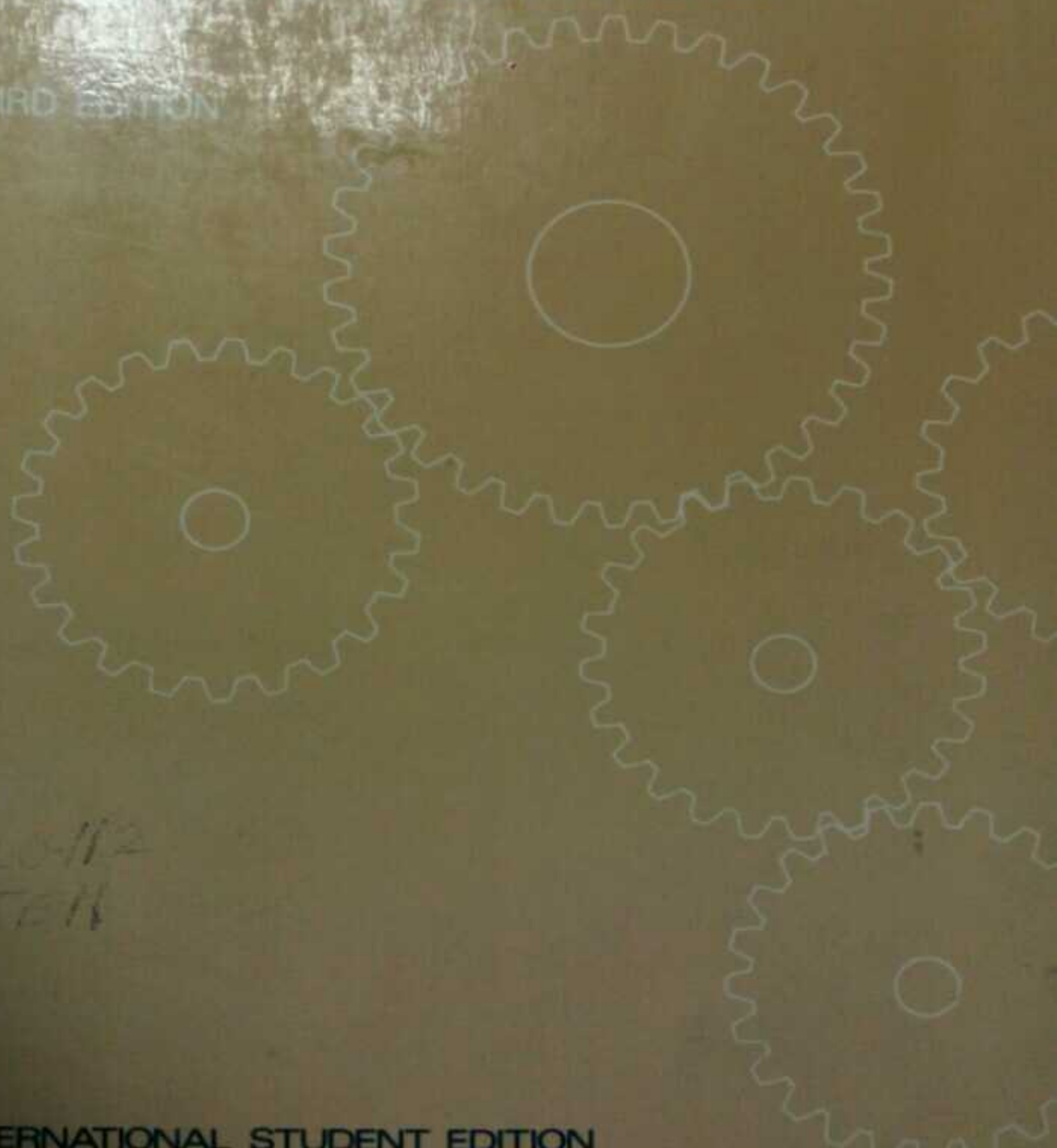


# STATICS AND STRENGTH OF MATERIALS

JENSEN AND CHENOWETH

THIRD EDITION



620-112  
JEH

INTERNATIONAL STUDENT EDITION

# Statics and Strength of Materials

Third Edition

by

ALFRED JENSEN

Emeritus Professor, Engineering  
University of Washington, Seattle

and

HARRY H. CHENOWETH

Associate Professor  
Civil Engineering, WD-10  
University of Washington, Seattle

373  
SEMINAR LIBRARY  
Department of Chemical Sciences  
UNIVERSITY OF KARACHI  
23-10-94

INTERNATIONAL STUDENT EDITION

MCGRAW-HILL KOGAKUSHA, LTD.

