Traction Engineering
Professor Hifjur Raheman
Department of Agricultural and Food Engineering
Indian Institute of Technology, Kharagpur
Lecture 18
Tractive Performance Prediction Models – Wismer and Luth

Hi everyone, this is professor H. Raheman from Agricultural and Food Engineering Department, IIT Kharagpur. I welcome you to this NPTEL course on Traction Engineering. This is lecture 18, where I will try to cover tractive performance prediction models. Basically, what is developed by Wismer and Luth?

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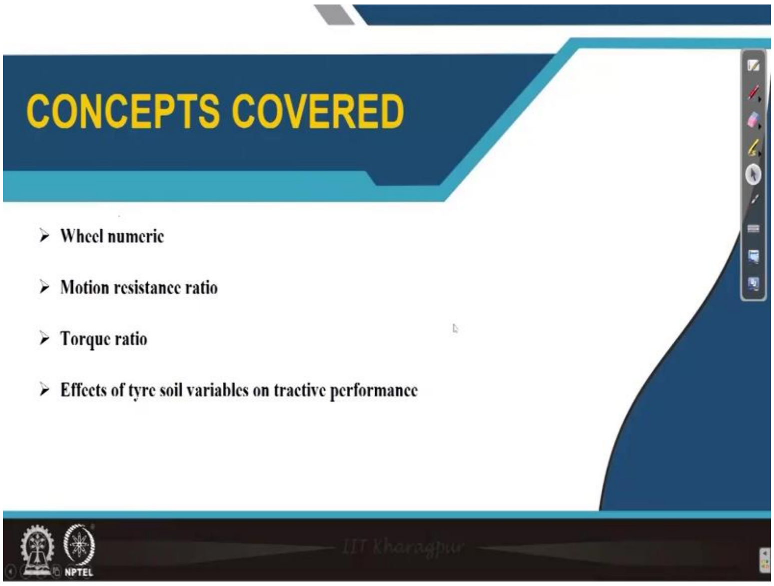

The concept which will be covered is wheel numeric, motion resistance ratio, torque ratio and effects of tyre soil variables on tractive performance. So, we have basically derived the theoretical equations, which will be necessary for developing the tractive effort. But if you look at those equations, those equations require, what is the distribution of normal pressure? What is the shear stress distribution? So, in practical field, it becomes really difficult to do that exercise. So, what you have to do is some equations or should be, some equations should be available.

So, that easily if you know, this is the weight which is coming and this is the soil condition then immediately you can say, okay, this is the available pull or this is the rolling resistance. So, to do that, there are scientists. They have carried out this kind of activities and based on different field data related to tractors, soil tyre combinations of different sizes, different soils, then based on the single wheel testing data, scientists Wismer and Luth, he has developed some equations related to tractive performance evaluation.

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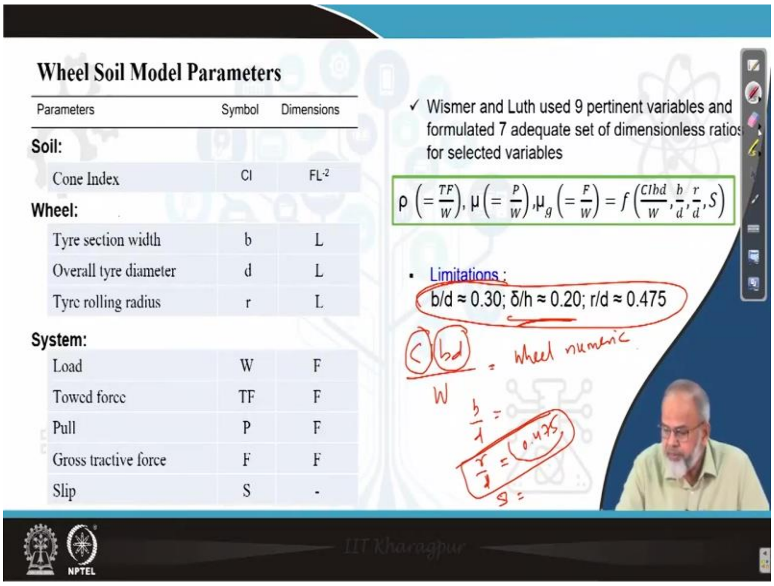

So, basically what he has done is he tried to identify which are the parameters which is going to affect the performance parameters. performance parameters means your pull, rolling resistance, tractive efficiency etcetera. So, he tried to identify this, in terms of soil parameters, in terms of wheel parameters, in terms of system parameters. So, let us see what are those parameters? Under soil, he identified a parameter called cone index. Basically, cone index gives the force required to push a cone shape probe into the soil that means, it will give indirectly the strength of soil.

