Rock Mechanics and Tunneling
Professor Debarghya Chakraborty
Department of Civil Engineering
Indian Institute of Technology, Kharagpur
Lecture 49
Methods of Construction (Continued)

Hello everyone. I welcome all of you to the third lecture of module 10. So, in module 10 we are discussing about the basic features of tunneling and we have started discussing about the methods of construction.

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So, today we will discuss about the tunnel excavation by mechanical means. In our previous class we have discussed about the drilling and blasting, so today, we will discuss about the tunnel excavations by mechanical means and I have mentioned in our previous lecture that under this tunnel excavation by mechanical, roadheader, and tunnel boring machine (TBM), these two things we will discuss mainly.

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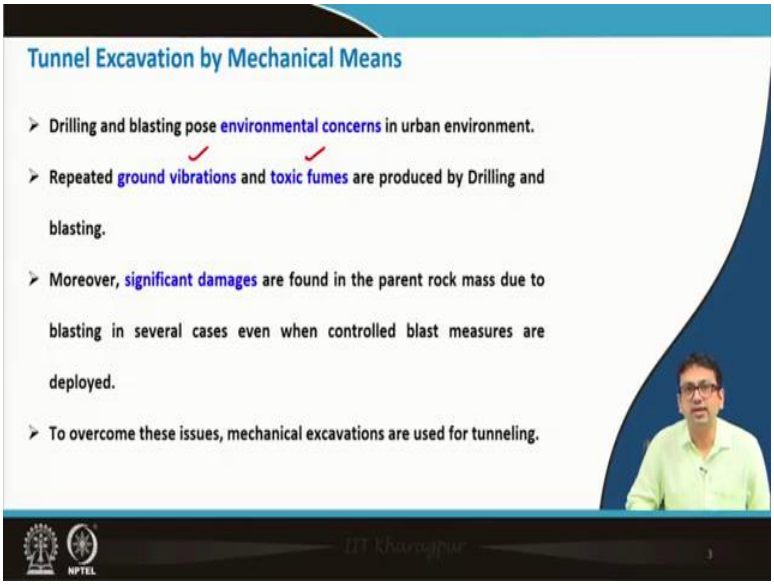

Now, the tunnel excavation by mechanical means; so now actually drilling and blasting pose environmental concerns in urban environment. Due to repeated ground vibrations and toxic fumes are produced by drilling and blasting, so, these are the main concerns. Moreover, significant damages are found in the parent rock mass due to blasting in several cases. Even when the control blast measures are deployed also. So, even though you are taking this control blast measures you are adopting, still actually significant damage are found damages are found in parent rock mass due to this blasting. Now to overcome these issues mechanical excavations are used for tunneling.

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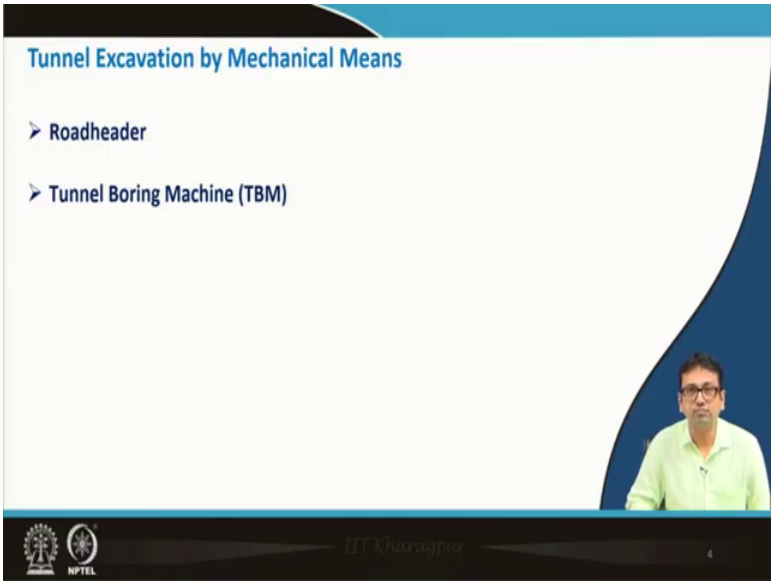

In the tunnel excavation by mechanical means, we will discuss roadheader and tunnel boring machine (TBM).

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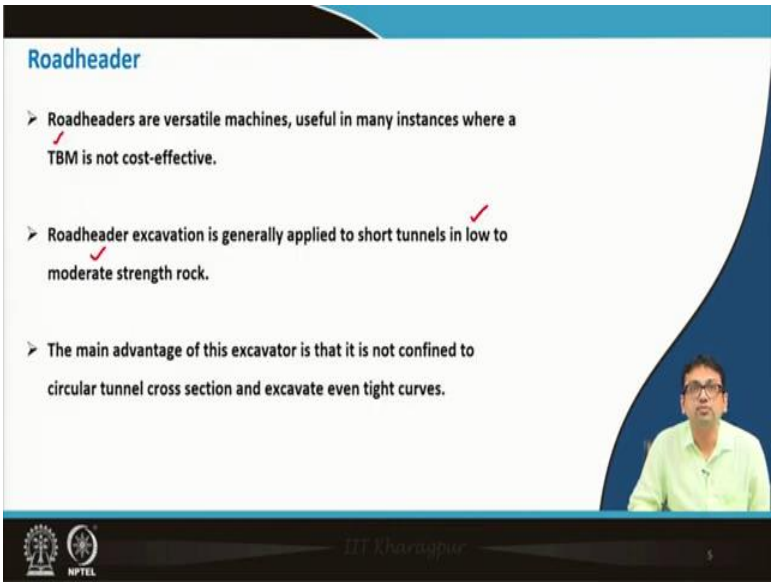

Roadheader

Roadheaders are versatile machines useful in many instances where a TBM is not cost effective. TBM is an excellent equipment but it is relatively costly actually means as compared to these roadheaders. It is costly machine actually, so that is why roadheaders are versatile machines

useful in many instances where a TBM is not cost effective. Then roadheader excavation is generally applied to short tunnels in low to moderate strength rock.

So, these roadheaders are mainly used for low to moderate strength rock and short tunnels. Otherwise, in general we have to go for this TBM though that is costly. And the main advantage of this excavator is that it is not confined to circular tunnel cross section and can excavate even tight curves. So, these are the some of the things that we can say about roadheader.

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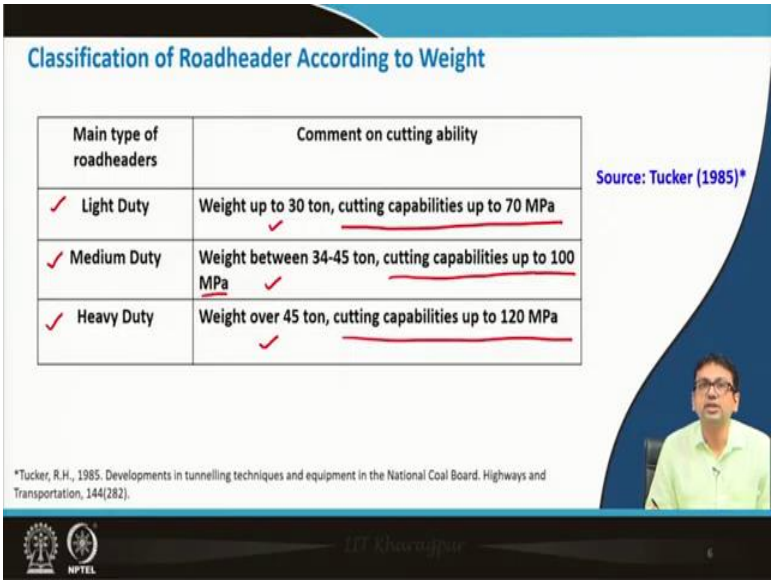

Now classification of roadheader according to weight; so with this is by Tucker (1985), so what is this way it is divided like light duty, medium duty, heavy duty. Now, the weight in case of light duty roadheader is 30 ton, medium rate is 34 to 45 ton and heavy duty is more than 45 ton. Now very important thing is cutting capability up to 70 mega Pascal in case of light duty.

