Traction Engineering
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Lecture 20
Tutorial 4: Tractive Performance Estimation
Using Brixius Model

Hi, everyone, this is Professor H. Raheman from Agricultural and Food Engineering Department, I welcome you all to this NPTEL course on Traction Engineering. This is lecture 20, where I will try to do some tutorials related to computation of tractive performance using Brixius model.

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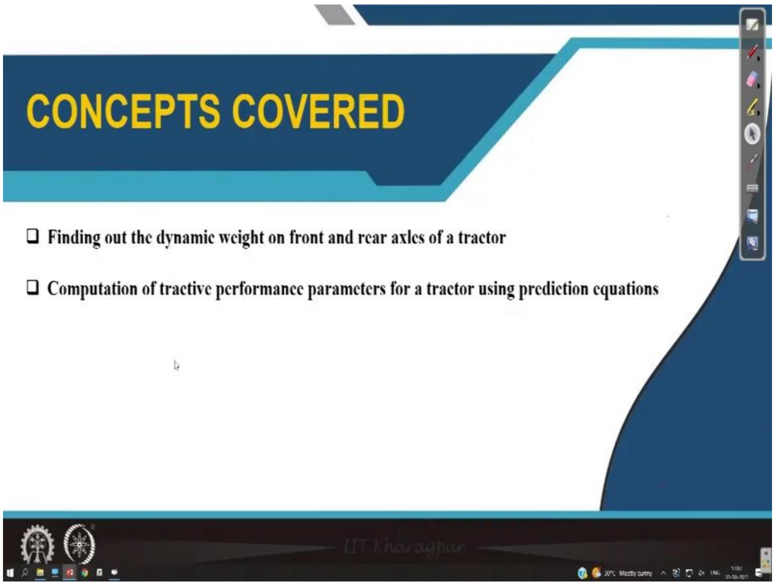

So, what I will cover here is, how to find out the dynamic weight on the front and rear axle of a tractor. Then I will try to compute the tractive performance parameters of a tractor using prediction equations.

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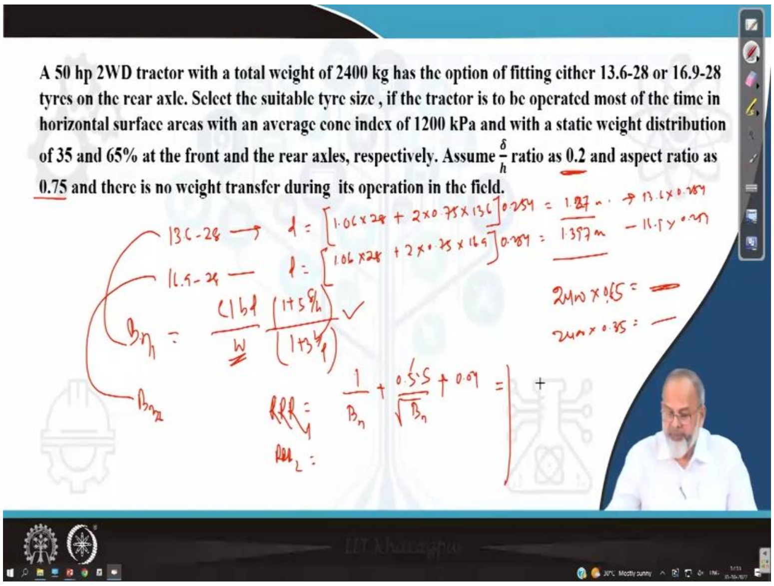

The first problem is, a 50 hp 2WD tractor with a total weight of 2400 kg has the option of fitting either 13.6-28 or 16.9-28 tyres on the rear axle. So, you have to select a suitable tyre size, if the tractor is to be operated most of the time in horizontal surface areas where with an average cone index of 200 kPa and with the static weight distribution of 35 and 65 per cent on the front and the rear axles, respectively.

And the δ/h ratio is to be taken as 0.2 and the aspect ratio is to be taken as 0.75 and there is no weight transfer during its operation in the field. That means, here the basic aim is to find out what is the equation which you are going to utilize for computing this or for selecting a suitable tyre. So, it is the again the coefficient of rolling resistance that is the main parameter and coefficient of gross traction. These are the two parameters which can be utilized to select a suitable tyre.

