Statics: Crash Course Physics #13

Crash Course: Physics
https://youtube.com/watch?v=9cbF9A6eQNA
https://nerdfighteria.info/v/9cbF9A6eQNA

The physics we're going to talk about today have saved your life! Whenever you step into a building or walk across a bridge, this is the science that keeps the building standing, the bridge stable and you alive. It's statics, the study of how objects behave when they're not accelerating, whether that means they're standing completely still or moving at a constant velocity. Statics can tell you a lot about the way things behave when you're trying to balance them or when they're being compressed or stretched, so engineers use statics for things like figuring out where to put building supports and how many of them there should be, or what type of bridge design would work best across that river in town. You can use it too, say, the next time you climb a ladder. If you do, you'll find that even though an object may not be moving, there are still all kinds of things affecting it, like stress and strain, and pressure. So who knows? Today's episode may someday save your life.

(INTRO)

Objects that aren't accelerating are said to be in equilibrium, a concept that we've touched on before. It means that there can be forces on an object, but there can't be net forces on it. Otherwise, that net force (M) would make the object accelerate. Torque affects equilibrium, too, since an object in equilibrium can't have rotational acceleration, either. So again, there can be torques on an object in equilibrium, but there can't be net torques on it. In other words, the net torques must be equal to zero. All of this means that for an object to be in equilibrium, all of the forces and torques on it have to balance out.

A classic example of forces and torques cancelling each other out is a ladder leaning against a wall. The ladder isn't accelerating or even moving, so it must be in equilibrium. But how much force is there on the ladder from both the wall and the floor? That's pretty easy to figure out. Let's say we know the bottom of the ladder is three meters from the wall, and the top of the ladder is four meters from the floor. The ladder itself is five meters long, and it has a mass of 10 kilograms. The first thing we've got to do is draw a free-body diagram. First, the force of gravity, mg, is pulling down on the center of the ladder. The force on the wall has only one component: it's pushing sideways on the ladder. Meanwhile, the force from the floor has two components, one pushing up on the ladder equal and opposite to the force of gravity, and one pushing on the ladder toward the wall, equal and opposite to the force from the wall. Let's talk about the force from the wall first. We don't know how strong it is, but we can figure that out by thinking about the torques acting on the ladder. The ladder isn't rotating, so any torques acting on it have to add up to zero, and we know from our previous lessons that torque is caused by force applied at a distance from an axis. So if we choose the point where the ladder touches the floor as our axis, we can see that there are two forces applying a torque to the ladder. In this case, the ladder is leaning to the right to meet the wall, so the force of gravity is applying a clockwise torque, and the force from the wall is applying a counterclockwise torque. And we know that both of those torques equal each other because the net torque on the ladder is zero. The torque from gravity is equal to the ladder's weight times the perpendicular distance from our axis to the center of the ladder, and that's 147 Newton meters, meaning that the torque from the wall is also 147 Newton meters in the opposite direction. Divide that by the vertical distance from where the ladder hits the wall to our axis of rotation and we get 36.8 Newtons, the force from the wall on the ladder. That's half of the problem done!

But what about the force on the ladder from the floor? Like we said, there are two components of the force from the floor, horizontal and vertical. The horizontal component will be equal to the force from the wall, so 36.8 Newtons, and the vertical component will be equal to the ladder's weight, so 98 Newtons. We've already talked about how to find the total magnitude of a force from its components: you square the components, add the results, then take the square root of that number, meaning that the total force from the floor on the ladder is 105 Newtons.

So once you know that an object's in equilibrium, you can use that fact to find the forces and the torques acting on it. That's important because those forces can affect the object's shape, and maybe even break it. That's why one of the main questions that engineers consider is, "When I apply a force to a thing, what will happen to it?" And generally, whatever happens will be one of these three main things.

First, you can apply just enough force so that the object will either stretch or compress but still spring back. In that case, the force is an arrange known as the material's elastic zone. But if you apply a little too much force, the object might become permanently deformed, meaning that the force has reached what's called the plastic zone. And apply way too much force and you'll get to the breaking point, otherwise known as fracture.

Ideally, engineers want to make sure that the objects they use to build things, like support beams, stay within the range of option number one, the elastic zone. Often, they'll also want to know how an object's shape changes based on the amount of force that's being applied to it, and the amount that an object stretches or compresses depends on a few different factors. First, there's the original length of the object - the longer it is, the more it will stretch or compress. The strength of the applied force also matters: more force means more stretching or compressing. Then there's the area of a cross-section of this object: basically, the thicker it is, the less it will stretch or compress. Finally, there's the type of material itself. Wood, steel, aluminum, granite - they're all going to have different amounts of elasticity. That's why engineers use something called Young's Modulus. It's a number, represented by a capital E, that tells you how hard it is to stretch or compress a given material based on that material's stiffness. The higher Young's Modulus is for a certain material, the less elastic it is. And all of these factors combine into one equation. It might look kind of messy, but this equation is just saying that the change in length of something that's being stretched or compressed depends on its original length, the force you apply, its cross-sectional area and Young's Modulus.

And we can use this equation to help define a couple of terms that engineers use a lot: stress and strain. Now those aren't the same feelings you get the night before a huge exam. Instead, stress is the force on an object divided by its cross-sectional area - basically, that F over A term, and strain is the object's change in length divided by its original length. This equation and Young's Modulus apply for two types of stress: tensile stress, which stretches objects out, and compressive stress, which compresses them.

But sometimes the forces you apply to objects aren't just compressing or stretching. For example, you could also apply what's known as shear stress. Maybe you've done this before. Say there's a really thick book laying on a table, say *Game of Thrones* or a big dictionary. If you push the top of the book parallel to the table, the pages will sort of slide over each other. Where before you had a nice rectangular-looking book, now you have more of a parallelogram. The sliding happens because you're applying a force to the top of the book while the table applies an equal and opposite force to the bottom. That's shear stress. And the way an object deforms under shear stress depends on the same kinds of factors that are involved when you compress or stretch something. Like if the original length were longer, meaning you have a thicker, taller book, that would mean more sliding. More force, more sliding. More area perpendicular to the force - in other words, a book with bigger pages - less sliding.

And then there's the inherent slidiness of the material that the

object's made of, which we call the Shear Modulus. Just like Young's Modulus, the Shear Modulus is different for every material and is just a number represented by capital G. The higher its Shear Modulus, the less the object will deform. Put all those factors together, and you get an equation that should look very familiar. It's just like the equation we had before for stretching and compressing. The only differences are that the original length, area and change in length represent different parts of the object, and that we use a different modulus.

We have one last type of shape change to consider: shrinking. This is what happens if you apply a force to all parts of an object at once, say, by putting it in water. The same factors affect the shape change here, too. The more volume the object originally had, the more it will shrink; in other words, the more its volume will change. When we're talking about something submerged in a fluid, we give a different name to the force divided by area, and instead of stress, we call it pressure. The more pressure you apply to an object, the more it will shrink.

Finally, some materials are more resistant to changes in volume, and that stiffness is measured by the Bulk Modulus, represented by capital B. Combined, these factors form an equation you can use to predict how much an object will shrink.

So you now know the three main ways that forces affect an object's shape: changing its length through tensile and compressive stress; deforming it through shear stress and changing its volume through pressure. And hopefully, now you also have a better understanding of all the thought that goes into making sure buildings and bridges stay up.

Today you learned that the net force and torque on an object in equilibrium must equal zero, and you saw how you can use that fact to calculate individual forces and torques. We also talked about the way objects deform under tensile, compressive and shear stress as well as pressure.