STRUCTURES

Second Edition

Daniel L. Schodek

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Harvard University

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PREFACE

There exist an invariant set of physical principles founded in the field of mechanics that can be used by designers as aids to understanding the behavior of existing structural forms and in devising new approaches. The development of these principles has flowered during the past three centuries to the extent that they are amazingly well established and documented. Some new understandings, of course, are continuing to occur and will hopefully always occur. Still, the analytical tools already available to the designer are extensive and enormously powerful. This is true to the extent that the real challenge in the field of structures lies not so much in developing new analytical tools but in bringing those currently in existence to bear in the designing and formulation of creative structural solutions with the intent of making better buildings.

In this book we discuss in an introductory way the nature of the invariant physical principles that underlie the behavior of structures under load. The primary goal of the book, however, is not simply to teach analytical techniques but more generally, to explore their role in the design of structures in a building context. Because of this larger goal, the book covers material discussed not only in specialized engineering curricula but also, to some extent, that covered in architectural curricula as well. The traditional hard boundaries between subdisciplines in engineering, (e.g., statics and strength of materials) have also been deliberately softened and a more integrative approach taken.

The book is divided into three major parts. Part I is an introduction to the subject and to fundamental concepts of analysis and design. Part II introduces the reader to most of the primary structural elements used in buildings and discusses their analysis and design. Each of the chapters in this part is divided into sections that (1) introduce the element considered and explain its role in building, (2) discuss its behavior under load in qualitative terms (an "intuitive" approach), (3) examine its behavior under load in quantitative terms, and (4) discuss methods for designing (rather than just analyzing) the element. Part III contains a unique discussion of the logic of structural design, as it is a part of the larger building design process. The Appendix generally discusses more advanced principles of structural analysis.

The book is intended largely as a resource for students and instructors wishing to design their own curriculum. For those wanting to adopt a strictly qualitative approach to the subject, for example, it is possible to read only Chapter 1 in Part I, the sections entitled "Introduction" and "General Principles" in each of the chapters in Part II, and all of Part III. This coverage will provide a brief qualitative overview of the field with a special emphasis on design rather than analysis. For those students who already have a background in the analytical aspects of structures, Part III contains summary information useful in a design context. Part III can be read independently by such students.

Within Parts I, II, and III there is a certain redundancy in the way analytical topics are covered so that students or instructors can integrate the material in the order seen best fit. Shear and moment diagrams, for example, are first introduced in an abstract way in chapter 2. They are reintroduced in connection with the analysis of a specific structural element—the truss. *Where* the different presentations are introduced, if at all, may be varied by the instructor. The author, for example, typically chooses to introduce shear and moment diagrams initially as a part of truss analysis and then follow up with the more abstract development of shear and moment diagrams in Chapter 2 before going into beam analysis and design. Other instructors may choose to approach the subject material differently. The book is designed to have sufficient flexibility to support different approaches. In any event the material is presented in such a way that a direct cover-to-cover reading is also appropriate.

The author is, of course, indebted to a vast number of people in either a direct or an indirect way for the approach taken in this book. Professor Spiro Pollalis contributed his time and help in revising the manuscript from the first edition. He directly contributed the new sections on reinforced concrete in Chapter 9 and on computer-based structural analysis methods in Chapter 4 and Appendix 12. David Thal, John Leeke, and Joe Kennard helped in preparing illustrations for the second edition. Especially important are Kay, Ned, and Ben Schodek, who provided their own special form of support. The endless patience and contributions of several years of students in the Graduate School of Design at Harvard who have taken courses involving the material contained herein is also greatly appreciated.

Daniel L. Schodek

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CONTENTS

part I

INTRODUCTORY CONCEPTS

The three chapters in Part I provide an overview and introduction to structures and their use in buildings. The first chapter is a self-contained overview of the field and discusses different ways of classifying structural elements and systems. The second chapter reviews certain fundamental principles of mechanics that are generally applicable to the analysis of any structure. The third chapter considers the loads that structures must be designed to carry and generally discusses the structural analysis and design process as it occurs in a building context.

chapter 1

STRUCTURES: AN OVERVIEW

1.1 INTRODUCTION

Definitions are a time-honored way of opening any book. A simple definition of a *structure* in a building context is that a structure is a device for channeling loads that result from the use and/or presence of the building to the ground. Important in the study of structures are many widely varying concerns. The study of structures certainly involves coming to understand the basic principles that define and characterize the behavior of physical objects subjected to forces. More fundamentally, it even involves defining what a force itself is, since this familiar term represents a fairly abstract concept. The study of structures in a building context also involves dealing with much broader issues of space and dimensionality. The words "size," "scale," "form," "proportion," and "morphology" are all terms commonly found in the vocabulary of a structural designer.

As a way of getting into the study of structures, it is useful to reconsider the first definition of a structure given above. Although valuable in the sense that it defines the purpose of a structure, the original definition unfortunately provides no insight into the makeup or characteristics of a structure: What *is* this device that channels loads to the ground? To adopt the complex and exacting style of a dictionary writer, a *structure* could be defined as a physical entity having a unitary character