So, as you know Brixius equations. First thing is, you have to come up with the mobility number. So, mobility number, for calculating mobile number we have to find out what is the tyre diameter. So, tyre diameter, there are two tyre specifications are given one is 13.6-28 tyre, the other one is 16.9-28 tyre. So, if δ/h ratio is 0.2 and aspect ratio is 0.75. So, diameter I can easily calculate (1.06×28+2×0.75×13.6).

Again, I multiply with 0.254. So, that will give you 1.27 meter. The same procedure I follow to find out for 16.9-28 tyres, 1.06×28+2×0.75×16.9×0.254 that will give us 1.397 meter. So, this is the diameter. Now, the section width we have to calculate. Simply multiply 13.6, so, here will be 13.6×0.254 and here it will be 16.9×0.254. So, first to calculate, suppose this tyre is B_{n1} and this tyre is B_{n2}. So, mobility number for tyre 1 is denoted as B_{n1}, mobility number of tyre 2 is denoted as B_{n2}. So, we calculate

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

So, W will be equal to, for single wheel you have to calculate, since the tractor is operating on horizontal surface. So, weight is given, distribution is given. So, 2400×0.65. So, that will give you the weight coming in the rear axle and 2400×0.35 that will give you the weight coming in the front axle. So, half of that will be your W. So, by this way we calculate mobility number and then you can compare the mobility number itself. So, which one is higher or which one is lower. Then we calculate the rolling resistance or motion resistance ratio.

So, that is nothing but

$$Motion\ resistance\ ratio = \frac{1.0}{B_n} + \frac{0.5s}{\sqrt{B_n}} + 0.04$$

Now, in this case, since slip is not given so what we will do is, you can assume is the slip value of 10 per cent and then come to rolling resistance for wheel 1, rolling resistance for wheel 2, and then compare which one will give you lesser wheel resistance. So, the wheel which is giving lesser resistance that is better. Further, what we can do is we can compute the coefficient of gross traction to ensure that yes, we have more tractive effort.

So, first thing is mobility number, second thing is rolling resistance, third is optional. From rolling resistance itself we can conclude that this tyre is better which one is giving you a lesser rolling resistance ratio. But you can always calculate the coefficient of gross traction from there also you can conclude which tractor is giving you more coefficient gross traction and the difference from there you can calculate to find out which one will give you more power or more pull. So, from there, you can make a selection which tyre is better. Next problem will be related to dynamic weight.

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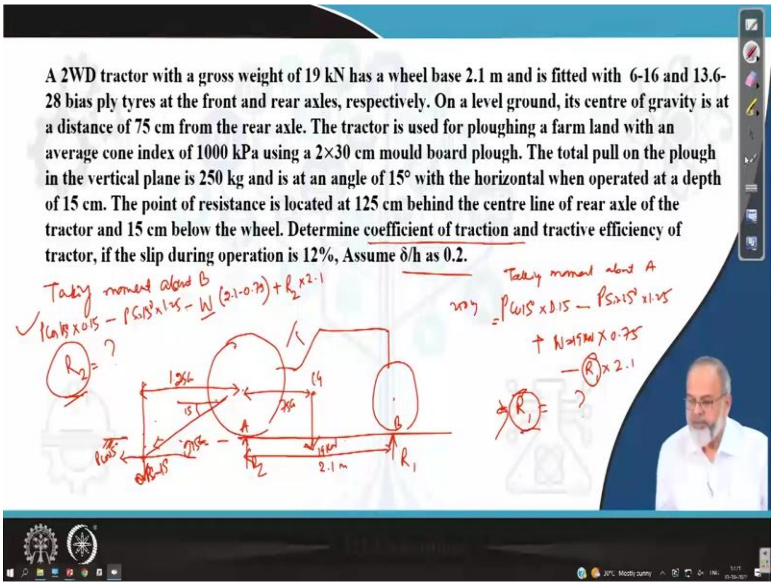

