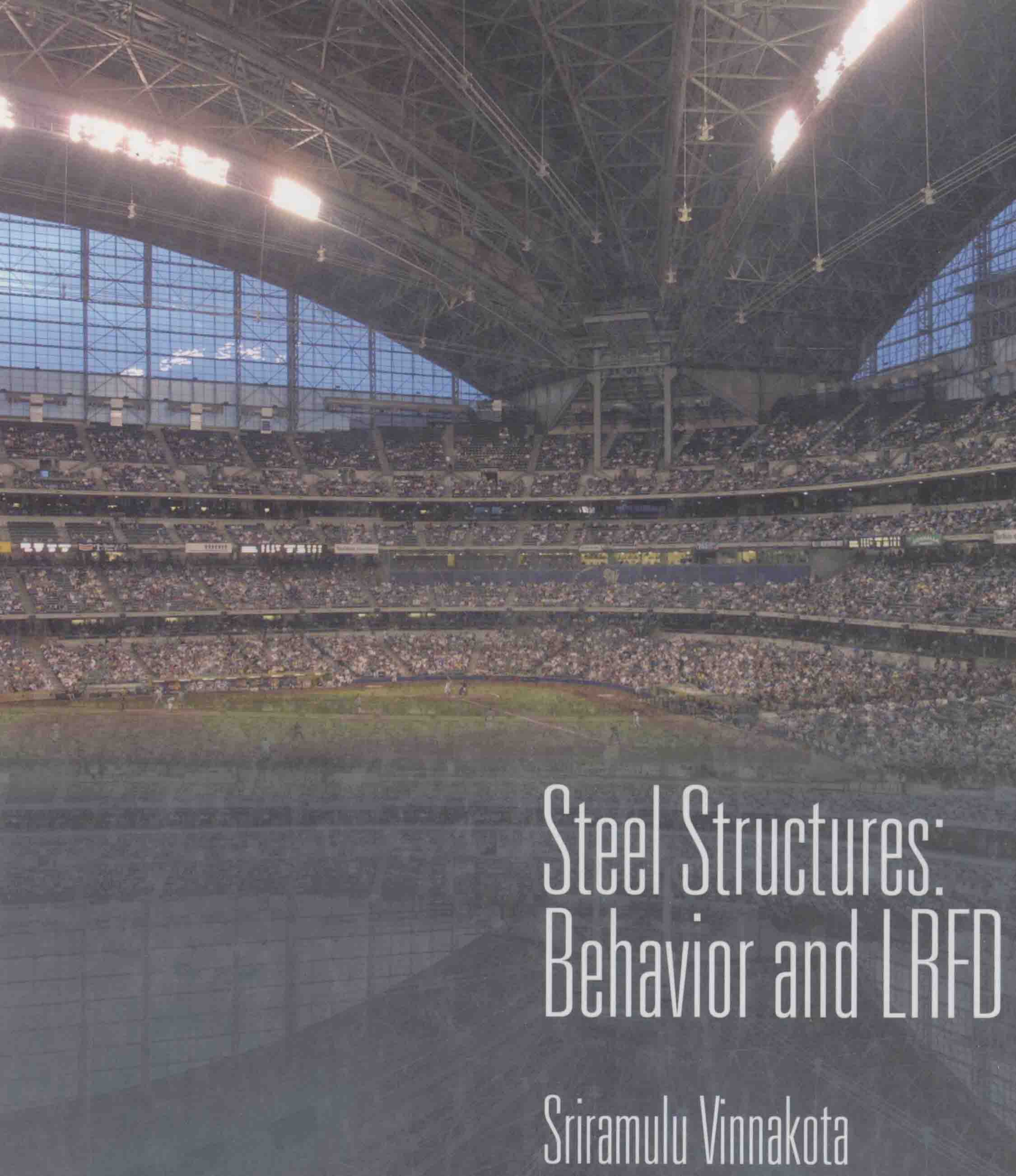

Steel Structures: Behavior and LRFD

Sriramulu Vinnakota

STEEL STRUCTURES
Behavior and LRFD

Sriramulu Vinnakota
Marquette University

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ABOUT THE AUTHOR

Sriramulu Vinnakota is Professor of Civil Engineering at Marquette University, Milwaukee, WI. He was born in 1937 in the village of Venuturumilli, Andhra Pradesh, India. He is a graduate of the College of Engineering, Kakinada, Andhra University, where he obtained a degree in Civil Engineering in 1957. After graduation he worked with the Central Water and Power Commission, Ministry of Irrigation and Power, New Delhi, India for 5 years on the design of various gate, hoist and power house structures. In 1962, he received a Swiss Government Scholarship for higher studies in Switzerland. Vinnakota obtained his D.Sc in Structural Engineering in 1967 from The Swiss Federal Institute of Technology (EPF), Lausanne, Switzerland, under the supervision of Prof. M. Cosandey. Subsequently he worked at the EPF-Lausanne where he was named Professor Titulaire in 1978 by the Swiss Federal Council of Ministers. After spending a year at Cornell University, Ithaca, NY and 2 years at the University of Wisconsin, Milwaukee as Visiting Associate Professor, he accepted a faculty position at Marquette University in 1981, where he still remains. He has been involved in teaching, research, design and consulting in structural engineering, particularly in the area of steel structures. He is a registered professional engineer in the state of Wisconsin. Professor Vinnakota has made important contributions in the area of stability of steel members and structures through the publication of numerous papers in the professional journals of international reputation.

Since 1997, Professor Vinnakota has been a member of the Task Committee 4: Member Design of the Committee on Specifications, American Institute of Steel Construction, and a corresponding member of its Committee on Manuals and Textbooks. He is a Fellow of the American Society of Civil Engineers and a member of the International Association of Bridge and Structural Engineers. Also, he is a life member of the Structural Stability Research Council and served as Chairman of its Task Group on Beams from 1982 to 2003. In the 1970s he had the privilege of being the Swiss Delegate to the Commission 5 Plasticity of the European Convention for Constructional Steelworks (ECCS) presided over by the late Professor Charles Massonnet; and he was a member of the Working-Group 8-1, Stability of the ECCS. Dr. Vinnakota contributed to several chapters of the fourth and fifth editions of the SSRC Guide to Stability Design Criteria for Metal Structures (Edited by Prof. T. V. Galambos).

