PEARSON Prentice Hall

国外大学优秀教材——土木工程系列（影印版）

混凝土结构

（第4版）

Reinforced Concrete Design

(Fourth Edition)

Leonard Spiegel
George F. Limbrunner

清华大学出版社 Pearson Education

EISBN: 1-13-490202-5
English reprint edition copyright © 2004 by **PEARSON EDUCATION ASIA LIMITED and TSINGHUA UNIVERSITY PRESS.**
Original English language title from Proprietor's edition of the Work.

Original English language title:Reinforced Concrete Design, 4/e, by Leonard Spiegel and George F. Limbrunner, Copyright © 1998.
All Rights Reserved.

Published by arrangement with the original publisher, Pearson Education, Inc., publishing as Prentice Hall, Inc.

This edition is authorized for sale and distribution only in the People's Republic of China (excluding the Special Administrative Region of Hong Kong, Macao SAR and Taiwan).
本书影印版由 Pearson Education 授权给清华大学出版社出版发行。

For sale and distribution in the People's Republic of China exclusively (except Taiwan, Hong Kong SAR and Macao SAR).
仅限于中华人民共和国境内(不包括中国香港、澳门特别行政区和中国台湾地区)销售发行。

北京市版权局著作权合同登记号 图字：01-2003-2083

版权所有，翻印必究。举报电话：010-62782989 13901104297 13801310933
本书封面贴有 Pearson Education（培生教育出版集团）激光防伪标签，无标签者不得销售。

图书在版编目(CIP)数据

混凝土结构 = Reinforced Concrete Design：英文/（美）施皮格尔（Spiegel, L.）等著. —影印本. —北京：清华大学出版社，2005.1
（国外大学优秀教材. 土木工程系列）
ISBN 7-302-09900-6

Ⅰ. 混… Ⅱ. 施… Ⅲ. 混凝土结构－高等学校－教材－英文 Ⅳ. TU37

中国版本图书馆 CIP 数据核字（2004）第 118091 号

出 版 者：清华大学出版社　　地　　址：北京清华大学学研大厦
http://www.tup.com.cn　　邮　　编：100084
社总机：(010) 6277 0175　　客户服务：(010) 6277 6969
责任编辑：徐晓飞
印 装 者：北京嘉实印刷有限公司
发 行 者：新华书店总店北京发行所
开　　本：185×230　印张：33.25
版　　次：2005 年 1 月第 1 版　2005 年 1 月第 1 次印刷
书　　号：ISBN 7-302-09900-6/TU・242
印　　数：1~3000
定　　价：49.80 元

本书如存在文字不清、漏印以及缺页、倒页、脱页等印装质量问题，请与清华大学出版社出版部联系调换。联系电话：（010）62770175-3103 或（010）62795704

国外大学优秀教材——土木工程系列（影印版）

序　言

土木工程专业是工科高等教育重要的方向，随着我国基本建设行业长期稳健发展，土木工程专业办学规模不断扩大、开设院校不断增加，对教材的要求也更加多样化和分层次化。同时，随着我国加入WTO、中国企业角逐国际工程、国外建筑企业挤入中国市场，使得土木工程专业教育对从内容到语言上能够与国际建筑业接轨的教材需求更加迫切。

鉴于这种趋势，清华大学出版社秉承在引进国外原版教材方面的领先优势，与全球高等教育出版巨擘——美国培生教育出版集团——合作，经过清华大学土木工程专业专家评审，精选出这套“国外大学优秀教材——土木工程系列（影印版）”教材。

“国外大学优秀教材——土木工程系列（影印版）”适合作为土木工程专业和相关建设类专业的原版教材，以及具有较好英文基础和专业背景、渴望了解国外相关领域知识的企业界人士学习使用。该系列第一批包括：《混凝土结构（第4版）》（Reinforced Concrete Design, 4e）和《钢结构（第4版）》（Applied Structural Steel Design,4e）。

另外，我社还出版了“国外大学优秀教材——建设管理系列（影印版）”，适合作为建设管理专业、相关经济类专业和土木工程专业使用，该系列包括：《房屋设计与施工案例分析》（Case Studies in Building Design and Construction）、《建筑工程合同（第3版）》（Construction Contracts, 3e）、《建筑工程估价（第5版）》（Estimating in Building Construction, 5e）、《建筑工程项目管理（专业版）》（Construction Project Management-Professional Edition）和《建筑施工计划与进度》（Construction Planning and Scheduling）。

对清华大学出版社相关教材最新资讯感兴趣的读者，可查询清华大学出版社网站http://www.tup.com.cn。

清华大学出版社

2004年12月

Preface

The primary objective of *Reinforced Concrete Design*, 4th edition, is to furnish the reader with a basic understanding of the strength and behavior of reinforced concrete members and simple concrete structural systems.

