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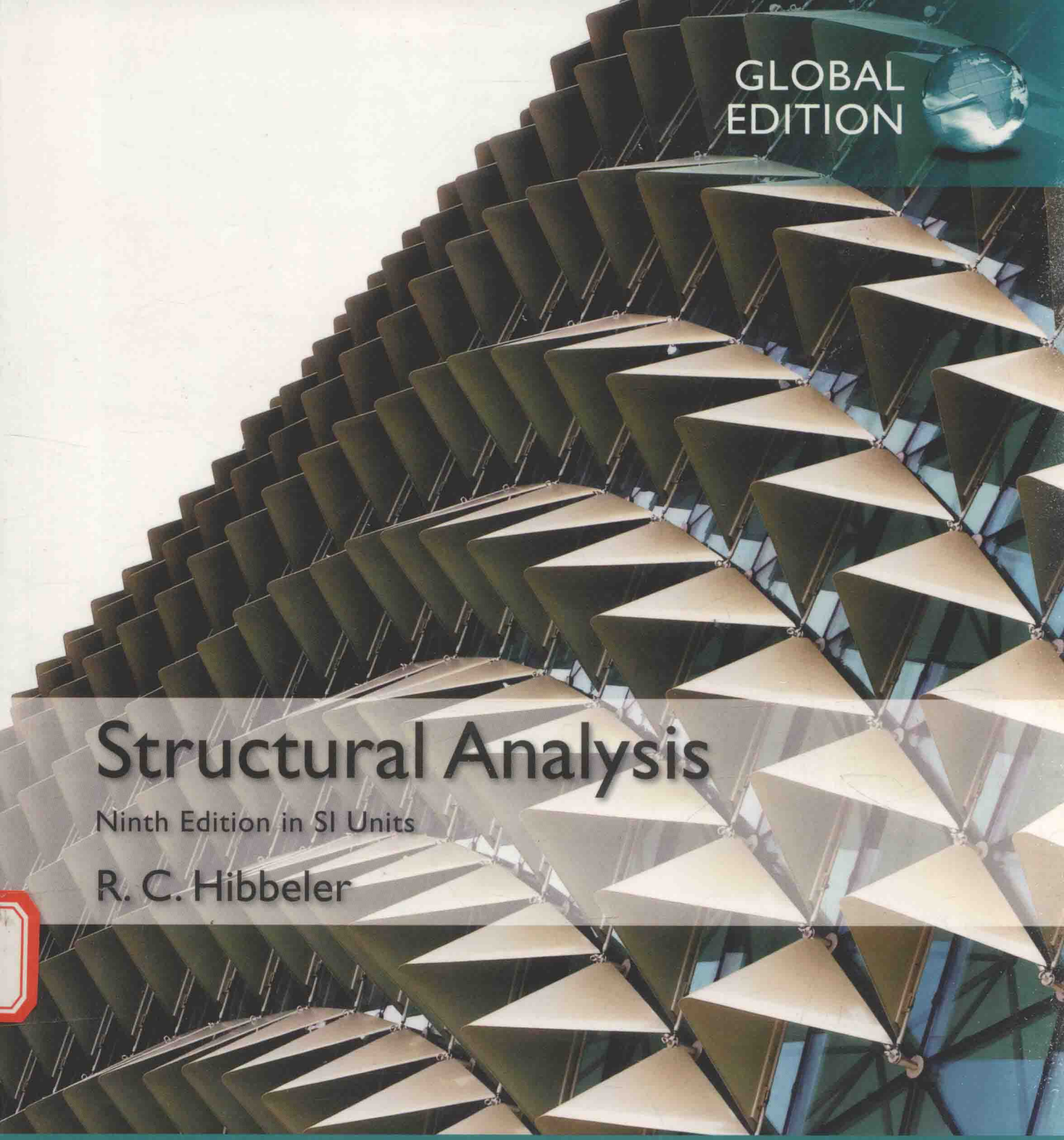

Structural Analysis

Ninth Edition in SI Units

R. C. Hibbeler

ALWAYS LEARNING

PEARSON

STRUCTURAL ANALYSIS

NINTH 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 Structural Analysis
and provide an acceptable guide to its understanding.