Tokyo Auckland Beirut Bogota Düsseldorf Johannesburg  
Lisbon London Lucerne Madrid Mexico New Delhi Panama  
Paris San Juan São Paulo Singapore Sydney



# Contents

## Preface

## BOOK 1 STATICS

### 1 Introduction

1-1	Definition of Mechanics . . . . .	3
1-2	Problems in Applied Mechanics . . . . .	3
1-3	Procedures in the Solution of Mechanics Problems . . . . .	4
1-4	Standards of Workmanship in Problem Solution . . . . .	4

### 2 Basic Principles of Statics

2-1	Force . . . . .	6
2-2	Types of Forces . . . . .	7
2-3	Characteristics and Units of a Force . . . . .	8
2-4	Vector and Scalar Quantities . . . . .	9
2-5	Transmissibility of Force . . . . .	9
2-6	Types of Force Systems . . . . .	10
2-7	Components of a Force . . . . .	10
2-8	Resultant of Two Concurrent Forces . . . . .	12
2-9	Moment of a Force . . . . .	15
2-10	The Principle of Moments. Varignon's Theorem . . . . .	17
2-11	Couples . . . . .	20
2-12	Resultant of Two Parallel Forces . . . . .	21
2-13	Resolution of a Force into Two Parallel Components . . . . .	22
2-14	Equilibrium of Force Systems . . . . .	24
2-15	Principles of Force Equilibrium . . . . .	26
2-16	Supports and Support Reactions . . . . .	27
2-17	Free-body Diagrams . . . . .	28
2-18	Problems in Equilibrium of Coplanar Force Systems . . . . .	29

### 3 Coplanar, Parallel Force Systems

		40
3-1	Introduction . . . . .	40



## vi CONTENTS

3-3	Resultants of Distributed Loads . . . . .	42
3-4	Equilibrium of Coplanar, Parallel Force Systems . . . . .	43

### 4 Coplanar, Concurrent Force Systems

4-1	Introduction . . . . .	
4-2	Resultants of Coplanar, Concurrent Force Systems . . . . .	50
4-3	Equilibrium of Coplanar, Concurrent Force Systems . . . . .	50
4-4	Trusses . . . . .	52
4-5	Stresses in Members of Trusses . . . . .	53
4-6	Ropes over Sheaves and Pulleys . . . . .	53
4-7	Stress in Trusses; Analytical Method of Joints . . . . .	57
4-8	Stresses in Trusses; the Graphical Method of Joints . . . . .	57
4-9	Stresses in Trusses; the Graphical Method of Combined Diagrams . . . . .	64
4-10	Three-force Members . . . . .	70
4-11	Graphical Determination of Reactions Using the Three-force Principle . . . . .	79

### 5 Coplanar, Nonconcurrent Force Systems

5-1	Introduction . . . . .	92
5-2	Resultant of a Coplanar, Nonconcurrent Force System . . . . .	92
5-3	Equilibrium of Coplanar, Nonconcurrent Force Systems . . . . .	98
5-4	Determination of Reactions; the Graphical String-polygon Method . . . . .	98
5-5	Determination of Reactions; the Analytical Method . . . . .	101
5-6	Pin Reactions; the Method of Members . . . . .	110
5-7	Stresses in Trusses; the Method of Sections . . . . .	114
5-8	Counter Diagonals in Trusses . . . . .	123

### 6 Noncoplanar, Parallel Force Systems

6-1	Introduction . . . . .	133
6-2	Resultant of a Noncoplanar, Parallel Force System . . . . .	133
6-3	Equilibrium of Noncoplanar, Parallel Force Systems . . . . .	135

### 7 Noncoplanar, Concurrent Force Systems

7-1	Introduction . . . . .	139
-----	------------------------	-----



## 9 Friction

9-1	Introduction	161
9-2	Coefficient of Friction, Angle of Friction, and Angle of Repose	162
9-3	Laws of Friction	163
9-4	Friction Problems	164
9-5	Belt Friction	171
9-6	Rolling Resistance	175

**Authors' Note:** The material contained in Chapter 10, Centroids and Centers of Gravity, and Chapter 11, Moments of Inertia of Areas, is also found in Chapter 5 of Book II. It was deleted here to avoid duplication. See Preface, third paragraph.