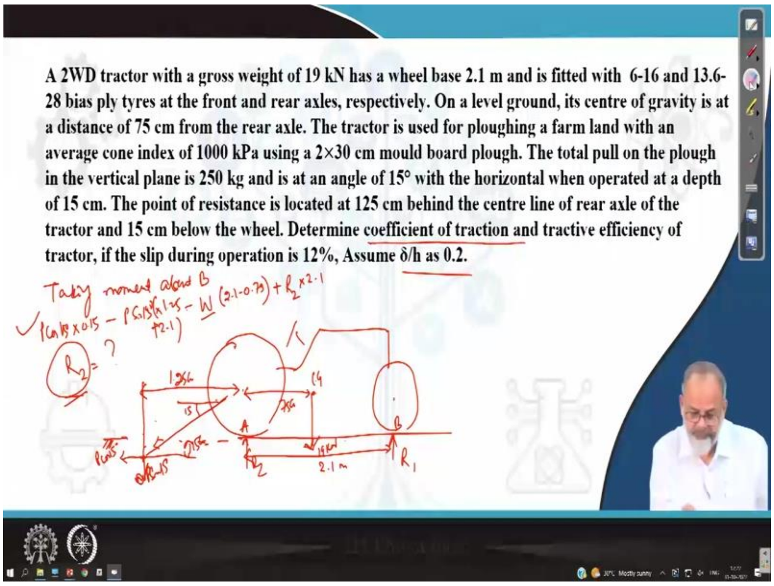

A 2 wheeled tractor with a gross weight of 19 kN has a wheel base of 2.1 meter and is fitted with 6-16 tyre at the front, 13.6-28 bias ply tyre at the rear axle. And on a level ground, the center of gravity is located at a distance of 75 cm from the rear axle. The tractor will be used for ploughing a farm land with an average cone index of 1000 kilo Pascal using a 2-bottom mouldboard plough. The total pull on the plough in the vertical plane is 250 kg and it is at an angle 15° with the horizontal when operated at a depth of 15 cm.

Then the point of resistance, center of resistance is located at 125 cm behind the centerline of the rear axle of the tractor and 15 cm below the wheel. So, what you have to compute is the coefficient of traction, tractive efficiency of the tractor when the slip is 20 per cent and δ/h ratio is 0.2. So, as usual the first thing is you have to calculate the diameter. You have to calculate the section width. Then comes your there is some weight transfer. So, first you have to draw the tractor this is R_2 and this is your CG.

So, weight is acting 19 kN and line of pull say it is saying 15° with the horizontal. So, line of pull is somewhere here and it is 15 cm below the ground. If this is the ground surface suppose this is the line of pull and so, line of pull like I can resolve at this point into two components, vertical component or horizontal component. Then what is given is this is making an angle 15°. So, that means, this component will be $P\cos 15°$ and the vertical component is $P\sin 15°$.

Now, we have to find out what is the dynamic weight because of the pull. So, we have to take moments about R_1 so that you can find out what is the dynamic weight at the rear wheel. Similarly, we have to take moment about R_2 and then find out what is the dynamic weight on the front axle. So, now if you take, suppose these are the points A and B. Now, take moments about B. So, $P\cos\alpha$, $P\cos 15° \times 0.15$, this distance is from the ground is 15 cm. So, 0.15, this is positive and then $P\sin 15°$ this is also positive. So, this is acting downwards so this is negative.

So, $-P\sin 15°$ and this is at a distance from the center is given as 125 cm from the rear of the rear axle, center of the rear axle. So, 1.25 meter so, into 1.25 then W is again positive. So, W is 19, W you can take as 19 kN into this. This distance is at a 75 cm that is 0.75. Then R_1 is negative, $-R_1 \times 2.1$. wheel base is given as 2.1 meter. So, if you solve it, so, you will find out expression P is given as 250 kg. So, you will find out R_1 has some value.

So, similar exercise you have to carry out for by taking moment about B. This is taking moment about A. Similarly, by taking moment about A, so we will get an equation. Equilibrium of moments will be, if we are taking this is again positive $P\cos 15° \times 0.15$ then P sin is, $-P\sin 15° \times 1.25$. Now, W will be oh sorry about B, About B so, $P\cos 15°$ is okay, this is minus okay. Now, W will be minus, W this is about B. So, W minus W into distance will be 2.1 minus 0.75 and then $R_2 + R_2 \times 2.1$ this is the equation.

Now, from here we can find while P is given. So, knowing a W is given so, we can find out what is R_2 value. So, these are the dynamic weight. These R_2 and R_1, these are the dynamic weight. Sorry R_1, these are the dynamic weight coming in the front and rear axles respectively. R_1 in the front axle, R_2 in the rear axle. So, then half of that, if you say that it is on a horizontal surface then half of that will act on each of the wheels. Next thing is we have to calculate the coefficient of traction. Once you decided what is the dynamic weight, next thing is calculate the coefficient of traction.

