**Traction Engineering**
**Professor Hifjur Raheman**
**Department of Agriculture and Food Engineering**
**Indian Institute of Technology, Kharagpur**
**Lecture – 04**
**Tractive Performance Parameters**

Hi everyone. This is Professor H. Raheman from Agricultural and Food Engineering Department, IIT Kharagpur. I welcome you all to this NPTEL online course on Traction Engineering. This is the Lecture 4 where I will try to cover different tractive performance parameters.

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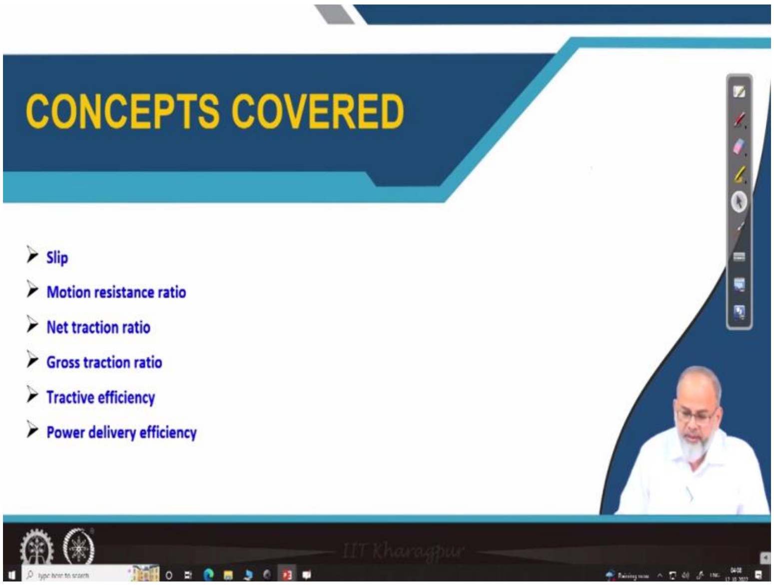


So, concept is slip, motion resistance ratio, net traction ratio, gross traction ratio, tractive efficiency, power delivery efficiency. These are the parameters which are associated with a tractor or a track during operation in the field. So, if you want to evaluate the performance then these are the parameters to be studied.

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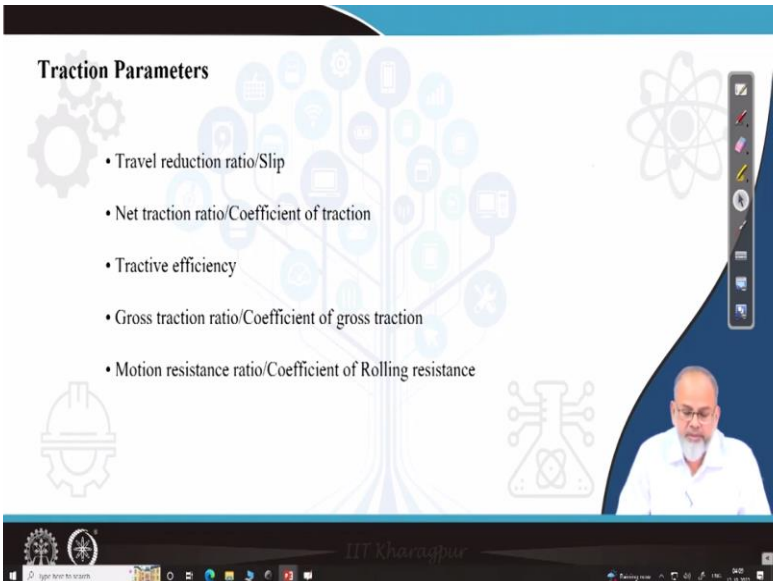


Under traction parameters, there will be travel reduction ratio which is otherwise called slip, the net traction ratio which is otherwise called coefficient of traction, then tractive efficiency, gross traction ratio which is otherwise called coefficient of gross traction then motion resistance ratio which is called coefficient of rolling resistance.

