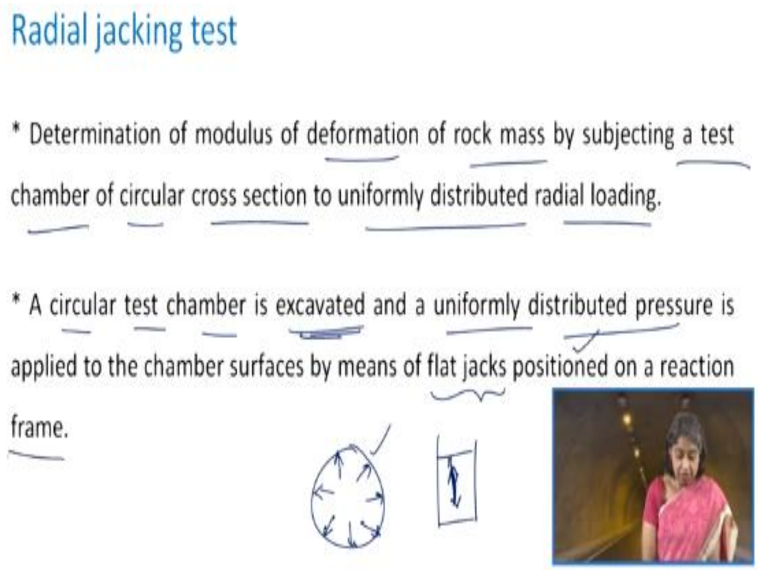
Under Space Technology
Prof. Priti Maheshwari
Department of Civil Engineering
Indian Institute of Technology, Roorkee

Module No # 08
Lecture No # 40
Modulus of Determination of Rock Mass: Radial Jacking Test and Goodman Jack Test

Hello everyone, in the previous class we learnt about the in-situ determination of modulus of deformation of rock mass using the plate jacking test or uniaxial jacking test. So, today we will take up 2 more methods to determine the in-situ modulus of deformation of rock mass these are radial jacking test and Goodman jack tests. So, as the name suggests first in the radial jacking test instead of the application of the load only in one direction as it was, in case of the uniaxial jacking test.

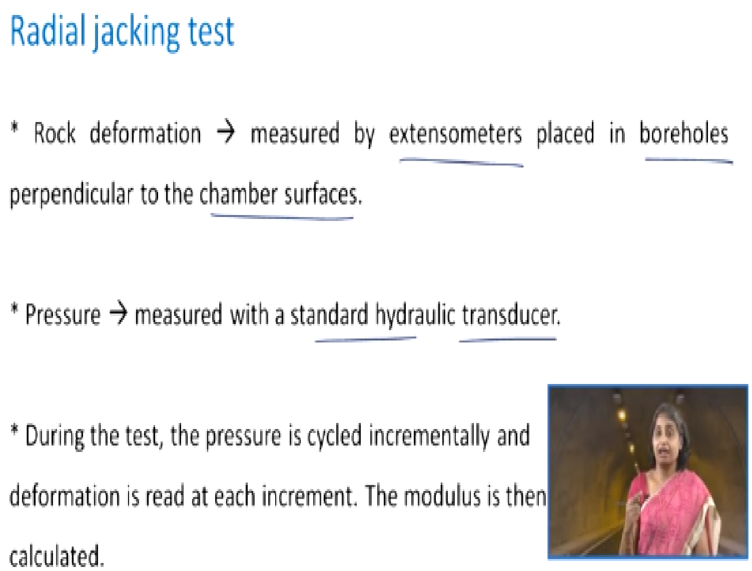
Here, the load is applied in the radial direction in throughout the cross section of the test chamber. So, let us take the first the radial jacking test.

(Refer Slide Time: 01:23)



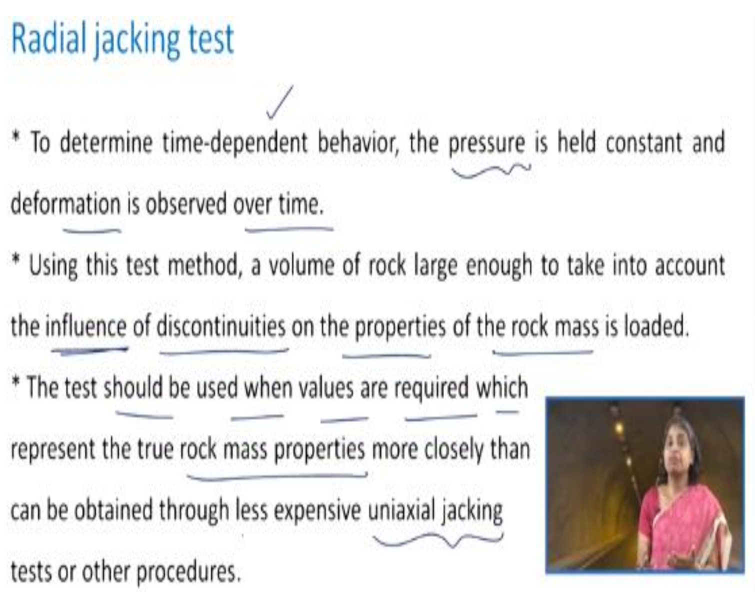
So, in this case we determine the modulus of deformation of rock mass by subjecting a test chamber of circular cross section to uniformly distributed radial loading so this is going to be something like this. Instead of loading only in one direction which was there in case of the uniaxial loading test here it is going to be this situation. So, in this case a circular test chamber is excavated and a uniformly distributed pressure is applied to the chamber surfaces by means of flat jacks which are positioned on a reaction frame. So, the loading situation will look something like this.

(Refer Slide Time: 02:14)



The deformation of the rock is measured by extensometers which are placed in the bore holes perpendicular to the chamber surfaces. The pressure is measured with the standard hydraulic transducer now during the test the pressure is incremented in a cyclic manner and the deformation is read at each increment. And, therefore, the modulus is calculated corresponding to each of these.

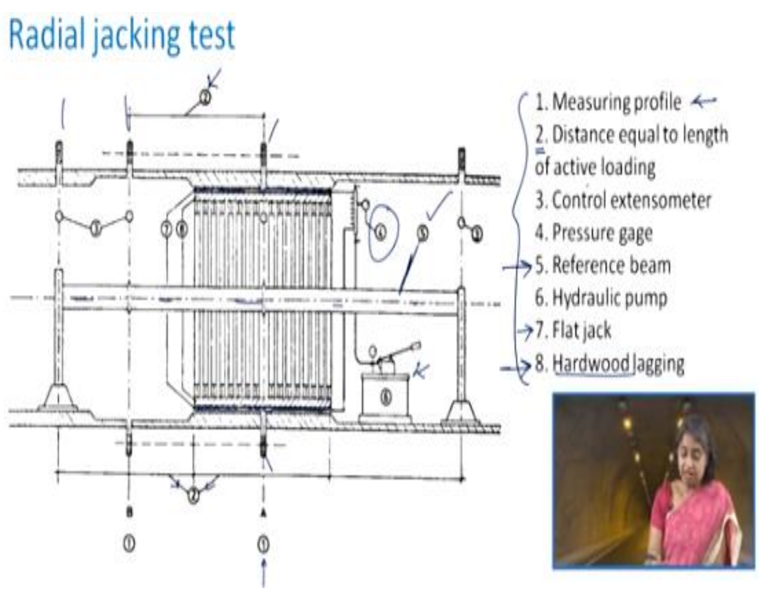
(Refer Slide Time: 02:51)



So, to determine the time dependent behavior what we need to do is we hold the pressure constant and then we observe the deformation with respect to time. Now, using this test method, we need to load the volume of the rock, which is large enough to take into account the influence of discontinuities on the properties of the rock mass. Because, if we do not take that large volume then this effect will not be reflected in the value of modulus of deformation of the rock mass.

