Rock Mechanics and Tunnelling
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Lecture 46
Rock Support Systems

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Hello everyone. I welcome all of you to the 5th lecture of Module 9. So, in Module 9, we are discussing about the foundations and rock support systems. So, in the previous four lectures, we have basically discussed about foundations and today is the last lecture of this module. So, today, we will discuss about the rock support systems.

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So, what are the things we will cover today, like first we will start with the introduction, then purpose of natural support, different types of natural supports. Then classification of natural supports, then pillar design approach. Okay, so, these are the things we will cover today. And finally, we will discuss briefly about the pillar failure and at the end, we will solve a problem.

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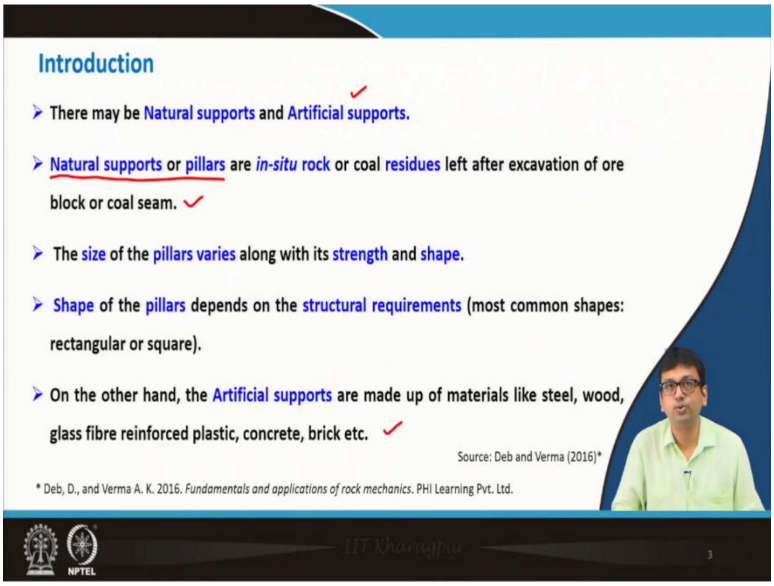

There may be natural supports and artificial supports. Now, what is natural support? So, these natural supports or the pillars (these are also known as pillars) are in-situ rock or coal residues left after excavation of ore block or coal seam. So, natural supports or pillars or in-situ rock or coal residues left after excavation of ore block or coal seam. The size of the pillars varies along with its strength and shape.

Now, shape of pillars depends on the structural requirements like most common shapes are like rectangular or square. Now, on the other hand, the artificial supports are made up of materials like steel, wood, glass fibre reinforced plastic, concrete, brick, etc.

So, as we can see, the natural supports or pillars are in-situ rock or coal residues left upon excavation of ore block or coal seam and on the other hand, artificial supports are made up of materials like steel, wood, glass fibre reinforced plastic, concrete, brick, etc.

So, in this part of our lecture, we will mainly focus on the natural supports or pillar and regarding artificial support, we will discuss about these different support systems in our last module, i.e., in our 12th module. So, today, we will focus on the pillars on natural supports.

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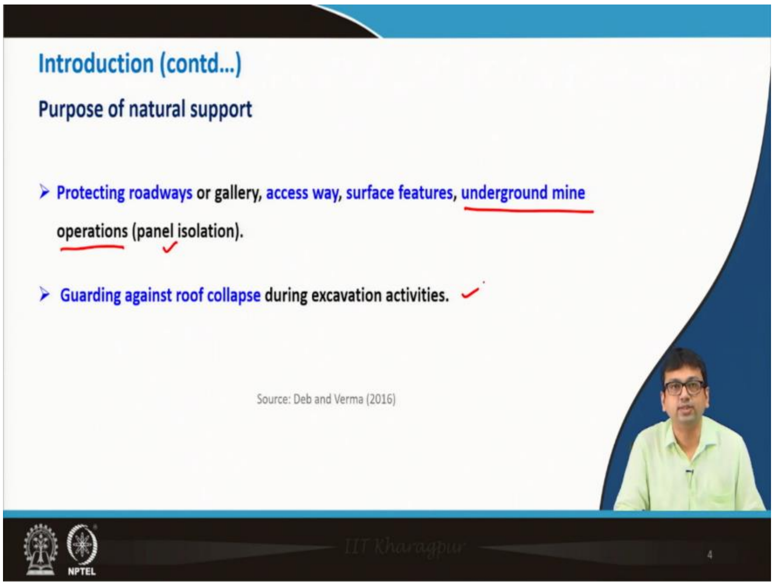

Now, purpose of natural support. (The natural support will come into the picture in the context of mining engineering). So, the purpose of natural support, (1) protecting roadways or gallery, access way, surface features, underground mine operations like panel isolations (i.e., underground mine operations like panel isolation).

Also guarding against roof collapse during excavation activities. So, when we are going for the underground excavation, at that time, there may be a chance of roof collapse. Then, these natural supports or pillars are used as safeguard. So, guarding against roof collapse during excavation activities.

