Rock Mechanics and Tunneling
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Lecture 58
Improvement of Rock Mass Response (Continued)

Hello everyone, I welcome all of you to the second lecture of module 12.

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So, in module 12, we are discussing about the improvement of rock mass response. So under that we will discuss started discussing rock bolts; then we will also discuss rock anchors, steel mats, precast concrete segments, shotcrete, grouting etcetera. So, let us continue our discussion.

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So today, we mainly continue our discussion which we have started in our previous lecture; that is on the rock bolt, so rock bolt only we will discuss today.

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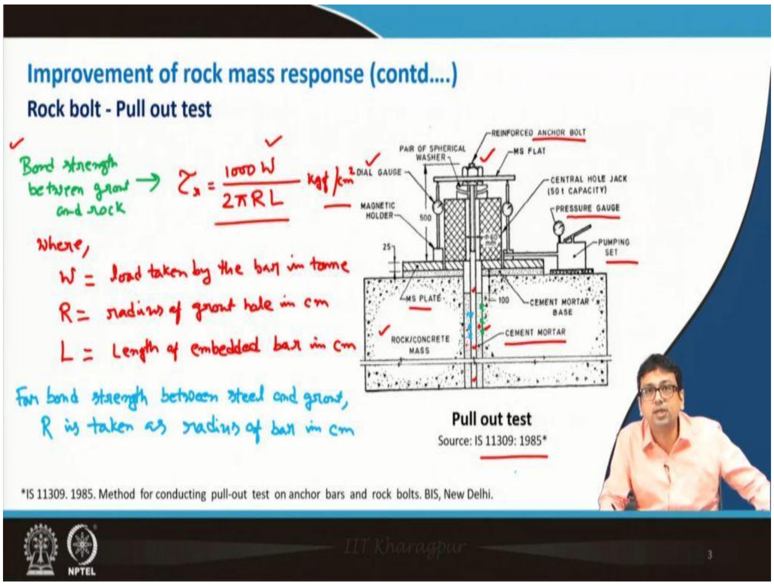

So, first is rock bolt pull out test; so, it is as per IS code 11309: 1985 this test may be conducted. So, definitely one can read this, this Indian Standard code for detailed procedure of conducting the test. But anyway, briefly, what we can see from this diagram is that you see the, this is the. As you can see rock or concrete mass, so this block you can see.

Over there this is an MS, this is MS plate you can see; and here is some pumping arrangement. So, you will see most important thing is the this is the bolt reinforced anchor bolts. So bolt is, see here also you can see the bolt, here is also you can see the, here also it is the bolt you can see.

Now, what you can see the surrounding region here, here, here; what is there cement mortar. So, this is nothing but the working as the grout material; so grouting material that is the cement mortar and this is the bolt. Now, through the following this IS 11309: 1985 explained procedure, one can find out the pull out resistance of the bolt.

And for to measure how much pressure is required or load you need to apply for this pull out, for to find out the pull out capacity; that can be obtained through this pressure gauge attached with this pumping set. And obviously the dial gauges are there to note the displacement; mean that what displacement.

Means, the basically, that we will get the load settlement kind of diagram from this test, and from where we can find out the peak load; or, at which failing that we can find out. So, now, some of the like related to this, one or two things what we can write down, the bond strength between grout and the rock.

So, again, as I have mentioned in my last lecture that the rock bolt may fail because of the failure of the interface between the grout and the rock, grout and the rock. Means at that interface also is along this interface also it may fail; one thing, so let us write down accordingly. So, what we can write the bonds.

So that is why finding out the bond strength of between the grout, or here cement mortar and rock is important. So, for that what we can do, the bond strength between grout and rock that can be obtained from this expression. Obviously, this is very simple like 1000 into W, W is in ton; that is why actually it is in 1000.

I am writing the IS code specified expression, and which is also you can also derive it, this is very simple. So, it is 2 pi R into L; now, what are the this? This is in kg f per centimeters square. Now, what is this let me write here, where W is what? W is nothing but the load taken by, load taken by the bar of this reinforced this bolt; this is the bar, that is what you can see the steel rod, load taken by the bar in tonnes.