PREFACE

This book is intended to provide the student with a clear and thorough presentation of the theory and application of structural analysis as it applies to trusses, beams, and frames. Emphasis is placed on developing the student's ability to both model and analyze a structure and to provide realistic applications encountered in professional practice.

For many years now, engineers have been using matrix methods to analyze structures. Although these methods are most efficient for a structural analysis, it is the author's opinion that students taking a first course in this subject should also be well versed in some of the more important classicial methods. Practice in applying these methods will develop a deeper understanding of the basic engineering sciences of statics and mechanics of materials. Also, problem-solving skills are further developed when the various techniques are thought out and applied in a clear and orderly way. By solving problems in this way one can better grasp the way loads are transmitted through a structure and obtain a more complete understanding of the way the structure deforms under load. Finally, the classicial methods provide a means of checking computer results rather than simply relying on the generated output.

New Material and Content Revision. This edition now includes examples of the causes of structural failures, the concept of a load path, and an enhanced discussion for drawing shear and moment diagrams and the deflection of beams and frames. Chapter 17 has been added, which now provides a discussion of structural modeling concepts and a general description of how computer software is applied. Included are some structural modeling projects, along with a set of problems that require a computer analysis.

Structural Terminology. There are several places throughout the text where illustrations and discussion of additional terminology has been added, so that the student becomes familiar with the basic forms of fundamental structures and the names of their members.

Problem Arrangement. Different from the previous edition, the problems in each chapter are now placed at the end of the chapter. They are grouped with section headings for the convenience of assigning problems for homework.

New Problems. There are approximately 70% new problems in this edition. They retain a balance of easy, medium, and difficult applications. In addition, some new fundamental problems have been added that stress the importance of drawing frame moment diagrams and drawing deflected structures. Apart from the author, the problems have been checked by four other parties, namely Scott Hendricks, Karim Nora, Kurt Norlin, and Kai Beng Yap.

Additional Photos. The relevance of knowing the subject matter is reflected by the realistic applications depicted in many new and updated photos along with captions that are placed throughout the book.

Organization and Approach

The contents of each chapter are arranged into sections with specific topics categorized by title headings. Discussions relevant to a particular theory are succinct, yet thorough. In most cases, this is followed by a "procedure for analysis" guide, which provides the student with a summary of the important concepts and a systematic approach for applying the theory. The example problems are solved using this outlined method in order to clarify its numerical application. Problems are given at the end of each chapter, and are arranged to cover the material in sequential order. Moreover, for any topic they are arranged in approximate order of increasing difficulty.

Hallmark Elements

- **Photographs.** Many photographs are used throughout the book to explain how the principles of structural analysis apply to real-world situations.
- **Problems.** Most of the problems in the book depict realistic situations encountered in practice. It is hoped that this realism will both stimulate the student's interest in structural analysis and develop the skill to reduce any such problem from its physical description to a model or symbolic representation to which the appropriate theory can be applied. This modeling process is further discussed in Chapter 17.
- **Answers to Selected Problems.** The answers to selected problems are listed in the back of the book. Extra care has been taken in the presentation and solution of the problems, and all the problem sets have been reviewed and the solutions checked and rechecked to ensure both their clarity and numerical accuracy.
- **Example Problems.** All the example problems are presented in a concise manner and in a style that is easy to understand.
- **Illustrations.** Throughout the book, an increase in two-color art has been added, including many photorealistic illustrations that provide a strong connection to the 3-D nature of structural engineering.
- **Triple Accuracy Checking.** The edition has undergone rigorous accuracy checking and proofing of pages. Besides the author's review of all art pieces and pages, Scott Hendricks of Virginia Polytechnic Institute, Karim Nohra of the University of South Florida, and Kurt Norlin of Laurel Technical Services rechecked the page proofs and together reviewed the Solutions Manual.
- **Fundamental Problems.** These problem sets are selectively located at the end of most chapters. They offer students simple applications of the concepts and, therefore, provide them with the chance to develop their problem-solving skills before attempting to solve any of the standard problems that follow. You may consider

these problems as extended examples since they *all have solutions and answers* that are given in the back of the book. Additionally, the fundamental problems offer students an excellent means of studying for exams, and they can be used at a later time to prepare for the exam necessary to obtain a professional engineering license.

