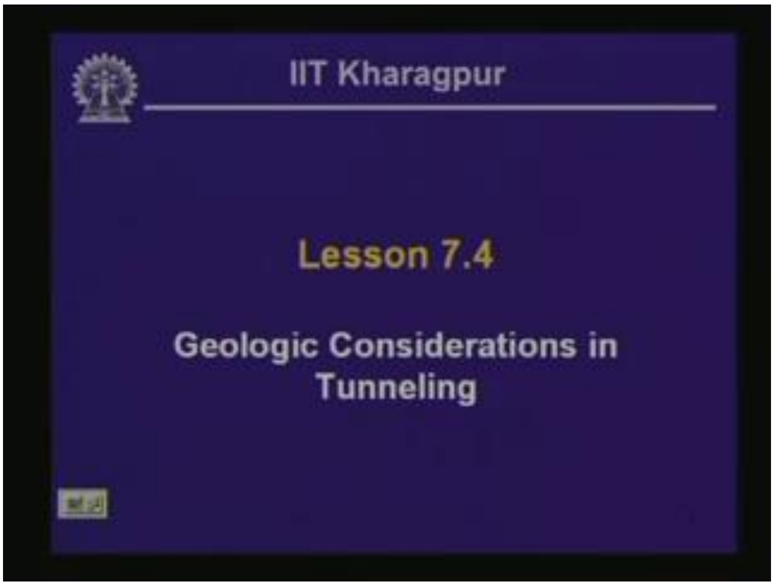
Engineering Geology
Prof. Debasis Roy
Department of Civil Engineering
Indian Institute of Technology, Kharagpur

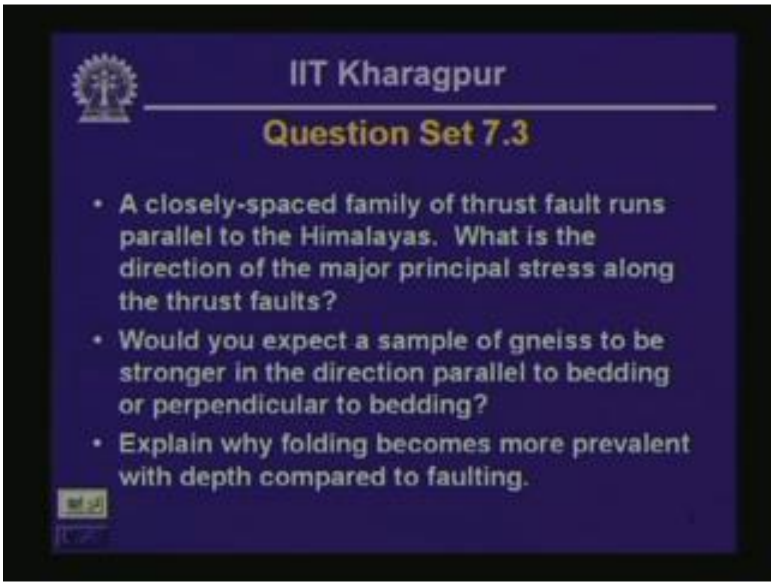
Lecture - 23
Geologic Considerations in Tunneling

(Refer Slide Time: 00:53)



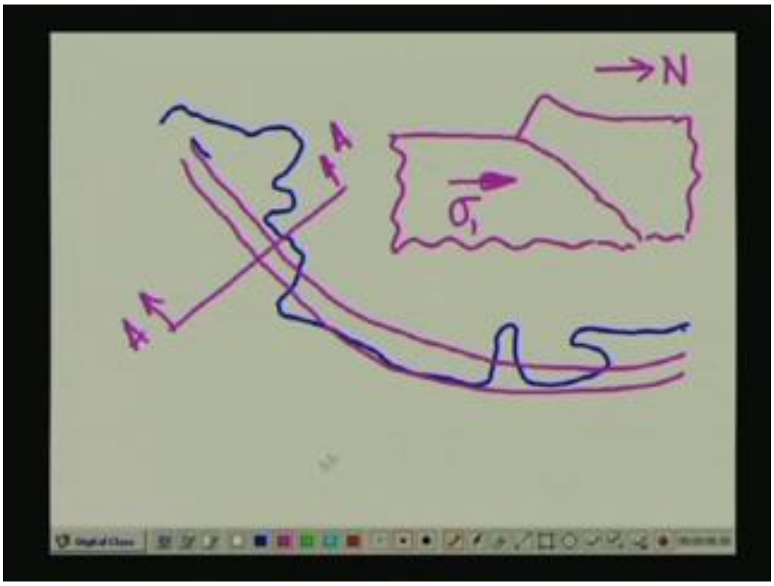
Hello everyone and welcome back. We are going to talk about geologic considerations in tunneling in today’s lesson, but as is the practice we are going to look at the solutions of the previous question set.

(Refer Slide Time: 01.03)



This is the question set that I gave you as part of the previous lesson. The first question was a closely-spaced family of thrust fault runs parallel to the Himalayas. What is the direction of the major principal stress along the thrust faults?

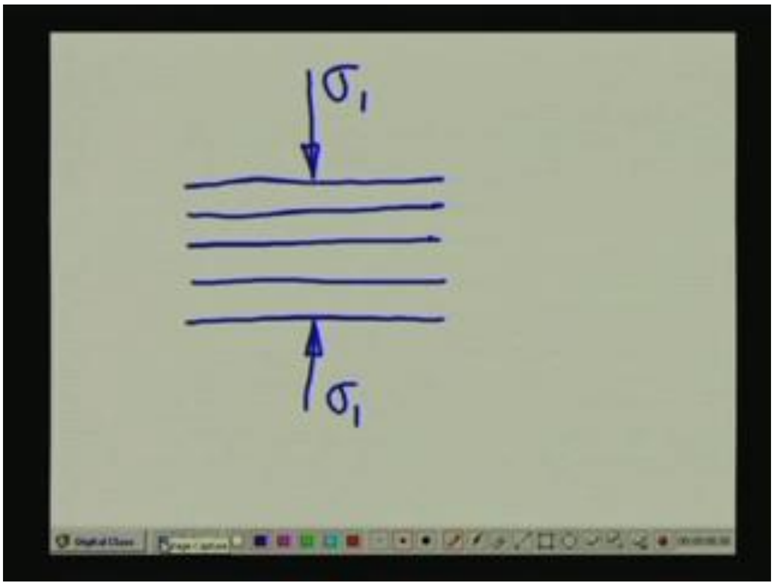
(Refer Slide Time: 01:32)



Let us say if you look at the northern part of the country, then it might actually look like this, and the Himalayas run in this direction. So, basically what we are having here is that there are a bunch of thrust faults that run near the foot hills of the Himalayas. So, basically if you look at the section here then the thrusting is going to be like this. So, this is section A A. So, basically what is happening is this is one block in this case, and another block to the further north is like that. So, this is the direction to the north, and this block basically is squeezing against the block that is to the north.

So, in this case, obviously, the direction of the major principle stress is towards the north. So, that is what I asked in the first question. Now let us look at the second one; would you expect a sample of gneiss to be stronger in the direction parallel or perpendicular to the bedding? Now let us consider this question once again.

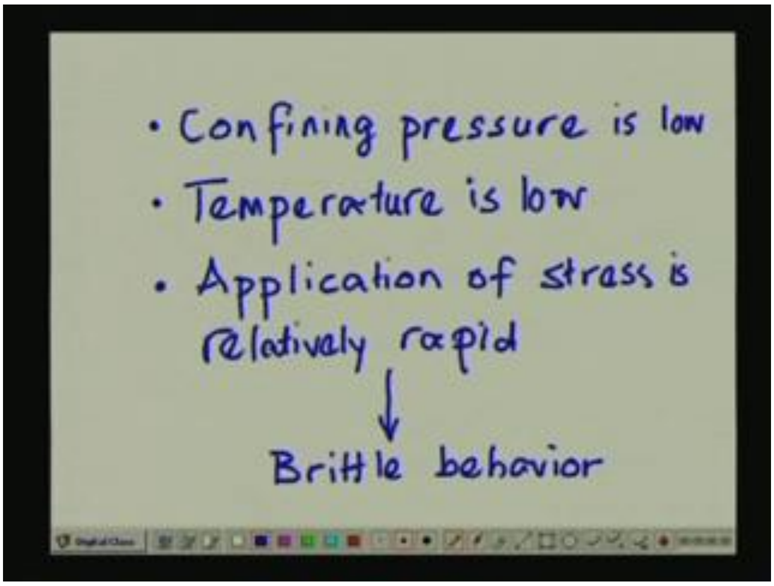
(Refer Slide Time: 03:21)



So, let us say that the gneissic rock has got bedding planes oriented in this manner. So obviously, the depositional environment was such that the environment under which this particular rock was formed was such that the major principle stress was in this direction. And as I have indicated in the previous lesson, the grain contacts are going to predominantly develop or more contacts are going to develop in the direction of the major principle stress. So, it is going to behave in a much stronger manner in the direction of the major principle stress. So, so that gives the answer.

