Traction Engineering
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Lecture 21
Effect of tyre parameters on tractive performance of tyre

Hi everyone, this is Professor H Raheman from Agricultural and Food Engineering Department, IIT Kharagpur. I welcome you all to this NPTEL course on Traction Engineering. This is lecture 21 where I will try to cover the effect of tyre parameters on the tractive performance of a tyre.

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The concept which will be covered is, by varying the diameter, width and stiffness of the tyre, how it is going to affect the tractive performance? Those things will be discussed in this class.

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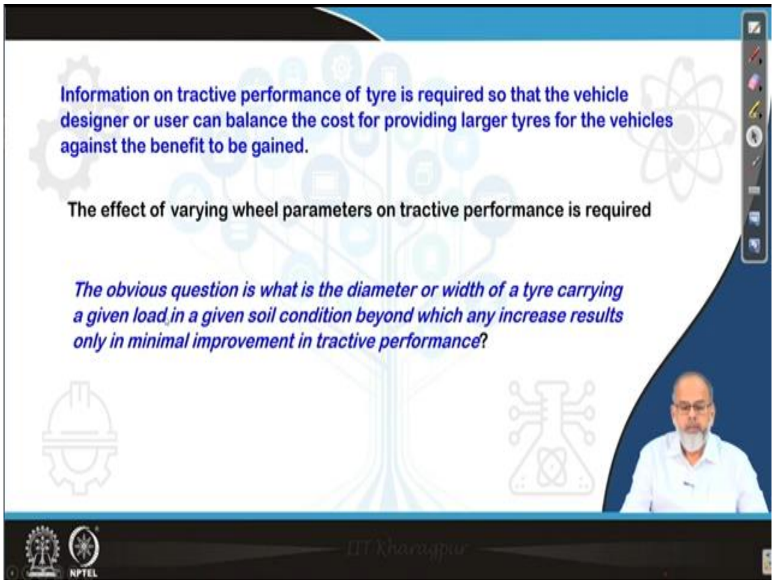

Some of the questions which will come to our mind is, do you have sufficient information on tractive performance of tyre? That is required so that the vehicle designer or user can balance the cost of providing larger tyres for the vehicles against what is the benefit he is gaining. So, to get this information, we need to study or we need to know, what is the effect of varying wheel parameters on tractive performance?

So, what diameter or what width of tyre carrying a given load in a given soil condition beyond which with increase in tyre diameter or with increase in tyre width, there is no further improvement in tractive performance. That means there is minimal improvement in tractive performance. So, do this kind of exercise or to gather this information, we need to know what is the effect of varying width or varying diameter so that we can calculate the tractive performance. When I say tractive performance, obviously, the questions which will come to our mind is what are the parameters I am going to study? The first parameter is your rolling resistance, the second parameter is your coefficient of traction and third parameter is coefficient of gross traction. In fact, coefficient of gross traction is nothing but summation of coefficient of rolling resistance plus coefficient of traction.

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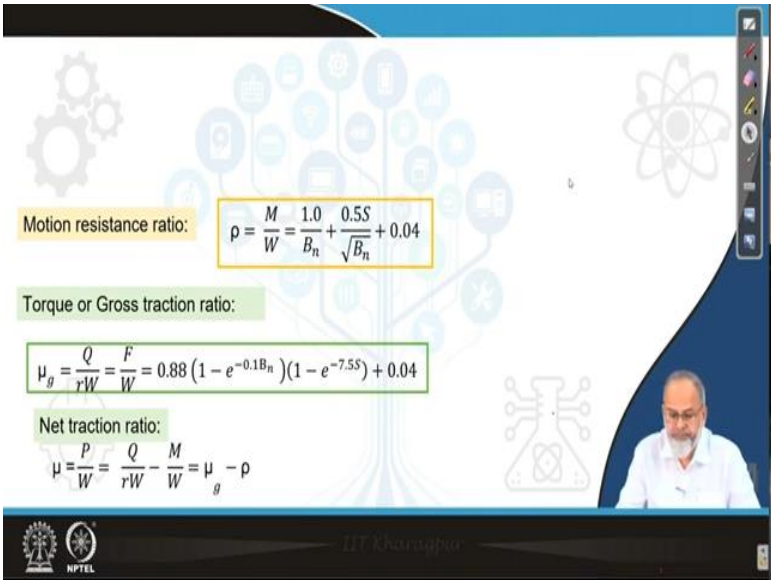

