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EDITION



# Engineering Mechanics STATICS

Fourteenth Edition in SI Units

R. C. Hibbeler

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ENGINEERING MECHANICS

# STATICS

FOURTEENTH EDITION IN SI UNITS

R. C. HIBBELER

*SI Conversion by*  
Kai Beng Yap

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## To the Student

With the hope that this work will stimulate  
an interest in Engineering Mechanics  
and provide an acceptable guide to its understanding.

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The main purpose of this book is to provide the student with a clear and thorough presentation of the theory and application of engineering mechanics. To achieve this objective, this work has been shaped by the comments and suggestions of hundreds of reviewers in the teaching profession, as well as many of the author's students.

---

## New to this Edition

**Preliminary Problems.** This new feature can be found throughout the text, and is given just before the Fundamental Problems. The intent here is to test the student's conceptual understanding of the theory. Normally the solutions require little or no calculation, and as such, these problems provide a basic understanding of the concepts before they are applied numerically. All the solutions are given in the back of the text.

**Expanded Important Points Sections.** Summaries have been added which reinforces the reading material and highlights the important definitions and concepts of the sections.

**Re-writing of Text Material.** Further clarification of concepts has been included in this edition, and important definitions are now in boldface throughout the text to highlight their importance.

**End-of-the-Chapter Review Problems.** All the review problems now have solutions given in the back, so that students can check their work when studying for exams, and reviewing their skills when the chapter is finished.

**New Photos.** The relevance of knowing the subject matter is reflected by the real-world applications depicted in the over 30 new or updated photos placed throughout the book. These photos generally are used to explain how the relevant principles apply to real-world situations and how materials behave under load.

**New Problems.** There are approximately 30% new problems that have been added to this edition, which involve applications to many different fields of engineering.

---

## Hallmark Features

Besides the new features mentioned here, other outstanding features that define the contents of the text include the following.

**Organization and Approach.** Each chapter is organized into well-defined sections that contain an explanation of specific topics, illustrative example problems, and a set of homework problems. The topics within each section are placed into subgroups defined by boldface titles. The purpose of this is to present a structured method for introducing each new definition or concept and to make the book convenient for later reference and review.

**Chapter Contents.** Each chapter begins with an illustration demonstrating a broad-range application of the material within the chapter. A bulleted list of the chapter contents is provided to give a general overview of the material that will be covered.

**Emphasis on Free-Body Diagrams.** Drawing a free-body diagram is particularly important when solving problems, and for this reason this step is strongly emphasized throughout the book. In particular, special sections and examples are devoted to show how to draw free-body diagrams. Specific homework problems have also been added to develop this practice.

**Procedures for Analysis.** A general procedure for analyzing any mechanical problem is presented at the end of the first chapter. Then this procedure is customized to relate to specific types of problems that are covered throughout the book. This unique feature provides the student with a logical and orderly method to follow when applying the theory. The example problems are solved using this outlined method in order to clarify its numerical application. Realize, however, that once the relevant principles have been mastered and enough confidence and judgment have been obtained, the student can then develop his or her own procedures for solving problems.

**Important Points.** This feature provides a review or summary of the most important concepts in a section and highlights the most significant points that should be realized when applying the theory to solve problems.

**Fundamental Problems.** These problem sets are selectively located just after most of the example problems. They provide students with simple applications of the concepts, and therefore, the chance to develop their problem-solving skills before attempting to solve any of the standard problems that follow. In addition, they can be used for preparing for exams.

**Conceptual Understanding.** Through the use of photographs placed throughout the book, theory is applied in a simplified way in order to illustrate some of its more important conceptual features and instill the physical meaning of many

of the terms used in the equations. These simplified applications increase interest in the subject matter and better prepare the student to understand the examples and solve problems.

**Homework Problems.** Apart from the Fundamental and Conceptual type problems mentioned previously, other types of problems contained in the book include the following:

- **Free-Body Diagram Problems.** Some sections of the book contain introductory problems that only require drawing the free-body diagram for the specific problems within a problem set. These assignments will impress upon the student the importance of mastering this skill as a requirement for a complete solution of any equilibrium problem.
- **General Analysis and Design Problems.** The majority of problems in the book depict realistic situations encountered in engineering practice. Some of these problems come from actual products used in industry. It is hoped that this realism will both stimulate the student's interest in engineering mechanics and provide a means for developing the skill to reduce any such problem from its physical description to a model or symbolic representation to which the principles of mechanics may be applied.

An attempt has been made to arrange the problems in order of increasing difficulty except for the end of chapter review problems, which are presented in random order.

- **Computer Problems.** An effort has been made to include some problems that may be solved using a numerical procedure executed on either a desktop computer or a programmable pocket calculator. The intent here is to broaden the student's capacity for using other forms of mathematical analysis without sacrificing the time needed to focus on the application of the principles of mechanics. Problems of this type, which either can or must be solved using numerical procedures, are identified by a "square" symbol (■) preceding the problem number.

The many homework problems in this edition have been placed into two different categories. Problems that are simply indicated by a problem number have an answer and in some cases an additional numerical result given in the back of the book. An asterisk (\*) before every fourth problem number indicates a problem without an answer.