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This book is dedicated to my parents Raju A. and Sarada M. Vinnakota for teaching me the importance of hard work, commitment to education and giving back to society, and to my children Rajiv and Jyothi whose achievements and contributions to society have made all of my efforts worthwhile.

PREFACE

To design steel structures efficiently, the designer must know steel as a structural material; understand how structures are assembled and braced, and how they sustain and transmit loads; know design philosophies and processes; and learn the proper selection of connectors and connections. The structure of the Load and Resistance Factor Design Specification (LRFDS) developed by the American Institute of Steel Construction (AISC) especially requires that designers have a better understanding of structural behavior since the different limit states of failure must be identified as an integral part of the design process.

The heart and soul of design is the ability for the designer to conceive a structure that will behave as desired and to develop an intuition regarding different framing options. In each chapter of *Steel Structures: Behavior and LRFD,* discussion of theory and the behavior of the member under the various combinations of loads it must resist is followed by a discussion of design applications according to the LRFDS. Practical, fabrication, and erection constraints are indicated where required.

- **Chapter 1** includes a brief description of several steel projects recently built in Milwaukee and elsewhere, so as to develop an interest in students to inspect existing steel structures in their own locality and to visit steel structures under fabrication and erection.
- **Chapter 2** presents steel as a structural material. Topics covered include making structural steels, forming steel shapes, tension tests, residual stresses, corrosion, and painting of structural steels.
- **Chapter 3** is a broad introduction to various types of structures (tier and industrial buildings), structural elements (tension members, compression members, beams, beam-columns, and connections), and structural components (walls, roofs, decking, bracing systems, diaphragms, etc.).
- **Chapter 4** gives the various kinds of loads acting on building structures, as per the ASCE Standards 7 (dead loads, live loads, and wind loads are covered in detail. A brief introduction to snow loads and seismic loads is also given). Probabilistic bases of the LRFD specification are briefly described. Load factors, load combinations, and resistance factors are introduced.
- **Chapter 5** gives simple examples on the calculation of required strengths of typical members of a 4-story, braced multi-story office building and of an unbraced, hinged base portal frame using ASCE Standards 7. These members are designed in later chapters of the book.

