Traction Engineering
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Lecture No. 33
Ballasting of Wheeled Tractors to achieve Maximum Power Output in Frictional-Cohesive soils

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 lecture 33 where I will try to cover ballasting of wheel, ballasting of wheeld tractors to achieve maximum power output in a frictional-cohesive soils.

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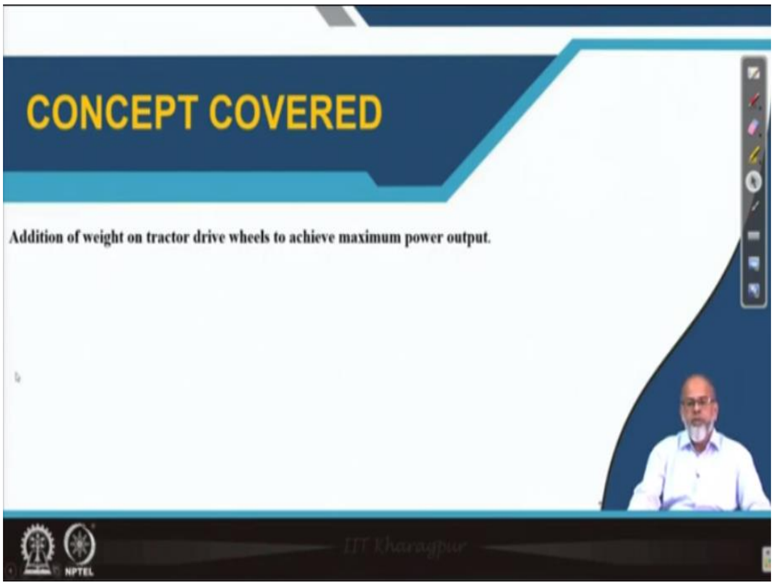

As I said ballasting, so, the concept will be addition of weight on tractor drive wheels to achieve maximum power output. Ballasting is basically nothing but addition of weight. You cannot weight to reduce the slip. So, thereby, there will be more interaction with the wheel and soil and that may lead to develop more tractive force. So, ballasting can be done in two ways. Either you add external weights, cast iron blocks, or you can add water in into the tube of the rear tyres. So, both are possible. Now, question comes to our mind is how much weight should be added or how much weight should be added on the rear axle so that slip is reduced.

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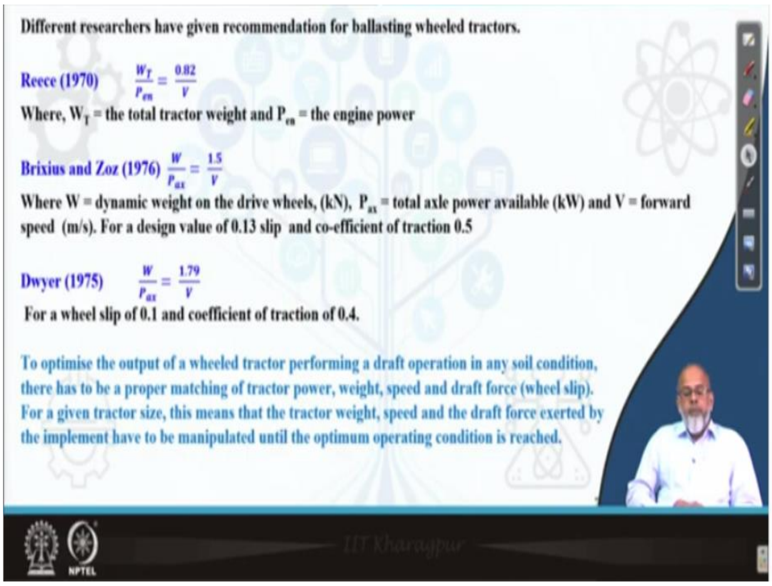

So, there are few research researchers who have recommended some, recommended some findings, like how much should be the weight of the weight on the axle and how much should be the weight on the axle so that you can get maximum output. So, one such researcher is Reece in 1970, he recommended that $\frac{W_T}{P_{en}}$, P_{en} means engine power. W_t is the total tractor weight. So, total tractor weight by engine power should be equal to $\frac{0.82}{V}$, V is the actual speed.

Now, Brixius and Zoz in the year 1976, they recommended that $\frac{W}{P_{ax}}$. W is the dynamic weight on the drive wheels and PX is the total axle power which is available. So, this ratio should be equal to $\frac{1.5}{V}$. V is the theoretical, V is the actual speed in meter per second. Power, total axle power will be in kilo Watt and W is the dynamic weight in kilo Newton.