So, cutting capability up to 70 mega Pascal means it is trying to say that it is actually indicating the UCS value so uniaxial compressive strength of rock mass. So, the light duty roadheader has the cutting ability up to 70 mega Pascal means rock is having 70 mega Pascal UCS value.

Likewise medium duty; in that case cutting capabilities up to 100 mega Pascal and in case of heavy duty cutting capabilities up to 120 mega Pascal.

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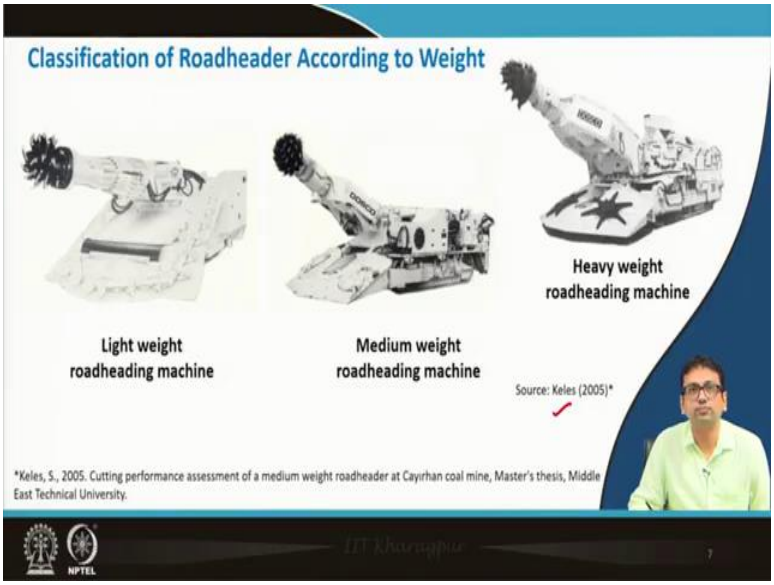

Now let us see the some of the pictures of this roadheader, how it looks actually; you see this is like light weight roadheader, this load reading machine, like this is the medium weight, and it is the heavy weight. So, just to give you some idea how it looks these pictures are provided. So, these things are actually means you can also find it in this master's thesis.

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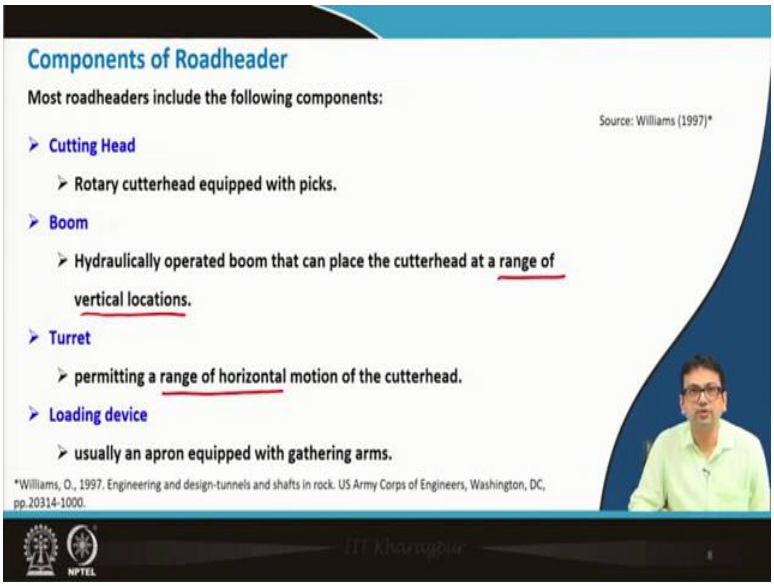

Now, components of roadheader, so most roadheaders include the following components like; cutting head

Now what is cutting head? Regarding that we can say rotary cutter head equipped with peaks, Boom

It is a hydraulically operated boom that can place the cutter head at a range of vertical locations.

Turret

Turret actually permitting a range of horizontal motion of the cutter head.

So, you see range of horizontal motion and here it is range of vertical location, so these things you should notice.

Loading device

Usually an apron equipped with gathering arms, so I will show you even one picture also in schematic diagram that will also clear your doubts means these components will be able to see there also.

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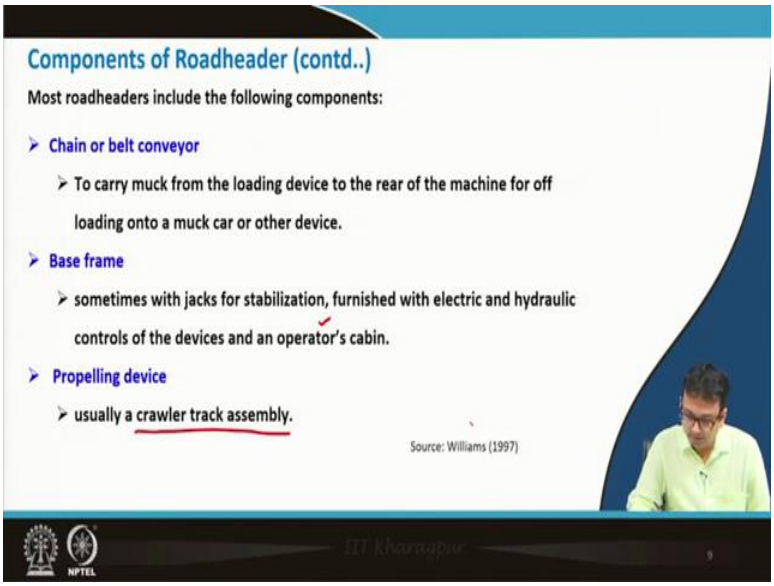

Chain or belt conveyor

To carry muck from the loading device to the rear of the machine for of loading onto a muck car or other device this chain or belt conveyors are present.

Base frame

It sometimes with jacks for stabilization furnished with electric and hydraulic controls of the devices and an operators cabin.

In addition, there will be one operator's cabin also and propelling device; usually a crawler track assembly. So, these things you can find in Williams, so the reference I have provided over here you see this reference, this is engineering and design tunnels and shafts in rock by US Army Corps of Engineers.

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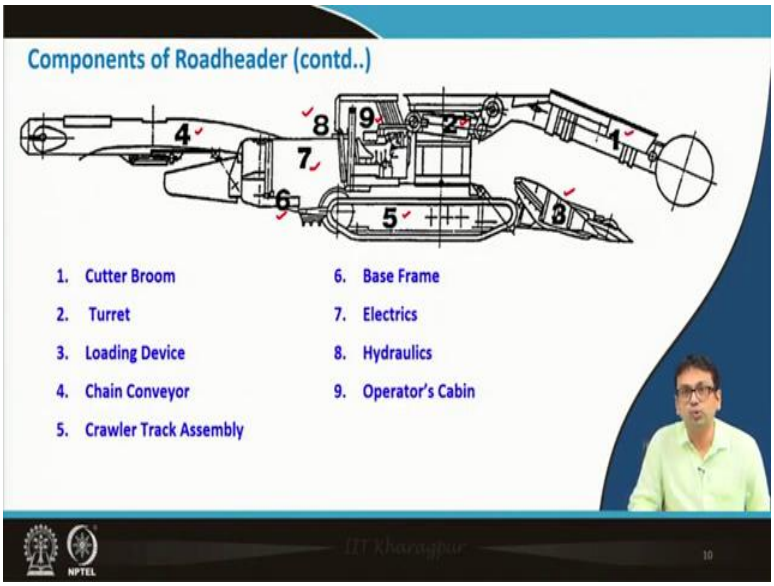
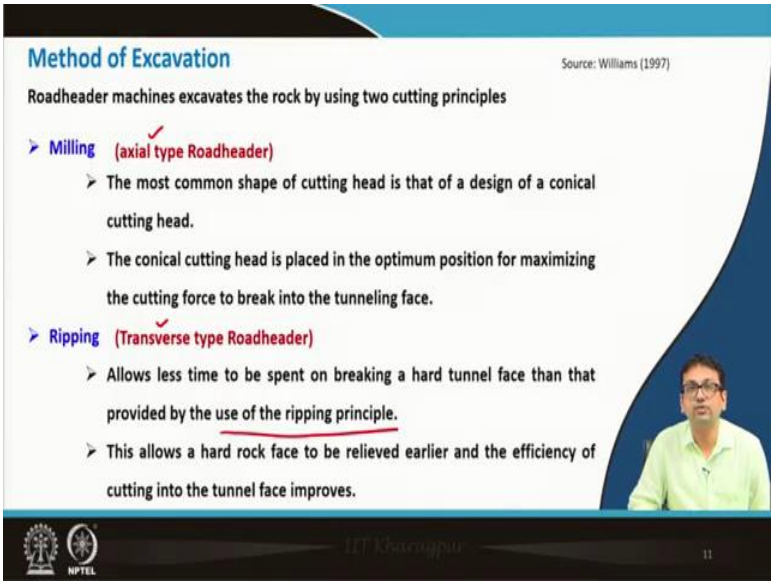