So, it is symbolized as CI and its dimension is FL^{-2}, force per unit area. Next, he identified what are the wheel parameters? Under wheel parameters, Wismer and Luth, they selected tyre section width, overall tyre diameter and tyre rolling radius and these are denoted as b, d and r and they the units are length units.

Then he tried to identify what are the system parameters? Under system parameters, he identified, these are the parameters like load, how much is the load acting on the wheel, what is the force required to tow the wheel which is nothing but your rolling resistance then, what is the pull which is developed then, what is the gross tractive force which is basically the summation of pull and rolling resistance and while developing the gross tractive force, what is the corresponding slip?

So, he has identified 9 parameters and he applied dimensional analysis technique to find out the relations, the dimensionless your variables to develop that tractive equation. So, if you are applying Buckingham π theorem for dimensional analysis technique, then 9 minus 2 will be 7 dimensionless variables. So, what are those 7 dimensionless variables? One is your towing force upon W, pull upon W, tractive force upon W. So, I have indicated here ρ as towing force upon W, μ coefficient of traction, which is nothing but p upon W and μ_g is a ratio of thrust upon W, tractive force upon W.

They are the functions of cone index, they are the function of the tyre parameters, they are function of wheel slip. Now, these parameters he tried to combine to find out 4 different dimensionless ratios. So, what are those parameters? One is CIbd/W that means, he has combined the strength of soil with the size of the tyre, b and d and then W, what is the weight coming in the, So, on the wheel.

So, CIbd/W, that is called as wheel numeric. He has combined these parameters, parameters of soil, parameters of wheel and what is the external load which is acting? So, this is denoted as wheel numeric. Then he defined another parameter, dimensionless parameter b/d then r/d ratio then S, slip is dimensionless. So, r/d, b/d. So, using these 4 parameters he tried to find out relationship and he developed 2 equations, one for pull, the other one is for rolling resistance. If you look at this one, CIbd, there have indicated that tyre rolling radius r, r/d, r/d for most of the tyre is around 0.475.

That means, it is basically a constant factor. This is not varying for the agricultural tyre. The other parameters which are varying is b/d and the slip. Slip again depends on what is the type of soil and what tool is developed? So, that depends on, slip is dependent on that. The only thing which is left is b/d ratio. So, Wismer and Luth, they have taken b/d ratio as 0.3 for all combination of tyre, they have tried in different soils they have maintained the b/d ratio is 0.3 and for all agricultural tyre, they have taken δ/h ratio. That means, tyre deflection to section height ratio a 0.2.

So, these are the practical limitations. In the sense, under these variables, he tried to develop some equations. Let us see what are those equations which are developed by Wismer and Luth? And then we will discuss what are its limitations later on.

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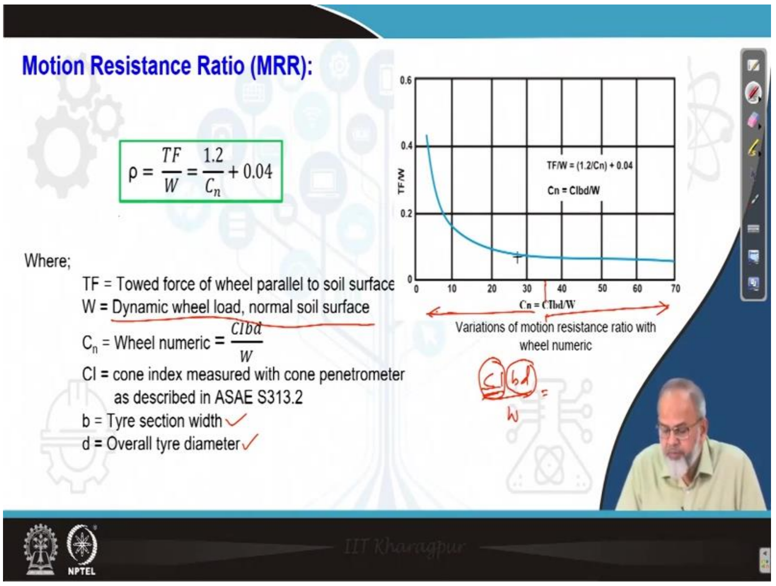