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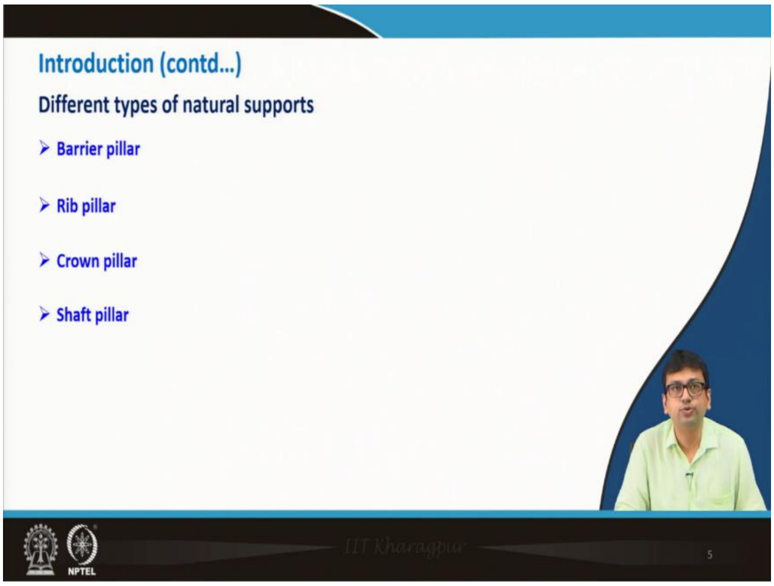

Now, different types of natural supports or pillars are like barrier pillar. So, this barrier pillar is generally used for the panel isolation. Other than that, few other pillars are like rib pillar, then crown pillar is also there, then shaft pillar is there. Shaft pillar is used for protecting the permanent structures like the shaft. Hence, these are the different types of pillars or natural supports.

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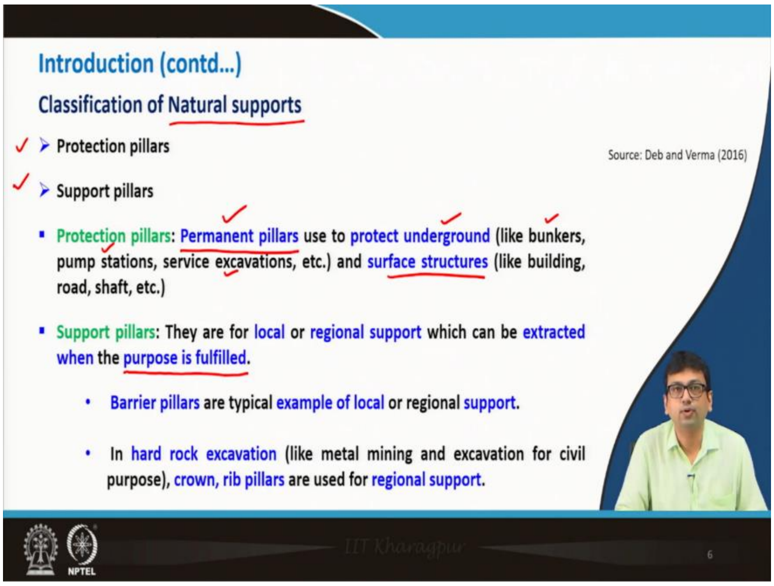

Now, the classification natural supports, now these natural supports or pillars may be classified into two categories broadly, protection pillars and support pillars.

Now, the protection pillars are the permanent pillars used to protect underground structures like bunkers, pump stations, service excavations, etc. This is used to protect underground and surface structures. Under surface structure what are there? like building, roads, shaft, etc. So, these are the permanent pillars which are used to protect underground and surface structures.

And another one is support pillars. The support pillars are there for local or regional support which can be extracted when the purpose is fulfilled.

For example, barrier pillars are typical example of local or regional support because as I have mentioned earlier that it is used for the panel isolation. So, once the mining operation is done at a particular location, then the barrier pillar is of no use and it can be removed. Likewise, in hard rock excavation like metal mining and excavation for civil purpose like tunnelling, the crown pillar and rib pillars are used for regional support.

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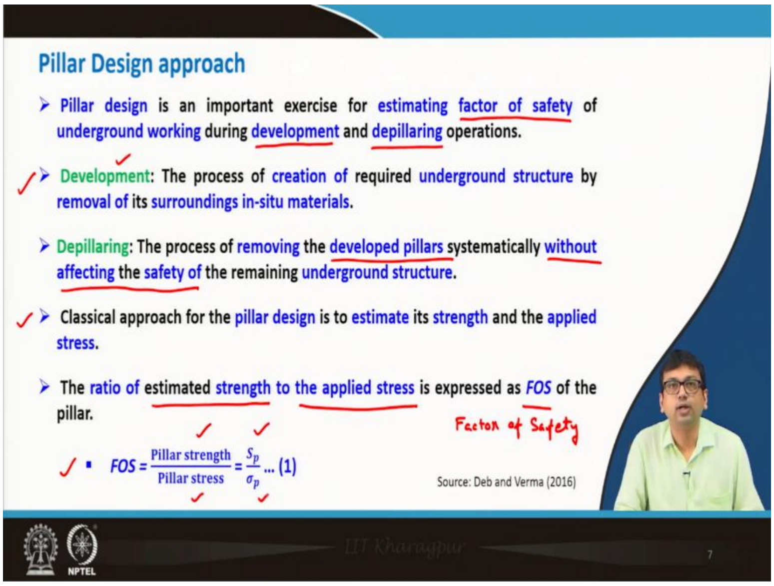

Now, pillar design approach. The pillar design is an important exercise for estimating factor of safety of underground working during development and depillaring operations. So, this is very important and that is why, we need to learn the design approach. Now, what do you understand by development and depillaring?

So, these two terms are new for us. So, the development means the process of creation of required underground structure by removal of its surrounding in in-situ materials. So, that is development. Now what do you understand by depillaring?

So, now, depillaring is the process of removing the developed pillars systematically without affecting the safety of remaining underground structure. So, without affecting the safety of remaining underground structures.