So, that is why since W is in ton 1000 multiplied to convert into kg. Now, obviously, R here for the bond strength between grout and rock, this R should be the radius of the grouted hole. And since here you can see the unit in centimeter squared kg f per centimeter; so that means, it should be the radius also should be in centimeter. So, the radius of grout hole in centimeter.

Then last parameter is L, which is nothing but the length of embedded bar; so length of embedded bar in centimeter, this is also. So, so this way we can very easily we can find out the; means it is nothing but 2 pi R into L, so the, this is like these cylindrical hole, the periphery we can find out; so the perimeter is nothing but 2 pi r.

And the length, if you multiply it, you will get the area. So, 2 pi R into L we will divide by this area; what you are dividing, nothing but the load, taken by the bar in ton. So, and this 1000 is for to convert into kg. So, so this is for the bond strength between grout and rock. Now, if it is asked to find out the bond strength between the this steel rod, let me mark it over here once again. There may be failure, as I mentioned between the, in the interface of this grout and the steel rod; so, along this interface.

So, if it is asked to find out the bond strength between the rod or the bar and the grout; then what will happen? Then simply nothing more you have to do, only the R which is here capital R is the radius of the grout hole. Instead of radius of grout hole, we have to use the radius of the steel rod or the bar; that that is it, that much only you have to do. So, let me write down here, for bond strength between steel and grout is R is taken as radius of bar in centimeter. So, in this way you can find out the pull out resistance; so it is as per IS 11309: 1985.

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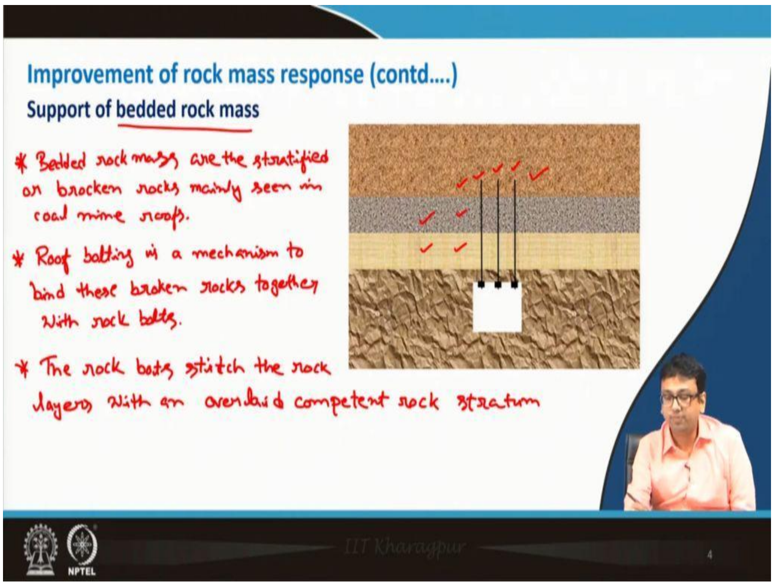

Now, one important thing we discussed now, that is the support of bedded rock mass. So, this picture is trying to is provided to clear your idea. So basically, what is this? Like this beaded rock. This bedded rock mass are the stratified or the broken rocks, mainly found in coal mines; so let me just write down at least this one.

So, bedded rocks, bedded rock mass as you can see here; bedded rock mass are the stratified or broken rocks mainly seen in coal mine. Now, coal mine where you see this is the, if it is the mine, suppose this mine tunnel. Now, here you see the here you can see the stratified or broke; this looks like some layers are there, and then broken rocks are there.

Thus these stratified or broken rocks are mainly seen in the coal mine roofs. So now, as you can see you from this diagram that how it can be stabilized by providing reinforcement in the form of rock bolts. You see the rock bolts are provided here. So what is done actually? Suppose these are the weak layers, this one and this one.

So, what can be done is we can provide these bolts rock bolts, and it should be embedded here in with this region is, suppose this is a strong rock layer maybe. So, it should be embedded into that the bolt, so pass through this stratified or broken rock to. Here it should be embedded into the strong rock layer.