So, the test should be used when the values are required which represent the true rock mass properties more closely than it can be obtained through less expensive tests which are uniaxial test or maybe the plate loading test. So, if we need more accurate prediction of the modulus of deformation of the rock mass then we must go for the radial jacking test. But then you need to keep in mind that it is not that simple a test to conduct in the field it is more expensive as compared to uniaxial jacking test or plate loading test.

(Refer Slide Time: 04:20)

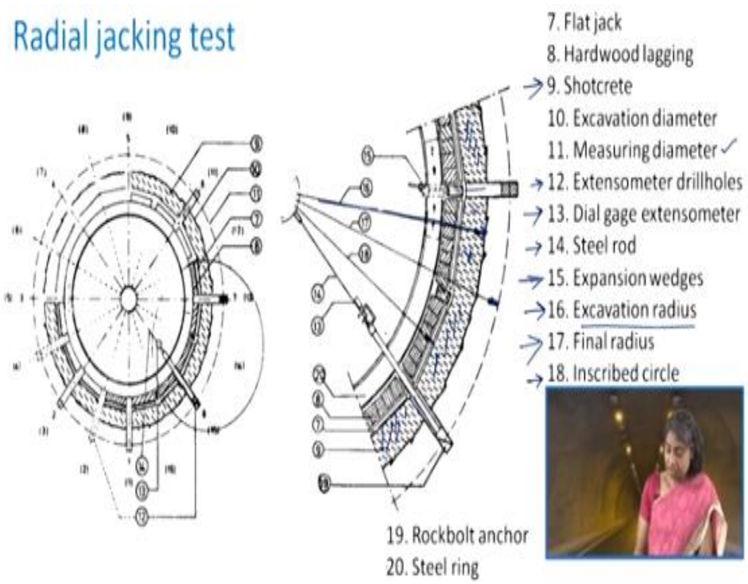


This is what the typically the line diagram with respect to the radial jacking test looks like. So, you can see the various components are there which I have listed here and corresponding to these each one of these that has been shown in the figure. So, the first one is the measuring profile which is this one so the measuring profile is there and then the extensor meters have been installed.

Second, is the distance equal to the length of the active loading, so that you can see that here it is second and then all these they are second this one and this one. Then the third one, is the control extensometer which is at these locations so these are the control extensometers pressure gauge is here through which the pressure will be mobilized to these jacks. Then come to the fifth one, which is the reference beam which is this one you see the center line of it.

So, this is what is the reference beam then we have the hydraulic pump with the help of which the load is mobilized you have the flat jack which is here you can see here this, this portion is the flat jack here as well as here. And then we need to provide the hardwood lagging which is here in between these reaction frames plus the flat jack.

(Refer Slide Time: 06:06)

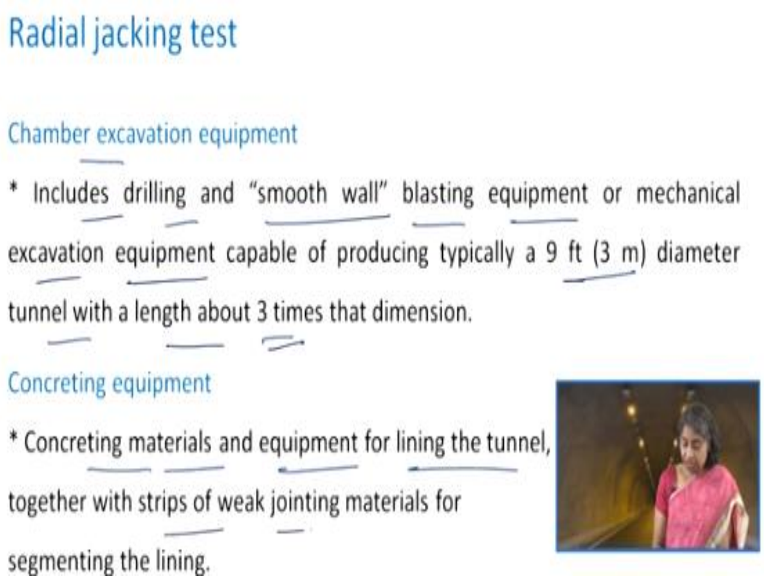


So, here the ninth number is the shotcrete layer which you can see here this has been provided here the shotcrete layer so basically the excavated diameter is this which is given by the 10th one or 16 also because it is showing excavation radius. So, you can see that this is what your 16 is so this is the excavated zone and on top of that you have applied the shotcrete layer so this ninth one is the shotcrete layer or the zone where the shotcreting has been done.

So, the 11th one is the measuring diameter then we have the extensometer drill holes which are these. Then, we have the dial gauge extensometers, then we have these steel rods which are provided, we have the expansion wedges, Which you can see here it is a part of the assembly for this extensometer and the related arrangement. Then we have the radius, which we are calling it so-called final radius that is the 17 one, then 18 is the inscribed circle.

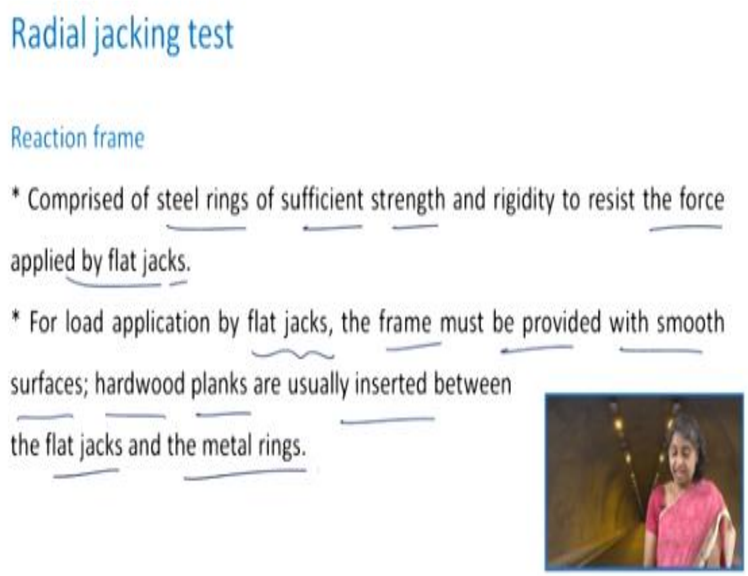
After the laying off of the shotcrete layer, then whatever is the resultant final radius that is what, is we are calling as inscribed circle. Then, we have the rock bolt anchors which are here this one also then the steel ring which is provided here you can see that.

(Refer Slide Time: 08:02)



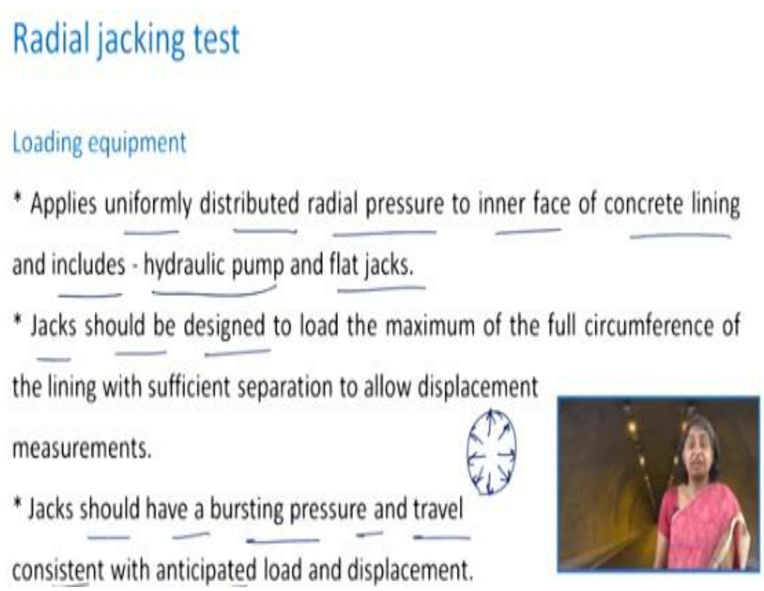
So, these are the various components, so let us see that, what is the equipment as far as the chamber excavation is there. This includes drilling and, the smooth wall blasting equipment or mechanical excavation equipment which is capable of producing typically a 3-meter diameter tunnel with a length about 3 times that dimension that means 9 meters. The concreting equipment includes the concreting the materials and equipment for the lining of the tunnel together with the strips of weak jointing materials for segmenting the lining.