This particular specimen of rock is thus going to behave in a much stronger manner if you consider the strength perpendicular to the bedding direction as opposed to the direction parallel to the bedding planes. The third question was explain why folding becomes more prevalent with depth compared to faulting.

(Refer Slide Time: 04:57)

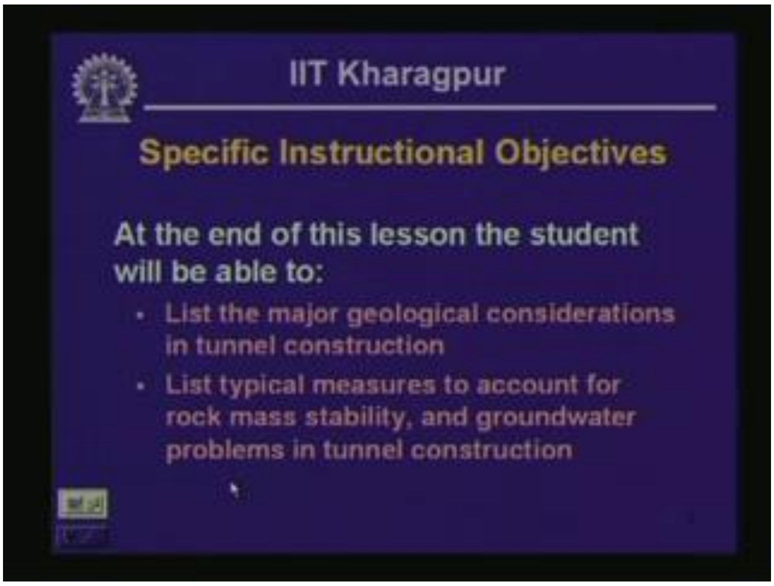


And this is something to do with the brittleness of the stress strain behavior of rock and what we have seen from previous lessons is that a rock is going to behave in a brittle manner provided the confining pressure is low; that means the rock is at a shallow depth below the surface of the earth. Then the second important aspect is that the temperature should also be low, and the third aspect here to consider is application of stress is relatively rapid. So, all these aspects are going to lead to a brittle behavior of the rock mass.

So, you look at the first two bullets here, and it will be obvious that if a rock specimen is near the surface of the earth, it is going to behave in a brittle manner because the confining pressure is low, and also the temperature is low near the surface. And temperature in fact, starts mounting up as the depth increases. For instance, if you go down to a depth of a kilometer or so, then the temperature over there is going to be about 30 degrees Celsius more than the temperature at the surface of the earth.

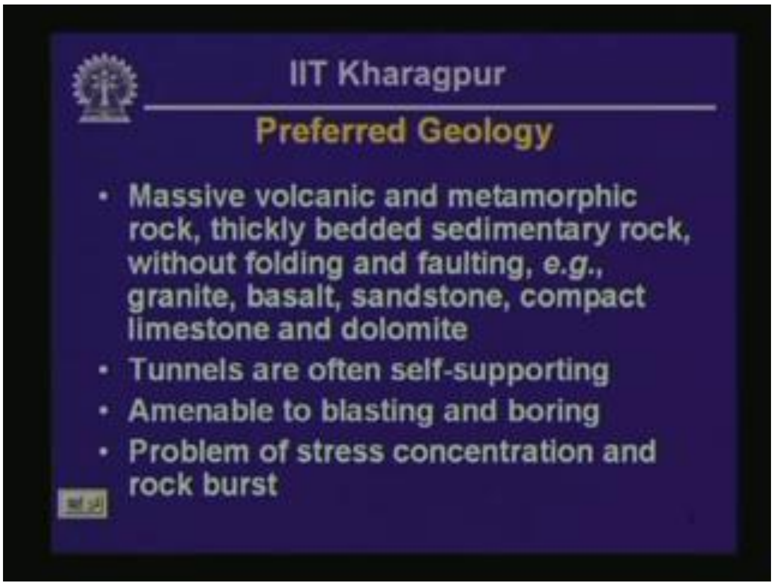
As a result of which if the same type of rock is occurring at a great depth a few kilometers below the surface of the earth, then it is going to behave in a much more ductile manner compared to the specimen which is near the surface. So, all these reasons are pointing towards the fact that we are going to get a brittle behavior when we have got we are considering an element near the surface. And because of the fact that brittle behavior leads to faulting and ductile behavior on the other hand leads to folding rather than faulting; we get more faulting near the surface of the earth, and the amount of faulting becomes less and less prevalent as the depth becomes more and more. So, those are the three answers to the questions of the previous lesson.

(Refer Slide Time: 08:06)



Now, we move on to today's lesson. What we want to accomplish at the end of today's lesson are as follows. We would like to be able to list the major geological considerations in tunnel construction. And we should be able to list the typical measures to account for various types of instability because of the rock mass behavior and because of ground water during the construction of tunnel and operation of tunnel.

(Refer Slide Time: 08:41)



So, first of all what comes to mind is what is a preferred geological setting to construct a tunnel. And if you try to just look at the problem logically, then it would appear that if you have got a very strong mass of rock which is relatively free from joints or other structural features like shear zones or faults or rather fractures, it is relatively free from bedding or lamination. Then that is going to give us a very ideal situation to construct a tunnel.

Now this if you construct a tunnel in that kind of geological setting, then such tunnels are going to be often self-supporting; the tunnel can be constructed by either blasting or boring. But here you have to account for a certain type of problem and that is associated with stress concentration, because in this case the rock mass is relatively strong. So, it is going to attract quite a large concentration of stress particularly near the corners of an underground excavation, and such concentration of stress could in fact become so large that under that amount of stress, the rock mass is going to fail in an often explosive manner, because strong rocks are often brittle.

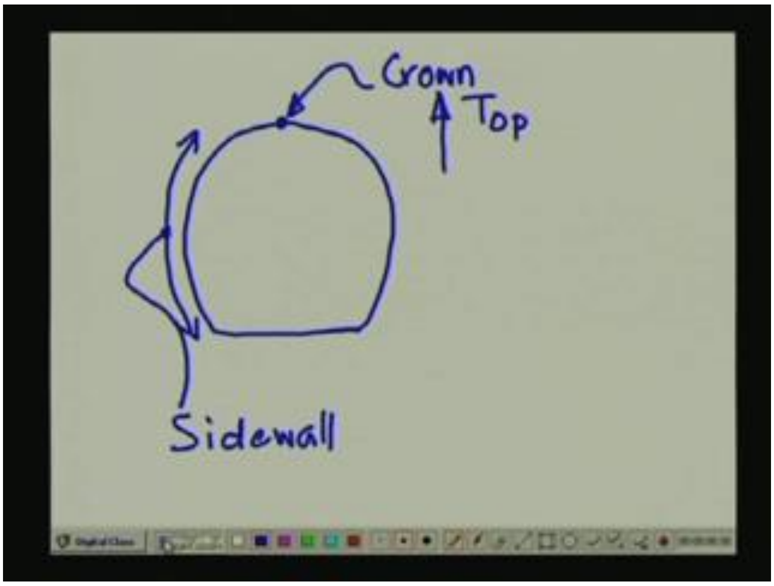
So, they are going to fail in an explosive manner, and what is going to end up in is a phenomenon called rock burst, okay. So, that gives us a preferred geological setting, but a preferred geological setting is not often the case, and what we are left with is a much worse situation than the ideal conditions that we just now discussed.

(Refer Slide Time: 10:46)

So, let us say you have to construct a tunnel through soft or jointed rocks. The condition here is typical of a terrain of clay stones, shells; brittle or poorly-compacted sandstone is just like cemented sand, in fact, is very soft. So, if you take a small piece of friable or poorly-compacted sandstone. Then under finger pressure the sandstone is going to crumble; it is so soft. Then chalk is another of those soft or jointed rock species. Limestone, dolomite, phyllite, slate and rock mass; all types of rock species that are crisscrossed with relatively closely spaced joints folds and faults are in this category.