**Accuracy.** As with the previous editions, apart from the author, the accuracy of the text and problem solutions has been thoroughly checked by four other parties: Scott Hendricks, Virginia Polytechnic Institute and State University; Karim Nohra, University of South Florida; Kurt Norlin, Bittner Development Group; and finally Kai Beng, a practicing engineer, who in addition to accuracy review provided suggestions for problem development.



**Animations.** On the Companion Website are eight animations identified as fundamental engineering mechanics concepts. The animations, flagged by a film icon, help students visualize the relation between mathematical explanation and real structure, breaking down complicated sequences and showing how free-body diagrams can be derived. These animations lend a graphic component in tutorials and lectures, assisting instructors in demonstrating the teaching of concepts with greater ease and clarity.

### 11.3 Principle of Virtual Work for a System of Connected Rigid Bodies



Each animation is flagged by a film icon.

Please refer to the Companion Website for the animation: *Principle of Virtual Work*

The method of virtual work is particularly effective for solving equilibrium problems that involve a system of several *connected rigid bodies*, such as the ones shown in Fig. 11-5.

Each of these systems is said to have only one degree of freedom since the arrangement of the links can be completely specified using only one coordinate  $\theta$ . In other words, with this single coordinate and the length of the members, we can locate the position of the forces  $\mathbf{F}$  and  $\mathbf{P}$ .

In this text, we will only consider the application of the principle of virtual work to systems containing one degree of freedom.\* Because they are less complicated, they will serve as a way to approach the solution of more complex problems involving systems with many degrees of freedom. The procedure for solving problems involving a system of frictionless connected rigid bodies follows.

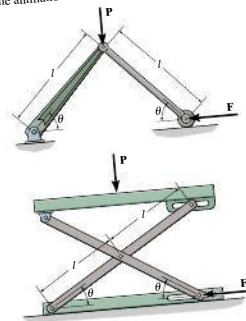


Fig. 11-5



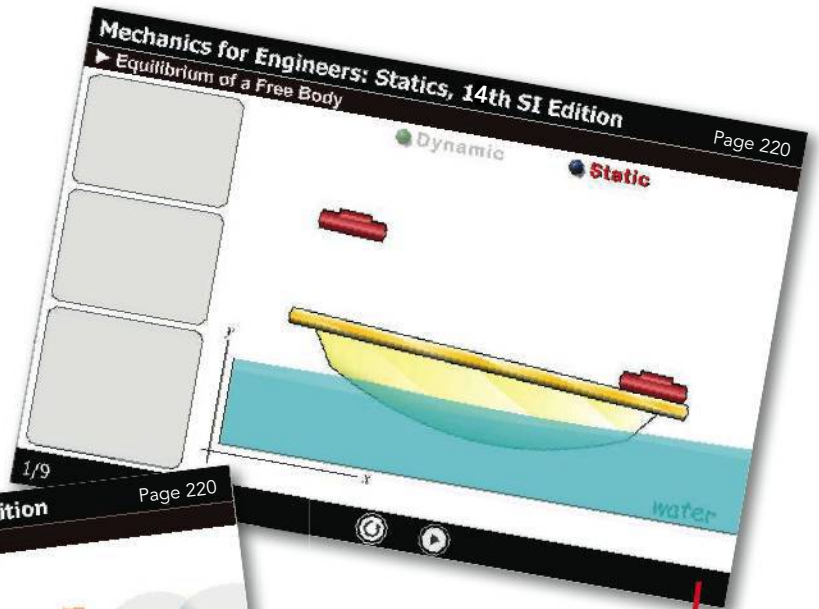
This scissors lift has one degree of freedom. Without the need for dismembering the mechanism, the force in the hydraulic cylinder  $AB$  required to provide the lift can be determined *directly* by using the principle of virtual work.

#### Important Points

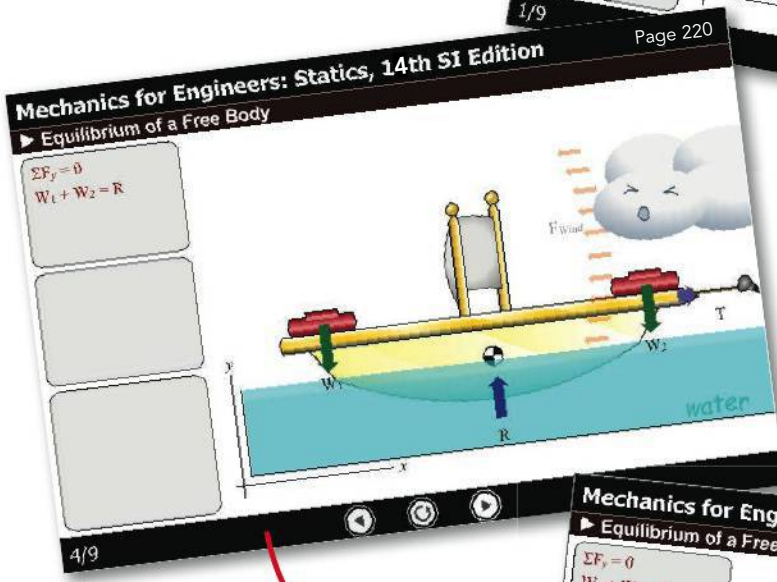
- A force does work when it moves through a displacement in the direction of the force. A couple moment does work when it moves through a collinear rotation. Specifically, positive work is done when the force or couple moment and its displacement have the same sense of direction.
- The principle of virtual work is generally used to determine the equilibrium configuration for a system of multiple connected members.
- A virtual displacement is imaginary; i.e., it does not really happen. It is a differential displacement that is given in the positive direction of a position coordinate.
- Forces or couple moments that do not virtually displace do no virtual work.