With relevant reinforced concrete research and literature increasing at an exponential rate, it is the intent of this book to translate this vast amount of information and data into an integrated source that reflects the latest information available. It is not intended to be a comprehensive theoretical treatise of the subject, because it is our belief that such a document could easily obscure the fundamentals that we strive to emphasize in the engineering technology programs. In addition, we are of the opinion that adequate comprehensive books on reinforced concrete design do exist for those who seek the theoretical background, the research studies, and more rigorous applications.

This fourth edition has been prepared with the primary objective of updating its contents to conform to the latest *Building Code Requirements for Structural Concrete (ACI 318-95)* of the American Concrete Institute. Since the ACI Code serves as a design standard in the United States, we strongly recommend that the code be used as a companion publication to this book.

In addition to the necessary changes to conform to the new code, many sections have been rewritten and new homework problems have been added. Answers to selected problems are furnished at the back of the text.

Throughout the four editions, the text content has remained primarily an elementary, noncalculus, practical approach to the design and analysis of reinforced concrete structural members using numerous examples and a step-by-step solution format. In addition, chapters use a conceptual approach on such topics as

prestressed concrete and detailing of reinforced concrete structures. The metric system (SI), the use of which is gradually gaining momentum in the reinforced concrete design and construction field in the United States, is introduced in a separate appendix with several example problems.

Since form design is an important consideration in most structural design problems involving concrete members, the chapter on the design of job-built forms (which was introduced in the second edition) has been updated to conform to the latest applicable codes, standards, and guides.

This book has been thoroughly tested over the years in our engineering technology programs and should serve as a valuable design guide and source for technologists, technicians, and engineering and architectural students. In addition, it will aid engineers and architects preparing for state licensing examinations for professional registration.

We extend our thanks to the reviewers of this edition for their help and constructive suggestions: Dr. Mark H. Hasso, Wentworth Institute of Technology; Joseph Murphy, Penn College; and Paresh S. Shettigar, Hawkeye Community College.

As in the past, we are indebted to our students and colleagues who have provided constructive comments and input for this edition.

Leonard Spiegel
George F. Limbrunner

此为试读，需要完整PDF请访问：www.ertongbook.com

Contents

PREFACE xi

CHAPTER 1 MATERIALS AND MECHANICS OF BENDING 1

1-1 Concrete 2
1-2 The ACI Building Code 2
1-3 Cement and Water 2
1-4 Aggregates 3
1-5 Concrete in Compression 3
1-6 Concrete in Tension 6
1-7 Reinforcing Steel 7
1-8 Beams: Mechanics of Bending Review 10
References 19
Problems 19

CHAPTER 2 RECTANGULAR REINFORCED CONCRETE BEAMS AND SLABS: TENSION STEEL ONLY 22

2-1 Introduction 23
2-2 Methods of Analysis and Design 24
2-3 Behavior under Load 25
2-4 Strength Design Method Assumptions 27

2-5 Flexural Strength of Rectangular Beams 28
2-6 Equivalent Stress Distribution 30
2-7 Balanced, Overreinforced, and Underreinforced Beams 34
2-8 Reinforcement Ratio Limitations and Guidelines 35
2-9 Strength Requirements 40
2-10 Rectangular Beam Analysis for Moment (Tension Reinforcement Only) 41
2-11 Summary of Procedure for Rectangular Beam Analysis for ϕMn (Tension Reinforcement Only) 45
2-12 Slabs: Introduction 46
2-13 One-Way Slabs: Analysis for Moment 47
2-14 Rectangular Beam Design for Moment (Tension Reinforcement Only) 51
2-15 Summary of Procedure for Rectangular Reinforced Concrete Beam Design for Moment (Tension Reinforcement Only) 59
2-16 Design of One-Way Slabs for Moment (Tension Reinforcement Only) 60
2-17 Summary of Procedure for Design of One-Way Slabs for Moment (to Satisfy ACI Minimum h) 63
2-18 Slabs on Ground 64
References 66
Problems 66