- **Chapter 6** covers the behavior and design of connectors used in steel structures (bolts, welds, and pins). Information from the 2000 Specification for Structural Joints Using A325 and A490 Bolts by the Research Council on Structural Connections (RCSC) is included.
- **Chapter 7** treats the behavior and design of tension members.
- **Chapter 8** covers the behavior and design of axially loaded columns.
- **Chapter 9** considers the behavior and design of adequately braced compact beams. Also covered here are the design of bearing plates for beams and base plates for columns, treated as examples of members in flexure.
- **Chapter 10** is concerned with the design of laterally unbraced beams.
- **Chapter 11** treats members under combined forces including beam-columns and biaxially bent beams.
- **Chapter 12** systematically discusses behavior and design of bolted and welded joints.
- **Chapter 13** covers the design of simple-shear connections and moment connections.

How to Use This Book

There is more material in this book than can be covered in a one semester course on steel design to allow the instructor sufficient flexibility in the selection of topics. The book can readily be made to fit courses of different lengths and of different content and objectives. The complete text was prepared with the purpose of offering sufficient material for a one-semester (3-credit) undergraduate, junior/senior level first course in steel design for civil engineering students, and a one-semester (3-credit) undergraduate/graduate level course.

As the title *Steel Structures: Behavior and LRFD* suggests, the book covers not only design but the behavior on which the design specifications are based. Many of the sections that cover behavior are placed on our website (www.mhhe.com/vinnakota), so as not to overwhelm a student taking the first course on steel design. These topics are typically covered in Steel Design 2 (elective undergraduate/graduate) and Advanced Steel Design (graduate level) courses.

Steel Structures: Behavior and LRFD is unique in that it has five introductory chapters (one each on steels, structures, loads, and required strengths, in addition to Chapter 1: Introduction). The coverage of loads in Chapter 4 is added to impress upon students that, in the design process, more errors are committed in the determination of loads and required strengths than in the calculation of design strengths. Chapter 5 on required strengths is added to clearly indicate the complementary nature of analysis and design procedures in the overall iterative process of designing new structures. The required strengths for members of two structures, determined in this chapter utilizing procedures usually learned in analysis courses, are used in later chapters of the book to design these members.

The book is also unique in that it has three large chapters (6, 12, and 13) devoted to connections. Connections are the most important and the least understood components of steel structures. Also, the economy of a steel structure often depends on the proper choice of connections. Further, the choice of the connectors and connections influences the type and magnitude of forces acting on a member. For these reasons, the introductory chapter on connectors, Chapter 6, is placed before the chapters on member design (Chapters 7 to 11).

Each chapter includes a number of example problems which are presented with more complete details than would be required by an experienced designer. Often these examples are selected so as to bring to the attention of the student certain design criteria, or to arrive at certain design tips, usually given as a set of remarks at the end of the solution. In addition, there are several design problems of members and connection elements for which the required strengths are obtained in Chapter 5. These examples help show structural members as components of real-world structures rather than as isolated elements. The author believes that in this way the student will better learn the fundamentals of the design procedure and the sequence of the calculations involved than if they are presented as isolated examples. A large number of problems for assignment are included at the end of each chapter to enable the student to test his or her mastery of the subject. It is absolutely necessary that students have a copy of the third edition *AISC Manual of Steel Construction: Load and Resistance Factor Design* as reference is made throughout the text to various requirements of the LRFD Specification and the tables in the LRFD Manual.

It has been my experience that students who rely on computer programs prepared by others, in a first design course, do not develop a capacity for critical evaluation of the resulting output. Thus, no attempt is made to include any computer software with this text. The present text uses T to represent axial force in a tension member, P to represent axial force in a compression member, B to represent force on a single bolt, and W to represent the force on a unit length weld, etc., with various subscripts added as appropriate. Thus, B_d represents the design strength of a bolt, B_{db} represents the design bearing strength of a bolt, B_{dbe} represents the design bearing strength of an end bolt, and so on. Most of these notations are obvious.

