the rock discontinuity condition as I have stated, this Lugeon test also gives us some idea about rock discontinuity, so it is very tight. Then Lugeon value is 1 to 5, so it is low and the hydraulic corner in this range it is tight. Likewise, when it is greater than 100, Lugeon is very high and the hydraulic conductivity with get the $1{\times}10^{-3}$ centimetre per second and open closely spaced or void.

So, likewise different you see both regarding conductivity, hydraulic conductivity cohesion permeability as well as rock discontinuity condition also we are getting several information's from here. So, this is very important test.

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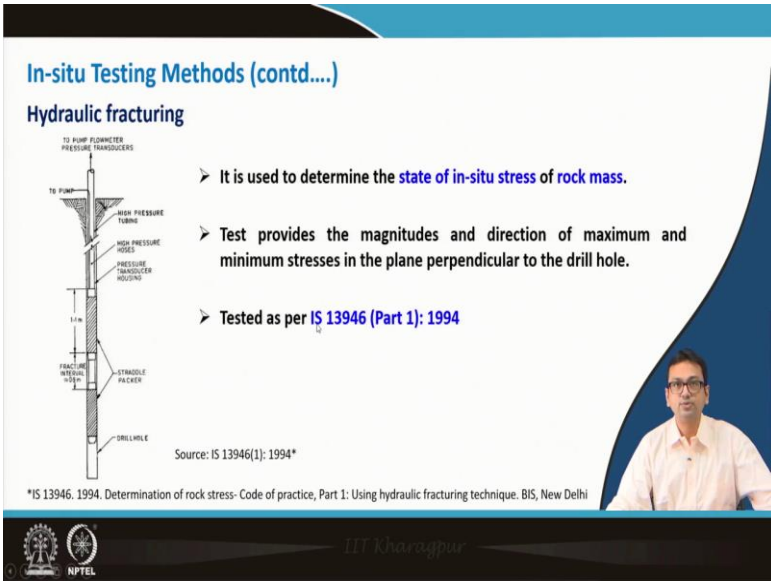

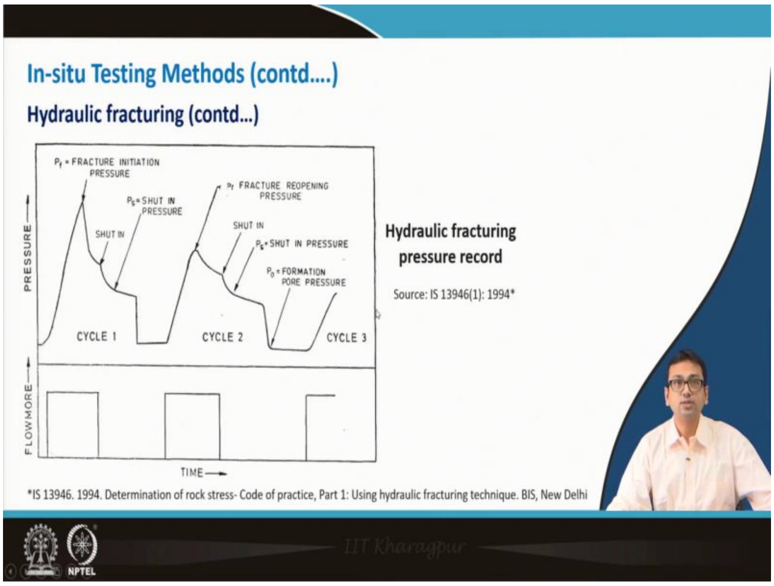

Now, hydraulic fracturing just now, we have discussed. So, similar type of arrangement, you see two packers are there, this portion isolated. Now, what is done here and why it is done it is used to determine the state of in-situ stress of rock mass. So, the test provides the magnitude and direction of maximum and minimum stresses in the plane perpendicular to the drill hole.

And that this test is conducted using IS 13946 (Part 1): 1994 and what we get, so pressure is increased you see, now here we want to develop the hydraulic fracture. So, fracture initiation pressure is these. So, now, if fracture initiates, so this flow of water will increase then this fracture shutting then it is reducing pressure again the fracture reopens and here flow is increasing then gradually decrease likewise it is done and we can get the In-situ stress by conducting this test as per this IS code.