Now Dwyer 19, in the 1975, he recommended that $\frac{W}{P_{ax}}$, that means dynamic weight on the dry wheel divided by the axle power, total axle power is equal to $\frac{1.79}{V}$ and this is recommended for a wheel slip of 10 percent and the coefficient of traction is around 0.4. So, all these recommendations that will give you an idea, how much should be the weight on the rear wheels if it is a two-wheeled tractor and so that you can get better output from the tractor.

So, to optimize the output of a wheeled tractor, which is performing a draft operation in any soil condition, there has to be a proper matching of tractor power, weight, speed, and the draft force or you can say the wheel slip. There should be a proper matching between this four. So, for a given tractor size, this means that the tractor weights, speed and the draft; draft force which is exerted by the implement, have to be manipulated until the operating conditions is reached.

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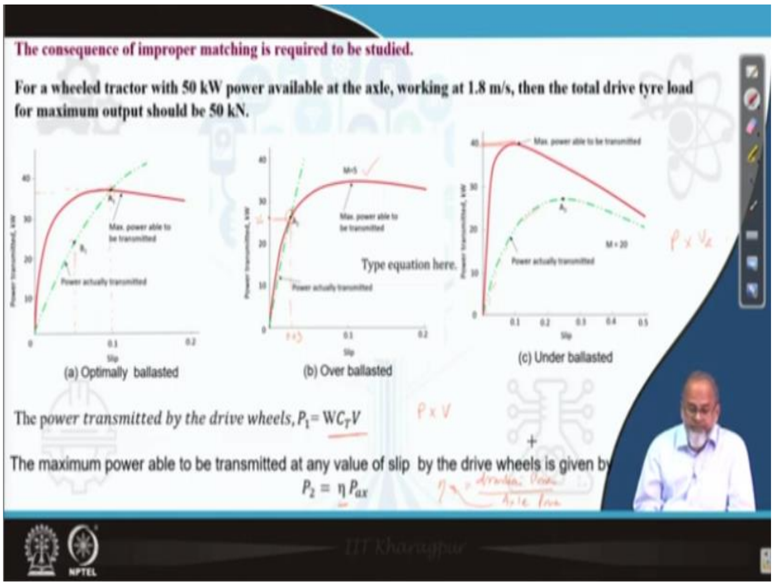

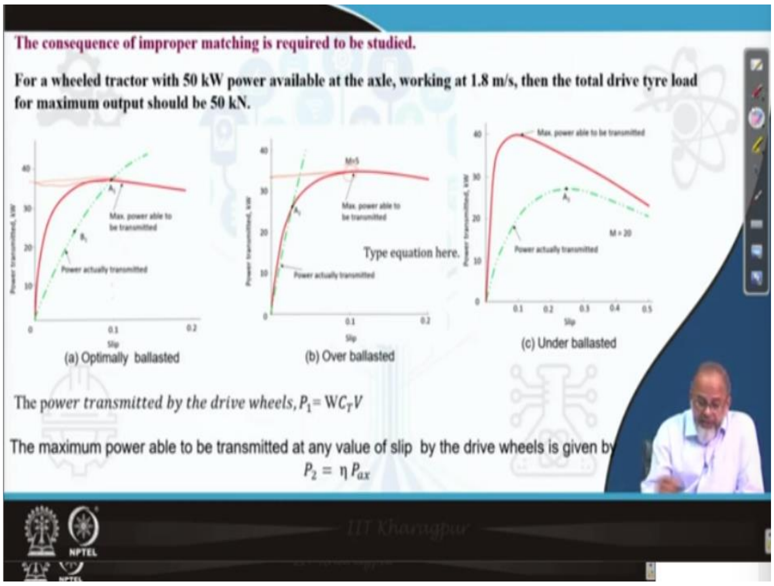

So, let us see a typical condition where the axle power is 50 kilo Watt and it is operating at a forward speed of 1.8 meter per second and the total drive load as per the recommendation of

Dwyer, it should be equal to 50 kilo Newton. So, now there are three conditions I have indicated here. One is optimally ballasted, what is coming from this Dwyer's equation. Then the other one is over ballasted and the third one is under ballasted.