My own experience as an engineer and teacher on three different continents (English units only; metric units only; and U.S. customary units only) indicates that first design courses and textbooks are better if limited to a single system of units only, in order for the student to get a feel for the results to be expected from the design process. Although metrication is inevitable and will likely be the only basis of future AISC Specifications and Manuals, the change has not yet taken place in the steel construction industry. The present text is, therefore, only in U.S. customary units.

Website

The website that accompanies *Steel Structures: Behavior and LRFD* (www.mhhe.com/vinnakota) contains a host of resources to complement the text. Web features include:

- **Extensive "Additional Information" sections.** These sections are integrated throughout the text and can be easily spotted by looking for our marginal website icon. These are **web-only bonus chapters,** covering advanced topics.

WWW

- A **downloadable list of important equations.** This is a handy reference guide for students.
- A **comprehensive list of symbols** used throughout the text.
- **Flowcharts** for some of the basic analysis and design procedures. They may be used to guide the student through the steps of a particular analysis or design problem.
- **Tips for instructors** on "Suggested Ways to Use This Book."
- **Historical insight** into the development of the technical specifications governing the structural steel industry.
- A **solutions manual,** available to instructors only, which provides detailed solutions for most of the text problems.

Acknowledgments

This book grew out of lectures which the author gave for a number of years to undergraduate and graduate students of civil engineering at Marquette University. Special thanks are extended to Professors Tom Wenzel, Steve Heinrich, and Chris Foley for their support and encouragement during the preparation of this book. The assistance of Robert Kondrad in the preparation of the numerical examples is gratefully acknowledged. Thanks are also due to Mike Loescher of Computersmith, L.L.C., Milwaukee for his help in the preparation of drawings in Chapters 3, 6, 11, and 12. Special thanks are due to Dr. Shilak Shakya of Pujara Wirth Torke, Inc., Milwaukee for his help in the preparation of the remainder of the drawings.

Former students Shubha Rao and John Peronto contributed to the problem solutions in this book through their homework. I would also like to thank Steve Miller, Bob Schumacher, Jim Hayes, Jason Sorci, Chris Bielefeld, and several other former students who participated in useful discussions about the text during their steel design classes at MU. Nick Hornyak and Carl Schneeman, graduate students; Aleisha Palaniuk and Tom Kennedy of Opus Corporation, Milwaukee; Loei Badreddine and K. Wood of Graef, Anhalt, Schloemer and Associates of Milwaukee; Michael Henke of Construction Supply and Erection, Germantown, Wisconsin; Dr. Surinder Mann (formerly of Ove, Arup and Partners of Los Angeles); Art Johnson of KPFF Consulting Engineers, Portland, Oregon; and Lawrence F. Kruth of Douglas Steel Fabricating Corporation of Lansing, Michigan provided photos and/or information regarding various projects described in this text. My thanks go to all of them. Construction Supply and Erection of Germantown also fabricated and donated the steel connection sculpture at Marquette University (chapter opening photo of Chapter 12).

The cooperation and help of the AISC through Charles J. Carter, Cynthia J. Duncan, and Fromy Rosenberg is greatly appreciated. Special thanks are due to Dr. Nestor Iwankiw and Professor Ted Galambos of SSRC for their encouragement during the preparation of this book.

My special thanks go to my brother Dr. Vara Prasada Rao for his continuous help and encouragement during strenuous times. This book would not

have taken this shape had it not been for the constant, constructive criticism of my wife Sreedevi, and I thank her for that.

