Engineering Mechanics
Professor Manoj K Harbola
Department of Physics
Indian Institute of Technology Kanpur
Module 2
Lecture No 14
Differential elements and associated forces and torques - I

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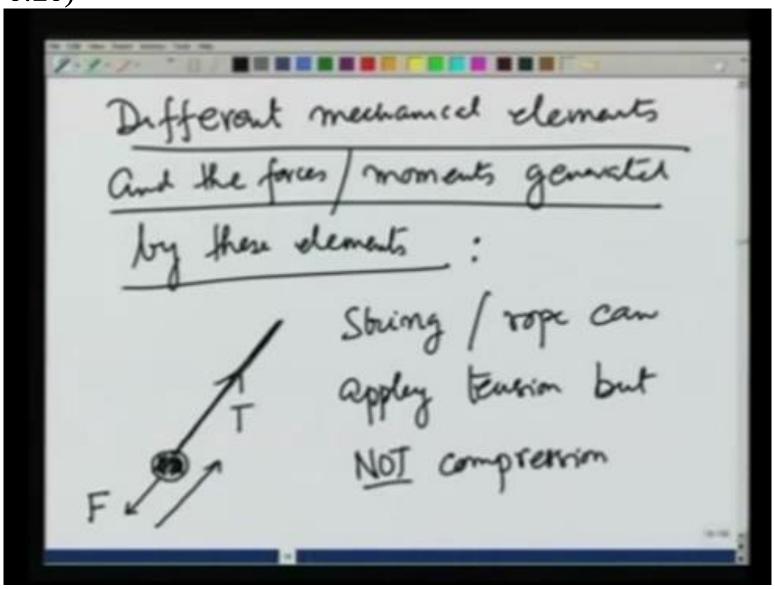

Next, we discuss different mechanical elements that are used in machines or structures and the forces moments generated by these elements. Our strategy would be, I will take each element, discuss about it and then solve a related example. The simplest of the elements is a string which can apply a tension. Suppose I am pulling a ball or something tied at the end of a string by force F and it is not moving.

Then the string applies a tension in the opposite direction. But remember as string or a rope can apply tension but not compression. That is if I push the ball the other way, the string would not be able to stop it.

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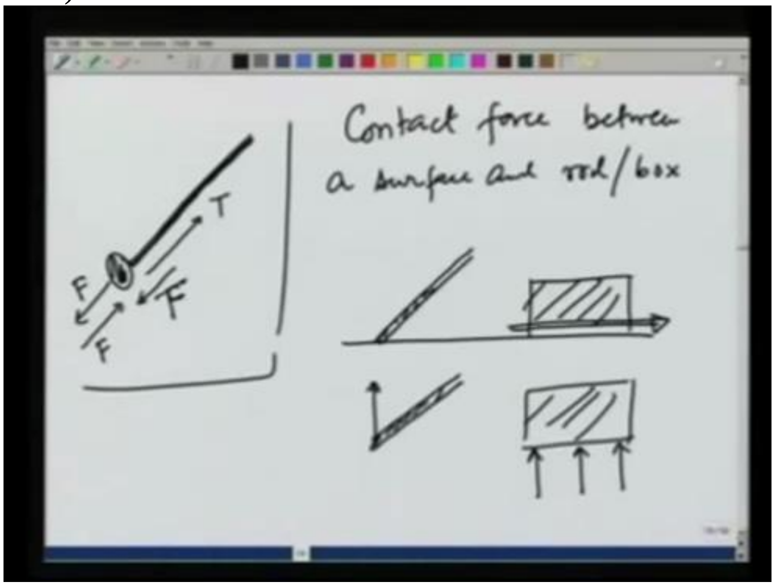

On the other hand, if I have a bar made out of a material, a rigid bar it can apply both a tension as well as a compressive force. So if I have a ball at the end of it, if I pull it by force F, it will apply a tension T. If the ball does not move, if I push it in by a force F, it will apply a compressive force of equal amount in the other direction. Next, let us discuss the contact force between a surface and say a rod or a box on it.

