Design of Farm Machinery

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Week - 01

Lecture – 02

Hi everyone, this is Professor H. Raheman.

I welcome you all to this course Design of Farm Machinery under Swayam NPTEL platform.

Today, I will discuss regarding the forces acting on a moldboard plough.

The concepts which will be covered are useful forces, parasitic forces, representation of forces acting on moldboard plough and center of resistance.

So, when an implement or a moldboard plough is pulled in a soil, it will be acted upon by forces and those forces are classified into two types.

One is useful force, the other one is parasitic force.

So, before that let me clarify in the sense, why you should require to measure the force?

The force measurement or the force acting on the tillage implement or moldboard plough is required from the standpoint of total power requirement, from the standpoint of proper hitching or application of the pulling force and design for adequate strength and rigidity of the components.

When a tillage implement is moving at a constant velocity, it will be subjected to three main forces or force systems.

What are those systems?

One is the force of gravity, which is acting upon the implement.

The other one is soil force acting on the implement. The third one is forces acting between implement and the prime mover.

So, these are the three forces which are acting and again these forces we can divide into two types one is useful force as I said in the beginning and the other one is parasitic force or parasitic forces.

When I said useful forces means, for a moldboard plough, useful forces, they come from the cutting, pulverizing, and inversion of soil. Ok.

So, these are the forces when we try to pull the implement or pull the moldboard plough. The purpose of moldboard plough is to cut a furrow slice, then lifts it, passes it towards the moldboard plough, then gradually it moves on the moldboard plough and then it is thrown to one side.

So, the forces involved can be categorized as useful forces.

Now, what are parasitic forces?

Those forces which are associated with friction.

Friction means the landside is sliding over the furrow. So, friction will come.

If a furrow wheel is there, then it will try to provide some rolling resistance.

So, those are coming under parasitic forces.

Now when a moldboard plough is operated, basically moldboard plough is not a symmetrical tool. It is not symmetrical about the vertical longitudinal plane through its center line.

So, the useful soil forces which are acting that will try to give a rotational effect and I will show you how to represent these forces which cause a rotational effect on the moldboard plough.

So, one way of representing is by two non-intersecting forces, which are denoted as R_h and V. R_h, before going to R_h, what is R_h?

R_h is the resultant of longitudinal or directional component of R which is indicated.

This is longitudinal component and S is the side component or the lateral component of R. Resultant of L and S is your R_h. So, we represent R_h and V, V is the vertical component of R.

The other way of expressing or representing the forces acting on a tillage tool is the force R, which is the resultant of L, S and V and a couple V_a.

The couple is in a plane perpendicular to the line of motion.

So, these are the two ways by which we can represent the forces acting on moldboard plough.

Forces mean useful forces.

Now this is again the same thing I am representing, but in a different way. R will have three components L, S and V.

R is the resultant of useful soil forces acting on the implement and basically this is showing you the soil reaction forces.

L is the longitudinal component of R, S is the lateral component of R and V is the vertical component of R.

And if you look at this one, V is always acting downward that is important. It helps in penetration of the implement into the soil.

Now, when a moldboard plough is pulled, there will be useful forces, there will be parasitic forces.

So, this figure which I am showing here that includes both useful force and parasitic force and P is the pull which is exerted by the tractor on the implement.

So, P, I have denoted as resultant pull exerted on the implement by the power unit. It could be a tractor it could be a power tiller depending on the power source.

And P_x and P_y, these are two components, components of P.

Component of P in a horizontal plane that is P_x, but P_y component of P in a plane, in a vertical longitudinal plane.

So, when I say P, it may have two angles: angle with respect to horizontal plane, angle with respect to vertical plane.

So, when it has two angles, then we have to find out what is the expression for draft, that is the horizontal component of pull in the direction of travel.

So, that component is denoted as L and since it has 2 angles, P has 2 angles.

So, $L = P\cos\theta.\cos\Phi$, that will give you the horizontal component of pull which is otherwise called draft.

Then the side draft is the horizontal component of pull, perpendicular to the direction of motion.

So, that is denoted as S. $S = P\cos\theta\times\sin\Phi$.

The third component is the lift force or the vertical component V, that will be equal to Psinθ.cosΦ, ok.

So, when both parasitic and useful forces are considered, then the horizontal component of useful soil reaction force consists of two components L and S and the resultant R_h will be equal to $\sqrt{L^2 + S^2}$.

So, after knowing how draft is to be expressed, after knowing pull and if the line of pull is making some angles, then I am giving you a problem here.

The first problem is the line of pull on an implement is 15 degree above the horizontal and it is in a vertical plane, which is at an angle of 10 degree with the direction of travel.

