Engineering Mechanics
Prof. Manoj Harbola
Indian Institute of Technology, Kanpur

Module – 02
Lecture - 03
Friction

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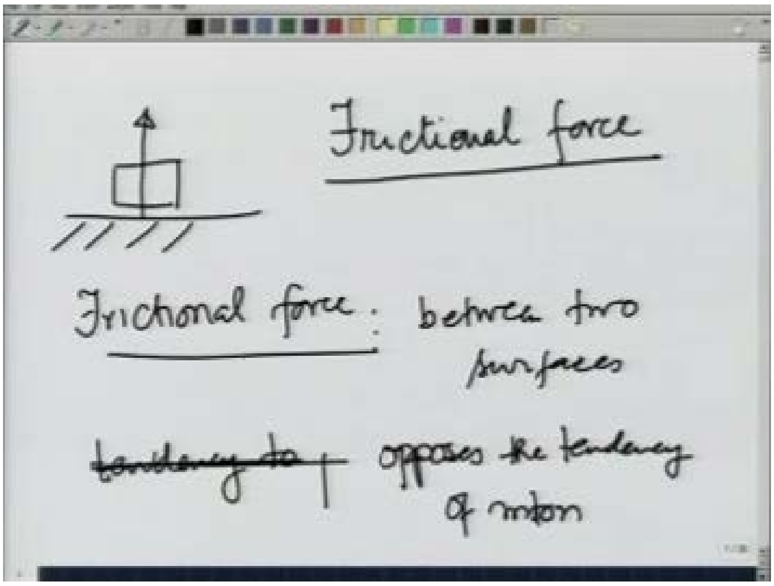

In our lecture on statics, so far you would notice that we have been taking the force on a body where it is on a surface mostly to be perpendicular to the surface by doing. So, we have been ignoring a very important force and the 1 that is all the time present, known as a frictional force. And in this lecture we pay attention to frictional force and discuss it in various different situations. So, to start with frictional force, could be between any 2 surfaces and it has a tendency to oppose or rather I would say, it has it opposes the tendency of motion. So, if a body tends to move in a particular direction frictional force opposes it.

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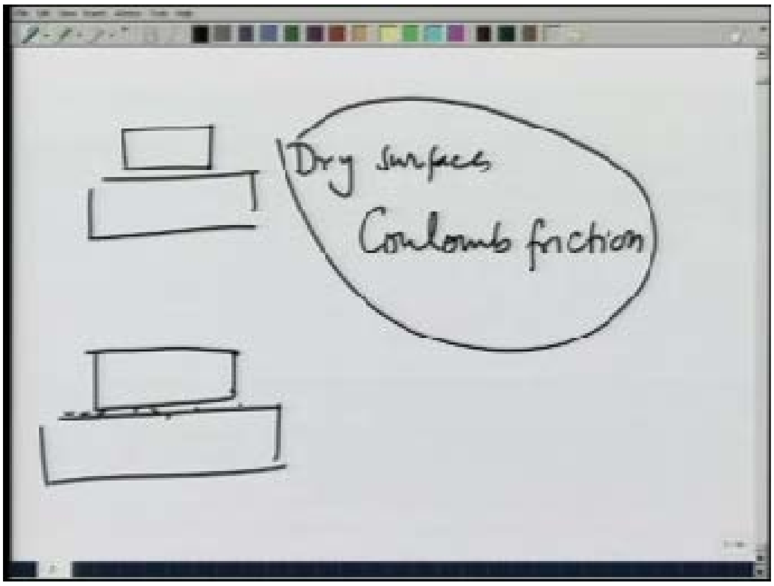

Now, the frictional could be between two dry surfaces and this is known as Coulomb friction, it could also be between two surfaces that have a thin layer of liquid in between this sort of wet friction. Friction is also present when something moves in a liquid, known as a viscous force. In this lecture we will be concern primarily with Coulomb friction or friction between 2 dry surfaces. To understand friction, let us perform a small experiment.

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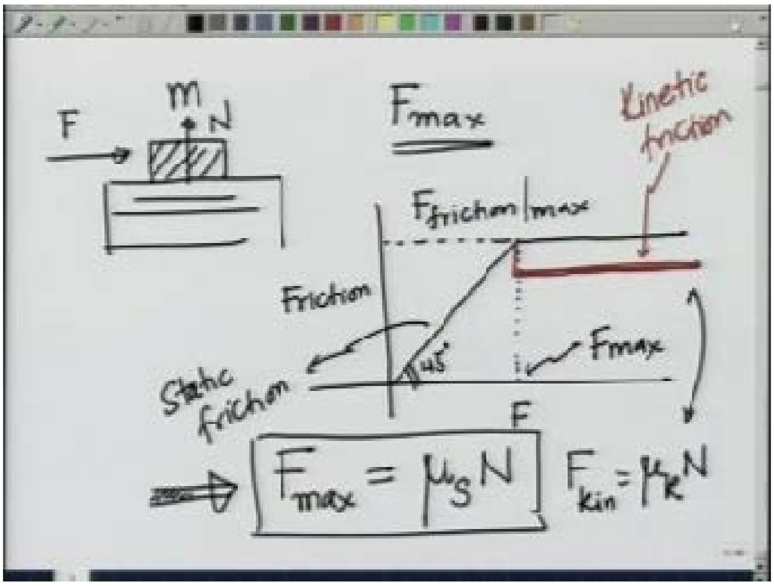

Let us take a block of mass m on a table or on a rough surface and push it by a force F, you notice that when force is small the block does not move. It does not because there is a frictional force opposing it. You keep increasing the force, the frictional force keeps on increasing, and it keeps the block in x position until you hit or you reach in F max, when you reach F max the block starts moving.

So, if I were to plot frictional force verses F, you would notice that friction adjust itself with F up to a certain point, which I will call F max, this would be 45 degree. So, that the frictional force is exactly equal to the force applied. As you go beyond F max the frictional force does not increase it sort of saturates. So, what you would notice after this is that frictional force would tend to saturate at that possible maximum value.

So, this is the maximum possible value of frictional force, and as you go beyond F max the body would tend to move, because now I am applying a force, which cannot be balanced in practice. The line does not go like this, but when the body is starts moving the frictional force reduces a bit. So, actually frictional force looks something like this, where it starts moving, when you go beyond F max frictional force goes below the maximum value of friction.

So, we call these two regions, this is called kinetic friction and as long as the body is not moving that is known as static friction. So, notice that frictional force, when you applying a force on a body, is not constant as you keep changing the force the frictional force keeps changing until you reach a maximum force beyond, which it cannot increase. And then the frictional force works at its maximum, what Coulomb observed is that this maximum value of the frictional force is equal to a constant, which I will call mu s for static times N, the normal reaction on the body.

This is the maximum possible value of friction static friction and once the body starts moving the kinetic friction F kinetic is equal to mu k mu kinetic times N, and you can make out from this figure that mu kinetic is slightly lower than mu static. Although, we write this formula F max equal mu s N. I again emphasize that this is a maximum possible value of friction. It is not that if I apply any force on a body the friction value would be mu s N, it will be less than mu s N. As I keep increasing the force, the frictional force will also keep increasing until it reaches its maximum value, which is mu s times N.