So, in this figure, three figure, I have drawn two curves in each figure. So, let us now concentrate on the optimally ballasted condition assuming that the tractor is performing a typical heavy draft operation such as ploughing and that the plough depth is gradually increase. So, as the draft force from the plough is increase, wheel slip will also increase and the power effect actually delivered by the drive wheels will be given by this dotted line. These are the dot line, this is the power actually delivered by the tractor and the red one is the power which is obtained by multiplying the tractive efficiency with axel power.

So, suppose we will consider a point here, somewhere here, say B1. Now corresponding to B1, what we are getting is, the slip is only 0.05. That means 5 percent and the, when you further increase the draft, what will happen till the slip is 10 percent, so, what will happen, wheel reach to a point here, A1 that is indicated as A1. Now this is the point where the absolute maximum power which the tractor can able to transmit is matching with the power which is actually transmitted. Let me repeat.

So, A1 is the point where the absolute maximum power which the tyres can transmit in this condition is matching with the power which is actually transmitted. That means, it is properly matching and the wheel slip is only 10 percent. So, this is a perfect case of matching and the power which is available is roughly around 36 kilo Watt.

Now suppose by chance we have overloaded instead of taking weight as 50 kilo Newton, we have overloaded it. So, when you overloaded by 2 times, so what will happen? The mobility number will be half because mobility number $\frac{CIbd}{W}\left(\frac{1+5\,{}^{\delta}/_{h}}{1+3\,{}^{b}/_{d}}\right)$. So, when W is increase, so obviously mobility number will decrease. So, if initially it was 10, then now it will become, M will be equal to mobility number will be equal to 5.

Now in this condition you can see the red line again shows the maximum power which is able to be transmitted by the tractor. That is nothing but the product of tractive efficiency into axle power. Now for the typical draft operation, so when we try to operate a mouldboard plough, so the power which is transmitted to the mouldboard plough for pulling, so this will follow this line, this dotted line green colour one. This is the actually power transmitted.

So, what we can observe here is, this is the limiting point. Beyond that, though I have indicated, but the engine will stall. So, this is the maximum point. So, corresponding to this, the slip is only 3 percent, 0.03, and the power transmit is only 27 or 26 around, 26 kilo Watt. So, the power actually transmitted, crosses the maximum power able to be transmitted at a point where the slip is only 3 percent. That means, we are unable to extract maximum power which a tractor is able to develop.

Now we look at the third curve where we have reduced the weight, instead of 50 kilo Newton, we have made it say 25 kilo Newton, we have made it half. So, in that case we can see the maximum power able to be transmitted is giving you the maximum value. You can see 40 kilo Watt, roughly. Whereas, when you are operating the same tractor under this condition by operating mouldboard plough and gradually increasing the depth, so this will be the path followed, that means power actually transmitted, which is nothing but P into pull into actual velocity. So, that will give you this line.

So, that indicates that there is never nowhere, it crosses this maximum power able to be transmitted by a tractor. That means, there is no power limitation, but the loss is we are never reaching to this peak point. So, from these three curves, what it can conclude is, whether you over ballast it or you under ballast it, there is a power loss. So, power which is transmitted by the drive wheels $P_1 = WC_T V$. That means W, CT is the coefficient of traction, W is the dynamic load.

So, this is nothing but $P \times V$, V is the actual velocity and maximum power able to be transmitted at any value of slip where the drive is given by P_2 is equal to tractive efficiency into power in the axle. Tractive efficiency is nothing but drawbar power by axle power. So, I have multiplied axle power with tractive efficiency to find out what is the drawbar power.

Now in these three cases, the, when the condition is under ballasted, the power which is actually transmitted, never reaches or never crosses the maximum power available, maximum power able to be transmitted by the tractor. But in other two conditions you can see, it is crossing. That means it is crossing at a lower point, where the maximum power which is able to be transmitted is somewhat higher; somewhat here. So, how to achieve this maximum power?

Here, yes, we are in the optimum ballasted condition, we have achieved the maximum power, but if it is under ballasted state or over ballasted state, then we will never reach to this maximum. So, how to achieve this?