Now this is different components of roadheaders, again what I have mentioned actually, so one; here you can see 1 is for cutter broom. This cutter broom is there right so as you have seen over here cutter head like so here that is what you can see from here. Then turret, then loading device, 2 means turret you must have understood and 3 is loading device as I mentioned 4, which is chain conveyor.

Yes, so chain conveyor the purpose of chain conveyor is what this one you see to carry mark from the loading device to the rear of the machine for offloading onto a marker or other device, then 5 is crawler track assembly; this you see crawler track assembly will be there, then base frame, sixth, so this is the base frame, so then electrics, hydraulics and operators cabin you see 9 is the operators cabin.

So, 7 is electrics; 8 here hydraulics and 9 is operators cabin so anyway this is I hope giving you some idea about the roadheader. So, just the actual picture if you once again see you will be able to clearly understand these things like you see the head part you can see and other components as I have mentioned, so you see the this crawler track you can see here very clearly how it looks. (Refer Slide Time: 11:03)



Now method of excavation, so roadheader machines excavates the rock by using two cutting principles; one is milling, milling means axial type roadheader, they use this technique and another is ripping; where transverse type rotator. Now milling; what do we understand by that, the most common shape of cutting head is that of a design of a conical cutting head.

The conical cutting head is placed in the optimum position for maximizing the cutting force to break into the tunneling phase and regarding ripping what we can say; so remember milling is axial type, ripping is transverse type that is the main difference, okay and regarding ripping we can say allows less time to be spent on breaking a hard tunnel phase than that provided by the use of the ripping principle and by the use of ripping principle okay.

And another one we can say that this allows a hard rock face to be relieved earlier and the efficiency of cutting into the tunnel phase improves. So, these are some of the comments that we can tell about all these things.

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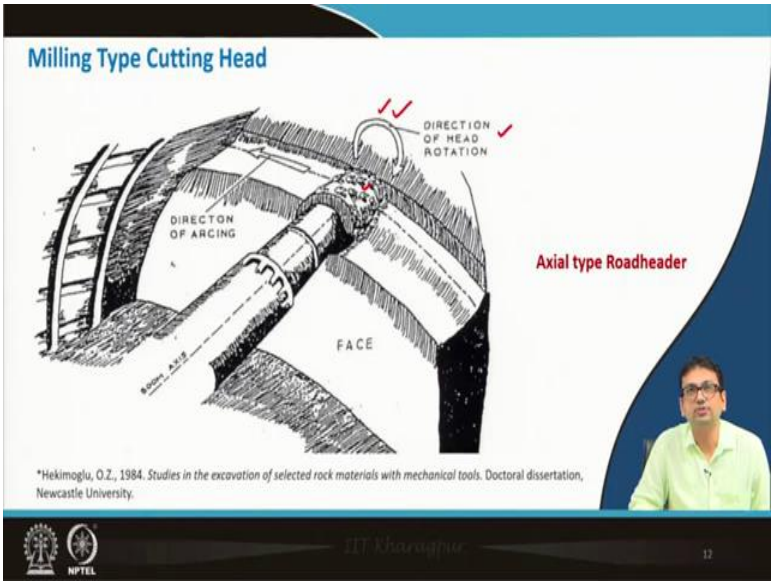

So, now milling type cutting head that is important we should understand at least these terms or what do they mean actually. You see here look at, so milling type cutting head is like your cutting head is here as you can see over here and direction of head rotation. So basically, it will rotate in this way this cutting head, so and it will obviously move forward there is no doubt about that in this way, so it will keep on rotating like this as you can see from here.

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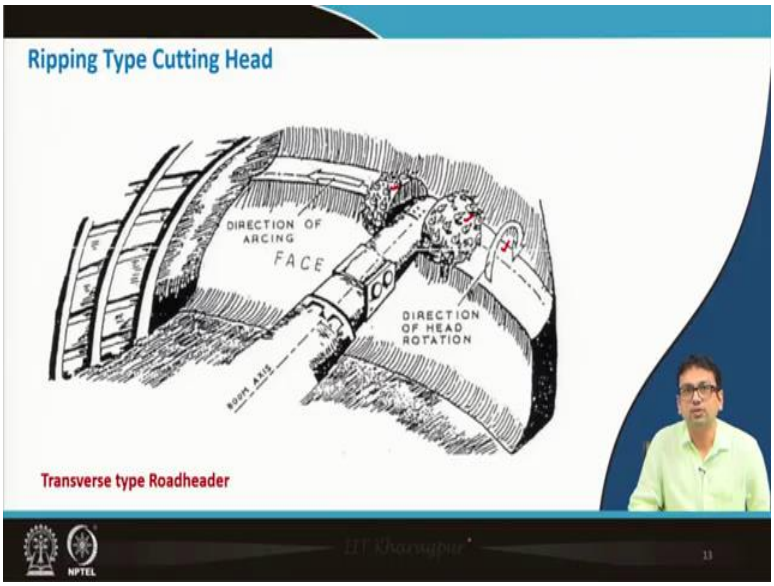

Whereas, the next picture will clear your doubts regarding the this ripping type, so you see in case of ripping type, what is happening these, the this once again you just see here, so here the

cutting head was you see here located whereas here it is cutting edge like this, so this is ripping type cutting head and direction of head rotation you see shown over here. So, these are two different types of like methods as we have mentioned; method of excavation milling and ripping.

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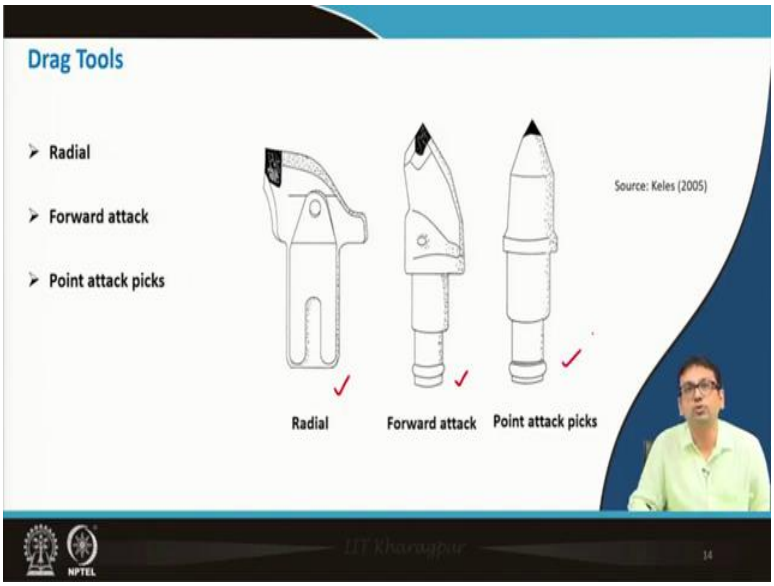

Drag tools

Different types of tools like radial, forward attack and point attack peaks are there. So, just pictures are proven it is the radial tool will look like this, forward attack tool will look like this, and point attack peaks will look like this, so I hope you can understand means these things as you can notice from radial, forward attack and point attack picks.

