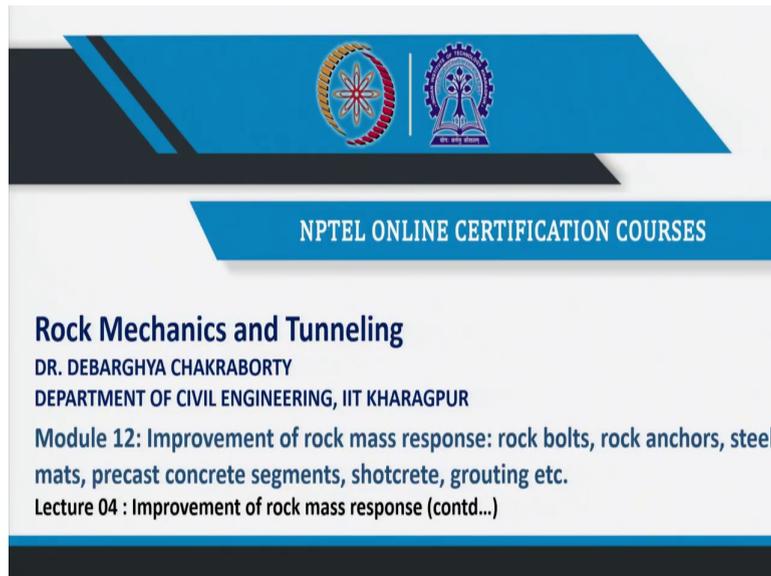


Rock Mechanics and Tunneling
Professor Debarghya Chakraborty
Department of Civil Engineering
Indian Institute of Technology, Kharagpur
Lecture 60
Improvement of Rock Mass Response (Continued)

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

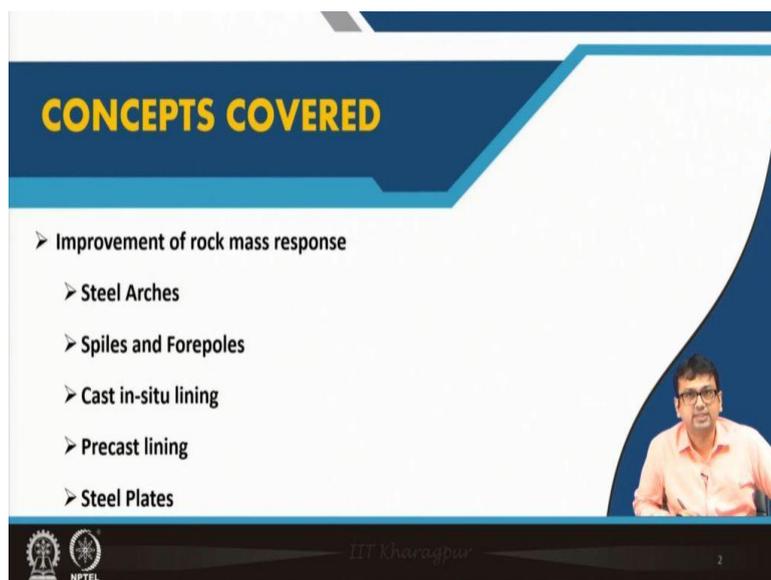
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The slide features a blue header with two logos: the Indian Institute of Technology Kharagpur logo on the left and the NPTEL logo on the right. Below the header, the text reads: "NPTEL ONLINE CERTIFICATION COURSES", "Rock Mechanics and Tunneling", "DR. DEBARGHYA CHAKRABORTY", "DEPARTMENT OF CIVIL ENGINEERING, IIT KHARAGPUR", "Module 12: Improvement of rock mass response: rock bolts, rock anchors, steel mats, precast concrete segments, shotcrete, grouting etc.", and "Lecture 04 : Improvement of rock mass response (contd...)"

So in module 12 we are discussing about the improvement of rock mass response; and we are learning about different techniques.

