Presents the basic concepts of structures, the stability and determinacy of structures, and the analysis of both statically determinate and indeterminate structures

ELEMENTARY THEORY OF STRUCTURES

YUAN-YU HSIEH

PRENTICE-HALL INTERNATIONAL SERIES IN DYNAMICS

Y. C. FUNG
Editor

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Elementary Theory of Structures by Yuan-Yu Hsieh
Foundations of Solid Mechanics by Y. C. Fung
Principles of Dynamics by Donald T. Greenwood

To
My Parents

PREFACE

This book is intended for elementary courses in the structural theory of civil engineering. In preparing material for it, the author has assumed that the reader is not familiar with the subject. The first seven chapters contain the basic concepts of structure and an analysis of statically determinate structures. Chapter 8 deals with elastic deformations. Chapters 9 through 15 are concerned with statically indeterminate structures, including the method of consistent deformations, least work, slope deflection, and moment distribution. Chapter 16 is devoted to an introductory discussion of matrix algebra. The scope is wide enough to provide adequate background for reading the remainder of the book. Finally, the last two chapters present a unified treatment of structures by matrix methods based on the finite-element approach. Since this is an elementary treatment, emphasis is on the development of general theory in terms of matrix operations rather than on the particular details of computer programs.

The elementary theory of structures is not difficult, involving as it does only a limited amount of higher mathematics. For most of the book, the only preparation needed is a knowledge of arithmetic and high school algebra. We may also say, however, that this theory is difficult, in that it generally requires careful study in order to achieve a thorough understanding of its basic philosophy. The author has endeavored to present clearly and lucidly the fundamentals of structural theory. These fundamentals are arranged in a systematic order and are supplemented by examples illustrating their application in some of the common structures—namely, beams, trusses, and rigid frames.

While written primarily for use as a textbook in the classroom, this book can also be of help to structural and architectural engineers in their independent study.

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Y. Y. H.

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CONTENTS

1-2. THEORY OF STRUCTURES DEFINED

The complete design of a structure is contained in the following stages:

1. Establishing the general layout. The general layout for a structure is selected from many possible alternatives. The primary concern is the performance requirement of the structure whether it is to house, to convey, or to support in space. Many secondary considerations should also be examined including the economic, aesthetic, legal, and financial aspects.

2. Investigating the loadings. General information about the loadings imposed on a structure is usually given in the specifications and codes. Basically it is part of the designer's responsibility to specify the loading conditions and to take care of exceptional cases. Loadings based on *static* consideration may be classified as:

a. Dead load. Dead load is the weight of the structure itself and is regarded as fixed in magnitude and location. Since the dead load must be assumed before the structure is designed, the original data are only tentative. Revision must be made if the estimate is not satisfactory.

b. Live load. Live load may be classified into movable load and moving load. *Movable loads* are loads that may be transported from one location to another on a structure, for example, people and furniture on a building floor. *Moving loads* are loads that move continuously over the structure, such as railway trains or trucks on a bridge.

c. Impact load. The effects of impact are usually associated with moving live loads. In structural design the impact load is treated as an increase in the live load if the live load is taken as a gradually applied static load.

3. Stress analysis. Once the external loads are defined, a *stress analysis* must be made to determine the internal forces, sometimes referred to as *stresses*, that will be produced in the various members. When live loads are involved, emphasis should be put on the maximum possible stresses in each member under consideration. To obtain this we must know not only what loading is imposed but also where it is placed.

4. Selection of members. The choice of materials and proportioning of the sizes for structure members are based on the results of Stage 3 together with the design provisions given by the specifications or codes.

5. Drawing and detailing. After the make-up of each part of the structure is determined, the final stage, drawing and detailing, provides the necessary information for construction.

The subject matter of the theory of structures is stress analysis with occasional reference to loadings. The emphasis of structural theory is usually on the fundamentals rather than on the details of design.

1-3. THEORIES OF STRUCTURES CLASSIFIED

Structural theories may be classified from various points of view. For convenience, we shall characterize them by the following aspects:

1. Statics versus dynamics. Ordinary structures are usually designed under static loads. Dead load and snow load are static loads that cause no dynamic effect on structures. Some live loads, such as trucks and locomotives moving on bridges, are also assumed as concentrated static load systems. They do cause impact on structures; however, the dynamic effects are treated as a fraction of the moving loads to simplify the design.

The particular, specialized branch that deals with the dynamic effects on structures of accelerated moving loads, earthquake loads, wind gusts, or bomb blasts is *structural dynamics*.

2. Plane versus space. No structure is really planar. However, structural analyses for beams, trussed bridges, or rigid frame buildings are usually treated as plane problems, although they are never two-dimensional in themselves. On the other hand, in some structures, such as towers and framing for domes, the stresses are interrelated between members not lying in a plane in such a way that the analysis cannot be simplified on the basis of component planar structures. Such structures must be considered as space frameworks under non-coplanar force system.

3. Linear versus nonlinear structures. Linear structure means that a linear relationship is assumed to exist between the applied loads and the resulting displacements in a structure. This assumption is based on the following conditions:

a. The material of the structure is elastic and obeys Hooke's law at all points and throughout the range of loading considered.

b. The changes in the geometry of the structure are so small that they can be neglected when the stresses are calculated.

Note that if the principle of superposition is to apply, a linear relationship must exist, or be assumed to exist, between loads and displacements.

A nonlinear relationship between the applied actions and the resulting displacements exists under either of two conditions:

a. The material of the structure is inelastic.

b. The material is within the elastic range, but the geometry of the structure changes significantly during the application of loads.

The study of nonlinear behavior of structures includes *plastic analysis of structures* and *buckling of structures*.

4. Statically determinate versus statically indeterminate structures. The term *statically determinate structure* means that structural analysis can be