PRACTICAL DESIGN of REINFORCED CONCRETE

Russell S. Fling

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RUSSELL S. FLING

Consulting Engineer

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This book is dedicated to
Engineers who Strive to Protect the Public
by Designing Safe, Serviceable Structures
While Earning a Living.

PREFACE

The purpose of this text is to help the student and structural engineer* design reinforced concrete buildings efficiently, correctly, and accurately. Insofar as possible, material is presented in logical order as the structural design would be prepared in a design office. Necessary deviations are made to explain basic concepts before they are used in design. Students and practicing engineers should thoroughly understand these basic concepts before applying design procedures in practice.

Structural investigation consists of predicting the behavior, such as load-carrying capacity or deflection, of a structural member, frame, or system when all necessary information is given. Presumably there is only one correct answer. *Structural design* consists of selecting the size, shape, materials, and details of a structural member, frame or system when the required behavior, such as load capacity and other conditions, are given. Sometimes it is necessary to employ an iterative procedure in which a design or certain conditions are assumed and then investigated. The design or conditions are modified based on the first investigation and are then investigated again. Iterations continue until convergence, that is, until the investigation indicates that the assumed design or conditions are satisfactory but not oversized. However, for efficiency, design should proceed without iterations.

Design is the opposite of investigation. In design, there are many correct solutions. Perhaps no one solution is the "best." Design is by far the most common activity of practicing structural engineers. Some people consider design more difficult than investigation because of the many options involved, but it need not be so. Description of investigation procedures sometimes must precede description of design procedures, but the latter is emphasized in this text.

For efficiency, design aids should be compact, pertinent, and few in number. Most preferable are aids that can be committed to memory for conditions most commonly encountered. It is the intent of this text to present graphs and tables that will illustrate visually the effect parameters have on final design. Some graphs and tables in Appendix A will also serve as design aids by giving values useful in design without further computation for situations most commonly encountered in design practice.

*I implicitly assume that students become designers and that those who design concrete structures present evidence of their competence to state authorities who then grant them the privilege of using the title of engineer.

Likewise, simplified or short procedures should be significantly shorter than complete or long procedures, without sacrificing safety or construction economy. The design should move quickly and directly to determine required information while promoting the engineer's understanding of structural behavior.

To facilitate reaching these goals, all chapters of this text list objectives for the subjects included in the chapter. A student should refer to the objectives again after having studied all material in the chapter. Also included are suggestions for short procedures, where appropriate, and an analysis of the premium to be paid in construction cost, if any, for use of such procedures.

The structural engineer's objective in designing a structure is to prepare contract documents that describe the reinforced concrete structure to be constructed. These documents should be completed with a minimum of time, cost, and effort while meeting all other design objectives. The engineer's objective is *not* to make calculations or prepare a design, per se. However, some authorities (e.g., the engineer's supervisor, the owner, or the building department) will require proof that this was done in a satisfactory manner, so it behooves the engineer to prepare design computations in a competent manner for such an eventuality.

Only cast-in-place reinforced concrete is covered in this text. It does not include precast, prestressed, or composite construction or related subjects such as determination of loads and rigorous methods of moment distribution.

English units are used throughout the text because it is unlikely that metric or SI units will be adopted or be used to a significant degree in the United States in the near future. Conversion tables are included in Appendix D.

Although engineering principles are the same all over the world, this text is directed toward achieving the maximum economy of design and construction of reinforced concrete structures of moderate size or smaller in the United States. Design procedures appropriate only for tall buildings (such as the P-delta method of evaluating column slenderness), or appropriate only for advanced design using computers (such as the equivalent frame method for analyzing two-way slabs), or used only by those preparing design aids (such as balanced conditions in columns), are not discussed. Instead, reference is made to other publications. Also, calculation of cutoff points for positive moment bars in flexural members is not covered because I am opposed to the use of short bars. Much calculation effort is required to determine length of short bars, and their use risks misplacement with potentially serious consequences.

In this text, I have introduced some subjective opinions distilled from many years of practice as a structural engineer engaged in the design of a wide variety of structures in reinforced concrete and other materials. Some of these opinions are found in the footnotes, which are intended to facilitate the task of understanding the engineering principles involved, as well as to present practical observations on construction of reinforced concrete. I have tried to distinguish between established theory on which there is general agreement, and personal opinion, which is still open to debate.