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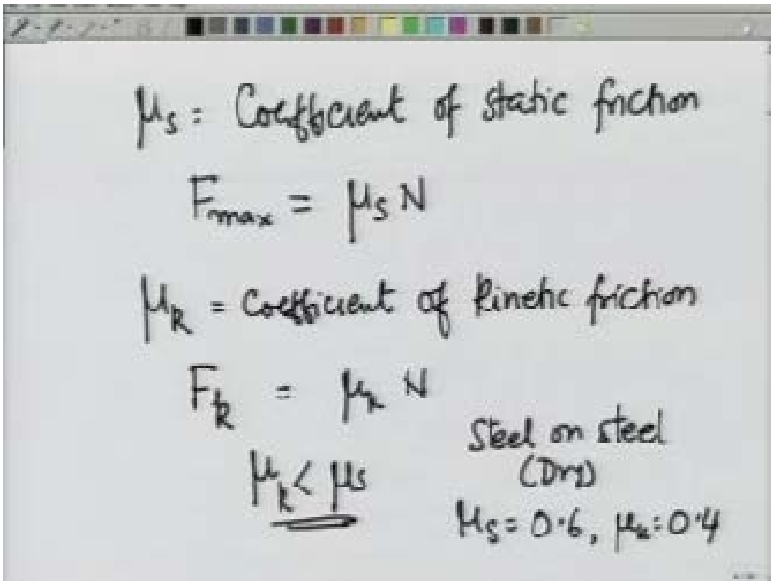

Mu s is known as the coefficient of static friction and F max maximum value of friction or maximum force up to which the body will not move is m u s times. The normal reaction on the body and m u k, which is coefficient of kinetic friction. So, when the body is moving the frictional force. I will call it F kinetic is equal m u k times N and it is observed that m u k is less than mu s. For example, for a steel moving on a steel, the steel on steel; obviously, I am talking about dry friction mu s is about 0.6 and mu k is 0.4. One thing about friction is that it is independent of the area of contact. So, having understood what frictional force is how it comes about. Now, let us solve 1 problem with it. So, that we get a better feeling about it.

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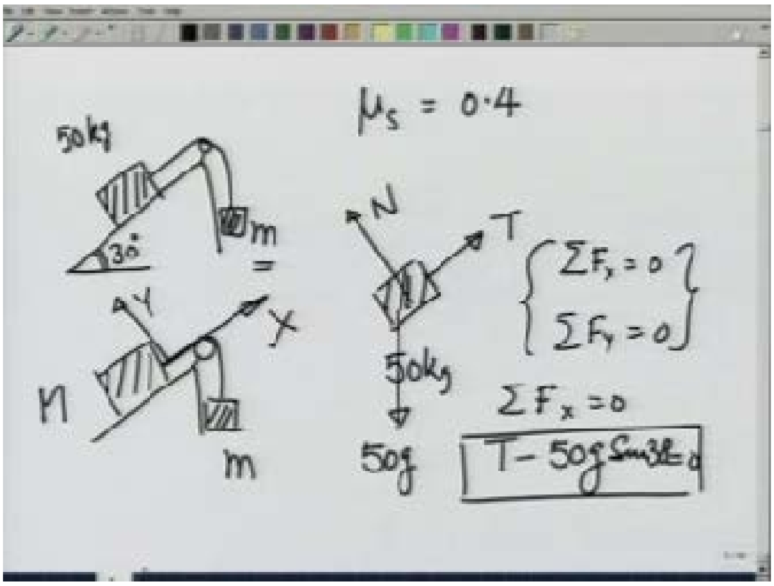

The problem I am going to solve is if, I have a block of say, 50 kg on a ramp with this angle being 30 degrees, and let us say, I tied with the pulley and have another mass here, small m. I want to know, for what range of mass m would this block of 50 kg remains static on the ramp given that mu as that is the coefficient of static friction between the 2 bodies is 0.4, why should small m have a range to start with, it has a range because there is frictional force acting on 50 kg block.

Suppose, there was no friction, let us say, if there was no friction what would happen if there was no friction only 1 particular value of m would balance the capital mass M, how? So, let us understand that if I make the free body diagram of the 50 kg mass. It would have tension T pulling it up, force 50 g pulling it down, and a normal reaction from the surface, if it is not to move then all the forces summation F x summation F y all the forces should satisfy these 2 equations. Let us for convenience take our x axis to be in this direction and y axis to be in this direction. Then, summation F x is equal to 0, gives me T minus 50 g sin of 30 is equal to 0.

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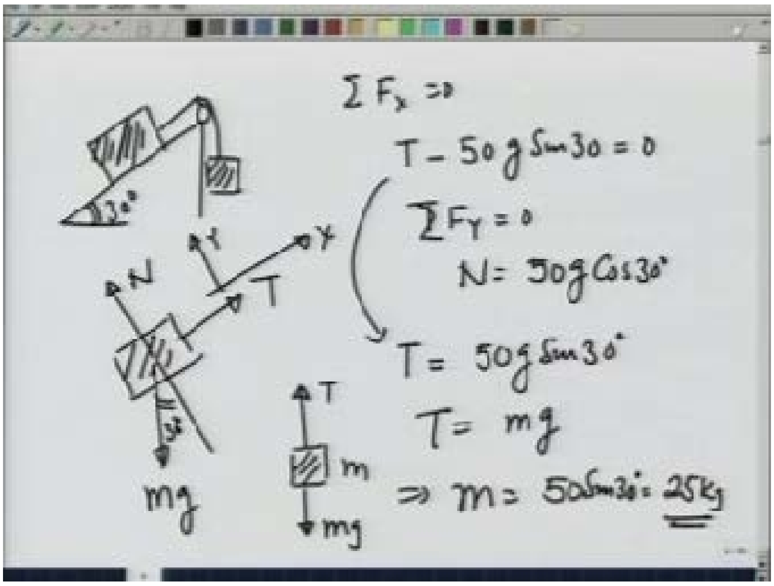

Let me go over to the next page, what we doing is having a mass 50 kg on a ramp of 30 degrees, when I make the free body diagram of this big mass, it has the tension T normal reaction N and mg pulling it down. This angle is going to be 30 degrees. So, summation F x equal to 0, if I take this to be the x axis and this to be the y axis, gives me T minus 50 g sin of 30 equal to 0, and summation F y equal to 0, gives me N equals 50 g cosine of 30 degrees. This gives me that the tension T should be equal to 50 g sin of 30 degrees. If I look at the free body diagram of this small mass m, it has a tension T pulling it up and mg pulling it down.

So, T equals mg and that gives me m is equals to 50 sin 30 or 25 kg, just 25 kg would balance this mass on the ramp, what happens when we introduce friction? Friction provides an additional force that opposes the motion and therefore, I can have a range of small mass m.

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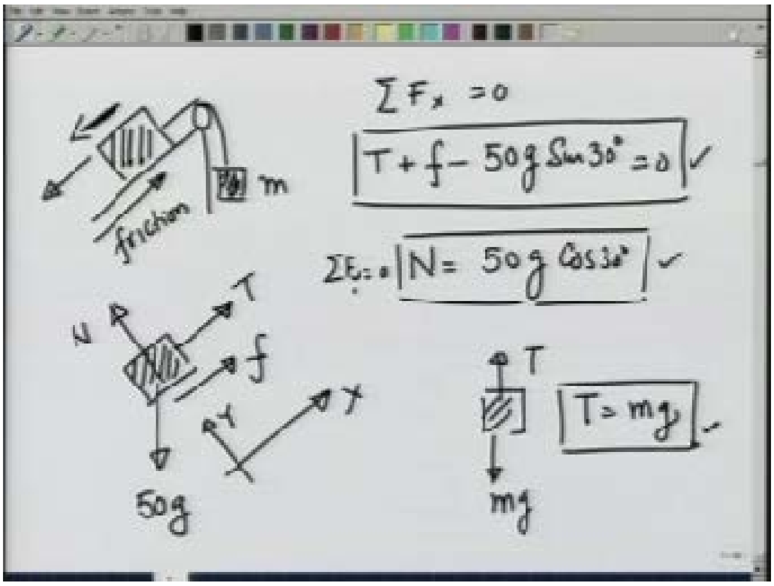

That would balance the bigger mass. Let us see, how let us see first that I reduce this mass below 25 kg. Then, the bigger mass would have a tendency to move down this way, If this has tendency to move down, this way there will be a frictional force opposing it and this frictional force that opposes it makes a possible to have mass m much less than 25 kg, and still have this block in equilibrium. Let us see, how? So, this mass of 50 g, now if I make a free body diagram has a frictional force.

Let me call it small f acting this way of the plane. There is 50 g pulling it down. There is a normal reaction N and a tension T pulling it up. Again taking this to be the x direction and taking direction perpendicular to the plane to be y direction summation F x equal to 0, gives me T plus f minus 50 g sin of 30 degrees is equal to 0. That is 1 equation, and the other equation that I have is N is equal to 50 g cosine of 30 degrees that comes from summation F y a equal to 0. If, I look at the equilibrium of small mass m, this has only 2 forces T and mg pulling it down. So, T must be equal to mg for equilibrium.