Now, he has developed this equation, motion resistance ratio which is nothing but the ratio of towing force to weight coming on the wheel. Weight when I said this dynamic weight. In case of a tractor when it will try to pull an implement that will be weight transfer from the implement side as well as from the front axle. So, the weight transfer is there. So, that means, if the starting condition weight distribution is 70:30 or 65:35 in the rear and the front axle then the 65 percent will be increased. So, if you take only 65 percent that means there are 2 wheels on the rear axle.

So, 65 percent of the total weight divided by 2. That will give you the weight coming on each wheel. Now, during pulling certain implement, since there is some weight transfer. So, what will happen? This 65 percent divided by 2 has to be increased. So, we should know, what is the dynamic weight which is coming on the wheel? Then only we can find out what is the motion resistance ratio? So, these W which I have indicated, written as dynamic wheel load. Now, this is equal to 1.2 divided by C_n, C_n is your wheel numeric, plus 0.04.

So, C_n is CIbd/W and CI has to be measured following the procedure, which is given in American society of agricultural biological engineers, standard 313.2. And we have to measure the tyre section width, we have to measure the overall diameter. So, then only you can find out the value of motion resistance ratio. So, when I tried to plot it versus different wheel numerics. So, wheel numerics are varied from say 5 to 70 then the nature of the curve will be like this.

Initially it is very high then afterwards it drops very rapidly then it becomes almost constant after 35. Why it is so, and what does it reflect? When I said wheel numeric is 5. Wheel numeric is 5 means CIbd for a given tyre size of the pneumatic wheel bd cannot be changed, only change is your CI that means strength of soil. So, when the soil is soft, what happens? Strength of soil is less so, the wheel will try to sink. So, resistance will increase. So, CIbd/W will reduce because CI is less in soft soil. So, CI will reduce. So, it will move to, if you are taking the centre point here then it will move towards this one or the strength of soil is reduced. If the strength of soil is increase, it will move towards this right side.

So, strength of soil is reflected by cone index. So, that means, if soft soil, we will get more rolling resistance. If hard soil then will move toward the right side, you will get the lesser rolling resistance. Because sinkage is less, compaction is less so, rolling resistance is less. So, basically on hard soil, it is a tyre deflection. So, that will give rise to rolling resistance. But in case of soft soil, it is not the tyre deflection. It is the sinkage that will come into picture. So, the nature of the curve is well justify looking at the strength of the soil.

But the only difficulty is, it does not differentiate between a powered wheel or a rigid wheel or a towed wheel, it will give the same value. If it is a powered wheel, is it is an unpowered wheel or towed wheel for both the cases it will give you same value of rolling resistance which is very difficult to say. Why? Because when there is a slip certain amount of sinkage will be there. So, that part is not reflected. So, we will discuss in detail what is the other difficulties? Let us now move to the other equation which has been developed.

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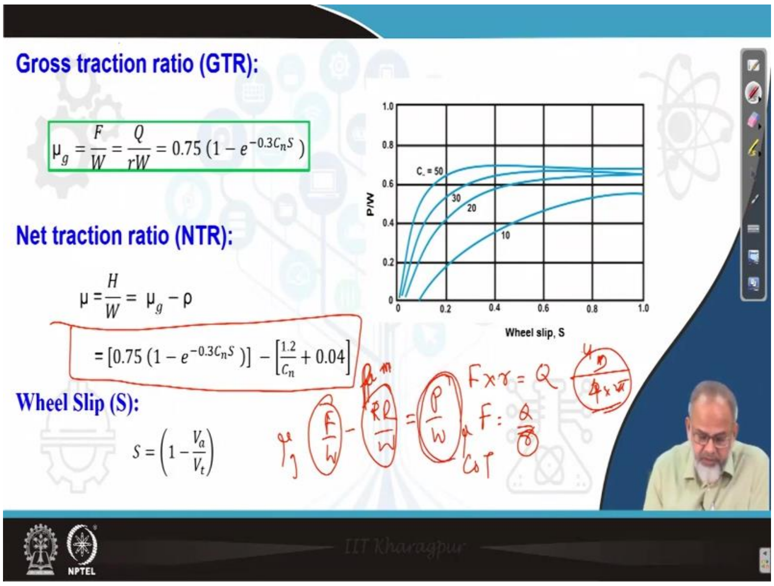