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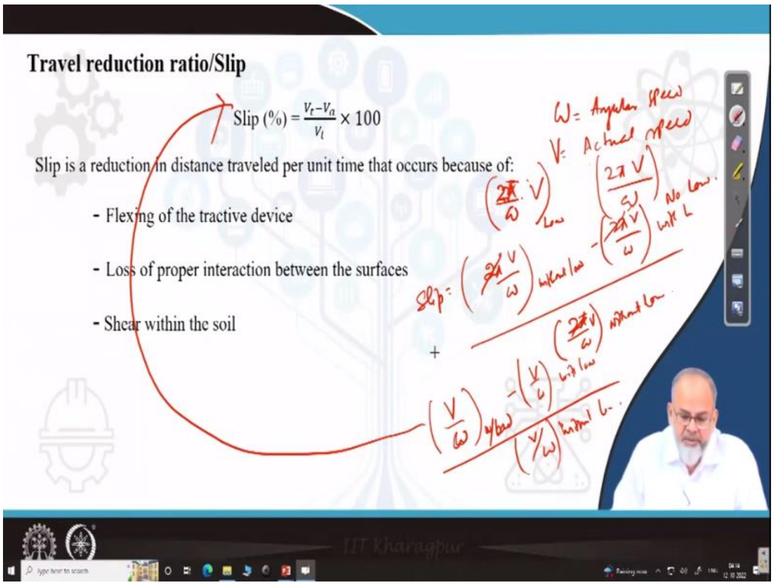


Now, I will discuss in detail how we define slip, how we define the other parameters in order. Now slip, as you know everyone says the wheel slips. What exactly is happening is, the wheel is not covering the same distance as it is supposed to cover. So, if the original velocity is $V_t$ that means, original means there is no load applied to the wheel, simply we roll the wheel. So that, if we denote it as $V_t$.

And when you apply load, because of the interaction with the soil and tyre, there will be slippage of wheel. So, wheel will not cover the same distance, so it will cover lesser distance, so speed is reduced so that we denote as $V_a$. So, that difference is expressed with respect to $V_t$ and that is expressed as percentage. Now, this is very simply I have written

$$Slip = \frac{V_t - V_a}{V_t} \times 100$$

Actually, what happens, if we are moving a tractor or if you are moving a wheel, single wheel at angular speed of ω; ω is the angular speed and V is the forward speed, ω is the angular speed and V is the actual speed. So, in one second, so the distance covered in one second will be

$$\frac{2\pi}{\omega} \times V$$

So, this is the basic. So, when there is load, when there is no load, so these two will be different.

Now slip, I can define as in the other way

$$\frac{\left(\frac{2\pi V}{\omega}\right)_{without\ load} - \left(\frac{2\pi V}{\omega}\right)_{with\ load}}{\left(\frac{2\pi V}{\omega}\right)_{without\ load}}$$

So, 2π/2π, if I cancel out, so

$$\frac{\left(\frac{V}{\omega}\right)_{without\ load} - \left(\frac{V}{\omega}\right)_{with\ load}}{\left(\frac{V}{\omega}\right)_{without\ load}}$$

So, when angular speed remains same then this is same as slip which is defined earlier. So, in this equation, the main important thing is, we should confirm that ω is remaining constant. So, that is the important thing.

And the slip, generally we consider at zero condition; zero condition means, zero condition refers to self-propelled condition. So that becomes a zero slip and slip is occurring because of tyre flexing, because of improper interaction between the tyre and the soil, because of these tyres sticking, because of the shearing within the soil. So, these are the factors which will try to influence slip, more the pull more will be the slip.

The best concept is, without slipping, a tractor cannot develop tractive force. So, slip has to be there. Now, question arises how much slip? So, that depends again on the soil condition, again on the type of tyre. So, roughly we say, within 20 percent is the allowable slip where you can get maximum tractive effort.

