Biomechanics
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Lecture – 22
Shoulder Problem 1: Biomechanical Analysis of Joints of Upper Limb

(Video Starts: 00:18) Welcome to this video on biomechanics, we have been looking at shoulder joint and muscles responsible for movements in shoulder. **(Video Ends: 00:32)**

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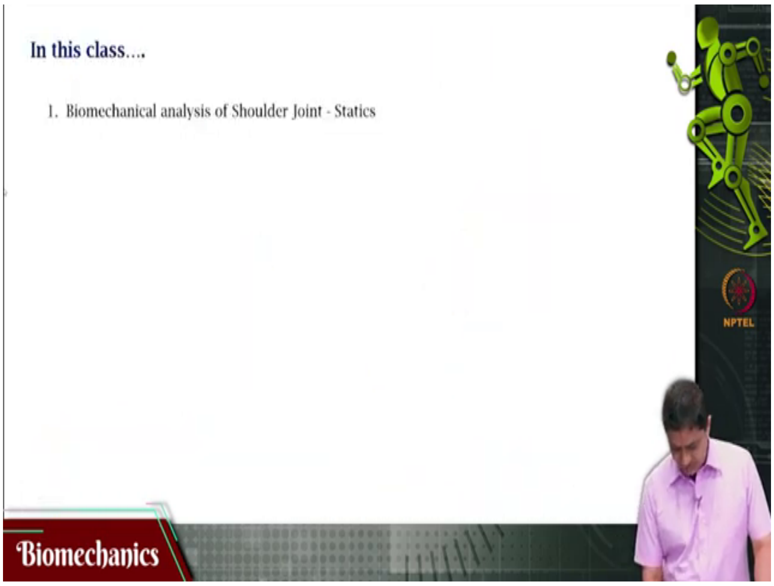

In this video we will be focusing on solving a couple of simple problems in statics in the shoulder joint.

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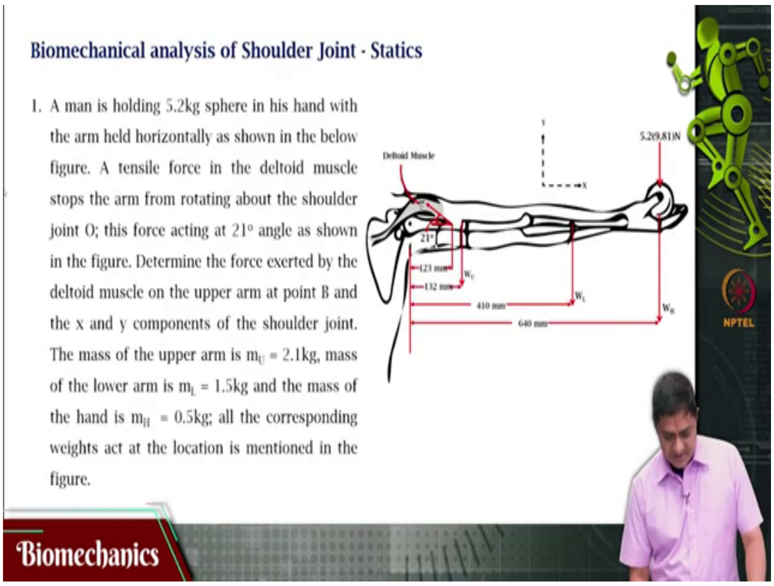

Consider this situation, it is a scary looking problem, but we will take step by step and try and solve this. Consider the situation, a person is holding a 5.2 kg sphere in his hand. So, the weight of this is 9.81 times 5.2. The mass is 5.2 kilograms. The hand is holding this and the arm itself is completely horizontal. The arm is completely horizontal arm held horizontally, as shown in the figure.

The muscle responsible for producing the force to overcome this load and the arm being held in horizontal position is the deltoid muscle. So, a tensile force in the deltoid muscle stops the arm from rotating above the shoulder joint. From here at this point, this is the shoulder joint. If there was no force produced by the deltoid muscle because of the mass of the upper arm and forearm and hand and the load in the hand, there is a tendency for the whole thing to rotate like this.

But that does not happen. That means that this deltoid muscle is producing a non-zero force to keep this whole thing or the whole arm in static equilibrium. This force is acting at an angle of 21 degrees shown here the value, as shown in the figure 21 degrees. The question is find the force exerted by the deltoid muscle? We need to know what is the deltoid muscle force? What is the force that is produced by the deltoid muscle?