\*This method of applying the principle of virtual work is sometimes called the *method of virtual displacements* because a virtual displacement is applied, resulting in the calculation of a real force. Although it is not used here, we can also apply the principle of virtual work as a *method of virtual forces*. This method is often used to apply a virtual force and then determine the displacements of points on deformable bodies. See R. C. Hibbeler, *Mechanics of Materials*, 8th edition, Pearson/Prentice Hall, 2011.

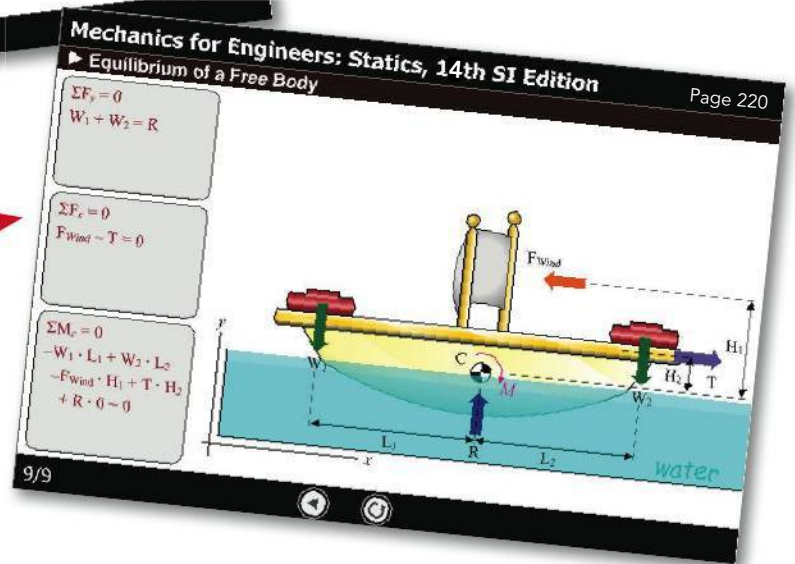
Instructors can demonstrate the different methods of analysis step-by-step. ▶



▶ Maximize the use of class contact time.



▶ Students can visualize how concepts are applied to the analysis of the structure.



**Video Solutions.** An invaluable resource in and out of the classroom, these complete solution walkthroughs of representative homework problems from each chapter offer fully worked solutions, self-paced instruction, and 24/7 accessibility. Lecturers and students can harness this resource to gain independent exposure to a wide range of examples applying formulas to actual structures.

# Internal Forces

## CHAPTER OBJECTIVES

- To use the method of sections to determine the internal loadings in a member at a specific point.
- To show how to obtain the internal shear and moment throughout a member and express the result graphically in the form of shear and moment diagrams.
- To analyze the forces and the shape of cables supporting various types of loadings.



Video Solutions are available for selected questions in this chapter.

Video solutions are available for certain questions.

## 7.1 Internal Loadings Developed in Structural Members

To design a structural or mechanical member it is necessary to know the loading acting within the member in order to be sure the material can resist this loading. Internal loadings can be determined by using the **method of sections**. To illustrate this method, consider the cantilever beam in Fig. 7-1a. If the internal loadings acting on the cross section at point  $B$  are to be determined, we must pass an imaginary section  $a-a$  perpendicular to the axis of the beam through point  $B$  and then separate the beam into two segments. The internal loadings acting at  $B$  will then be exposed and become **external** on the free-body diagram of each segment, Fig. 7-1b.

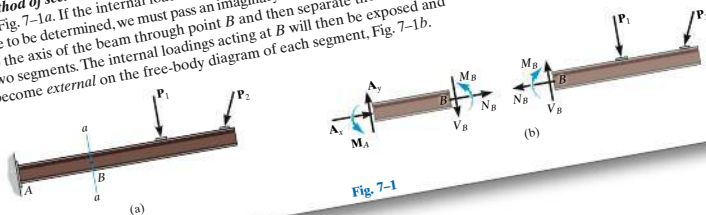


Fig. 7-1

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Chapter 2: Sections 7, 8 Video Solution

### Force Directed Along a Line

This problem shows how we can use position vectors to define force vectors corresponding to chains, cables, and ropes. In these problems, we know that the force is directed along the direction of the cable, so we define a position vector in that direction, then use the position vector to derive an expression for the force vector. The usual outcome is that the force vector is expressed as a magnitude (the tension in the cable) times a unit vector in the direction of the cable.

Created by Edward Berger, PhD, University of Virginia

11:35

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### Force Directed Along a Line

The window is held open by cable AB. Determine the length of the cable and express the 30 N force acting at A along the cable as a Cartesian Vector.