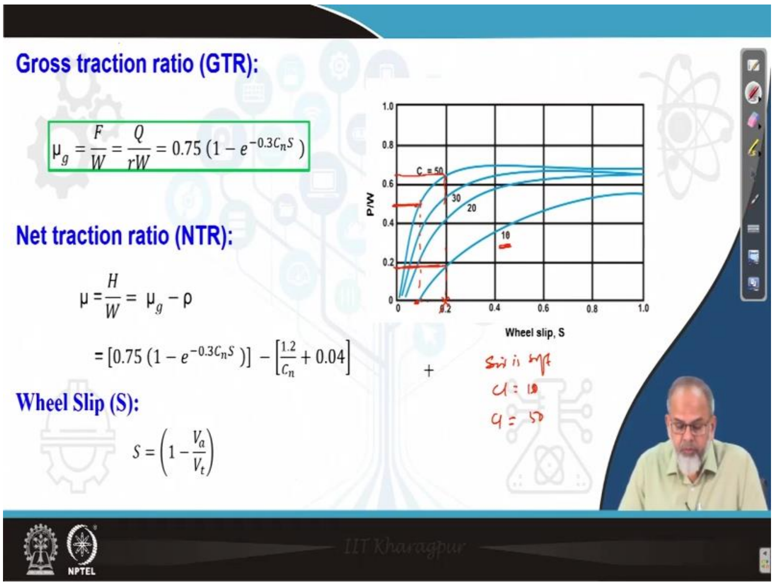

The second equation which he developed is related to gross traction ratio. So, gross traction ratio means if the ratio of the tractive force which is developed at the contact patch divided by the dynamic weight coming in the wheel. So, in other words, we can replace F with Q/r. So, Q/r, Q is the torque which is acting on the axle, r is the rolling radius. So, that way thrust×radius will give you Q. So, we have replaced F that is tractive force with F×r, tractive force into rolling radius as Q.

And F we are replaced, we have replaced as Q/r. This rolling radius is found out on a hard surface, hard smooth surface at self-propelled condition. We have to run the wheel and then taking the number of revolutions. we have to divide it by n×2π. Suppose we make 4 revolutions then whatever distance it covers D/(4×2π). So, that will give you what is the rolling radius.

Now, Q/rW and W is the dynamic weight

$$\frac{Q}{rW} = 0.75 \times (1 - e^{-0.3C_n s})$$

Where C_n is the wheel numeric, s is the slip. So, once you know the gross traction ratio, if you deduct the rolling resistance ratio, then it becomes

$$\frac{F}{W} - \frac{R}{W} = \frac{Pull}{W}$$

That means this is your coefficient of traction, this is your motion resistance ratio MR, RR and this is μ_g, μ is coefficient of traction and ρ is the rolling resistance.

So, when I deduct it then it becomes. This is the equation for the pull which is developed, pull by W ratio 0.75 into 1 minus e to the power 0.3 CnS, this is gross tractive effort, minus 1.2 by Cn plus 0.04. So, that will give you the coefficient of traction. And slip, we define as 1 minus Va upon Vt, Va is your actual speed and Vt is the theoretical speed. Now, when you try to plot these P by W that means, net traction ratio versus wheel slip starting from say 0.01 to 100 percent. So, and this has been plotted for different soil conditions which are reflected as wheel numeric are 10, 20, 30, 50 like that.

So, what we observed is when we decrease the slip, the nature of the curve, what we say, we are getting lesser slip whether it is at wheel numeric 10 or whether it is a numeric 20 or whether is at wheel numeric 30, if I draw a line somewhere at 10 percent. So, this is the pull which is developed, COT. Now, when I increase the pull to, the slip to 20 percent then you can see this is the case. So, that means after certain slip these values are almost maintaining a constant value.

