Vehicle Dynamics

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Lecture – 14
Ply Steer and Conicity (Part 2)

In the last class, we were looking at the lateral force development.

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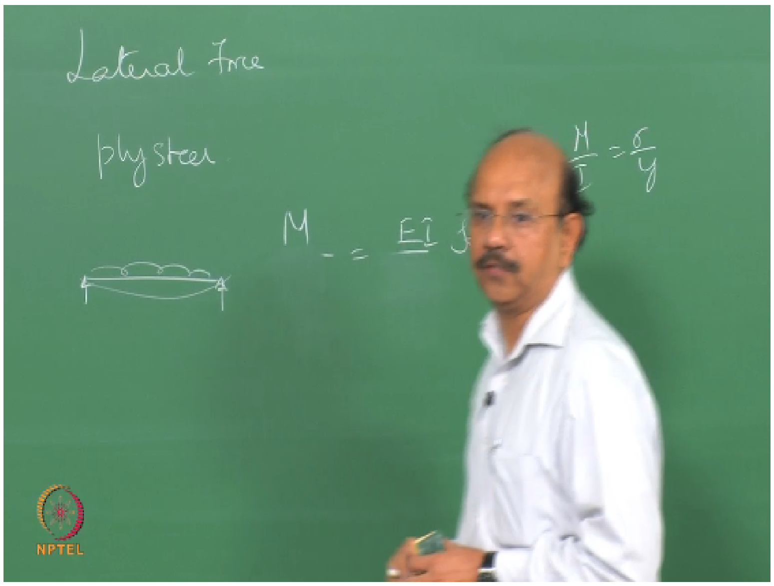

Due to other reasons than just taking a turn and maneuvering. In other words, we found that even when the vehicle runs straight, there are lateral forces and these forces are generated due to 3 factors we saw one is that what we called as ply steer. This is because of the fact that there are what we called as belts or composite material and we found that these composite structure which are due to the steel.

For example in the case of truck tires which are called as steel, you know all steel radials or steel radials if it is called then the steel is the material which is used as a reinforcement for the belt it runs at angle and we said that in the composite laminate ply theory when you stretch this kind of composite material there is a coupling that happens and that when I stretch it there is going to be a moment or in another words force and moment there is a coupling term that is there.

One of the questions that was asked by her is that she said what is this consicity equation? You suddenly said m versus kappa. What is this m versus kappa? I know you might not have the background in composite material. And you might be wondering why this suddenly one kappa is coming and why is that it is just not sigma versus epsilon curves and so on. It is easier to write like that way you can solve any of these things.

Any of these structures using a general 3 dimensional concept but that is not the way it is done because for bending we have for example beam. So, if you look at beam you know how do I look at this kappa? If I look at beam all of you know M/I=E/R of course it is equal to sigma by Y as famously written. For example, rewrite this equation as M/I will just remove that EI/R. So, what exactly have we done note that I have say for example a beam, say a simply supported beam.

And say that I have some uniformly distributed load on it. So, what essentially have we done here so there is a displacement of course and which results in a radius in another words change in curvature. So, 1/R is the curvature. So, I can write that as EI into kappa. So, you see that even in your regular strength of materials you had a used or you had learnt that there is a radius change. Of course, many of you would not have used this equation.

The equation that is usually used is M/I=sigma/Y is what you would have used. You might not have used E/R. I just wanted to point out that it is not a very new equation or not a very new way of writing is exactly what you have written in your earlier classes. So, in another words what did we do here? We changed the curvature this is exactly what we said we are changing the curvature.

Image that I had a beam like this and I am applying a load and changing the curvature like that is essentially what you did when the tire rolls.

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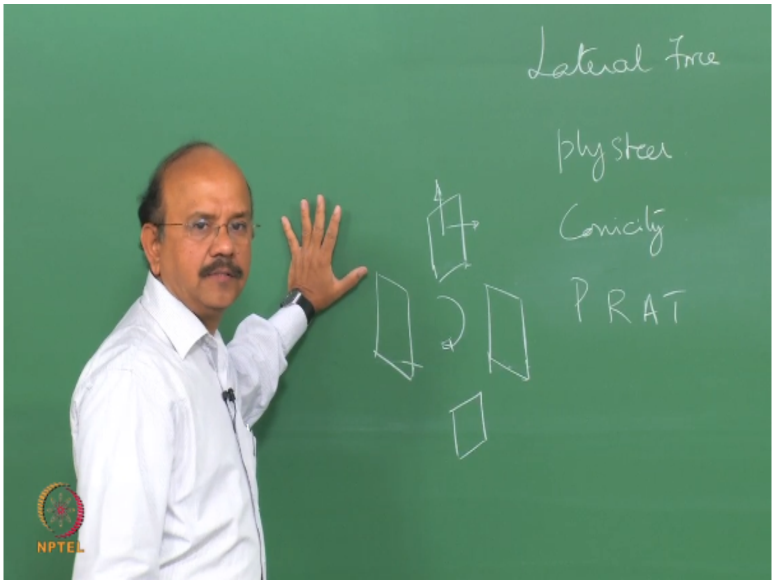