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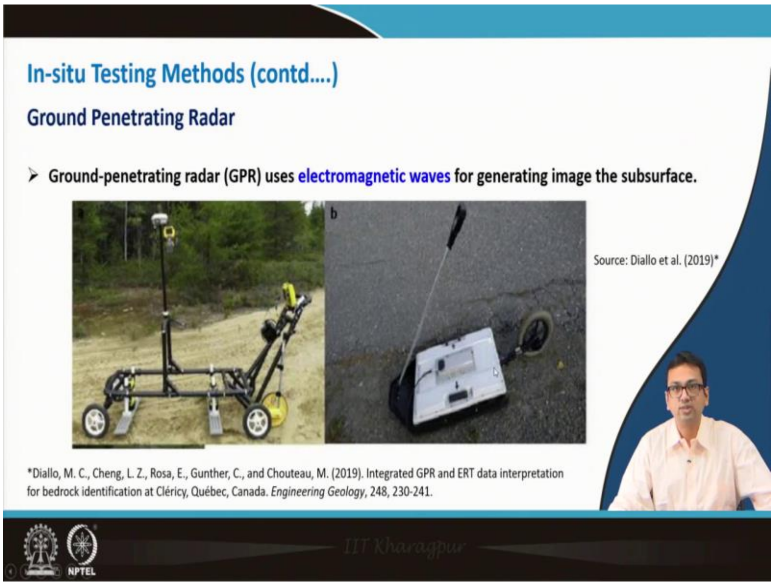

Now, briefly we just discovered the ground penetrating radar, all of us probably have heard about this instrument. So, ground penetrating radar uses electromagnetic waves for generating image of the subsurface. So, these two are the typical pictures of the ground penetrating radars you see, this type of small equipment this with the help of these wheels we can move very easily from a location to another location and continuous reading you need to take, these are these this is even a smaller arrangement as you can see.

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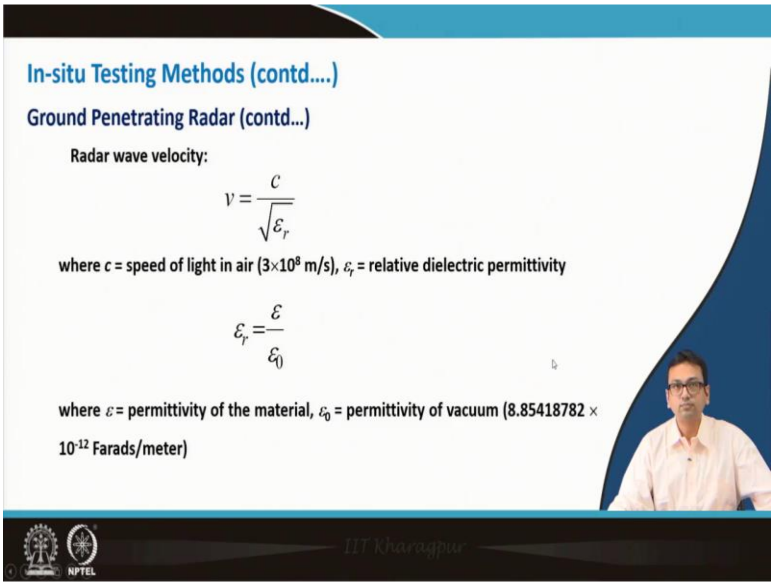