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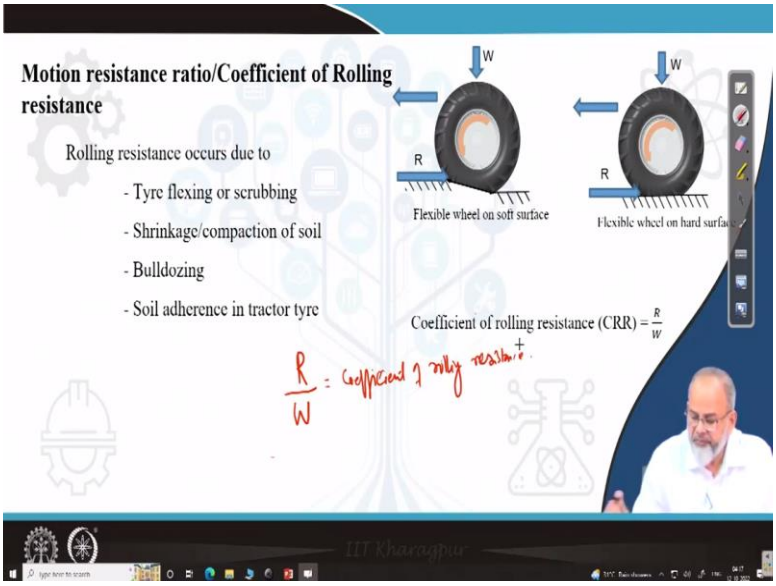


Next is, we will discuss the other performance parameters, motion resistance ratio or in other words we call it coefficient of rolling resistance. So, if you look at this figure, this is the pneumatic tyre operating on a soft soil, this one and this is the pneumatic tyre which is operated on a hard surface. What is the difference? If you look at, the tyre is deflected. In a soft soil, tyre has sunk, there is deflection as well as the tyre has sunk that means it has entered the soil.

Whereas in case of hard soil, the tyre is only deflected. So, the rolling resistance in both the cases are not same. In a soft soil, since tyre has sunk into the soil, so rolling resistance for the same operating condition will be little higher, whereas in case of a hard surface, since tyre has not sunk only it has been flattened so the rolling resistance will be little lesser than the rolling resistance which is experienced in soft soil.

So, from this discussion, what you can conclude is, yes, rolling resistance which is nothing, but sum of the forces acting opposite to the direction of motion. If you look at this figure, you can see the R has been indicated opposite to the direction of travel. This is the direction of travel and the R has been indicated opposite to that. So, this R depends on certain factors like what will be the tyre flexing, how much is the sinkage, how much is the bulldozing and how much soil is adhered to the tractor tyre.

So, we define rolling resistance divided by ‘W’ as coefficient of rolling resistance that means we measure rolling resistance then divide by W. W is the weight coming on the wheel. That becomes coefficient of rolling resistance.

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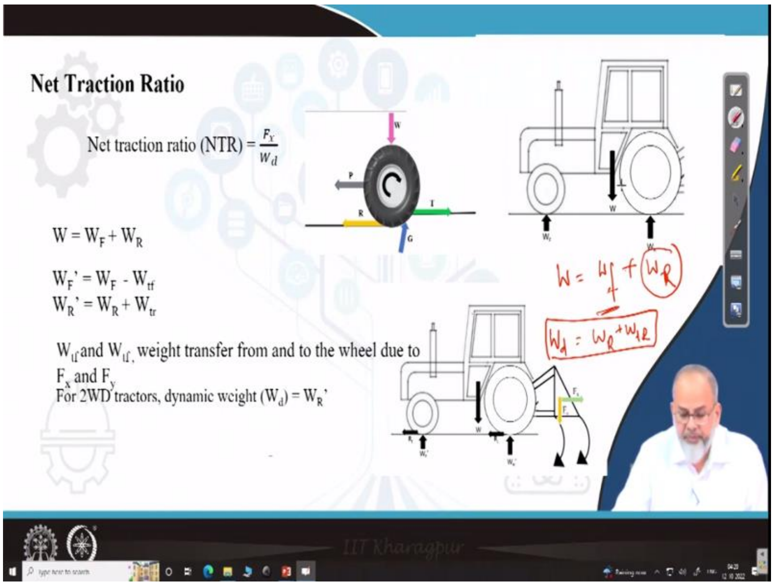