So, when you are interested in finding out coefficient of rolling resistance then what are the equations available and how can I utilize these equations? The most important or most commonly used equations nowadays is your Brixius equation which we discussed in our previous classes. And there is the rolling resistance expression has been given as

$$Rolling\ resistance = \frac{M}{W} = \frac{1}{B_n} + \frac{0.5s}{\sqrt{B_n}} + 0.04$$

Brixius has also given an equation for coefficient of gross traction in terms of torque ratio. So, which is given as

$$\frac{Q}{rW} = \frac{F}{W} = 0.88 \times (1 - e^{-0.1B_n})(1 - e^{-7.5s}) + 0.04$$

So, knowing these two equations, the third equation which is nothing but the traction ratio that can be computed. But in this equation the important thing is what is B_n? And how do you calculate B_n? As you know B_n is nothing but the mobility number and mobility number can be calculated if you know the strength of the soil that is core index and the tyre section width and the tyre diameter. In fact, tyre diameter has to be derived from a tyre section with knowing the aspect ratio.

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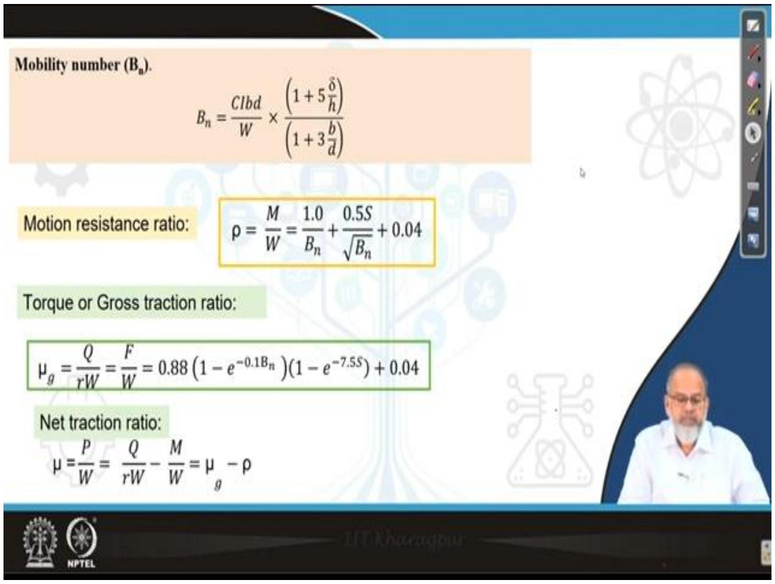

So, first thing is, I will try to calculate mobility number and mobility number is nothing but

$$B_n = \frac{CIbd}{W} \times \frac{\left(1 + 5\frac{\delta}{h}\right)}{\left(1 + 3\frac{b}{d}\right)}$$

So, here the parameters which are going to affect the mobility number is cone index then section width, diameter, W is the weight coming on the wheel, then δ/h ratio, b/d ratio, these are the parameters which are going to affect.

Now, for a given tyre, suppose in the market we have tyre sizes starting from 12.4-28, 13.6-28 16.9-28, so, what is the diameter, corresponding diameters? If we know then we can take one such wheel and then what is the load coming in the axle if we know then we can calculate and δ/h ratio you have to assume 0.2.

So, in this class I will try to explain what will happen if I increase b keeping d and δ/h constant. Then increasing d, keeping b constant and δ/h constant. So, how it is going to affect the rolling resistance that is motion resistance ratio and the torque or gross traction ratio? Again, in the end I will try to cover by keeping b and d constant. I will try to vary the tyre stiffness, tyre stiffness means nothing but the δ/h ratio. So, usually we take 0.2 but will vary this and we will see how it is going to affect those traction parameters.