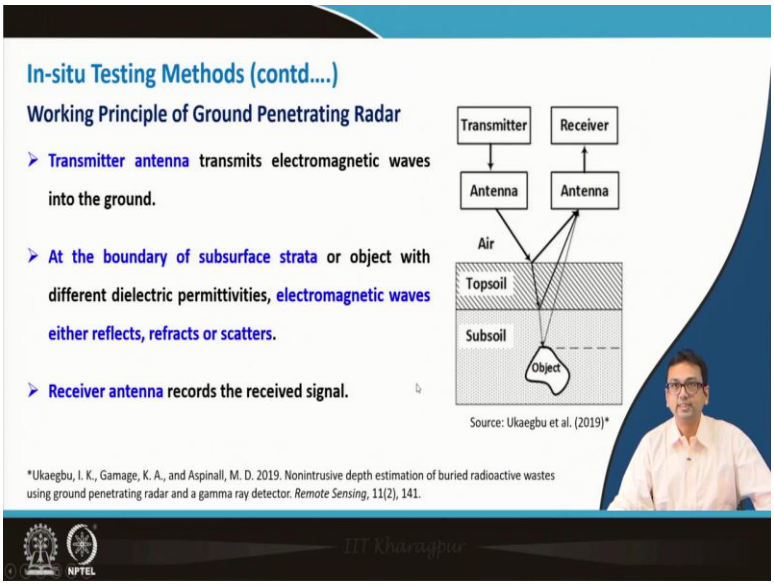

Now, the philosophy is like the radar wave velocity is nothing $C/\sqrt{\varepsilon_r}$. Now, C is the speed of light and this parameter is nothing but the relative dielectric permittivity. Now, this is again equal to relative dielectric permittivity. So, $\varepsilon_r = \varepsilon/\varepsilon_0$. Now, the ε is the permittivity of the material and ε_0 is the permittivity of vacuum.

So, using this simple philosophy means, the velocity is determined with the help of that, the subsurface, information of the subsurface condition is obtained. So, working principle, very simple way you find to show you that the transmitter antenna you see the transmitter antenna transmits electromagnetic waves into the ground like this.

Then at the boundary of subsurface strata or object with different dielectric permittivity is electromagnetic waves either reflects, refracts or scatter. So, you see here and this topsoil it will reflect then here it refracts and then again from here it may reflect and again like this it can go and again some subsoil it can reflect and finally, the receiver antenna records the received signals.

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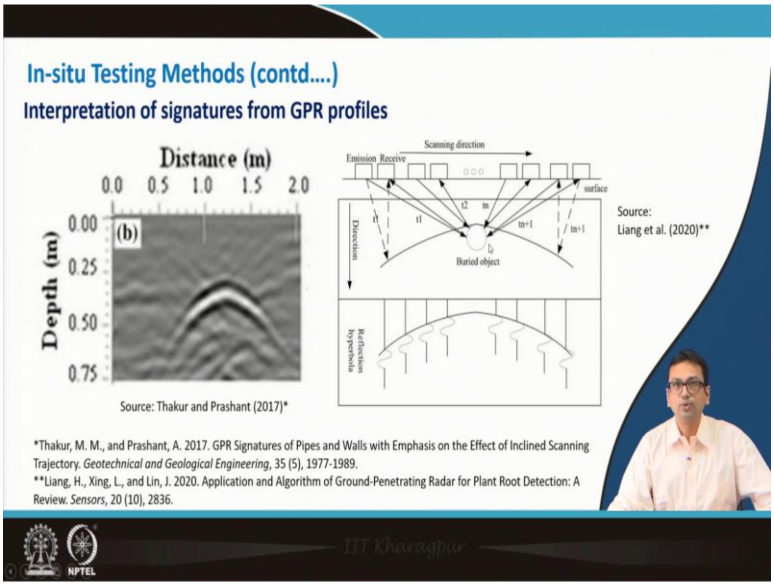

Now, finally, what we get this type of picture it develops where with distance, means that you will travel with your radar in this direction and you will get a picture like this. Now, you see what is happening, you see the scanning direction is this. So, when we are here, so from here it is getting reflected and you are getting the emission and the emission here is received. Now, when you are here, so, different magnetic electromagnetic waves are emitting from here and finally, you will get the reflection wave over here.

So, in this way you will completely scan this zone here and you will get like this reflection hyperbola as you can see, ultimately will look like this. So, you will understand that there must be some object present over there. So, if you get this type of pattern, you have to understand that some object is probably present there.