You change the curvature as it hits the ground. The other one which we saw is called as conicity. We said that conicity is basically because of the unsymmetric geometry that results when a tire is inflated for example due to say a belt shift and that produces a force and depending upon which side this belt actually shifts the conicity also would vary whether what they call as the serial side where things are written or the other side depending upon that there would a change.

Now, there is as I said there is always a confusion whether the tire has moved in the clockwise direction, anticlockwise direction the forces change or they keep the same. There is a lot of confusion on that. Please note that the ply steer for example if I have, let us say there is a top belt by which it is represented and if I have a force that is acting here imagine that you know, even if you rotate it would look like this.

All right this point say for example may take go and take that point say it will look like this so actually you do not rotate at a tire in the clockwise and the anticlockwise direction. So, it is always clockwise direction it always looks like this. So, the ply steer forces will be acting like that. The last one which we talked about is due to remember we talked about the ply steer that is still aligning torque and this is also due to the tread patterns.

We said that tread patterns are again so let us say that I have tread patterns like that and just simply we are representing the tread patterns is much more complex than that and we said the tread also has a coupling term. Like we saw that day and that results also in a lateral force giving rise to a longitudinal force and vice versa and because of which there is a torque that is created and this is what we called it as ply steer PRAT. There are standards for this.

How much it should? Some of them may say that PRAT should be PRAT should be 0 and so on. And so what we call as the design of tread has lot to do with many-many things, one of them being this. The other of course the most important thing is how water is carried and so on. We will have a brief discussion on that in one of the later classes before we close this, tires. So, this has a number of effects you know, there is a kind of the conicity in ply steer as a number of effects.

"**Professor - student conversation starts"** anything that happened is mainly from external force, it is from the road property, so how are these properties allowed to road tire interaction. So, the question is that all of them happen due to road tire interaction. So what happens because of these properties or because of this forces generated that is the question, right. How do these properties allow the forces. This is exactly what it is. So, when you say for example if I have a tire so what really in another word, I will just post this question slightly differently. So what happens to these forces?

What are the results of this? Do these forces? Do these forces really happen when the road tire interaction is there and because of which what would happen to the vehicle, right this is the question. Good question. Very good question and let us see what happens to the vehicle.

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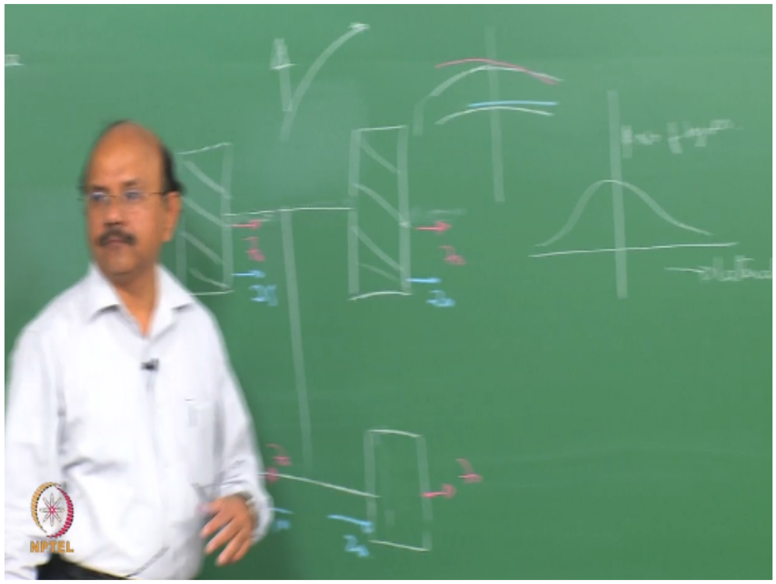

So, first thing is that when I roll the tire on the road remember that ply steer is due to the change in that curvature so when I roll the tire in the vehicle okay automatically a force is generated a a lateral force is generated, right. So, lateral force is generated in the front and the rear. Let us say that is my rear tire. Let us say that is the vehicle. Now, I have a number of forces that are acting let me do that let us say that is the say a force due to ply steer.

Let us give some values taking from the original paper so let say that I have some values then I have other forces, all right. Conicity forces let us for example for the time being we will this talk we will just leave it for time being and we will look at conicity forces. Conicity forces depend upon as I said because of this belt offset can be in any direction. Let us say that it acts in this direction.