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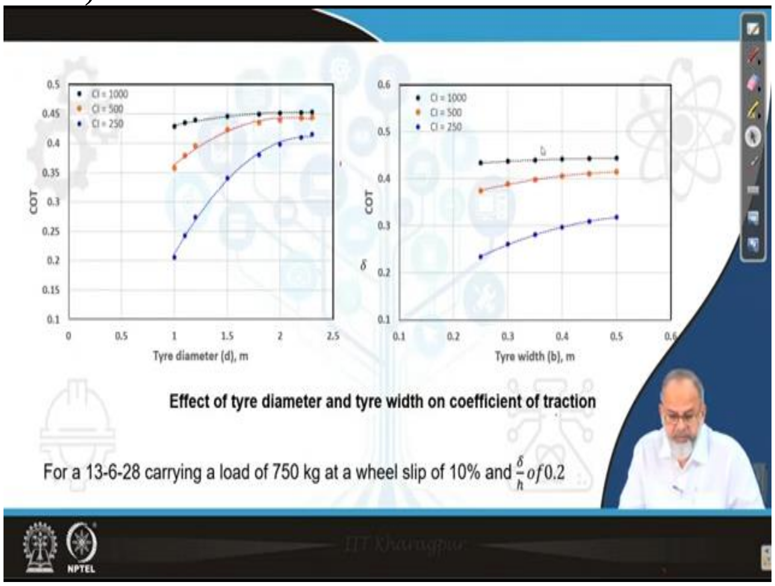

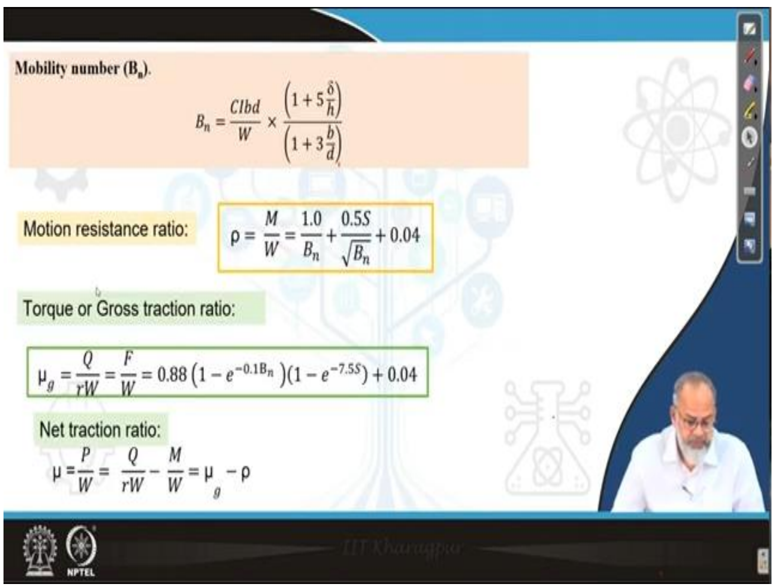

So, what I have done is I have taken a 13.6-28 tyre, is a bias ply tyre, which will give you a diameter roughly around 1.27 meter and the section width is 0.345 meter. And for wheel slip of 10 per cent and δ/h of 0.2, I tried to vary the diameter. So, I varied the diameter starting from 1 meter to 2.4 meter and this exercise was carried out for three different soil conditions. As I said soil condition is represented by CI and CI is nothing but 1000 kPa which is corresponding to hard soil CI 500 means 500 kPa means, it corresponds to medium soil and CI 250 kPa means it corresponds to soft soil.

So, these are the three typical soil conditions and there I will try to see how the COT is varying and COT was calculated as I said in the beginning in the previous slide, COT is nothing but mu and this is the formula which will be used and taking this, I have calculated and then plotted.

So, these are the three curves which I got the blue, black one is corresponding to CI of 1000 kPa and the orange one is corresponding to 500 kPa and the blue one corresponds to 250 kPa. So, in all these three cases what you can observe is, by increasing the diameter from 1 to 2.4 meter there is increase in coefficient of traction but the rate of increase is less in hard soil and more in soft soil and medium soil is in between, lying in between.

So, that means there is a benefit but the benefit is reduced after 2 meter, if you go beyond 2 meter in soft soil, there is not much increase, if you go beyond 1.8 meter, there is no increase in case of medium soil and in case of hard soil after 1.6 meter 1.7 meter there is not much gain in coefficient of traction.