So, in this way we can stabilize the, this bedded rock mass; and we can avoid failure of this type of the failure of the roof; means mainly the coal mine roofs failure, we can prevent by properly designing these bolts. So how, what should be the, number one the what should be the, like how many rows you require.

How many, what should the spacing between the bolt that we should design. Also obviously the strength of the material the steel rod; that should also be we have to design accordingly, that that should also have enough yielding strength. So, these are the things we have to remember, we will see that now only.

Other than that the regarding bedded rock, what we can say. So, what I was telling that the rock this roof with the help of this rock bolts, the roof bolting; roof bolting is used actually here, and is a mechanism to bind these broken rock. Roof bolting is a mechanism to bind these broken rocks together with rock bolts.

So, as I have mentioned only, that is only it is stated; and another point we can write that the rock bolts stitch the rock layers. The Rock bolts stitch, rock bolt, basically stitch the rock layers with an overlaid competent rock stratum. So, these are the things we can say, I mean, it is a, as I mentioned that the rock bolts stitches the rock layers, these weak rock layers, with an overlaid competent rock stratum. So, this is what is nothing but a competent rock stratum.

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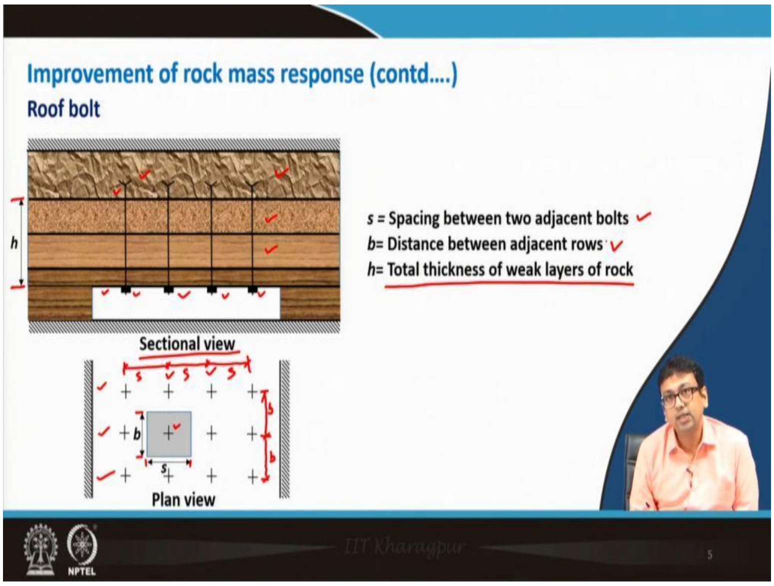

Now, as we already know that the. Suppose this is regarding now the how to regarding the means the (()) (15:19) design part if we consider. See, designing rock bolts means, you have to check already have understood rock this bolting may fail due to several reasons. Like one reason was the entire rock mass is failing, that may be one thing. Other than that, what may happen?

The failure in the, along the interface of the, of we are using a rock grouted rock bolt if we are using there; so, there may be the failure between the rock and the, in failure at the interface between the rock and the grout we have understood. Then there may be failure due to the in between the steel rod or tendon and the grout, that can be one thing. And another thing can be the itself the rock, the bond and the steel tendon; that steel rod is failing, that can also happen.

Now, suppose let us see as I have mentioned, suppose these are the stratified layers or the broken rocks; and this is a competent layer, where it is actually with the help of these bolts, it is actually stitched. These layers are stitched with the competent layer. Now, this is the sectional view; now, if you see the plan view. Suppose how the rock bolts are arranged over here? These are the…

Now, one thing also here you look at, it is the h is the, suppose this height is suppose. Means the, from this exposed surface to this point; it is suppose h. And beyond this, it is actually means here only the point of anchorage you can see. Now, here what is s? s is nothing but, as you can see spacing between two adjacent bolts; so this is one bolt, this is one bolt; so, the spacing between these two bolts that is s.

So that means, here in this way we can present the influence area of this one. This one bolt can be in this side, it can be considered as simply s, means half to half this side half this side. Similarly, if b is what? Distance between the adjacent rows; so this is one row, this is another row, this is another row. So, the distance between these rows are b; this is also b. Similarly, this is also s, this is also s. So, now, if I consider and h is the total thickness of the weak layer of rock, so that is fine.