And it can be anything it is not a constant because it is due to the manufacturing and so on. Let us say that it is 25, 20, 15, 10 or whatever it is. Then the rear tire let us assume that they are the same as 70 because the tire design may not be the same but let us just assume that in 70 or 60 or whatever it is. Let us say that the rear conicity factor is say 10 in this direction and 20 in this direction, all right.

Now, in other words definitely there is an imbalance in this vehicle. The force distribution now is remember that it is going straight, clear. Now, this is the distribution as it goes straight. So, what is the effect of this kind of distribution? Obviously, the vehicle is not going to go straight. So, there will be a tendency for the vehicle to actually travel like that. Right there will be a tendency to pull in, in other words there is a steering pull.

So, you have to constantly steer the vehicle in order that it goes straight when these force distributions are not uniform. So, one of the things that you can do is to actually shift the tires so that this kind of distribution is not bad. You can eliminate it completely, difficult. But at least you can make it small but what is the effect of this. The effect of this is obviously that I am going to constantly steer the vehicle.

Which means that this opposite for has to be generated which means that there will be a slip angle and hence there will be wear. These kinds of forces would cause wear and that is the reason why? You know wear will depend upon whether it is front or rear and that is the reason why there is always a rotation what the tire company is called as a rotation plan so that the forces that are generated does not harm the wear of the or does not acts in a way that wears the tires.

So, this is what is the effect. The other effects which is called as the dog trailing when the rear get shifted and the front is like this. This is what is called as dog trailing that happens. The direction of the forces, why it depends on the front of the vehicle. Here no, I did not. I am just doing that arbitrarily. You can have 15 that is why I said this can be 15 10, 15 5, 0 and what about the magnitudes? Yeah, that is exactly. The direction so this is what we plotted.

If you remember that if you go to a factory and if I take 100 tires and then plot the lateral forces say for example that is the lateral force. Forget for a moment ply steer I know what is the ply steer value? So, I can find out what is the conicity value then the distribution would something be like this. So, in another words there will be positive this is what this number of tires lateral force distribution will be something like this.

Because I said that this is due to belt offset and belt offset can be in either direction. So, because of which you will have a minus lateral force and a plus lateral force whether the cone is going to become like that or the cone is going to become like this. Why is there a cone? Remember that when there is a belt in the tire, the belt get shifted one side become stiff. The other side is not as stiff as this.

So, in another words just go to the only the crown of the tire let us say that is the center and that is the buttress region and so on. Let us forget about that for a minute and so I have a distribution of the belt and if the belt now gets these offset, say for example instead of being symmetric about the center if the belt happens to be something like this offset in one direction we show those belts the other day and when the belt is shifted then due to inflation pressure.

So, now the belt is like this so this side due to inflation pressure would go up more, then this side which is stiffer because that belt offset. So, it would not get a nice symmetric shape and the shape of the tire after inflation would look something like that in fact. So the crown of the tire is not going to be symmetric but would incline. So, when this tire is rolled you produce what is called as the. Now, unfortunately these are not the only things which produce lateral forces.

The lateral forces are also produced by what is called the camber.

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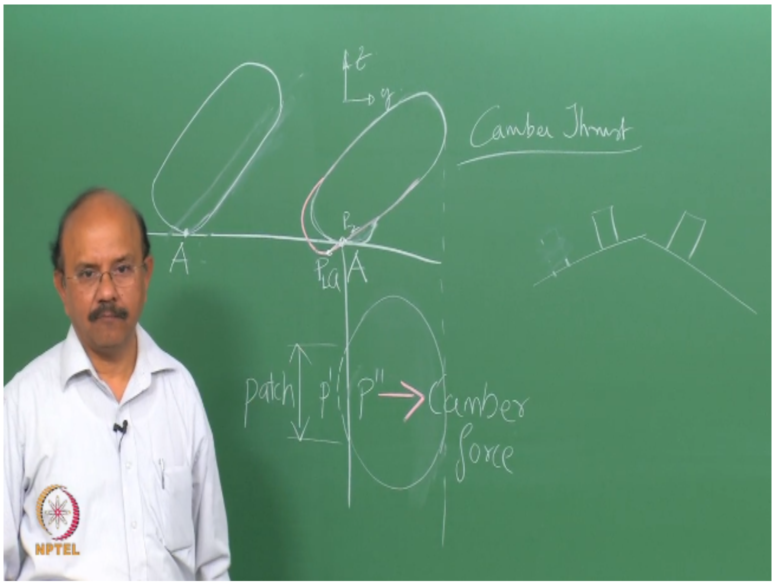

This is actually a motorcycle camber exaggerated just to illustrate a point that there is a camber. And you know about camber, the camber also produces a thrust. Yes. Why do we have the offset in belt? We do not introduce that why is that there are offset in the belts. This is a manufacturing process.