## 12 Miscellaneous Problems

12-1	Introduction	204
12-2	Intensity and Direction of Hydrostatic Pressures	204
12-3	Buoyancy	205
12-4	Hydrostatic Loads	205
12-5	Stability of Retaining Walls	211
12-6	Flexible Cables; Rigid Arches; Concentrated Vertical Loads	214
12-7	Flexible Cables, Horizontally Uniform Loads	219

## BOOK 2 STRENGTH OF MATERIALS

## 1 Stress and Deformation

1-1	Scope of Text	1
1-2	Definition of Stress	2
1-3	The Basic Stresses	2
1-4	Ultimate Stress, Allowable Stress, Factor of Safety, Units	4
1-5	The Direct-stress Formula	6
1-6	Simple Structural Members	7
1-7	Problems in Analysis and Design	8
1-8	Axial Deformation of Strain	13
1-9	Elasticity. Elastic Limit	14
1-10	Hooke's Law. Modulus of Elasticity	14
1-11	Shearing Deformation and Poisson's Ratio	18
1-12	Determination of Allowable Stress and Modulus of Elasticity. The Stress-Strain Diagram	20
1-13	Stress Concentration	23
1-14	Axial Stresses in Members of Two Materials	25
1-15	Temperature Stresses	27



## 2 Engineering Materials and Their Properties

2-1	Introduction	25
2-2	Definitions of Some Properties of Materials	26
2-3	Methods of Manufacture	26
2-4	Wood	27
2-5	Preservation of Wood	27
2-6	Iron and Steel	28
2-7	Cast Iron	28
2-8	Wrought Iron	29
2-9	Steel	30
2-10	The Manufacture of Steel	40
2-11	Aluminum	41
2-12	Stone, Brick, and Concrete	42

## 3 Riveted and Welded Joints. Thin-walled Pressure Vessels

3-1	Riveted Joints	45
3-2	Types of Riveted Joints	46
3-3	Failures of Riveted Joints	46
3-4	Stresses in Riveted Joints	48
3-5	Analysis of Riveted Structural Joints	51
3-6	Design of Riveted Structural Joints	54
3-7	Riveted Boiler Joints	59
3-8	Strength and Efficiency of Riveted Boiler Joints	62
3-9	Stresses in Thin-walled Pressure Vessels	62
3-10	Allowable Stresses for Boiler Joints	65
3-11	Analysis and Design of Boiler Joints	66
3-12	Eccentrically Loaded Riveted Joints	69
3-13	Welded Joints	76
3-14	Types of Welds	76
3-15	Strength of Welded Joints	78
3-16	Eccentricity in Welded Joints	80
3-17	Design of Welded Joints	81

## 4 Torsion

4-1	Twisting Moments, Torque	88
4-2	Stresses in Circular Shafts. The Torsion Formula	89
4-3	Analysis and Design of Circular Shafts	92
4-4	Shaft Couplings	
4-5		



## 2 Engineering Materials and Their Properties

2-1	Introduction . . . . .	20
2-2	Definitions of Some Properties of Materials . . . . .	21
2-3	Methods of Manufacture . . . . .	22
2-4	Wood . . . . .	23
2-5	Preservation of Wood . . . . .	24
2-6	Iron and Steel . . . . .	25
2-7	Cast Iron . . . . .	26
2-8	Wrought Iron . . . . .	27
2-9	Steel . . . . .	28
2-10	The Manufacture of Steel . . . . .	29
2-11	Aluminum . . . . .	30
2-12	Stone, Brick, and Concrete . . . . .	31