Now, why this portion is shaded? It is only showing that influence area of one bolt. Actually the bolt, one bolt influence area of this one bolt; how can we find out? Obviously. So, this side is half s, this side is half s; so total influences area is here. Means the length of this influence zone is s.

Similarly, here half b and half b, so total is b; so, this shaded zone is nothing but the, basically, you can think of it as the rock mass of volume b into s into h will be the volume of the weight of the rock mass, having volume b into s into h will be taken by the this one bolt.

So, the weight of the rock mass having volume b into s, b is the distance between the adjacent row, s is the spacing between two adjacent bolt, and h is the total thickness of the weak rock of the weak layers of rock. So, that will give us the volume of the rock block. And if we multiply that with the unit weight of the rock mass, so we will get the weight of the rock mass for, which will be taken by one single bolt, so now.

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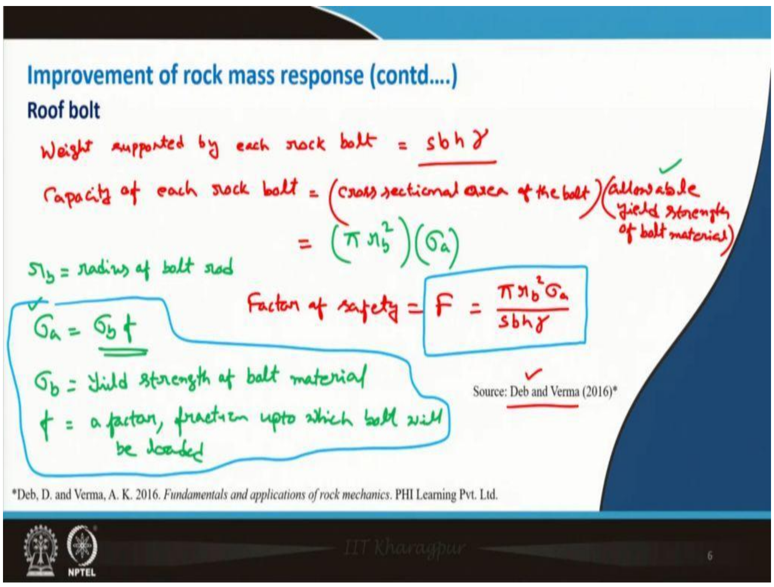

So, for this, again, if you want to learn the designing and all if you want to learn in detail, you should follow, you can read; means I can I have followed the book of Deb and Verma 2016. So, so now regarding this part, what we can say the weight as I have mentioned. So, weight supported by each rock bolt is equal to nothing but what s b, h and gamma as I have mentioned; so, weight supported by each rock bolt will be this.

Similarly, capacity of each rock bolt is equal to what is nothing but the cross sectional area of the bolt, into the, you can consider as the allowable yield strength of the bolt. So, for the steel material of the bolt, so allowable yield strength of bolt material, generally it is made of steel. So, that is what we have to consider. So, basically, this is equal to nothing but, if we consider; suppose rb is the, suppose this is the radius of bolt rod, so radius of bolt rod.

So, then its cross sectional area is pi rb square. This should be multiplied with allowable yield strength of bolt material; suppose that is sigma a. So, sigma a is what the allowable yield strength of bolt material. Now, it can, it is nothing but what it is nothing but, basically the sigma b into f. Now, what is this sigma b over here? Sigma b is nothing but the yield strength of bolt material and sigma is the allowable bolt.

So, this is the allowable, this is important; allowable is sigma a. Now, it is only sigma b is suppose the yield strength of bolt material for the steel. And f is nothing but a maybe a factor; a factor, which is nothing but the fraction of. or means, this is a fraction means less than 1, that means it can be 0 to anything, based on which you will decide the like that how much is allowable.

So, we can write over here little bit fraction, up to which bolt will be loaded. So, anyway so this is you can clearly understand; so directly I have written over here sigma a. So, these are things just for our own information. So now, this is the capacity of the each bolt. So, that means what we can get, we if we want to find out the factor of safety, so factor of safety.