So for example if there is a smooth surface and there is a rod here which is being pushed or whatever and there is a box here, the only force a smooth surface can apply is perpendicular to itself and therefore it is capable of applying a force on this rod which is perpendicular to itself. Similarly, it is capable of applying a force on the box may be distributed, maybe at the same point, which is perpendicular to the surface. Why is it perpendicular?

Imagine if it were not perpendicular, what would happen? Then this box now because of the component parallel to the surface, would start moving by itself. That does not happen. And therefore we conclude that a smooth surface applies a force perpendicular to itself.

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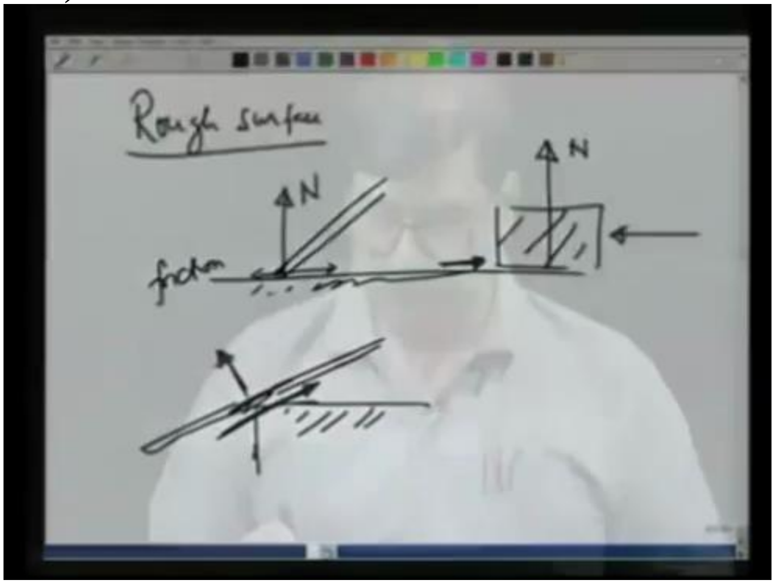

On the other hand, if we take a rough surface, it can apply a force along the surface also, opposite to the tendency in which, opposite to the direction in which the object has the tendency to more. And therefore, this would be direction of frictional force due to the rough surface and of course there is a normal force. Similarly, if there is a box and if I am pushing it this way, it will experience a normal force as well as a frictional force parallel to the surface.

So a smooth surface applies a force perpendicular to itself, rough surface applies a force which also has a component parallel to the surface. By similar logic, if I have a plank or a rod on a smooth on an edge then the force on this plank is perpendicular to the surface of the plank due to the edge. Of course, I the direction in this side would not be there. The only direction in which the edge can apply a force onto the plank is in this direction.

If on the other hand, there is some roughness, then there could be a force, frictional force in this direction also.

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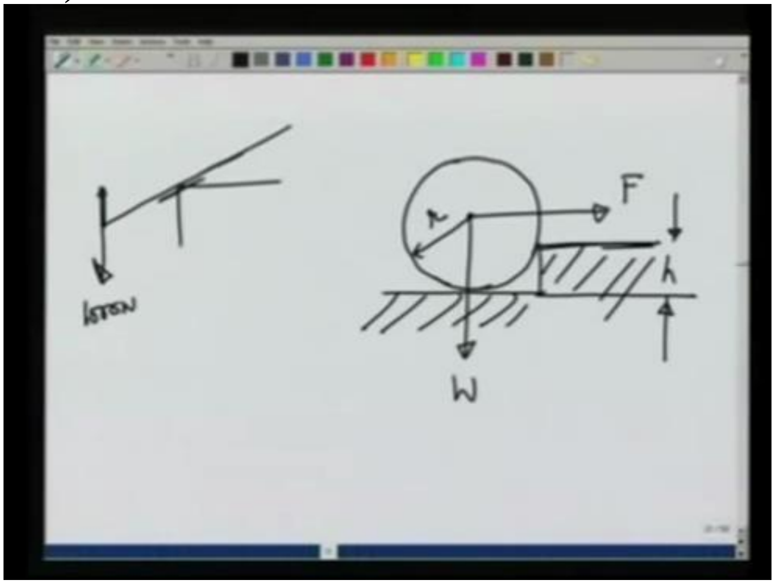