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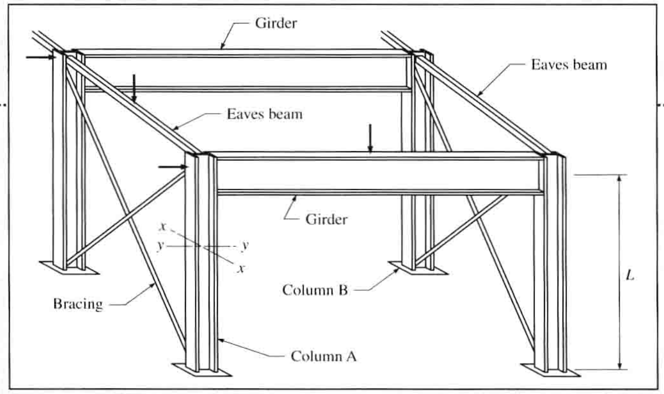
Finally, I would like to take this opportunity to record my profound appreciation for the McGraw-Hill staff during the planning and production of the book: Suzanne Jeans, Kate Scheinman, Peggy Selle, Carrie Burger, Megan Hoar, Elizabeth Kenyon, and Jill Barrie.

Note The author and the publisher have taken special care to reduce errors to a minimum but cannot hope for perfection in a book including so large a number of design examples and figures; they will welcome notification of errors and suggestions for improvement. The author can be contacted at sriramulu.vinnakota@marquette.edu.

Sriramulu Vinnakota



Steel Structures: Behavior and LRFD stresses both the **behavior and design** of steel members and structures under various loading conditions.

The current editions of the **LRFD Specifications** and the **LRFD Manual** are used and extensively referenced throughout the text. Where appropriate, additional design aids are provided.

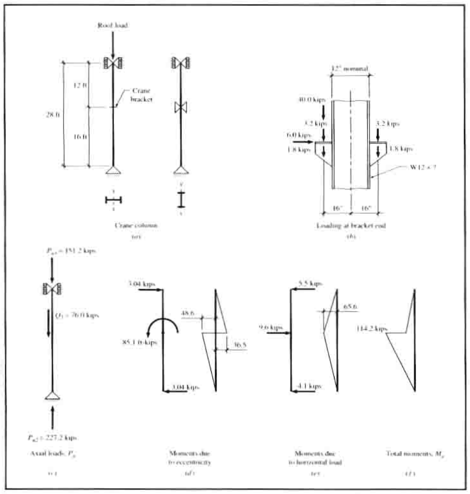
TABLE 6.8.2

Design Bearing Strength at STD End Bolt Holes, B_{dbe}, for Various End Distances (kips/in. thickness)

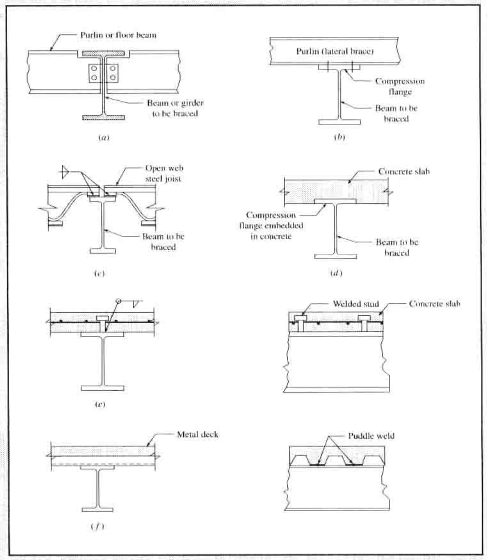
	F_{up} = 58 ksi			F_{up} = 65 ksi		
d (in.)	$\frac{3}{4}$	$\frac{7}{8}$	1	$\frac{3}{4}$ 1	$\frac{7}{8}$	
$1\frac{1}{2}d$ (in.)	$1\frac{1}{8}$	$1\frac{5}{16}$	$1\frac{1}{2}$	$1\frac{1}{8}$	$1\frac{5}{16}$	$1\frac{1}{2}$
$2.5d + \frac{1}{32}$ (in.)	$1\frac{15}{16}$	$2\frac{1}{4}$	$2\frac{9}{16}$	$1\frac{15}{16}$	$2\frac{1}{4}$	$2\frac{9}{16}$
L_e (in.)↓						
$1\frac{1}{4}$	44.0	40.8	37.5	49.4	45.7	42.0
$1\frac{3}{8}$	50.6	47.3	44.0	56.7	53.0	49.3
$1\frac{1}{2}$	57.1	53.8	50.6	64.0	60.3	56.7
$1\frac{3}{4}$	70.1	66.9	63.6	78.6	75.0	71.3
2	78.3	79.9	76.7	87.7	89.6	85.9
$2\frac{1}{2}$	78.3	91.3	103	87.7	102	115
$\geq 2\frac{3}{4}$	78.3	91.3	104	87.7	102	117