Suppose, F is nothing but equal to what? The capacity of the bolt that is pi rb square into sigma a divided by, like this s b h into gamma, so s b h into gamma. Maybe this s is write it as this is small s, same only both the, so, this is what is important. When, as far as the factor of safety with respect to the failure of the steel rod or the tendon, with respect to that it is important.

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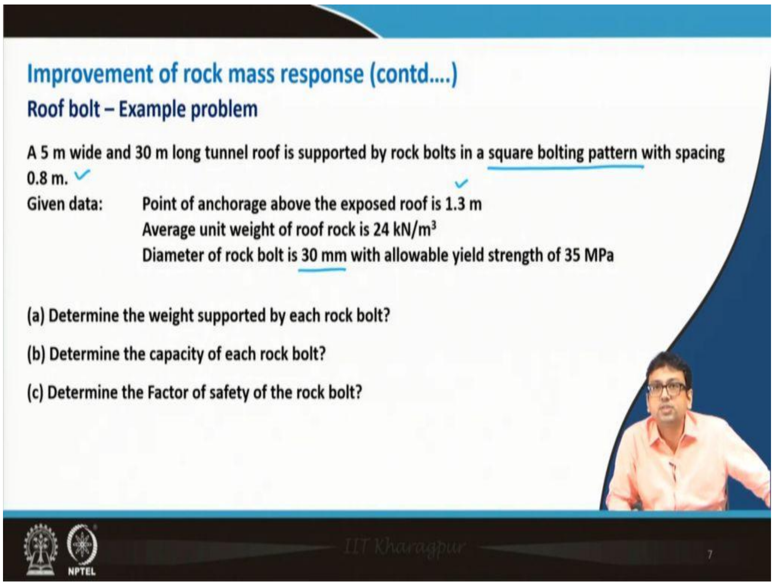

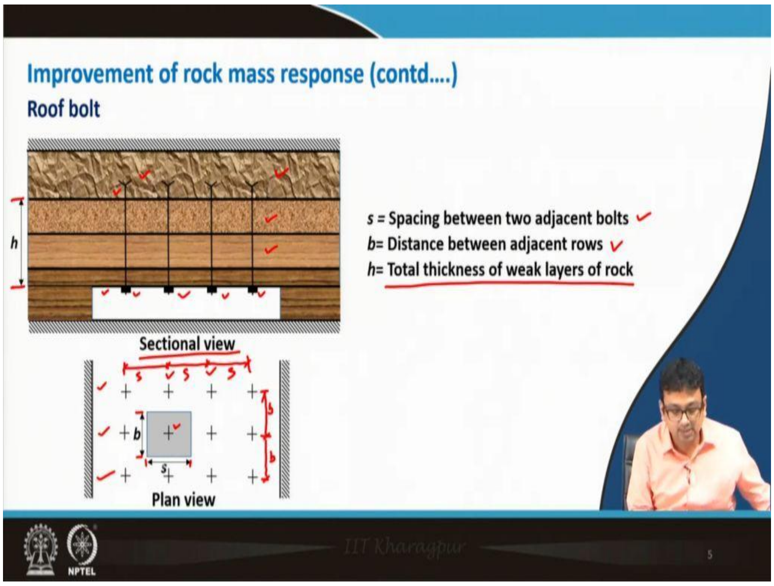

Now, let us take a small problem. A 5 meter wide and 30 meter long tunnel roof is supported by a by rock bolts in a square bolting pattern; so square bolting pattern. That means what? That means if you square; that means b should be equal to s. So, instead of this rectangular influence area, it will be a square; so b is equal to f. So that we have understood with spacing of 0.8 meter; so, b and s both are 0.8. Given data like point of anchorage above the exposed roof is 1.3 meter; that means, this is nothing but my h. Average unit weight of rock roof rock is 24 kilo Newton per meter cube.

Because we need to find out the weight s b into h into this gamma, you need to multiply to get the weight. And what is given? Diameter of rock bolt is 30 millimeter with allowable yield strength of 35 mega Pascal's. So, determine the weight supported by each rock bolt, determine the capacity of each rock bolt, and determine the factor of safety of the rock bolt. So, it is basically related to the tensile failure of the, basically failure of our the steel rod or the steel tendon of the rock bolt. So anyway, we can solve it in this way.