Recall the example that we did earlier where we had a brick on which I had a rod and I was trying to lift a weight like this which applied a force downwards of 1000 newtons here. We realise that without this roughness here, the rod would tend to slip. Let me now do one example of this problem. Let us say I want to pull a roller. This is a very standard problem, over a step like this.

The height of the step is H and I am applying a force F in this direction, parallel to this and weight of the roller is W, the radius of the roller is R. I want to know what force should I apply in order to take this roller over the step? Let us see what all can we do.

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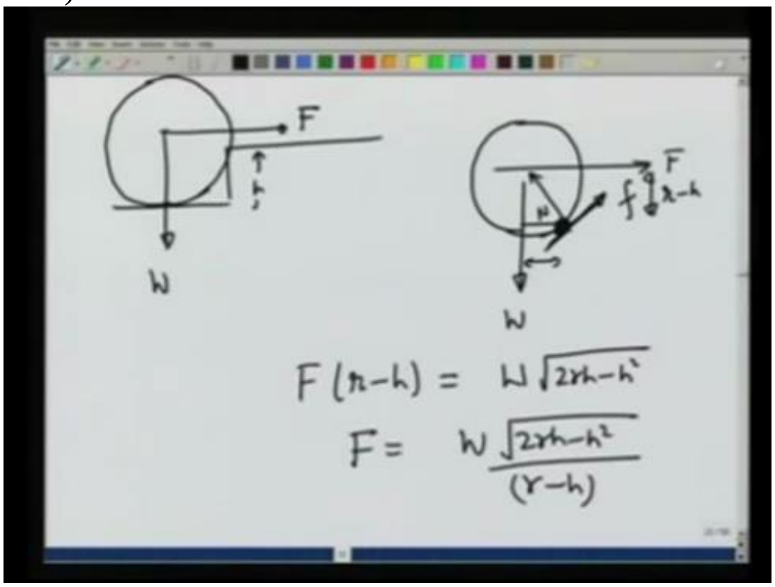

So let me make this again. I have this roller on which I am applying a force at the Centre to the right. This height is H. It is being pulled down by W. Now the possible forces on the roller if the corner is rough is a force like this, frictional force and a force towards the centre, the normal force. Then, the supposed that we are applying, F and the weight, W. To find F, it is very convenient to take this point as the origin and balanced torque about it.

That would straightaway give in order for equilibrium, F times R - H because this distance is R - H is going to be equal to W times this distance which if you workout is going to come out to be 2RH - H Square. And therefore, the force that I apply should be W times square root of 2RH - H Square over R - H. That should be enough to take it over the step. What about these forces, the force F and the force N?

Let us calculate those also. So you see, now in this problem, I am applying the torque equation 1st and the forces equation later.