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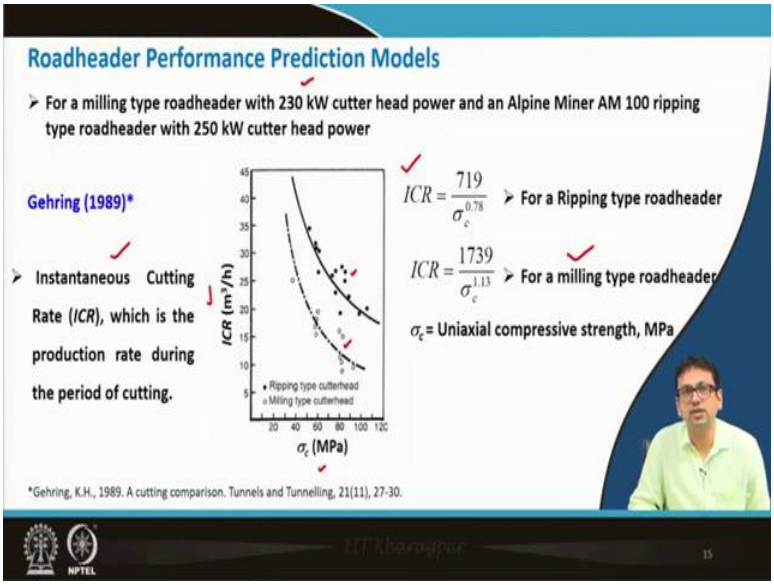

Now, roadheaders this performance prediction models, so for a milling type roadheader with 230 kW cutter head power and an alpine minor AM 100 ripping type roadheader with 250 kW cutter head power. Gehring (1989) gave some like formula or expressions for that based on the data actually, so one term was introduced like instantaneous cutting rate ICR, which is the production rate during the period of cutting.

Instantaneous cutting rate commonly known as ICR, so it is, the unit is meter cube per hour and the plot is like ICR versus σ_c, now σ_c is nothing but the as we know it is the UCS value so reaction compressive strength of rock. So now, you see these you see the solid dots, you can notice here and you can see the hollow dots. So, solid dots are those are the data points for the ripping type cutter head and for the milling time cutter head the hollow dots are there.

And a best fit line is drawn as you can see, now so that gives actually an equation for ripping type roadheader, this equation basically ICR is equal to 719 by σ_c to the power 0.78 and on the other hand ICR for milling type roadheader is 1739 by σ_c to the power 1.13 and as I have mentioned σ_c is the uniaxial compressed strength in mega Pascal, so this is obviously one of the important guideline you can say. So, the new term we have learnt is instantaneous cutting rate ICR.

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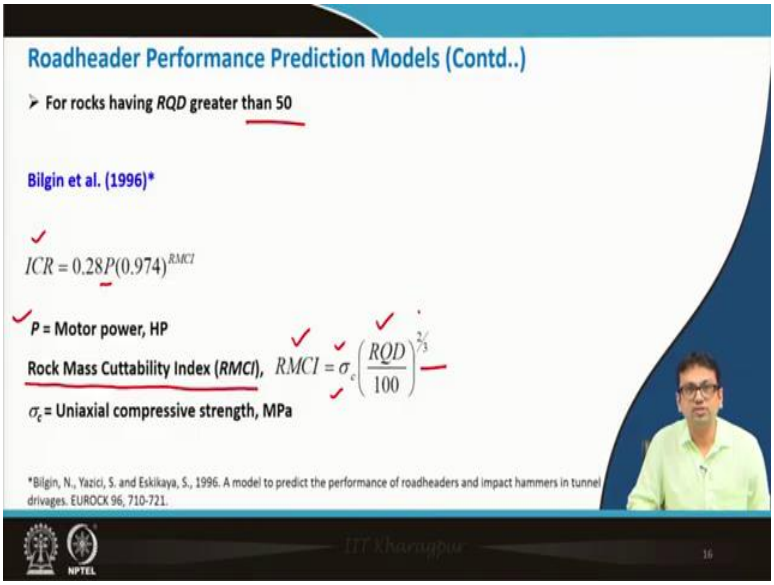

Now for rocks having RDQ value greater than 50 actually, then Bilgin et al. (1996) they have given some equation like ICR, the same thing instantaneous, ICR is instantaneous cutting rate so ICR is equal to 0.28 p into 0.974 to the power RMCI, now what is this RMCI? Obviously, the p here you can see p is the motor power in horse power HP, what is the RMCI? The full form is rock mass cuttability index.

So, RMCI is equal to σ_c into RQD by 100 to the power two third, so remember this is for RQD greater than 50 means, RQD present in terms per percentage as you know so σ_c into RQD by 100 to the power two third.

So, this is the RMCI and obviously σ_c is the initial compressive strength of rock in mega Pascal, so RMCI if you can find out from σ_c and RQD we can find out ICR that is which is nothing but instantaneous cutting rate what we have seen over here. So anyway, so I think we have learnt this part also, so I think we have discussed, means understood basic things about roadheaders.

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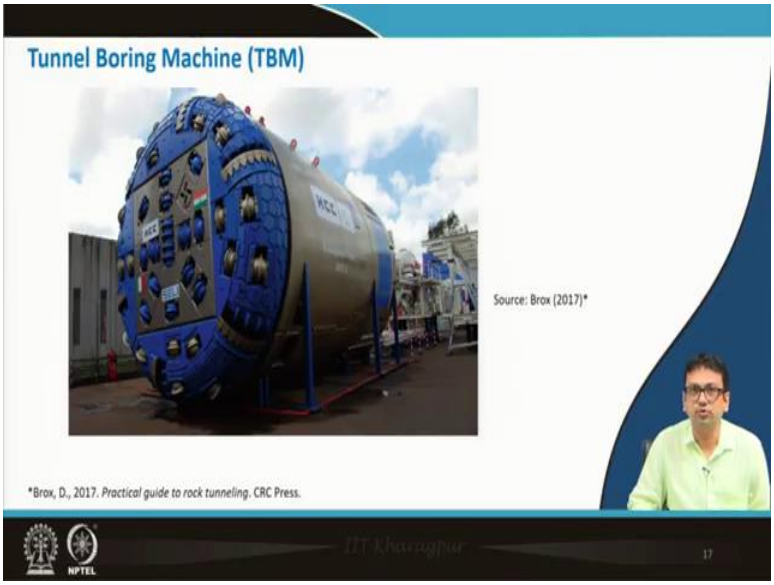

Now the analog means the next one is tunnel boring machine which is like you can see the picture; huge equipment, you can understand it is a huge equipment and obviously extremely effective useful equipment and throughout the world. It is used like frequently for tunnel construction. Only thing is you see as it is very big, so it is costly as well as operating cost is also quite high.

So, that is why as I have mentioned if possible to reduce the project cost, we go for roadheaders but if we have to go for a very long tunnel in hard rock. Then, we have to go for this tunnel boring machine basically.