So, under frictional force, when this mass bigger mass has a tendency to move down the equations for equilibrium are going to be this. Notice I have written this to be small f, the frictional force to be small f not mu N, because mu s times N is the maximum possible value of friction, if 50 g sin 30 minus T is such that it is below the maximum possible value of friction. The block will remain in equilibrium and f would be equal to that value, which is less than mu N. So, let us look at the equation much more.

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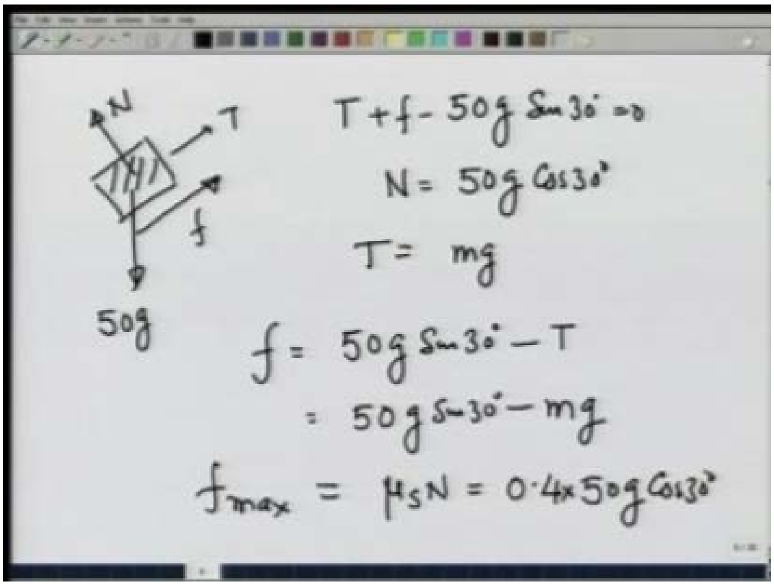

So, I have this bigger mass, which has a frictional force acting this way T acting this way normal reaction acting this way and 50 g pulling it down, and the equations that I wrote, what T plus f minus 50 g sin of 30 equal to 0 N equals 50 g cosine of 30 degrees. And T equals mg putting it altogether, gives me f is equal to 50 g sin 30 degrees minus T or 50 g sin 30 degrees minus mg.

Now, the maximum possible value that f could have is mu s times N, which is equals to 0.4 into 50 times 50 g cosine of 30 degrees. That is a maximum possible value of the frictional force.

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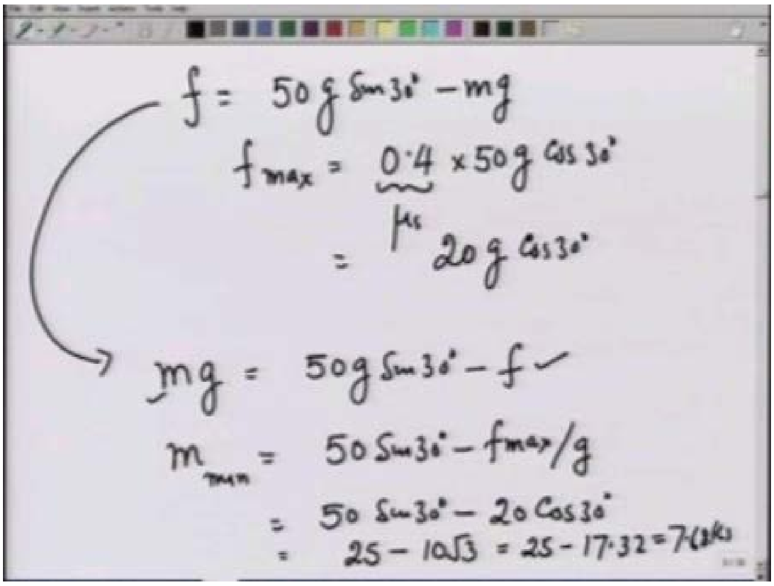

So, we have equation f equals 50 g sin 30 degrees minus mg and f max possible is equal to 0.4, which is mu s times 50 g cosine of 30 degrees, which is equal to twenty g cosine of 30 degrees. So, therefore, if I convert this equation to get m, I get mg equals 50 g sin of 30 degrees minus f, when f is maximum, m is the minimum possible value of small m that gives me equilibrium.

So, m minimum will give equilibrium would be equal to 50. I am dividing by g on both sides sin 30 minus f max divided by g, which is nothing but 50 sin 30 minus f max is 20 cosine 30 degrees g divide by g. So, cancels out by putting in the numbers. You get this equal to 25 minus 10 root 3, which is 25 minus seventeen point 3 2 or 7.68 kg. So, you see because of the friction. I could have a much smaller value of small m 7.68 kg, and still the whole system could be in equilibrium. This is when the bigger block has a tendency to move now.

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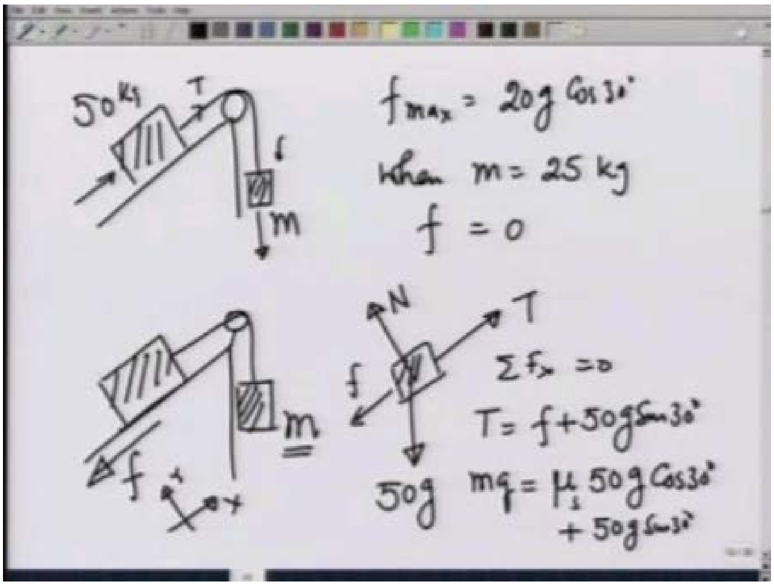

So, on this ramp this is mass m. This is 50 kg, if I have 7.68 kilograms m equal to 7.68 kilograms. This block is in equilibrium although it has a tendency to move now, what happens when I start increasing the mass on it. So, I go beyond 7.68 may be I may get 8 9 kg 10 kg, 11 kg and so on, when I increase the mass, I would increase the tension, if I increase the tension, I would not require that large a frictional force to keep the big block in equilibrium.

So, frictional force will go below its maximum possible value, which was 20 g cosine 30 degrees. So, f maximum we are calculated was 20 times g cosine of 30 degrees, if I increase, this mass it will start going down. In fact, when m equals 25 kg and we had calculated earlier that for m equals 25 kg. I do not really need any friction to have equilibrium f frictional force would be 0, what if I go beyond 25 kg, if I go beyond 25 kg. This mass would now start pulling the bigger mass up, and the direction of frictional force would change.

So, the other limit of this whole scenario is going to be have this pulley that if I increase this mass m, it tends to pull 50 kilogram mass up. And therefore, if I go beyond 25 kg, this mass has a tendency to move up and therefore, the frictional force on this would be in the opposite direction. The question we ask now is up what value of m can I go. So, that the system remains in equilibrium, again if I make a free body diagram of the bigger mass, it has 50 g pulling it down normal reaction N T pulling it up and frictional force is in the opposite direction.

This is x, this is y summation F x equal to 0. Now, gives me T equals f plus 50 g sin of 30 degrees, T is nothing but mg as we have calculated earlier is equal to f is nothing but mu times 50 g cosine of 30 degrees and plus. I have 50 g sin of 30 degrees, and therefore, if I put in the numbers.