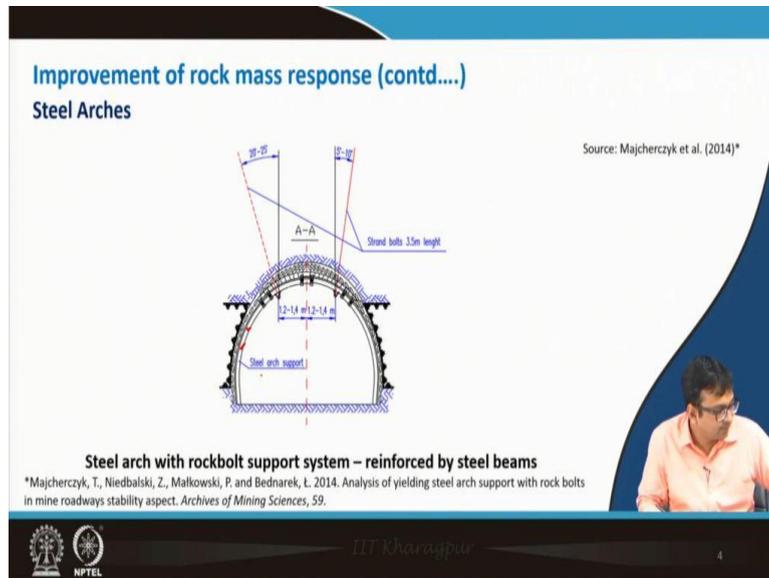
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The slide has a blue header with the text "CONCEPTS COVERED" in yellow. Below the header, a list of concepts is shown with right-pointing chevrons: "Improvement of rock mass response", "Steel Arches", "Spiles and Forepoles", "Cast in-situ lining", "Precast lining", and "Steel Plates". In the bottom right corner, there is a small video inset showing a man in an orange shirt. At the bottom of the slide, there are logos for IIT Kharagpur and NPTEL, and the text "IIT Kharagpur" and "NPTEL".

So, today we will discuss about all these topics like steel arches, spiles and forepoles, then cast in-situ lining, then precast lining, as well as steel plates briefly discussed today.

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So, steel arches, basically this is actually how it looks let us first see. So, these are the Steel arch support you see here steel arches arch is provided to support this tunnel. So, you see in our last lecture we have discussed about lattice girder as well as sprayed concrete like wet mix, then dry mix all these things.

Wet mix is nothing but the shotcrete, all these things we have learned. And they are mainly used for primary to use for the providing the tunnel supports. So, this likewise this steel arches are also very common; they are very commonly used to provide the tunnel support. So, as you can see from this diagram steel arches are provided like this.

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Improvement of rock mass response (contd....)
Steel Arches

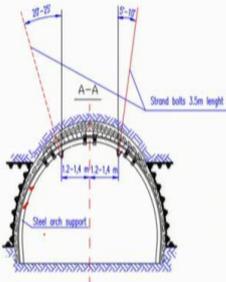
- * These are arch supports that are made by steel beams and rock bolts.
- * Steel arches are generally used to provide roof support



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Improvement of rock mass response (contd....)
Steel Arches

Source: Majcherzyk et al. (2014)*



Steel arch with rockbolt support system – reinforced by steel beams

*Majcherzyk, T., Niedbalski, Z., Małkowski, P. and Bednarek, Ł. 2014. Analysis of yielding steel arch support with rock bolts in mine roadways stability aspect. *Archives of Mining Sciences*, 59.

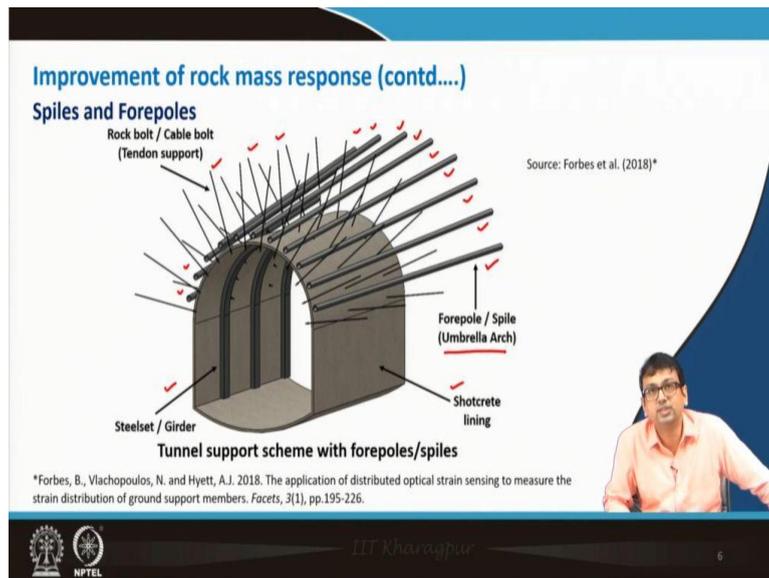


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Now, we can write little bit like these are made of steel frames; and obviously, these are the means there will provide mainly the steel beams, steel beams and the rock bolts. With the help of that you will see if you see the diagram also, you will understand the steel beams are there as well as the it is fixed with the help of rock bolts also.