B_{dbe} = min [B_{dbo}; B_{dbte}]; $B_{dbo} = 1.8\,F_{up}\,t$; $B_{dbte} = 0.9\,(L_e - 0.5d_h)F_{up}\,t$
d = nominal diameter of bolt, in.; d_h = diameter of bolt hole = d + $\frac{1}{16}$ in. for STD punched holes considered
B_{dbe} = design bearing strength at an end bolt hole; L_e = end distance, in.; t = plate thickness = 1 in.
B_{dbo} = strength corresponding to ovalization of bolt hole; B_{dbte} = strength corresponding to shear tear-out of plate
Design strengths controlled by ovalization of bolt hole are shown shaded.

Numerous worked-out **example problems** emphasizing the application of design concepts are included.



Four hundred and fifty carefully drawn **figures** of structural systems, members, and bolted and welded joints illustrate the text, and **photographs** of real-world construction projects are included.



Throughout the text, a web icon references readers to the book's **website** (http://www.mhhe.com/vinnakota), which contains extensive additional coverage of advanced topics.

WWW Web Chapter 9
Adequately Braced Compact Beams
W9.2: Open Web Steel Joists and Joist Girders

WWW Web Chapter 12
Joints and Connecting Elements
W12.1: Ultimate Strength Method for Bolted Joints in Eccentric Shear

Our website contains additional **resources for both instructors and students.**

- For instructors, a comprehensive solutions manual as well as tips on how best to use the text for your course.
- For students, a comprehensive list of equations, a detailed list of symbols, and several flowcharts.

MOST COMMONLY USED SYMBOLS

A	area of the cross section; area, in.^{2}
A_b	nominal unthreaded body area of bolt or threaded rod, in.^{2}
A_e	effective net area of tension member, in.^{2}
A_f	gross area of one flange, in.^{2}
A_g	gross area, in.^{2}
A_{gt}	gross area subject to tension (limit state of block shear rupture), in.^{2}
A_{gv}	gross area subject to tension (limit state of block shear rupture), in.^{2}
A_n	net area of tension member, in.^{2}
A_{nt}	net area subject to tension (limit state of block shear rupture), in.^{2}
A_{nv}	net area subject to shear (limit state of block shear rupture), in.^{2}
A_w	area of beam web, in.^{2}
B_1, B_2	magnification factors used in determining second-order moment for combined bending and axial compression when first-order analysis is employed
B_d	design strength of a bolt, kips
B_{db}	design bearing strength of a bolt, kips
B_{dbe}	design bearing strength of an end bolt, kips
B_{dbi}	design bearing strength of an interior bolt, kips
B_{dbo}	design bearing strength of connected plate element for the limit state of ovalization of bolt hole, kips
B_{dbte}	design bearing strength of an end bolt for the limit state of shear tear-out of connected plate element, kips
B_{dbti}	design bearing strength of an interior bolt for the limit state of shear tear-out of connected plate element, kips
B_{dv}	design shear strength of a bolt, kips
B_n	nominal strength of a bolt, kips
BF	beam factor
C_b	bending coefficient dependent on moment gradient for lateral-torsional buckling strength of beams
C_d	design strength of connectors in a joint, kips
C_{db}	design bearing strength of connectors in a joint, kips
C_{dv}	design shear strength of connectors in a joint, kips
C_m	coefficient applied to bending term in interaction formula for prismatic members and dependent on column curvature caused by applied moments
C_w	warping torsional constant of a cross section, in.^{6}
D	dead load; fillet weld size in sixteenths of an inch
E	earthquake load
E	modulus of elasticity or Young's modulus (= 29,000 ksi for steel)
E_s	strain hardening modulus, ksi
E_t	tangent modulus, ksi
F_{BM}	nominal strength of the base material to be welded, ksi
F_{EXX}	classification number of weld metal (minimum specified ultimate tensile stress)
F_L	smaller of ($F_{yf}-f_r$) or F_{yw}, ksi
F_{cr}	critical stress, ksi
F_e	elastic buckling stress, ksi
F_{ex}	elastic flexural buckling stress about the major axis, ksi
F_{ey}	elastic flexural buckling stress about the minor axis, ksi
F_r	compressive residual stress in flange (10 ksi for rolled shapes; 16.5 ksi for built-up shapes)