For calculating coefficient of traction, you have to take the torque ratio given by Brixius. Then coefficient of rolling resistance given Brixius and again we have to calculate the mobility number. So, they are CIbd/W. Again, CI is given, b is given, d is given and W will be coming whatever R_2 value we are getting here divided by 2 and for front wheel it will be $R_1/2$.

In case of a front wheel, we will only calculate the coefficient of rolling resistance. Because this is a two wheel drive tractor. The torque or the tractive effort is only developed at the rear wheels. So, $P\sin\alpha$ which I have given, h is 1.25 plus, I have 1.25+2.1. You are taking moment about B, so plus 2.1. So, that will be so.

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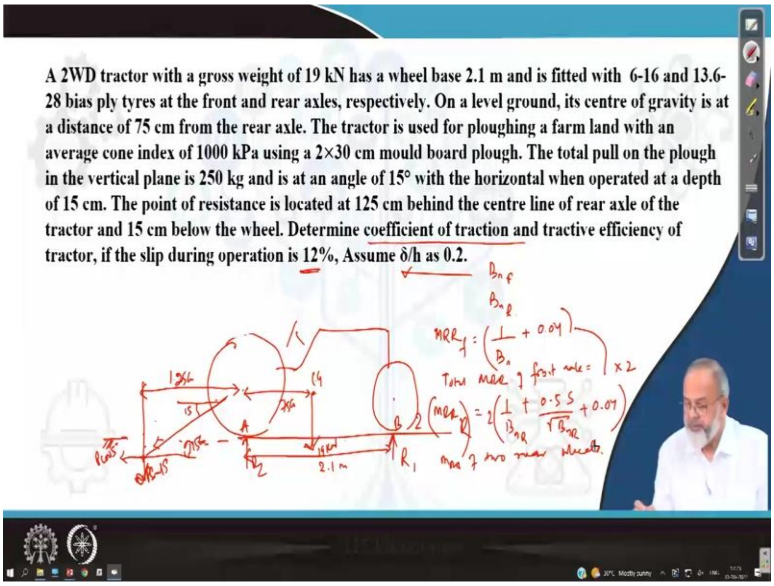

Now, after knowing the dynamic weight, next thing is we have to calculate B_n. B_n for front wheel, B_n for rear wheel and where the δ/h value is given as 0.2. So, now, for calculating the rolling resistance ratio or motion resistance ratio for front wheel, since there is no slip so directly you can write as $[(1/B_n)+0.04]$. So, whatever value you are getting just multiply with the 2. So, the total motion resistance of front axle. That means for both the wheels in the front. So, this expression into 2.

Similarly, for calculating the motion resistance ratio of rear wheel, we have to take a slip into consideration

$$Motion\,resistance\,ratio = \frac{1.0}{B_n} + \frac{0.5s}{\sqrt{B_n}} + 0.04$$

So, slip we can take as 12 per cent is given. So, substituting here, so this will B_{nR}, B_{nR}. So, now you will find out what is the motion resistance of a single wheel provided at the rear axle then you multiply with 2. 2 on this side, 2 on this side. So, that will give you motion resistance of 2 rear wheels. Next, thing is what is the power which is developed? That means gross traction ratio.

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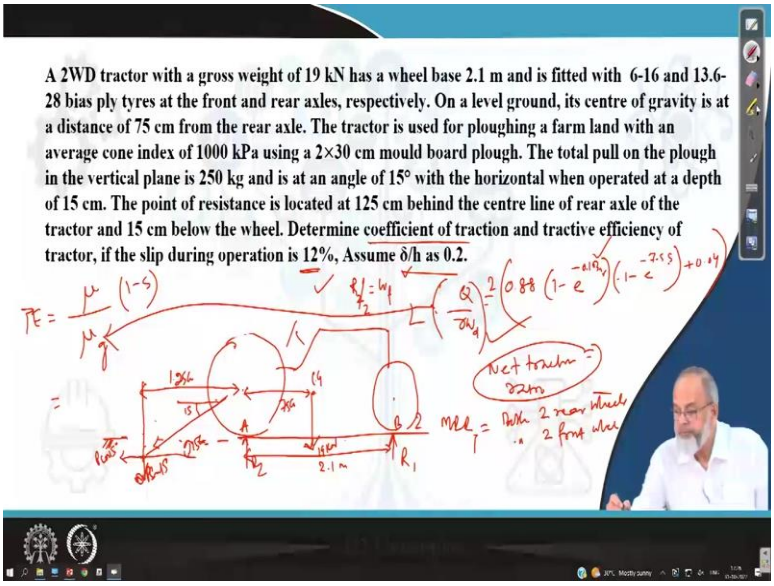

