Chapter 1

Predicting Behavior with Mechanics of Materials

In This Chapter

- Defining mechanics of materials
- Introducing stresses and strains
- Using mechanics of materials to aid in design

Mechanics of materials is one of the first application-based engineering classes you face in your educational career. It's part of the branch of physics known as *mechanics,* which includes other fields of study such as rigid body statics and dynamics. Mechanics is an area of physics that allows you to study the behavior and motion of objects in the world around you.

Mechanics of materials uses basic statics and dynamics principles but allows you to look even more closely at an object to see how it deforms under load. It's the area of mechanics and physics that can help you decide whether you really should reconsider knocking that wall down between your kitchen and living room as you remodel your house (unless, of course, you like your upstairs bedroom on the first floor in the kitchen).

Although statics can tell you about the loads and forces that exist when an object is loaded, it doesn't tell you how the object behaves in response to those loads. That's where mechanics of materials comes in.

Tying Statics and Mechanics Together

Since the early days, humans have looked to improve their surroundings by using tools or shaping the materials around them. At first, these improvements were based on an empirical set of needs and developed mostly through a trial-and-error process. Structures such as the Great Pyramids in Egypt or the Great Wall of China were constructed without the help of fancy materials or formulas. Not until many centuries later were mathematicians such as Sir Isaac Newton able to formulate these ideas into actual numeric equations (and in many cases, to remedy misconceptions) that helped usher in the area of physics known as mechanics.

Mechanics, and more specifically the core areas of statics and dynamics, are based on the studies and foundations established by Newton and his laws of motion. Both statics and dynamics establish simple concepts that prove to be quite powerful in the world of analysis. You can use *statics* to study the behavior of objects at rest (known as *equilibrium*), such as the weight of snow on your deck or the behavior of this book as it lies on your desk. *Dynamics*, on the other hand, explains the behavior of objects in motion, from the velocity of a downhill skier to the trajectory of a basketball heading for a winning shot.

What statics and dynamics both have in common is that at their fundamental level, they focus on the behavior of *rigid bodies* (or objects that don't deform under load). In reality, all objects deform to some degree (hence why they're called *deformable bodies*), but the degree to which they deform depends entirely on the mechanics of the materials themselves. *Mechanics of materials* (which is sometimes referred to as *strength of materials* or *mechanics of deformable bodies*) is another branch of mechanics that attempts to explain the effect of loads on objects.

The development of mechanics of materials over the centuries has been based on a combination of experiment and observation in conjunction with the development of equation-based theory. Famous individuals such as Leonardo da Vinci (1452–1519) and Galileo Galilei (1564–1642) conducted experiments on the behavior of a wide array of structural objects (such as beams and bars) under load. And mathematicians and scientists such as Leonhard Euler (1707–1783) developed the equations used to provide the basics for column theory.

Mechanics of materials is often the follow-up course to statics and dynamics in the engineering curriculum because it builds directly on the tools and concepts you learn in a statics and dynamics course, and it opens the door to engineering design. And that's where things get interesting.

Defining Behavior in Mechanics of Materials

The fact that all objects deform under load is a given. Mechanics of materials helps you determine how much the object actually deforms. Like statics, mechanics of materials can be very methodical, allowing you to establish a few simple, guiding steps to define the behavior of objects in the world around you. You can initially divide your analysis of the behavior of objects under load into the study and application of two basic interactions: stress and strain.

With the basic concepts of stress and strain, you have two mechanisms for determining the maximum values of stress and strain, which allow you to investigate whether a material (and the object it creates) is sufficiently strong while also considering how much it deforms. You can then turn your attention to specific sources of stress, which I introduce a little later in this chapter.

Stress

Stress is the measure of the intensity of an internal load acting on a cross section of an object. Although you know a bigger object is capable of supporting a bigger load, stress is what actually tells you whether that object is big enough. This intensity calculation allows you to compare the intensity of the applied loads to the actual strength (or *capacity*) of the material itself. I introduce the basic concept of stress in Chapter 6, where I explain the difference between the two types of stress, *normal stresses* and *shear stresses.*

With this basic understanding of stress and how these normal and shear stresses can exist simultaneously within an object, you can use *stress transformation* calculations (see Chapter 7) to determine maximum stresses (known as *principal stresses*) and their orientations within the object.