- **Animations.** On the Companion Website, students have access to specially created animations. These animations cover concepts that are important for teaching. Students can access the Companion Website with the Access Code provided. The animations help students visualize the relation between mathematical explanation and real structure, breaking down complicated sequences and building up fuller analysis. They lend a graphic component in tutorial and lecture, assisting lecturers in demonstrating the teaching of concepts with greater ease and clarity.

List of Animations

1. Method of Joints
   Page 98
   Example 3.2

2. Method of Sections
   Page 106
   Example 3.6

3. Internal Loadings M & V
   Page 150
   Section 4.3

4. Method of Superposition
   Page 166
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5. Influence Lines
   Page 213
   Example 6.1

6. Qualitative Influence Lines
   Pages 225, 226, and 227
   Examples 6.9(a), 6.10(b), and 6.11(b)

7. Moment-Area Theorems
   Page 325
   Example 8.8

8. Conjugate-Beam Method
   Page 334
   Example 8.14

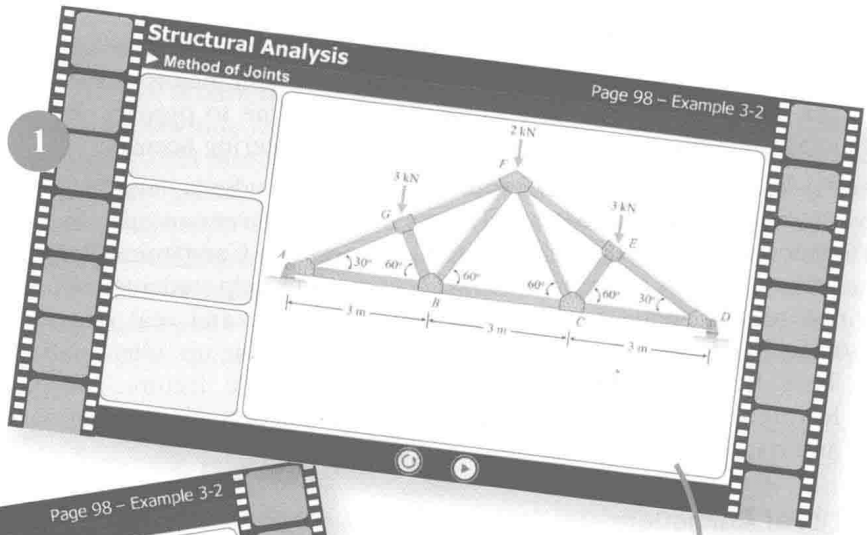
9. Principle of Virtual Work
   Page 359
   Example 9.1

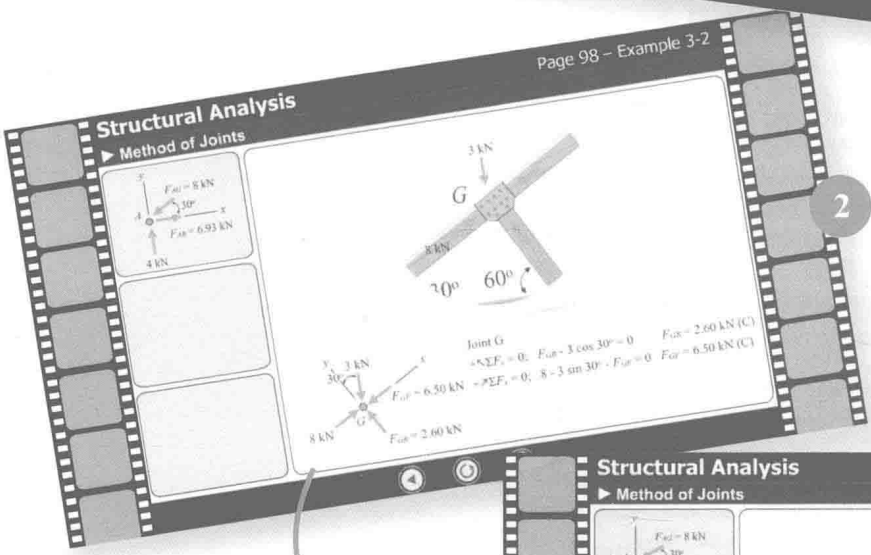
10. Force Method of Analysis
    Pages 408 and 409
    Figures 10-3 and 10-4