So, for calculating gross traction ratio we will again take the help of Brixius equation which is given as Q/rW is equal to, here W is your dynamic weight and whatever value we are getting as R_2, R_2, will be equal to $R_2/2$ will be equal to W_d in one wheel. So,

$$\frac{Q}{rW_d} = 0.88 \times \left(1 - e^{-0.1B_n}\right) \times \left(1 - e^{-7.5s}\right) + 0.04$$

So, in this equation, B_n we have calculated. B_n for the rear wheel and s is given 12 per cent, 0.12. So, just putting it you can find out one of the wheels, what is the torque ratio and if you multiply with 2 that will give you a total tractive force developed total gross traction in the rear wheels.

So, you know the gross traction. You know the rolling resistance. So, the net traction you can find out. Net traction ratio will be, this is only for the rear wheels not front wheels. Now, for the total rolling resistance we have to consider both rolling resistance of 2 rear wheels as well as rolling resistance of both 2 front wheels. So, we calculated net traction ratio, we calculated motion resistance ratio. The next thing is, we have to find out tractive efficiency. So, for calculating tractive efficiency,

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

So, μ_g, I have already calculated this value. So, this will be a total μ_g. μ is the net traction ratio. So, that will give you what is the tractive efficiency of the tractor while carrying out the ploughing operation in the given condition.

So, basically you have to consider in a 2-wheel tractor the power which is developed is only from the rear axle not from the front axle. That means, the rear wheels are responsible for developing power, tractive power. And for calculating the total rolling resistance you have to take sum of the 4 wheels not only 1 wheel and the 2 wheels and the rear axle that you have to take into consideration.

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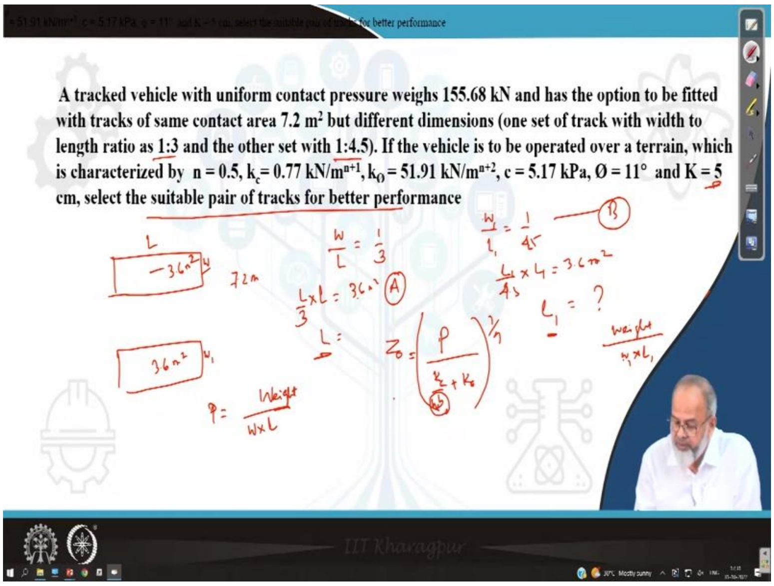