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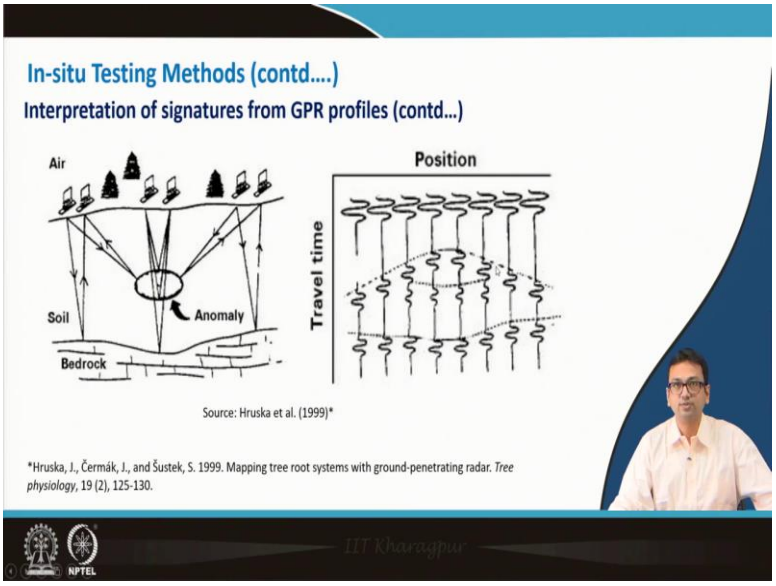

So, again another picture you see some object is here. So, from here suppose oil bedrock here it is getting reflected, here it is getting reflected like that is happening. So, ultimately what you are getting you see for the bedrock this type of one pattern for the object you see this hyperbolic reflection you are getting.

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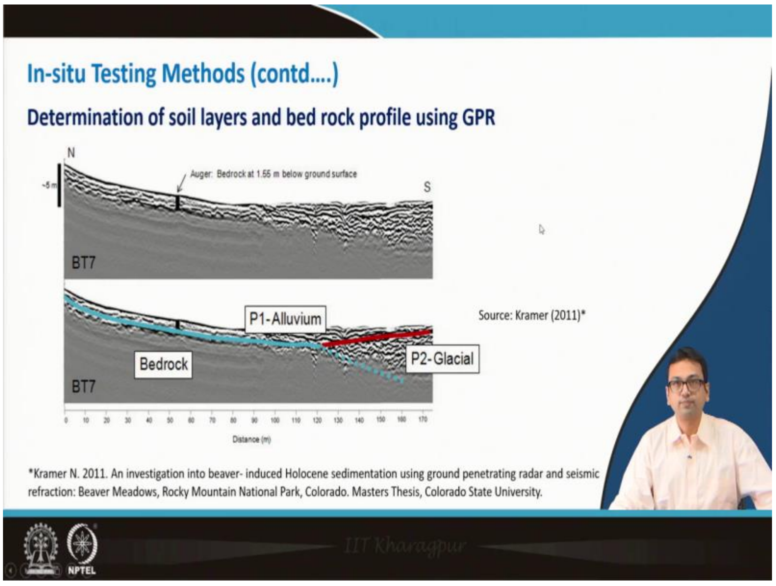

So, finally, this may give you a wide area means you can get this type of GPR obtained picture you can get. Now, in order to verify whether your GPR data is correct or not. So, you can perform some borehole tests to get what type of samples are there.

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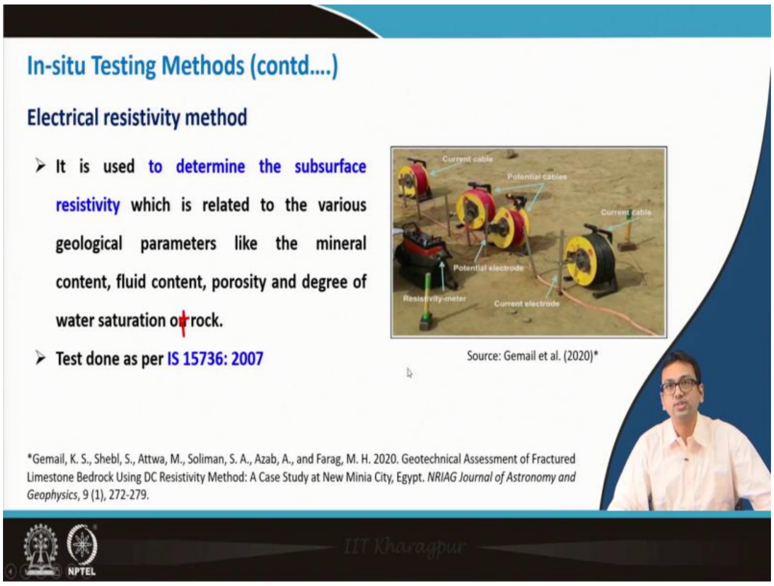