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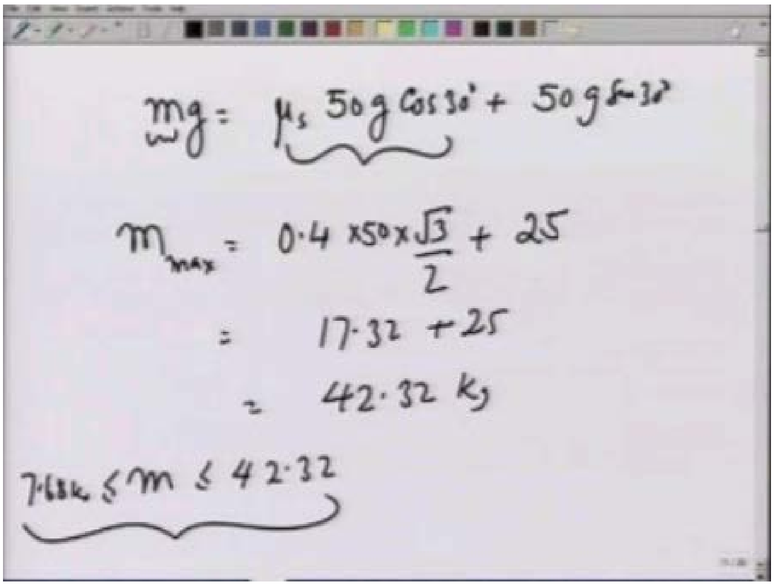

Number, I am getting m g is equal to mu s 50 g cosine of 30 degrees plus 50 g sin of 30 degrees. This is the maximum possible friction. So, this gives me maximum possible mass m that will keep the whole thing in still in equilibrium. So, m max is going to be mu s, which is 0.4 times 50 cosines 30, which is square root of 3 over 2 plus 25, which gives me 17.32 plus 25 or 42.32 kg. So, for m less than 42.32 kg and greater than seven 7.68 kg, in this range the system would remain in equilibrium.

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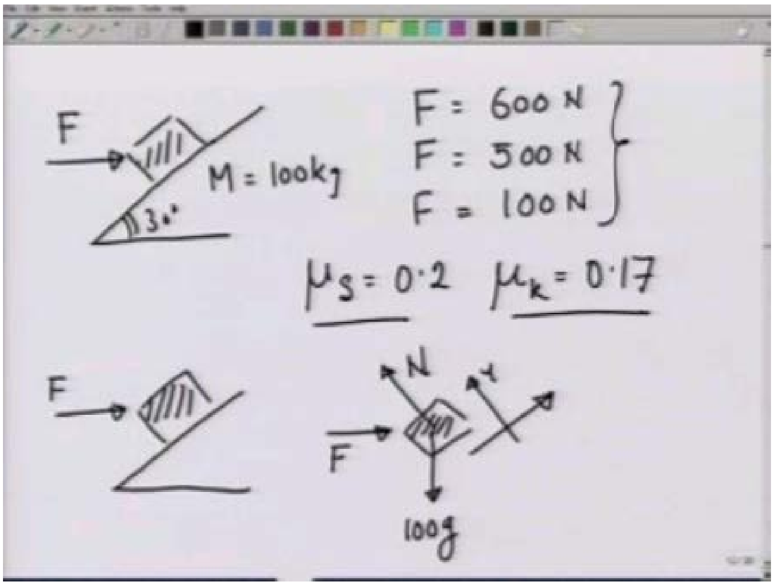

As a second example, let us take the case where again I take a ramp at 30 degrees from the horizontal put a block here of mass m equal to 100 kg and apply a force in this direction F. I would like to know, what happens to the block, if F equals 600 Newton, if F equals 500 Newton, and F, if F equals 100 Newton. I want to know in these 3 cases does the block move, does it remains stationary and so on.

This is an interesting problem because in this case number 1, I do not know whether the block would be moving or stop or would remain static, number 2 I do not know, a priory whether the block has tendency to move up or the tendency to move down. So, we have to check all these possibilities. The parameter I did you give you earlier is mu static is equal to 0.2, and mu kinetic, which is less than the static coefficient of friction is 0.17.

So, what we should really check for is whether the block is moving or not moving, and calculates friction accordingly using either mu k or mu s. If, it is static, does the friction act up the slope or does a friction act down the slope. These questions we have to answer the 2 different ways this can be done in. I will do it in 1 particular way and leave the other way for you to work out.

To see, which way does the block have a tendency to move under an applied force F. I will first assume that there is no friction, and calculate the force F that is required to keep the block in equilibrium. If, I increase the force then the force would have a larger component of the plane and therefore, the block would have a tendency to move up, if I decrease the force below that equilibrium force, it will have a tendency to move down.

Let us then proceed, if I make a free body diagram of the block, the force is acting this way there is mg 100 g acting down and normal reaction N acting this way. Let me in this case take again the x axis to be in this direction, and y axis in this direction.

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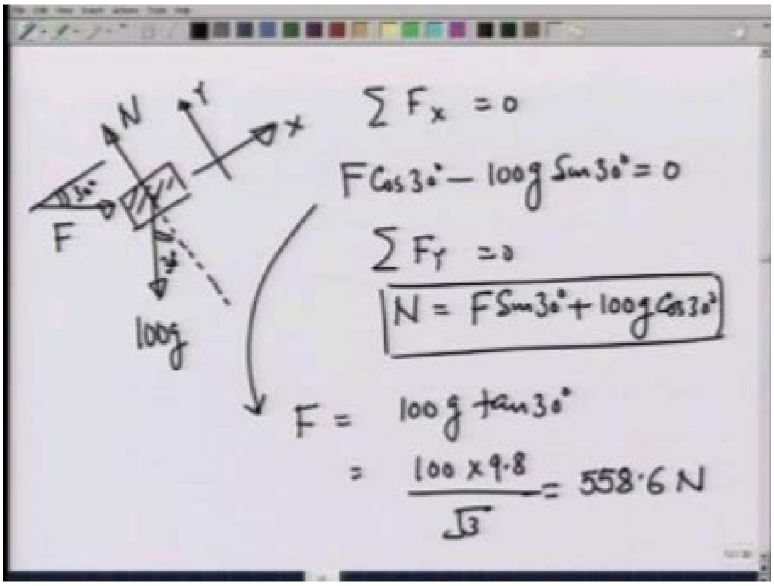

What I have is this block 100 g pulling it down, N acting this way and F in this way. Let me take this to be the x axis, and this to be the y axis summation F x is equal to 0 gives me, let me make the angles, this is 30 degrees. So, it gives me F cosine of 30 degrees minus 100 g sin of 30 degrees is equal to 0. The balance in y direction gives me N is equal to f sine of 30 degrees plus 100 g cosine of 30 degrees.

This equation I do not need to calculate F. I will calculate F straight from this equation, which gives me F, is equal to 100 g tangent of 30 degrees, which is 100 times 9.8 divided by square root of 3, and you can calculate this number. This comes out to be 558.6 Newton. So, without friction 558.6 Newton gives me a force that will keep the block in equilibrium.

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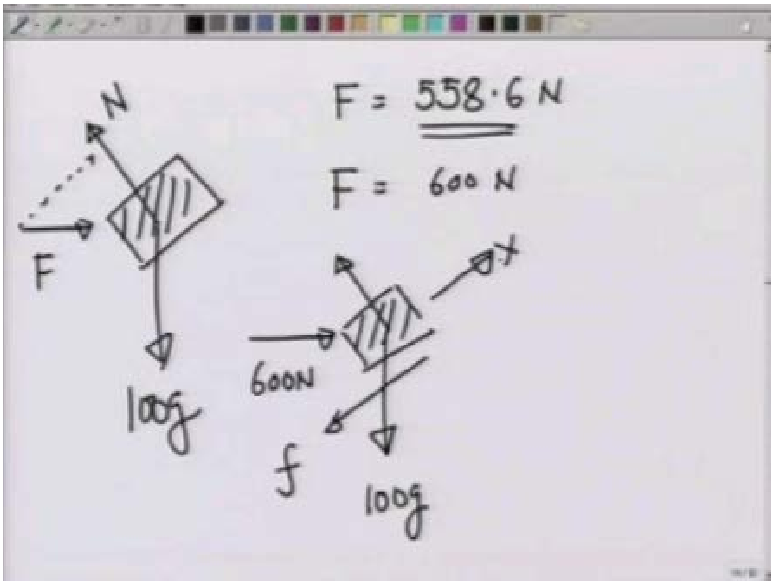

So, let me make this block again 100 g normal reaction a force F, if F is equal to 558.6 Newton the block is in equilibrium and frictional force is 0. I can say that because with this I do not need any frictional force to have the block in equilibrium. If, I go beyond 558.6 Newton, this force would have a larger component up the plane and therefore, the block would have a tendency to move up.