11. Force Method of Analysis
    Page 410
    Figure 10-5

12. Moment Distribution for Beams
    Page 501
    Section 12.2

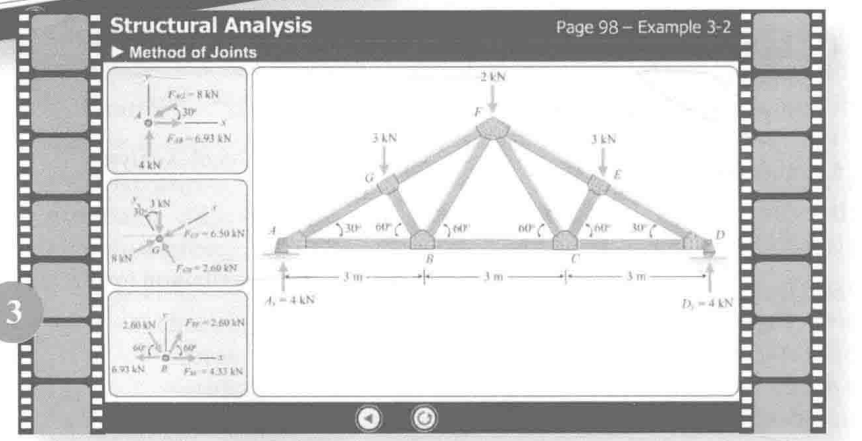
Lecturers can demonstrate the different methods of analysis step-by-step.





Maximize the use of class contact time.

Students "see" how the variables they apply in the mathematical equations affect the analysis of the structure.



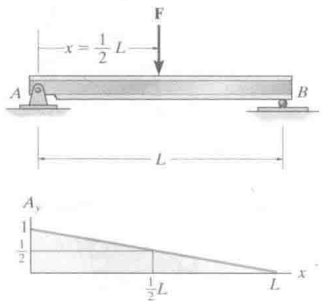
• **Video Solutions.** An invaluable resource in and out of the classroom, these complete solution walkthroughs of representative homework problems, offer fully-worked solutions, self-paced instruction and 24/7 accessibility. Lecturers and students can harness this resource to gain independent exposure to a wide range of examples applying formulae to actual structures. Each Video Solution is flagged by a monitor icon.

6.2 Influence Lines for Beams

Since beams (or girders) often form the main load-carrying elements of a floor system or bridge deck, it is important to be able to construct the influence lines for the reactions, shear, or moment at any specified point in a beam.

Loadings. Once the influence line for a function (reaction, shear, or moment) has been constructed, it will then be possible to position the live loads on the beam which will produce the maximum value of the function. Two types of loadings will now be considered.

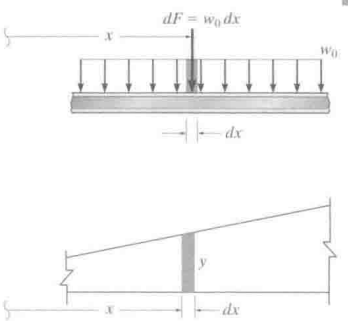
Concentrated Force. Since the numerical values of a function for an influence line are determined using a dimensionless unit load, then for any concentrated force **F** acting on the beam at any position x, *the value of the function can be found by multiplying the ordinate of the influence line at the position x by the magnitude of* **F**. For example, consider the influence line for the reaction at A for the beam AB, Fig. 6–7. If the *unit load* is at $x = \frac{1}{2}L$, the reaction at A is $A_y = \frac{1}{2}$ as indicated from the influence line. Hence, if the force F kN is at this same point, the reaction is $A_y = \left(\frac{1}{2}\right)(F)$ kN. Of course, this same value can also be determined by statics. Obviously, the *maximum influence* caused by **F** occurs when it is placed on the beam at the same location as the *peak* of the influence line—in this case at $x = 0$, where the reaction would be $A_y = (1)(F)$ kN.



