Traction Engineering
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Lecture 37: Lateral force developed by an unpowered tractor wheel

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. Today is lecture 37, where I will try to cover the lateral force developed by an unpowered tractor wheel.

In my previous class in lecture 36, where I tried to discuss about the cornering force, where I have given examples related to car tyres and truck tyres. The reason is, we do not have much literature related to cornering force developed by the tractor tyres. So, there are very little literature available and in IIT Kharagpur, we have conducted a study how to measure the lateral force developed by an unpowered tractor wheel, so that I am going to discuss today. So, basically, I will try to find out what are the factors which are affecting the lateral force developed by an unpowered wheel.

Unpowered wheel means is the tractor front wheel. In a two-wheel tractor the tractor front wheels are unpowered wheels. And then we will try to develop equations, how to estimate the coefficient of lateral force from which we can find out what will be the lateral force developed for a given soil condition. As you know that the lateral force developed when camber angle is 0, depends on slip angle, it depends on normal load, it depends on type of tyre. So, the experiments which you conducted, first we tried to develop a setup where you can vary these parameters.

Parameter means the slip angles, parameters mean the normal load and the inflation pressure, is because we are talking about contact patch, the lateral force which is developed at the contact patch. So, obviously, the normal load and the inflation pressure both are responsible for developing a contact for developing a contact area ok. More the load, lesser the pressure, more will be the contact area, so likewise. So, the setup which we developed I have given you different views in addition to that I have given you isometric view, there will be a wheel 6-16 8 ply rating wheels which are normally provided in a 2-wheel drive tractor. And there is a provision to vary the slip angle.

So, you can see in the figure top view there is a plate given, ok, where the axle of the wheel can be rotated. If you change the positions, that will give you different slip angles. So, slip angles can be varied from 0 to 40°. The one end of the axle, which is fitted, on which the wheel is fitted is supported on this plate, the other end is supported, is supported on a transducer, extended octagonal ring transducer which is a pivoted at one at one point, so that you can easily rotate the wheel. The axle of the wheel is inserted into this extended octagonal ring transducer.

So, there is a bush to which the axle can be inserted then whatever force side force is coming that will be recorded. So, this is the kind of arrangement. I will show little bit how the forces are recorded. So, when you try to pull the wheel forward there will be forces acting. So, I have resolved these forces. The side force is the $P\cos\alpha + F_s\sin\alpha$, where $F\sin\alpha$, where F is nothing, but the pulling or the rolling resistance we can say.

So, we are interested about the side force $P\cos\alpha$ and $F\sin\alpha$. So, summation of $P\cos\alpha+F\sin\alpha$, so that will be the total side force which is acting on the wheel and that has to be measured by a Wheatstone bridge extended octagonal ring transducer, where the Wheatstone bridge are, principles are, Wheatstone bridge principle is used to measure the forces. The axle is inserted in this bush and one end is mounted on the frame, so that you can easily change the position of the axle. So, thereby you can change the slip angle. Now once you know the arrangement then what are the parameters we try to vary.

So, this study has been conducted in a sandy clay loam soil where the properties are given here, are listed here like what is the coarse sand percentage, fine sand percentage, silt, clay, then what is the bulk density, a moisture content, cone index value, cohesion, frictional angle. C and ϕ values are given. So, we try to study the lateral force measurement in a sandy clay loam soil at a cone index value of 456 kPa which is nothing but your medium soil, soft to medium soil and then at a moisture content of 13 percent. And the parameters which we varied is normal load, then inflation pressure. Normal load we vary from 1.6 kN to 2.6 kN, then inflation pressure we varied from 165 kPa to 207 kPa and the slip angle which we tried is from 0° to 30°.

0° means, the wheel is vertical we are not changing. 5°, in steps of 5°, we studied and the parameters we measure are the lateral force, rolling resistance, tyre deflection and tyre contact area. Now when you try to plot the lateral force versus slip angle for this condition which I just now told. So, you can see that lateral force is increasing at a faster rate than it is slowing down and thereafter somewhere it is increasing, somewhere it is going down. So, lateral force is a function of slip angle, is a function of normal load, more the load more the lateral force. And the relationship between lateral force and the slip angle is linear up to a certain degree of slip angle beyond that the relationship is irregular. Why it has happened? Because irregularity is because of the accumulation of soil, because the soil on which we tried to test, it is a soft soil.

So, virtually the wheel is dragging some amount of soil in the front because of that, when there is accumulation of soil the resistance will increase. So, the lateral force will increase. So, that is the reason why there is an increase or decrease in the lateral force at a higher slip angle. So, this is the case when the inflation pressure is 165 kPa. Now increase the inflation pressure to 186 kPa and I tried the same experiments that means I varied the same variables like normal load and slip angle and what we observed is the same trend up to 10° the lateral force is increasing at a faster rate they are almost linear, the lateral force and slip angle they are related after that somewhere it is decreasing, somewhere it is increasing, the reason is same.