Therefore, for F equals 600 Newton, the frictional force on the block would be acting down. If, I make a free body diagram for F equals 600 Newton. I would have 600 Newton acting this way 100 g pulling it down, normal reaction N, and frictional force down the plane. This would be the free body diagram and therefore, again taking x axis in this direction and y axis in this direction, if we now look at the equation of equilibrium they look like.

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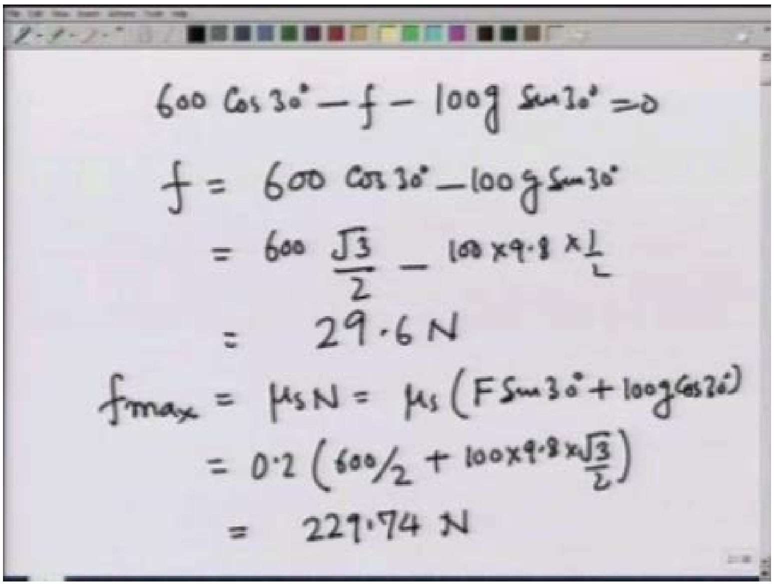

600 cosines of 30 degrees minus f minus 100 g sin of 30 degrees equal to 0 or f equals 600 cosines of 30 degrees minus 100 g sin of 30 degrees. This number comes out to be 600 square roots of 3 by 2 minus 100 times 9.8 times 1 over 2, which is equal to 29.6 Newton. So, for equilibrium we require a frictional force of 29.6 Newton, if the maximum frictional force that can be generated is greater than this. The block will be in equilibrium, if not then the block will start moving.

So, let us see, what is maximum possible value of the frictional force? This is mu s N and we have already calculated that N is equal to F sin of 30 degrees plus 100 g cosine of 30 degrees. So, in this case this will come out to be 0.2 times 600 divided by 2 plus 100 times 9.8 times square root of 3 by 2. This number you can calculate comes out to be 229.74 Newton.

So, you see when I apply a force of 600 Newton, the maximum possible friction that can exist is 229.5 Newton, and the frictional force that I require to keep the block in equilibrium is only 29.6 Newton. And therefore, the block will remain in equilibrium.

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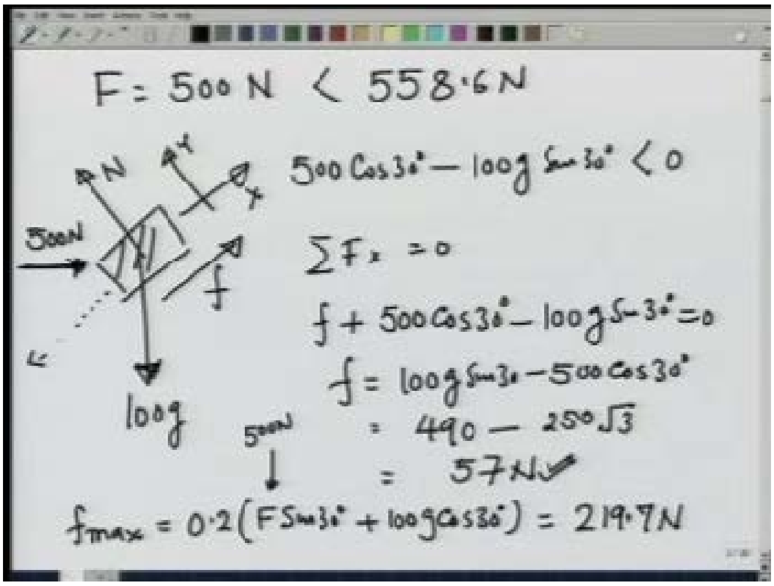

Let us now take the second case of F equals 500 Newton, and I had earlier calculated that for 0 frictional forces. The force required to keep the block in equilibrium is 558.6 Newton. So, this is less than that and therefore, in this block, when I apply a force of 500 Newton, normal reaction the component of this 500 Newton force up the plane is going to be less than the component of 100 g down the plane. That means 500 cosine of 30 degrees minus 100 g sin of 30 degrees is less than 0 is negative. And therefore, the block will have a tendency to slide down the plain because now the component of 100 g down the plain would be winning.

In this case the frictional force would be acting up because a block has a tendency to slide down, again the equation for equilibrium summation F x equal to 0, gives me taking this to be the x direction. And y to be the perpendicular direction to the plain f plus 500 cosine of 30 degrees minus 100 g sin of 30 degrees is equal to 0 Or f equals 100 g sin of 30 degrees minus 500 cosine of 30 degrees. I plug in the numbers I get 490 minus 250 root 3 will comes out to be 57 Newton.

So, the force that I require the frictional force that I require to keep the block in equilibrium is 57 Newton. Let us see, what is a maximum possible frictional force that I can have? So, f max in this case is again going to be mu s 0.2 times the normal reaction and I have been calculating it. So, F sin 30 degrees plus 100 g cosine of 30 degrees F in this case is 500 Newton. You calculate this number and it comes out to be 200 and 19.7 Newton.

So, again I see that the maximum possible friction that can be generated, when I apply a force of 500 Newton in this direction is 200 and 19 degrees, and it is much greater than 57 Newton force that I require to keep the block in equilibrium. And therefore, the block will remain in equilibrium. Let us take the third case of F equals 100 Newton.

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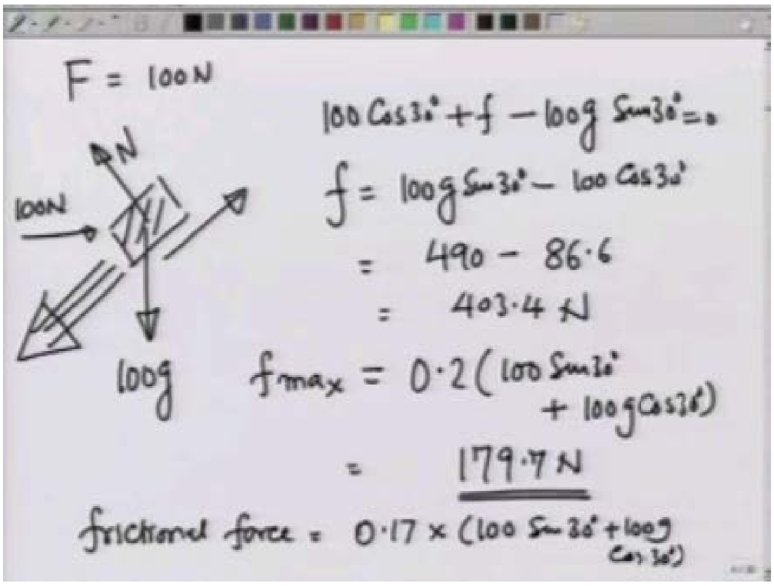

I am applying a force of 100 Newton in this direction 100 g is pulling it down. There is normal reaction N, and again 100 Newton is much smaller than five 558. So, frictional force could be acting up the plain to keep the block in equilibrium. I should again have that 100 cosines of 30 degrees plus f minus 100 g sin of 30 degrees should be 0 or the frictional force should be equal to 100 g sin of 30 degrees minus 100 cosines of 30 degrees, and this comes out to be 490 minus 86.6, which is nothing but 403.4 Newton.