But in case of this wheel numeric when it is 10 it is still increasing beyond 80 percent you can say, is still increasing. So, what does it 10 indicates? That means the soil is soft CI 10 and CI 15 means soil is hard. So, in hard soil the pull which is developed or the COT which is developed is much higher than the COT which is developed in soft soil. That means, if you look at this point, if you look at this point, there is a difference of nearly 0.45, 0.5 like that.

Now, 20 percent slip again same difference if you look at this one, if you look at this one, so, there is a difference of 0.45. So, we conclude from here that the P by W or the coefficient of traction is more in hard soil that means in hard soil, the tractor could be able to develop more pull. In soft soil the tractor will be developing less pull, why? Because the power is lost in overcoming the rolling resistance. So, the net pull available will be less in soft soil whereas in hard soil the rolling resistance is lesser hence your pull developed will be more and your coefficient of traction will be more.

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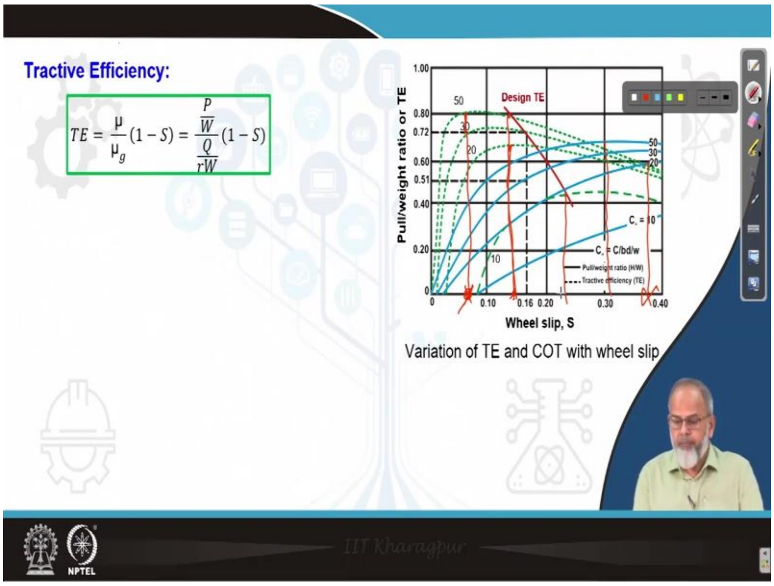

Now, once you know the coefficient of traction, then rolling resistance and gross coefficient of traction then the one most important component which is computed while calculating or while evaluating the performance of a tyre is your tractive efficiency. So, tractive efficiency is basically the output by input. So, in case of a tractor or in case of a single wheel output is your drawbar power or output is your tractive power and which is the pull into forward speed and the input will be your axle power.

So, if I take the ratio so

$$Tractive\ efficiency = \frac{\mu}{\mu_g} \times (1-s)$$

So, P/ W which is the coefficient of traction and the denominator is a Q/rW, Q is the tractive force divided by W×(1-s). So, this is basically derived from fundamental equations. So, once we know those equations which have been developed by Wismer and Luth, next is we can put those values here to find out the tractive efficiency.

Now, based on the output data from Wismer and Luth, it has been plotted how the pull to weight ratio is varying that COT is varying which is indicated by these blue lines and the tractive efficiency is varying which is indicated by the dotted green lines for different wheel numeric, CIbd/W starting from say 10 to 50. So, what we observe here is the slip at which you are getting maximum pull or COT value and the slip at which you are getting maximum tractive efficiency.

If I draw a line suppose at wheel numeric of 50, this is the maximum tractive efficiency you are getting. So, this corresponds to your wheel slip of say around 8 percent. Now, the maximum pull which you are getting is from this point only 30 percent. So, there is a difference, the slip at which we are getting tractive efficiency, maximum tractive efficiency, the slip at which you are getting maximum pull. Now, if you look at 20. Suppose this is 20 lines, so, maximum we are getting, maximum tractive efficiency is here which is corresponding to slip of say around 15 percent and the pull which we are getting at 20 is still increasing. So, maybe around this slip is here.