This is due to the manufacturing process as the tire is built the belt is placed on a drum so and then it is taken over to a curing presses and it goes through what is called as a curing process. So, when this tire is manufactured and then placing the belt and then cured and so on. The belts do not stay in place remember that these materials are viscoelastic materials and the viscoelastic, when it is in a stage where pre-cured stage when the curing has not yet taken place.

It is in a pre-cured state. Its viscoelastic property becomes highly viscoelastic in another word it starts flowing in a very short time. So, due to so many reasons these belts are not necessarily symmetric. So, these belts gets you know offset. Why do you put a longer belt? Whatever be the belt width it is called a shift. There are other things you know into design. It is a good question. But then we are going into tire design. Very good question, we just have a long belt and be done with it.

One of the cardinal principles in tire design is that your belts edges are singularity points. And as far as possible you do not get the singularity point into regions where the stresses are high. You do not get that singularity point it is what is called in our mechanical engineering design stress raisers. So, the tip of the belt is the stress raiser so it is good not to get that into region where the stresses are already high.

You know that when you have a very sharp corner for example which is singularity point then you will have stress concentration and so when there is stress concentration the stresses increase. So, that is the reason why you cannot have as long a belt or as big width of the belt as you would like to have because you would enter into regions where the stresses are high so the belt adjust would become very vulnerable.

Would not be able to go further on then that because of lack of time but tire design has so much of engineering principle it is such an exciting field because there are so many things that add. **"Professor - student conversation ends”.** So, in fact if you look at tire design you would learn the mechanics of material at the highest level. Because you are dealing with composite material, you are dealing with a material which is not linear.

You are dealing with the system where not only failures you have to avoid which is very, very important but also the durability, the wear characteristics had to be nice with very good. You have to design in such a fashion that handling characteristics are not affected. The noise of the tire is low, the wipe does not produce vibration. Now, you have covered the whole of engineering.

So, that is why tire design becomes very exciting because the whole of engineering whatever you have learnt tell me a course and you have an application here. You studied for example long chain macro molecules, right. The behaviour of mscro molecules in your first year that was you chemistry course So, a macro molecular chains, how they act completely forms the bases for the behaviour of the tires. How does the macro molecules?

This is a macro molecular structure, this is an elastomer. So, whatever you studied in chemistry is applicable here. So, tell me a course and I will tell you where it is applied in tire. So, that is why it is very exciting. Come back and we will look at, does that answer your questions so there are forces. But unfortunately the forces do not stop there and we will come to the camber part of it. There 2 things that are important one is the camber of the vehicle. Can be 0 camber in a car.

It can be .5. It can be 1.5 in a truck and so on. So, there is a camber of the tire. The camber of the tire is superimposed on the camber of the road. So, there are 2 cambers and they act together. For example the camber of the road it can be like this and the vehicle can be going here like that. If it happens to be a 2-lane traffic and in some of the what you would call as kacha road or village roads where it may not be like this. You may be going in this way, whether it would be one or so on.

So, these kinds of cambers are given for the water to be drained out and so that is also going to have an effect and what is the effect? The effect of camber is to give what is called as the camber thrust or camber force. From the point of view of a vehicle stability, this become very important in a motorcycle tire from the point of view of wear especially in truck tires the camber thrust becomes important.

Let us see just what happens as is our practice let us go and sit down in the tire and see what really happens and how this force is generated. So, if assume that there is no road if there is no road actually this would be the tire profile. That would be the tire profile. Imagine as if it is penetrating the road. Now when you roll, it the tire would take an elliptic curve goes like that. No, that is not the case.

Road has an important affect and the road actually pushes a point say for example which is here on to this posture. So let me call this as P and our P1 and P2, if you go and sit at a point P1 you will not be following P1 but you will be shifted to P2, actually you will come here. Is that clear? So, this is actually the shape that is taken by the tire is that what is seen in the white line. So, in another words there is a shift in the z direction.

If you call it as z direction and there is a shift in the y direction. This is our y direction. So, there is a shift. Of course, this shift in the z direction produces from the road that reason which we called it as fz remember that this is what we did all the time before. But the road also pushes this point.

So, it goes like that and then goes like this. So, just exaggerate that so from here to here when the point is pushed which we call as P1 and the other one is P2. So, it takes the route from here to here and here to here. So, in another words there is a force with actually pushes the point in the lateral direction so that the P1 reaches P2. If you look at the plan view then for example the points which are lying here are now completely shifted in the plan view to the points here.