So, the force that I require to keep the block in equilibrium is 403.4 Newton. Let us see, what is f maximum possible value? f maximum possible value is 0.2. The static friction 100 sin of 30 degrees plus 100 g cosine of 30 degrees. You plug in the numbers sin 30 is 1 half cosine 30 is root by 2, and the answer you get is 179.7 Newton. Thus the maximum frictional force that is possible in this case, when I apply a 100 Newton force is less than the frictional force required to keep the block in equilibrium.

Therefore, the block would start sliding down, if the block starts sliding down that means, a frictional force will no more be static, and frictional force in that case would be a kinetic friction, which will be 0.17 times 100 sin 30 degrees plus 100 g cosine of 30 degrees. You calculate this number and this comes out to be the frictional force.

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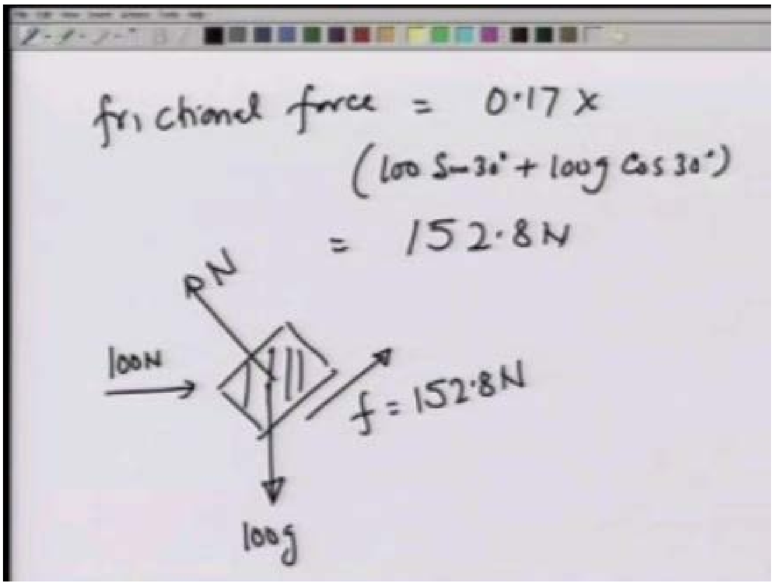

Let me write it again because now the block is sliding down is going to be 0.17 times 100 sin 30 degrees plus 100 g cosine of 30 degrees. To calculate this number, it comes out to be 1 52.8 Newton. So, therefore, the frictional force will be slightly less this time and the block would be moving down the plain. Is 100 Newton here, is 100 g? This is the normal reaction and this is a frictional force of 152.8 Newton. As I said earlier there is another way of doing this problem that would be that.

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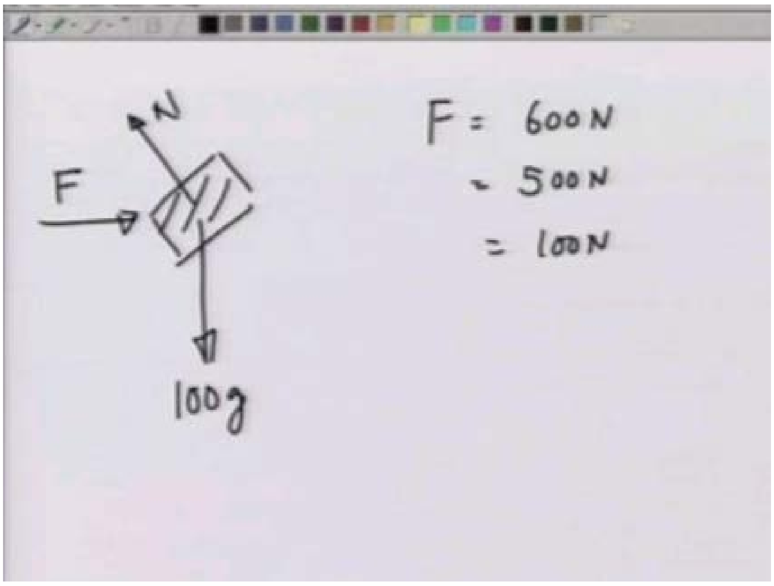

Given this block and given this force F, which could be 600 Newton or 500 Newton or 100 Newton? To calculate the force required to keep the block in equilibrium and calculate the maximum possible frictional force, if the force required to keep in equilibrium is more than the frictional force maximum possible frictional force. The block would move, if it is less the will remain in equilibrium. In a way that is what we did, but you can proceed along the calculations in a slightly different way having done 2 simple examples of frictional forces. Let us now move 1 and look at some other situations, one particular situation that I want to look at is what we call a dry thrust bearing, what this is nothing but a cylinder against a wall.

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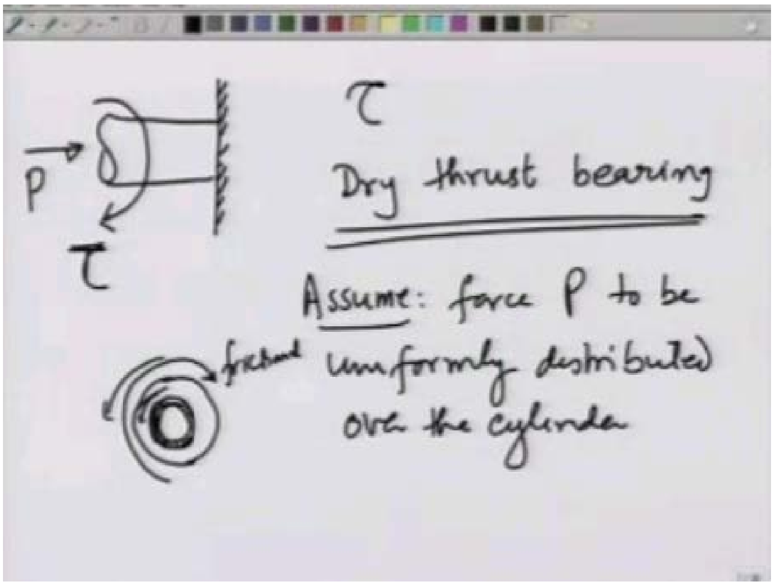

The cylinder is being pushed by a force P and we apply a torque on this. So, I would like to know for what 2 value of torque tau can the cylinder remain static. This is known as what I said earlier is dry thrust bearing. So, let us see, what is happing, if the cylinder is being pushed against the wall, and if I look at the cross section at the wall. The cylinder experiences a normal force because of which it is in equilibrium, if we assume force P that is pushing the cylinder to be uniformly distributed over the cylinder. Then, each ring I can calculate, the force in each ring of the cylinder that I am making here.

This ring because of the torque being applied tends to move and this motion is opposed by the frictional force. However, frictional force has a maximum possible value. So, only up to that maximum possible value can 1 oppose the motion of can the cylinder oppose the motion, and after that it will start rotating. So, let us do that calculation.

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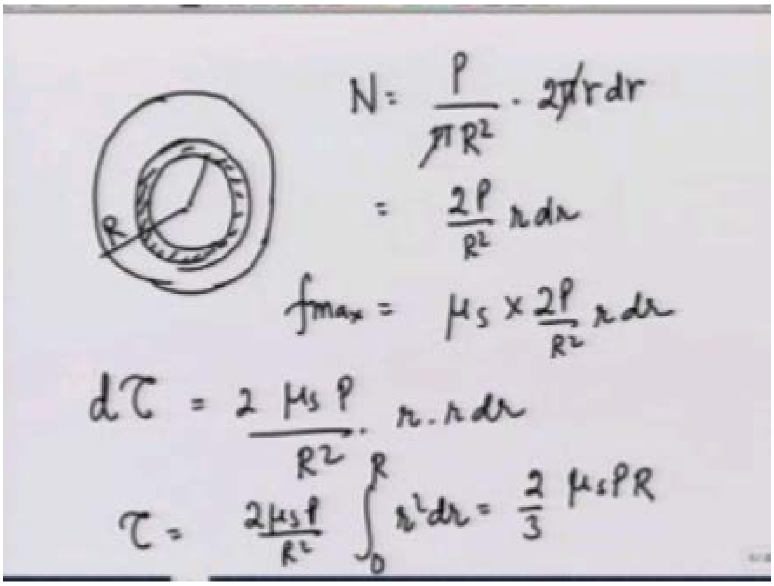

So, look at this cylinder and if I look at this ring at a distance R. The normal reaction of the wall on this ring is going to be a force per unit area, where capital R is the radius of the cylinder times 2 pi r d r. Pi cancels and I get this to be 2 P over R square r d r and therefore, the maximum possible friction on this ring is going to be mu s time 2 P over R square r dr. The torque d tau due to this friction is going to be mu s 2 mu s P over R square times r times r d r and I integrate to get the total torque, which is going to be 2 mu s P over R square integration r square d r 0 to R. It comes out to be 2 thirds mu s P R. So, that is the maximum possible torque that can be generated by the friction and therefore, the maximum possible torque…

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Tau that I can apply without moving the cylinder is going to be 2 thirds mu s P R. Next, we consider a different kind of friction a case which is known as belt friction. In this case we consider if a belt or a rope goes over an object, which is rough. So, that there is a frictional force possible between them, what is the value of this frictional force, what is maximum possible value of this frictional force?