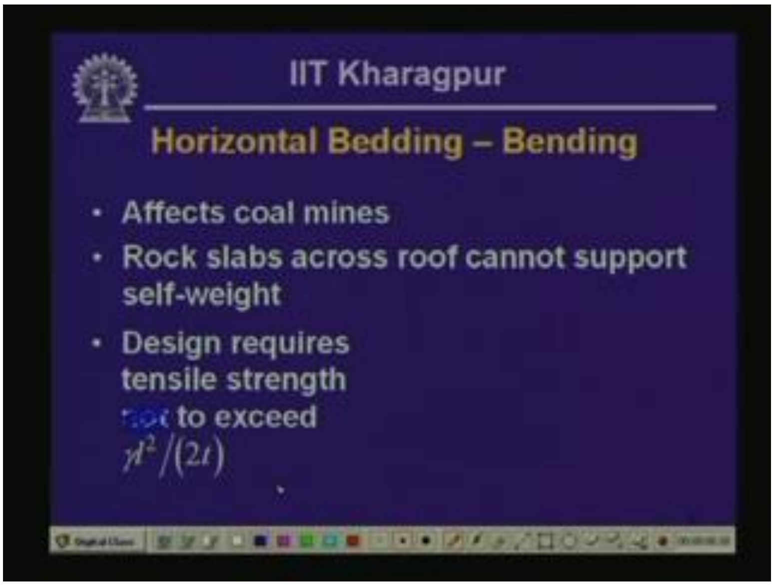
Now if you have got a rock of this type, then the tunnels that are going to be constructed the tunnel walls, in fact, are not going to be self-supporting. So, more often than not we are going to be set with the problem of designing some measures in order to stabilize the possible failure mechanisms along the walls of the tunnel. Now the problems here are related to the crown and sidewall stability, swelling and squeezing of rock and problems related to groundwater. Now two new terms are appearing here. Let me illustrate those two terms with the sketch.

(Refer Slide Time: 13:03)



So, let us say you have got a tunnel like this; I am drawing the cross section of the tunnel. So, this is towards the top. So, this point is called the crown of the tunnel, and this is the side wall that I alluded to in the previous slide, okay. So, we are likely to have some problems of rock stability, stability of rock mass near the crown and sidewall if the tunnel is to be constructed through soft or jointed rock. Now we are going to look at the problems that are typically encountered in greater detail as we run through this lesson.

(Refer Slide Time: 14:07)

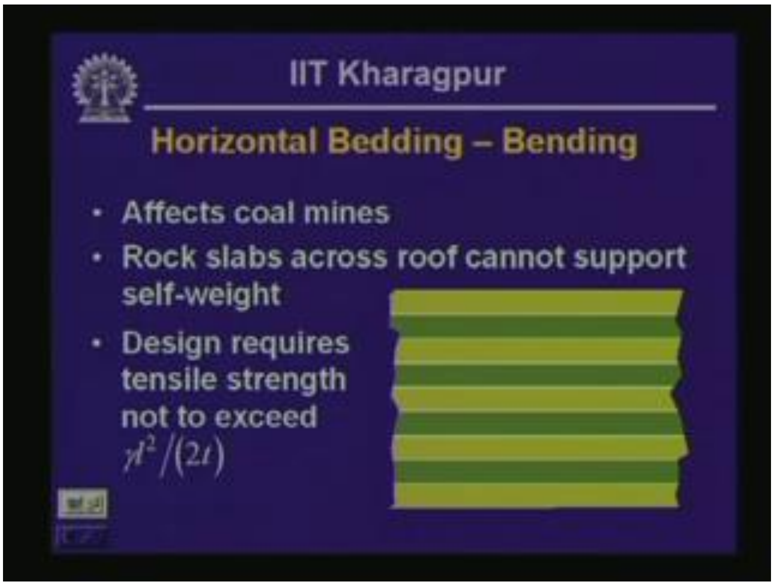


Okay, the first problem that we consider here is related to a tunnel constructed through a bed rock mass which has got horizontal bedding plane. Now here the structural nature of the problem is dictated by bending failure by tension caused by bending. This clause of problem is quite often encountered in coal mines. What happens because of this is that rock slabs across the roof cannot support its self-weight, because it wants to bend, and it wants to sag and because the sagging, in fact, becomes so large that tension cracks develop near the bottom of the slab. And as a result the slab could fail.

Design requirement in this case is that the tensile strength of the rock actually requires the tensile strength to exceed, not to exceed; actually I should remove this word here. So, it is not not to exceed, but it is to exceed. The design requires that the tensile strength should exceed gamma l square by 2 t where t is the thickness of the rock slab at the roof of the tunnel; l is the span is the width of the tunnel, and gamma is the total unit rate of the rock slab, okay.

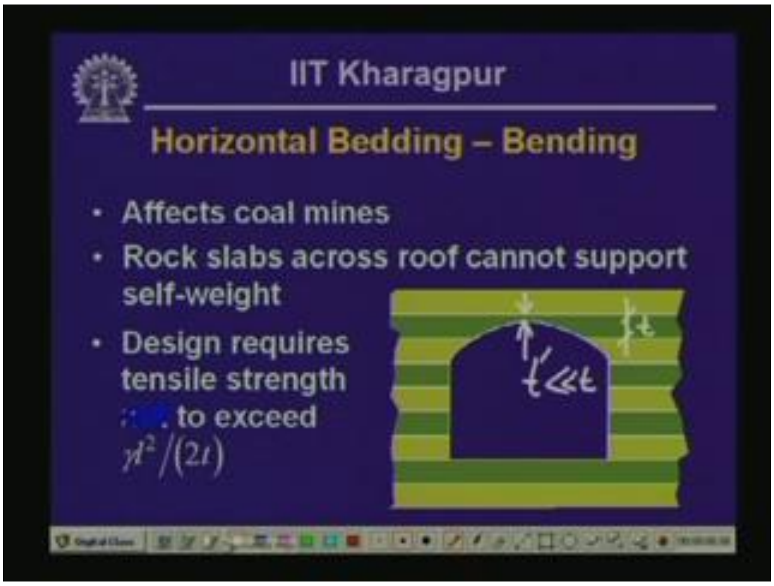
So, if the tensile strength is more than the quantity gamma l square by 2 t, then the slab at the roof of the tunnel is going to remain stable in this case. Now let us look at the failure; you should have noticed that I wiped off the word not. So, you should take a note of that. When I come back to the slide show it is again going to appear, but you should correct your notes accordingly. So, let us look at an animation which illustrates the type of failure in this case.

(Refer Slide Time: 16:45)



So, what we have got here is a horizontally bedded rock, and we are trying to construct a square tunnel. And you can see as soon as the opening is made, then the slab near the roof of the tunnel is going to sag.

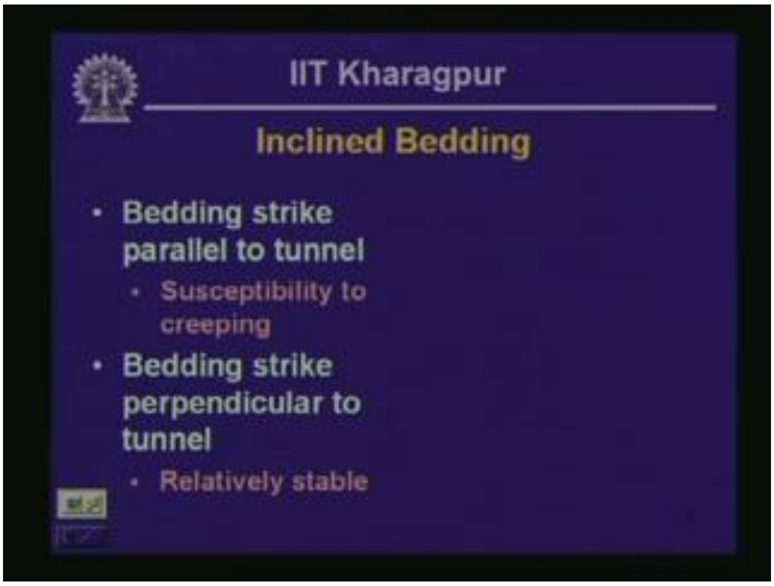
(Refer Slide Time: 17:06)



And these are the dimensions that are indicated on the equation on the expression there at the bottom of the slide there. So, t is the thickness as I have already indicated, and l is the span or the width of the tunnel. So, basically what is preferred in this particular case and that is often adopted in design is that a square cross section of the tunnel is often preferred is because if you have got a square cross section, then the slab near the tunnel the roof of the tunnel is not likely to lose any thickness. And as a result the stability is going to be much more if you have got a square cross sectional tunnel.