CHAPTER 3 REINFORCED CONCRETE BEAMS: T-BEAMS AND DOUBLY REINFORCED BEAMS 72

3-1 T-Beams: Introduction 73
3-2 T-Beam Analysis 75
3-3 Development of T-Beam $A_{s\,max}$ 79
3-4 Analysis of Beams Having Irregular Cross Sections 82
3-5 T-Beam Design (for Moment) 85
3-6 Summary of Procedure for Analysis of T-Beams (for Moment) 92
3-7 Summary of Procedure for Design of T-Beams (for Moment) 93
3-8 Doubly Reinforced Beams: Introduction 94
3-9 Doubly Reinforced Beam Analysis for Moment (Condition I) 95
3-10 Doubly Reinforced Beam Analysis for Moment (Condition II) 101
3-11 Summary of Procedure for Analysis of Doubly Reinforced Beams (for Moment) 106
3-12 Doubly Reinforced Beam Design for Moment 108
3-13 Summary of Procedure for Design of Doubly Reinforced Beams (for Moment) 111

3-14 Additional Code Requirements for Doubly Reinforced Beams 113
Problems 114

CHAPTER 4 SHEAR IN BEAMS 122

4-1 Introduction 122
4-2 Shear Reinforcement Design Requirements 125
4-3 Shear Analysis Procedure 130
4-4 Stirrup Design Procedure 131
4-5 Torsion: Introduction 142
4-6 Design of Torsion Reinforcement 144
Problems 144

CHAPTER 5 DEVELOPMENT, SPLICES, AND SIMPLE-SPAN BAR CUTOFFS 148

5-1 Development Length: Introduction 149
5-2 Development Length: Tension Bars 150
5-3 Development Length: Compression Bars 158
5-4 Development Length: Standard Hooks in Tension 159
5-5 Development of Web Reinforcement 164
5-6 Splices 166
5-7 Tension Splices 167
5-8 Compression Splices 167
5-9 Simple-Span Bar Cutoffs and Bends 168
5-10 Code Requirements for Development of Positive Moment Steel at Simple Supports 177
Problems 180

CHAPTER 6 CONTINUOUS CONSTRUCTION DESIGN CONSIDERATIONS 185

6-1 Introduction 186
6-2 Continuous-Span Bar Cutoffs 188
6-3 Design of Continuous Floor Systems 190
Problems 212

CHAPTER 7 SERVICEABILITY 214

7-1 Introduction 215
7-2 Deflections 215
7-3 Calculation of I_{cr} 217
7-4 Immediate Deflection 221

7-5 Long-Term Deflection 222
7-6 Deflections for Continuous Spans 226
7-7 Crack Control 227
Problems 229

CHAPTER 8 WALLS 232

8-1 Introduction 232
8-2 Lateral Forces on Retaining Walls 235
8-3 Design of Reinforced Concrete Cantilever Retaining Walls 239
8-4 Design Considerations for Bearing Walls 269
8-5 Design Considerations for Basement Walls 273
Problems 274

CHAPTER 9 COLUMNS 277

9-1 Introduction 278
9-2 Strength of Reinforced Concrete Columns: Small Eccentricity 278
9-3 Code Requirements Concerning Column Details 282
9-4 Analysis of Short Columns: Small Eccentricity 284
9-5 Design of Short Columns: Small Eccentricity 287
9-6 Summary of Procedure for Analysis and Design of Short Columns with Small Eccentricities 291
9-7 The Load–Moment Relationship 292
9-8 Columns Subjected to Axial Load at Large Eccentricity 293
9-9 Analysis of Short Columns: Large Eccentricity 294
9-10 ϕ Factor Considerations 305
9-11 Design of Eccentrically Loaded Columns (ACI Chart Approach) 305
9-12 The Slender Column 308
Reference 312
Problems 312

CHAPTER 10 FOOTINGS 316

10-1 Introduction 317
10-2 Wall Footings 317
10-3 Wall Footings under Light Loads 328
10-4 Individual Reinforced Concrete Footings for Columns 329
10-5 Square Reinforced Concrete Footings 333
10-6 Rectangular Reinforced Concrete Footings 341
10-7 Eccentrically Loaded Footings 351
10-8 Combined Footings 351

10-9 Cantilever or Strap Footings 355
Problems 359

CHAPTER 11 PRESTRESSED CONCRETE FUNDAMENTALS 361

11-1 Introduction 362
11-2 Design Approach and Basic Concepts 362
11-3 Stress Patterns in Prestressed Concrete Beams 365
11-4 Prestressed Concrete Materials 367
11-5 Analysis of Rectangular Prestressed Concrete Beams 369
11-6 Alternative Methods of Elastic Analysis: Internal Couple Method 374
11-7 Alternative Methods of Elastic Analysis: Load Balancing Method 376
11-8 Flexural Strength Analysis 384
11-9 Notes on Prestressed Concrete Design 387
References 388
Problems 388