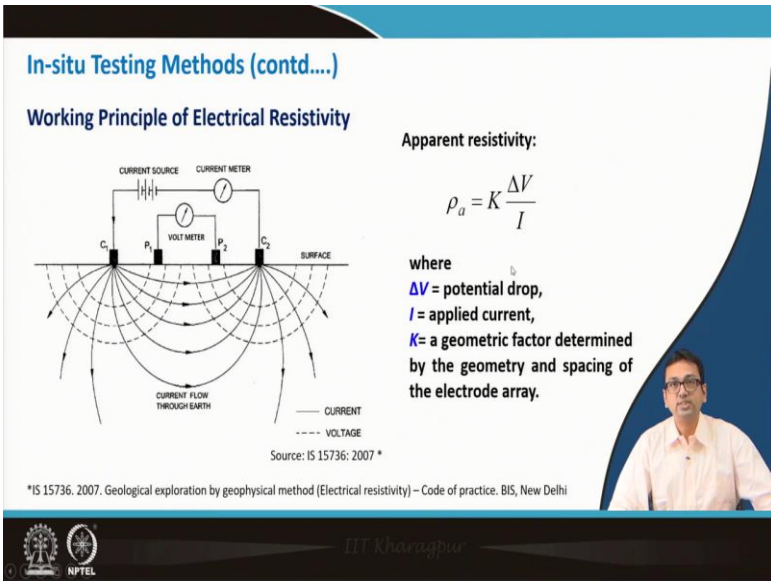

Now, briefly the electrical resistivity method. So, this is used to determine the subsurface resistivity which is related to the various geologic parameters like the mineral content, fluid content, porosity and degree of water saturation on rock. So, the test is done as what IS 15736: 2007. So, these are the different electrodes are shown over here current electrodes and potential electrodes.

So, I will show you a pictorial diagram as part of this IS 15736: 2007. So, you see in this test the two current electrodes are used and two your potential electrodes are used and from here you see that these are nothing but the current flow you can see and there you see the voltage difference and potential drop you can also measure with the help of this voltmeter and current metre to measure the current. So, this is the current source.

So, apparent resistivity is represented by this equation K(ΔV/I). Now, ΔV is what, this is nothing but the potential drop and I is the applied current and what is K, K is a geometric factor determined by the geometry and spacing of the electrode array.

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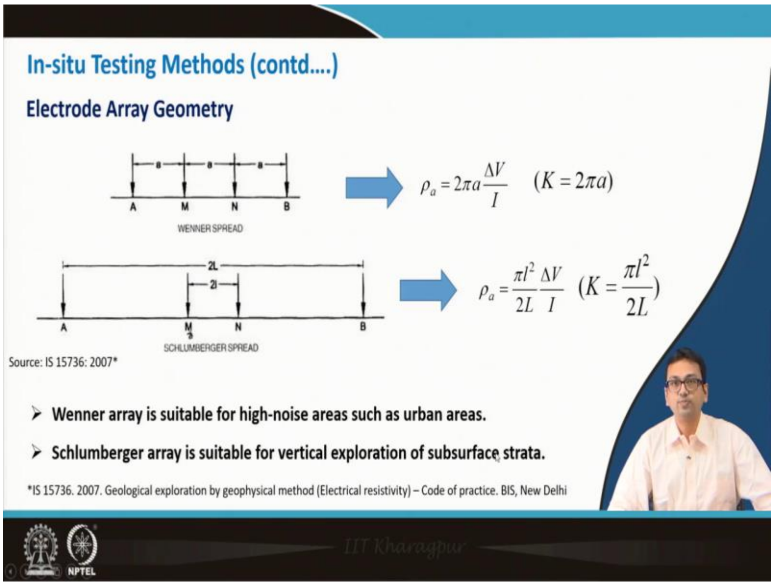