F_u	specified minimum ultimate tensile stress of the type of steel being used, ksi
F_{ub}	ultimate tensile stress of bolt material, ksu
F_w	nominal strength of the weld electrode material, ksi
F_y	specified minimum yield stress of the type of steel being used, ksi
F_{uy}	ultimate shear stress, ksi
F_{yv}	shear yield stress, ksi
G	shear modulus of elasticity (= 11,200 ksi for steel)
G_A, G_B	relative stiffness factors at ends A and B of a column
H	horizontal force, kips
I	impact factor; moment of inertia, in.^{4}
I_c	moment of inertia of a column, in.^{4}
I_g	moment of inertia of a girder, in.^{4}
I_x, I_y	moment of inertia about the x- or y-axis, respectively, in.^{4}
I_p	polar moment of inertia, in.^{4}
J	torsional constant for a section, in.^{4}
K	effective length factor for a column
K_x, K_y	effective length factor for flexural buckling about x axis and y axis
K_z	effective length factor for torsional buckling
L	live load due to occupancy
L	story height or panel spacing; span
L_b	laterally unbraced length; length between points which are either braced against lateral displacement of compression flange or braced against twist of the cross section
L_c	clear distance, in.
L_{ce}	clear distance for an end bolt, in.
L_{ci}	clear distance for an interior bolt, in.
L_{con}	length of connection in the direction of loading, in.
L_e	end distance of a bolt measured in direction of line of force; edge distance, in.
$L_{e,\text{full}}$	limiting value of end distance above which limit state of bolt ovalization controls bearing strength, in.
L_{lw}	length of longitudinal weld, in.
L_{tw}	length of transverse weld, in.
L_p	limiting laterally unbraced length for full plastic bending capacity, uniform moment case (C_b = 1.0), in.
L_{pd}	limiting laterally unbraced length for plastic analysis, in.
L_r	limiting laterally unbraced length for inelastic lateral-torsional buckling, in.
L_r	roof live load
L_s	side distance of a bolt measured perpendicular to line of force, in.
L_w	length of fillet weld, in.
M	bending moment
M_A	absolute value of moment at quarter point of the unbraced beam segment, in.-kips
M_B	absolute value of moment at centerline of the unbraced beam segment, in.-kips
M_C	absolute value of moment at three-quarter point of the unbraced beam segment, in.-kips
M_{cr}	elastic lateral-torsional buckling moment of a beam or a beam segment
M^o_{cr}	elastic lateral-torsional buckling moment of a beam or beam segment under uniform moment
M_{lt}	maximum first-order factored moment in a beam-column due to lateral frame translation only
M_n	nominal bending strength of a member
M_d	design bending strength of a member
M^o_{dI}	design bending strength of a beam segment under uniform moment, for $L_p < L_b \leq L_r$
M^o_{dE}	design bending strength of a beam segment under uniform moment, for $L_b > L_r$
$M_{\max}$	absolute value of the maximum moment within the unbraced length (including the end points)