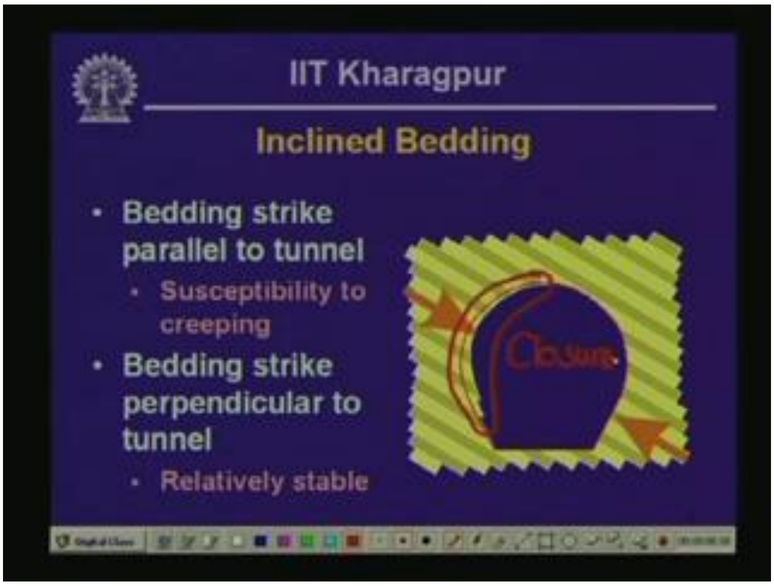
Now compare that with another tunnel which has got this type of geometry. Here what you see is that the thickness the thickness of the rock slab which is supposed to self support its rate; that thickness has reduced considerably over the thickness of the bedding originally. As a result the stability of this slab near the crown is going to be compromised quite severely if this type of tunnel cross section is chosen. So, the bottom line is in this case a square cross section of the tunnel is preferable.

(Refer Slide Time: 19:01)



The second type of problem that we consider here is related to inclined bedding. So, what we are going to consider here are two cases. In the first case the bedding strike is parallel to the tunnel. And the second case we are going to consider when the bedding planes strike perpendicular to the tunnel. The first option is more susceptible to difficulties during the construction and operation of the tunnel. And the second option in which the strike of the bedding planes is parallel to the tunnel provides a relatively stable configuration. In order to illustrate this I am going to show another animation.

(Refer Slide Time: 20:01)

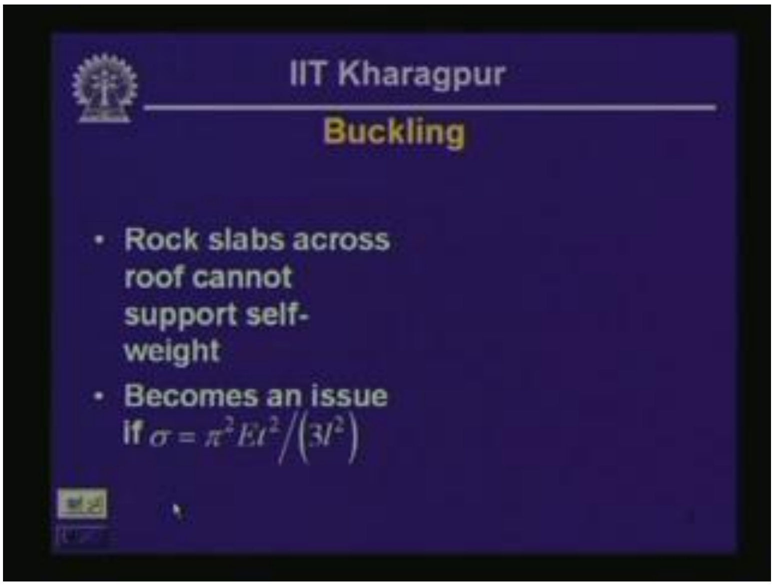


Now let us say we have got a tunnel constructed through a bed rock for which the bedding planes are inclined in that manner. And let us consider in this case the major principle stress has got the directions indicated by orange arrows. What is going to happen as soon as the opening is made because of the direction of the major principle stress? The rock mass within bedding planes they are going to try to squeeze into the tunnel and this is particularly a case in case of tunnels constructed through ductile rock and what you are going to end up with is a situation like this.

So, here you can see that the portion which is to the top left of the tunnel alignment, we are again looking at the cross section of the tunnel. So, the portion which is towards the top left of the tunnel is closing into the tunnel, and this kind of a problem is called closure. So, what if we superpose the original tunnel cross section, then what we get is a situation like this.

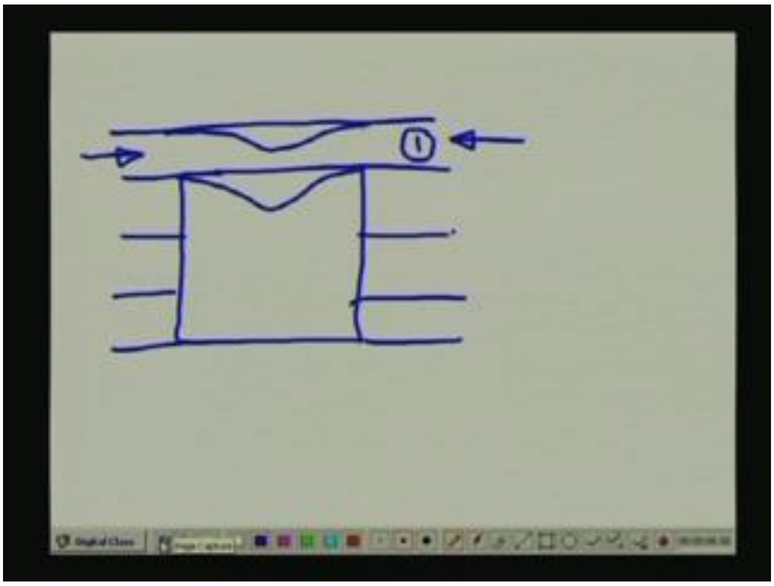
So, basically this portion here is affected by the problem of closure. This cross section is taken from a real life problem. There recently a head race tunnel was constructed approximately more than 27 kilometers long head race tunnel was constructed in Himachal Pradesh as part of a project called Nathpa Jhakri. It is a project in which a 60 meter high dam was constructed for power generation, and the head race tunnel was affected by a problem which is illustrated in that animation of the previous slide. Here the rock that was transected by the tunnel was basically phyllite and which is a ductile type of rock, and the tunnel was affected by closure as well as another type of problem which we are going to see a little bit later on.

(Refer Slide Time: 23:16)



Then the third problem that we are going to get in case of tunnel constructed through a rock which is laminated and the laminations are inclined. In this case actually the slabs they cannot support the self-weight as was the case when we were discussing the horizontal bedding, but the problem is accentuated because of the direction of the major principle stress or the confinement or the confining stress. And if you recall there will be a confining stress, and if I want to illustrate this problem let me draw a sketch here to illustrate the problem.

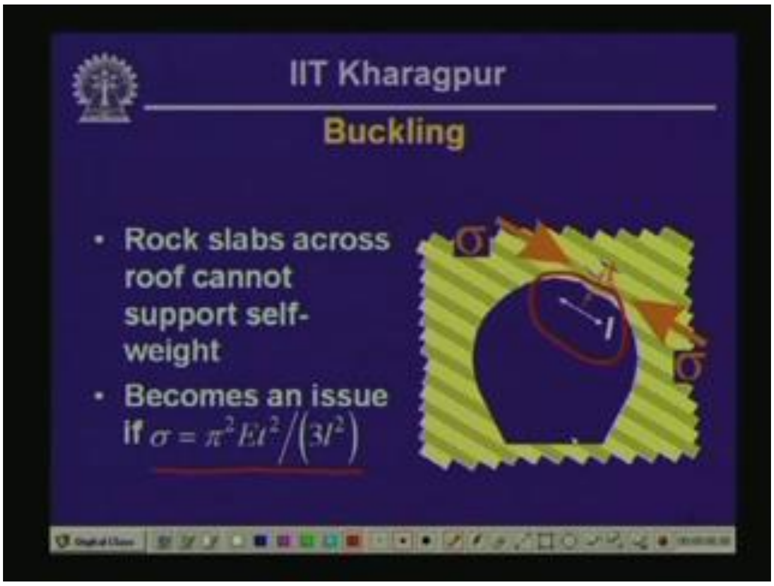
(Refer Slide Time: 24:15)



Let us say you have got a tunnel with a cross section like this, and the tunnel is constructed through horizontally bedded bed rock. And what we are going to get in this case if the self rate for this slab number one becomes too large, then it is going to sag as we have seen in one of the previous slides. Now if in addition to it we have got large horizontal pressure acting on this particular slab, then you can easily notice that the problem of sagging is going to get accentuated. And this may actually become so severe that the slab near the top of the tunnel is going to fail in this process.