Now, classical approach for pillar design is to estimate its strength and the applied stress. So, this is a classical approach. Now, what is this factor of safety? Basically, the ratio of estimated strength to the applied stress is expressed as factor of safety of the pillars. So, *FOS* is the factor of safety.

So, *FOS* = (Pillar strength / Pillar stress). Here, S_p represents the pillar strength and σ_p represents the pillar stress.

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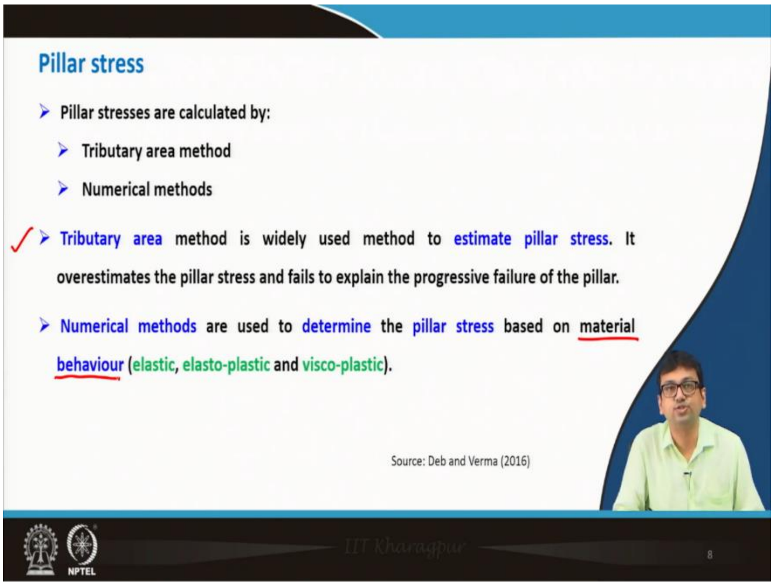

Now, let us understand the pillar stress. Pillar stress are calculated by tributary area method and numerical methods. Now, tributary area method is widely used method to estimate the pillar stress and it is very simple approach, but it overestimates the pillar stress and fails to explain the progressive failure of the pillar. It is one of the disadvantage of tributary area method. However, it is a widely used method. On the other hand, numerical methods are used to determine or estimate the pillar stress based on material behaviour.

So, the material behaviour means the elastic, elasto-plastic and visco-plastic, all these material behaviours are taken into consideration. Hence, it is much rigorous, but on the other hand, the tributary area is very simple approach and that is why, it is widely used.

But if we want to go for more accurate and robust analysis, then obviously we have to go for the numerical methods where the pillars stress is determined based on the material behaviour. However, here, we will mainly focus on the tributary area method.

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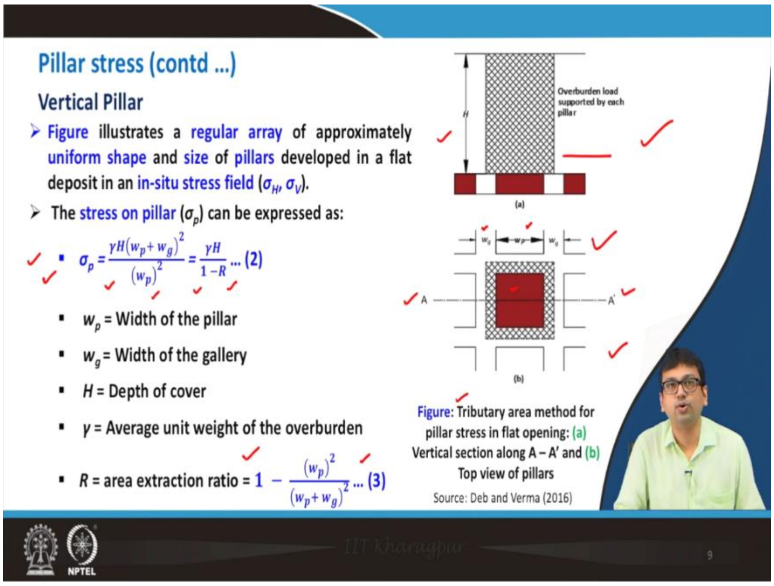

Now, refer to the figure for the vertical pillar. The figure illustrates a regular array of approximately uniform shape and size of pillars developed in a flat deposit in an in-situ stress field, σ_H, σ_V. Now, look at this figure little carefully, what is stated here, tributary area method for pillar stress in flat opening: (a) the vertical section along A – A' and (b) Top view of the pillar.

So, Figure (b) is the top view and Figure (a) is the vertical section along A – A'. So, this is what we can see from over here. Now, it is written over Figure (a) that the overburden load is supported by each pillar. So, the pillars are clearly visible and we are quite clearly understanding the things.

According to this configuration, the stress on pillar, i.e., σ_p as I have mentioned earlier. Now, $\sigma_p = \frac{\gamma H (w_p + w_g)^2}{(w_p)^2}$, where γ is the average unit weight of the overburden, H is the depth of cover as shown in the figure, w_p is the width of the pillar, and w_g is the width of the gallery.

And again, we can see that the equation is also written in this form, i.e., $\sigma_p = \frac{\gamma H}{1-R}$, where R is known as the area extraction ratio which is equal to $1 - \frac{(w_p)^2}{(w_p + w_g)^2}$.