CHAPTER 12 CONCRETE FORMWORK 391

12-1 Introduction 392
12-2 Formwork Requirements 392
12-3 Formwork Materials and Accessories 393
12-4 Loads and Pressures on Forms 398
12-5 The Design Approach 400
12-6 Design of Formwork for Slabs 409
12-7 Design of Formwork for Beams 420
12-8 Wall Form Design 427
12-9 Forms for Columns 435
References 440
Problems 441

CHAPTER 13 DETAILING REINFORCED CONCRETE STRUCTURES 443

13-1 Introduction 444
13-2 Placing Drawings 445
13-3 Marking Systems and Bar Marks 448
13-4 Schedules 450
13-5 Fabricating Standards 451
13-6 Bar Lists 451
13-7 Extras 457

13-8 Bar Supports and Bar Placement 457
13-9 Computer Detailing 459
References 463

APPENDIX A TABLES AND CHARTS 464

APPENDIX B SUPPLEMENTARY AIDS AND GUIDELINES 486

B-1 Accuracy for Computations for Reinforced Concrete 486
B-2 $A_{s,max}$ for Doubly Reinforced Beams 488
B-3 Flow Diagrams 490

APPENDIX C METRICATION 494

C-1 The International System of Units (SI) 494
C-2 Style and Usage 496
C-3 Conversion Factors 499
References 509

ANSWERS TO SELECTED PROBLEMS 510

INDEX 513

此为试读,需要完整PDF请访问: www.ertongbook.com

CHAPTER 1

Materials and Mechanics of Bending

1-1 CONCRETE

1-2 THE ACI BUILDING CODE

1-3 CEMENT AND WATER

1-4 AGGREGATES

1-5 CONCRETE IN COMPRESSION

1-6 CONCRETE IN TENSION

1-7 REINFORCING STEEL

1-8 BEAMS: MECHANICS OF BENDING REVIEW

1-1 CONCRETE

Concrete consists primarily of a mixture of cement and fine and coarse aggregates (sand, gravel, crushed rock, and/or other materials) to which water has been added as a necessary ingredient for the chemical reaction of curing. The bulk of the mixture consists of the fine and coarse aggregates. The resulting concrete strength and durability are a function of the proportions of the mix as well as other factors, such as the concrete placing, finishing, and curing history.

The compressive strength of concrete is relatively high. Yet it is a relatively brittle material, the tensile strength of which is small compared with its compressive strength. Hence steel reinforcing rods (which have high tensile and compressive strength) are used in combination with the concrete; the steel will resist the tension and the concrete the compression. *Reinforced concrete* is the result of this combination of steel and concrete. In many instances, steel and concrete are positioned in members so that they both resist compression.

1-2 THE ACI BUILDING CODE

The design and construction of reinforced concrete buildings is controlled by the "Building Code Requirements for Structural Concrete" (ACI 318-95) of the American Concrete Institute (ACI) [1]. The use of the term *code* in this text refers to the ACI Code unless otherwise stipulated. The code is revised, updated, and reissued on an approximate 6-year cycle. (The previous edition, ACI 318-89, was published in 1989.) The code itself has no legal status. It has been incorporated into the building codes of almost all states and municipalities throughout the United States, however. When so incorporated, it has official sanction, becomes a legal document, and is part of the law controlling reinforced concrete design and construction in a particular area.

1-3 CEMENT AND WATER

Structural concrete uses, almost exclusively, hydraulic cement. With this cement, water is necessary for the chemical reaction of *hydration.* In the process of hydration, the cement sets and bonds the fresh concrete into one mass. *Portland cement,* which originated in England, is undoubtedly the most common form of cement.

Portland cement consists chiefly of calcium and aluminum silicates. The raw materials are limestones, which provide calcium oxide (CaO), and clays or shales, which furnish silicon dioxide (SiO_2) and aluminum oxide (Al_2O_3). Following processing, cement is marketed in bulk or in 94 lb (1 ft^3) bags.

In fresh concrete, the ratio of the amount of water to the amount of cement, by weight, is termed the *water/cement ratio.* This ratio can also be expressed in terms of gallons of water per bag of cement. For complete hydration of the cement in a mix, a water/cement ratio of 0.35 to 0.40 (4 to 4½ gal/bag) is required. To increase the *workability* of the concrete (the ease with which it can be mixed, handled, and placed), higher water/cement ratios are normally used.