We need more power to be developed at the same time we need more efficiency. So, what to do now? We have to find or we have to compromise, compromise between whether we require more pull or whether we require more tractive efficiency. So, that is why a design tractive efficiency curve is given. So, it is at the higher wheel numeric values it is the slip, the corresponding slip is 15 percent. At lower numeric, wheel numeric values the slip is more than 20-25 percent.

So, you have to find out a suitable slip value to make a compromise between these design, between the tractive efficiency and the COT. But nevertheless, the equation which has developed by Wismer and Luth are very simple in the sense only 2-3 parameters are required to compute the performance parameters of a wheel.

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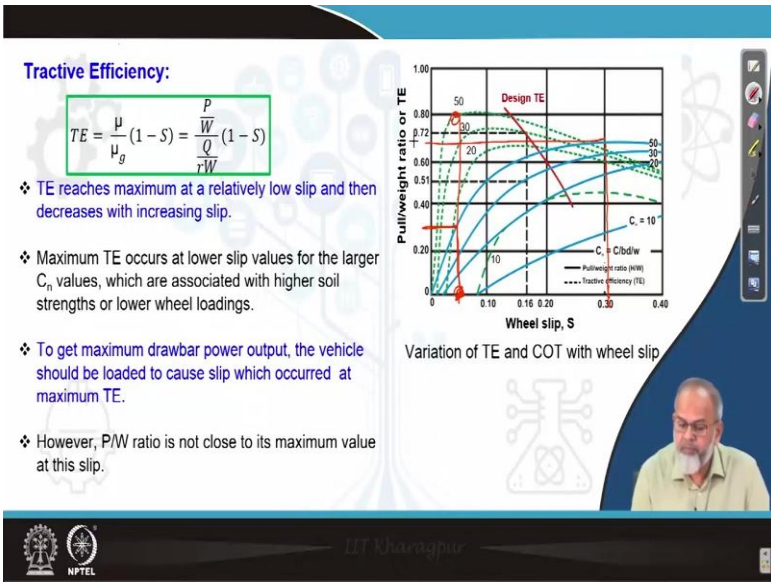

The limitations if you look at tractive efficiency reaches a maximum at a relatively low slip value and then it decreases with increase in slip. So, maximum tractive efficiency occurs at lower slip values for the largest C_n values which are associated with higher soil strengths. That means when CI is more, cone index is more, you will get better tractive efficiency or wheel loading is less than you will get better tractive efficiency. To get maximum drawbar power output, the vehicle or the wheel should be loaded to cause slip which is occurring at maximum tractive efficiency.

Otherwise, you will not get maximum output. So, you have to load the wheel in such a way that the slip should be around this. Suppose in 50. So, we have to load in such a way that the slip is around 5 percent and get the maximum tractive efficiency and if you require more pull then you have to have more slip then only get maximum pull. So that is why in end I have a P by W ratio that is COT ratio, coefficient of traction is not close to its maximum value at this slip.

If this is the maximum tractive efficiency, the slip corresponded maximum tractive efficiency, at here only you are getting 0.3, whereas at 30 percent you are getting near to 0.72. So, you have to make a compromise between maximum COT and maximum tractive efficiency.

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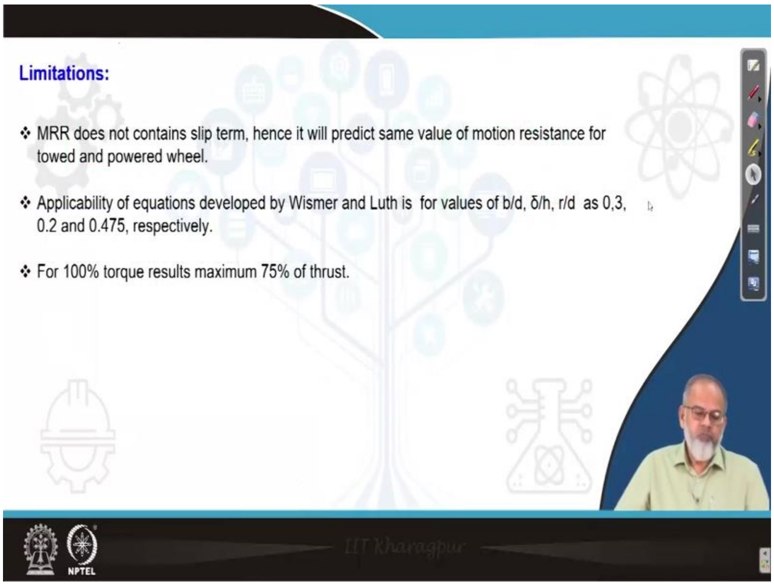