Now, next thing is the COT. How it is varying with the width, tyre width? So, here what we have done is we kept the wheel diameter as 1.27 meter and then we vary the section width starting from 0.25 to 0.5 and this exercise was carried out for three different soil conditions again, hard soil, medium soil and soft soil, and what you observed is COT in all these three conditions were increasing.

The increase is more in case of soft soil whereas, it is very minimal in case of hard soil and the medium soil is lying in between. So, that means there is a benefit in increasing the tyre width about beyond 0.4 meter. In case of hard soil or in case of a medium soil there is not much gain, and in case of soft soil even increasing the width to 0.5 meter has some benefit. So, in all these two cases I have kept δ/h ratio as 0.2.

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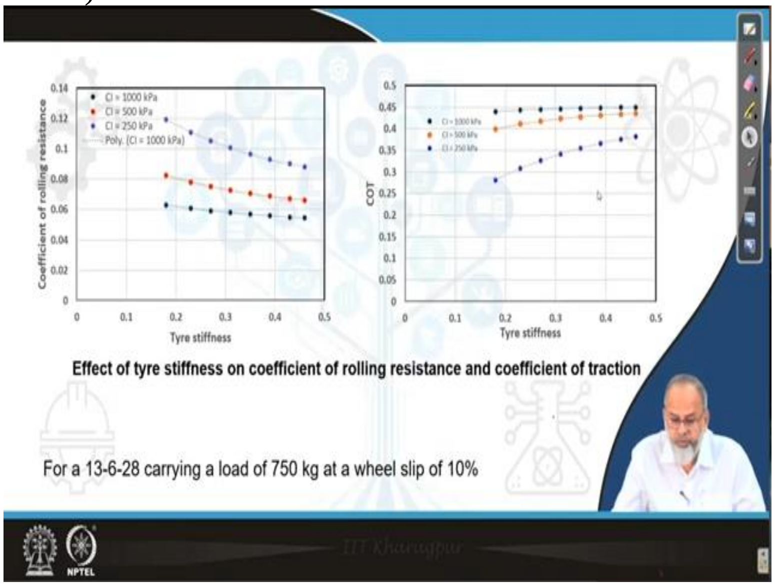