Now, the other parameter is net traction ratio or in other words we call it coefficient of traction which is nothing but the pull which is developed divided by weight. But weight here, I have indicated as $W_d$; $W_d$ means dynamic weight. The tractor which I have indicated in the right side and this is the single wheel. In case of a single wheel, we can take $W_d$ as equal to W itself. But in case of a tractor, we cannot take W which is the weight of the tractor in the denominator. The reason is, if it is a two-wheel drive tractor there will be distribution of weight; distribution of weight to the front axle there will be weight distributed to the rear axle. So, if total weight is W, then we can divide it. So, W is divided in front axle plus rear axle, capital R. So, but in case of a single wheel it is the same weight.

Whereas in case of a two-wheel drive tractor, only the rear wheels are powered wheel. So, we are not concerned about the front wheel. The net traction ratio will be related to the rear wheels. So, in rear wheels what happens, when we try to pull certain implement, there will be weight transfer from the front wheel to the rear wheel. There will be weight transfer from the implement side to the rear wheel.

So, that means, in a static condition when there is no implement attached then the weight distribution that means the weight coming in the rear axle is $W_r$. In the dynamic condition that $W_r$ does not remain as $W_r$, some additional weight is coming from the front wheel side, coming from the implement side. So, the

$$Dynamic\ weight\ on\ rear\ axle = W_r + weight\ transfer\ (W_{tr})$$

So, while calculating the coefficient of traction, you have to divide the pull which is developed with this dynamic weight, not the static weight which I have written as $W_r$. So, that is the difference for net traction ratio in case of a single wheel and in case of a tractor.

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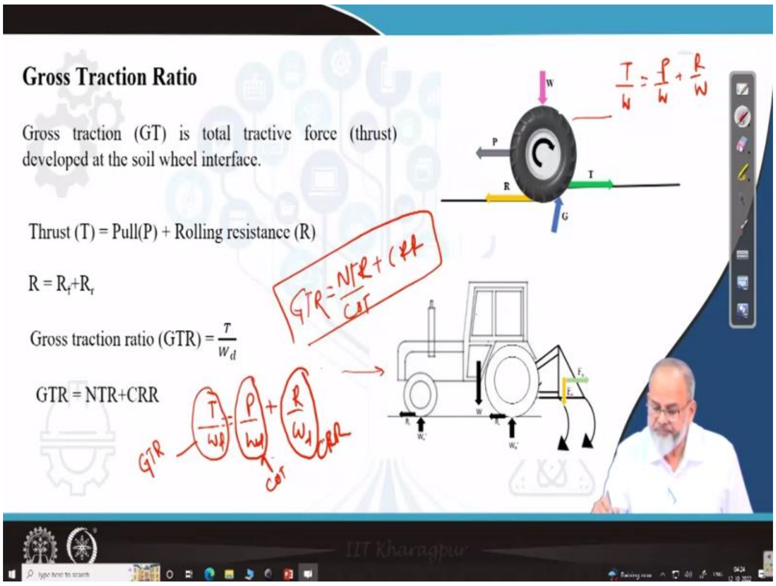


Now coming to gross traction ratio, this is the total tractive force or thrust which is developed at the interface of soil and wheel divided by the weight. It is in the same way, weight means, if it is a single wheel then we simply divide it by weight, if T is the thrust which is developed then thrust divided by weight. If it is a single wheel whatever weight is coming on the wheel, I can directly take as W.

But again, if you look at the tractor rear wheel, when it is used for pulling and implement during that time there will be weight transfer from the front, there will be weight transfer from the implement side to the rear axle. So, what will happen, the initial distribution which is denoted as $W_f$ and $W_r$ that will no longer remain as $W_f$ and $W_r$. So, $W_f$ will be reduced, that is the weight coming on the front axle will be reduced.