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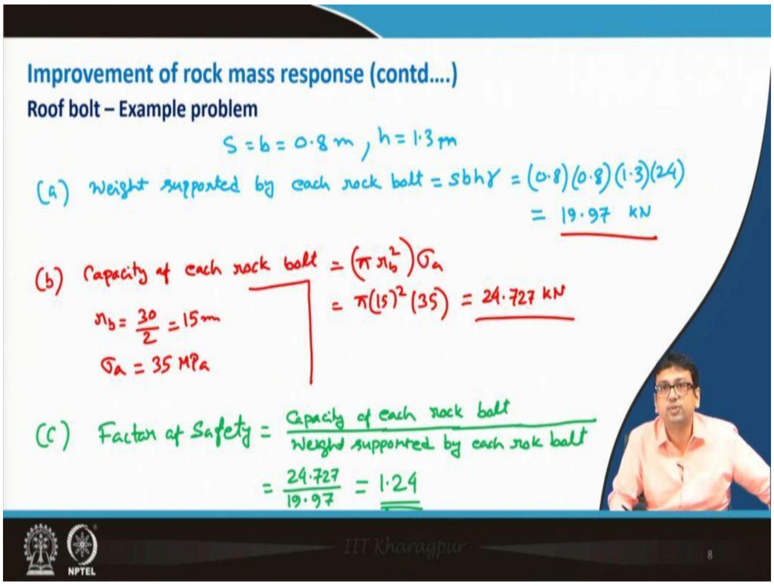

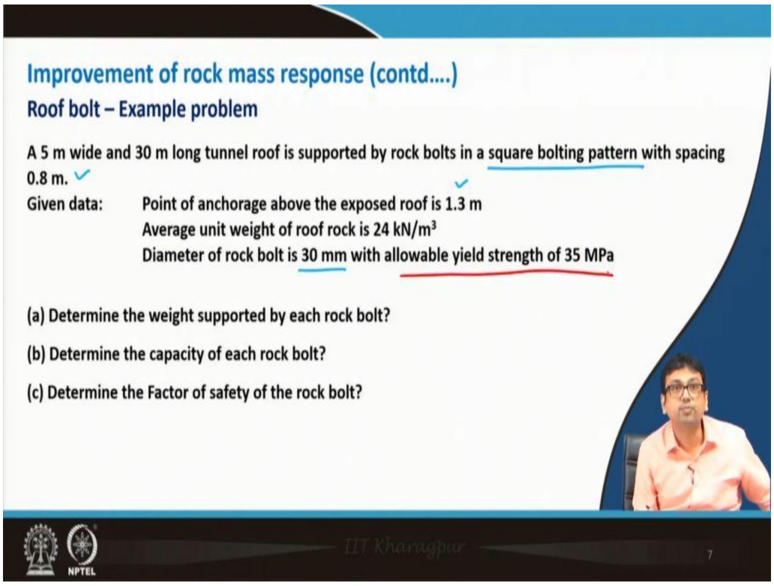

So, what we can write? First write the, let me here question was, determine the weight supported by each rock bolt. a; determine the capacity of each rock bolt b, and determine the factor of safety, fine. So a: a is; weight supported by each rock bolt is equal to s b h into gamma we know. Now s, now here s is equal to b is equal to 0.8 meter, and h is given as 1.3 meter, I hope so upon 1.3 meter.

And gamma is given us 24 kilo Newton per meter cube. So, what we can do? We can write over here that 0.8 into 0.8 into 1.3 into 24. So, if you simplify it, you will get it as 19.97 kilo Newton, this is one answer, this is one answer.

Now b: b is; the determine the capacity of each rock bolt. So, capacity of each rock bolt is equal to nothing but the pi rb square into what sigma a. Now, rb is equal to here how much, rb is given diameter is given; so, 30 was the diameter 30 mm; 30 by 2 is equal to 15 m. And sigma a is given as sigma a is how much allowable yield strength 35 mega Pascal's; so 35 mega Pascal or Newton per millimeter square.