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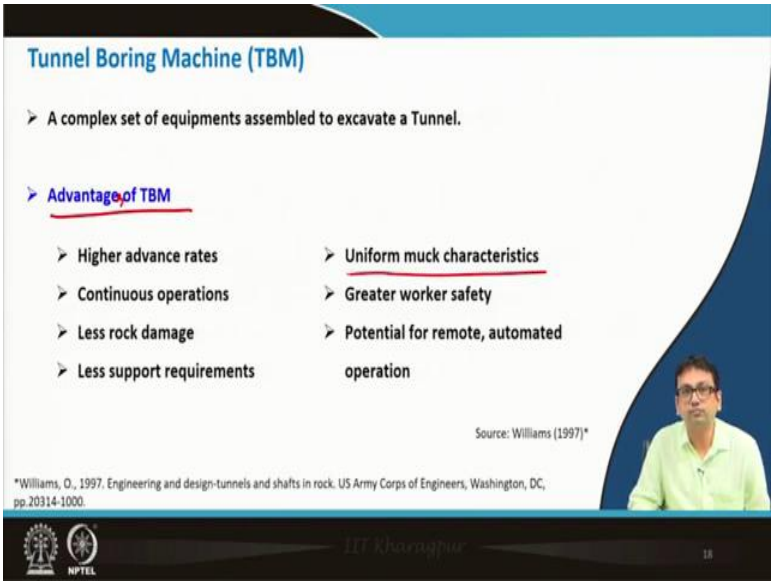

Tunnel boring machine is actually a complex set of equipments assembled to excavate a tunnel. Now, there are some advantage of TBM tunnel boring machine in short we frequently call it as TBM, so basically some of the advantages like higher advance rates. Therefore, it is quite fast and continuous operations can be performed. It has less rock damage; obviously surrounding rock will not be damaged that much as compared to the drilling and blasting as we can understand.

Then also less support requirements and also uniform muck characteristics, so that is also one of the important thing, uniform mark characteristics and greater worker safety, see human safety is very important, the people who are working there for constructing this tunnel. Their life is very important, obviously, human life is extremely important so if we think about the safety obviously TBM is very useful because it gives greater worker safety.

Then, the potential for remote and automated operation is also there.

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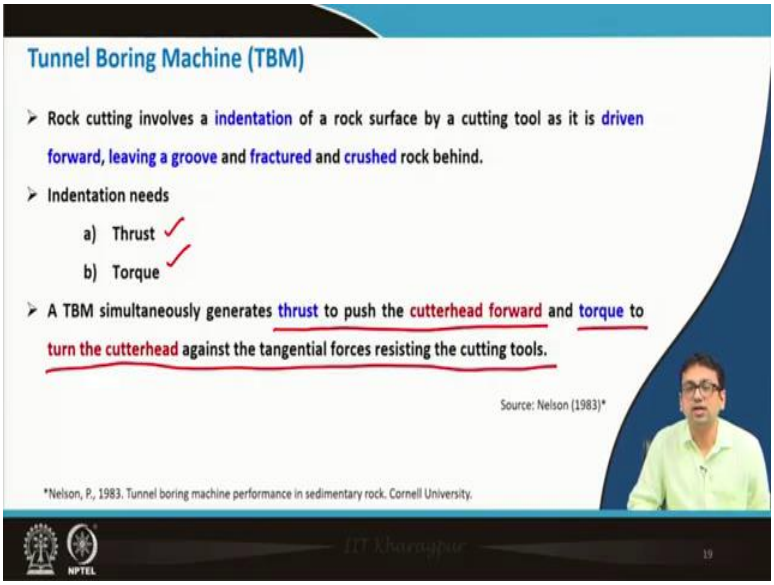

Now, again what we can say that rock cutting involves an indentation of a rock surface by a cutting tool as it is driven forward leaving a groove and fractured and crushed rock behind. Now indentation needs two thing; thrust and torque. Now, a TBM simultaneously generates thrust to push the cutter head forward and torque to turn the cutter head against the tangential forces resisting the cutting tool.

So, this is the beauty of this TBM, a TBM simultaneously generates thrust to push the cutter head forward and torque to turn the cutter head against the tangential forces resisting the cutting tools.

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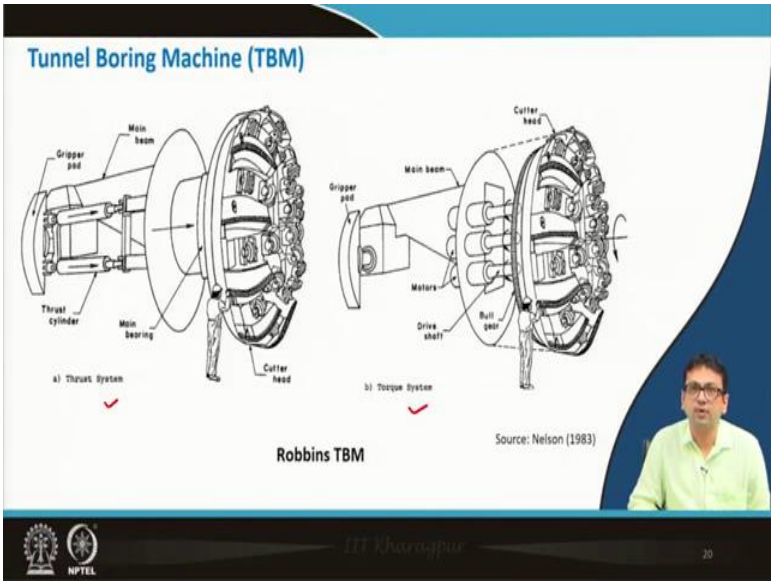

Now, there are different TBMs available, so this is actually the picture of the Robins TBM, Robins TBM there you see the, this is the thrust system is shown over here and torque system is shown over there in the Robbins TBM, Robbins tunnel boring machine.

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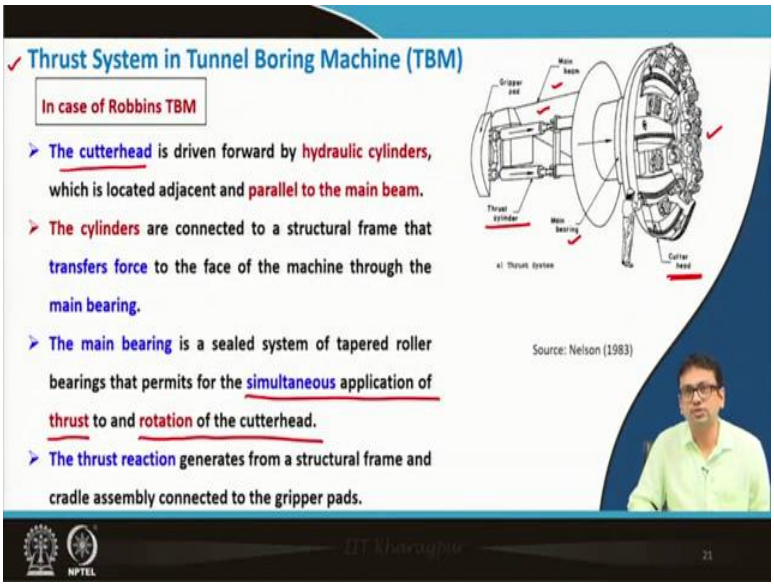

In case of this Robbins TBM, the cutter head as you can see here clearly mentioned that this is our cutter head. The cutter head is driven forward by hydraulic cylinders. Therefore, you can see that it is regarding the thrust system in TBM, so in case of Robbins TBM this for this third system you see third cylinders are there.

So, the cutter head is driven forward by hydraulic cylinders which are located adjacent and parallel to the main beam. Main beam is here you can see. The cylinders are connected to a structural frame that transfers force to the face of the machine through the main bearing. You can see that the main bearing is indicated over here. The main bearing is a sealed system of tapered roller bearing that permits for the simultaneous application of thrust.

And this simultaneous application of thrust to and rotation of the cutter head, and the thrust reaction generates from a structural frame and cradle assembly connected to the gripper pads. So that is what also which means we are learning from here.