So, I will get a number of points which are here so these points now go to those places. So, because of this pushing of this point I develop a force. So, that force is the camber thrust and it acts like this. So, there is again a lateral force that is generated I did not do anything I did not even corner again a lateral force is generated due to the camber that is present either in the vehicle or on the road and the result is that is to be added to the forces that I already have.

So, the camber thrust produces a lateral force. **"Professor - student conversation starts"** Sir, actually camber is not a (()) (25:39). Yes, this is a positive camber and a negative camber you know. We are looking at camber in just one of it say for example there is a camber I have provided depending upon you can have a camber like this or you can have a camber like that if the camber is in the opposite direction the force will be in the other direction.

So, it does not make a difference how the camber is for example you can look at it as a motorcycle which is taking a turn where you are just leaning and that is what happens. Clear. **"Professor - student conversation ends"**. So, the thrust of course depends upon what the camber you give and also please note that the camber is quite complex. It is made quite complex because of the road. Let us say that I have a camber which is given like this. I am just exaggerating.

It is very important for trucks and it is very important that the truck manufacturers actually look at what is their camber, they give a big range but that would have a lot of effect on the tire. It also goes with the road camber. Now, this is straight road. Suppose you are going like this on the road then what would happen? The road is inclined the road is given a camber. What do I mean by road camber? That is the question.

The road is not always straight. It is not a flat region like that. A road is given a camber and the road camber is say for example is something like this. Why do I give this because all of them are exaggerated will be so you know mountain, no, no. We are talking about 1 degree. This angle is in India usually it is about a degree. Now, this may vary from place to place and so on but let say that it is about 1 degree. Why are be giving it?

Because it is a beautiful drainage that has to be broad, go and look at any road you would not have noticed it stand here and look at it you see that camber given automatically. So, it would be not so sharp. So, now if this is the flat road let us say this is the camber and now I am going to change the camber of the road and make it say like this. I am giving a camber. So, what happens now what was sitting this is the angle now it becomes that is the angle.

And what was this angle now becomes that angle. It is something like it is like this I change the camber of the road or in another words I put one more angle. Let me draw that clearly. Let us say that is the road. I have the initial angles. So, now I am giving a camber to the road. So, the road camber I am putting it like this. Now, the tire is going to now sit like this. So, there are 2 angles now this is how the tire is now going to sit.

So, in another words what was straight here for this side you have rotated it in this direction which means that you have made it more towards 0 camber or reduce the camber. Now, what happens this side. Now this side, actually it is going like this. So, in another words this angle now is reduced. **"Professor - student conversation starts"** You can just look at the vehicle inclines like this. Of course, gravity is always acting in that direction. That is the only thing that differentiate that, say 0 degree or 1 degree camber. No, no, no. This is geometry.

Please note that I cannot resolve it you know, camber is not resolved. Note that carefully. Say for example let us forget about road for a minute. Suppose, I have this is very important the point which you said suppose I have a camber like that. Let us take this. Let us forget road for a minute that makes it complex. Let us say that I have a flat road where I have a camber and how does the load act? What you call as gravity load or g load. It acts like this.

And camber how does it act? Perpendicular to it so how can you resolve a perpendicular force into vertical force into a horizontal force, it cannot be solved. So, camber is not resolving the force along horizontal direction. This is a very important point. Camber is because of deformation of rubber, the camber thrust is because of the deformation of the rubber and that is what we show here moving from P1 to P2.

So you do not resolve it effect of camber thrust is of course a force that is acting on the tire. The tire is equilibrated by an equal force on the axile and there are 2 forces that is acting in the tire. Is it equivalent to a situation where on flat road with no camber, if you suppose somehow if you are able to generate a body force in a horizontal direction, is it equivalent? There is no body force involved in this. What is body force? Body force is a force that acts throughout. It is not a body force. It is a force that is acting at the tire road interaction.

I mean due to tire road interaction and is acting as the interface between the road and the tire. Clear. So, it is not a body force. Body force means it would be acting throughout the volume of the body. So, I know this confusion, I understand this confusion that may people think that camber is due to any inclination and resolve this in this direction, that would not work. Because this force you cannot resolve it to get this force, all right. So, in another words if you look at road camber you just look at it as if there is a change in the camber angle. **"Professor - student conversation ends"**

So that is what is called as the camber thrust or a camber force and that is added to all this forces that are happening. So, the situation is not that straight forward. That is why this is so exciting. So, the tire manufacturer recommend that you rotate the tire because so many forces are acting you do not know the forces and these forces have an effect on wear and you want an uniform wear best thing to do is to have a rotation plan.