## 3 Riveted and Welded Joints. Thin-walled Pressure Vessels

3-1	Riveted Joints . . . . .	32
3-2	Types of Riveted Joints . . . . .	33
3-3	Failures of Riveted Joints . . . . .	34
3-4	Stresses in Riveted Joints . . . . .	35
3-5	Analysis of Riveted Structural Joints . . . . .	36
3-6	Design of Riveted Structural Joints . . . . .	37
3-7	Riveted Boiler Joints . . . . .	38
3-8	Strength and Efficiency of Riveted Boiler Joints . . . . .	39
3-9	Stresses in Thin-walled Pressure Vessels . . . . .	40
3-10	Allowable Stresses for Boiler Joints . . . . .	41
3-11	Analysis and Design of Boiler Joints . . . . .	42
3-12	Eccentrically Loaded Riveted Joints . . . . .	43
3-13	Welded Joints . . . . .	44
3-14	Types of Welds . . . . .	45
3-15	Strength of Welded Joints . . . . .	46
3-16	Eccentricity in Welded Joints . . . . .	47
3-17	Design of Welded Joints . . . . .	48

## 4 Torsion

4-1	Twisting Moments. Torque . . . . .	49
4-2	Stresses in Circular Shafts. The Torsion Formula . . . . .	50
4-3	Analysis and Design of Shafts . . . . .	51



**5 Centroids and Moments of Inertia of Areas**

5-1	Centroids	106
5-2	Centroids of Simple Geometric Areas	108
5-3	Centroids of Composite Areas	109
5-4	Moments of Inertia of Areas	112
5-5	Approximate Determination of Moment of Inertia	113
5-6	Moments of Inertia of Simple Areas	114
5-7	Moments of Inertia of Composite Areas	116
5-8	Radius of Gyration	117

**6 Shear and Moment in Beams**

6-1	Types of Beams	120
6-2	Loads of Beams	120
6-3	Beam-support Reactions	128
6-4	Shear and Moment in Beams	129
6-5	Critical Sections in Beams, Sections of Maximum Moment	135
6-6	Shear and Moment Diagrams	138
6-7	Applications of Shear and Moment Diagrams	142
6-8	Moving Loads	146

**7 Stresses in Beams**

7-1	Tensile and Compressive Stresses in Beams	153
7-2	Relation among Bending Moment, Fiber Stress, and Moment of Inertia: The Flexure Formula	156
7-3	Section Modulus	161
7-4	Shearing Stresses in Beams	163
7-5	Relationship between Vertical and Horizontal Shearing Stresses in Beams	164
7-6	The General Shear Formula	165
7-7	Variation of Shearing Stressing in Beams	171
7-8	Special Shear Formulas	173
7-9	Load Capacity of Given Beams	175

**8 Design of Beams**

8-1	Considerations in Beam Design	181
8-2	Design of Timber Beams	182
8-3	Design of Steel Beams	194
8-4	Laterally Unsupported Beams	199



## x CONTENTS

8.5	Design of Laterally Unsupported Simple Steel Beams . . . . .	201
8.6	Design of Laterally Unsupported Overhanging and Cantilever Steel Beams . . . . .	201

## 9 Deflection of Beams

9.1	Relationship between Curvature and Stress . . . . .	209
9.2	Relationship between Curvature and Bending Moment . . . . .	210
9.3	Deflection of Beams . . . . .	211
9.4	Deflection by the Beam-diagram Method . . . . .	212
9.5	Deflection by the Moment-area Method . . . . .	217
9.6	The First Moment-area Principle . . . . .	218
9.7	The Second Moment-area Principle . . . . .	221
9.8	Deflection of Cantilever Beams . . . . .	222
9.9	Bending-moment Diagrams by Parts . . . . .	223
9.10	Deflection of Symmetrically Loaded Simple Beams . . . . .	226
9.11	Deflection of Unsymmetrically Loaded Beams, Overhanging Beams . . . . .	229
9.12	Derivation of Deflection Formulas . . . . .	234
9.13	Cantilever Beam with Concentrated Load at Free End . . . . .	234
9.14	Cantilever Beam with Uniformly Distributed Load . . . . .	234
9.15	Simple Beam with Concentrated Load at Center . . . . .	236
9.16	Simple Beam with Uniformly Distributed Load . . . . .	237
9.17	Simple Beam with Two Equal Concentrated Loads Symmetrically Placed . . . . .	238
9.18	Summary of Deflection Formulas . . . . .	239

## 10 Statically Indeterminate Beams

10.1	Statically Indeterminate Beams . . . . .	245
10.2	Derivation of the Three-moment Equation . . . . .	246
10.3	Load Terms for the Three-moment Equation . . . . .	248
10.4	Applications of the Three-moment Equation . . . . .	252
10.5	Indeterminate Beams with Fixed Ends . . . . .	256
10.6	Determination of Support Reactions . . . . .	261
10.7	Shear and Moment Diagrams . . . . .	263