Approach

1. write position vector from A → B,  $\vec{r}_{AB}$
2. magnitude of  $\vec{r}_{AB}$  (length of cable)
3.  $\vec{r}_{AB}$
4. express force as a Cartesian vector

B: (0, 0.15, 0.25) m  
A: (0.3 cos 30, 0.5, -0.3 sin 30) m

11:35

Flexible resource for students where they can learn at a comfortable pace without relying too much on their instructors.

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### Force Directed Along a Line

1. position vector A → B

$$\vec{r}_A, \vec{r}_B \Rightarrow \vec{r}_{AB} = \vec{r}_B - \vec{r}_A$$

$$\vec{r}_{AB} = \underbrace{(0.15\vec{j} + 0.25\vec{k})}_{\vec{r}_B} - \underbrace{(0.26\vec{i} + 0.15\vec{j} - 0.15\vec{k})}_{\vec{r}_A}$$

$$\vec{r}_{AB} = (-0.26\vec{i} - 0.35\vec{j} + 0.4\vec{k}) \text{ m}$$

2. magnitude

$$|\vec{r}_{AB}| = \sqrt{(-0.26)^2 + (-0.35)^2 + (0.4)^2}$$

$$|\vec{r}_{AB}| = 0.59 \text{ m}$$

11:20

---

## Contents

The book is divided into 11 chapters, in which the principles are first applied to simple, then to more complicated situations. In a general sense, each principle is applied first to a particle, then a rigid body subjected to a coplanar system of forces, and finally to three-dimensional force systems acting on a rigid body.

Chapter 1 begins with an introduction to mechanics and a discussion of units. The vector properties of a concurrent force system are introduced in Chapter 2. This theory is then applied to the equilibrium of a particle in Chapter 3. Chapter 4 contains a general discussion of both concentrated and distributed force systems and the methods used to simplify them. The principles of rigid-body equilibrium are developed in Chapter 5 and then applied to specific problems involving the equilibrium of trusses, frames, and machines in Chapter 6, and to the analysis of internal forces in beams and cables in Chapter 7. Applications to problems involving frictional forces are discussed in Chapter 8, and topics related to the center of gravity and centroid are treated in Chapter 9. If time permits, sections involving more advanced topics, indicated by stars (★), may be covered. Most of these topics are included in Chapter 10 (area and mass moments of inertia) and Chapter 11 (virtual work and potential energy). Note that this material also provides a suitable reference for basic principles when it is discussed in more advanced courses. Finally, Appendix A provides a review and list of mathematical formulas needed to solve the problems in the book.

**Alternative Coverage.** At the discretion of the instructor, some of the material may be presented in a different sequence with no loss of continuity. For example, it is possible to introduce the concept of a force and all the necessary methods of vector analysis by first covering Chapter 2 and Section 4.2 (the cross product). Then after covering the rest of Chapter 4 (force and moment systems), the equilibrium methods of Chapters 3 and 5 can be discussed.

---

## Acknowledgments

The author has endeavored to write this book so that it will appeal to both the student and instructor. Through the years, many people have helped in its development, and I will always be grateful for their valued suggestions and comments. Specifically, I wish to thank all the individuals who have contributed their comments relative to preparing the fourteenth edition of this work, and in particular, O. Barton, Jr. of the U.S. Naval Academy, K. Cook-Chennault at Rutgers, the State University of New Jersey, Robert Viesca of Tufts University, Ismail Orabi of the University of New Haven, Paul Ziehl of the University of South Carolina, Yabin Laio of Arizona State University, Niki Schulz of the University of Portland, Michael Reynolds of the University of Arkansas, Candace Sulzbach of the Colorado School of Mines, Thomas Miller of Oregon State University and Ahmad Itani of the University of Nevada.



There are a few other people that I also feel deserve particular recognition. These include comments sent to me by J. Dix, H. Kuhlman, S. Larwood, D. Pollock, H. Wenzel. A long-time friend and associate, Kai Beng Yap, was of great help to me in preparing and checking problem solutions. A special note of thanks also goes to Kurt Norlin of Bittner Development Group in this regard. During the production process I am thankful for the assistance of Martha McMaster, my proofreader and Rose Kernan, my production editor. Also, to my wife, Conny, who helped in the preparation of the manuscript for publication.

Lastly, many thanks are extended to all my students and to members of the teaching profession who have freely taken the time to e-mail me their suggestions and comments. Since this list is too long to mention, it is hoped that those who have given help in this manner will accept this anonymous recognition.

I would greatly appreciate hearing from you if at any time you have any comments, suggestions, or problems related to any matters regarding this edition.

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## Global Edition

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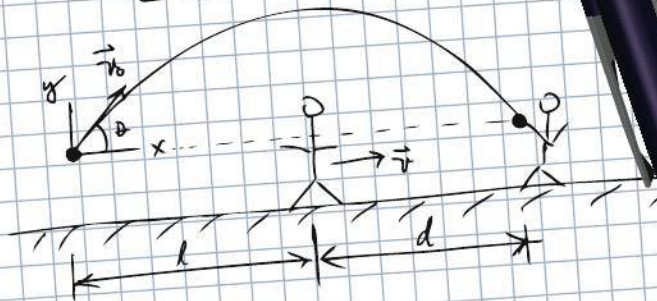
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# your work...