Now what is asked is, calculate draft and side draft for a pull of 500 Newton. That means, P is given. P is given, θ is given as 15 degree and Φ is given as 10 degree.

So, utilizing the equation which I gave just now, L is equal to, L is nothing but your draft, is equal to PcosθcosΦ.

So, now, you substitute for P $\cos\theta$ and $\cos\Phi$ then you will find out what is the expression, what is the value of L. Similarly, I have asked draft, side draft.

So, side draft S. S will be PcosθsinΦ.

So, the third one which I have asked is, what is the drawbar power required to pull the implement.

So, when a drawbar power is required that means, drawbar power is nothing, but draft × forward speed.

So, draft we have calculated by utilizing this equation and speed is given as 4 km/h.

So, you can find out, draft is in Newton, speed is in km/h. You can convert it $4 \times \frac{10}{36}$ that will give you m/s.

So, 40 by 36 m/s.

So, ultimately you will get a value in terms of Watt that will be the drawbar power requirement.

Now this is the solution. It comes around 528.47 Watt.

Now the question is draft varies from implement to implement.

Suppose I have a 2 bottom moldboard plough, I have a 3 bottom moldboard plough, obviously, 3 bottom moldboard plough will give you higher draft as compared to 2 bottom moldboard plough, when all other conditions are same.

So, this is not a right expression.

If you want to compare, then you have to express in terms of a parameter called unit draft or specific draft.

So, what is that specific draft or unit draft?

It is defined as the draft per unit cross-sectional area of the furrow.

When a moldboard plough is pulled, it will cut a furrow slice, and in the behind it will leave a furrow, opening of the soil.

And that furrow, shape of the furrow could be a rectangular, it could be a trapezoidal, it could be a triangular one, depending on the condition of the share, depending on the soil condition, depending on the hitching arrangement.

So, the ideal furrow cross-section should be rectangular. Why I am saying this is because, if it is not rectangular, if it is a trapezoidal what happens the next row when you try to come it will come like this.

So, this is the portion which will be remaining unplowed.

So, you have to run the plough at least two to three times, then only this unplowed land will be cultivated.

So, if it is a rectangular one, the next row when you come again, comes like this.

So, there is no unplowed land left.

Same is the case with a triangular one, if you are, if the furrow is triangular then this is the space which is unplowed.

So, you have to cross plow again, so that no land is left unplowed.

So, we assume that the cross-section of the furrow made by a moldboard, a moldboard plough is rectangular, and we try to express the specific draft in terms of force per unit area. Unit area means cross-sectional area of the furrow.

That means, this is your depth of operation, this is your width of operation.

So, depth × width is a rectangular cross-section.

So, depth × width will give you cross-sectional area of the furrow and if you know the draft you can divide draft with the cross-sectional area of the furrow to find out unit draft.

So, now, whether it is a 2 bottom plough, 3 bottom plough does not matter. We try to express in terms of unit draft.

So, the plough which is having lesser unit draft is better that means, it will consume less power.

So, that unit draft again depends on different soil conditions.

So, for a particular soil, it could be light, it could be medium, it could be heavy, it could be very heavy.

So, these are classifications based on strength of soil or indirectly you can say cone index of soil.

So, I have given a sample. If it is a light soil the range is 1.96 to 2.04 N/cm^2.

If it is medium soil, the range of unit draft is 3.92 to 4.9. If it is heavy soil 5.88 to 7.84 and if it is a very heavy soil 8.82 to 14.71.

So, heavy soil, light soil, light soil means loose soil.

So, obviously, force required per unit cross-sectional area is less. Heavy soil means more force will be required.

So, if the concept of unit draft is clear, now I will give you a problem.

A three bottom trailed type moldboard plough which experiences a draft of 150 kg, while operating at a depth of 15 centimeter in sandy clay loam soil at a forward speed of 3 km/h. Calculate the unit draft, if the bottom size is 40 centimeter and the cross-section of the furrow is rectangular.

So, the data which are given is draft value is directly given.

Then it is a 3 bottom moldboard plough and bottom size is 40 centimeter.

That means, width will be equal to number of bottoms × bottom width.

So, that way 3 bottom × 40. So, it will give you 120 centimeter.

Now, depth is given as 15 centimeter.

So, it is a rectangular cross section. Cross-sectional area of the furrow is: depth is 15 and width is 120.

So, 120 × 15 that is the cross-sectional area of the furrow and you know the draft is directly given.

So, you can find out draft by cross-sectional area of the furrow.

So, that will give you unit draft.

So, I hope now you are clear with how to calculate or how to find out cross-sectional area, unit draft.

The next thing is I have given a problem, one more problem.