Now we are going to illustrate this problem with another animation. And this is the same tunnel that we are looking at when we were talking about squeezing in because of large in-plane compressive stress in the previous slide and let us see what happens in this case.

(Refer Slide Time: 25:47)



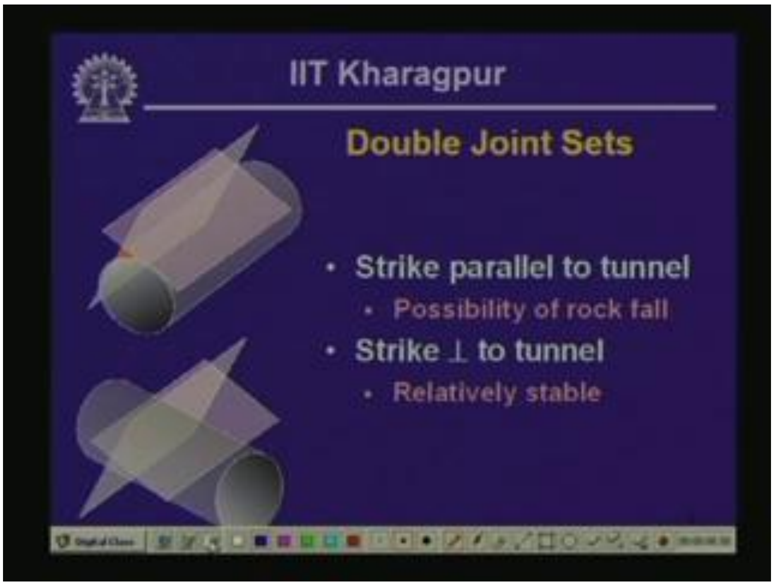
So, we are looking at the same tunnel, in fact, as in the previous case. And here again I have marked the direction of the major principle stress but by thick orange arrows. And it is quite obvious that as soon as the tunnel opening is made, then the slabs are going to buckle in that manner because of the removal of confinement near the top right portion of this particular tunnel. So, that is the area where the tunnel is going to be affected by buckling problem.

So, what is happening here is that because of the excavation of the tunnel, the confinement to the rock slab has been removed. And because of that the rock slab can no longer resist the buckling tendency that arises because of the presence of the pressure, the in plane compressive stress sigma, and consequently, the slab buckles into the opening. This becomes an issue when you have got sigma equal to pi square E t square over t3 l square. And in this case E is the deformation modulus of the rock slab that we are considering; T is the thickness of the rock slab. And pi is the constant 3.14, and l is the unsupported span of the slab which is shown; all these dimensions are shown on the cross section near the right of this particular slide.

Now if sigma is less than the value calculated on the right hand side, then there is no problem; if sigma exceeds this value then the possibility of buckling has to be taken care of in the tunnel design or supports have to be designed in order to prevent such occurrences. As I have mentioned that this particular problem was also encountered in the head race tunnel of Nathpa Jhakri project in Himachal Pradesh, in addition to the squeezing in problem that we discussed a few minutes back.

Okay, then we have to look at also the joint sets. How the joint sets are oriented with respect to the alignment of the tunnel, and if you recall joint sets are essentially cracks in the rock mass. Many times they are closely spaced; they follow a regular pattern and all the joints that occur in a parallel direction, we are calling them as one joint set in this case. So, two joint sets means two parallel sets of joints relatively closely spaced parallel sets of joints oriented in an arbitrary direction with respect to the tunnel alignment. Now let us look at the problem that is associated with this type of geologic setting.

(Refer Slide Time: 29:52)

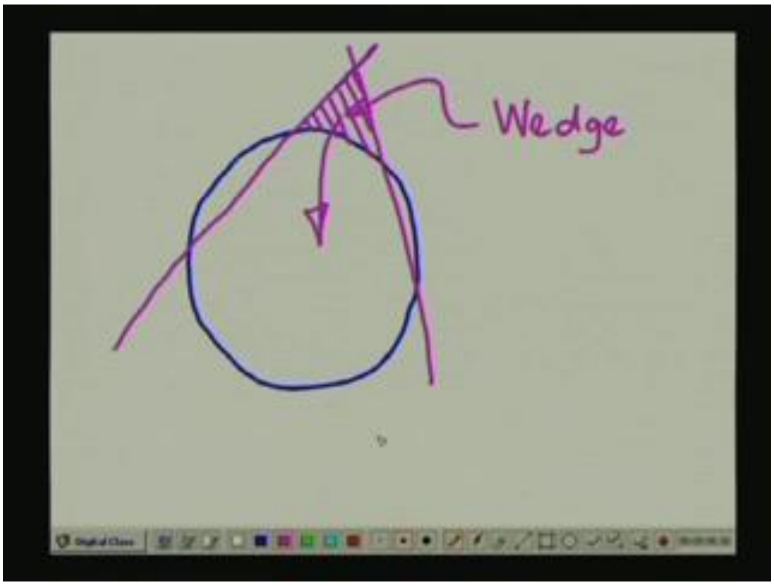


So, here again we are going to consider one tunnel let us say the tunnel alignment is like that, and the first joint set is oriented in that manner, and the second joint set is oriented in this manner. So, both these joint sets are striking parallel to the axis of the tunnel. So, in this case what is going to happen is that shaded area shown by orange shading near the crown of the tunnel is going to be susceptible to failure as soon as the tunnel opening is made.

It is quite obvious we will see the details of this thing once again a little bit later. Now let us consider another possibility in which the tunnel is oriented in a direction perpendicular to the previous tunnel. If you have got the same joint sets as before, then in this particular case for the construction of the tunnel no particular instability is going to be expected.

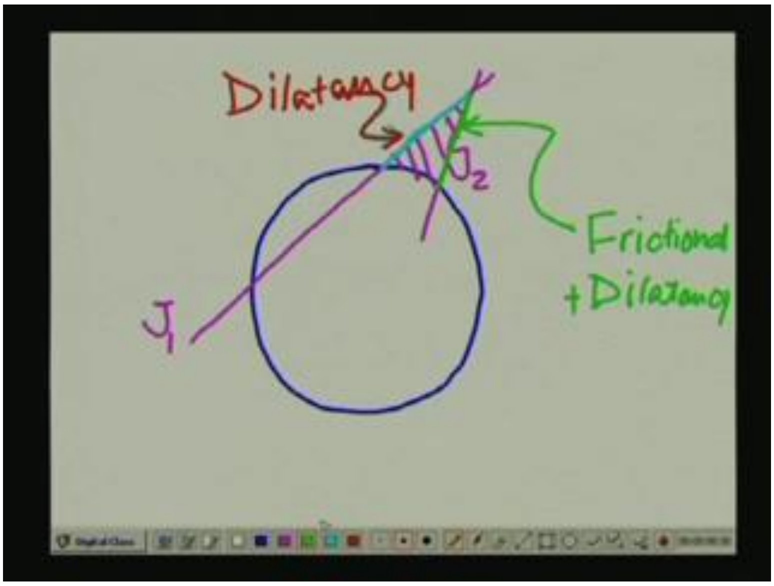
So, to summarize what we talked in this particular problem involving double joint sets. If you have got strike of the joint sets parallel to the tunnel then you should consider the possibility of rock-fall, and if you have got a strike perpendicular to the tunnel then you are going to have a relatively stable configuration. Let us look the first point in a little bit greater detail.

(Refer Slide Time: 31:42)



Let us say you have got a tunnel with a circular cross section as we considered in the previous slide, and you have got one joint set which is oriented in this manner. Then as soon as the tunnel opening is made then this particular wedge of rock, this particular wedge is going to fall over into the opening that is made. Now there is another possibility that is this is not always going to be the case, because we could have a joint set that is oriented in a different manner.