Now if you compare figure A with figure B the difference is the lateral force which is developed at an inflation pressure of 165 kPa and the lateral force which is developed at 186 kPa they are not same. The force which is developed with maximum load you can say 2.6 kN is roughly around, maximum force is around 2000 N whereas, in case of 186 kPa it is around 1700 N. The reason is the contact area. Since the lateral force is developed at the contact patch, more the contact area more will be the lateral force and lesser the contact area lesser will be the lateral force developed. The same exercise we tried with 207 kPa and what we observed same thing that lateral force is increasing with increase in slip angle up to certain degree and beyond that there is either it is constant or decreasing or increasing.

So, from these three figures what we can conclude is lateral force is a function of normal load, is a function of inflation pressure and slip angle for a given tyre and in a given soil condition that is to be taken otherwise no it is also dependent on ah soil condition. So, once you identify then how to estimate this lateral force? So, what we did is we tried to define a parameter called coefficient of lateral force. What is it? It is the ratio of lateral force to normal load. So, when you try to plot the coefficient of lateral force for three different conditions, conditions mean three different inflation pressure for three different, three different normal loads. What we observed here is it is basically an exponential relationship which is fitted for all these three conditions whether it is a inflation pressure 165 kPa, whether it is an inflation pressure of 186 kPa or whether it is an inflation pressure of 207 kPa.

In all these cases the curves are merged into one curve and that can be expressed by this equation. $C_{\alpha f}$ which is nothing but the coefficient of lateral force ok is equal to $a \times (1-e^{-B\alpha})$ where, α is the slip angle in degrees ok. Now $C_{\alpha f}$ is dimensionless because lateral force by normal load, it is a dimensionless. So now it becomes easier for us to estimate the lateral force because if $C_{\alpha f}$ is related to α by a simple equation if you know α then you can estimate the coefficient of lateral force provided we know the values of a and B. So, we try to find out now what are the values of a and B. So, these values are listed in this table which I am going to show now.

For different inflation pressures, we try to find out the values of a, B and the relationship the equations which we developed, what is it is R^2, what is the standard error of estimate. So now what we observed here is with increase in inflation pressure, the coefficients are decreasing whereas B is increasing in the third digit we can see 1.174, 0.175, 0.176 and the R^2 value is very high and standard error estimate is also very low.

So that means if you know A value B value, simply put these values in that equation and then find out what is the coefficient of lateral force. But we then try to develop that instead of calculating individually if you can relate this A and B with inflation pressure as we saw that this is varying. So, we try to correlate these values of A with inflation pressure and what we obtained is, they are linearly related to the inflation pressure. A can be written as, A is related to the inflation pressure by an equation: -0.0028P+1.1725.

Similarly, B can be related to inflation pressure: $4\times10^{-0.5}$P+0.1668 that means if you know the inflation pressure in this equation the pressure is in kPa. So, immediately we will find out. Once you know the pressure at which you are going to operate then the A and B values can be calculated then these values can be substituted in that equation as $C_{\alpha f}$ lateral force is equal to $A\times(1-e^{-B\alpha})$ and what is the slip angle if you know, immediately you can calculate what is the value of $C_{\alpha f}$. Now, we know what is the load acting on the wheel so $C_{\alpha f}$ × load will give you the lateral force which is developed at the contact patch. So, in brief what we have done is we try to find out what are the parameters which are affecting then we try to study how these parameters are influencing the lateral force for a tractor front tyre which is 6-16, 8 ply rating tyre and we tried in a particular soil condition in a soft soil and then we try to find out how this lateral force can be estimated.

So, the equation which we developed this has to be a verified whether it is applicable to the experimental values which are done later or not on the basis of experimental values which are used for developing the equation. To verify this model, we tried it by conducting some more experiments and what we observed is very good result that means R^2 is nearly 1 and then we can confirm that the equations which is developed, that is exponential relationship which we developed between the coefficient of lateral force and the slip angle can be utilized for estimating the lateral force developed by a tractor tyre. So, in brief the lateral force which is developed by a tractor and powered wheel is found to be a function of slip angle, is a function of normal load, is a function of inflation pressure for any particular soil condition and we tried to study this lateral force by varying this parameter. Then we tried to develop an equation and we found that an exponential relation be sufficient to estimate the coefficient of lateral force for an unpowered tractor front wheel at a slip angle between 0 to 30°. So, this indirectly a study which we conducted at IIT Kharagpur that has been discussed since no much literature related to tractor tyres are available that is why I presented it. So, this has been taken from one of the papers which I published in a journal of Terramechanics in the year 2014. Thank you.