It is a 2 × 30 centimeter moldboard plough when operating at a depth of 12 centimeter and at a speed of 3 km/h, the contributions to total draft due to cutting, pulverization, inversion and motion resistance are 45 per cent, 20 per cent, 20 per cent and 15 per cent, respectively.

What is asked is to calculate the percentage change in unit draft when the depth of operation is increased to 15 centimeter.

Assume that the cutting force is proportional to the cross-sectional area of the furrow slice and the force required for pulverization and inversion is proportional to the volume of soil handled and motion resistance is remaining constant.

So, as you know that draft is due to cutting, due to pulverization, due to inversion, these are useful forces and motion resistance is your parasitic force.

So, now, total draft, if it is D then unit draft will be D/A, cross-sectional area of the furrow.

Now, what is cross-sectional area of the furrow in the first case?

I said it is a 2 × 30 centimeter moldboard plow that means, it is a 2 bottom moldboard plow with a bottom width of 30 centimeter.

So, the cutting width will be 2 × 30 that is 60 centimeter and depth is 12 centimeter.

So, cross-sectional area of the furrow is a rectangle. Assuming that it is a rectangular cross section, then $12 \times 60 = 720\ cm^2$, that is the cross sectional area of the furrow.

Now, if I denote that unit draft as u. For that particular soil, unit draft is u, then the total draft will be u × 720 that means, I can write as 720 u unit. Draft if I said in kg fine.

So, it will be 720 u kg.

Now, out of this, 45 per cent is due to cutting.

So, what is that force due to cutting?

So, force due to cutting will be 45 per cent. So, 45 per cent means $\frac{45}{100} \times 720$ u. Similarly, force due to pulverization 20 per cent.

So, $\frac{20}{100} \times 720$ u and force due to inversion is again 20 per cent.

So, $\frac{20}{100} \times 720$ u and motion resistance is 15 per cent.

So, motion resistance is 15 per cent. So, $\frac{15}{100} \times 720$ u.

So, that way you can find out, the contribution from different components like cutting, pulverization, inversion and motion resistance.

So, what is asked now is, the depth is changed.

So, when the depth is changed what happens?

Your cross-sectional area of the furrow will change.

So, the new cross-sectional area of the furrow will be 12 into 60 sorry 15 is the new depth.

So, 15 × 60.

So, 900 cm^2 is your new cross-sectional area.

So, what is asked is, what is given is force - cutting force is proportional to the cross-sectional area of the furrow slice.

So, initially the cutting, cross-sectional of the furrow slice was 720 cm^2 and we are getting a draft of this much.

Now, for this much area, 900 cm^2 area, the force due to cutting will be this divided by 900 this divided by 900.

Similarly, for pulverization, force is proportional to cross-sectional area of the furrow slice. The force required for pulverization and inversion is proportional to the volume of soil handled.

So, again this has to be divided by 900 this has to be

Sorry

So, it is not divided.

In 720 centimeter square we are getting a draft of this much.

So, in 900,

So, this will be $\frac{45\times720}{100\times720}\times900$.

So, that way. Same thing is here $\frac{20\times720}{100\times720}\times900$.

So, likewise you have to calculate. But the last component is motion resistance which will be remaining constant. It will be same for both the cross-sections of the furrow.

So, now, we will find out what is the output of this one, what is the output of this one and then we will find out what is the difference.

So, now, if I will show the solution, the solution is: the first one - in case of this one, this is coming around 324 u. This will be coming around 144 u, this will be coming around 144 u and the last one will be 108 u. Now, for the new, for the new cross-section, when you change the depth.

So, force - this will come as 405 u

And the second one, force required for pulverization that will be given as 180 u and third one due to inversion 180 u and this is remaining constant, ok.

So, now the total draft will be summation of these. 405 plus 180 plus 180 plus 108. 108 this one.

So, that way we will get 873 u and in the first case we are getting 720 u. This is the expression, ok.

Now, by changing the depth it is coming around 873 u.

So, total draft is 873 u. Now, unit draft will be because in the question which is asked is what is the unit draft change, percentage change in unit draft.

So, draft - total draft we calculated as 873 u then divided by 900. So, that will give you unit draft - will be draft divided by cross section of the furrow.

So, 873 u by 900, ok, that will give you the unit draft.

So, that way it comes around 0.97 u. So, initially the unit draft we have assumed as u, now the unit draft we are getting as 0.97 u. So, the percentage change will be $\frac{u-0.97u}{u} \times 100$. So, that way you will get 3 per cent. That way you have to calculate.

I hope, I have given you how to calculate unit draft and how to utilize this unit draft in dividing the total draft into different components like pulverization, inversion, motion resistance and cutting.

Then comes the horizontal forces or the location of R_h. In this figure what I have shown is a moldboard plough and it is moving at a constant velocity.