So, basically, $\sigma_p = \frac{\gamma H (w_p + w_g)^2}{(w_p)^2}$ and $\sigma_p = \frac{\gamma H}{1-R}$ both are same if we place R as $1 - \frac{(w_p)^2}{(w_p + w_g)^2}$, we will get $\sigma_p = \frac{\gamma H (w_p + w_g)^2}{(w_p)^2}$. So, we are learning about a new term, R known as the area extraction ratio. So, we will use this equation to find out the stress on pillar for vertical pillar.

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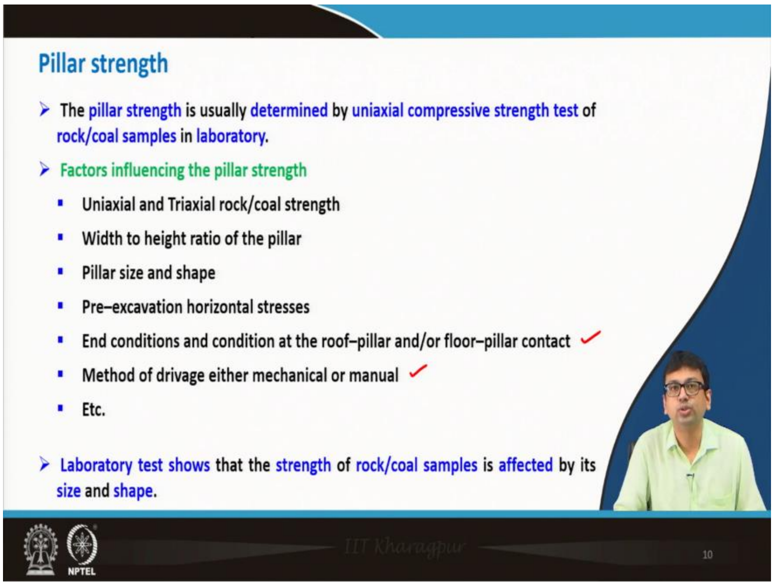

So, here, we are discussing about the vertical pillars only. There may be other types of pillar like inclined pillars but we will not discuss about them. We are restricting our discussion to the vertical pillars only. Now, the pillar strength. We have learnt how to find out the pillar stress. Now, the pillar strength is usually determined by uniaxial compressive strength test of rock or coal samples in laboratory. Now, factors influencing the pillar strength are like uniaxial and triaxial rock / coal strength. Then, the width to height ratio of the pillar.

Then pillar size and shape. Then the pre-excavation horizontal stresses which can affect the pillar strength. Also, the end conditions and condition at the roof-pillar and/or floor-pillar contact. Also, the method of drivage either mechanical or manual. Pillar strength will depend on this also. And, etc. So, these are the some of the factors which affects the pillar strength. Now one important thing is that the laboratory test shows that the strength of rock/coal samples is affected by its size and shape.

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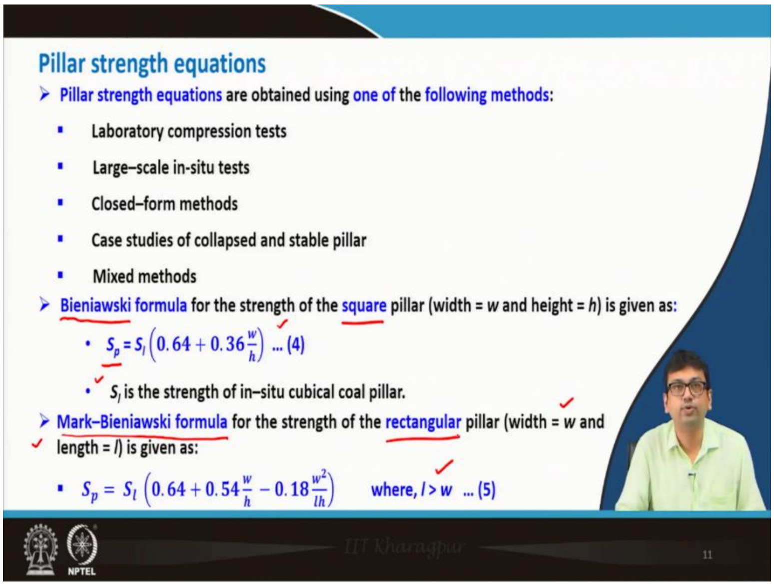

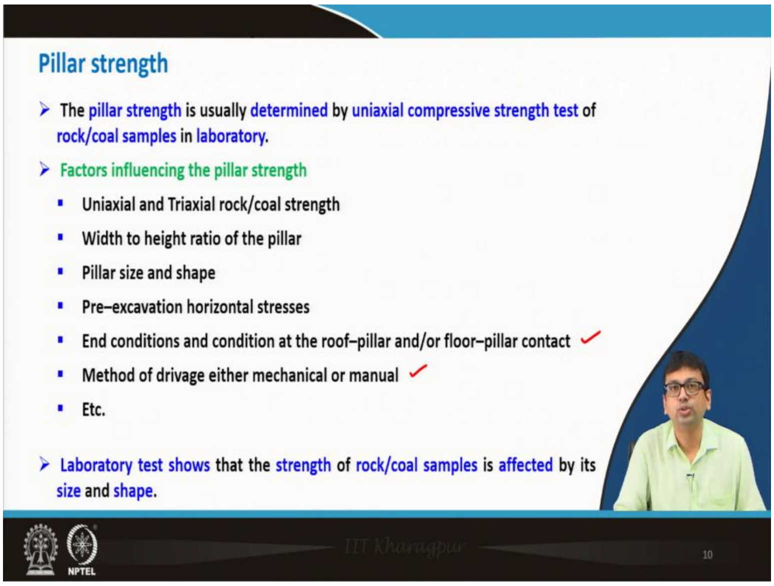

So, we have learnt about the pillar stress equations. Now, we have to learn the pillar strength equations, then only we will be able to design. So, the pillar strength equations are obtained using one of the following methods like laboratory compression test, large scale in-situ tests, closed form methods, case studies of collapsed and stable pillar, and also the mixed methods.