(Refer Slide Time: 08:52)



We have a reaction frame, as I mentioned to you, when I was showing you the figure, so this comprised of steel rings of sufficient strength, and also the rigidity to resist the force which is applied by the flat jacks. So, for the load application which is done by the flat jacks, the frame must be provided with smooth surfaces and therefore the hardwood planks are inserted between the flat jacks and the metal rings. This, I already showed you in the figure but take a look again here see these are the hardwood leggings, which are provided between the reaction frame and the flat jack.

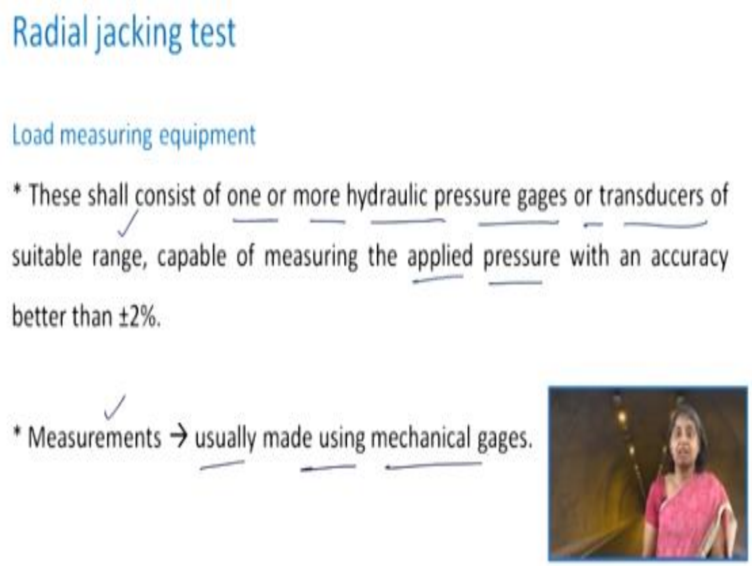
(Refer Slide Time: 09:41)



As far as loading equipment's are concerned these help in applying the uniformly distributed radial pressure to the inner face of concrete lining and it includes the hydraulic pump and the flat jacks. So, these jacks should be designed to load the maximum of the full circumference of the lining with sufficient separation to allow the measurement of displacements.

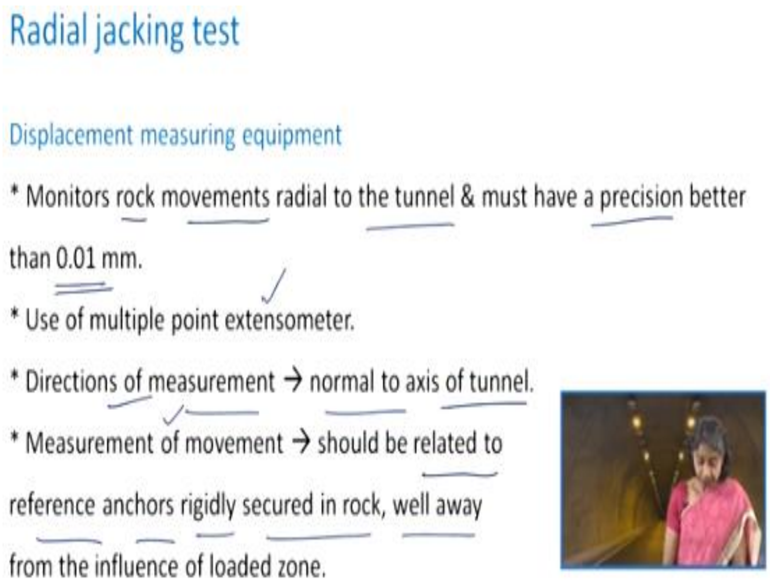
So, the loading will not be in a particular area but it will be throughout like this these jacks should have a bursting pressure and the travel consistent with anticipated load and the displacement, so accordingly, we need to choose the jacks

(Refer Slide Time: 10:38)



The load measuring equipment shall consist of one or more hydraulic pressure great gauges or transducers of suitable range which are capable of measuring the applied pressure with accuracy better than plus minus 2 percent. The measurements are usually made using mechanical gauges.

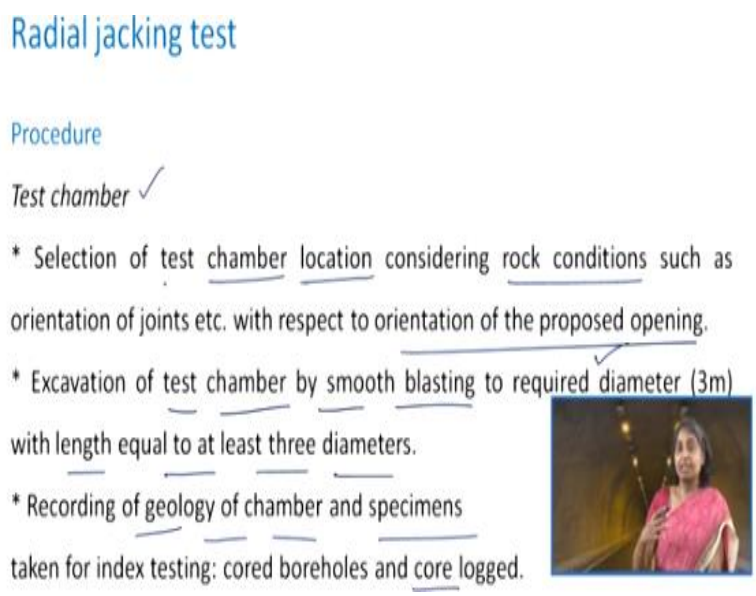
(Refer Slide Time: 11:07)



Coming to the next part of the radial jacking test which is the equipment for the measurement of the displacement. So, these equipment's basically monitor the rock movements which are radial to the tunnel and, they should have a precision which is better than 0.01 millimeter. And, here the use of multiple point extensometer, will come into picture, what all are these how these are installed what exactly are they there working everything we will discuss towards the end when we discuss the chapter on monitoring and instrumentation.

The directions of the measurement of the displacement is normal to the axis of the tunnel and measurement of the movement it should be related to the reference anchors which are rigidly secured in rock and these are well away from the influence of the loaded zone.

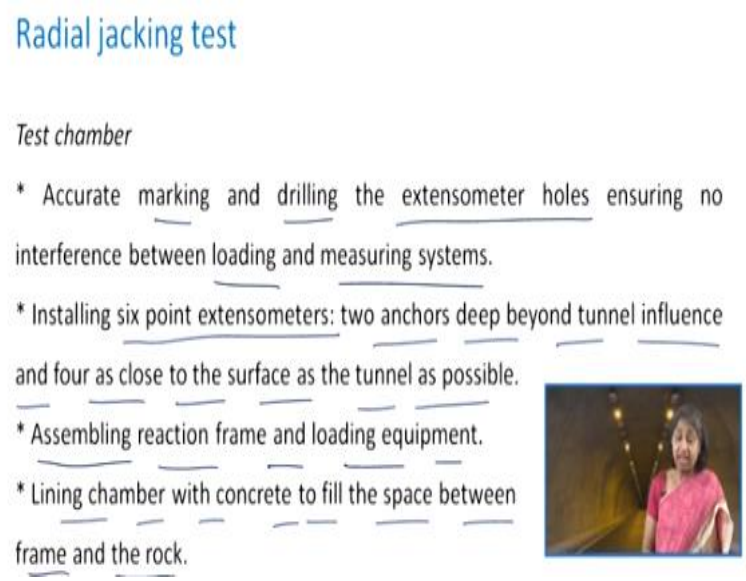
(Refer Slide Time: 12:15)



The procedure for conduct of the test is that with reference to this test we need to first prepare the test chamber. So, selection of this chamber location considering the rock conditions such as the orientation of the joints and other relevant parameters with respect to the orientation of the proposed opening. Because, the test chamber may align or may not with respect to the orientation of the proposed opening so we need to be careful.