So, one more derivation which I have to do and we will stop here for a minute or may for 5, 10 minutes this class because I know that you have a quiz coming up and if there are questions you can ask them so that we will clarify some of them. **"Professor - student conversation starts"** Conicity is also called camber? No, no, no. Camber is from the vehicle, conicity is from the tire. The tire becomes a cone so the reason is not the same.

The deformations may be similar but the reason is not the same when we say camber thrust. It is coming from the vehicle where I give a particular camber. So, hereafter when you look at the tire go and see what is the camber? How the wear of the tire? We are referring camber forces to the deformation in tire. Absolutely, I agree with you. This is due to the deformation of the tire and so the origin is tire. Ultimately, the force origin is due to an interaction between the road and the tire beautiful question.

No doubt about it. But why is that interaction taking place in camber? The interaction is taking place because there is a voluntary camber that is given that camber is what is causing this kind of minute deformations that are taking place at the interface. On the other hand, the shape of the tire when it is put in the road is changed not by the road. It is first changed by the manufacturing defect or whatever it is.

Then there is a deformation in the road which makes it flat like what we have said and then it causes so in that sense both camber thrust as well as conicity is produced because of deformation of tire which is running on the road, no doubt about it. Any other questions? Can you just go through PRAT? What is PRAT? Unfortunately, we do not have the slides but I hope you remember the slides. Remember that when the question, how do you create PRAT, the direction and what is PRAT?

This is a very simple thing which I did, but let us understand what it is?

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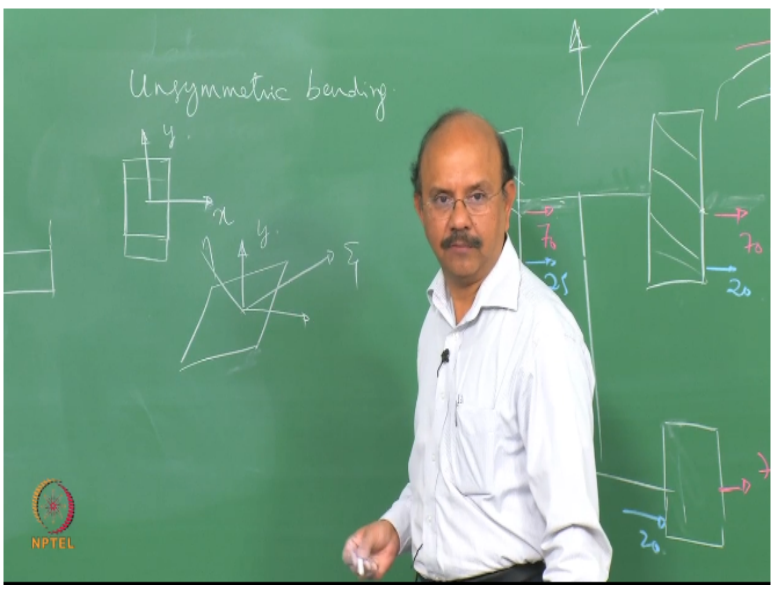

The fundamental reason for this PRAT is what is called as unsymmetric behaviour called as say unsymmetric bending and so on. So, it is the unsymmetric bending you are going to face this quite often in your next course on automatic structures, going to look at unsymmetric bending in very closely lots and lots of equations. So, the equation can wait for some more time but let us look at what is unsymmetric bending?

All of us has looked at symmetric bending where there is a symmetric say for example it can be a rectangular beam or a square beam where there is a very clearly draw it. There is a symmetric, the axis is symmetric about whether the geometry is still symmetric about the 2 axes. Now, when this for example I have a cantilever beam and when it is symmetric and you bend it. When there is bending then it would not get suppose I displace it.

I displace this and then the displacement would be only in this direction and would not get displaced in the other direction which I would call that as x. Now, if my loading is not in the same direction as this or in another words if the loading is the same but if the structure does not have symmetry like this say for example I have a structure which is like that and then I have my axis as defined like this and I have a force that is acting in the y direction that being the y then the displacement is also in the x direction.

So, a y force also produces a displacement in the other direction. When would it not produce? There exist what are called principle axis for this kind of structure which may run like this. Let us call that as psi and eta, which we are going to see in the next course that if you apply forces along this principle axis then this kind of coupling would not take place. So, there exists this principle axis about which say for example if I apply force along the psi direction or eta direction.

There would not be any displacement in psi direction and so on. But as long as there is unsymmetry in this kind of loading then it would produce a force in the other direction. So, now this is the fundamental. Now, I have lateral forces and longitudinal forces even in free rolling let us say that I am doing a free rolling. I have lateral forces. You have already seen that there are forces let us say that I have this is my tread profile at a particular region.