So, the pillar strength can be derived based on these five methods. There are different equations provided by different researchers. So, Bieniawski formula for strength of the square pillar: $S_p = S_l\left(0.64 + 0.36\frac{w}{h}\right)$. So, this is this equation for strength of the square pillar, where w is the width of the pillar, h is the height of the pillar, and S_l is the strength of in-situ cubicle coal pillar. S_p is the pillar strength and the factor of safety (*FOS*) is equal to $\frac{S_p}{\sigma_p}$. We have already understood how to estimate the stress on vertical pillar, i.e., σ_p.

This is the equation for the strength of square pillar. Now as I mentioned in the first slide that the rectangular pillars are also quite common. So, we need to know the equation for rectangular pillar also. Mark and Bieniawski formula for strength of a rectangular pillar: $S_p = S_l\left(0.64 + 0.54\frac{w}{h} - 0.18\frac{w^2}{lh}\right)$, where w is the width of the pillar, l is the length of the pillar, and l is greater than w.

There should not be any confusion between H and h. H is the depth of the cover, but h is the pillar height. So, these two equations will be useful when we will solve the problem. So, we have already learnt how to find the pillar stress and the pillar strength. So, we are in a position to find the factor of safety.

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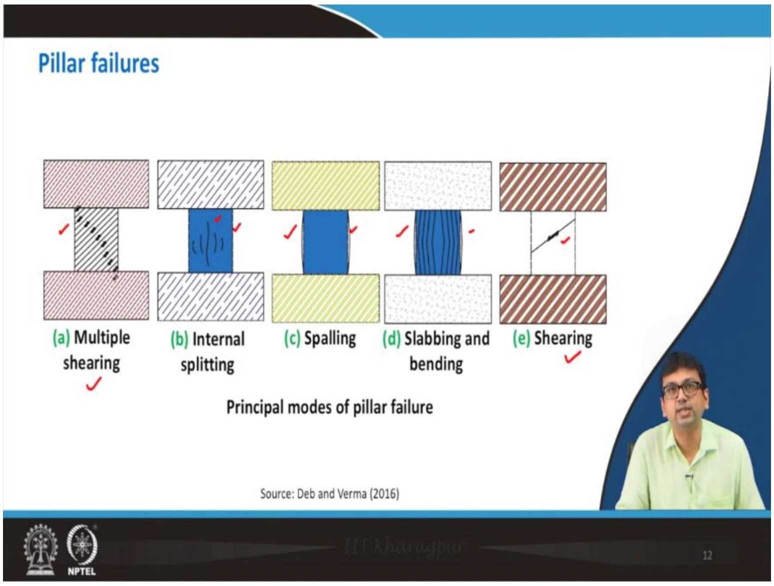

So, we will solve a problem but before that, another small thing let us discuss that is the pillar failure. So, basically, these are different modes of pillar failure. So, principal modes of pillar failure. So, in the diagram, we can see five modes of pillar failure. First one [i.e., (a)] is multiple shearing.

So, if you look at over here you see, multiple shearing whereas it is the only shearing [i.e., (e)] where you can see that only one shear zone is developing. But, in the case of multiple shearing, multiple shear zones are developing. Likewise, there may be another modes of pillar failure. So, now here we can see internal splitting.

So, if you look at here very carefully, you can see internal splitting we can observe. Now here, we can see little bit of bulging. This type of failure is called spalling and then this one is known as the slabbing and bending. So, we can clearly see that it is bending and the slabs are forming. Hence, it is called slabbing and bending. So, we may observe these types of pillar failure in mines or any other underground excavations, where we go for the natural supports or pillars.

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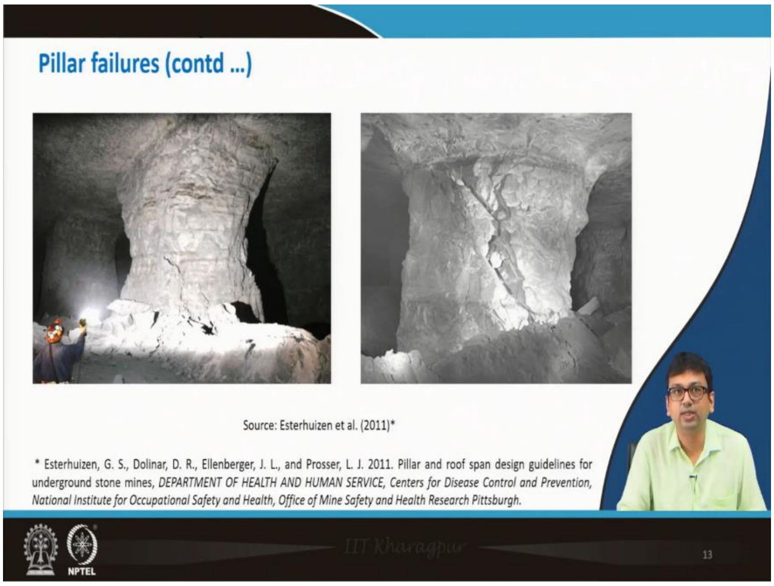

So, just to give you a little bit more idea, I am showing you some of the real pictures which will give you a better feeling. The pictures are taken from inside of a mine. So, here, you can see how the shearing is happening.