The excavation of test chamber by smooth blasting to the required diameter which is of the order of 3 meter with length equal to at least 3 diameters that is, 9 meter should be done. Then, recording of the geology of the chamber and the specimens which are taken for the index testing these should be properly done, with the help of code bore logs and proper logging of the course like at what location you have collected this particular core all those things should be properly maintained.

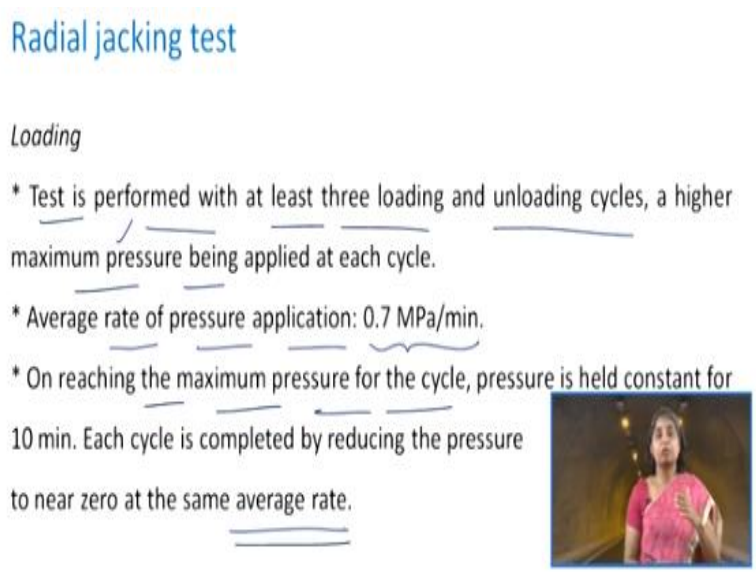
(Refer Slide Time: 13:31)



Then, accurate marking and drilling of the extensometer holes should be done as this ensures no interference between loading and the measuring system. This should be done properly because, if this is not there, there is going to be the effect of loading or the influence of loading on the measurement system with reference to the displacement, so that will give us, erroneous results.

So, one needs to go for the installation of six-point extensometers where 2 anchors should be deep beyond the tunnel influence and 4 should be as close to the surface as the tunnel as possible assembling the reaction frame and the loading equipment is done after that then the lining chamber with concrete is made to fill the space between the frame and the rock.

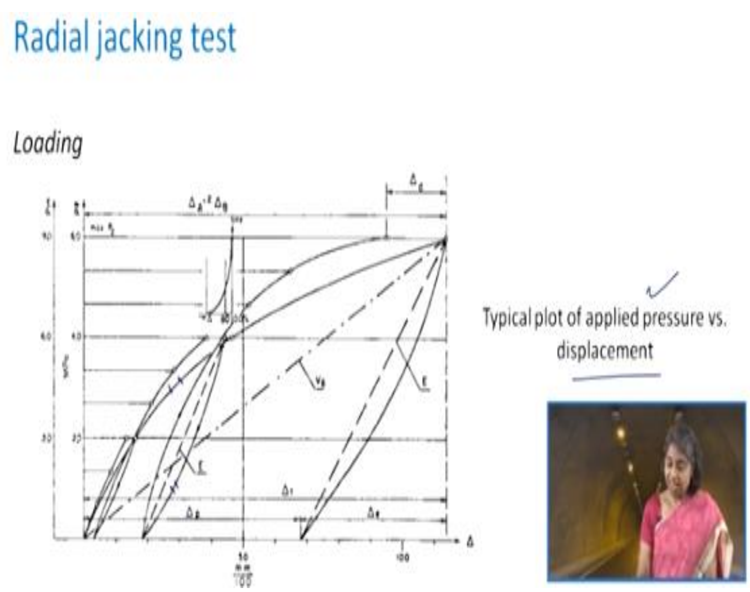
(Refer Slide Time: 14:41)



Coming to the loading aspect of the test, so the test is performed with at least three loading and unloading cycles, this I also mentioned earlier. A higher maximum pressure will be applied at every cycle, I mean every consecutive cycle you have to apply for the little bit larger maximum pressure. The average rate of pressure application is recommended to be 0.7 mega Pascal per minute.

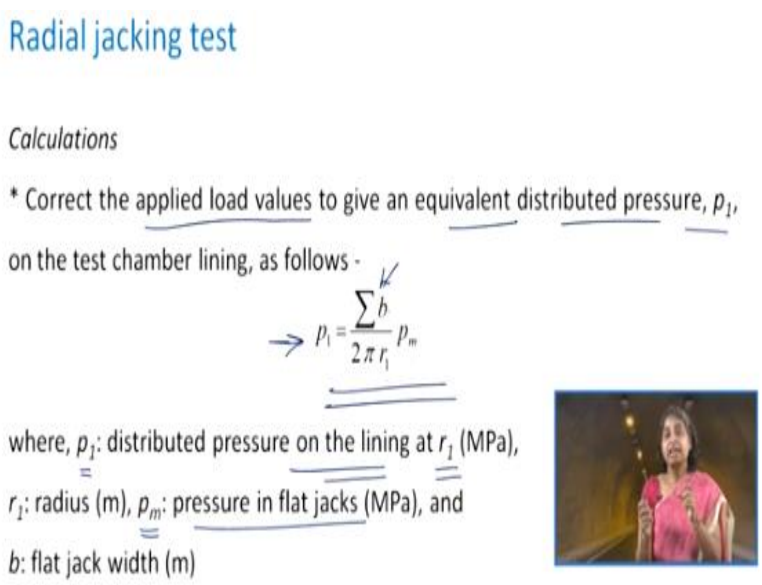
On reaching the maximum pressure for the cycle the pressure is held constant for about 10 minutes and then each cycle is completed by reducing the pressure to near zero in the same time maybe, with the following the same average rate, so what we do is in the first loading cycle you reach up to the maximum load then you maintain that load for about 10 minutes and then you remove that load near to 0 and again while unloading you need to follow the similar average rate.

(Refer Slide Time: 15:51)



So, this is how the typical plot of applied pressure versus displacement, it looks like so you can see that we have the loading portion and then the unloading portion like 3 cycles are there, so wherever this is kept constant this is delta d deformation.

(Refer Slide Time: 16:14)

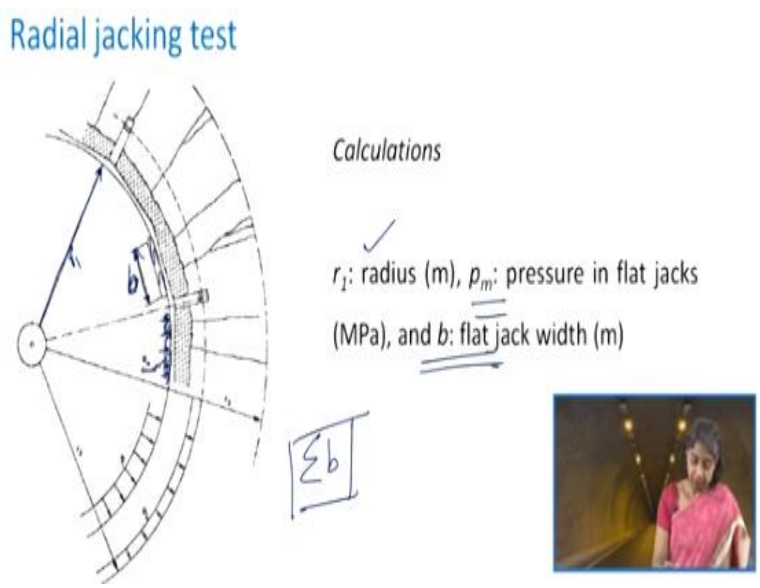


Coming to the calculation aspect related to radial jacking test we need to correct the applied load values to give an equivalent distributed pressure that is p_1 which is on the test chamber lining is as follows this we have to do it using this particular expression where