At a particular point so that is the contact patch. I have tread profiles like that and let me say that I have edges tread profiles like this.

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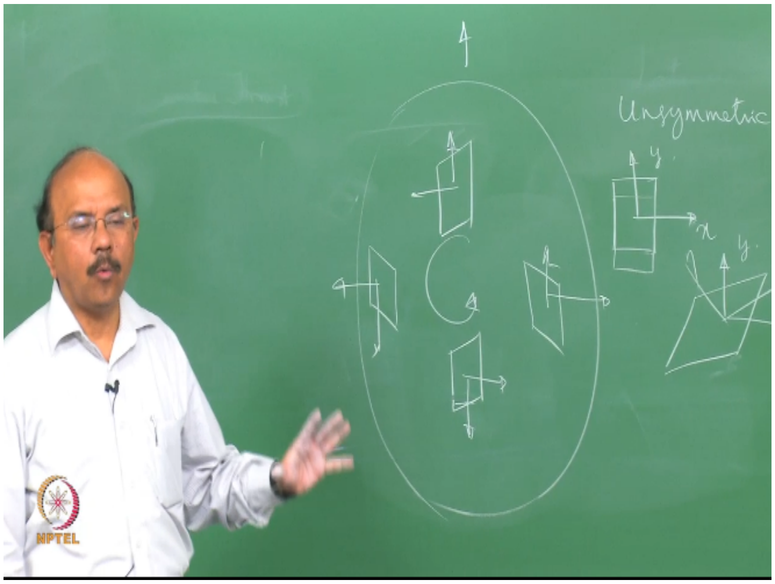

Now, we have seen for example that the lateral or the longitudinal forces, any questions? There are longitudinal forces that are acting at the, this is the leading edge in another words that is how the vehicle moves. There are longitudinal forces at the either end and remember there is a positive.

And it come back negative you know, the longitudinal force and there are also lateral forces in other directions. Which is spreading out at the edges, at the shoulder of this contact patch. Is this because of the straight force or this is? Yes. There is a side wall there is a thrust and because of which there is a lateral force that is happening. That is what we saw in the last slide.

Remember that we said in contact patch there is local effect, there is global effect and all those things. Let us forget it for a minute. Let us say that I have a tread which is something like this. So, now these guys are going to now produce additional forces which are perpendicular to these forces which are actually thrust on them because of the contact patch. So, there will be a force like this. There will be a force like this. These are due to the coupling terms.

So, these coupled forces now create a torque around it. Now, questions are the tread is as simple as this? No, we are not saying that the treads are as simple as this. But you can use for example finite element analysis in order to understand how, what is PRAT? How it is produced and what are actually the shapes of these treads and all those things blah, blah, blah you can do that.

"Professor - student conversation ends". So, actually then the next question is can I treat the tread like simple cantilever beam?

No, these are stubs, why are we producing, I mean what are the other things that are happening because there are shear stress become important with what are called shear deformations and so on all of them I brought out very cleanly with my finite element analysis and the theory of which as we said we will learn later. Is that clear? So this kind of cross linking due to unsymmetric bending is the reason for what we call as PRAT.

"Professor - student conversation starts" PRAT is because of the unsymmetry? Yes, this is the shape which is not symmetric. It is not necessary that it should be shape like this, a rhombus or something as you have seen in any tire, you would see that the shapes are very complex. The shape of tread also depends upon its ability or its requirement that it carries water. So, that is what it is. May be after sometime we will see about what is wet traction?

I mean we will go ahead we will do lateral and then we will come back and look at wet traction and so on. We are spending lot of time on tires. I understand that it is a very important topic but we are not yet gone to lateral dynamics which is exciting in its own sense and how the tire is going to have a huge impact on lateral dynamics is what I am most interested to project and we have already seen we have already entered lateral dynamics.

In the sense that we know how lateral forces are developed by the tires. Any other question? I have a doubt on contact pressure, when we have a uneven contact pressure actually all the points on the ground are actually the axis of rotation. Hence if we are writing our titles to i omega we can write about all the points? Can you show me what is the question so that I can repeat it to others. We have found the f equivalent equal to tr=f*rd about this.

So, it is actually all the points are equivalent in this case so we can actually, can be apply about the point where the equivalent begins. Let me see what I understand from your question suppose the contact pressure distribution which we said which is unsymmetric because of the viscoelastic forces and there is a contact force, the whole of the reaction is happening like this.