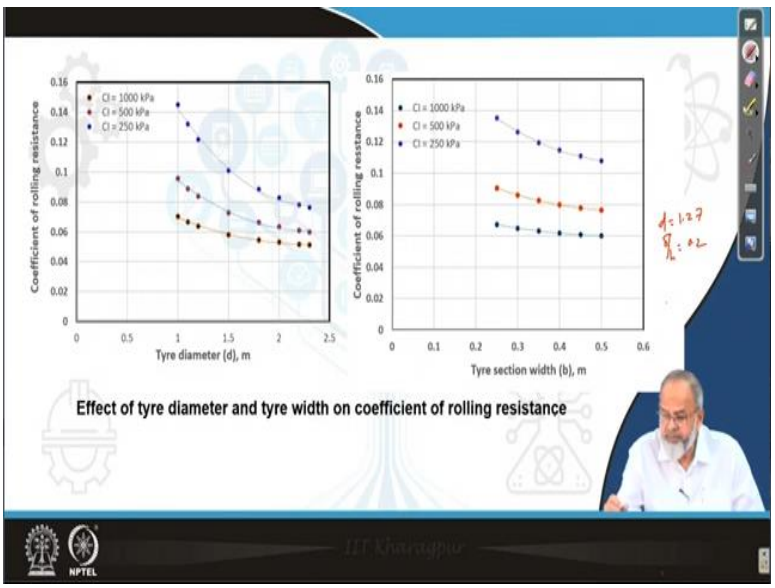

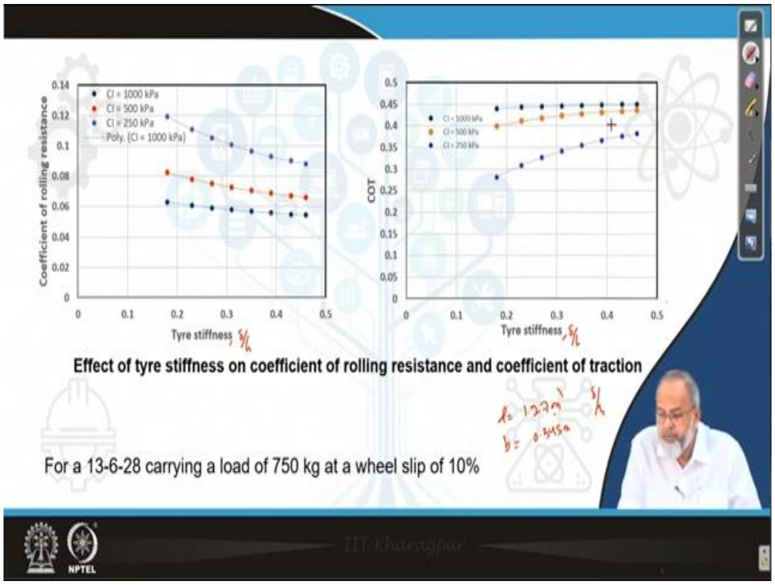

Let us now see, how the coefficient of rolling resistance is affected, because only coefficient of traction will not help you, we have to also see what is the effect of this tyre diameter and tyre section width on coefficient of rolling resistance. So, the left side figure what I have done is I have taken diameter as 1.32 then varied the, no I have taken section width. as 0.345 meter and then varied the diameter from 1 to 2.4 meter and keeping δ/h constant that is 0.2 and the weight coming on the axle I have taken as 7.5 kN. So, the reason is, in a two wheeled tractor the normal weight is 2400 kg so, that taking 65 per cent 35 per cent weight distribution in static condition we come to a value of 7.5 on each of the wheel, rear wheels.

Now, what we observed here is again coefficient of rolling resistance is decreasing. It is decreasing for the three soil conditions soft, medium and hard when you increase the diameter from 1 meter to 2.4 meter, but the rate of decrease is more in case of soft soil as compared to hard soil. No doubt there is decrease in coefficient of rolling resistance, but the rate of decrease is reducing with increasing soil strength that means from soft soil to hard soil if we move at, the rate of decrease is reduced.

Similar, exercise we have carried out for tyre section width that means I have kept diameter is 1.27 meter, diameter I have taken 1.27. δ/h as 0.2 and then vary the section width from 0.25 to 0.5 meter and this exercise was carried out taking into consideration the soil condition. Soil condition means the CI value I changed to 1000 kPa then 500 kPa and 250 kPa.

So, if you look at this figure we can see there is a reduction, reduction is more in soft soil and it is medium in 500 kPa cone index soil and the rate of decrease is less in case of 250 kPa that means sorry, in case of 1000 kPa. So, in hard soil again the gain is a little lesser as compared to your soft soil.

So, these are the two parameters, then the third most important parameter is stiffness, tyre stiffness. Usually the tyre stiffness is expressed as δ/h ratio. The more softer the tyre, there will be more deflection, harder the tyre, deflection is less. So, that is why δ is taken as this indication for tyre stiffness. So, δ/h ratio you have taken, so, this tyre stiffness is nothing but δ/h ratio.

So, in this Brixius equation while calculating the mobility number we keep the diameter as 1.327 meter and section width of the tyre as 0.345 meter and only we vary δ/h starting from 0.18 to 0.45 and this exercise was carried out for three different soil conditions 1000 kPa, 500 kPa, and 250 kPa. So, what we observed is, in case of hard soil the lowest side figure, lowest curve we can see the rate of decrease in coefficient of rolling resistance is very minimal. You can see at 0.18 it was 0.061, at 0.4 you can see it was 0.058 like that whereas, in case of a medium soil there it is little higher. That means rate of decrease in rolling resistance is little higher as compared to hard soil.