References given at the end of each chapter direct the reader to detailed information on important subjects. Reference lists are not complete but provide only an initial supplementary reading for those interested in pursuing a subject further.

Some references are classic papers, which, though 10 to 20 years old, still provide the most definitive discussion of their subject.

Extensive reference is made to American Concrete Institute (ACI) Building Code Requirements for Reinforced Concrete (ACI 318-83). Hereafter, it is referred to as the ACI Code, or simply, the Code. Practicing structural engineers should obtain a copy of the Code and the accompanying commentary for use in design practice [1].* The ACI Code has been widely adopted by many governmental jurisdictions throughout the United States, as well as by many foreign countries.

In the text, those equations used most often in design (prime equations) are emphasized by being enclosed in a box. Prime equations and their derivations should be memorized by practicing engineers. Certain other equations are as important as prime equations but are not used as often in design and therefore need not be memorized. Some equations are secondary equations used in deriving or supporting prime equations.

I welcome any suggestions for improving the wording, correcting any errors, and including or omitting any material in future revisions. I may be contacted through the publisher, John Wiley & Sons.

Russell S. Fling

Selected References

1. ACI Committee 318. *Building Code Requirements for Reinforced Concrete, (ACI 318-83); Commentary on Building Code Requirements for Reinforced Concrete.* American Concrete Institute. Detroit, Michigan, 1983.
(ACI Code and Commentary are available from the American Concrete Institute, Box 19150, Redford Station, Detroit, Michigan 48219. Because these documents are mentioned throughout the text, they are not listed as references for each chapter.)

*Number in brackets refers to reference at the end of this preface.

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The inspiration for this book had its genesis with my early employment by Raymond C. Reese, a vigorous and perceptive engineer who later became chairman of the ACI Code Committee and President of ACI. The inspiration was nurtured and developed, unbeknown to me at the time, by ACI committees on which I served for many years. If you are pleased with this book, give credit to ACI and its committees. I take full blame for any failure to fulfill the aims and objectives in its preparation.

Credit should also be given to clients and contractors who challenged me in my years of active practice.

During preparation of the book, I received much encouragement from friends, Mary K. Hurd, Paul F. Rice, and others, and audiences before which I spoke. Without their support this book would not have been written. The offices of Paul J. Ford and Lantz, Jones & Nebraska reviewed each chapter during preparation and contributed many useful suggestions, ideas, and criticisms. I am grateful for their help.

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APPENDIXES

CHAPTER 1

INTRODUCTION

1.1 OBJECTIVES

The twin goals of every engineer should be to perform his or her work competently and efficiently. These goals can only be approached if the engineer has a clear mental picture of the results to be expected from the design. With a firm, well-defined view of the objectives, the engineer can begin to strive toward perfection in performance and to make intelligent decisions on how best to spend his or her time and effort most effectively. The following objectives of the design process for reinforced concrete buildings are listed approximately in descending order of priority. Structural safety is clearly the most important objective and must take precedence over all other objectives.

1. Assure Structural Safety Structural safety refers to freedom from collapse or failure of the structure to support the loads imposed upon it. Such failure could mean that the structure and everything supported by it falls to the ground or that the structure simply deforms excessively. Because failure results in loss of property and could also result in injury or death, it must be prevented.

Structural safety, in some cases, also includes safety during construction. For example, long span bridges usually must be designed for the various stages of construction when only a part of the completed structure is in place. Designers of building structures should be alert to similar circumstances. For example, composite construction (not covered in this book) requires consideration of construction stages. Shoring and reshoring are normally the responsibility of the contractor, but if these cannot be done in the usual manner, the structural engineer should change the design or give special instructions to the contractor.

The term *factor of safety* usually means the ratio of the load that would cause collapse to the service load. Service loads are the actual weight of materials, such as concrete, masonry, partitions, windows, ceilings, and so forth (dead loads), and an assumed actual weight of people, furniture, stored material, and other building contents (live loads). Service loads also include the actual forces exerted by wind, soils, and liquids on the structure.