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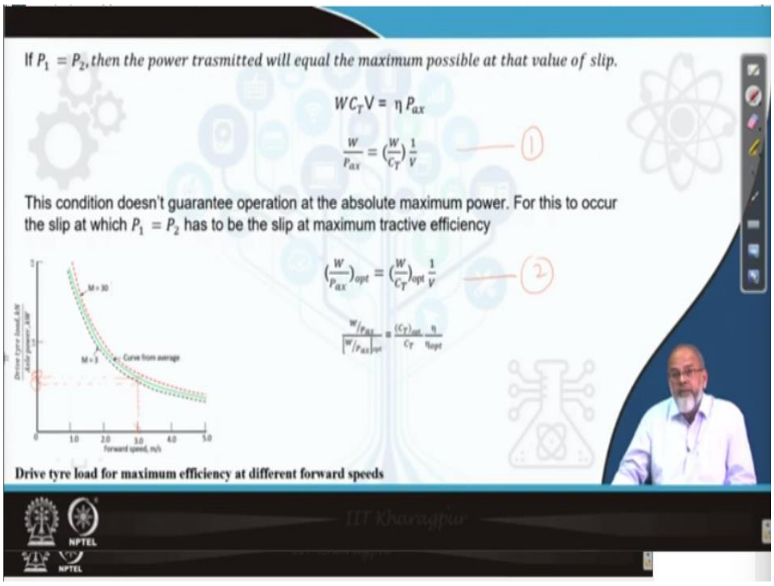

If $P_1 = P_2$, that means the maximum power able to be transmitted is equal to the power which is actually transmitted by the tractor. Then the, the power transmitted will equal to, will equal the power maximum will equal the maximum possible at that value of slip. That means, $W C_T v = \eta P_{ax}$ and $\frac{W}{P_{ax}}$, if I divide in this one, $\frac{W}{P_{ax}}$ is nothing but $= (\frac{W}{C_T}) \frac{1}{V}$. This does not guarantee that the operation which is carried out is at the absolute maximum power.

That means, we are never reaching to the maximum power which the tractor is able to transmit. If you want to reach to that point, then the slip at which P1 is equal to P2 should be equal to the slip at which you are getting maximum tractive efficiency. That is important. Then only you can achieve the max peak value just like I have shown in the previous slide, you will reach to this point. So, that means $P_1 = P_2$ at a slip where the, that slip should be equal to the slip at which we are getting maximum tractive efficiency.

So, in other words, we can denote it as optimum condition. So, $\left(\frac{W}{p_{ax}}\right)_{opt} = \left(\frac{W}{C_T}\right)_{opt} \times \frac{1}{V}$. So, this is the optimum condition. Now if I take the ratio, ratio between this one and this one, so this comes to $\frac{W/P_{ax}}{[W/P_{ax}]_{opt}} = \frac{(C_T)_{opt}}{C_T} \frac{\eta}{\eta_{opt}}$. Now what is the drive tyre load which is required? That means this W by axle power. What is required at different forward speed, has been plotted for mobility number 3 to 30 and the middle one is mobility number around 10.

So, if my tractor is to operate at 3 meter per second, I will simply draw the vertical line here. Suppose my mobility number is 3 and then I will draw a horizonal line here. So, this will, this point will indicate what should be the drive tyre load for the given axle power so that I can reach to the optimum condition. Similarly, if my mobility number is higher, so I will just extend it wherever it touches, so, from there I will try to draw a horizontal line. So, that will touch the Y axis. So, that point will indicate what should be the drive tyre load require to get that maximum tractive efficiency.

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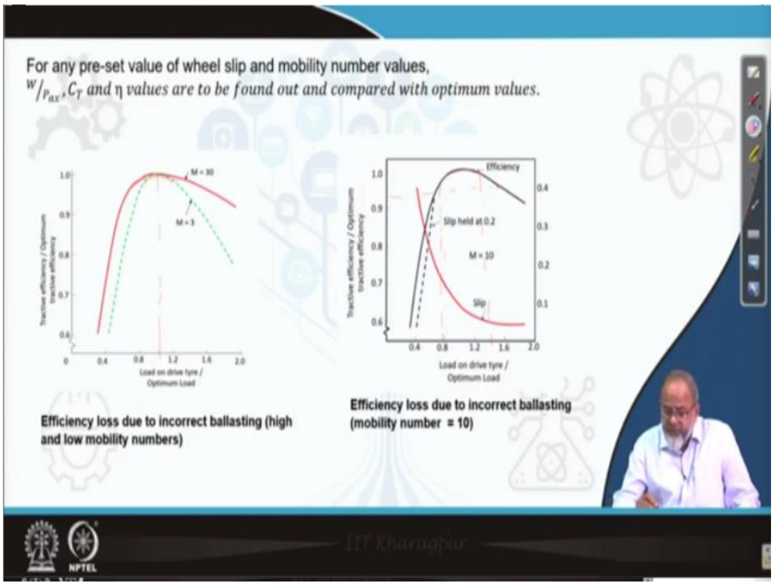