So now, if I write down over here, it will be pi, so again pi 15 square; and it is 35, so this will give us the thing in Newton. And if we divide it by 1000, we will get it in kilo Newton; so this will be 24.77 kilo Newton directly writing it in kilo Newton. So, 24.77 kilo Newton this is another answer.

So now, see the factor of safety. So, the factor of safety is nothing but the capacity of each rock bolt, of each rock bolt by weight supported by each rock bolt, so it is 24.77 divided by 19.97. So, 24. sorry 24.727 it is, just small mistake in writing this should be 24.727; and this one is. So, obviously here also I have to modify, so 24.727 divided by 19.97, which will give us about 1.24, so this is another answer.

So, this way means a part of our rock bolt design can be done, and also the regarding the grout, the interface failure between grout and rock, or the grout and the steel; we have already seen how to find out, as per the IS code recommendation.

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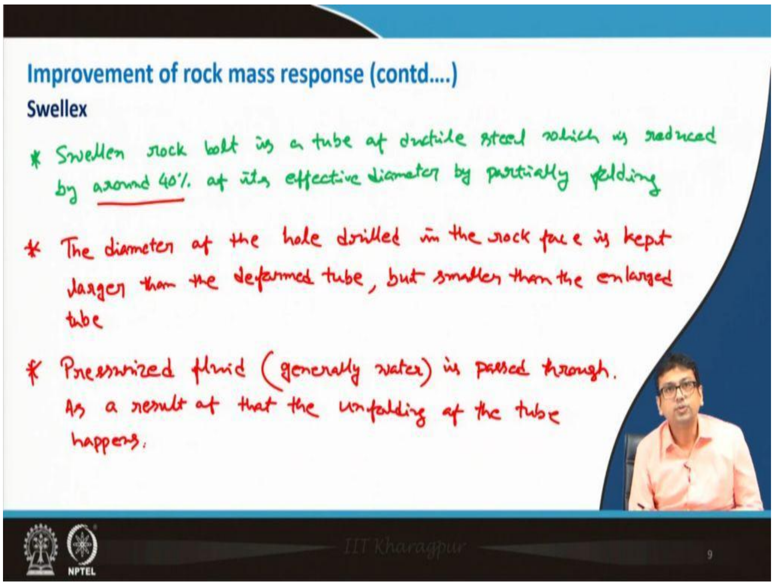

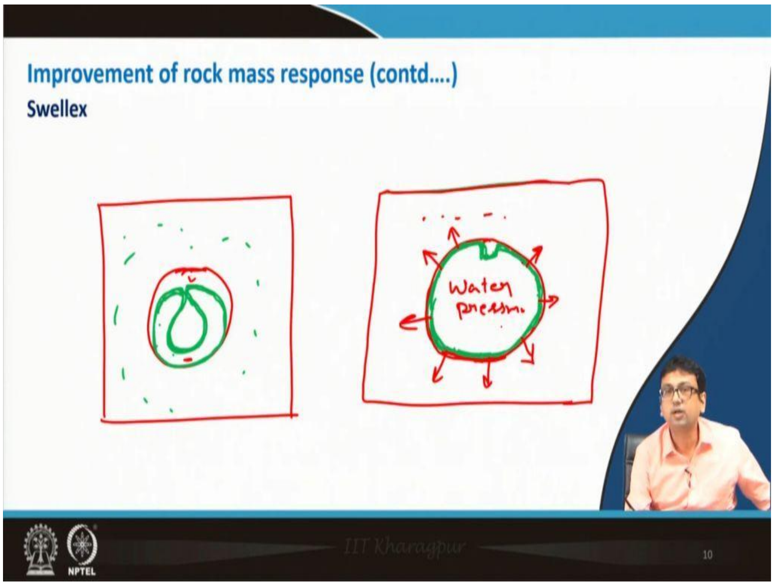

Now, one thing as I was telling swellex. Swellex is what? It is a nice thing; it is actually a special type of rock bolt. So, it is a type of rock bolt, swellex rock bolt. At least it is kind of a tube, which is made of ductile steel actually; and which can be folded. And it is actually the like its effective diameter can be reduced because of folding.