For simplicity we take a pulley a fixed pulley and let a rope go around it at some angle. So, that angle from here to here is theta 0. In this case may be the contact angle here is theta 0, if the coefficient of friction between the 2 is mu s, what is the maximum possible value of frictional force between these 2.

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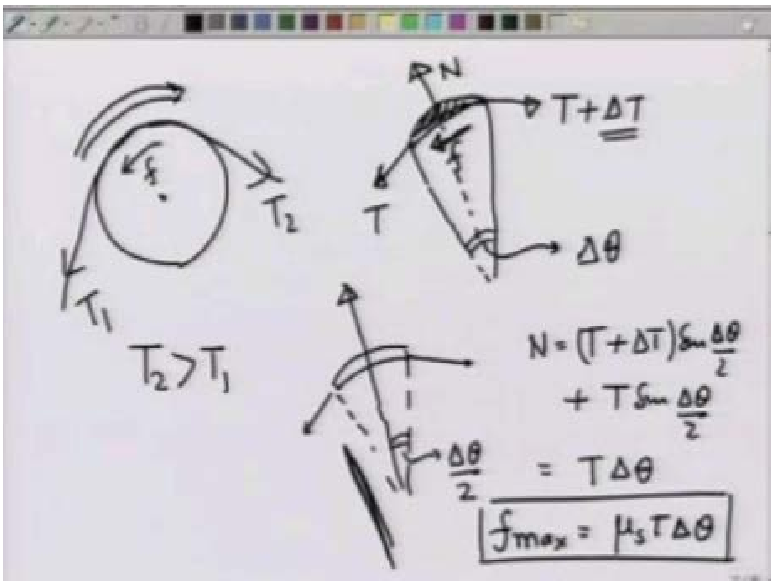

So, for this let us take a small portion of the rope going over the pulley. Let this small portion have an angle delta theta. Let the rope be pulled by tension T 1 in this direction and T 2 in this direction and without loss of generality. I take T 2 to be greater than T 1. So, that the rope has a tendency to move clockwise and the force frictional force is opposing it. So, here in this section of the rope frictional force is, in this direction there is a normal reaction of the pulley on the rope the tension in this direction is T plus some delta T, where the friction pulling it back is T.

Now, we want to relate what maximum possible value of delta T would prevent would keep rope from moving. And therefore, that will give me the maximum possible friction value. Now, you see if I calculate the normal reaction. Let me make this picture again. Let us draw this line through the center of the section, this will then be delta theta divided by 2. Since the force in this direction would be balance that will give me N is equal to T plus delta T sin of delta theta by 2 plus T sin of delta theta by 2 and keeping only the first order term. I get N to be T delta theta. So, that is the value of normal reaction therefore, f maximum possible is going to be equal to mu s T delta theta.

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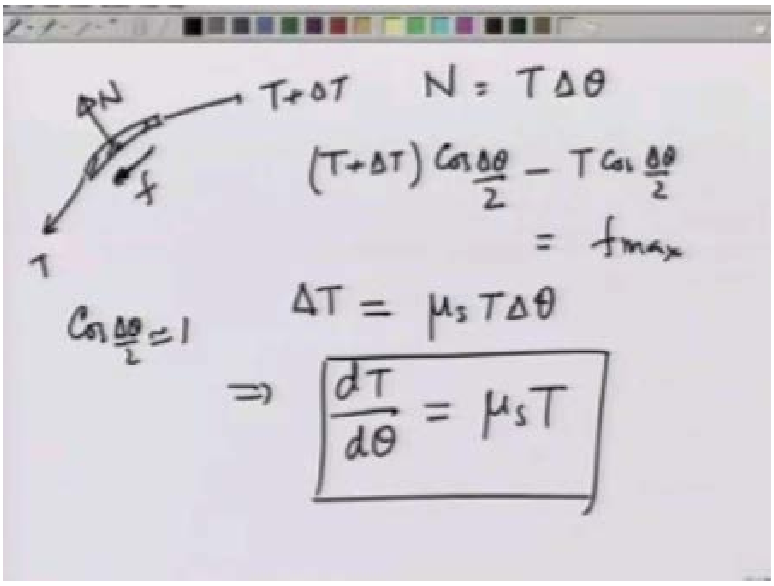

So, again making this picture I had tension T, this way tension T plus delta T. This way frictional force, this way normal reaction, this way and I found value of N to be T delta theta. And the maximum possible delta T that I can have is maximum possible value of friction. So, therefore T plus delta T cosine delta theta by 2 minus T cosine delta theta by 2 would give me f max and this gives me delta T is equal to f max, which is mu s T delta theta, because T cosines delta theta by 2 cancels and cosine delta theta by 2 is roughly equal to 1. And this gives me equation for the relation between tension and the angle is equal to T.

The maximum possible value of friction is mu s times N, and this gives me the relationship between the maximum possible difference of tension that will still keep rope in equilibrium, will keep the rope form moving under the different tensions and under this friction. If, I calculate now as I said earlier there is a.

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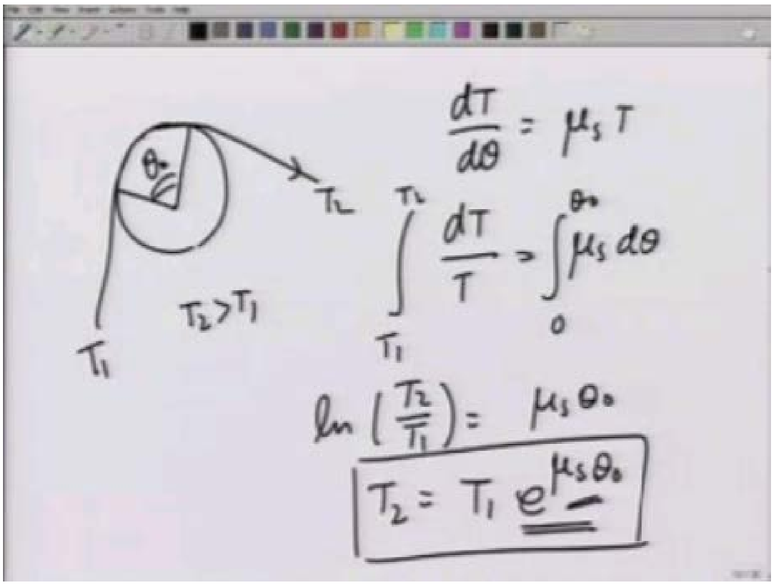

Pulley and the rope makes an angle theta 0 from T 1 T 2 such that T 2 is greater than T 1, and the equation is d T over d theta equals mu s T. If, I solve this equation by writhing d T over T equals mu s d theta integrate this from T 1 to T 2 integrate this from 0 to theta 0. I get log of T 2 over T 1 is equal to mu s theta 0 or T 2 equals T 1 e raise to mu s theta 0.

Thus, if I apply T 2 this tension, which is T 1 times this number e raise to mu s theta 0 rope would remain in equilibrium. It will not move, you see because of this exponential the force difference is quite large even for very small mu s. Let me show this to you by a demonstration. Here you see, what have done is taken a bottle filled with water.