Some more details are given. We cannot assume that the upper arm and forearm are massless. They have mass and their corresponding centres of gravity or centre of mass are given. So, the centre of mass of the upper arm is at a distance of 132 mm and the mass is given to be 2.1 kg. The centre of mass of the forearm is given to be at 410 mm from the point O and that mass is 1.5 kg.

The mass of the hand itself is 0.5 kg and it is centre of mass is at a distance of 640 mm from the point O. And we can assume that the external mass of 5.2 kg is also acting along, the centre of mass of the hand, so both are aligned. In other words, you are keeping this sphere exactly at the aligned with the centre of mass of your hand, something like this. Now, the question is given that these are all the forces that are acting and these are the distances at which this is acting.

And I know that the deltoid muscle is inserting at a distance of 123 mm from the joint. And it is force is acting at an angle of 21 degrees to the horizontal, can you tell, what is the force that is produced by the deltoid muscle? This is all we need to know. For before we get into the analysis, let us try and get an idea of the total mass of this system that is being overcome by the muscle. Let us just add all these masses.

This is not the solution. I am just trying to get an idea of the total force. The total mass 2.1, 1.5, 0.5, 5. 2 let us add this so that would be 9.3 kg. They are all not acting at the same point I understand that so they are all not acting they are not having a or at least we do not know the centre of mass of this whole system. So that is not the point roughly I am trying to understand what must be the total force that must be produced?

If they were all acting along the same idea, so I am trying to develop an intuitive or a ballpark figure in my head. This is critical because sometimes students find this answer and then they will write out the answer as 9.3 Newton. They might get some answer. We do not know they might get some answers say not necessarily 9.3, they might get some 12.6 Newton. It is extremely unlikely for this to be cut. Why is that?

Because the scales with which you are operating and the angle with which you are operating, it is very unlikely for this answer to be correct. So, we need to develop this intuitive or back of the envelope calculation mindset before we solve problems. But this is not the rigorous way of solving the problem. I am just trying to see, what is the approximate order the scale in which the solution is expected to be?

And that is not in the order of units of Newton, it is definitely in hundreds of Newtons. That is my expectation, but let us see let us try to solve this. Or perhaps it may even be in thousands of Newton's, but not many thousands of Newton's. It is going to be in the high hundreds of Newton's because of the way this muscle is attaching, but let us try and solve this problem.

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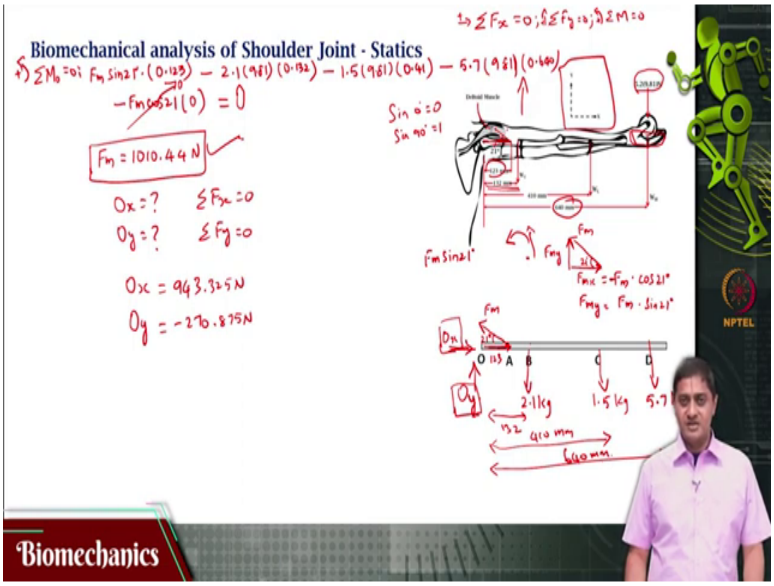

So, here in this slide, we present the situation and I have modelled this whole arm as a bar that can rotate about the point O. But cannot translate along the x axis or y axis for these x y axis that are shown. That means that there will be a reaction force ox along the x axis and the reaction force oy along the y axis. Because this bar cannot accelerate in the x or y direction, but it can rotate at point A is where the muscle attaches.