$$p_1 = \frac{\sum b}{2\pi r_1} p_m$$

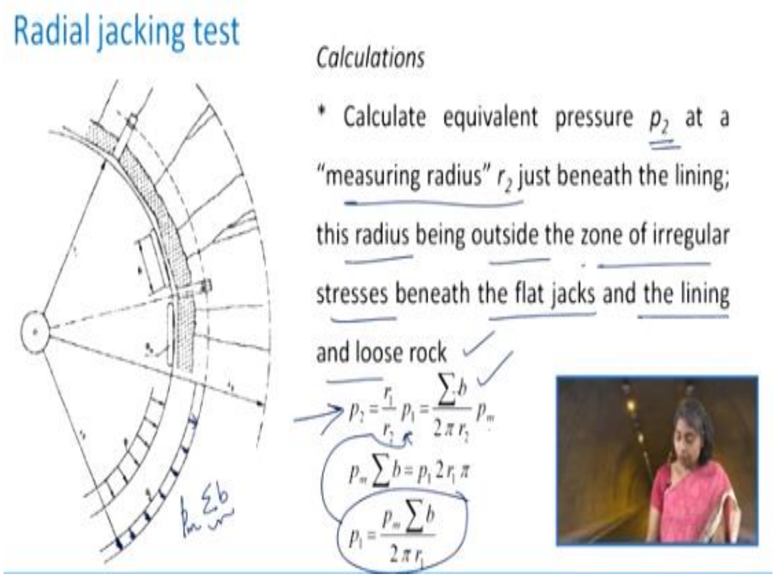
Where this p_1 is the distributed pressure on the lining at the radial distance of r_1, p_m is the pressure in flat jacks and b is the flat jack width. So, when I write here summation of b means, that we have various flat jacks. So, it is the summation of width of each of those flat jacks.

(Refer Slide Time: 17:09)



So, you can take a look here that this is what one flat jack this is another so this dimension is b. So, accordingly depending upon the flat jacks then you have to have $\sum b$. This r_1 radius you can see, here it is this radius which is r one and pm is the maximum pressure, which is shown here that is, whatever is the pressure here in the flat jack b is the width of the flat jack here this one is p this dimension is b.

(Refer Slide Time: 17:50)



So, again then we calculate equivalent pressure p_2 at a measuring radius r_2 this is just beneath the lining. So, you see that where this r_2 it is just this is the lining so just beneath that so here it is p_2 which is applied like this. So, this radius, being the outside of the zone of irregular stresses beneath the flat jacks and the lining and loose rock. So, this is how

$$p_2 = \frac{r_1}{r_2} p_1 = \frac{\sum b}{2\pi r_2} p_m$$

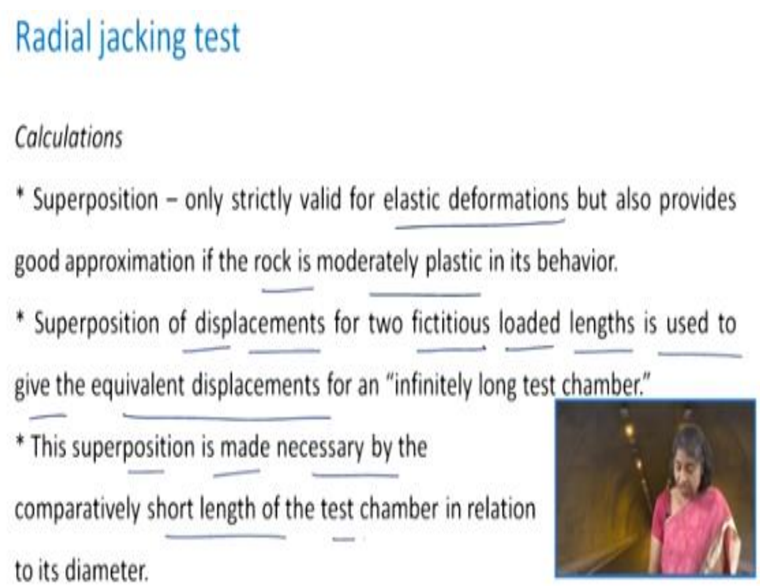
you just substitute the expression for p_1 and like here this is what the expression for p_1 is.

So, you just substitute it here and this is what is the expression that you are going to get so

$$p_m \sum b = p_1 2 r_1 \pi$$

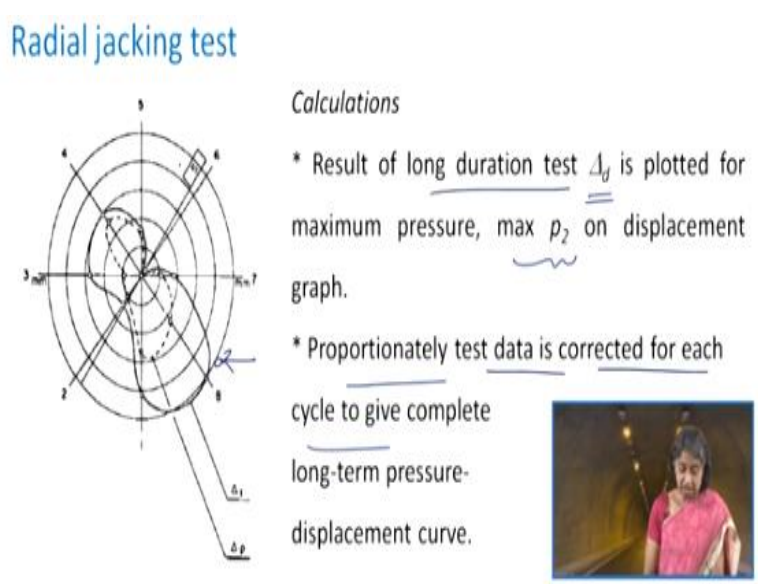
p_m is the maximum pressure in flat jacks and summation b is the total width of the flat jacks.

(Refer Slide Time: 19:07)



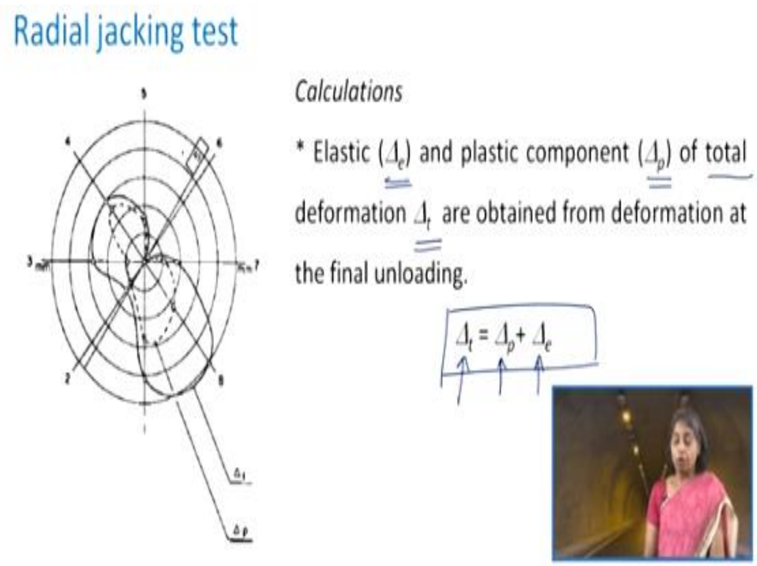
This type of superposition is only strictly valid for the elastic deformation but it also provides a reasonable approximation if the rock is moderately plastic in its behavior. So, although this is strictly for elastic deformation but if the rock is moderately plastic and not very heavily plastic in its behavior then also you can use this expression. So, superposition of the displacements for 2 fictitious loaded lengths is used to give the equivalent displacement for an infinitely- long test chambers. So, this superposition is made necessary by comparatively short length of the test chamber in relation to its diameter.