(Refer Slide Time: 32:39)



Let us say you have got a tunnel alignment like that, and the joint set is oriented in this manner. This is joint set one, and that one is joint set two. Then you cannot always say whether this particular wedge is going to be susceptible to falling over into the tunnel opening, because the frictional strength of the bottom surface of the joint and the dilatancy along the top surface of the joint the strength because of dilatancy near the top surface of the joint. So, dilatancy here and at the bottom you are going to have a frictional strength plus dilatancy.

So, these two factors are going to contribute to the stability of the wedge, and it may so happen that the wedge is going to be inherently stable, and it is not going to be susceptible to fall over into the opening at all.

(Refer Slide Time: 34:23)

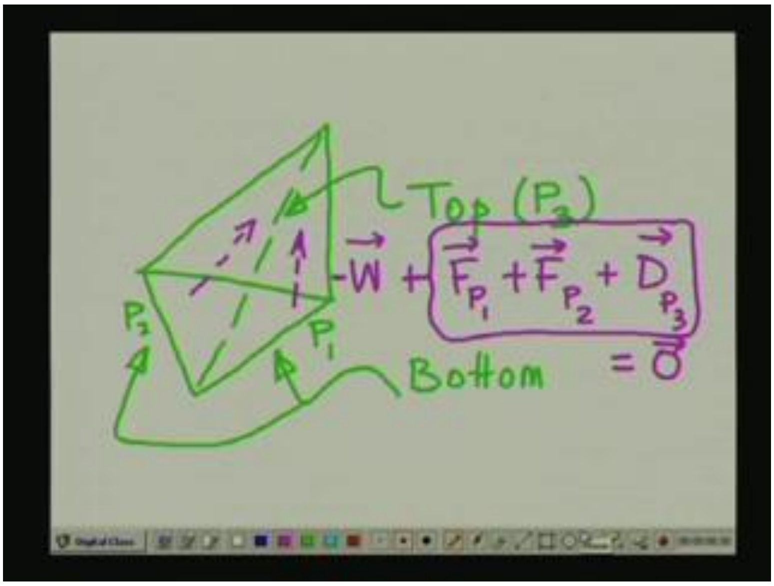
We are going to consider this one using the problem involving multiple joint sets in this particular slide. Now like what you had in case of two joint sets, you could have a tunnel alignment where there are more than two joint sets, and the problem here essentially from the stand point of mechanics is quite comparable to what we discussed in the previous case. Here you might have actually rock wedges falling from the roof of the tunnel or there could be wedges falling into the tunnel by sliding from the sides of the tunnel from the sidewall of the tunnel. And those two problems are illustrated with the two sketches near the bottom right of this particular slide.

So, here what we have is this is the tunnel cross section; this is the tunnel opening, and this is the falling wedge. This type of wedge is called falling wedge, and if the wedge wants to slide into the tunnel from the side then it is generally called a sliding wedge. Now as a designer your problem is to assess the stability of falling wedge and sliding wedge. So, considerations are essentially the same as we discussed in the case of two joint sets in the previous slide involving joints striking parallel to the tunnel alignment.

Now here you have to consider the orientation average depth and dip direction of all the different joint sets that are going to generate a possible sliding or falling wedge. And then from that using the concept of Mohr-Coulomb stability you are going to assess whether a particular joint is going to behave in an unstable manner, or it is going to behave in a stable manner; it is going to remain inherently stable.

And then finally, if you find that in some cases you have got the problem of possible instability of involving falling wedge or sliding wedge then you have to support these potentially unstable wedges. Now, let us look at this thing a little bit in greater detail.

(Refer Slide Time: 37:51)

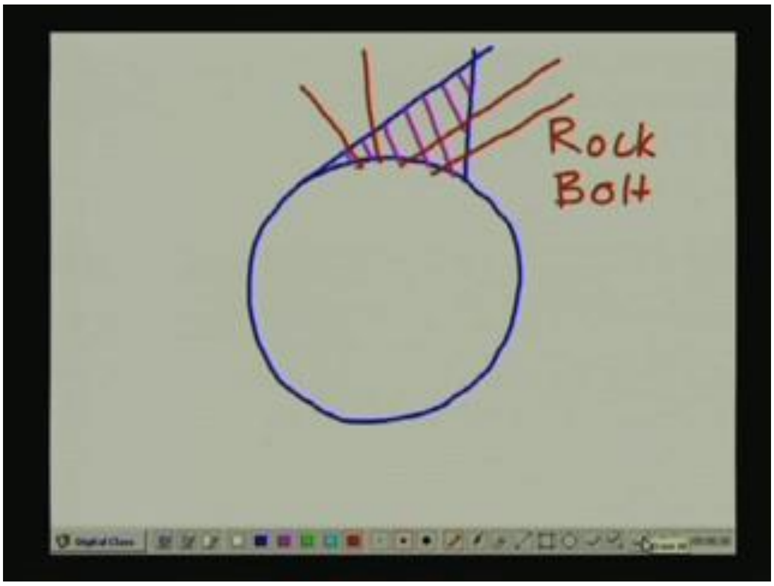


Now let us say you have got a sliding wedge like this; we are looking at the face of the tunnel wall. So, this is the top surface of the sliding wedge and the bottom surfaces of the sliding wedge are not visible actually from this angle. I am drawing an isometric here. So, these are the two bottom surfaces. So, this particular wedge is going to be if it has to remain stable, then you have to consider the frictional resistance that is going to get mobilized on those three planes and these actually two planes. So, this one here is a plane one, the bottom left plane is plane two, and the plane at the top let us call it plane three.

So, you are going to estimate the frictional force on plane one, then frictional force on plane two and the resistance, because of all these things is going to be vectorial. They are vectorial quantities and the resistance because of dilatancy along plane three vector sum of those three resistances is going to be if you add rate of the wedge to it, then what you should get is a null vector. Then this particular wedge is going to remain stable. Now if these three quantities, when you add these three quantities, then if it exceeds the weight then also the wedge is going to remain stable; otherwise, this particular wedge is going to become unstable.

So, here you have to consider the unit normal to the directions of the three planes p 1, p 2 and p 3, and these are the tunnel alignment in order to compute the stability of this particular wedge. Now if you find that the wedge is going to be unstable then what do you do?

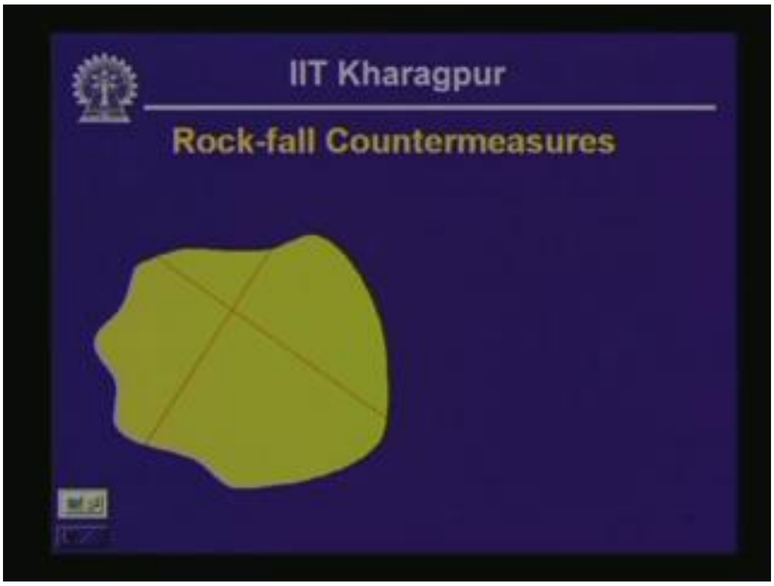
(Refer Slide Time: 41:10)



Let us illustrate this problem using a simpler configuration. Let us say lets revert back to the problem of the two joint sets striking parallel to the tunnel alignment, and let us assume that based on the principle of mechanics we have assessed that the wedge which is cross hatched with the purple color there is unstable. Then what could you do is to install rock bolts in this manner in order to stabilize this particular wedge and prevent it from falling into the tunnel opening.

Now also what you have to design is what these individual rock bolts are going to, what work load these individual rock bolts are going to carry. So, these are rock bolts and also what is the length of each one of these rock bolts. So, that is one of the counter measures often used in order to stabilize the problem of falling or sliding wedges.

(Refer Slide Time: 42:39)



Okay, now rock-fall counter measures we discussed very briefly in the previous slide. So, let us say we have got two joint sets; we have got a rock mass with two joint sets like that.