PART A



$$\text{given: } v = 7.000 \text{ m/s}; t = 2.000 \text{ s}; l = 18.00 \text{ m}$$

$$d = v \cdot t \Rightarrow d = (7.000 \text{ m/s})(2.000 \text{ s}) = 14.00 \text{ m}$$

$$x = l + d \Rightarrow x = 18.00 \text{ m} + 14.00 \text{ m} = 32.00 \text{ m}$$

$$g = 9.807 \text{ m/s}^2$$

$$v_{0x} = \frac{x}{t} = \frac{32.00 \text{ m}}{2.000 \text{ s}} = 16.00 \text{ m/s (COMP. X)}$$

$$v_{0y} = \frac{1}{2}gt = \frac{1}{2}(9.807 \text{ m/s}^2)(2.000 \text{ s}) = 9.80 \text{ m/s (COMP. Y)}$$

$$v_0 = v_{0x} + v_{0y} = 16.00 \text{ m/s} + 9.80 \text{ m/s} = 25.80 \text{ m/s (TOTAL)}$$

$$\boxed{v_0 = 25.80 \text{ m/s}}$$

# your answer **specific feedback**

$v_0 =$   m/s

[submit](#) [hints](#) [my answers](#) [show answer](#) [review part](#)

Try Again; 4 attempts remaining

**Feedback** Close

This is the sum of the components of the velocity. You need to use the Pythagorean theorem to find the total velocity.

You may need to review [Vector Magnitudes](#).



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## Resources for Instructors

- **MasteringEngineering.** This online Tutorial Homework program allows you to integrate dynamic homework with automatic grading and adaptive tutoring. MasteringEngineering allows you to easily track the performance of your entire class on an assignment-by-assignment basis, or the detailed work of an individual student.
- **Instructor's Solutions Manual.** This supplement provides complete solutions supported by problem statements and problem figures. The fourteenth edition manual was revised to improve readability and was triple accuracy checked. The Instructor's Solutions Manual is available on the Pearson Higher Education website: [www.pearsonglobaleditions.com](http://www.pearsonglobaleditions.com).
- **Instructor's Resource.** Visual resources to accompany the text are located on the Pearson Higher Education website: [www.pearsonglobaleditions.com](http://www.pearsonglobaleditions.com). If you are in need of a login and password for this site, please contact your local Pearson representative. Visual resources include all art from the text, available in PowerPoint and JPEG format.
- **Video Solutions.** Developed by Professor Edward Berger, University of Virginia, video solutions are located in the study area of MasteringEngineering and offer step-by-step solution walkthroughs of representative homework problems from each section of the text. Make efficient use of class time and office hours by showing students the complete and concise problem-solving approaches that they can access any time and view at their own pace. The videos are designed to be a flexible resource to be used however each instructor and student prefers. A valuable tutorial resource, the videos are also helpful for student self-evaluation as students can pause the videos to check their understanding and work alongside the video.

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## Resources for Students

- **MasteringEngineering.** Tutorial homework problems emulate the instructor's office-hour environment, guiding students through engineering concepts with self-paced individualized coaching. These in-depth tutorial homework problems are designed to coach students with feedback specific to their errors and optional hints that break problems down into simpler steps.
- **Statics Study Pack.** This supplement contains chapter-by-chapter study materials and a Free-Body Diagram Workbook.
- **Video Solutions.** Complete, step-by-step solution walkthroughs of representative homework problems. Videos offer fully worked solutions that show every step of representative homework problems—this helps students make vital connections between concepts. Videos are available in the Study Area of MasteringEngineering.

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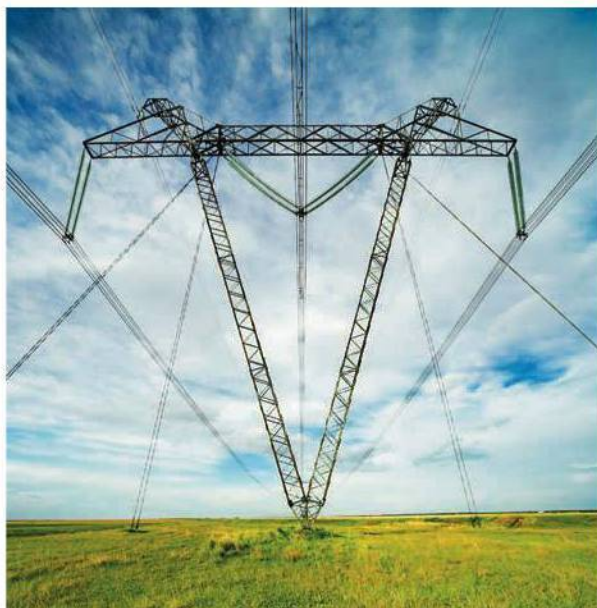
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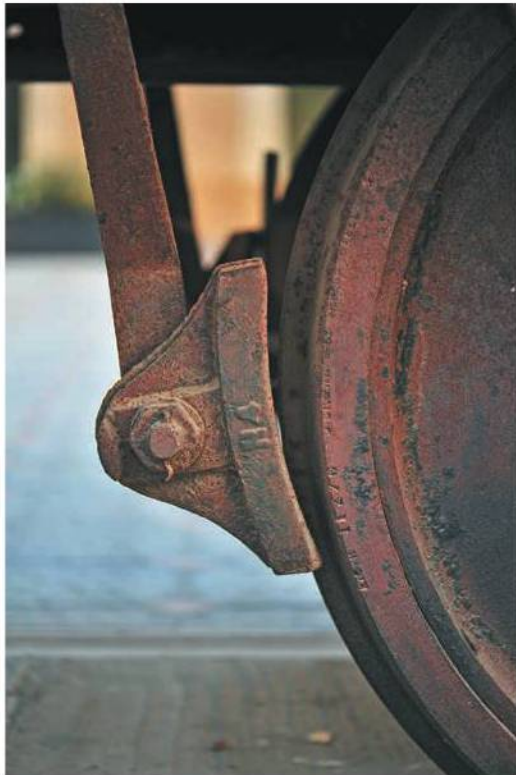