1-4 AGGREGATES

In ordinary structural concretes the aggregates occupy approximately 70% to 75% of the volume of the hardened mass. Gradation of aggregate size to produce close packing is desirable because, in general, the more densely the aggregate can be packed, the better are the strength and durability.

Aggregates are classified as fine or coarse. *Fine aggregate* is generally sand and may be categorized as consisting of particles that will pass a No. 4 sieve (four openings per linear inch). *Coarse aggregate* consists of particles that would be retained on a No. 4 sieve. The maximum size of course aggregate in reinforced concrete is governed by various ACI Code requirements. These requirements are established primarily to ensure that the concrete can be placed with ease into the forms without any danger of jam-up between adjacent bars or between bars and the sides of the forms.

1-5 CONCRETE IN COMPRESSION

The theory and techniques relative to the design and proportioning of concrete mixes, as well as the placing, finishing, and curing of concrete, are outside the scope of this book and are adequately discussed in many other publications [2–5]. Field testing, quality control, and inspection are also adequately covered elsewhere. This is not to imply that these are of less importance in overall concrete construction technology but only to reiterate that the objective of this book is to deal with the design and analysis of reinforced concrete members.

We are concerned primarily with how a reinforced concrete member behaves when subjected to load. It is generally accepted that the behavior of a reinforced concrete member under load depends on the stress-strain relationship of the mate-

rials, as well as the type of stress to which it is subjected. With concrete used principally in compression, the compressive stress-strain curve is of primary interest.

The compressive strength of concrete is denoted f'_c and is assigned the units *pounds per square inch* (psi). For calculations, f'_c is frequently used with the units *kips per square inch* (ksi).

A test that has been standardized by the American Society for Testing and Materials (ASTM) [6] is used to determine the compressive strength (f'_c) of concrete. The test involves compression loading to failure of a specimen cylinder of concrete. The compressive strength so determined is the highest compressive stress to which the specimen is subjected. Note in Figure 1-1 that f'_c is not the stress that exists in the specimen at failure but that which occurs at a strain of about 0.002. Currently, 28-day concrete strengths (f'_c) range from 2500 to 9000 psi, with 3000 to 4000 psi being common for reinforced concrete structures and 5000 to 6000 psi being common for prestressed concrete members. Concretes of much higher strengths have been achieved under laboratory conditions. The curves shown in Figure 1-1 represent the result of compression tests on 28-day standard cylinders for varying design mixes.

A review of the stress-strain curves for different-strength concretes reveals that the maximum compressive strength is generally achieved at a unit strain of approximately 0.002 in./in. Stress then decreases, accompanied by additional strain. Higher-strength concretes are more brittle and will fracture at a lower maximum strain than the lower-strength concretes will. The initial slope of the curve varies, unlike that of steel, and only approximates a straight line. For steel, where stresses are below the yield point and the material behaves elastically, the stress-strain plot will be a straight line. The slope of the straight line is the modulus of elasticity. For concrete, however, we observe that the straight-line portion of the plot is very short, if it exists at all. There-

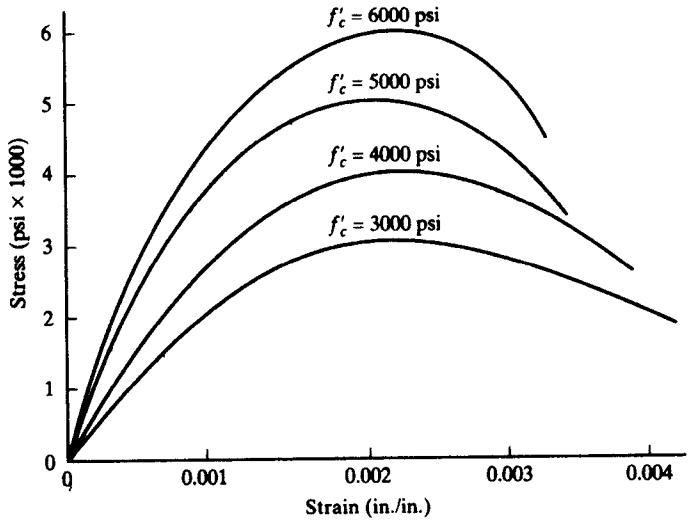

FIGURE 1-1 Typical stress-strain curves for concrete.

fore, there exists no constant value of modulus of elasticity for a given concrete since the stress-strain ratio is not constant. It may also be observed that the slope of the initial portion of the curve (if it approximates a straight line) varies with concretes of different strengths. Even if we assume a straight-line portion, the modulus of elasticity is different for concretes of different strengths. At low and moderate stresses (up to about $0.5f'_c$), concrete is commonly assumed to behave elastically.