Now, then, we define different types of array, popular one is Wenner Spread where you see that these are A, B at the current electrodes and M, N at the potential electrodes. So, you see the distances are a, a, a, whereas Schlumberger Spread here you see if this is 2L and this l and this is two L. So, here these differences are a, a but where it is not fixed. So only thing is the distance from here to here and the distance from here to here are fixed.

So, now, for this type of array, which is very common, so, we use the K value as 2πa, this a, a distance and for this type of this type of wenner array is suitable for high noise areas such as urban areas. And whereas, this one where ρ_a is this equation we can use and where we can see $K = \pi l^2/2L$.

So, 2L is the distance between A and B and l is nothing but half of the distance between M and N. So, this is 2l. So, here we are using L. So, this Schlumberger array is suitable for vertical exploration of subsurface data.

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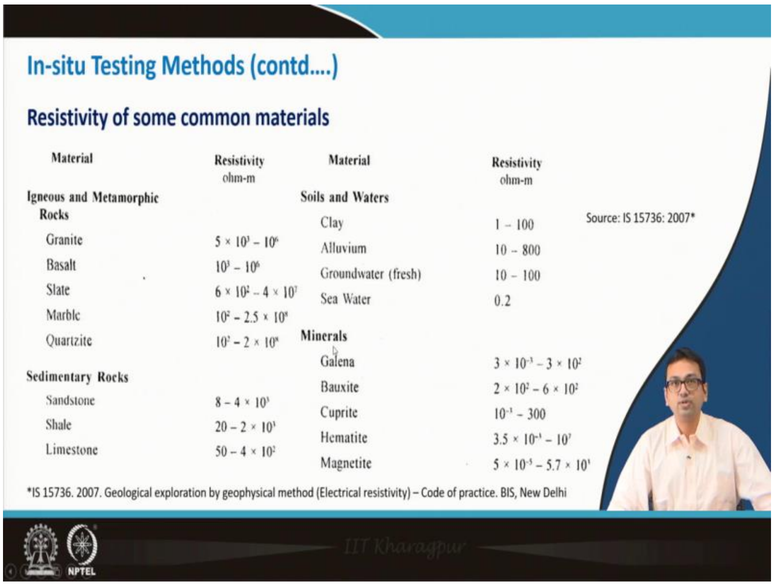

Now, these are in IS code only you can find it. So, these are different type of materials means igneous and metamorphic rocks and their resistivity in ohmmeter it is provided over here. So, different material, these are the rocks even the sedimentary rocks or else it is given then the clay, alluvium all these things see what are what it is and minerals also it is given. So, anyway we are interested in this part rock part.

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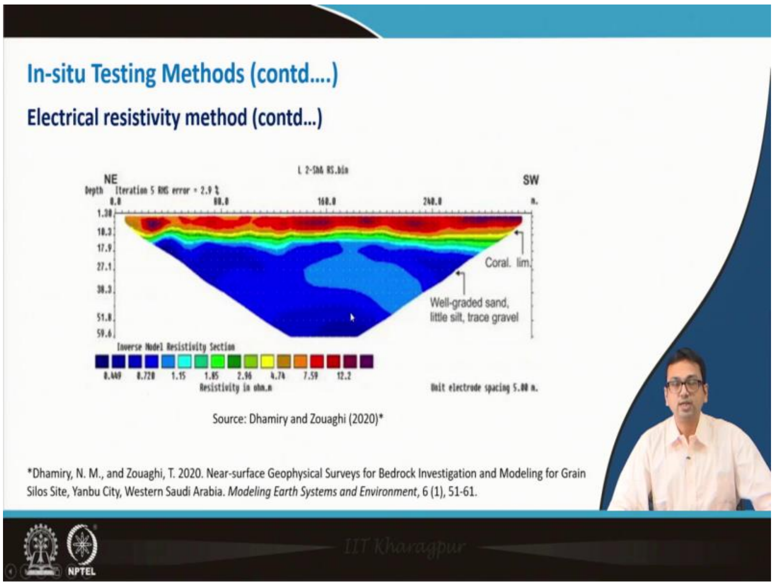

So, now, based on these after conducting electrical resistivity survey, we get this type of contour and from that contour by comparing with the values, what are given in this table you can state that which portion is made of which type of rock or what type of material are present there. So, this way you can very easily get an idea about the subsurface condition.