Weight coming on the rear axle will be increased because of the weight transfer from the implement side, because of the weight transfer from the front axle. So, the new weight which I denote as $W_r$, better we can write $W_{dr}$. So, for a tractor, we can define the coefficient of gross traction

$$GTR = \frac{T}{W_{dr}}$$

and we know that thrust is equal to your pull and the rolling resistance.

So, that means pull plus rolling resistance will be equal to thrust. Now, if I divide W throughout the equation,

$$\frac{T}{W} = \frac{P}{W} + \frac{R}{W}$$

This W is the dynamic weight if we are talking about tractor. So, then this ratio is called coefficient of gross traction. This is GTR which is equal to

$$\frac{P}{W_d} + \frac{R}{W_d}$$

$P/W_d$ nothing but COT, coefficient of traction or coefficient of net traction then, $R/W_d$ which is nothing but coefficient of rolling resistance.

So, in other words I can say, GTR will be equal to coefficient of net traction NTR or we can say COT plus coefficient of rolling resistance. So, here one thing I have to take into consideration that 'W' should be dynamic weight. It is not the static weight whereas in case of the single wheel we can do in the same way. But here, it will be simply the W. There is no weight transfer in case of a single wheel. So, we can take these as

$$\frac{T}{W} = \frac{P}{W} + \frac{R}{W}$$

This W is not the dynamic weight. Here, the dynamic and static weight they remain same.

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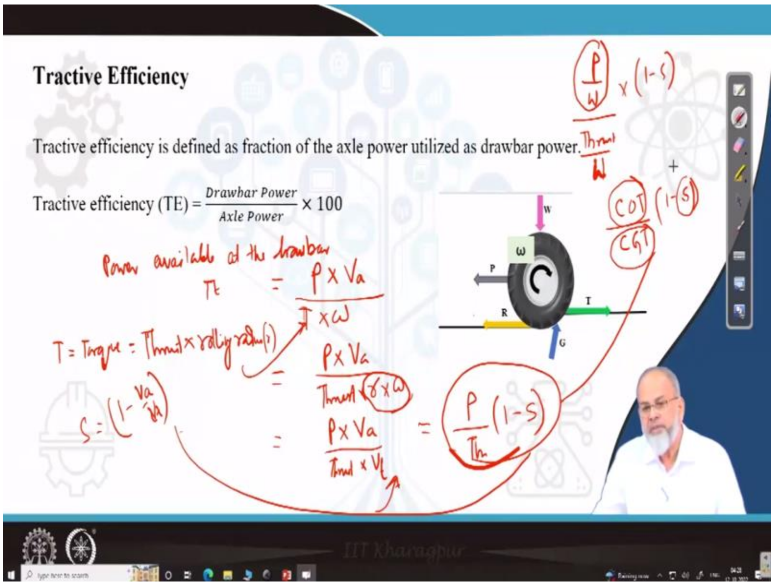


Next is tractive efficiency. This is a very important parameter while evaluating the performance of a tyre or a tractor. So, as the name implies tractive efficiency. So, efficiency means there will be some output, there will be some input. So, output by input is your efficiency. Now, what is tractive efficiency? It is the drawbar power divided by the axle power and it is expressed in percentage.

So, in other words we can say, the tractive efficiency indicates how much of the axle power is being utilized as drawbar power. So, what is drawbar power? If somebody is interested to find out what is drawbar power, it is the power available at the drawbar. So, power available at the drawbar will be equal to power available or the drawbar this will be equal to

$$P \times V_a$$

$V_a$ is the actual velocity.