So, just we can write at least that much that, these are arch supports that are made by steel beams and rock bolts. Primarily, the purpose is you can see, is to provide the support to the roof; so, it is mainly used for the roof support. So, used how it is used maybe let me write down. So, these steel arches are generally used to provide roof support; so, mainly that is the purpose. So, these are this is what we can say about the these steel arches.

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So now, another thing is these spiles and forepoles. Now, first let me show you that diagram, then you will be able to understand. You see this is the tunnel as you can see, and already you know what a shotcrete. So, shotcreting is provided there, then the girder you can see over here; so lattice girder you have learned how it is. And this, this is also through this diagram what you can understand how they may look like also.

And now along with what you can see? These are the rock bolts, rock bolts are there fine. And now, these are the something new, this type like structure so you can see. So, this is nothing but the, these forepoles or this pipe. So, this is you can see in bracket is an umbrella arch; so, it is like taking a shape of umbrella.

These pipes are like this, the way it is arranged; you see nicely it is, how it is arranged throughout the periphery of this tunnel, mainly in the upper part in roof region as you can see. These are nothing but the spiles and forepoles.

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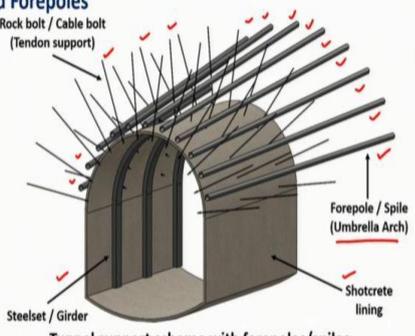
Improvement of rock mass response (contd....)
Spiles and Forepoles

- * Spiles and Forepoles are the support elements for tunnel.
- * Pipe
- * They provide temporary support (generally)



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Improvement of rock mass response (contd....)
Spiles and Forepoles



Source: Forbes et al. (2018)*

Tunnel support scheme with forepoles/spiles

*Forbes, B., Vlachopoulos, N. and Hyett, A.J. 2018. The application of distributed optical strain sensing to measure the strain distribution of ground support members. *Facets*, 3(1), pp.195-226.



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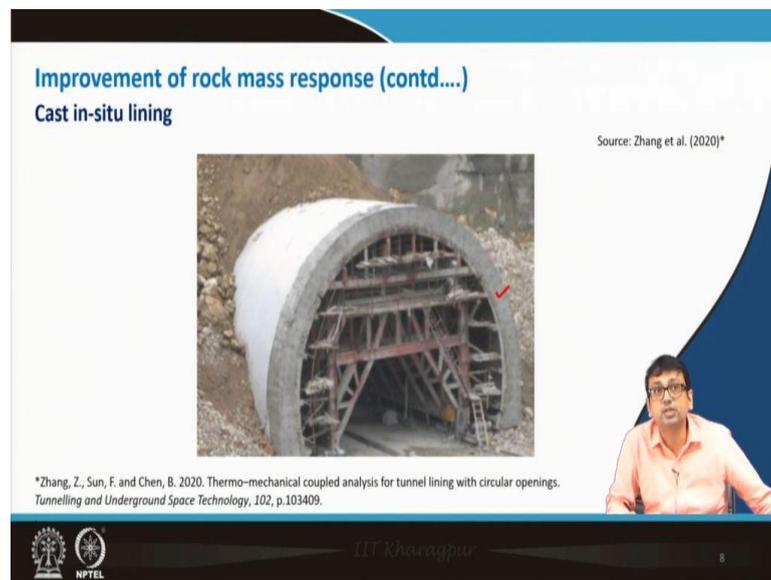
So, now we can write one or two lines regarding this like, these are nothing but the support elements. So, these spiles and forepoles are the support elements for tunnel. Generally, what we have seen the, it looks like the pipe; so, these are like steel pipe kind of thing. So, pipes are there and also they are mostly used as a temporary support; so, they provide the temporary support generally.

So, these are the things I think we can say. And again, all these design of all of all these things are actually depend on the, where the construction is going on. How much strength is available for the rock mass, where the construction is going on; and what are the things we are looking like, if you are going for lattice girder? Then which girder as we have learned that generally it is the lattice girder, the shotcreting is provided.

So, if that is the case, your design will be something; or if you provide for roof support if you use arches, then your design will be different. Again, if you use forepoles or spiles, so then also your design will be different. But, at least here what I am trying to cover in this module is, I am trying to introduce you with the different techniques.