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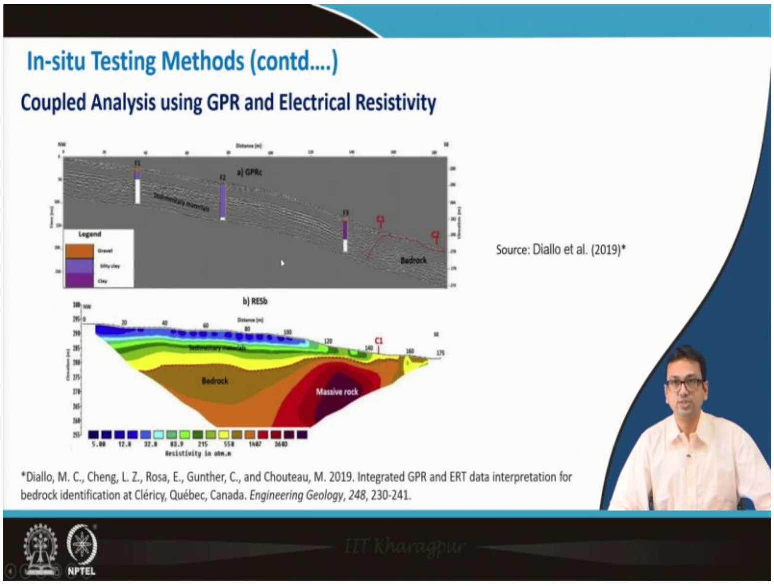

And now, if you see use the both GPR and electrical resistivity method then that can be a great thing. So, with the help of the GPR you may get this type of picture and whereas, using electrical is you can get this type of picture. So, combining these two, you can understand in a better way of definitely or obviously you can perform some of the verbal study also to get a better and complete idea about the subsurface condition.

Now, these two GPR and electrical resistivity also we could have discussed under our geophysical testing, but they are mainly focused on seismic waves related methods and but I thought about keeping these two tests brief discussion about these two tests in this module where we are discussing how the In-situ test.

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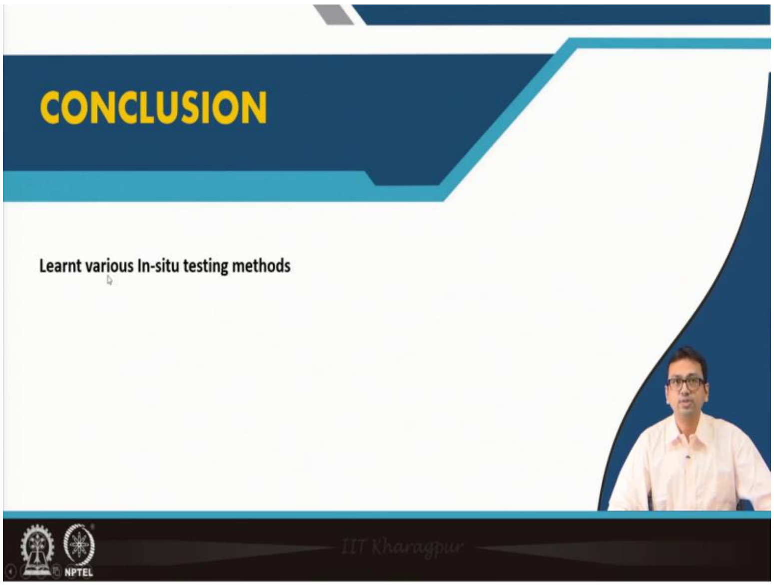

So, in this lecture, we have learnt about various In-situ testing methods and with this I am concluding this module. So, thank you.