So, the P_x is the pull which is exerted by the power unit and it is along the direction of travel.

Then if P_x is equal to R_h, then the draft will be equal to $-$L, L is the longitudinal component.

But actually what happens and there will be no side force. But actually the side force will be there because landside is there.

So, the side force which is shown here as S. Because of the side force, there will be a parasitic force developed.

So, the parasitic force, T which is called thrust. This will be developed to counteract S.

Now, since the landside is sliding over the furrow.

So, there will be a frictional force that frictional force will be equal to μ times that means, coefficient of friction into T. thrust

So, two forces are acting: one is T to counteract S and the μT which is opposite to the direction of travel.

So, resultant of T and μT is denoted as Q_h, which is the horizontal component of parasitic force.

Ok, R_h is the horizontal component of useful force.

Now, the resultant of Q_h and R_h is your P_x which is nothing but draft, if it is in the direction of travel.

So, since P_x is in the direction of travel, we can directly say that P_x is the draft.

Now, I will show you another figure.

Here, what happens the line of pull is no more in the direction of travel. It is angled.

So, that is why I have written angled pull.

Now, P_h, this is the line of pull.

So, if you want to find out draft, then you have to take the horizontal component of P_h. So, which is P_x. Now, Q_h and R_h, the resultant will give you P_h and if you know the angle, this angle then you can find out what is the draft P_x

So, I have written here, $Q_h = \sqrt{T^2 + (\mu T)^2}$.

So, that will give you Q_h. So, once you know Q_h and R_h, which is the resultant of L and S lateral force and side force, then a square root of that will give you P_h.

And if you know the angle, then from that you can find out $P_x = P_h cos\theta$.

So, here the Q_h and R_h, wherever they meet that is called horizontal location of centre of resistance and that is important for stability of plow during operation.

So, I will give you one more figure where you can see the landside length has been increased now.

Same plough, you have increased the landside length.

So, what happened now?

The H has moved. The point H that is horizontal location of center of resistance has moved towards the landside that means, the operation is more stable, ok.

And the line of pull you can say P_x. So, Q_h and R_h, the orientation of R_h does not change that is why H has to move backward when Q_h is changing.

So, H has to move backward so that they can intersect closer to the landside.

So, whenever you are designing a moldboard plough, this thing you should keep in your mind that we have to have a landside, the length should be sufficient, so that it will give enough stability to the plough during operation.

Now, I will give you a problem. A right handed moldboard plough bottom which experiences a draft of 1.96 kN when it operates without side draft.

The thrust on the land side is 590 N and coefficient of soil metal friction is 0.35.

What will be the change in draft if the plough is pulled at an angle 10 degree towards the left side of the plough?

The useful soil reaction forces are unchanged.

That means, what is given is: draft is given, P_x is given and we have to find out Q_h. Because, thrust is given. Thrust is given as 590 N. Coefficient of metal friction, soil metal friction is given.

So, μT that will give you this frictional force. T is given.

So, resultant you can find out.

$$Q_h = \sqrt{T^2 + (\mu T)^2}$$

So, T is given 590. μ is given, T is given.

So, you can find out Q_h and P_x is given.

So, $(P_x)^2 - (Q_h)^2$ that will give you R_h^2.

So, R_h will be square root of this. Ok.

So, that way we will find out.

Then I will give the solution.

The second part is : when a pull is at an angle of 10 degree then towards the left side plough.

So, figure will be like this now.

So, here what we have known is : this P_h we know and R_h we know, then you find out P_x. This one is your P_x. So, P_h you have calculated from the previous figure.

R_h. So, the angle, angle now has to be calculated. This angle we have calculated as 18.6 degree.

Now applying Lami's theorem - in that right angle triangle, if you apply Lami's theorem, the total angle is your 28.6 degree. 10 degree is given and we have calculated θ as 18.6 degree.

So, R_h by this angle. This angle is $90 - (10 + \theta$, which is 28.6 degree). This will be equal to P_h by sin 90, this angle.

You have already calculated.

So, P_x will be equal to P_h will be equal to because R_h you have calculated.

So, from this equation you can find out P_h and then P_h once you know, $P_x = P_h \cos 10^0$.

So, that way you will find out what is the draft.

Now, the question which is asked is what is the change in draft?

Initially draft was 1960 N and now you are getting 2083.65 N.

So, the difference will give you what is the change in draft.

So, this example will supplement what we discussed in the previous slide about location of center of resistance.

So, these are the references and then in conclusion what I can say is we discussed about what are the forces acting on the moldboard plough and how they are represented and how to compute the unit draft then how to compute drawbar power requirement again how to find out center of resistance.

Thank you.