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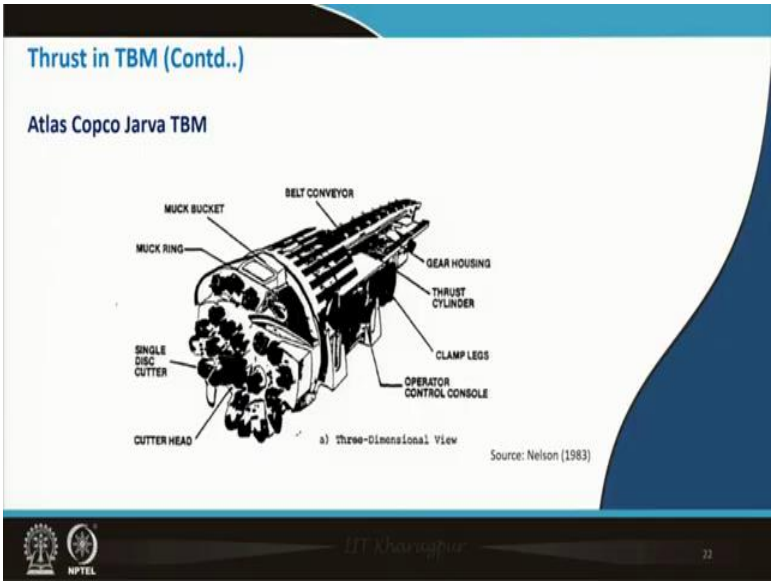

Another type of TBM is Atlas Copco Jarva TBM. Atlas Copco Jarva is another company, so like Robbins TBM another popularly means this is also one of the popular TBM, so Atlas Copco Jarva TBM produces thrust in TBM, how it happens?

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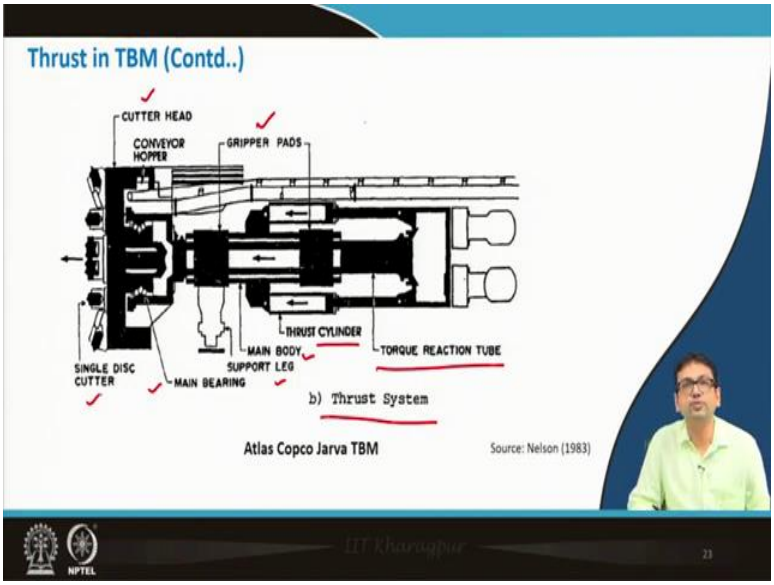

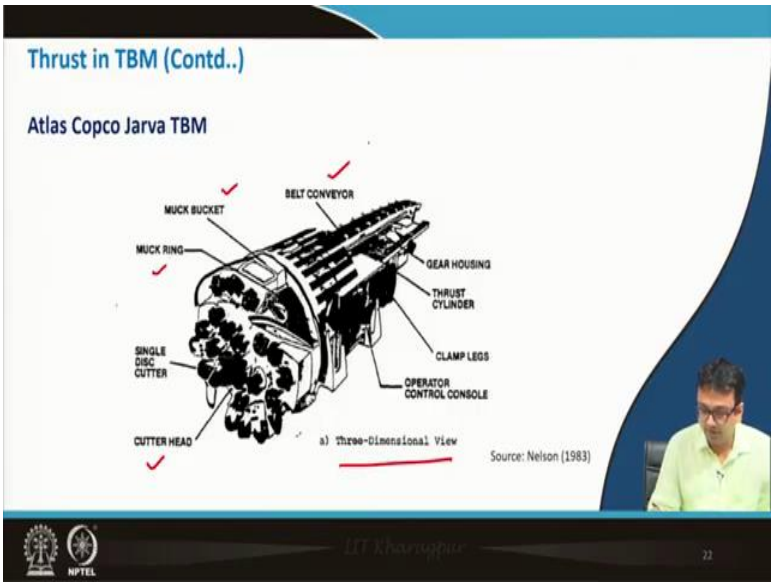

So basically, this was the three dimensional view here you can see the cutter head then like muck ring, muck bucket and like the belt conveyor all these things are there, anyway and this is the you see the for thrust system, you see the cutter head will look these gripper pads, and torque reaction tube all these things, thrust cylinder all these things are shown and main body, support legs all these things are shown over here like, main bearing is also there and single disk cutter all these things you can clearly observe.

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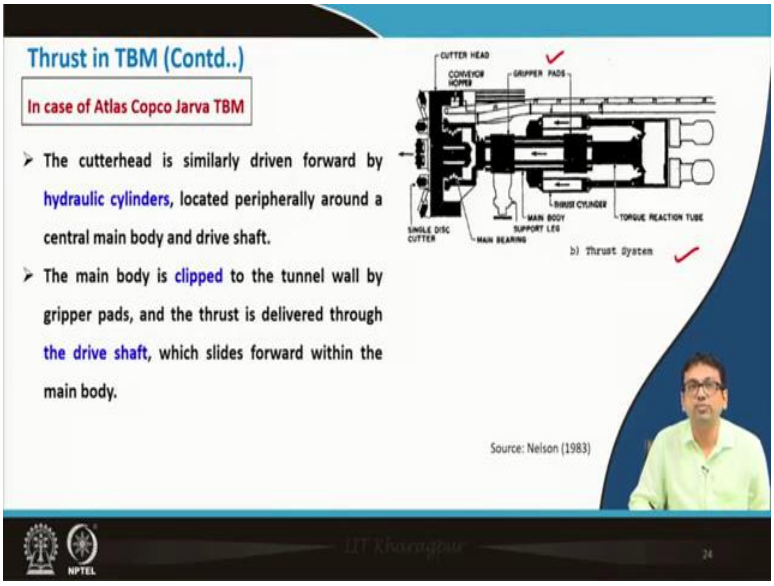

Now in case of Atlas Copco Jarva TBM, the same diagram only shown over here; the cutter head is similarly driven forward by hydraulic cylinder located peripherally around a central main body and drive shaft and the main body is clipped to the tunnel wall by gripper pad. So, this gripper person actually for that purpose the main body is clipped to the tunnel wall by gripper pads and the thrust is delivered through the drive shaft which slides forward within the main body.

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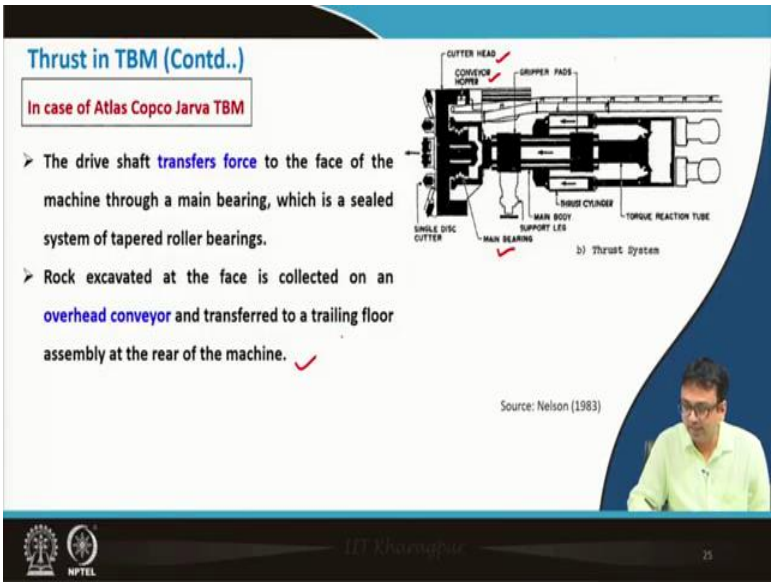

We can say the drive shaft transfers force to the face of the machine through a main bearing as we can see over here. The drive shaft transfers force to the face of the machine through a main

bearing which is a sealed system of this tapered roller bearings and rock excavated at the face is collected on an overhead conveyor as it is shown over here.