influence line for A_y

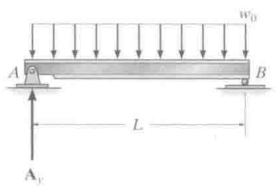
Fig. 6–7

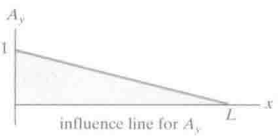
Uniform Load. Consider a portion of a beam subjected to a uniform load w_0, Fig. 6–8. As shown, each dx segment of this load creates a concentrated force of $dF = w_0\,dx$ on the beam. If $d\mathbf{F}$ is located at x, where the beam's influence-line ordinate for some function (reaction, shear, moment) is y, then the value of the function is $(dF)(y) = (w_0\,dx)y$. The effect of all the concentrated forces $d\mathbf{F}$ is determined by integrating over the entire length of the beam, that is, $\int w_0 y\,dx = w_0 \int y\,dx$. Also, since $\int y\,dx$ is equivalent to the *area* under the influence line, then, in general, *the value of a function caused by a uniform distributed load is simply the area under the influence line for the function multiplied by the intensity of the uniform load.* For example, in the case of a uniformly loaded beam shown in Fig. 6–9, the reaction $\mathbf{A}_y$ can be determined from the influence line as $A_y = (\text{area})(w_0) = \left[\frac{1}{2}(1)(L)\right]w_0 = \frac{1}{2}w_0 L$. This value can of course also be determined from statics.