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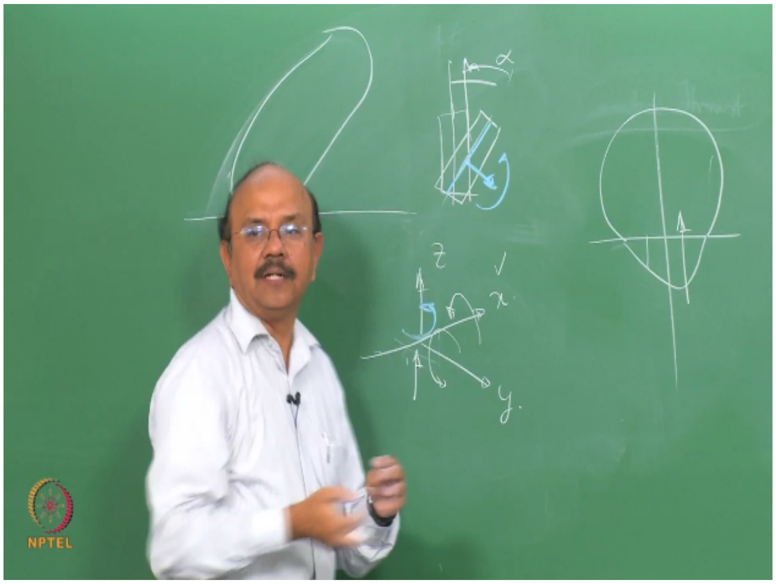

And that is going to rotate the tire in the opposite sense in the sense that there is a talk. The question is can I just replace all these forces that are acting by an equivalent force there? Of course and that causes the movement. So, in another words, oh god I removed it may be Apoorva draw it. They have drawn it beautifully I am going to replace that in another words when there is camber for example look at the motor cycle.

There are lot more to it we are not there is what is called as turn slip and so on. We are not entering into a lot more tire mechanics and tire dynamics. But please note that the complete force does not act right at the center of the contact patch. It acts here in this case like this if you look at it from the top it act actually to the side which gives an over turning movement. So, in actual case that gets deformed and so the force is acting like that.

So, in another words completely resolved forces do not act symmetrically at the center because of which there are so many moments that are created. Clear. So, can I replace the complete contact pressure by means of an equivalent force that is the question. Of course we will do it and of course what we did for all the longitudinal forces and that is exactly what we are going to do for the lateral force.

So, for the lateral force generation we are going to look at the equivalent force as well as the moment which we called as the aliening. What are the effects of moments on other directions. No, no. Absolutely, there are moments in the other direction which is an overturning moment. There can be moment which tries to overturn which is say for example you have the 3 directions. Say for example this is traveling direction of the vehicle.

Let say v and that is the lateral direction of the vehicle y and this is the normal to the ground. Any questions? Why it is unsymmetrical? We talked about the viscoelasticity remember that is what it is. You told it stress loading will be. Absolutely, this is with respect to that but the other moments are created due to other reasons. Remember that we had what is called as an aliening torque. Remember that we had if it is a plan view a vehicle which is going straight like that has to take a turn.

And so we give a steering angle and that produced what is called as the alpha in order that we get the centripetal force and the centripetal force again does not act right at the center. And acts, if this is the line that is the centre it acts away and because of which there is a moment that is generated and that moment actually makes the vehicle or makes this to go straight again. So, it is called as aligning moment.

So, that aligning in another words that is the moment, aligning moment and the rolling resistance of this produces a moment about y. This is the moment is produced like that. This is rolling assistance moment. The other third moment in the x direction is because of the fact that there is a camber and the contact point is not exactly along the x direction and can be shifted away from x. So, the normal force acts not exactly here but away from it.

Look at this. This is the center point but actually it acts away from it. So, that is the force that is actually acting if this is the contact patch so because of which there is another moment that acts along the x which is the overturning moment. So, there are 3 forces the normal force, the longitudinal force which gives the traction or breaking and there is a lateral force which is the centripetal force along with it there are 3 moments.

These forces produce moments in other direction that is what we saw now. So, it is not symmetric. The contact patch is not symmetric that is most important point. Yes, though you may say we assumed a nice parabolic distribution I am going to do that again in the next class for the combined cornering and braking. But that is an assumption that should be made. Will that loading and unloading be constant throughout the free rolling? But then we are looking at the draft that I drew was for a point.

The question is how do we view this loading, unloading? View the loading, unloading from the point of view go and sit in a tread and look at it. Actually, the tread is at different positions in the contact patch. So, that we maybe do in the next class and then you see that each one of this point will get loaded and unloaded. That is the graph we should solve. But then sir, how can we assume it to be a constant? Because there is a steady state and every tread undergoes.

This is what we call it as steady state. So, every tread under goes a loading, unloading characteristic so at the end you can look something like this. Freeze the position and then view it. That is what you get. **"Professor - student conversation ends".** So, we will stop here and we will continue in the next class on Wednesday.