And it is force is acting at an angle of 21 degrees and the force produced by this muscle. I am calling as Fm. This is what I do not know. This is what I am interested in: finding and that distance is 123 mm. At that point B, the weight of the upper arm is acting that is 2.1 kg and that distance is 132 mm. and at point C, the weight of the forearm or the lower arm is acting.

And it is mass, is 1.5 kg and that distance is 410 mm and the hand and the external mass together is 5.7 kg how did I get this? Because the external mass itself is 5.2 kg the hand are known to be having a mass of 0.5 kg. I am adding the 2 and I am getting that mass as 5.7 kg and it is acting at a distance of 640 mm. So, we are interested in finding Fm. So, let us write out the equations of static equilibrium that we have seen previously in our introduction videos on engineering mechanics.

In this case, sigma F x = 0 sigma F y = 0 and sigma M = 0. Counter clockwise considered positive. It is considered positive. Just considered positive, these are the equations that we are interested in solving. It seems like before we go out and write out the force equations and because the question only states find the force Fm and it is not asking me to find the other unknowns Ox and Oy.

Although it would be instructive to try and find those, let us start by finding a way to find the force Fm. It seems to me like that is not something that I can find by merely solving the force equations sigma F x = 0 and sigma F y = 0. Alone may not give me this this. Why do I have this feeling? Because Fm is not along x, axis or y axis, it is inclined, so that means it will have both an x component and a y component.

And because there are two other unknowns Ox and Oy each acting respectively in the x and y direction. I will have two equations and two unknowns if I solve F x and or x component of Fm and y component of Fm and ox and Oy essentially. So, there will be many unknowns I will anyway have to write out the moment equation. And in the moment equation if I take the moment about O which is reasonable point to take the moment about.

Then there will only be one unknown because all other distances and forces are known to me. So, it is likely that I will simplify this problem by writing out the moment equation and expanding it, in which case I will have only one variable and one equation. And it will be a simple solution except, of course, bookkeeping is a problem, because there are many forces and many distances that are involved, you need to be very cautious about how this is being done.

So, if you are carefully doing this and if you are keeping the books clean, it is very likely that you will be successful in solving this. So, let us write out the moment equation which is sigma M about the point O counter clockwise considered positive is 0. That is the equation that I am attempting to write. Now, let us consider, let us look at this force Fm itself. Fm is acting at an angle of 21 degrees.

It is magnitude, is what I am interested in finding it will have a vertical component and a horizontal component. The y component will be along the positive y axis and the horizontal component will be along the negative x axis, something to remember. And what will be the I am going to call this as some Fmx That would be Fm cos 21 degrees is it not. And Fmy would be Fm sin 21 degrees.

Note that I have not actually included the s i g n sign for this. So, when I am writing out in the actual equation, or let me draw, let me write out that. So, this will be minus this in the or rather, if the arrow was pointed like this then Fmx would be – Fm times cos 21. Now, let us write out the moment equation and try to solve this. What are all the various things that are there?

Let us count the number of forces. There are two components of force from Fm, one from the weight of the upper arm one from the weight of the forearm and one from the weight of the hand plus the external mass. So, there are essentially five with five different distances, except that one of this this Fm and it is components will have the same momentum will they? Perhaps not because only one of these components will have that momentum.
Something to keep in mind, let us try and write this out so that it is a bit clear for us. A question that comes is will the x component of this have a moment? Will this cause a moment? That is a question that we will have to come to, but for completeness it makes sense for me to write this out. I know that immediately, because this x component is acting along O. It will probably not cause this in this case it is shown to be acting a long verb, but that need not be the case.

Maybe the joint is here and the muscle is attaching at some distance from the joint in along the y axis. In that case, the moment arm will exist for the x component of the force, so it makes sense to completely write out this equation. Not just write the y component. Let us not assume that because this is the first problem that we are solving, let us for completeness it makes sense to write out the entire equation.

So, I will start out by writing Fm sin 21 times 123 by 1000 why is that? Or rather 0.123, 123 mm times 0.1 what is this? This is 123 mm x + in its SI units. Which is meters, so, 0.123 minus will this be a positive moment or a negative moment? Well, because Fmy is acting in this direction and the joint is here it will be a counter clockwise moment which is positive. So, Fm sin 21 times 0.123 is positive – 2.1 into 9.81, 2.1 is the mass into 9.81 is the acceleration due to gravity.