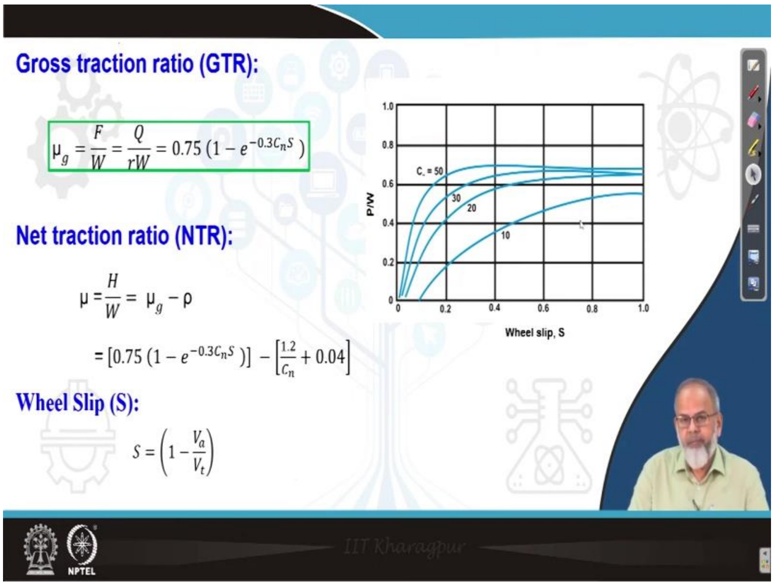

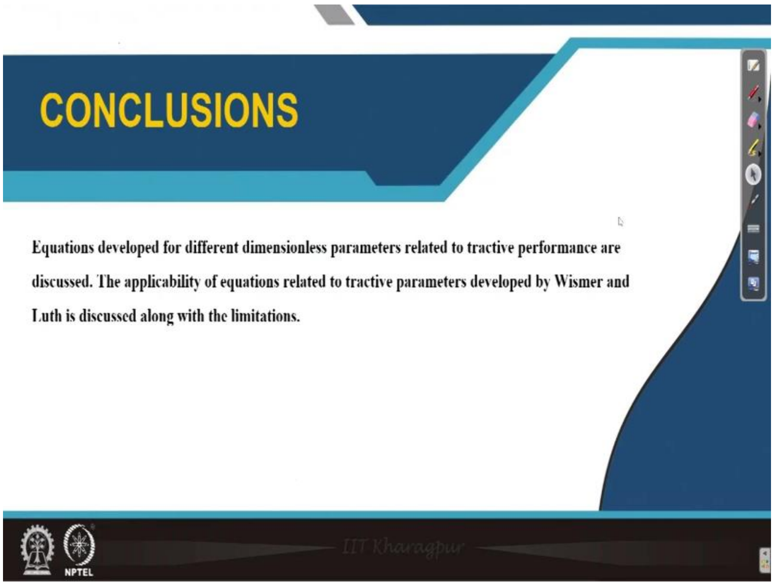

Now, looking at the limitations of Wismer and Luth equation, the motion resistance ratio as I told in the beginning, it does not contain a slip term. So, that is why it will predict the same value of motion resistance for a towed wheel as well as a powered wheel. Applicability of equation which is developed by Wismer and Luth is only limited to b/d ratio as 0.3, δ/h ratio as 0.2, and r/ d ratio as 0.475. So, these are the limited applicability.

If you exceed the b by d ratio, if you exceed δ/h ratio or because r/d ratio is nearly constant. So, these are the 2 values 0.3 and 0.2. If we exceed then applicability of Wismer and Luth is not known.

And another limitation is if you look at the equation given by Wismer and Luth, maximum we can develop 75 percent of the torque which is applied to tractive force that is another limitation. So, with these limitations, since these equations are very simple and they can be easily handle so that is why it was getting popularity earlier. So, I took these equations and try to discuss. Thank you.