influence line for function

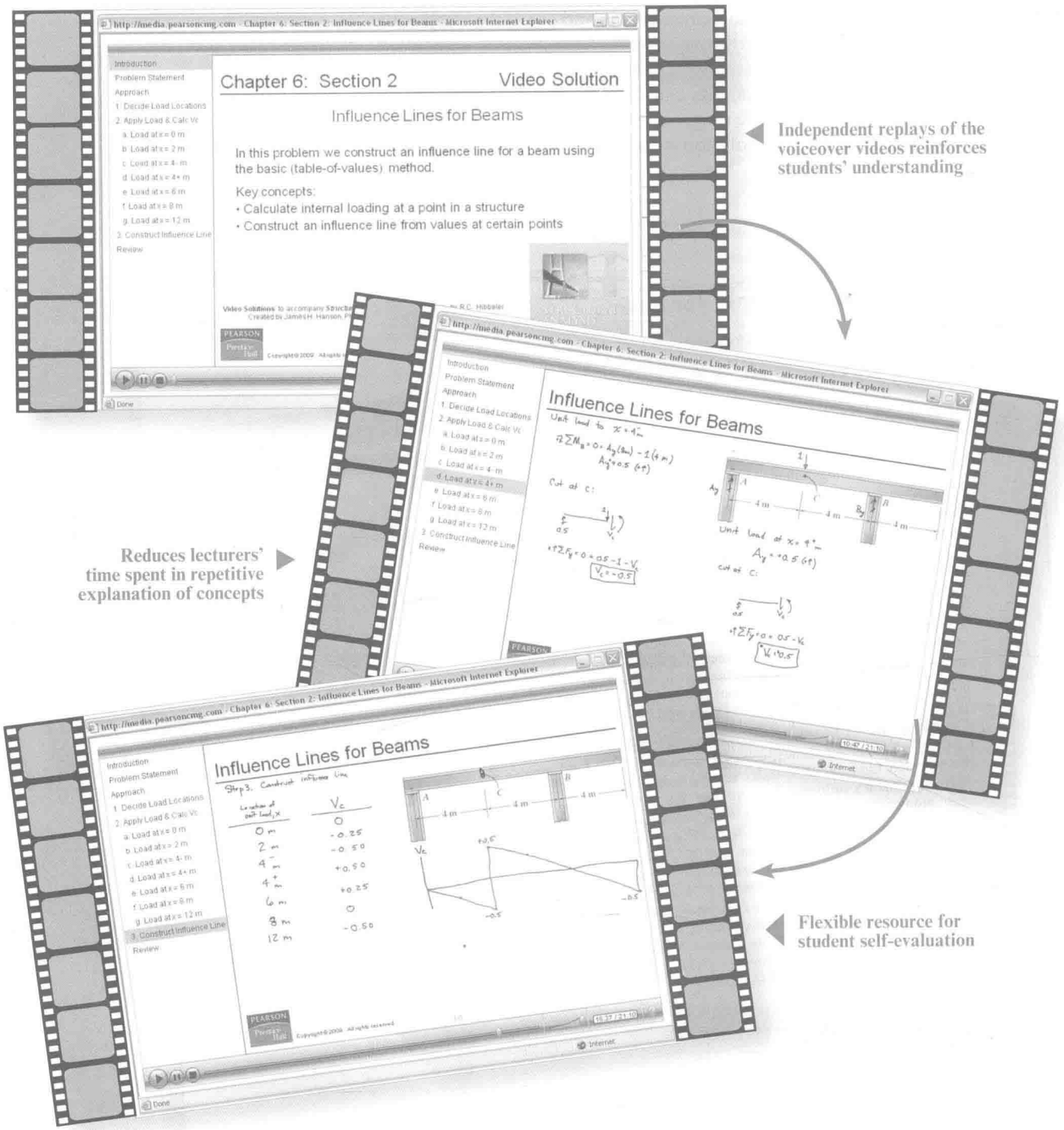
Fig. 6–8





influence line for A_y

Fig. 6–9


Chapter 6: Section 2 Video Solution
Influence Lines for Beams
In this problem we construct an influence line for a beam using the basic (table-of-values) method.
Key concepts:
• Calculate internal loading at a point in a structure
• Construct an influence line from values at certain points
Influence Lines for Beams
Influence Lines for Beams
Independent replays of the voiceover videos reinforces students' understanding
Reduces lecturers' time spent in repetitive explanation of concepts
Flexible resource for student self-evaluation

Contents

This book is divided into three parts. The first part consists of seven chapters that cover the classical methods of analysis for statically determinate structures. Chapter 1 provides a discussion of the various types of structural forms and loads. Chapter 2 discusses the determination of forces at the supports and connections of statically determinate beams and frames. The analysis of various types of statically determinate trusses is given in Chapter 3, and shear and bending-moment functions and diagrams for beams and frames are presented in Chapter 4. In Chapter 5, the analysis of simple cable and arch systems is presented, and in Chapter 6 influence lines for beams, girders, and trusses are discussed. Finally, in Chapter 7 several common techniques for the approximate analysis of statically indeterminate structures are considered.

In the second part of the book, the analysis of statically indeterminate structures is covered in six chapters. Geometrical methods for calculating deflections are discussed in Chapter 8. Energy methods for finding deflections are covered in Chapter 9. Chapter 10 covers the analysis of statically indeterminate structures using the force method of analysis, in addition to a discussion of influence lines for beams. Then the displacement methods consisting of the slope-deflection method in Chapter 11 and moment distribution in Chapter 12 are discussed. Finally, beams and frames having nonprismatic members are considered in Chapter 13.

The third part of the book treats the matrix analysis of structures using the stiffness method. Trusses are discussed in Chapter 14, beams in Chapter 15, and frames in Chapter 16. Finally, Chapter 17 provides some basic ideas as to how to model a structure, and for using available software for solving problem in structural analysis. A review of matrix algebra is given in Appendix A.

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.** An instructor's solutions manual was prepared by the author. The manual was also checked as part of the Triple Accuracy Checking program.
- **Presentation Resources.** All art from the text is available in PowerPoint slide and JPEG format. These files are available for download from the Instructor Resource Center at www.pearsonglobaleditions.com/hibbeler. If you are in need of a login and password for this site, please contact your local Pearson representative.

- **Video Solutions.** Located on the Companion Website, Video Solutions offer step-by-step solution walkthroughs of representative homework problems. Make efficient use of class time and office hours by showing students the complete and concise problem solving approaches that they can access anytime 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. Access the videos at www.pearsonglobaleditions.com/hibbeler.
- **STRAN.** Developed by the author and Barry Nolan, a practicing engineer, STRAN is a downloadable program for use with Structural Analysis problems. Access STRAN on the Companion Website, www.pearsonglobaleditions.com/hibbeler and follow the links for the *Structural Analysis* text. Complete instructions for how to use the software are included on the Companion Website.