So, this becomes your power available at the drawbar. Now, what is axle power? Input axle torque, it is denoted as T.

$$Axle\ power\ = T \times \omega$$

omega is the angular speed. So, I can write this expression

$$Tractive\ efficiency\ = \frac{P \times V_a}{T \times \omega}$$

So, this input torque, I can write as thrust into rolling radius. Now, if I substitute here, so

$$\frac{P \times V_a}{T \times \omega}$$

T is nothing, but your

$Thrust \times rolling\ radius(r)$

Suppose I denote it as

$$r \times \omega$$

So, this ωr is nothing, but your theoretical speed. If omega is the angular speed, multiplying the rolling radius that will give you theoretical speed. So,

$$\frac{P \times V_a}{Thrust \times V_t}$$

$V_t$ is theoretical speed. So, I can write in other words,

$$\frac{P}{Thrust} \times (1 - slip)$$

because earlier we have defined

$$Slip \ = \ 1 - \frac{V_a}{V_t}$$

So, now I am substituting in this equation so that gives you P by thrust.

$$\frac{P}{Thrust} \times (1 - slip)$$

Further, if I want to express in terms of coefficient of traction or in terms of coefficient of gross traction then what I can do is, I just simply

$$\frac{P/_W}{T/_W} \times (1 - s)$$

This W is dynamic weight in case of tractor, in case of single wheel it is the same weight. So, this P/W, we have already defined as coefficient of traction which is COT, then Thrust/W, which I have defined as coefficient of gross traction CGT, '×(1-s)'.

So, tractive efficiency is the ratio of

$$\frac{COT}{CGT} \times (1 - s)$$

That means, it takes care of pull, it takes care of the thrust. It takes care of the slip which is associated while developing thrust. So, this is a composite parameter. We can call which takes into account the different other parameters which are associated.

Next is one more performance parameter I am going to define, which is called power delivery efficiency. It is again efficiency. So, that means output by input, but here I will take the output as drawbar power, but input will be no more limited to axle. It will be extended to engine.

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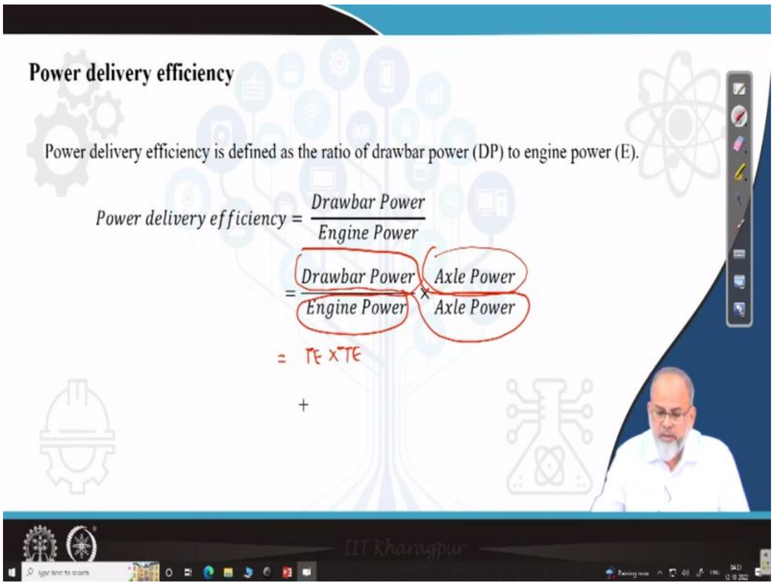


Power delivery efficiency, which is defined as the ratio of drawbar power to engine power. Now,

$$Power\ delivery\ efficiency = \frac{Drawbar\ power}{Engine\ power}$$

So, I just multiply in the numerator and denominator, axle power by axle power. So, if I take

$$\frac{Drawbar\ power}{Axle\ power} \times \frac{Axle\ power}{Engine\ power}$$

So, the first ratio drawbar by axle power is nothing, but your tractive efficiency. And the axle power, engine power will take care of the transmission efficiency. So, it is a product of two efficiencies; out of this engine power how much power is converted to drawbar power that can be determined by utilizing this parameter. So, the tractive efficiency is a component of this power delivery efficiency whereas power delivery efficiency gives you the overall efficiency.