Only regarding rock bolting we have solved a problem; but other things I have within the short period, I cannot cover. That I am keeping beyond the scope of this course. But anyway, I am trying to introduce you with these terms.

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Now, cast in-situ lining. So, again this is also mainly related to the tunnel. So, now, cast in-situ lining now; first let me show you maybe the diagram. So, you see that this is the concrete lining as you can clearly see; this is actually cast in-situ means in the in-situ construction, it was actually created, it was not pre constructed; or it was not precast concrete, it was cast in-situ. In the when the excavation time excavation going on; immediately means this lining construction also, in this case keep on going. And these are nothing but cast in-situ lining.

(Refer Slide Time: 09:07)

The slide is titled "Improvement of rock mass response (contd....)" and has a sub-heading "Cast in-situ lining". It contains two handwritten bullet points in red ink: "* Cast in-situ lining is used to provide the tunnel support" and "* It is prepared directly on the field using concrete." The slide also features a small inset video of a man in an orange shirt in the bottom right corner, and logos for IIT Kharagpur and NPTEL at the bottom.

Now, some of the advantages we have for this type of cast in-situ lining. What are they? Let me just tell you one or two points at least. These are mainly used to provide tunnel support, definitely. Cast in-situ lining is used to provide the tunnel support. Now, it is prepared directly on the field; so it is prepared directly on the field using concrete. Now, it is having because of this reason, it is having some advantage.

What is that? Since you are constructing it at the field; so you can, it is your the shape of the tunnel, may not as per the requirement may, it may little bit vary in some particular location, depending on the maybe the situation; so that you can very easily accommodate actually.

And also, if some irregular shape is, because of that if some irregular shape is if developed; so that also you can take care, if you go for this cast in-situ lining. That is actually the biggest advantage of this type of lining.

(Refer Slide Time: 11:22)

Improvement of rock mass response (contd....)
Cast in-situ lining

- * Suitable for lining of any excavation irrespective of the dimensions of the excavation
- * Irregularities can be filled with concrete very easily.



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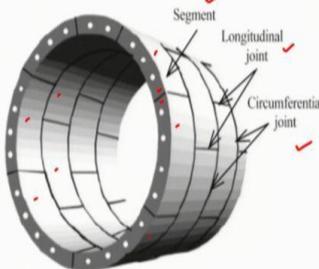
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So, we can write little bit like suitable for lining of any excavation irrespective of the dimensions of the excavation. And as I have mentioned irregular or irregularities maybe I can write, can be filled with concrete very easily; these are the some of the advantages.

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Improvement of rock mass response (contd....)
Precast lining



Segment ✓
Longitudinal joint ✓
Circumferential joint ✓

Source: Guan et al. (2015)*

*Guan, Z., Deng, T., Wang, G. and Jiang, Y. 2015. Studies on the key parameters in segmental lining design. *Journal of Rock Mechanics and Geotechnical Engineering*, 7(6), pp.674-683.



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Improvement of rock mass response (contd....)

Precast lining

- * Precast concrete segment lining is prefabricated and then transported to the site
- * Generally used in case of tunnel construction where TBM is used.

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Similar to that another thing is precast lining. So, it is what as name suggests, the lining will be made beforehand only. In case of precast lining, you will construct the lining inside the tunnel; you will construct at the field. But in case of precast line, it will be pre-constructed. So, I can show you on diagram.

So, it will be constructing segments as you can see, and see several segments of these is; here also you can see, these are the different segments of lining. And they will be the longitudinal joints will be there, and circumferential joints will be there to lock them.

But the thing is to see since it is precast, it will be well designed; these joints should be match with each other; this face and this face should match to each other properly. And your that excavation should be very much perfect; so that is why this type of precast linings are generally used for like in case of TBM.

We have learned about tunnel boring machine; that is very efficient equipment for tunnel construction. There you must have seen how the tunnel boring machine looked like, I have shown you. So, there it construct the, like you create the excavation quite accurately; so for those cases, this type of precast linings are used widely.

Otherwise, what may happen if your dimension actually changes depending on the situation; then the precast lining will not fit there properly, that is one of the disadvantage. But advantage is what? It is since it is precast; so you can like, it means you do not have to wait for 28 days till it is gaining its inter strength.

As we know, if we construct we go for the cast in situ; then we have to give some time to, time to the this cement concrete to gain its full strength, approximately suppose 28 days. So,

in that on the other hand, in this case if you go for precast lining; then you do not have to worry about that. Means immediately it will, since it is precast; so it will means you do not have to wait for that much long time.