Now, in case of soft soil, yes you are getting maximum benefits that means, if you go on increasing the δ/h ratio beyond 4.4 still it is decreasing. So, there is a substantial benefit which can be obtained in soft soil if you increase the tyre stiffness. Now, if you look at the right-side figure where I have indicated the COT value coefficient of traction value. How it is varying with tyre stiffness? So, again tyre stiffness I have varied from 0.18 to 0.446 and then for three different soil conditions, I tried to carry out using the Brixius equation what will the value of COT. Now, what you observe now, you are getting maximum value of COT when the soil is hard, but by varying the stiffness from 0.18 to 0.3 at 0.32 after that, there is no gain, almost constant. Whereas in case of medium soil, the increase in COT is still continuing beyond 0.4 up to 4.41 still you are getting benefit and in soft soil even beyond 0.46 also that means, when the δ/h ratio value is beyond 0.46 still we are getting some benefit.

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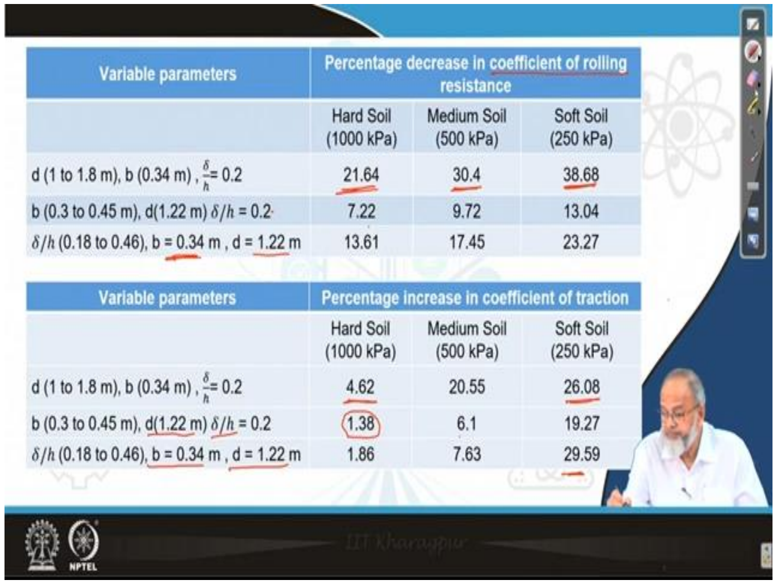

Variable parameters	Percentage decrease in coefficient of rolling resistance		
	Hard Soil (1000 kPa)	Medium Soil (500 kPa)	Soft Soil (250 kPa)
d (1 to 1.8 m), b (0.34 m) , $\frac{\delta}{h}$= 0.2	21.64	30.4	38.68
b (0.3 to 0.45 m), d(1.22 m) δ/h = 0.2	7.22	9.72	13.04
δ/h (0.18 to 0.46), b = 0.34 m , d = 1.22 m	13.61	17.45	23.27

Variable parameters	Percentage increase in coefficient of traction		
	Hard Soil (1000 kPa)	Medium Soil (500 kPa)	Soft Soil (250 kPa)
d (1 to 1.8 m), b (0.34 m) , $\frac{\delta}{h}$= 0.2	4.62	20.55	26.08
b (0.3 to 0.45 m), d(1.22 m) δ/h = 0.2	1.38	6.1	19.27
δ/h (0.18 to 0.46), b = 0.34 m , d = 1.22 m	1.86	7.63	29.59

So, let us now put in a tabular form, what is the benefit which you get when we try to increase the b value, when you try to increase the d value, when you try to increase the stiffness. All those things are summarized in this table. So, let me go through this. The table in the first case, this is referring to coefficient of rolling resistance. So, coefficient of rolling resistance, how it is changing, when you are keeping b fixed? That means section width fixed, δ/h ratio fixed and only varied the diameter from 1 to 1.8 meter, then the reduction in coefficient of rolling resistance in hard soil is only 21.64 per cent and in medium soil it is 30.4 per cent and in soft soil it is 38.68. That means maximum reduction is possible in soft soil and minimum reduction is possible in hard soil. In the second case, I kept d that is diameter as 1.22 meter and then vary section width from 0.3 to 0.45 keeping δ/h ratio as 0.2. So, what I observed is, there is a reduction in coefficient of rolling resistance. It was only 7.22 per cent, and in medium soil 9.72 per cent and in hard soil 13.04 per cent.