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This is about a liter of water. So, this is about 1 kilogram and going to balance this with the very small mass on the other hand, which is just these bunch of keys and you will see that the 2 wheel balance because of friction. Let me take this pen, and if I just put the rope on the string over the pen. Once you see the bottle is not balanced it goes down.

Let me increase the number of turns I make it 2 more turns and you will because of friction. Now, the bottle is still going down, but slightly less. So, If I make it 1 more round that means, I am basically increasing theta the bottle is still going down not balanced. Now, therefore, let me increase the turns quite a lot and you will see now that with this small mass may be 100 grams maximum I am balancing a w 8 of 1 kilo gram.

On the other side and it is all because the tension difference between these 2 could be as large as e raise to now for each turn. I get a 2 pi turn and therefore, e raise that many turns times 2 pi times mu, and that can balance the a large tension on this side with a very small tension on this side. So, in this example what we have therefore, seen is that.

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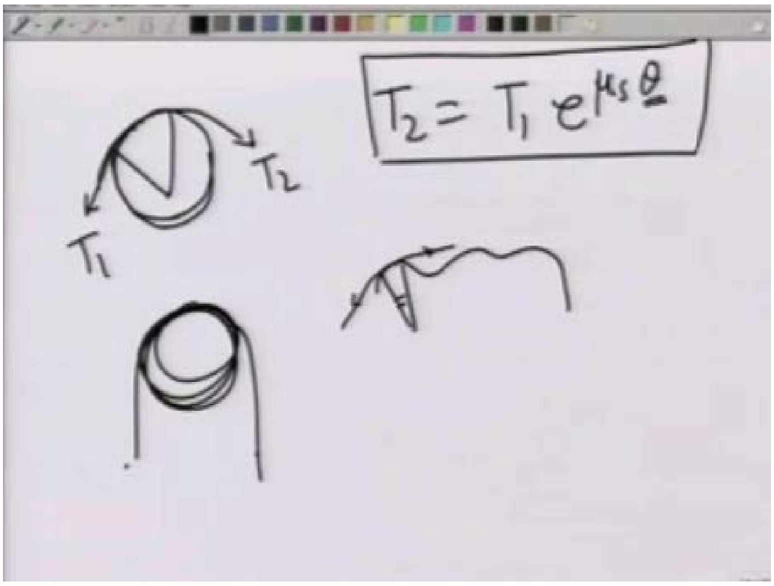

If rope is passing over rough object, then, the tension between the 2 sides maximum could differ by T 1 e raise to mu s theta. So, as we keep increasing theta, the frictional force keeps going up and a larger and larger difference of T 1 and T 2 can be balanced. I like to point out 1 thing, although for simplicity we took a round object here this theta could be over any shape of object. For example, I could have a shape like this rope going over this and this edge making an angle theta. Then, also the difference in the tension between sides will be equal to e raise to mu theta.

It does not depend on the shape of the object. It does not have to be spherical as long as this there is a, there is an angle theta over which the rope is passing over the rough surface the tension difference between the 2 maximum could be this. Let us now solve 1 example using this.

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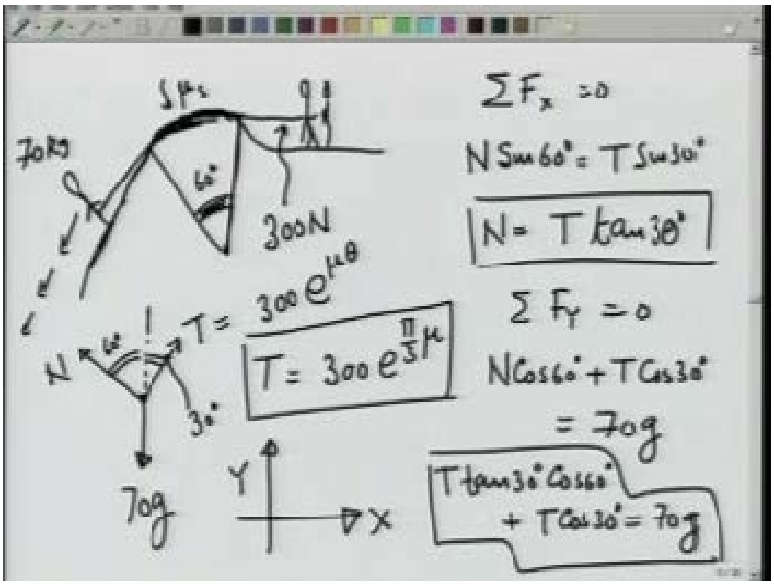

Let us take a mountain here whose is climbing down a cleft of 60 degrees. His rope is holding here is making an angle of contact angle of 60 degrees with this mountain lift 2 of his friends are holding rope on this side. And the mountain here is slowly going down. His mass is 70 kilograms. These friends are applying a force of 300 Newton on this side, what you would like to know is what the coefficient of friction mu s is. Here and everything is sort of an equilibrium and the mountaineer is slowly going down.

So, let us look at the free body diagram of this mountain here, is being pulled up by tension T. There is a normal reaction of the of the cleft and its weight down is 70 g. The normal reaction would be making an angle 60 degrees, the vertical just like this angle here, and tension T is parallel to the mountain side is making an angle 30 degrees with the vertical.

This T is going to be equal to 300 times, e raise to mu theta, where theta is pi by 3. So, the tension T on the rope on the left side of this mountain top is 300 e raise to pi by 3 mu and now under this tension, and the normal reaction his own way the mountaineer is in equilibrium. If, I take this to be the x axis and this to be the y axis, I can write summation F x is equal to 0, and that gives me N sin of 60 degrees is equal to T sin of 30 degrees.

And therefore, N equals T tangent of 30 degrees. Summation F y is equal to 0 gives me N cosine of 60 degrees plus T cosine of 30 degrees is equal to 70 g, but we have already calculated, what N is putting that value I get T tangent of 30 degrees cosine of 60 degrees plus T cosine of 30 degrees, is equal to 70 g.

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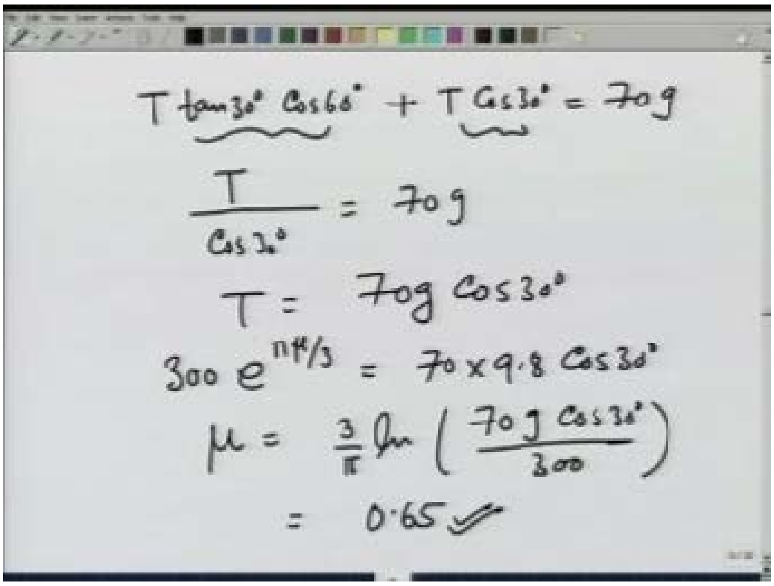

So, the answer we have is T tangent 30 degrees cosine of 60 degrees plus T cosine of 30 degrees is equal to 70 g. You can simply by trigonometric manipulations and you get T sin square 30 degrees plus cosine is square 30 degrees divided by cosine of 30 degrees is equal to 70 g. And T therefore, is 70 g cosine of 30 degrees T we have already calculated is 300 Newton times e raise to pi mu divide 3 is equal to 70 times 9.8 cosine of 30 degrees.

Therefore, mu comes out to be 3 over pi log of 70 g cosine 30 degrees over 300. You calculate this number, and this comes out to be 0.65. And therefore, with this 300 Newton, when 70 kilogram mountaineer can slowly go down as if he is in equilibrium. The coefficient of friction between the rope and the mountain top is 0.65.