(Refer Slide Time: 20:03)



So, what we do is the result of these long duration test that is delta d is plotted for the maximum pressure that is maximum p_2 on the displacement graph. So, proportionately the test area is corrected for each cycle to give the complete long term pressure displacement curve as has been shown in this figure.

(Refer Slide Time: 20:33)

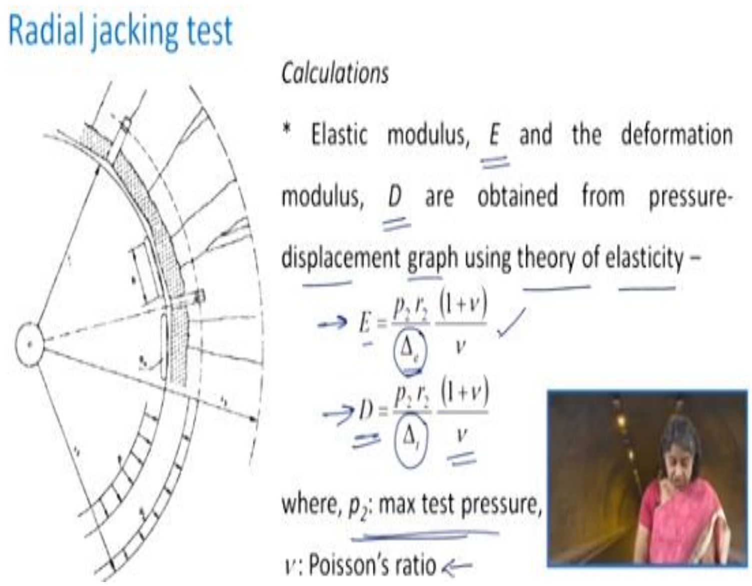


So, in this case, the elastic and the plastic component will be the part of the total deformation and these can be written by this that is the total deformation is going to be the plastic component plus the elastic component

$\Delta_t = \Delta_p + \Delta_e$

So, these can be determined from the deformation at the final unloading, so, when you are unloading only the elastic deformation will be recovered and, the remaining one which is there that will be the plastic deformation, so, that these 2 components can be separated out using the unloading test data.

(Refer Slide Time: 21:16)



Now, how to determine the elastic modulus E and the deformation modulus D, so, these can be obtained from the pressure displacement graph and, using the theory of elasticity by adopting these 2 expressions, where

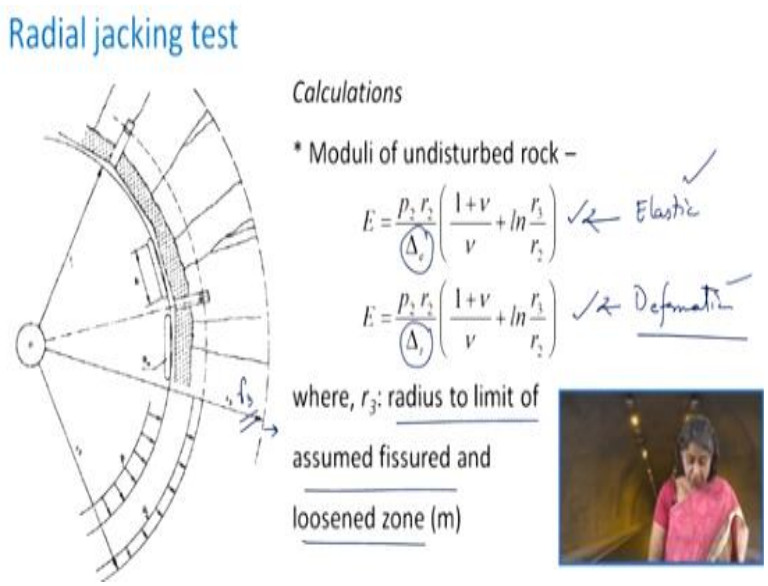
$$E = \frac{p_2 r_2}{\Delta_e} \frac{(1+v)}{v}$$

and if you just substitute instead of Δ_e the total deformation Δ_t. Then this expression will give you the modulus of deformation that is

$$D = \frac{p_2 r_2}{\Delta_t} \frac{(1+v)}{v}$$

where this p_2 is the maximum test pressure and v is the poisons ratio.

(Refer Slide Time: 22:08)

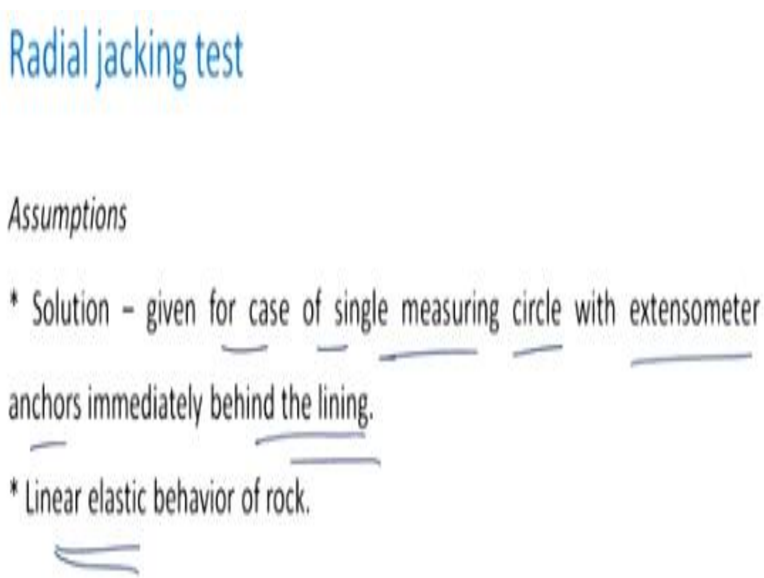


$$E = \frac{p_2 r_2}{\Delta_e}\left(\frac{1+\nu}{\nu} + ln\frac{r_3}{r_2}\right)$$

$$E = \frac{p_2 r_2}{\Delta_t}\left(\frac{1+\nu}{\nu} + ln\frac{r_3}{r_2}\right)$$

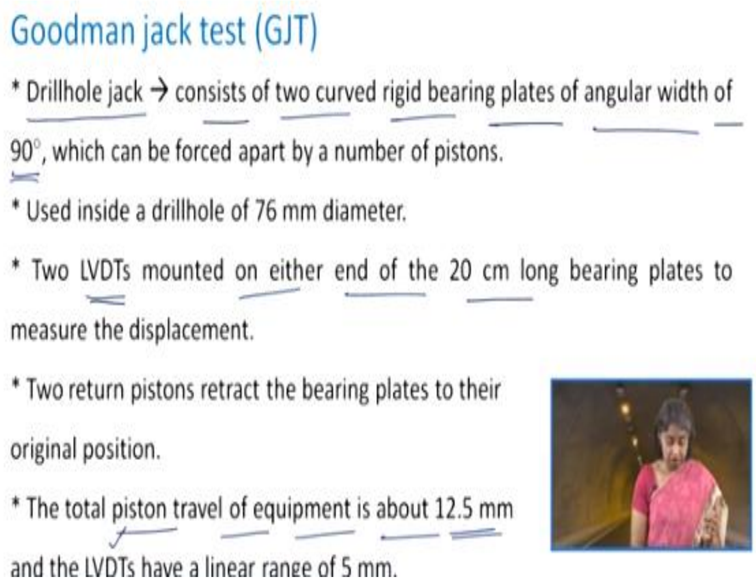
The moduli of the undisturbed rock can also be determined, so, what we do is we anticipate a radial distance may be say r_3 that is this one. Beyond this, there is no fissured or loose zone, so this if we consider this r_3 as a radius two limit of assumed fissured and loosened zone. Then, we can use these expressions to obtain the modeling of the undisturbed rock, so, the first expression talks about the elastic modulus and the second one is for the modulus of deformation, see here we are using Δ_t and here we are using Δ_e so this basically differentiates the elastic modulus and the deformation modulus.