So, that means as compared to b and d there is more reduction in increasing d as compared to b. So, if you look at this 30.4-9.72, 38.68-13.04. So, there is more benefit in increasing the diameter rather than increasing the section width. Now, the third component whichever it is δ/h ratio, where I kept this section width as 0.34 meter and diameter 1.22 meter and then what I observed is there is a reduction, reduction in coefficient of rolling resistance in hard soil as well as medium soil and soft soil. In hard soil the reduction is 13.61 per cent, in medium soil the reduction is 17.45 per cent and in soft soil it is only 23.27. So, that means, there is a benefit in increasing δ/h ratio, but the benefit is more in case of soft soil as compared to hard soil.

So, this is one part of the story that means, only coefficient of rolling resistance we have observed. Similar exercise also we carried out for the coefficient of traction and coefficient of traction. What we observed is, by keeping b constant and δ/h constant 0.2 and varying d from 1 to 1.8 meter, you can see the change in coefficient of traction. It is only, there is an increase, increase in only 4.62 per cent. Whereas, the increase in case of soft soil is 26.08 per cent. So, there is an increase but the increase is more in soft soil.

Now, by keeping d constant δ/h constant, width varied be from 0.3 to 0.45 meter and what we observed is there is an increase of 1.38 per cent in hard soil. That means there is absolute there is no much gain 1.3 it is no gain, but there is certain amount of gain like very minimal gain, coefficient of traction that is around 6.1 per cent and in soft soil is around 19 percent and keeping b as 0.34 meter, diameter as 1.22 meter, when I increase the δ/h ratio from 0.18 to 0.46, again in hard soil the increase in coefficient of traction is only 1.86 per cent is very minimal. And in medium soil, it was 7.63 per cent and in hard soil sorry, in soft soil it is 29.59 per cent. So, the benefit if you want to really gain then increasing diameter or increasing section width or increasing δ/h ratio. The benefit is more in case of soft soil as compared to hard soil. As usual, whatever you have observed in case of coefficient of rolling resistance, the diameter has more influence in reducing coefficient of rolling resistance. Similar observations also we have we got in case of coefficient of traction. Here you can again see, the reduction is 26 per cent as compared to increase in b it has only 19 per cent and δ/h ratio that is giving very high value 29 per cent. So, what we observed from these calculations based on Brixius equation is, there is a benefit in increasing these tyre parameters, but the benefit is mostly gain in case of soft soil and in case of hard soil there is no much gain.

And if your tractor is spending most of the time in medium to soft soil, there is a possibility that yes, we can go for increasing the tyre diameter rather than increasing the section width and in addition to tyre diameter if we can increase the δ/h ratio to say 0.4 then the benefit will be still better.

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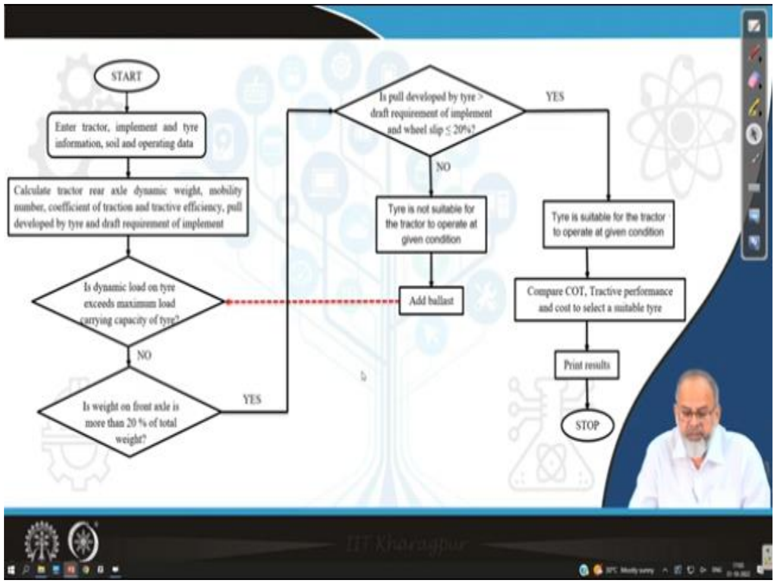

We have to calculate the rear axle dynamic weight then based on that and using Brixius equation you have to find out different traction parameters like COT, CRR then tractive efficiency then you have to calculate from COT what is the pull available and then what is the draft required by the implement. So, once all these parameters are calculated, next thing is the dynamic weight which is coming at the rear axle and part half of that will come on each of the wheels.