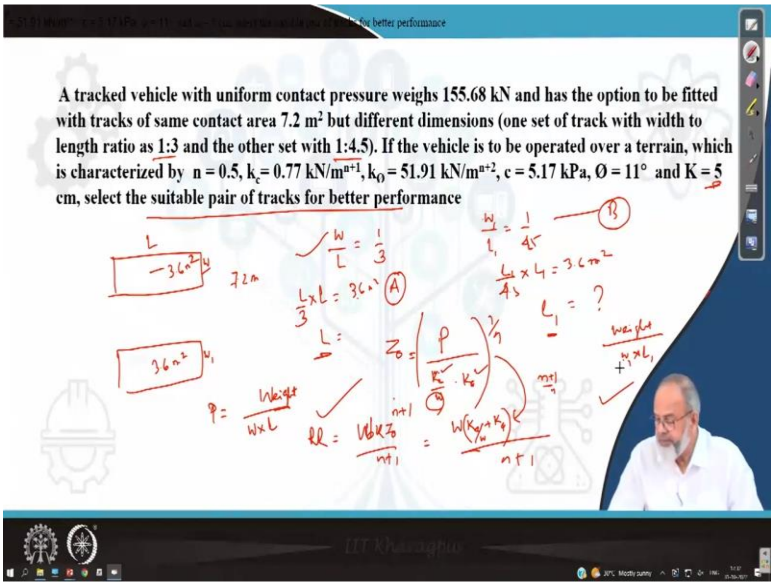

The next question is related to track. A tracked vehicle with uniform contact pressure weighs 155.68 kN and it has the option to be fitted with tracks of same contact area which is 7.2 m^2 but different dimensions. One set of tracks with width to length ratios 1:3, the other 1:4.5. The vehicle is to be operated over a terrain, which is characterized by the exponent of sinkage n as 0.5. Coefficient modulus of sinkage 0.77 kN/m^{n+1}, k_{ϕ} frictional modulus of sinkage 51.91 kN/m^{n+2} and cohesion as 5.17 kPa, angle of internal friction 11° and modulus of sinkage shear modulus of sinkage, shear deformation modulus as 5 cm.

Under these conditions, we have to find out which one is the suitable pair of tracks which has to be recommended.

So, here what we have to do is a tracked vehicle that means, there will be 2 tracks and area sum of the areas of the two tracks are 7.2 m^2. That means, each area will be 3.6 m^2. But one track is having length to width ratio, if this is w this is L, width:length ratio in one track it is 1:3. The other track it is 1:4.5. So, now, we have to find out what is the width. So, area will be w×L. So, w will be equal to L/3. So, L/3×L is equal to 3.6 m^2.

So, now, from here we have to find out what is the value of L? Similarly, here 4.5, (L/4.5)×L is equal to 3.6 m^2. So, this is better. If I write L_1, L_1, w_1, so L_1 will be equal to how much? So, once you know L_1, once you know L then you can find out what is its width w and w_1. Now, I have decided the dimensions of the track for two different conditions. The next step is what is the sinkage z_0. So, if this refers to vehicle A, this refer to vehicle B, 1:4.5 then vehicle A,

$$z_0 = \left(\frac{p}{\frac{k_c}{b} + k_\phi}\right)^{1/n}$$

Now, p is nothing but weight divided by w×L and in this case, this will be weight, weight will be remaining same only the dimension will change that was area is also same. So, that does not make much difference. So, pressure will be same for both the tracks. So, p is given, k_c value is given, b will change, b means this will be here w and in this case it will be w_1. So, better I should write w. So, that it becomes

$$z_0 = \left(\frac{p}{\frac{k_c}{w} + k_\phi}\right)^{1/n}$$

So, k_c value is given k_ϕ values given, w we have calculated from here. So, you can calculate z_0. The next thing is what will be the rolling resistance?

$$Rolling\ resistance = \frac{wkz_0^{n+1}}{n+1}$$

$$k = \frac{k_c}{w} + k_\phi$$

And z_0 you can substitute here raised to the power n plus 1 by n divided by n plus 1. So, this way you can calculate for rolling resistance of first track, rolling resistance second track, which is having a length and width to length ratio as 1:4.5. So, once you calculate rolling resistance then you can compare which one is giving you lesser rolling resistance. Then comes your, what is the gross tractive effort or thrust which is developed that is important thrust which is developed by the two tracks even though their area is same.