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ENGINEERING MECHANICS

# STATICS

FOURTEENTH EDITION IN SI UNITS

# Chapter 1



(© Andrew Peacock/Lonely Planet Images/Getty Images)

Large cranes such as this one are required to lift extremely large loads. Their design is based on the basic principles of statics and dynamics, which form the subject matter of engineering mechanics.

# General Principles

## CHAPTER OBJECTIVES

- To provide an introduction to the basic quantities and idealizations of mechanics.
- To give a statement of Newton's Laws of Motion and Gravitation.
- To review the principles for applying the SI system of units.
- To examine the standard procedures for performing numerical calculations.
- To present a general guide for solving problems.



Video Solutions are available for selected questions in this chapter.

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## 1.1 Mechanics

**Mechanics** is a branch of the physical sciences that is concerned with the state of rest or motion of bodies that are subjected to the action of forces. In general, this subject can be subdivided into three branches: *rigid-body mechanics*, *deformable-body mechanics*, and *fluid mechanics*. In this book we will study rigid-body mechanics since it is a basic requirement for the study of the mechanics of deformable bodies and the mechanics of fluids. Furthermore, rigid-body mechanics is essential for the design and analysis of many types of structural members, mechanical components, or electrical devices encountered in engineering.

Rigid-body mechanics is divided into two areas: statics and dynamics. **Statics** deals with the equilibrium of bodies, that is, those that are either at rest or move with a constant velocity; whereas **dynamics** is concerned with the accelerated motion of bodies. We can consider statics as a special case of dynamics, in which the acceleration is zero; however, statics deserves separate treatment in engineering education since many objects are designed with the intention that they remain in equilibrium.

**Historical Development.** The subject of statics developed very early in history because its principles can be formulated simply from measurements of geometry and force. For example, the writings of Archimedes (287–212 B.C.) deal with the principle of the lever. Studies of the pulley, inclined plane, and wrench are also recorded in ancient writings—at times when the requirements for engineering were limited primarily to building construction.

Since the principles of dynamics depend on an accurate measurement of time, this subject developed much later. Galileo Galilei (1564–1642) was one of the first major contributors to this field. His work consisted of experiments using pendulums and falling bodies. The most significant contributions in dynamics, however, were made by Isaac Newton (1642–1727), who is noted for his formulation of the three fundamental laws of motion and the law of universal gravitational attraction. Shortly after these laws were postulated, important techniques for their application were developed by other scientists and engineers, some of whom will be mentioned throughout the text.

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## 1.2 Fundamental Concepts

Before we begin our study of engineering mechanics, it is important to understand the meaning of certain fundamental concepts and principles.

**Basic Quantities.** The following four quantities are used throughout mechanics.

**Length.** *Length* is used to locate the position of a point in space and thereby describe the size of a physical system. Once a standard unit of length is defined, one can then use it to define distances and geometric properties of a body as multiples of this unit.

**Time.** *Time* is conceived as a succession of events. Although the principles of statics are time independent, this quantity plays an important role in the study of dynamics.

**Mass.** *Mass* is a measure of a quantity of matter that is used to compare the action of one body with that of another. This property manifests itself as a gravitational attraction between two bodies and provides a measure of the resistance of matter to a change in velocity.

**Force.** In general, *force* is considered as a “push” or “pull” exerted by one body on another. This interaction can occur when there is direct contact between the bodies, such as a person pushing on a wall, or it can occur through a distance when the bodies are physically separated. Examples of the latter type include gravitational, electrical, and magnetic forces. In any case, a force is completely characterized by its magnitude, direction, and point of application.

**Idealizations.** Models or idealizations are used in mechanics in order to simplify application of the theory. Here we will consider three important idealizations.