(Refer Slide Time: 23:00)



The assumptions which are involved in the radial jacking test is that, the solution which is given is for the case of single measuring circle with extensometer anchors immediately behind the lining. And, it is also assumed that the rock is behaving as a linear elastic material which may not be the case but then this assumption more or less holds good if the rock is behaving, as the moderately plastic as I already told you.

(Refer Slide Time: 23:41)

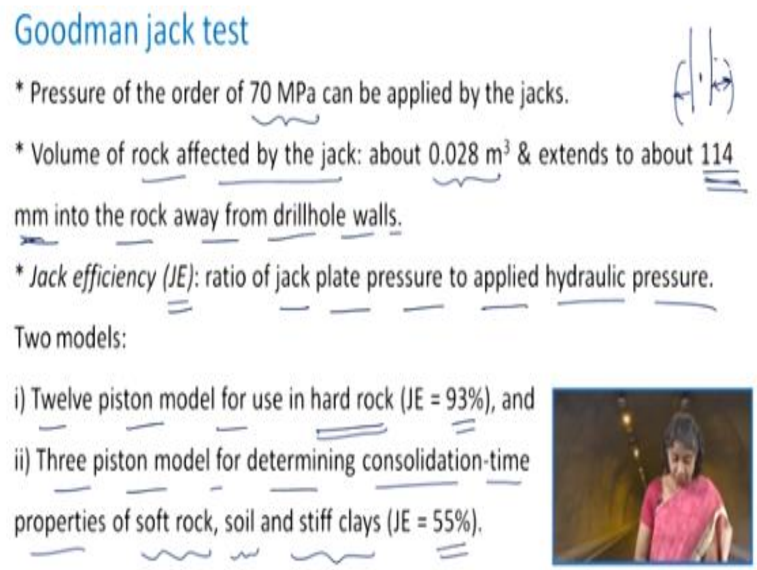


Coming to the next test, which is the Goodman jack test, so you saw that in case of the radial jacking test, you have to prepare a test chamber which is of size 3 meter in diameter and length to be at least 3 times the diameter of this test chamber. So, this is a large excavation so sometimes it may not be possible to go for such large excavation, so, in that case Goodman jack test comes to our rescue.

So, here the test is conducted in the drill hole, so, all we need to have is a drill hole and we have a drill hole jack in this case so this drill hole jack is it consists of two curved rigid bearing plates of angular width of 90 degree which can be forced apart by a number of pistons and these are used inside a drill hole of 76 millimeter diameter. So, we do not need to make very large excavation for the conduct of Goodman jack test.

Now, two LVDT's are mounted on either end of the 20-centimeter-long bearing plates to measure these, displacement to return pistons retract the bearing plates to their original position the total piston travel of the equipment is about 12.5 millimeter and the LVDT 's have the linear range of about 5 millimeter.

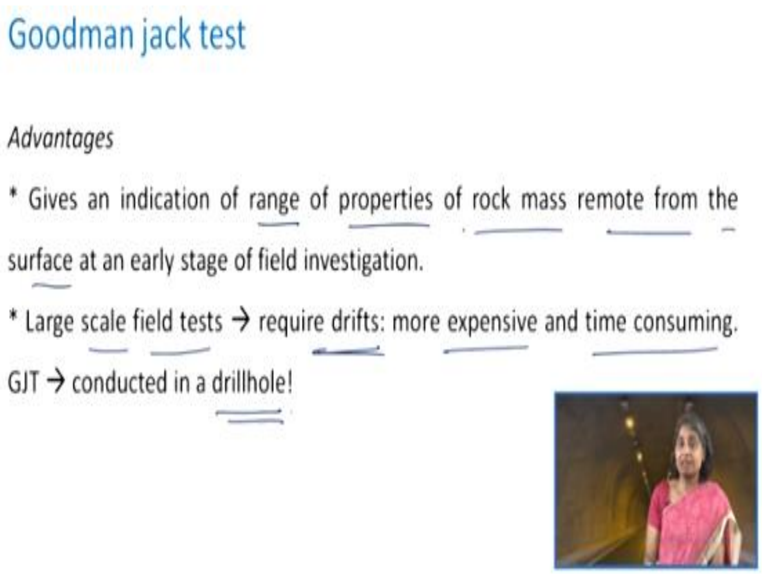
(Refer Slide Time: 25:23)



We can apply the pressure of the order of 70 Mpa, by these Goodman jacks volume of the rock which is affected by the jack is approximately about 0.028 meter cube, and it extends to about 114 millimeter into the rock which is away from the drill hole wall. So, let us say this is the drill hole wall and let us say at this depth you are conducting the test, so, it extends about 114 millimeter into the rock which is away from the drill hole walls, that means this extent.

There comes a term called jack efficiency, which is the ratio of jack plate pressure to applied hydraulic pressure there are 2 models, which are used the first one is the 12-piston model which is used in hard rock it has the jack efficiency as 93 percent. And the second one is the three-piston model for determining the consolidation time properties in case of the soft rock soil or the stiff place this has the jack efficiency of 55 percent**.**

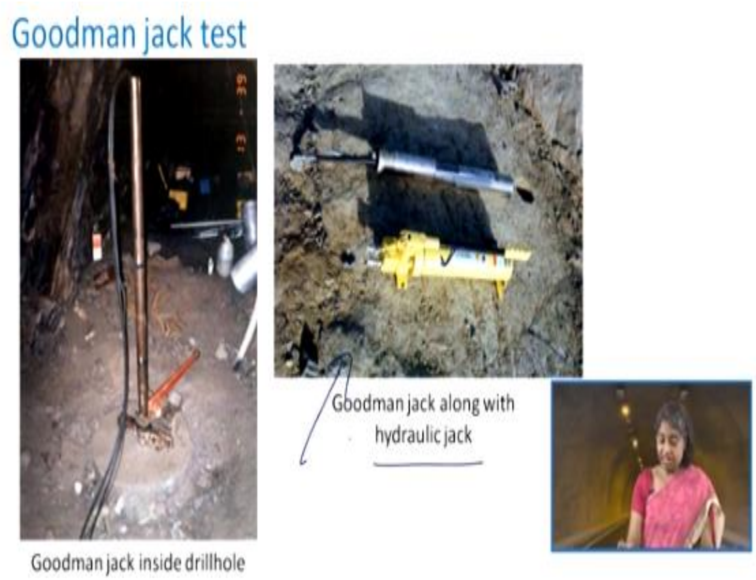
(Refer Slide Time: 26:44)



The advantage of the Goodman jack test include, that it gives an indication of the range of properties of the rock mass remote from the surface at an early stage of field investigation. Because, it is conducted in a bore hole so it is possible to reach too few remote locations from the surface. Large-scale field tests, they require the drifts to be conducted properly and therefore they are more expensive and time-consuming.