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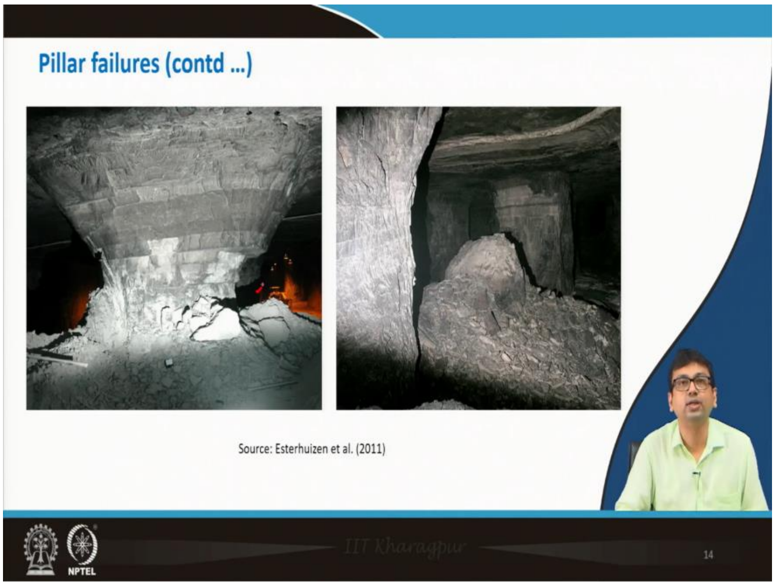

So, some typical diagrams over here. In this case, you can see that the bottom portion of the pillar is failing. It has already seen that the failure debris are there. So, you can clearly notice over here. So, it has failed.

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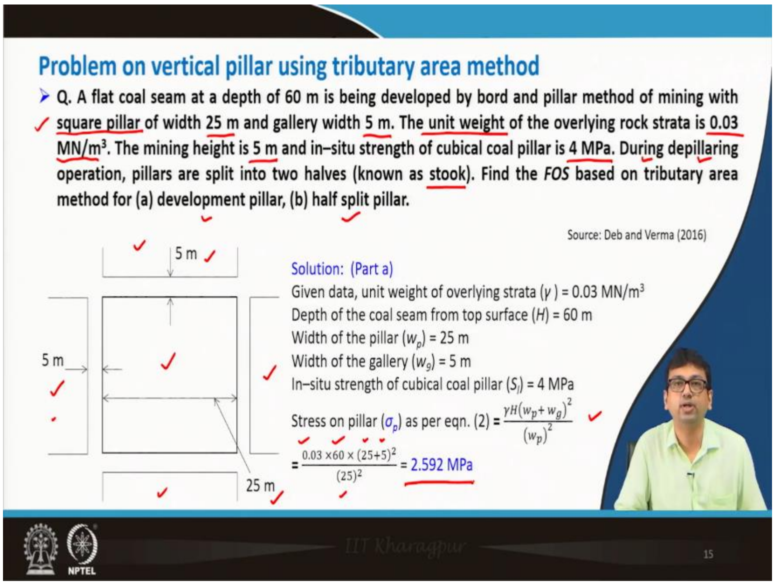