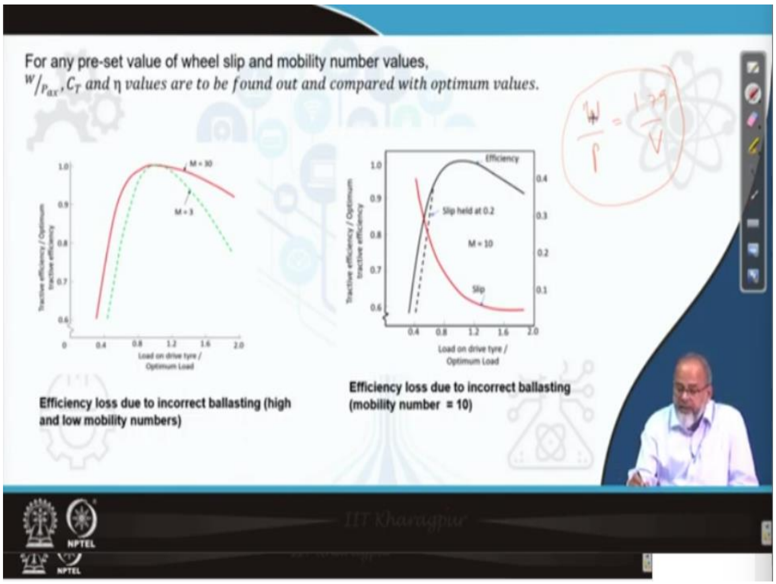

Then question comes, whether it is always possible to operate at this drive tyre load or if you reduce this drive tyre load by 20 percent, what is happening or if you reduce further, what is happening? To verify this one, we have plotted tractive efficiency, $\frac{\eta}{\eta_{opt}}$ for two different mobility numbers 3 and 30. And the right side we have plotted $\frac{\eta}{\eta_{opt}}$ for mobility number 10.

So, what you observed here is, at when the eta by eta maximum or optimum is 1. If you can draw a line here, this around 1. So, there is a fairly gentle slope here. M is equal to 30 or M is equal to 3, there is a fairly, fairly gentle slope. Same is the case in a M is equal to 10. That means, if you are operating up to this range, operating up to this range, there is not much reduction in the tractive efficiency.

So, what we can observe from here is, if you reduce the weight, say by 20 percent from the optimum, you are not to losing much. But if you are reducing further, reducing weight further, then there is a drastic reduction. Same is the case with the overweight. Suppose the optimum weight is X, now have increased to 1.2 X. So, that is not going to harm anything. You are not losing anything because this curve is flat for a range, say, starting from 0.8 to 1.3 like that. But if you further increase it, then it will land up at somewhat here, then your eta by eta efficiency will be reduced drastically.

So, what you can conclude from here is though the recommendations are given by the, researchers. The, the most commonly used one is the Dwyer's recommendation, which is nothing but,

$\frac{W}{P} = \frac{1.79}{V}$, W is the dynamic weight, P is the axle power, V is the actual velocity. So, if you follow this, well and good or by chance the weight which is required to satisfy this condition is reduced by 20 percent or increase by 20 percent, it is not going to harm much. That means, we are getting the same tractive efficiency as we are getting at the recommended value of W.

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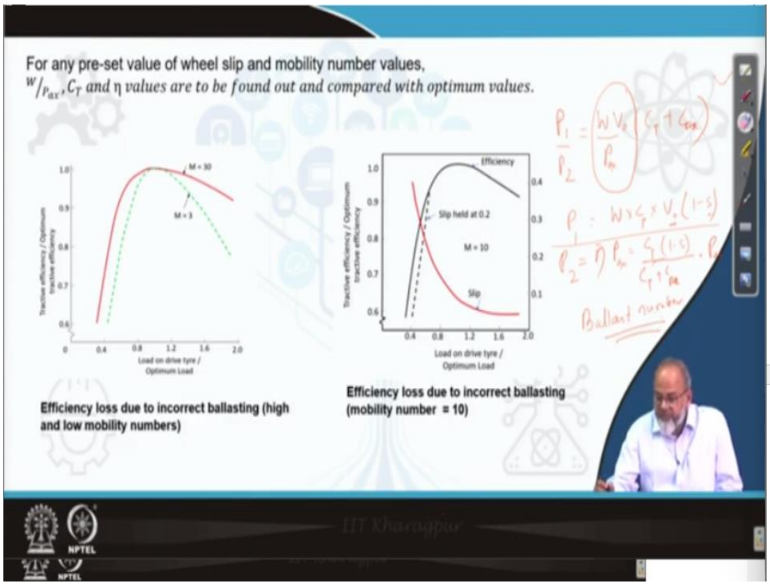