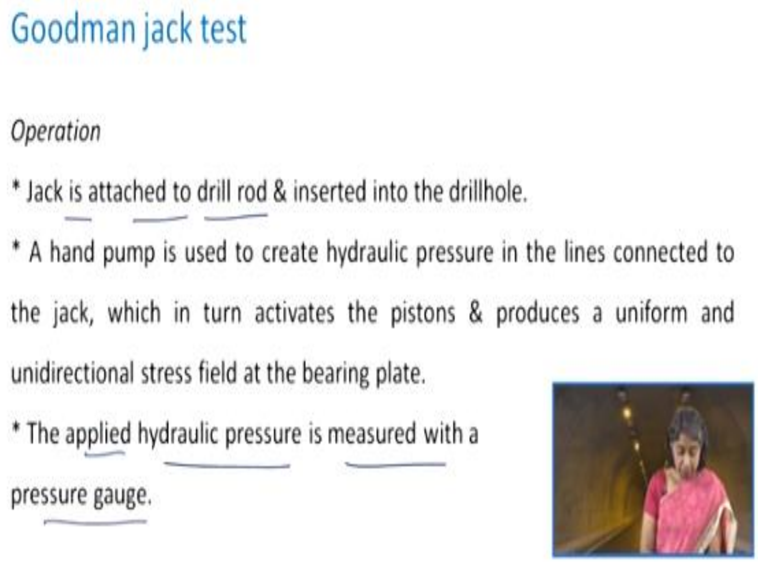
And therefore, Goodman jack test is adopted because, it is conducted in a drill hole so as compared to making a drift or an edit or a test chamber it is always much more cheaper to have the drill hole and therefore the cost associated with Goodman jack test reduces drastically

(Refer Slide Time: 27:51)



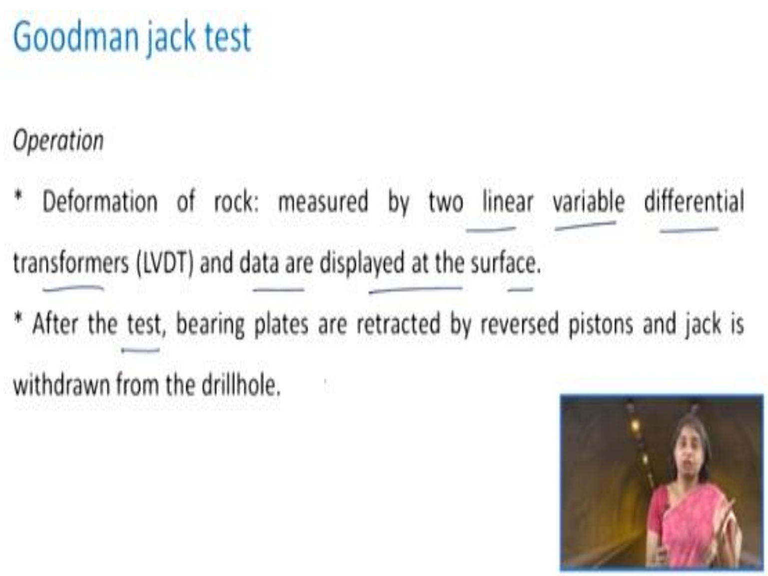
This is how the test setup looks like, so this picture shows you the Goodman jack along with the hydraulic jack, so this is what the hydraulic jack this is the Goodman jack is. And the Goodman jack in this case in this picture has been installed inside the drill hole, that means this is the test which is in progress

(Refer Slide Time: 28:13)



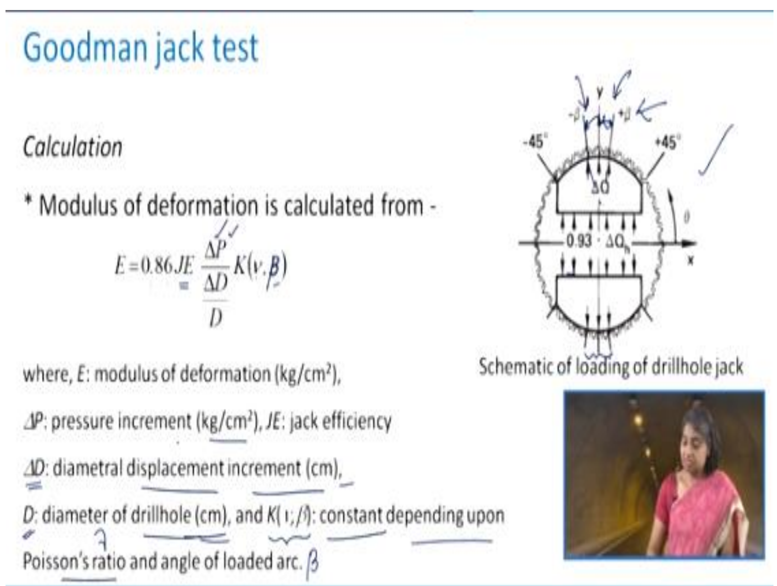
How the operation of this test takes place is that, the jack is attached to the drill rod and it is inserted into a drill hole. Then a hand pump is used for creation of the hydraulic pressure in those lines which are connected to the jack what happens when you use this pump in turn it activates the piston and produces a uniform and unidirectional stress field at the bearing plate which are there inside the drill hole the applied hydraulic pressure is measured with the help of the pressure gauge.

(Refer Slide Time: 29:00)



Then the deformation of the rock can be measured by two linear variable differential transformers, which we call those them as LVDT and the data these are displayed at the surface because, all these are connected at the surface. So, after the tests, these bearing plates are retracted by the reverse action of the piston and then the complete jack is withdrawal from the drill hole.

(Refer Slide Time: 29:34)



Coming to the calculation like we have conducted the test then how to obtain the modulus of deformation. So, you see that this is the schematic of loading of drill hole jack, so, it is at a particular location and this is how the loading will be there you see. So, the angle beta basically it shows the angle of the loaded arc so you can see that this is what is this angle beta so from here it is plus beta here it is minus beta.

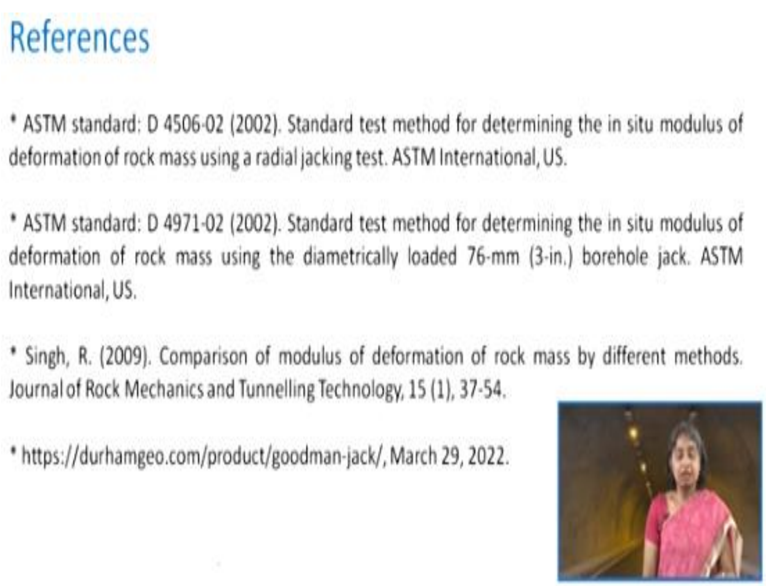
So, the modulus of deformation can be determined by this expression which is

$$E = 0.86JE\frac{\Delta P}{\frac{\Delta D}{D}}K(v, \beta)$$

which is a function of poisons ratio and the angle of the loaded arc so here it should be beta. So, this delta P is the pressure increment in kg per square centimeter, JE be the jack efficiency, ΔD is the diametral displacement increment in centimeter.

D is the original diameter of the drill hole which is in centimeters, and as I mentioned $K(v, \beta)$ is a constant which depends upon the poisons ratio which is v, an angle of the loaded arc beta which is shown here in this figure. So, based upon what type of piston that you are using for this, this jack efficiency can be either 93 percent or it can be 55 percent so as you can see that in this case it is the 93 percent so because it is multiplied by 0.93 here. So, this is how the calculation for the modulus of deformation can be done using the Goodman jack test.

(Refer Slide Time: 31:43)



So, these are some of the references from which the material was taken for the preparation of this particular lecture. So, this finishes our discussion on the in-situ determination of modulus of deformation of rock mass which is a very important property as far as rock masses are concerned. In the next class, we will start with a new chapter which is on the rock mass tunnel support interaction analysis. So, first I will explain you the concept of rock mass tunnel support interaction and, then we will see one particular analysis which is Ladanyi's analysis, thank you very much.