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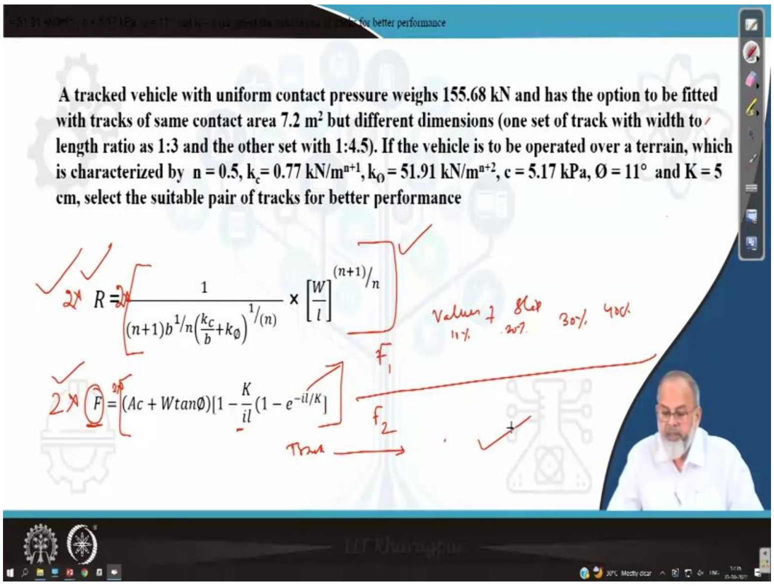

So, you can utilize this equation F is equal to, this is the tractive. So, this is the tractive force which has developed.

$$F = [Ac + W tan\emptyset]\left[1 - \frac{K}{iL}\left(1 - e^{-iL/K}\right)\right]$$

W here is the weight in each track. K is the shear deformation modulus which is given as 5. So, length of the track we have already calculated. So, yo can calculate F for different values of slip at 10 percent, 20 percent, 30 percent can go up to 40 percent and c value is given, ϕ is given, A will be remaining same for both the cases.

So, this value is giving you the tractive effort developed by a single track. So, if you want to find out the total tractive force then you multiply with 2. So, twice of this will give you the value of a total tractive force. You know the rolling resistance of 2 different types of tracks. We know the total tractive force. Again, also rolling resistance you have taken for one track, so you have to multiply with 2. So, we know the tractive force, you know the rolling resistance then you have to compare at different slip values or what are the tractive force you are getting for track1. What are the tractive force you are getting for track2 and then wherever you are getting higher torque, higher tractive force that you have to select.

To confirm that once again you have to check the rolling resistance for both the tracks. That means, you have to carry out comparison of tractive force for both the tracks and the rolling resistance for both the tracks. Then from there, wherever you are getting higher tractive force and lesser rolling resistance that has to be selected, that has to be selected. So, obviously, will come to an end in the sense, the track which is having higher length will give you better tractive force and lesser rolling resistance this will be the conclusion from this problem.

So, I have solved 3 problems, which are related to one is related to utilizing the Brixius equations for finding out to suitable tyre size. The other one is related to find out the dynamic weight how to utilize dynamic weight in Brixius equation? And the third one is related to track, how to calculate rolling resistance and tractive force developed by a track and then you can compare.

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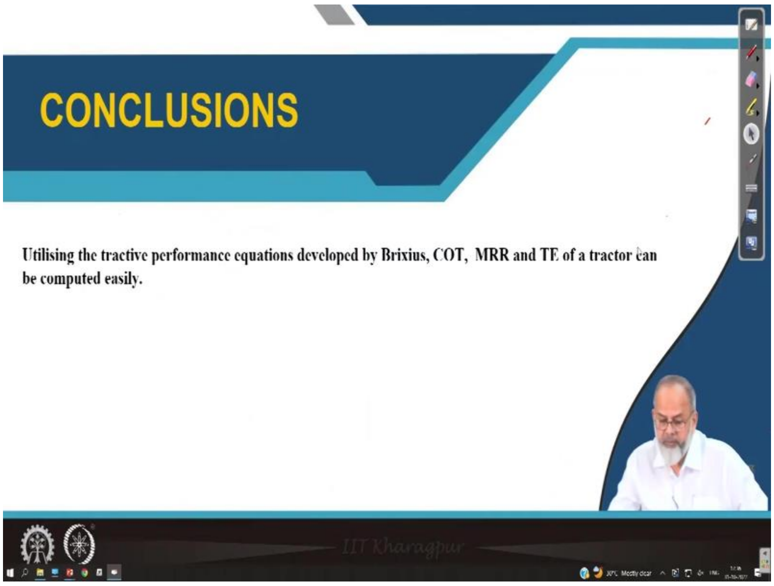

So, using the tractive performance equations developed by the Brixius such as coefficient of traction, motion resistance ratio and tractive efficiency of a tractor can be computed. Thank you.