If engine power is say ‘x’, out of that x, how much power is converted to drawbar power. So, that is the way by which you can calculate power delivery efficiency. There are details of variation of this power delivery efficiency, tractive efficiency and coefficient of traction, coefficient of gross traction and coefficient of rolling resistance, variation of these parameters with slip, we will be discussing in the coming lecture.

So, in brief what I can say, we have discussed different performance parameters which are associated in evaluating the performance of a single wheel or in a tractor. So, if you are utilizing these parameters to evaluate performance for tractor, then we have to be very careful in the sense, we have to always go for taking the dynamic weight. If you by mistake take the original weight that means without weight transfer, then all your calculations will be wrongly interpreted.

So, the two differences you should take into consideration; one is how much weight is transferred and that should be reflected in your coefficient of traction or coefficient of gross traction or coefficient of rolling resistance.

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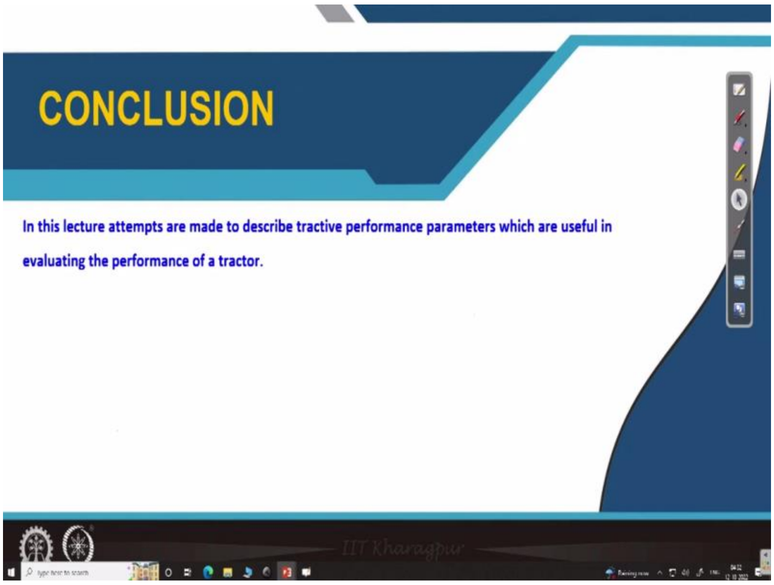


So, in brief, in this lecture, I attempted to describe the different tractive performance parameters which are useful in evaluating the performance of a tractor.

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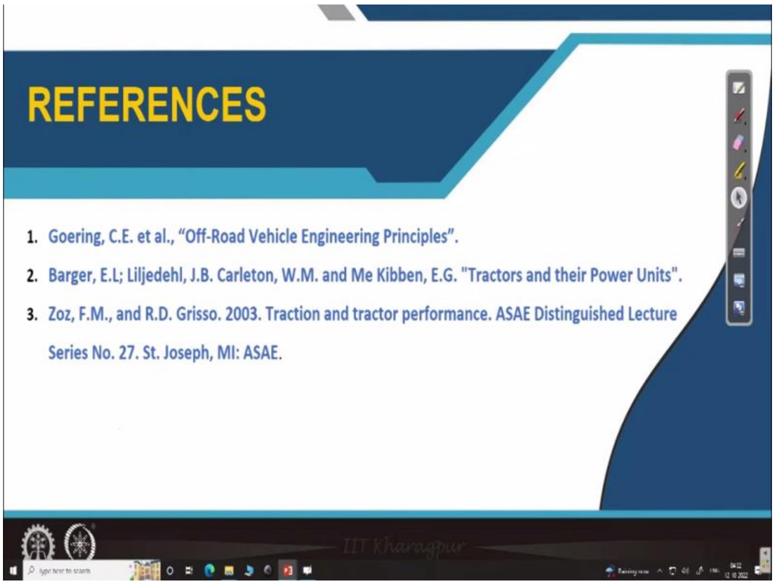


Then, these are the books which you can refer where you can get some more information how to calculate those things and that will give you a better idea about this tractive performance parameter. Thank you.