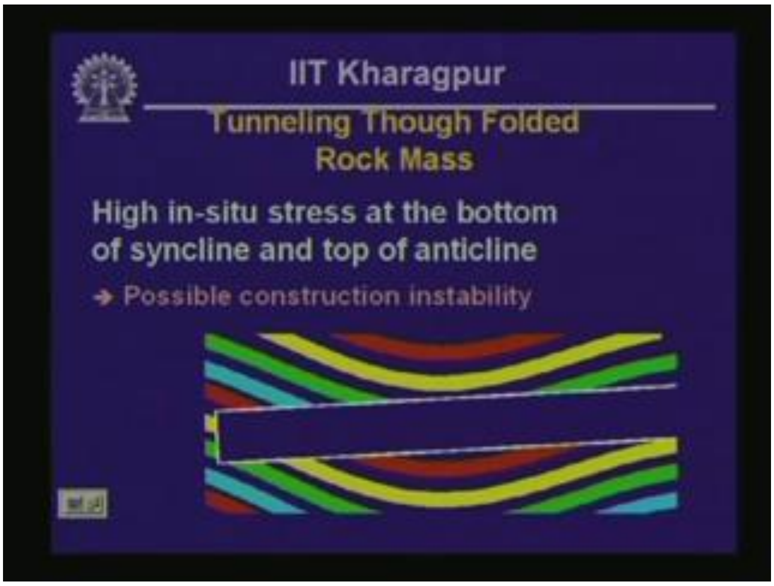
(Refer Slide Time: 42:49)

And we are going to construct a circular tunnel of that of that fashion. So obviously, in this particular case the wedge near the crown of the tunnel is going to be susceptible to falling over into the tunnel opening. And in this case we can stabilize actually this problem of falling wedge by installing rock bolts as we have just now discussed.

(Refer Slide Time: 43:23)

Now, another case which is the case involving involving a squid orientation of the wedge. Now here as I have indicated that the wedge is not always going to be unstable. You have to assess first whether the wedge is going to be stable or unstable. If you decide that the wedge is going to be unstable, then you can install rock bolts in order to stabilize this particular wedge from falling into the tunnel opening, okay.

(Refer Slide Time: 44:09)

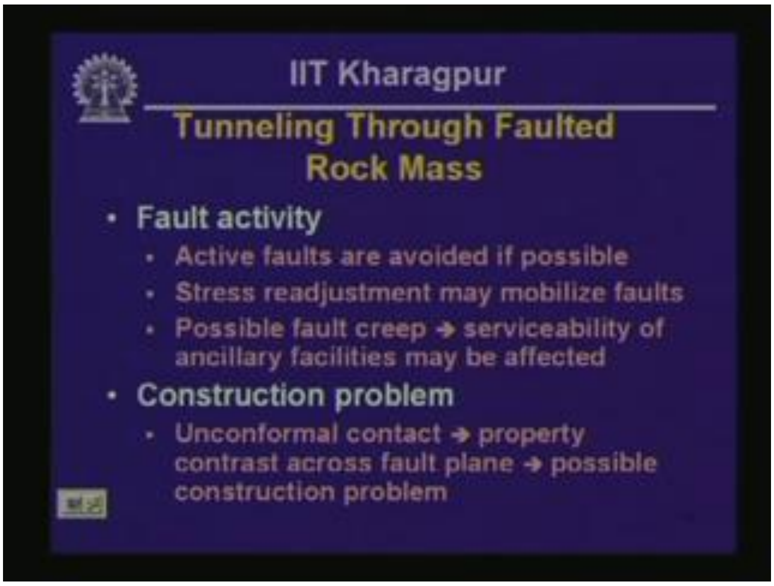


Then what we are going to consider now is tunneling through folded rock mass. Now if you recall the the presentation of previous earlier lessons then what we have discussed that there is a strong dependence of the in-situ state of stress and the regional topography. And we have indicated that the in-situ stress at the bottom of a syncline actually increases several folds may be three times over the value dictated in a horizontally bedded area. And consequently, that increased state of stress is going to affect the stability of tunnel construction as we are going to see in the next little bit.

Now what is going to happen let us say if you have got a tunnel being constructed through a fold of that type shown at the bottom right of this particular slide. If you recall your previous lessons then this type of fold is in fact an anticline. Now here in this particular case what you are going to get is a much larger stress near the crowns of these folded layers. As a result you are going to encounter difficulties; you might actually encounter difficulties of rock-fall problems associated with rock-fall as the increased stress is released when the tunnel opening is made while crossing these folded layers.

You could have similar problem in case of a syncline fold. Now here as we have discussed is the vertical stress near the bottom of the fold is going to be the largest, and that is true for each one of the layers that we have seen on this particular slide. So, this localized increased value of stresses you will have to be considered when the tunnel alignment is decided and the stability issues of the tunnel wall is addressed, okay.

(Refer Slide Time: 46:53)



Now, we have looked at the problem associated with the tunneling through folds. Now let us look at the problems that you might encounter in case of construction of tunnels through faulted rock mass. So, the problems are essentially of the following types. You have to consider the activity of the fault whether the fault has been active in recent past or not. Active faults are typically avoided during construction of tunnels if possible, and if possible is the key word there, because often times what happens you have to construct a tunnel through faults which have been active over relatively recent geologic past, say, over a few hundred years or few thousand years.

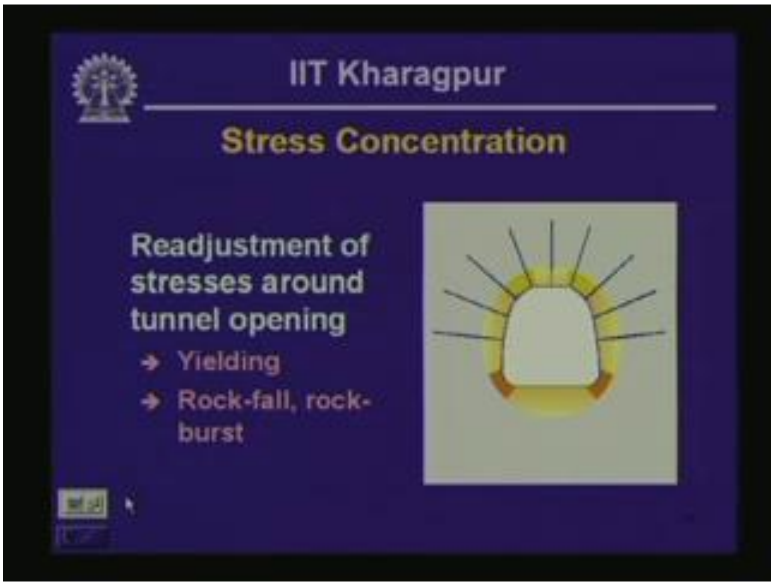
In that case you have to account for the possible movement of the fault in the design of the tunnel itself. The second aspect related to fault activity is that the stress readjustment because of the tunnel opening itself may mobilize faults. And that is indeed a case in case of very deep underground mining operations, and it has been seen in many cases in operations of hard rock mines which can go a few kilometer, say, two to three kilometers below the earth surface. And in those situations the readjustment of stress because of the construction of tunnel opening or underground openings to accommodate mines facilities could be so large.

They in fact have mobilized previously inactive faults which crisscross that area in which the mines are constructed in a systematic manner. So, this particular fault movement actually can generate earthquakes and those earthquakes are so near to that mines operation that they are quite hazardous from the point of view of the safety of the tunnels. So, mine induced seismicity is a big problem of tunnel stability in case of deep underground mines operating in hard rock areas.

Now you have to also account for possible fault creep; although, the fault is not failing by a sudden movement, it could actually creep because of the removal of support or confinement in the process of construction of a tunnel opening. And this particular problem could actually lead to the difficulty of operation of ancillary facilities such as operation of railways to cart out mind material inside the tunnel opening. And this particular problem could be very severe incase of underground mines that operate over a relatively large number of years.