So, we try to develop a ballast number, which is nothing but $\frac{P_1}{P_2} = \frac{WV_0}{P_{ax}}(C_T + C_{RR})$. So, how I arrive at this point is P1 is nothing but $WC_T V$, which is nothing, but V I can write as $WV_0(1 - S)$. V_0 is the theoretical speed and S is slip. Similarly, P_2, I can write it, write as eta into axle power. So, axle power we have taken as P axle. So, I can write as $\frac{C_T}{C_T + C_{RR}}(1 - S)$. This is nothing but tractive efficiency into P axle.

Now, if I take the ratio of these two expressions, then I will land up with this value $\frac{P_1}{P_2} = \frac{WV_0}{P_{ax}}(C_T + C_{RR})$. Now this $\frac{WV_0}{P_{ax}}$ is called ballast number. This is a non-dimensional number and we call it ballast number. So, immediately we can calculate this ballast number and then compare with the optimum condition. If it is lesser than that or higher than that, then we will immediately say that, this is not going to give you the maximum output.

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So, next thing is, after deciding this weight or the ballast number, which is recommended by different researchers, the next thing is we have to satisfy these three conditions. First thing is when we are recommending a load, the drive tyre load, the drive tyre should be large enough to carry this load. That should the, that is the main condition. So, and the recommended load adjust the drive tyre load to the value which is shown in this fig, in this figure, this figure. So, depending on our mobility number, immediately can find out what should be the drive tyre load from this figure.

Now this drive tyre load, once you decided, next thing is the tyre should be able to carry this load at a low inflation pressure, not at a higher inflation pressure. Then the third condition is, adjust the draft load so that the wheel slip is around 10 percent, maximum you can go up to 15 percent. So, after getting the desired load to be added for ballasting, you have to satisfy these three conditions. Then only you get the maximum benefit.

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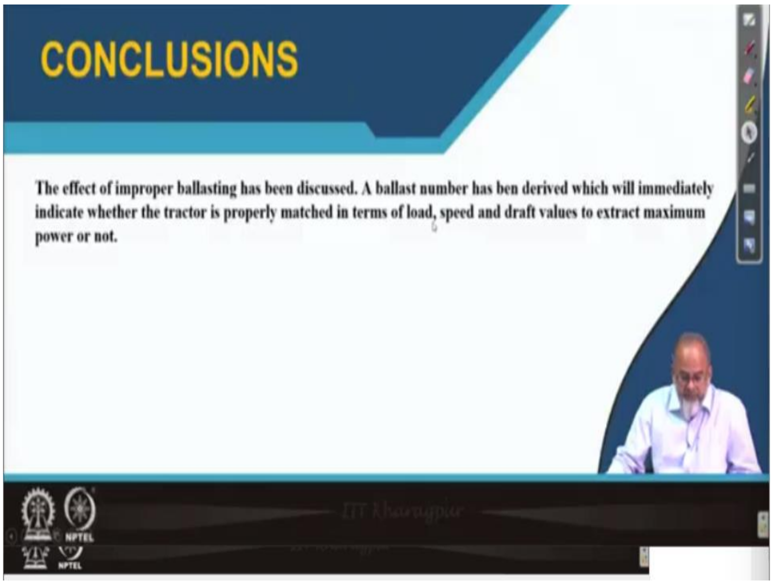

So, in short, we can say, I have discussed about, what is ballasting and how do you ballast it? Then what will happen if you go for, you go for improper ballasting, that means whether when you add more weight or when you reduce less weight. When you reduce weight, so, how it is going to affect the performance. Then we have discussed about the ballast number which is derived from those recommendations given by the researchers. So, our aim is to ballast it so that we can maximize the output of a tractor by properly matching the weight, the speed, the draft. That is all. Thank you.