Always assume acceleration due to gravity is 9.81 kindly avoid assuming acceleration due to gravity as 10. It is not a matter of convenience in your actual problems, I will expect you to assume G to be 9.81 meter per second square 9.81. Are we done? No, because we will have to write out the corresponding momentum and that momentum is 132 mm so I am putting a 0.132. Yes, I have written negative in this. Is that correct?

Yes, because this force is acting downward and this is where the joint is. It will cause a waste moment it will cause a clockwise moment like this. And because of this reason it will be negative, because I am considering counter clockwise to be considered positive. Again –1.5 times 9.81 times what is this distance? 0.41 – 5.7 into 9.81 times 0.640 this is the entire equation, but we are not done yet. I said we will also write out the x component.

What is this x component? x component is Fm cos 21 is it not? If there was that would be – Fm cos 21, but it is acting along the x axis this component is acting along the x axis it is not having a momentum. Because of the reason this will become 0. The momentum would be 0 and this whole thing sums to 0. I am not doing the numerical I request you to try and solve for Fm. This is a single equation in one variable.

You will only have to simplify this equation and when you simplify this equation, you will find and there is no Fm cost 21 this becomes the whole thing is 0. This whole thing is 0, Fm cos 21 is 0. As in that term Fm cost 21 times 0 the term is 0. If you get that you will find after some simplification Fm is actually 1010 point 4 4 Newtons or 4 3 8 Newtons. Let us go back and take a look at the situation.

To hold a mass of 5.2 kg the deltoid muscle is producing a force of 1000 Newtons are 5.2 kg, say even at G = 10, 5.2 kg is about 52. Let us say 50 Newtons for 50 Newtons to be overcome, the muscle will have to be produced 1000 Newtons. Of course, there are other masses that I have not discussed. There is a mass of the upper limb, there is mass of the upper arm, there is mass of the lower arm, the mass of the hand.

All these things considered, even if you add all of them. I said it is about 9.x. We in the previous slide we saw there is about 9.3, even if you say it is about 90 Newtons. For example, for the sake of discussion, the muscle produces about 10 times as much force. Why is this? Why does the muscle have to produce a force that is 10 times as much as the force that is produced or the weight of the entire arm? That does not make much sense.

Why is this? Because there are several things at play here one is the margin is attaching at a small momentum, whereas the external load is acting at a very large momentum. The muscle is acting here at 123 mm. Whereas the external load is acting at 640 mm very large, but not just that only the vertical component can overcome this. And it would be helpful if the muscle is acting entirely along the y-axis.

But that is not what is happening because the component of force that is going to overcome this is the y component and F from sin 21 is a much smaller number then Fm sin 90. So, the angle of attachment of the muscle is small. Because sin 0 is 0 and sin 90 is 1, 21 is closer to 0 than 90. From this I know that it is attaching at an inconvenient angle slightly less much less actually not slightly less at a much lesser angle, than a what can be a very convenient solution.

Although we look at this from these points of view, what actually happens is there is a need for evolution to produce these kinds of forces to overcome this loads. So, this is the reality for the human musculoskeletal system in many cases not always in many cases. Now, what is also not known but not asked in the problem is what is Ox? And what is Oy? This is not asked, but I request you to go back and write out sigma F x = 0 and sigma F y = 0.

Now that we know Fm the x component of Fm and the y component of Fm is also something that we know. Because I wrote that the y component of Fm is Fm sin 21 x component of Fm is Fm cos 21. And so I can write out the sigma F x = 0, sigma F y = 0, including Ox and Oy and solve for this and try and find the values of Ox and Oy. Because each of them will be one equation in one variable the other variable that will be there is Fmx and Fmy.

But we know Fm so, you can compute that after that you will find Ox and Oy to be respectively 943.325 Newtons and Oy to be –270.875 newtons. That means Oy is minus in the given y direction, so it is acting downward like that. Something to remember so this reaction forces. Please do take a few seconds few minutes to solve for this reaction forces using sigma F x = 0 and sigma F y = 0.

So, with this, we come to the end of this video on a simple problem. We will continue our discussion on simple problems on shoulders our upper limb in the next videos. Thank you very much for your attention.