So, these are some of the advantages, disadvantages are there; let me write down one or two points related to that. So, these are like the precast concrete segment lining is prefabricated and then transported to the site. Generally, as I have mentioned, generally used in case of tunnel construction, where TBM is used.

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Improvement of rock mass response (contd....)

Precast lining

Advantage

- * It starts supporting the tunnel immediately after fixing in position.

Disadvantage

- * The dimensions are pre-fixed
- * Need have space for storing the precast lining segments.

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Improvement of rock mass response (contd....)

Cast in-situ lining

Advantages

- * Suitable for lining of any excavation irrespective of the dimensions of the excavation
- * Irregularities can be filled with concrete very easily.

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Advantage like it supporting the tunnel phase or tunnel it starts supporting the tunnel immediately after fixing in position. That is the biggest advantage of this, and that is the

biggest advantage; let me write down here the advantage. Otherwise, you will not remember so; and may be you can write one disadvantage also.

The irregular shapes cannot be accommodated easily. So, the dimensions are prefixed actually. Once that is done, you cannot then alter; then you need some space to store them in in your, means prefixed precast. So, you need to store them, you need to have need to have space for storing the precast segments lining segments. So, these are some of the advantages and disadvantages; let me so write down here also the advantages.

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Improvement of rock mass response (contd....)
Steel Plates

1) Steel plates are flexible tunnel lining.
2) The supporting capacity results from its ability to deformation under load.

Source: Chen et al. (2020)*



*Chen, H., Lai, H., Qiu, Y. and Chen, R. 2020. Reinforcing Distressed Lining Structure of Highway Tunnel with Bonded Steel Plates: Case Study. *Journal of Performance of Constructed Facilities*, 34(1), p.04019082.

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Now, the steel plates. So, steel plates or you can see like the, these I will show you the first the diagram. You see, these are placed on the tunnel periphery, as it is shown in the diagram. So, now the advantages of this using these plates are like they are flexible, very much flexible and lightweight; so, you can carry it very easily.

So, steel plates are flexible tunnel lining; that is one thing. Or, you can say also it is supporting capacity depends on how much deformation can be allowed to these steel plates; so, depending on the capacity changes obviously. So, let me write down the supporting capacity results from its ability to deformation under load. So, this much we can say.

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Improvement of rock mass response (contd....)
Steel Plates

Advantages

- 1) They are light weight .Hence, transportation becomes easy .
- 2) Assembly is very easy .



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Improvement of rock mass response (contd....)
Steel Plates

- 1) Steel plates are flexible tunnel lining.
- 2) The supporting capacity results from its ability to deformation under load.



*Chen, H., Lai, H., Qiu, Y. and Chen, R. 2020. Reinforcing Distressed Lining Structure of Highway Tunnel with Bonded Steel Plates: Case Study. *Journal of Performance of Constructed Facilities*, 34(1), p.04019082.



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Also like the advantage, advantages. If I say, like it is very lightweight, and so that is why it can be easily transported. They are lightweight, hence transportation become easy and that is one of the biggest advantage; and easily, it can be easily assembled also. As you can see, these plates can be very easily assembled, and in this way, that lap steel plates.

So, with the help of lap steel plates, so this, it will be of certain length obviously. Now, you may have to provide this kind of laps to attach one plate with another; so, these kinds of laps are provided. So, it is very easy to assemble also; so, assembly is very easy, that also we can say about this.

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Improvement of rock mass response (contd....)
Steel Plates

Limitation

- 1) Corrosion (as it is made of steel)
- 2) Concreting will be needed for fire protection.

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And if I say about the disadvantage or limitation. Limitation means, so, since it is made of steel; so, there is a chance of corrosion. So, corrosion is a problem, as it is made of steel; this is one of the biggest problem or limitation. And also if we are using this type of steel plate for, in the case where we are going using the TBM there, the thrust actually developing or applied to the this TBM should be less than the load carrying capacity of the plate.

So, we can write that also; or may be that we can understand. Since, it is having certain load carrying capacity, so it is related to the how much; means if you are using TBM, so accordingly you have to apply the thrust. Another thing what I think I should write that is, since it is made of steel; so, if we are constructing led tunnel where should, which is fire resistant also.

In that case, as we know if it is made of only; since it is made of only steel, so, if I want to construct a tunnel which is resistant to fire there, it will not work certainly. So, what we have to provide? We have to provide the concreting also over there; so that is what we can I think. That is one of the important limitation that is like, the concreting will be needed for fire protection. So, that I think we can write; and I think with this let us conclude our today's lecture. Thank you.