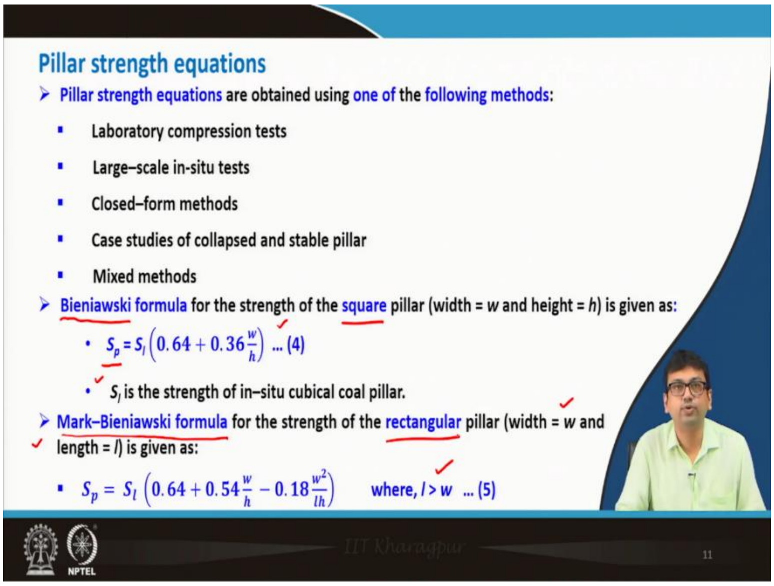

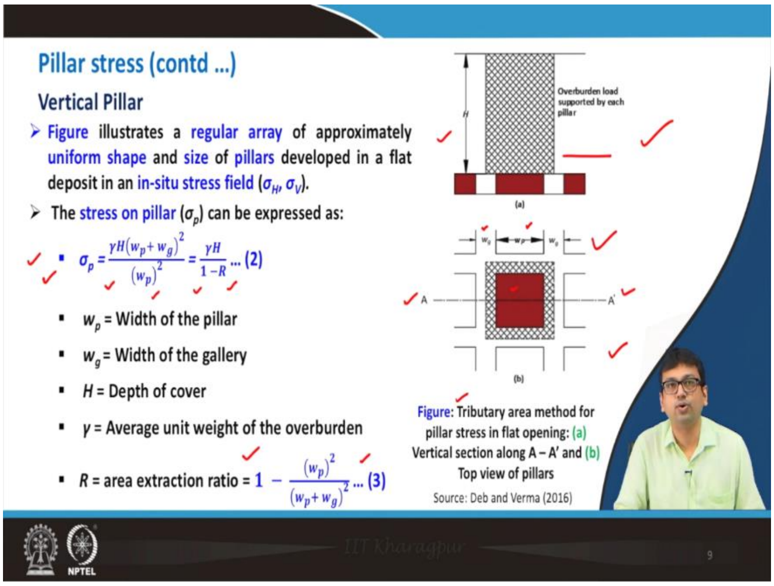

Now, let us take a problem and let us try to understand how to design a pillar and how to find out the factor of safety. So, the problem is on vertical pillar using the tributary area method. Problem says, a flat coal seam at a depth of 60 m is being developed by bord and pillar method of mining with square pillar. So, this is square pillar of width 25 m and gallery width is of 5 m.

The unit weight of the overlying rock strata (γ) is 0.03 MN/m^3 and the mining height is 5 meter, and the in-situ strength of cubicle coal pillar (S_l) is 4 MPa. Now, during depillaring, the pillars are split into two halves (known as stook). So, find the factor of safety based on tributary area method for (a) development pillar and (b) half split pillar.

So, basically what we can see that for the development pillar, the shape of the pillar is square. But, during depillaring operation, pillars are split into two halves. So, the half-split pillars will no longer remain square in shape. It will become rectangular in shape.

You see, the width of the pillar, w_p is given as 25 m and the width of the gallery, w_g = 5 m as shown in the plan view. You can understand that these are the pillars. So, for the (a) part of the problem where the pillar is square. So, the given data, unit weight of overlying strata (γ) = 0.03 MN/m^3 and the depth of coal seam from top surfaces, H = 60 m.

The in-situ strength of cubicle coal pillar which we have represent by S_l in Eq. (4) for square pillar and Eq. (5) for rectangular pillar.

The pillar stress can be expressed as: $\sigma_p = \frac{\gamma H (w_p + w_g)^2}{(w_p)^2} = \frac{0.03 \times 60 \times (25+5)^2}{(25)^2}$ = 2.592 MPa. So, we are getting σ_p as 2.592 MPa.

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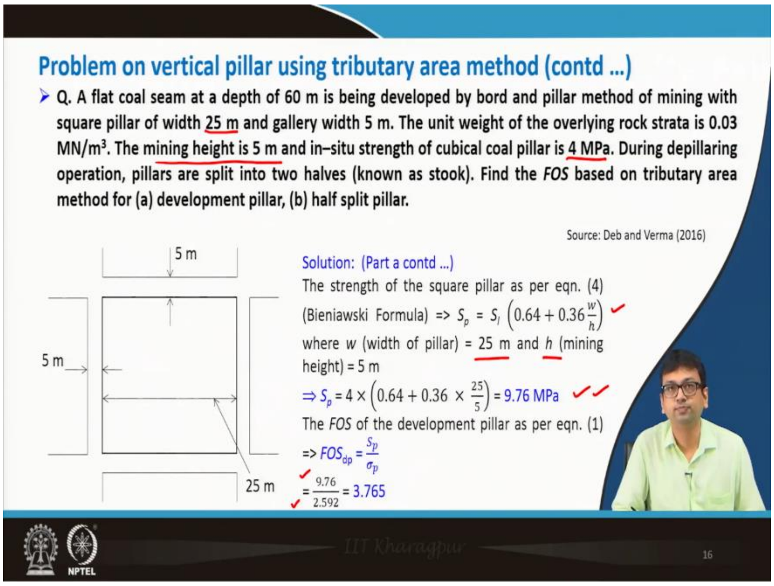

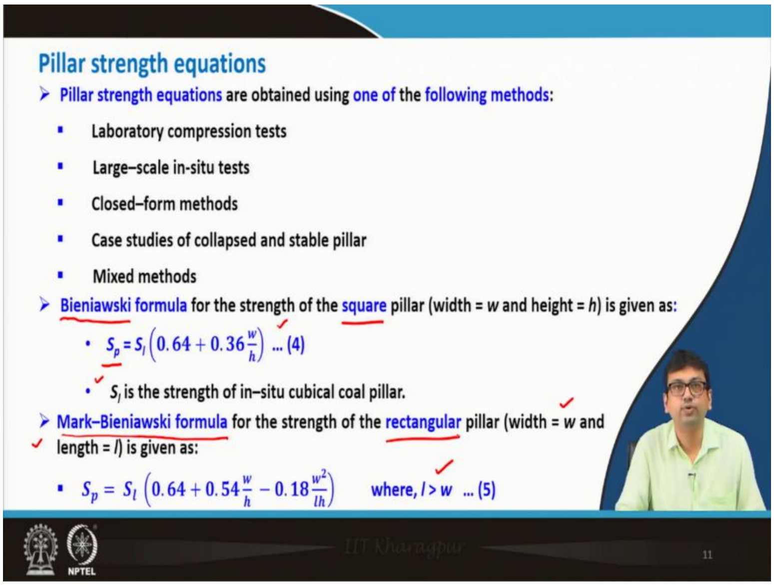

Now, we have to find out the S_p. So, the strength of square pillar as per Eq. (4) will be $S_p = S_l\left(0.64+0.36\frac{w}{h}\right) = 4\times\left(0.64+0.36\times\frac{25}{5}\right)$ = 9.76 MPa. Here, the height of the mine, h = 5 m. So, the S_p will be 9.76 MPa.