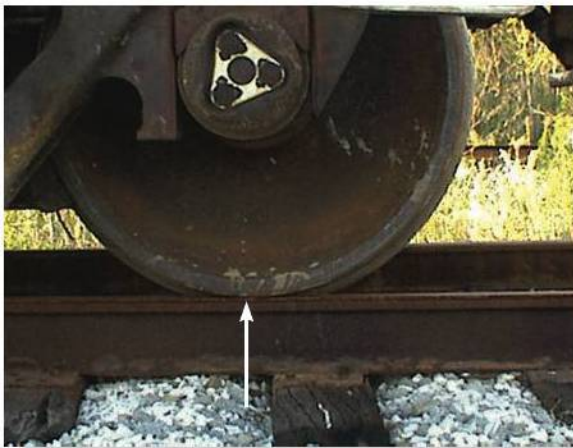
**Particle.** A *particle* has a mass, but a size that can be neglected. For example, the size of the earth is insignificant compared to the size of its orbit, and therefore the earth can be modeled as a particle when studying its orbital motion. When a body is idealized as a particle, the principles of mechanics reduce to a rather simplified form since the geometry of the body *will not be involved* in the analysis of the problem.

**Rigid Body.** A *rigid body* can be considered as a combination of a large number of particles in which all the particles remain at a fixed distance from one another, both before and after applying a load. This model is important because the body's shape does not change when a load is applied, and so we do not have to consider the type of material from which the body is made. In most cases the actual deformations occurring in structures, machines, mechanisms, and the like are relatively small, and the rigid-body assumption is suitable for analysis.

**Concentrated Force.** A *concentrated force* represents the effect of a loading which is assumed to act at a point on a body. We can represent a load by a concentrated force, provided the area over which the load is applied is very small compared to the overall size of the body. An example would be the contact force between a wheel and the ground.



Three forces act on the ring. Since these forces all meet at a point, then for any force analysis, we can assume the ring to be represented as a particle.

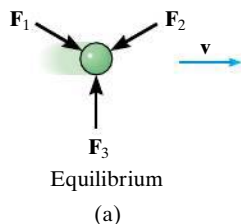


Steel is a common engineering material that does not deform very much under load. Therefore, we can consider this railroad wheel to be a rigid body acted upon by the concentrated force of the rail.



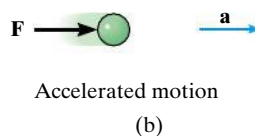
**Newton's Three Laws of Motion.** Engineering mechanics is formulated on the basis of Newton's three laws of motion, the validity of which is based on experimental observation. These laws apply to the motion of a particle as measured from a *nonaccelerating* reference frame. They may be briefly stated as follows.

**First Law.** A particle originally at rest, or moving in a straight line with constant velocity, tends to remain in this state provided the particle is *not* subjected to an unbalanced force, Fig. 1-1a.

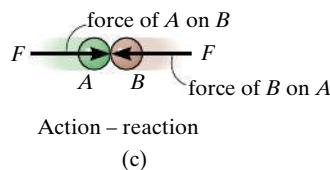


**Second Law.** A particle acted upon by an *unbalanced force*  $\mathbf{F}$  experiences an acceleration  $\mathbf{a}$  that has the same direction as the force and a magnitude that is directly proportional to the force, Fig. 1-1b.\* If  $\mathbf{F}$  is applied to a particle of mass  $m$ , this law may be expressed mathematically as

$$\mathbf{F} = m\mathbf{a} \quad (1-1)$$



**Third Law.** The mutual forces of action and reaction between two particles are equal, opposite, and collinear, Fig. 1-1c.



**Fig. 1-1**

\*Stated another way, the unbalanced force acting on the particle is proportional to the time rate of change of the particle's linear momentum.

**Newton's Law of Gravitational Attraction.** Shortly after formulating his three laws of motion, Newton postulated a law governing the gravitational attraction between any two particles. Stated mathematically,

$$F = G \frac{m_1 m_2}{r^2} \quad (1-2)$$

where

$F$  = force of gravitation between the two particles

$G$  = universal constant of gravitation; according to experimental evidence,  $G = 66.73(10^{-12}) \text{ m}^3/(\text{kg} \cdot \text{s}^2)$

$m_1, m_2$  = mass of each of the two particles

$r$  = distance between the two particles

**Weight.** According to Eq. 1–2, any two particles or bodies have a mutual attractive (gravitational) force acting between them. In the case of a particle located at or near the surface of the earth, however, the only gravitational force having any sizable magnitude is that between the earth and the particle. Consequently, this force, termed the **weight**, will be the only gravitational force considered in our study of mechanics.

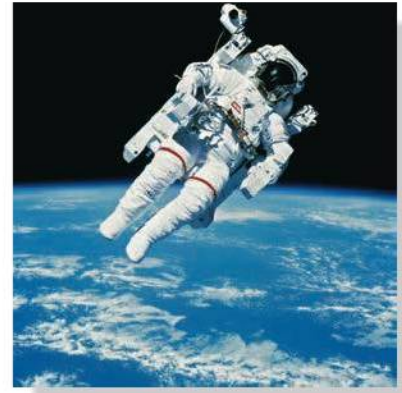
From Eq. 1–2, we can develop an approximate expression for finding the weight  $W$  of a particle having a mass  $m_1 = m$ . If we assume the earth to be a nonrotating sphere of constant density and having a mass  $m_2 = M_e$ , then if  $r$  is the distance between the earth's center and the particle, we have

$$W = G \frac{m M_e}{r^2}$$

Letting  $g = GM_e/r^2$  yields

$$W = mg \quad (1-3)$$

By comparison with  $\mathbf{F} = m\mathbf{a}$ , we can see that  $g$  is the acceleration due to gravity. Since it depends on  $r$ , then the weight of a body is *not* an absolute quantity. Instead, its magnitude is determined from where the measurement was made. For most engineering calculations, however,  $g$  is determined at sea level and at a latitude of  $45^\circ$ , which is considered the “standard location.”