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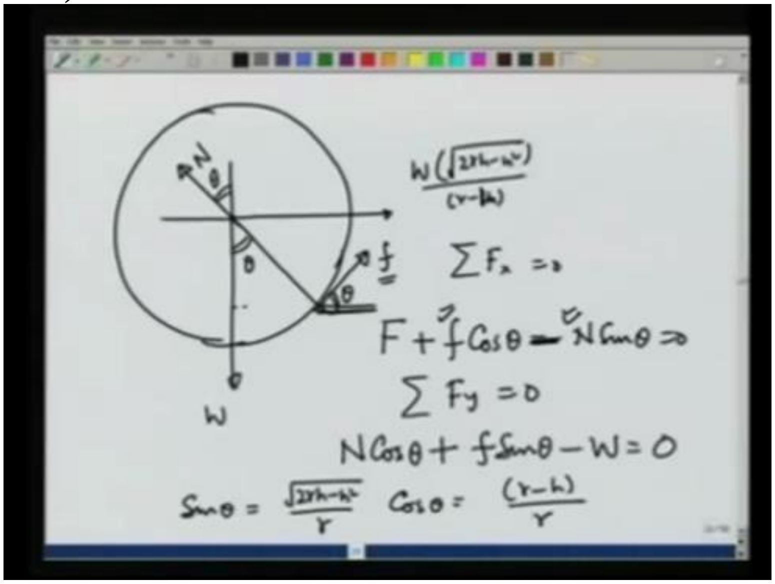

Let me make this brick and now we see that this force is W times square root of RH - H Square over R - H. This force is W, this force is N and there is a force F like this. If I take summation over FX is equal to 0, then the horizontal component of the force F, frictional force should balance the horizontal forces (inaudible 9:05) apply. So I find that F, that is the force that we are applying + f.

Let us say this angle is theta. Cosine of theta should be equal to, if this angle is theta then this angle would also be theta because this is perpendicular to F and this line is perpendicular to the line. So it will be - N sine theta is equal to 0. And similarly, for the vertical forces, summation FY is equal to 0 would give me N cosine of theta + F sine of theta - W is equal to 0.

These 2 equations are enough to determine small F the frictional force and the normal reaction N. Here, since this angle is theta you can see that this angle is also theta. And therefore sine theta is nothing but square root of 2RH - H square over R. And cosine theta is nothing but R - H over R.

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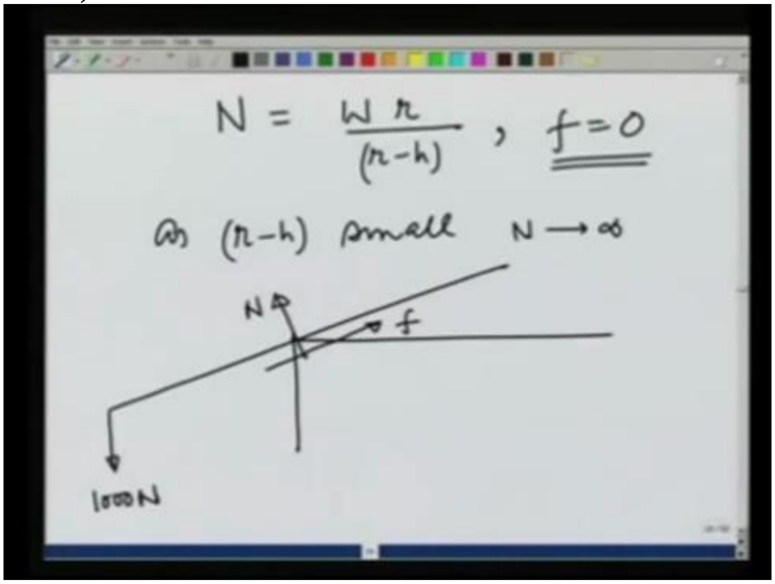

If we substitute these values in the equation, we find N is equal to WR over R - H and S is equal to 0. And this is a very special case where to take the roller over the step, you do not really need any frictional force on the edge. Notice that as R - H becomes small, N goes up. Therefore the normal reaction keeps on increasing as H becomes larger and larger and larger. Compare this with the case that I discussed a while ago and also worked out in detail in the previous lecture where we had a rod lifting a 1000 newtons weight.

In that case, in order that the rod not slip over the edge we had to apply or we required a frictional force on the edge. So what we learn is that a rod or a plank on an edge can apply a normal force in case of smooth surfaces. And normal force and a frictional force when the edges and surface are rough.