Resources for Students

- **MasteringEngineering.** Tutorial homework problems emulate the instrutor's office-hour environment.
- **Companion Website.** The Companion Website provides practice and review materials including:
  - **Video Solutions**—Complete, step-by-step solution walkthroughs of representative homework problem.

    Videos offer:
    - **Fully worked Solutions**—Showing every step of representative homework problems, to help students make vital connections between concepts.
    - **Self-paced Instruction**—Students can navigate each problem and select, play, rewind, fast-forward, stop, and jump-to-sections within each problem's solution.
  - **STRAN**—A program you can use to solve two and three dimensional trusses and beams, and two dimensional frames. Instructions for downloading and how to use the program are available on the Companion Website.

An access code for the Companion Website is included with this text. To redeem the code and gain access to the site, go to www.pearsonglobaleditions.com/hibbeler and follow the directions on the inside front cover.

Acknowledgments

Through the years, over one hundred of my colleagues in the teaching profession and many of my students have made valuable suggestions that have helped in the development of this book, and I would like to hereby acknowledge all of their comments. I personally would like to thank the reviewers contracted by my editor for this new edition, namely:

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I would greatly appreciate hearing from you if at any time you have any comments or suggestions regarding the contents of this edition.

Russell Charles Hibbeler
hibbeler@bellsouth.net

Global Edition
Pearson would like to thank Kai Beng Yap for his contribution to the ninth edition.

Kai Beng Yap is currently a registered professional engineer who works in Malaysia. He has BS and MS degrees in Civil Engineering from the University of Louisiana, Lafayette, Louisiana; and he has done further graduate work at Virginia Polytechnic Institute in Blacksberg, Virginia. His professional experience has involved teaching at the University of Louisiana and doing engineering consulting work related to structural analysis and design and its associated infrastructure.

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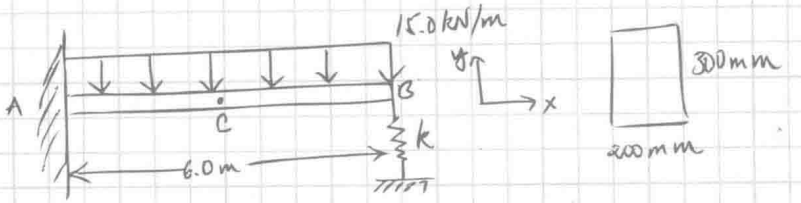
Samit Ray Chaudhuri, Department of Civil Engineering, *Indian Institute of Technology Kanpur*

your work...

PART B



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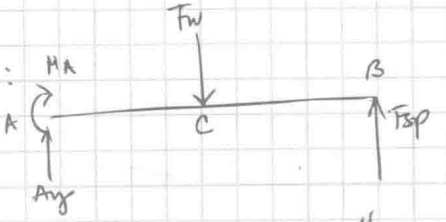

$$v_B = v_B' - v_B'' \qquad v_B' = w\frac{L^4}{8EI} \qquad v_B'' = -\frac{PL^3}{3EI}$$

$$F_{sp} = kv_B \Rightarrow F_{sp} = 3wL^4\frac{k}{8(3EI + kL^3)}$$

$$I = \frac{1}{12}(0.3\text{m})(0.2\text{m})^3 = 2\times10^{-4}\ \text{m}^4$$

$$F_{sp} = \frac{3}{8}\left(15\ \frac{\text{kN}}{\text{m}}\right)(6.0\text{m})^4\frac{15.0\ \text{kN/m}}{3(200\text{GPa})(2\times10^{-4}\text{m}^4) + \left(15.0\frac{\text{kN}}{\text{m}}\right)(6.0\text{m})^3}$$

$$\boxed{F_{sp} = 15.99\ \text{kN}}$$

your answer specific feedback

Part B - Spring force at *B*

Using the method of superposition, determine the force $\mathbf{F}_{sp}$ that the spring at *B* exerts on the bar. Assume that this force acts in the positive *y* direction.

Express your answer to three significant figures and include the appropriate units.

$\mathbf{F}_{sp} =$ 15.99 kN

reset shortcuts help

Submit Hints My Answers Give Up Review Part

Incorrect; Try Again

Review the equation used for the moment of inertia of the cross section.

CONTENTS