Factor of safety can also apply to component parts of the construction or to serviceability conditions. Then the term should be modified appropriately as, for example, "factor of safety against shear failure" or "factor of safety against excessive deflection."

Due to their importance, structural safety concepts are explained more fully in Section 1.2.

2. Meet Functional Requirements The owner or architect gives the structural engineer certain requirements that must be met by the completed structure. Typically, the structure must meet the following requirements:

- Provide a certain floor area and volume.
- Meet certain dimensions and locations of walls, columns, and other elements.
- Meet building code requirements, other than structural design, such as fire resistance, inclusion of stairs, elevators, and so forth.
- Allow installation of under-floor duct work in the concrete for electrical, computer, and telecommunication wiring or allow drilling holes through the floor to reach conduit below floor construction.
- Meet special requirements for equipment that the owner will install in the building, such as concrete foundations for heavy machinery or deflection limits for sensitive laboratory equipment.
- Facilitate attaching or constructing other portions of the building.
- Allow completion within a certain time period.
- Present aesthetically pleasing surfaces where exposed to view or allow installation of finishing materials.
- Provide security against intrusion, especially for buildings with valuable contents, such as museums and financial institutions.
- Provide extra security against tornadoes and other severe weather conditions for buildings housing critical equipment, such as computers for centralized data processing.

3. Meet Serviceability Requirements It is normally not sufficient that the structure avoid collapse and meet the functional requirements of the owner. It must also behave in a satisfactory manner during its service life. Following are the most important requirements.

- Deflection must be limited for a variety of reasons. Because this is a complex subject, it is covered in detail in Chapter 8.
- Premature or excessive cracking must be limited in certain circumstances.
- Weathering, abrasion, erosion, and corrosion must be avoided. These are important subjects, but they are beyond the scope of this text and will not be discussed in detail.

4. Reduce Construction Cost Thousands of years ago, mankind proved that it was possible to construct durable, permanent, attractive structures that met the needs of society. The real challenge to today's engineer is to continue to do so at the lowest possible cost. Changing market conditions, materials, and labor, as well as new ideas and techniques, make this an on-going challenge. Suggestions for reducing construction cost will be found throughout this book, especially in Chapter 14, Preliminary Design.

5. Reduce Design Cost Clients have limits to the amount that they will pay for preparation of a structural design, so it is in the engineers' best interest to complete their work as efficiently as possible. In some cases, the success of this effort will determine whether engineers have a job, and in other cases, it will determine the level of their compensation. Suggestions for saving design time will be found throughout this text.

6. Reduce Time of Construction At the time this text was written, interest on construction loans was 1% per month or more. It follows that saving a month during construction will save 1% of the costs expended in construction to date of the time saving. The owner may realize additional savings by occupying the building earlier.

7. Coordination with Other Construction Activities and Building Services Structural frames are rarely built in isolation. Plumbing lines, and heating, ventilating, and air-conditioning ducts pass through and below floor framing. Electrical conduit is buried in concrete. Walls, doors, and windows attach to the concrete frame. Owners will insist that the structural frame accommodate other parts of the building with ease.

8. Personal Preferences Practicing engineers quickly learn that owners, architects, and contractors frequently have personal preferences for a type of structural frame, method of construction, and materials. Successful engineers will at least consider such preferences.

Practicing engineers must comply with local building codes, which include provisions for design of electrical and mechanical systems, architectural layouts, fire safety, site work, and foundations, as well as structural design. The ACI Building Code Requirements for Reinforced Concrete (ACI 318-83), referred to in this text as the ACI Code, is usually a part of local building codes.

The ACI Code is written by a committee (ACI 318) organized by the American Concrete Institute, a private, nonprofit organization. ACI Committee 318 is composed of a carefully balanced group of practicing engineers, college professors, concrete researchers, contractors, government representatives, and industry representatives. The first ACI 318 Code was published in the early part of this century. Since then, it has gained widespread recognition as the most complete, authoritative set of rules, written in English, guiding the design of reinforced concrete. However, as the product of a private organization, the ACI Code has no legal authority, even though ACI membership is open to everyone (even worldwide), and its standards are adopted by a lengthy, strict procedure.