M_{nt}	maximum first-order factored moment in a beam-column assuming there is no lateral translation of the frame
M_p	plastic bending moment of a section
M_r	bending moment in a section when the extreme fiber stress reaches $(F_y - F_r)$
M_u	required bending strength of a member under factored loads
M_u^*	required flexural strength of a beam-column under factored loads, including second-order effects
M_{ueq}^o	equivalent factored uniform moment capacity for the segment considered
M_y	moment corresponding to onset of yielding at the extreme fiber from an elastic stress distribution ($= F_y S$ for homogeneous sections)
M_1	smaller moment at the ends of a laterally unbraced segment of a beam or beam-column
M_2	larger moment at the ends of a laterally unbraced segment of a beam or beam-column
N_s	number of shear planes in a joint
P_{cr}	critical buckling load
P_d	design strength of an axially loaded column, kips
P_E	Euler buckling load
P_e	elastic buckling load
P_{e1}	elastic buckling load used in the determination of magnification factor B_1, kips
P_{e2}	elastic buckling load used in the determination of magnification factor B_2, kips
P_n	nominal strength of an axially loaded column, kips
P_u	axial force under factored loads; required axial strength of a column, kips
P_{ueq}	equivalent axial load used in selecting a trial shape for design of a beam column
P_y	yield (squash) load of a section, ($= F_y A_g$), kips
Q	concentrated transverse load on a member, kips
Q'	first moment of area in shear flow formula, in.^{3}
R	rain load
R_n	nominal strength
S	elastic section modulus, in.^{3}; snow load
T_b	specified pretension load in high-strength bolt, kips
T_d	design strength of a tension member, kips
T_n	nominal strength of a tension member, kips
T_u	factored tension load, required tensile strength due to factored loads, kips
U	reduction factor to account for shear lag
V	shear
V_d	design shear strength, kips
V_n	nominal shear strength, kips
V_u	shear force under factored loads, kips
W	wind load
W_d	design strength of a 1 in. long fillet weld
Z	plastic section modulus, in.^{3}
b	compression element width perpendicular to load direction, in.
b_f	flange width, in.
c	distance from neutral axis to extreme fiber where flexural stress is computed
d	nominal bolt diameter, in.; d overall depth of member, in.
d_b	beam depth, in.
d_c	column depth, in.
d_e	effective width of bolt hole, in.
d_h	diameter of bolt hole, in.
d_i	distance between the center of gravity of an element, i of a cross section to the center of gravity of the cross section (for use in parallel axis theorem)
e	base of natural logarithm = 2.71828; eccentricity of load
f	computed compressive stress
f_c'	specified 28-day compressive strength of concrete, ksi

g	transverse center-to-center spacing (gage) between bolt gage lines, in.
h	clear distance between flanges less the fillet or corner radius for rolled shapes; and for built- up welded sections, the distance between flanges, in.
k	distance from outer face of flange to web toe of fillet; plate buckling coefficient
p	pitch of bolts, in.
p_{full}	limiting value of pitch above which limit state of bolt ovalization controls bearing strength, in.
q	uniformly distributed transverse load on a member, klf
q_{sv}	shear flow, kli
r	radius of gyration, in.; radial distance
r_x, r_y	radius of gyration about x and y axes, respectively, in.
s	staggered pitch, in.
t	thickness of element, in.
t_f	flange thickness, in.
t_w	web thickness, in.
w	leg size of fillet weld, in.
x	subscript relating symbol to member strong axis
$\bar{x}$	x-coordinate of center of gravity
$\bar{x}_{con}$	connection eccentricity, in.
y	subscript relating symbol to member weak axis
$\bar{y}$	y-coordinate of center of gravity
z	subscript relating symbol to member longitudinal axis
α	shape factor
γ	load factor
δ	deflection
Δ	sway
Δ_{oh}	translation deflection of the story under consideration, in.
ϵ	strain
ϵ_y	yield strain
μ	Poisson's ratio (= 0.3 for steel); coefficient of static friction; mean slip coefficient for slip- critical connections
τ	stiffness reduction factor
λ	slenderness parameter
λ_c	column slenderness parameter
λ_p	limiting slenderness parameter for compact element
λ_{pf}	limiting slenderness parameter for the flange of a compact I-shape
λ_{pw}	limiting slenderness parameter for the web of a compact I-shape
λ_r	limiting slenderness parameter for noncompact element
ϕ	resistance factor
ϕ_b	resistance factor for flexure (= 0.90)
ϕ_c	resistance factor for compression (= 0.85)
ϕ_t	resistance factor for tension
ϕ_v	resistance factor for shear (= 0.90)