Strain

Strain is a measure of the deformation of an object with respect to its initial length, or a measure of the intensity of change in the shape of a body. Although stress is a function of the load acting inside an object, strain can occur even without load. Influences such as thermal effects can cause an object to elongate or contract due to changes in temperature even without a physical load being applied. For more on strain, turn to Chapter 12.

As with stresses, strains have maximum and minimum values (known as *principal strains*), and they occur at a unique orientation within an object. I show you how to perform these *strain transformations* in Chapter 13.

Using Stresses to Study Behavior

Stresses are what relate loads to the objects they act on and can come from a wide range of internal forces. The following list previews several of the different categories of stress that you encounter as an engineer:

- **Axial**: *Axial stresses* arise from internal axial loads (or loads that act along the longitudinal axis of a member). Some examples of axial stresses include tension in a rope or compression in a short column. For more on axial stress examples, turn to Chapter 8.
- **Bending:** *Bending stresses* develop in an object when internal bending moments are present. Examples of members subject to bending are the beams of your favorite highway overpass or the joists in the roof of your house. I explain more about bending stresses in Chapter 9.
- **Shear:** *Shear stresses* are actually a bit more complex because they can have several different sources. *Direct shear* is what appears when you try to cut a piece of paper with a pair of scissors by applying two forces in opposite direction across the cut line. *Flexural shear* is the result of bending moments. I discuss both of these shear types in Chapter 10. *Torsion* (or *torque*) is another type of loading that creates shear stresses on objects through twisting and occurs in rotating machinery and shafts. For all things torsion, flip to Chapter 11.

Studying Behavior through Strains

You can actually use strains to help with your analysis in a couple of circumstances:

- **Experimental analysis:** Strains become very important in experiments because, unlike stresses, they're quantities that you can physically measure with instruments such as electromechanical strain gauges. You can then correlate these strains to the actual stresses in a material using the material's properties.
- **Deformation without load:** Strain concepts can also help you analyze situations in which objects deform without being subjected to a load such as a force or a moment. For example, some objects experience changes in shape due to temperature changes. To measure the effects of temperature change, you must use the concepts of strain.

Incorporating the "Material" into Mechanics of Materials

After you understand the calculations behind stress and strains, you're ready to turn your attention to exploring the actual behavior of materials. All materials have a unique relationship between load (or stress) and deformation (or strain), and these unique material properties are critical in performing design.

One of the most vital considerations for the stress-strain relationship is Hooke's law (see Chapter 14). In fact, it's probably the single most important concept in mechanics of materials because it's the rule that actually relates stresses directly to strain, which is the first step in developing the theory that can tell you how much that tree limb deflects when you're sitting on it. This relationship also serves as the basis for design and the some of the advanced calculations that I show you in Part IV.

Putting Mechanics to Work

When you have the tools to analyze objects in the world around them, you can put them to work for you in specific applications. Here are some common mechanics of materials applications:

- **Combined stresses:** In some cases, you want to combine all those single and simple stress effects from Part II into one net action. You can analyze complex systems such as objects that bend in multiple directions simultaneously (known as *biaxial bending*) and bars with combined shear and torsion effects. Flip to Chapter 15 for more.
- **Displacements and deformations:** *Deformations* are a measure of the response of a structure under stress. You can use basic principles based on Hooke's law to calculate deflections and rotations for a wide array of scenarios. (See Chapter 16.)
- **Indeterminate structures:** For simple structures, the basic equilibrium equations you learn in statics can give you all the information you need for your analysis. However, the vast majority of objects are much more complex. When the equilibrium equations from statics become insufficient to analyze an object, the object is said to be *statically indeterminate*. In Chapter 17, I show you how to handle different types of these indeterminate systems by using mechanics of materials principles.

- **Columns:** Unlike most objects that fail when applied stresses reach the limiting strength of the material, columns can experience a geometric instability known as *buckling,* where a column begins to bow or flex under compression loads. Chapter 18 gives you the lowdown on columns.
- **Design:** *Design* is the ability to determine the minimum member size that can safely support the stresses or deflection criteria. This step requires you to account for factors of safety to provide a safe and functional design against the real world. Head to Chapter 19 for more.
- **Energy methods:** *Energy methods* are another area of study that relates the principles of energy that you learned in physics to concepts involving stresses and strain. In Chapter 20, I introduce you to energy method concepts such as strain energy and impact.