## 11 Combined Stresses

11.1	Combined Axial and Bending Stresses . . . . .	269
11.2	Combined Stresses Caused by Eccentric Axial Load . . . . .	273
11.3	Stresses on Inclined Cutting Planes . . . . .	277
11.4	Combined Shearing and Bending Stresses in Circular Shafts . . . . .	282



## 12 Columns

12-1	Introduction	
12-2	Types of Column Cross Sections	287
12-3	Slenderness Ratio and Column Groups	287
12-4	Critical or Buckling Loads on Columns	289
12-5	Euler's Formula for Analysis and Design of Slender Columns	289
12-6	Effect of End Restraint on Column Strength, Effective Length	290
12-7	Limitations of Euler's Formula	291
12-8	Analysis of Long Columns by Euler's Formula	293
12-9	Design of Long Columns by Euler's Formula	294
12-10	Intermediate Columns	295
12-11	Column Formulas, Structural Steel	297
12-12	Some Practical Aspects of Column Design	300
12-13	Analysis of Structural-steel Columns	300
12-14	Design of Structural-steel Columns	302
12-15	Analysis and Design of Structural-aluminum Columns	306
12-16	Analysis and Design of Timber Columns	308
12-17	Eccentrically Loaded Columns	311
12-18	Design of Eccentrically Loaded Steel Columns	313
12-19	Design of Eccentrically Loaded Timber Columns	314

## 13 Special Topics

13-1	Impact or Dynamic Loading	322
13-2	Strain Energy	322
13-3	Impact Loading	325
13-4	Prestressed Beams	329

<i>Appendix A</i>	Centroids of Areas by Integration	333
<i>B</i>	Moments of Inertia of Plane Areas	337
<i>C</i>	Derivation of the Laws of Beam Diagrams	343
<i>D</i>	Derivation of the Flexure Formula. Location of the Neutral Axis	347
<i>E</i>	Tables	350

*Indices*

Book 1	Statics	372
Book 2	Strength of Materials	376

## TABLES IN BOOK 2

1-1	Engineering Units and Abbreviations	6
1-2	Some Average Properties of Structural Materials (Steady Loads), PSI	16



## xii CONTENTS

1-3	Average Coefficients of Thermal Expansion (Per °F) . . . . .	28
3-1	Allowable Stresses for Structural Rivets, Bolts, and Pins, AISC Specifications. Recommended for Structural Joints . . . . .	50
3-2	Ultimate and Allowable Stresses. ASME Boiler Code. Recommended for Boilers and Tanks . . . . .	65
3-3	Recommended Maximum Sizes of Edge Fillet Welds with Allowable Loads $F$ in Pounds per Linear Inch . . . . .	79
5-1	Moments of Inertia and Radii of Gyration of Simple Areas . . . . .	115
8-1	Allowable Unit Stresses for Stress-Grade Lumber, PSI . . . . .	184
8-2	Design of Timber Beam . . . . .	186
8-3	Design of Laterally Unsupported Steel Beam . . . . .	203
9-1	Beam-deflection Formulas . . . . .	239
10-1	Load Terms for Use with the Three-moment Equation . . . . .	257
12-1	Effective Length of Column . . . . .	293
12-2	Limitations of Euler's Formula . . . . .	294
	 Average Mechanical Properties of Some Engineering Materials . . . . .	352
E-1	Average Mechanical Properties of Some Engineering Materials . . . . .	353
E-2	Timber Sizes . . . . .	354
E-3	Screw Threads . . . . .	355
E-4	Rivet Gages . . . . .	355
E-5	Weights and Areas of Bars . . . . .	356
E-6	Wide-flange Shapes . . . . .	359
E-7	Wide-flange Shapes: Miscellaneous Columns and Beams . . . . .	361
E-8	American Standard Beams (S) . . . . .	362
E-9	American Standard Channels (C) . . . . .	363
E-10	Angles, Equal Legs . . . . .	364
E-11	Angles, Unequal Legs . . . . .	366
E-12	Two Unequal Angles, Properties of Sections . . . . .	368
E-13	Section Moduli for Shapes Used as Beams . . . . .	370
E-14	Allowable Stresses for Compression Members . . . . .	371
E-15	Steel Pipe Sections . . . . .	