So, let me write down one line, so swellex rock bolt is a tube of a ductile steel, which is reduced by around 40 percent of its effective diameter, while folding or partially folding. So, basically, let me just try to draw a diagram, you will understand. What is done over here is suppose this is the rock domain of here, the hole is created.

Now, this one this swellex is will look like; so basically it is a just I am drawing another, making it little bit thicker; so that you can understand. So, this is a tube and this is supposed the rock mass. Now, what is done actually pressurized fluid is passed through this tube; so, now let me draw one another one. So, pressurized fluid, once again imagine the same hole it is.

Now, what will happen is, so now here if you apply water pressure; means water pressure if we apply over here. So, what will happen? It will unfold. So, now after unfolding it will take this shape. So, this one is now inflated and it will almost fill up the entire this gap, these gaps will be filled up and it will inflate and take this kind of shape. So, this is nothing but the swellex, so a little bit we can write.

As I mentioned, swellex rock bolt is a tube of ductile steel, which is reduced by around 40 percent of its effective diameter by partially folding. And we can also say that important thing is you see the diameter of the hole, what will we actually drill there should be more than the folded this swellex; folded diameter of this one this tube swellex.

And it should be but that the diameter of the hole should be again, lesser than the unfolded tube, so that is what we can also write down over here. So, the diameter of the hole drilled in the rock face is kept larger, as I have mentioned larger than the deformed tube; but the smaller than the enlarged tube.

So, obviously, the reason is very clear because if it is the diameter less than the enlarged tube, then only proper contact will develop. And it will try to further expand in a size, so the bonding will be better that we can understand. So, there it will always be in touch with the surrounding like the periphery of the hole.

And also one point as I mentioned the pressurized fluid, generally water actually, so is passed through and pass through, as a result of that the unfolding of the tube happens. What I have mentioned like pressurized fluid or water, water pressure we will apply; and it will inflate and it may unfold, and it will take this shape.

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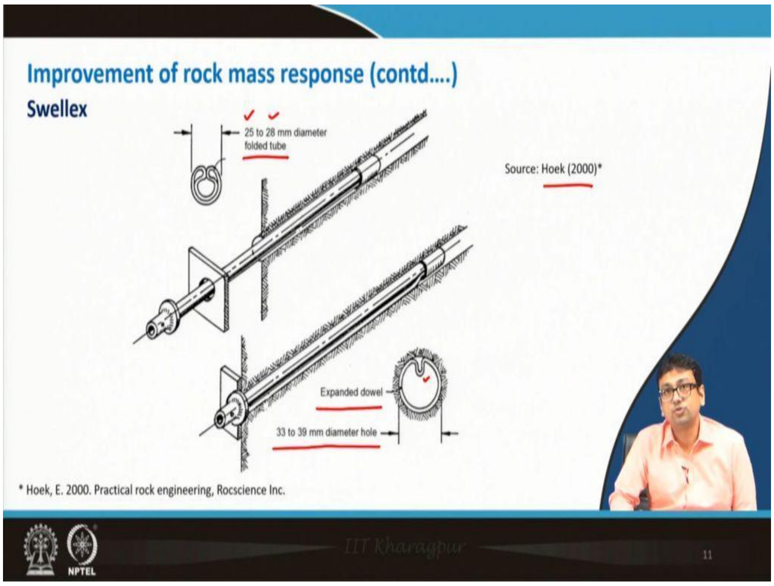

Now, just some of the picture from the book of Hoek. We can see, you see initially, this is important, like 25 to 28 millimeter diameter of the folded tube. Now, after expansion what is happening? 33 to 39 millimeter diameter of the hole is there; and it has not expanded. So the hole diameter is 33 to 39 millimeter, and now this 25 to 28 millimeter diameter tube is now unfolded.

And you see, even it could not unfold fully; in this portion you can see this kink. That means, if that do not happen that means entire other portions are in full contact with the periphery of the hole; so, that will obviously generate a very good bondage. So, this is what swellex which is very useful for, I mean which is used quite frequently, for as this rock bolt effective rock bolt. So, with this let us conclude our today's lecture; so thank you.