So, the dynamic load on the tyre whether it exceeds the maximum load carrying ability of the tyre that condition has to be checked. If it is yes, then the tyre is not suitable for tractor. I can straightaway reject this size of tractor. If it is no, then the next is whether the weight on the front axle is more than 20 per cent of the total weight or not, this will help you in steering that means front wheel weight utilization factor this much of weight is required minimum weight for easy steering. If this condition is no, if weight on the front axle is not more than 20 per cent then we have to say that the tyre is not suitable for the tractor to operate in this given conditions, then what you have to do is you have to add ballast that means you have to add weight. Once you add weight again the we have to go back to check whether the total weight coming in the wheel is lesser than the load carrying ability of the tyre or not, if no, then again we check the weight whether the weight on the front axle is more than 20 per cent or not. If those conditions are satisfied, then we have to go for checking whether the pull which is developed by the tractor keeping a power reserve of 50 per cent is equal to the draft which is required by the tillage implement. In our case it is a mouldboard plough and when this condition is satisfied that the next check is that the pull should be available at less than or equal to 20 percent of the wheel slip that is important. If wheel slip is more than 20 per cent, then it is not recommended. So, we have to say that the tyre is not suitable for the tractor to operate for the given condition.

So, to reduce slip, again we add weight and again the same exercise will be carried out. That means, you are going back to again check whether the tyre is able to carry this load or not then the front axle weight all this checking’s if it is satisfied, then we go for saying that the tyre is suitable if these three conditions are satisfied, then will the tyre be suitable for the tractor to operate that means pull is greater than the pull required and wheel slip is less than 20 percent at the front wheel utilization front wheel utilization factor is more than 20 percent.

So, we go for we can say that the tyre is suitable for the tractor to operate in these conditions and then you compute COT tractive performance and cost. So, that could be a possibility that two three tyres may satisfy this operating requirement like whatever conditions we have imposed. So, in that case, we have to find out the least cost of the tyre and which is satisfying these conditions. So, that tyre can be selected if you are getting little benefit in by paying some slightest increase in price then that is also preferred. So, the main thing is the technical requirement which you discuss that those parameters has to be satisfied. So, in this way, we can carry out selection of a tyre okay.

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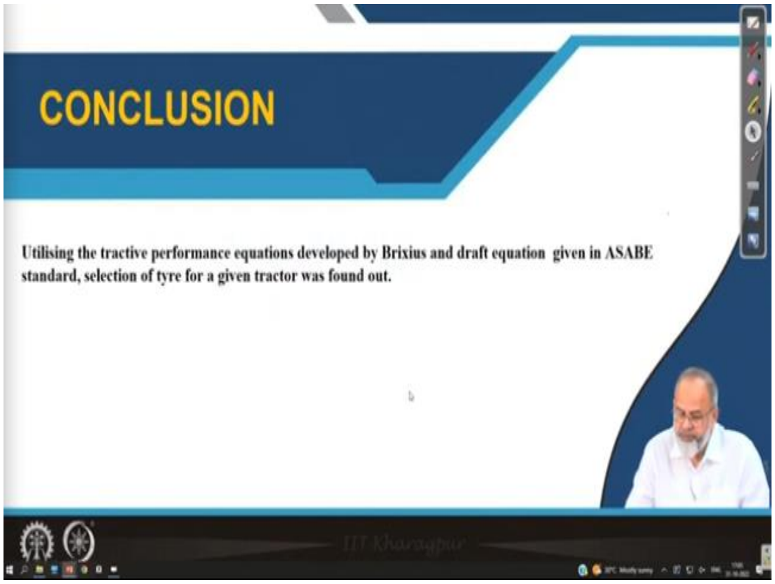

And this what you can summarize here is the Brixius equation, it is the ASABE draft equation and the front rate utilization factor and the wheel slip these are the four factors which will control how to select a tyre for a given soil conditions and operating condition. Thank you.