The astronaut's weight is diminished since she is far removed from the gravitational field of the earth. (© NikoNomad/Shutterstock)

## 1.3 The International System of Units

The four basic quantities—length, time, mass, and force—are not all independent from one another; in fact, they are *related* by Newton's second law of motion,  $\mathbf{F} = m\mathbf{a}$ . Because of this, the *units* used to measure these quantities cannot *all* be selected arbitrarily. The equality  $\mathbf{F} = m\mathbf{a}$  is maintained only if three of the four units, called **base units**, are *defined* and the fourth unit is then *derived* from the equation.

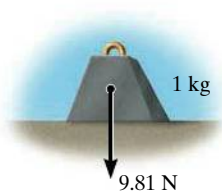


Fig. 1-2

The International System of units, abbreviated SI after the French *Système International d'Unités*, is a modern version of the metric system which has received worldwide recognition. As shown in Table 1-1, this system defines length in meters (m), time in seconds (s), and mass in kilograms (kg). The unit of force, called a **newton** (N), is *derived* from  $\mathbf{F} = m\mathbf{a}$ . Thus, 1 newton is equal to a force required to give 1 kilogram of mass an acceleration of  $1 \text{ m/s}^2$  ( $\text{N} = \text{kg} \cdot \text{m/s}^2$ ).

If the weight of a body located at the “standard location” is to be determined in newtons, then Eq. 1-3 must be applied. Here measurements give  $g = 9.806\,65 \text{ m/s}^2$ ; however, for calculations, the value  $g = 9.81 \text{ m/s}^2$  will be used. Thus,

$$W = mg \quad (g = 9.81 \text{ m/s}^2) \quad (1-4)$$

Therefore, a body of mass 1 kg has a weight of 9.81 N, a 2-kg body weighs 19.62 N, and so on, Fig. 1-2.

TABLE 1-1 International System of Units

Quantity	Length	Time	Mass	Force
SI Units	meter	second	kilogram	newton*
	m	s	kg	$\frac{\text{N}}{\left(\frac{\text{kg} \cdot \text{m}}{\text{s}^2}\right)}$
*Derived unit.				

**Prefixes.** When a numerical quantity is either very large or very small, the SI units used to define its size may be modified by using a prefix. Some of these prefixes used are shown in Table 1-2. Each represents a multiple or submultiple of a unit which, if applied successively, moves the decimal point of a numerical quantity to every third place.\* For example,  $4\,000\,000 \text{ N} = 4\,000 \text{ kN}$  (kilo-newton)  $= 4 \text{ MN}$  (mega-newton), or  $0.005 \text{ m} = 5 \text{ mm}$  (milli-meter). Notice that the SI system does not include the multiple deca (10) or the submultiple centi (0.01), which form part of the metric system. Except for some volume and area measurements, the use of these prefixes is to be avoided in science and engineering.

TABLE 1–2 Prefixes

	Exponential Form	Prefix	SI Symbol
<i>Multiple</i>			
1 000 000 000	$10^9$	giga	G
1 000 000	$10^6$	mega	M
1 000	$10^3$	kilo	k
<i>Submultiple</i>			
0.001	$10^{-3}$	milli	m
0.000 001	$10^{-6}$	micro	$\mu$
0.000 000 001	$10^{-9}$	nano	n

\*The kilogram is the only base unit that is defined with a prefix.

**Rules for Use.** Here are a few of the important rules that describe the proper use of the various SI symbols:

- Quantities defined by several units which are multiples of one another are separated by a *dot* to avoid confusion with prefix notation, as indicated by  $N = \text{kg} \cdot \text{m}/\text{s}^2 = \text{kg} \cdot \text{m} \cdot \text{s}^{-2}$ . Also,  $\text{m} \cdot \text{s}$  (meter-second), whereas ms (milli-second).
- The exponential power on a unit having a prefix refers to both the unit *and* its prefix. For example,  $\mu\text{N}^2 = (\mu\text{N})^2 = \mu\text{N} \cdot \mu\text{N}$ . Likewise,  $\text{mm}^2$  represents  $(\text{mm})^2 = \text{mm} \cdot \text{mm}$ .
- With the exception of the base unit the kilogram, in general avoid the use of a prefix in the denominator of composite units. For example, do not write N/mm, but rather kN/m; also, m/mg should be written as Mm/kg.
- When performing calculations, represent the numbers in terms of their *base or derived units* by converting all prefixes to powers of 10. The final result should then be expressed using a *single prefix*. Also, after calculation, it is best to keep numerical values between 0.1 and 1000; otherwise, a suitable prefix should be chosen. For example,

$$\begin{aligned} (50 \text{ kN})(60 \text{ nm}) &= [50(10^3) \text{ N}][60(10^{-9}) \text{ m}] \\ &= 3000(10^{-6}) \text{ N} \cdot \text{m} = 3(10^{-3}) \text{ N} \cdot \text{m} = 3 \text{ mN} \cdot \text{m} \end{aligned}$$