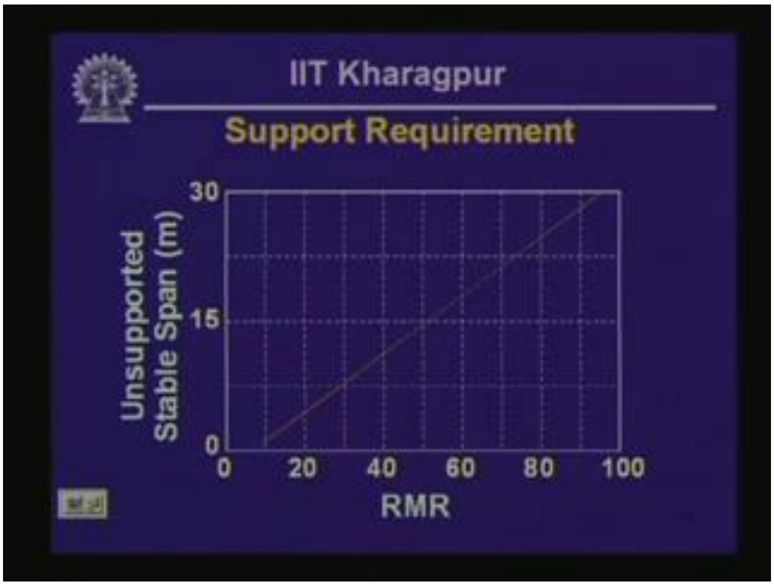
Then construction problem might arise in case of construction of tunnels through faulted areas, and in this case the problem is essentially involves because of the fact that faults are unconformal contacts in which the rock mass on either side of the fault plane; they could be of remarkably different stiffness and strength characteristics construction or boarding of the tunnel through such areas itself could be very difficult and needs to be specially taken care of during the planning of the construction of tunnel itself.

(Refer Slide Time: 51:36)



Okay, stress concentration is another issue that should be tackled while designing a tunnel. Readjustment of stresses around tunnel opening over and above its background value which developed over because of geologic processes may lead to yielding rock-fall and rock-burst. We discussed these topics previously. So, I am not going to get into the details of these things right now.

(Refer Slide Time: 52:15)



Now support requirement is an issue that needs to be tackled; it becomes apparent that in jointed rock mass, you have to support the possible unstable blocks of rock around the tunnel opening. So, assessment of support requirement is another issue tackled by engineering geologists and tunnel designers. Here I have shown a simple plot between rock mass rating and unsupported stable span of an underground permanent opening. And what you can see is that as the rock mass rating increases a large length can be left unsupported without any necessity to provide any particular support in order to stabilize the rock mass. That actually illustrates one of the applications of rock mass rating that we have considered sometime back.

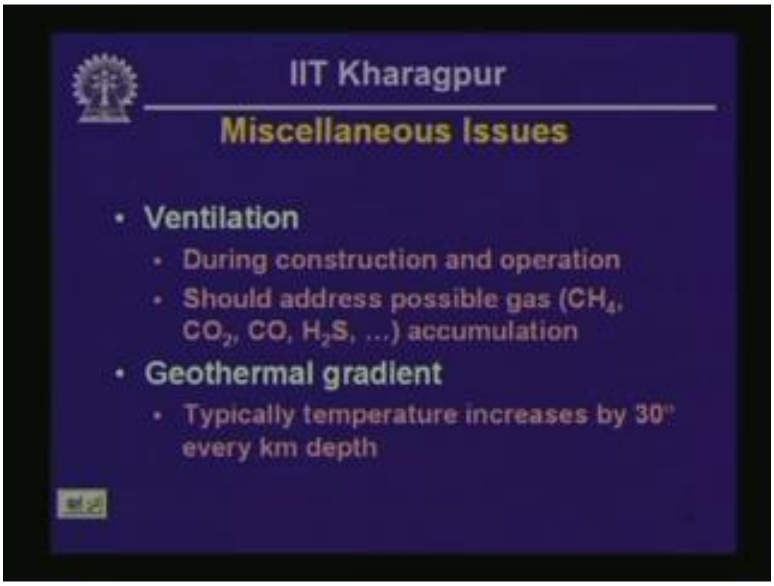
(Refer Slide Time: 53:31)

Tunnel supports, what type of tunnel supports we can have? We could install frames of steel and timber inside the tunnel opening, and that is going to support the possible unstable blocks on the roof and the sidewall of the tunnel we could install rock bolts as we have seen or we could install liners. They include shotcrete, concrete or steel liners which are actually all in close contact along the entire surface of the tunnel wall with the surrounding rock. And because of the contact these measures they provide stability to the possible unstable rock mass near the wall and roof of the tunnel.

(Refer Slide Time: 54:23)

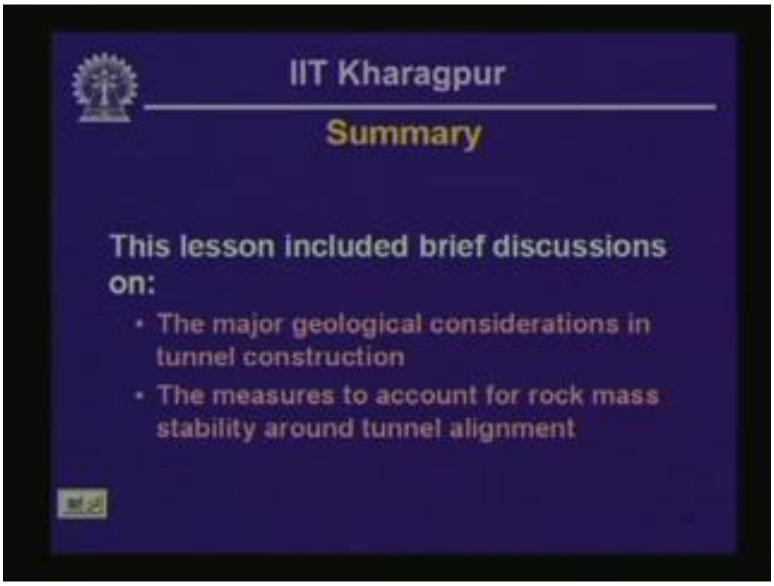
Groundwater issue is another issue tackled by engineering geologists while designing a tunnel. This issue particularly arises in case of alignment that is near water bearing permeable rock layers, seepage and interception and dewatering becomes a problem here. And particularly if the rocks are fractured and highly permeable you have to also consider groundwater chemistry in this case. If you have got acid rock drainage in sulfate bearing rocks that is a possibility, then that could actually lead to accelerated weathering of the rock near the wall of the tunnel and consequently reduction of rock strength. Sulfates are another problem because if you use concrete lining in case of a tunnel where groundwater is sulfate rich, then the concrete may deteriorate.

(Refer Slide Time: 55:35)



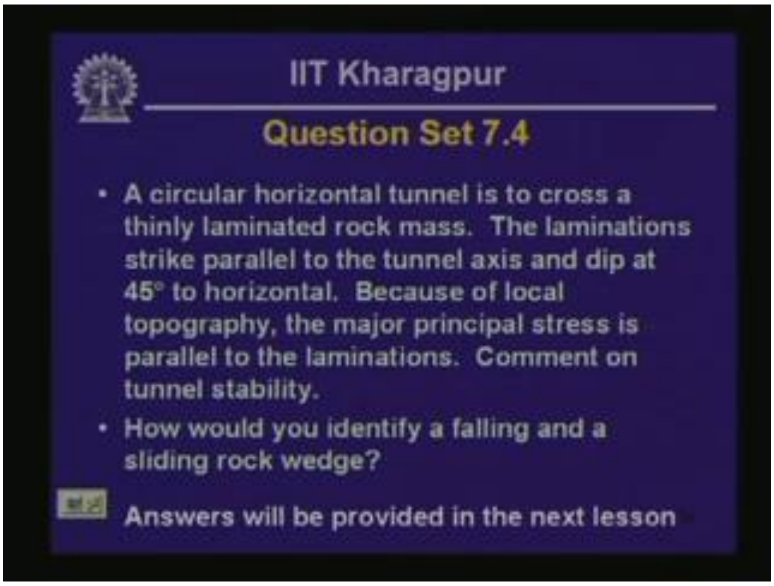
There are other issues that need to be considered. One issue is involving ventilation; gases could escape in to the tunnel. These things have to be appropriately taken care of. And then geothermal gradient has to be taken care of while designing a tunnel facility, because as we have discussed typically temperature increases by about 30 degree Celsius for every kilometer depth.

(Refer Slide Time: 56:09)



To summarize this particular lesson, what we discussed here are major geological considerations in tunnel construction, and we looked at the measures to account for possible rock mass instability around a tunnel alignment.

(Refer Slide Time: 56:27)



Now to wrap things up here is the question set. Try to answer these questions at your spare time. And the first question is, a circular horizontal tunnel is to cross a thinly laminated rock mass. The laminations strike parallel to the tunnel axis and dip at 45 degree to horizontal. Because of local topography the major principal stress is parallel to the laminations. Comment on tunnel stability. Second question, how would you identify a falling and a sliding rock wedge? Try to think over these solutions. I am going to give you my solutions when we meet with the next lesson. So, until now bye for now.

Thank you.