So, the factor of safety (*FOS*) of the developed pillar as per Eq. (1) will be: $FOS_{dp} = \frac{S_p}{\sigma_p}$. The subscript 'dp' is written for developed pillar. So, $FOS_{dp} = \frac{9.76}{2.592} = 3.765$. So, we will get the factor of safety = 3.765.

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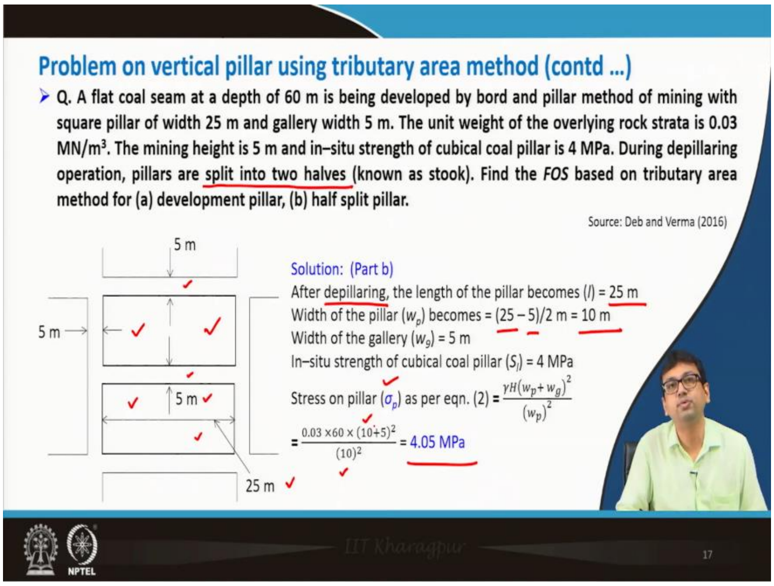

Now, the second part of the problem says to find out the factor of safety for the half-split pillar. Now, we can see the diagram, previously the width of the pillar was 25 m, but now it is half split. So, the pillars are split into two halves.

Now, in between the two newly developed pillar, there is a gallery of 5 meter. So, after depillaring, the length of the pillar (l) becomes 25 m. But, width of the pillar (w) becomes $\frac{25-5}{2} = 10\,\text{m}$. So, the width of the pillar after half splitting (w_p) = 10 m. Width of the gallery (w_g) remains 5 m and the in-situ strength of cubicle coal pillar (S_l) is same as it is given as 4 MPa.

Now, after half splitting, the pillar stress can be expressed as:

$$\sigma_p = \frac{\gamma H (w_p + w_g)^2}{(w_p)^2} = \frac{0.03 \times 60 \times (10+5)^2}{(10)^2} = 4.05\,\text{MPa}$$

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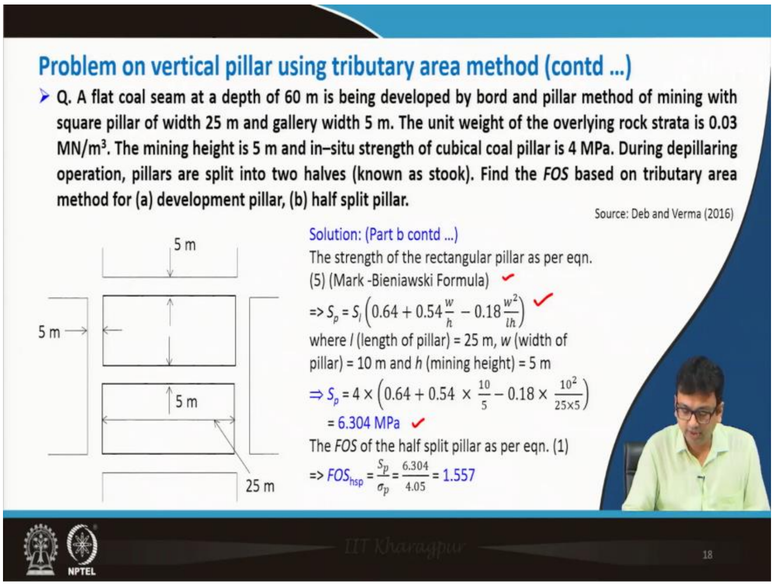

Now, we have to find out S_p. Here, we have to use the Eq. (5) to find out the pillar strength. So, the strength of the rectangular shaped pillar can be expressed as:

$S_p = S_l\left(0.64 + 0.54\frac{w}{h} - 0.18\frac{w^2}{lh}\right)$, where the length of pillar (l) is 25 m, the width of pillar (w) is 10 m, and the mining height (h) is 5 m.

So, $S_p = 4\times\left(0.64 + 0.54\times\frac{10}{5} - 0.18\frac{10^2}{25\times 5}\right) = 6.304\,\text{MPa}.$

So, the factor of safety (*FOS)* is for this half-split pillar is $FOS_{hsp} = \frac{S_p}{\sigma_p} = \frac{6.304}{4.05} = 1.557$. So, by placing S_p = 6.304 MPa and σ_p = 4.05 MPa, we can get the *FOS* for half split pillar as 1.557.

So, what we can see that for half-split pillar, the factor of safety is 1.557 and for part (a), the factor of safety was 3.765. So, it is much higher. However, in the case of depillaring, the pillars are split into two halves. So obviously, factor of safety is definitely going to reduce. So, in the case of square pillar, the *FOS* was 3.765 and in the case of rectangular pillar, the *FOS* has become 1.557.

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So, with this I am concluding our today's lecture, also I am concluding the Module 9. So, thank you.