And transferred to a trailing floor assembly at the rear of the machine. So, you see the conveyor and all are there as I have shown you in that picture.

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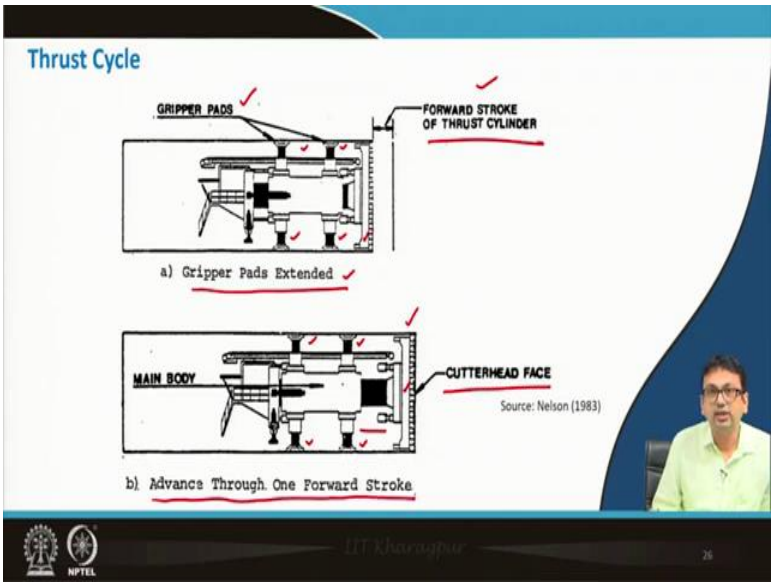

Now this is very nice, you see, pictorial representation of this thrust cycle. What is happening? forward stroke of thrust circle as you can see now this is gripping pads extended. Now next stage, what is done?

The, see this was the forward stroke of this thrust cylinder as you can see, now what is happening you see this has extended and cutter head is now here at this level. So, cutter head face is here, now that means this part has extended means this part, this one has now (ex) come over here. Now what is done, you see still these gripper pads are here touching with the periphery of the tunnel. So it is written as gripper pads extended, here it is written advanced through one forward stroke.

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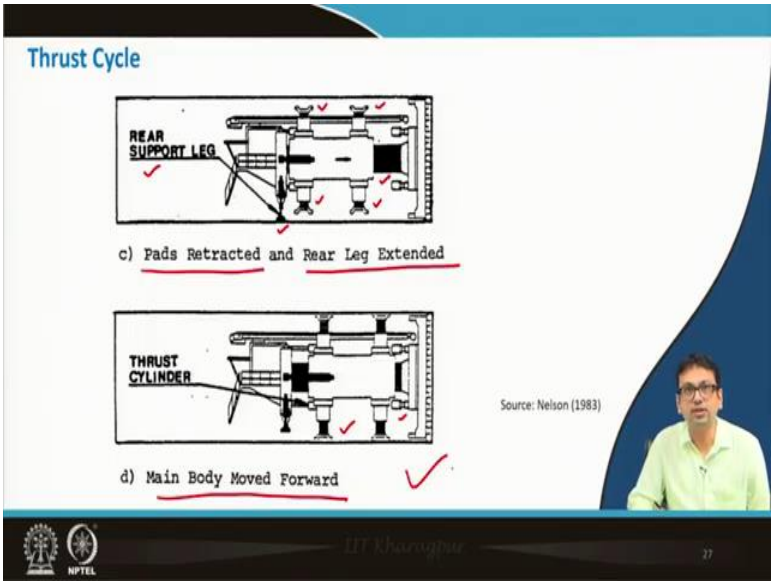

Now next picture is; what is written pads retracted and rear leg extended. So, you see pads are now retracted and the rear support leg you see is extended. So now, what will be done is, so then this main body moved forward, how? Because you see now in this gap was there, now you see there is no gap, entire thing has come forward and now again, these gripper pads are further extended.

So, now what is happening, so because of this means in this thrust cycle see the main body moved forward, so that is very nicely shown through these pictures.

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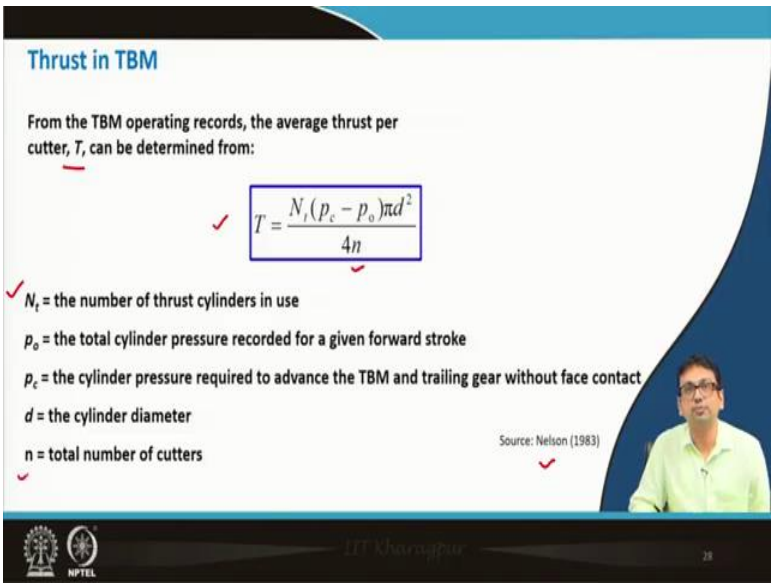

Now from the this TBM of this means let us try to learn see some expressions for this thrust per cutter. What is stated from the TBM operating records the average thrust per cutter that is *t* can be determined from this equation, so this you can find in obviously in this Nelson (1983) as the previous diagram is also from Nelson (1983) as it is shown and the reference is provided earlier, I can show you reference also yeah.

So, this is the reference, so here actually N_t is the number of thrust cylinder in use, P_0 is the total cylinder pressure recorded for a given forward stroke, P_c is the cylinder pressure required to advance the TBM and trailing gear without face contact and small *d* is the cylinder diameter and in this *n* is the total number of cutters. Now we have discussed the thrust, now torque system in TBM.

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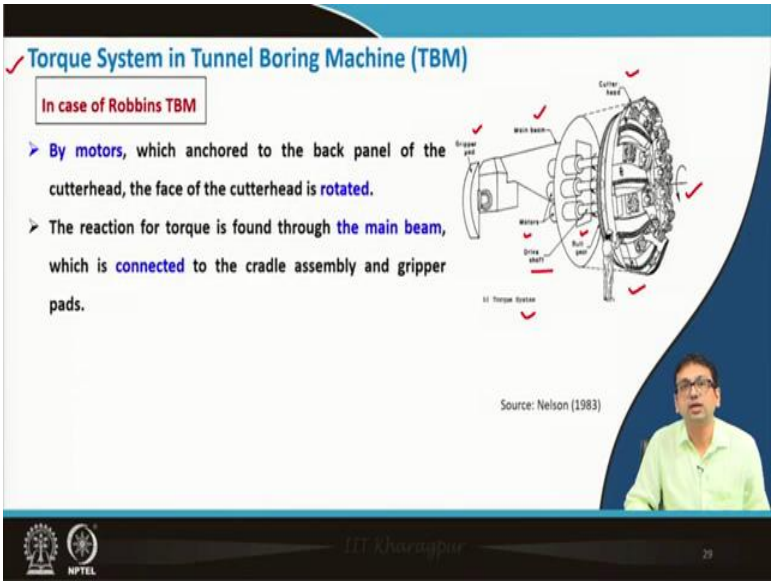

In case of Robbins TBM, by motors, you see again the, this Robbins TBM torque system you see here look at here, so torque you can clearly means this is for the torque and earlier one was for thrust. So by motors which anchored to the back panel of the cutter head, the face of the cutter head is rotated. The reaction for torque is found through the main beam which is connected to the cradle assembly and gripper pads actually.