The ACI Code, Section 8.5.1, provides the accepted empirical expression for *modulus of elasticity:*

$$E_c = w_c^{1.5} 33\sqrt{f'_c}$$

where

E_c = modulus of elasticity of concrete in compression (psi)

w_c = unit weight of concrete (lb/ft^3)

f'_c = compressive strength of concrete (psi)

This expression is valid for concretes having w_c between 90 and 155 lb/ft^3. For normal-weight concrete, w_c may be taken as 145 lb/ft^3, and

$$E_c = 57{,}000\sqrt{f'_c} \qquad \text{(see Table A-6 for values of } E_c\text{)}$$

It should also be noted that the stress-strain curve for the same-strength concrete may be of different shapes if the condition of loading varies appreciably. With different *rates of strain* (loading), we will have different-shape curves. Generally, the maximum strength of a given concrete is smaller at slower rates of strain.

Concrete strength varies with time, and the specified concrete strength is usually that strength that occurs 28 days after the placing of concrete. A typical strength-time curve for normal stone concrete is shown in Figure 1-2. Generally, concrete

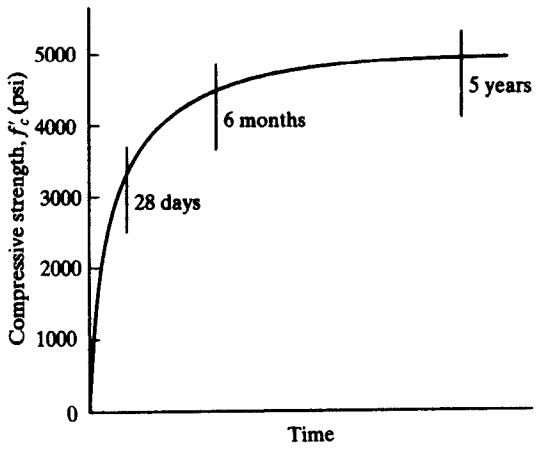

FIGURE 1-2 Strength-time relationship for concrete.

attains approximately 70% of its 28-day strength in 7 days and approximately 85% to 90% in 14 days.

Concrete, under load, exhibits a phenomenon termed *creep*. This is the property by which concrete continues to deform (or strain) over long periods of time while under constant load. Creep occurs at a decreasing rate over a period of time and may cease after several years. Generally, high-strength concretes exhibit less creep than do lower-strength concretes. The magnitude of the creep deformations is proportional to the magnitude of the applied load as well as to the length of time of load application.

1-6 CONCRETE IN TENSION

The tensile and compressive strengths of concrete are not proportional, and an increase in compressive strength is accompanied by an appreciably smaller percentage increase in tensile strength. According to the ACI Code Commentary, the tensile strength of normal-weight concrete in flexure is about 10% to 15% of the compressive strength.

The true tensile strength of concrete is difficult to determine. One common approach has been to use the *modulus of rupture* f_r (which is the maximum tensile bending stress in a plain concrete test beam at failure) as a measure of tensile strength. The ACI Code recommends that the modulus of rupture f_r be taken as $7.5\sqrt{f'_c}$ for normal-weight concrete (with f'_c in psi). The moment that produces a tensile stress just equal to the modulus of rupture is termed the *cracking moment* M_{CR} and may be calculated using methods discussed in Section 1-8.

The *split-cylinder test* has also been used to determine the tensile strength of concrete and is generally accepted as a good measure of the true tensile strength. The split-cylinder test uses a standard 6-in.-diameter, 12-in.-long cylinder placed on its side in a testing machine. A compressive line-load is applied uniformly along the length of the cylinder, with support furnished along the full length of the bottom of the cylinder. The compressive load produces a transverse tensile stress, and the cylinder will split in half along a diameter when its tensile strength is reached. The tensile stress at which splitting occurs is referred to as the *splitting tensile strength* f_{ct} and may be calculated by the following expression derived from the theory of elasticity:

$$f_{ct} = \frac{2P}{\pi LD}$$

where

f_{ct} = splitting tensile strength (psi)

P = applied load at splitting (lb)

此为试读，需要完整PDF请访问：www.ertongbook.com