You see drive shaft, gull gear all this cutter head, main beam, motors all this thing you can see gripper pad, so what is state, the reaction for torque is found through the main beam which is connected to the cradle assembly and gripper pads.

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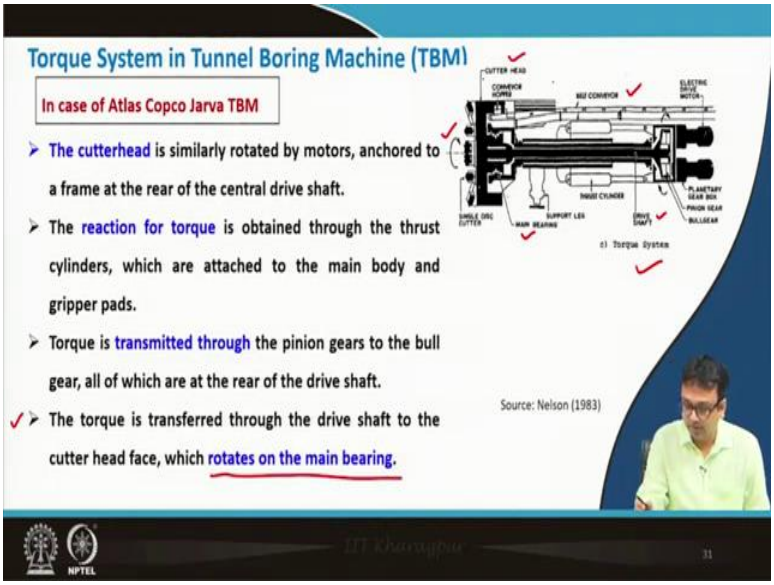

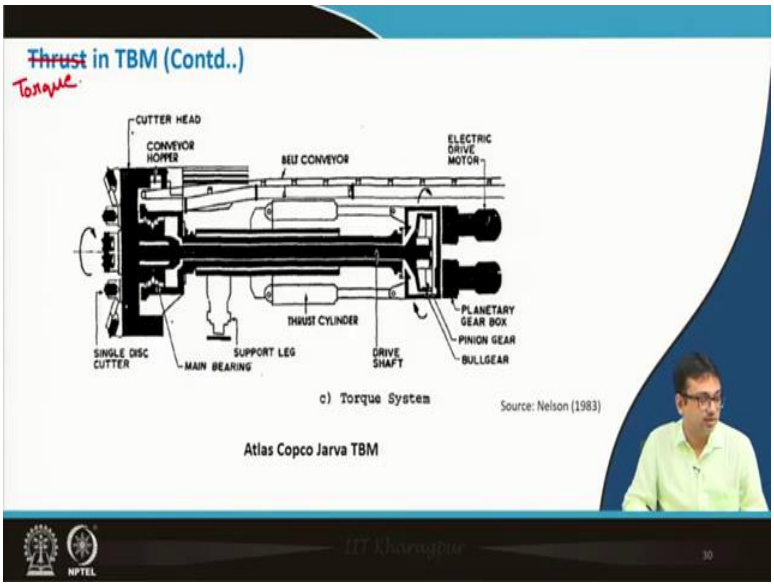

Now in case of, this is for the torque system in the Atlas Copco Java TBM, sorry here it should be, the torque, this is not for this, this is for the torque, torque in TBM we are discussing about that. So now, torque system in TBM in case of Atlas Copco Java TBM so same diagram as it is shown in previous slide, the cutterhead similarly rotated by motors anchored to the frame at the rear and the central drive shaft.

The reaction for torque is obtained through the thrust cylinders which are attached to the main body and gripper pads, torque is transmitted through the pinion gear to the bull gear all of which

are at the rear of the drive shaft and the torque is transferred through the drive shaft to the cutter head face which rotates the main, this bearing which rotates on the main bearing.

So, all these things are nicely shown in this one, you can see the torque is applied, this is the cutter head, so this is all about the Atlas Copco Jarva TBM. So another one was Robbins TBM.

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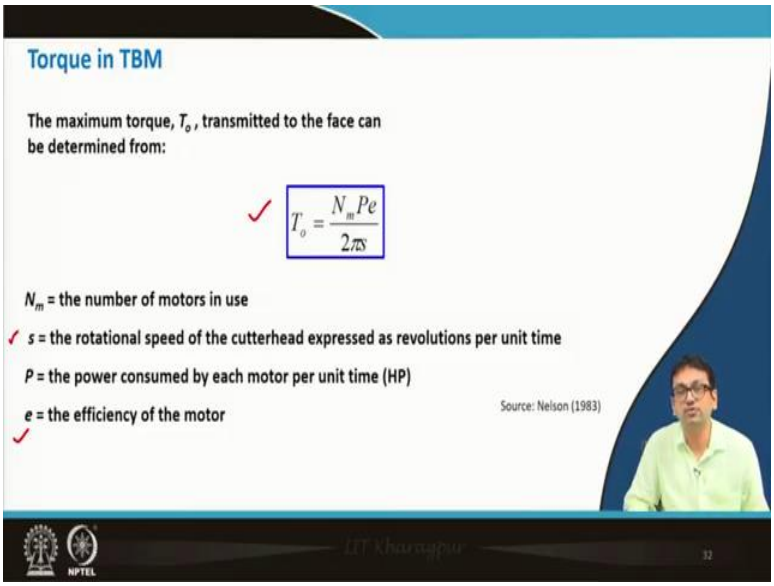

Now torque in TBM; the maximum torque T_0 transmitted to the face can be determined from this simple equation; T_0 is equal to N_mPe /2πs. Now N_m is the number of motors in use, s is the rotational speed of the cutter head expressed as revolutions per unit time, P is the power consumed by each motor per unit time, this should mean horsepower HP and e is the efficiency of the motor, so based on that one can find out the maximum torque T_0.

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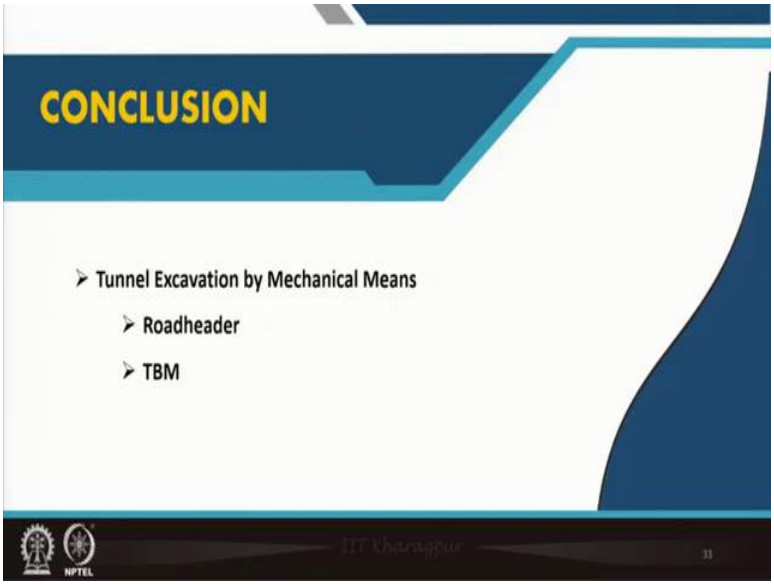

So, so actually today we have learnt about the tunnel excavation by mechanical means. There are two equipments like roadheader and TBM. Roadheader is obviously, as I have mentioned that when means relatively less costly means as compared to the TBM. TBM is quite huge machine, so costly and operating cost is quite high.

So, if possible people generally go for the roadheader but TBM is become like essential when maybe you have to go for a few kilometers tunnel. You have to construct in hard rock then TBM use of TBM becomes very much essential. We have learnt about different types of TBMs also and we have tried to understand the mechanism how it works. So, thank you. Let us conclude here.