

6th Edition

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The Steel  
Construction  
Institute

Editors  
Buick Davison &  
Graham W. Owens

# STEEL DESIGNERS' MANUAL



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This classic manual on structural steelwork design was first published in 1955, since when it has sold many tens of thousands of copies worldwide.

The sixth edition retains the restructuring that was introduced in the fifth edition, published in 1992. All chapters have been comprehensively reviewed and revised. Key features of the new edition are:

- Text and worked examples revised in accordance with BS5950-1:2000 and BS5400-3:2000.
- A completely new chapter on brittle fracture and fatigue, explaining the theory behind the current requirements of BS5950 and BS5400.
- New chapter on simple connections and moment connections, summarising industry best practice in these important areas.
- New chapter on sustainability and steel construction reflecting the rapidly growing importance of this topic.
- New chapter on the Eurocodes, summarising the principal differences with current national standards.
- Rewritten chapter on steel piling capturing recent developments.

The book continues to provide, in one volume, the essential knowledge for the design of conventional steelwork.

### **From reviews of last edition**

*'Steel Designers' Manual is a must for anyone involved in steel design.'* –  
Journal of Constructional Steel Research

*'gives an excellent background to the use of structural steel in its many forms ... of interest to both students and practitioners alike'* –  
New Steel Construction

*'gives a lucid presentation of the behaviour and design of steel structures ... a worthwhile addition for many design office libraries'* –  
Construct in Steel (Australia)



# STEEL DESIGNERS' MANUAL

SIXTH EDITION

**The Steel Construction Institute**

Edited by

**Buick Davison**

*Department of Civil & Structural Engineering, The University of Sheffield*

**Graham W. Owens**

*Director, The Steel Construction Institute*

**Blackwell**  
Science

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The Steel Construction Institute (SCI) promotes the proper and effective use of steel in construction.

Membership is open to organisations and individuals that are concerned with the use of steel in construction, and members include clients, designers, contractors, suppliers, fabricators, academics and government departments. SCI is financed by subscriptions from its members, revenue from research contracts, consultancy services and by the sale of publications.

SCI's work is initiated and guided through the involvement of its members on advisory groups and technical committees. A comprehensive advisory and consultancy service is available to members on the use of steel in construction.

Dr Graham Owens has 34 years' experience in designing, constructing, teaching and researching in structural steelwork. After six years' practical experience and 16 years at Imperial College, he joined the Steel Construction Institute at its formation in 1986. He was made director in 1992.

Dr Buick Davison is a Senior Lecturer in the Department of Civil and Structural Engineering at the University of Sheffield. In addition to his wide experience in teaching and research of steel structures, he is a Chartered Engineer and has worked in consultancies on the design of buildings and stadia.

# Introduction to sixth edition

At the instigation of the Iron and Steel Federation, the late Bernard Godfrey began work in 1952 on the first edition of the *Steel Designers' Manual*. As principal author he worked on the manuscript almost continuously for a period of two years. On many Friday evenings he would meet with his co-authors, Charles Gray, Lewis Kent and W.E. Mitchell to review progress and resolve outstanding technical problems. A remarkable book emerged. Within approximately 900 pages it was possible for the steel designer to find everything necessary to carry out the detailed design of most conventional steelwork. Although not intended as an analytical treatise, the book contained the best summary of methods of analysis then available. The standard solutions, influence lines and formulae for frames could be used by the ingenious designer to disentangle the analysis of the most complex structure. Information on element design was intermingled with guidance on the design of both overall structures and connections. It was a book to dip into rather than read from cover to cover. However well one thought one knew its contents, it was amazing how often a further reading would give some useful insight into current problems. Readers forgave its idiosyncrasies, especially in the order of presentation. How could anyone justify slipping a detailed treatment of angle struts between a very general discussion of space frames and an overall presentation on engineering workshop design?

The book was very popular. It ran to four editions with numerous reprints in both hard and soft covers. Special versions were also produced for overseas markets. Each edition was updated by the introduction of new material from a variety of sources. However, the book gradually lost the coherence of its original authorship and it became clear in the 1980s that a more radical revision was required.

After 36 very successful years it was decided to rewrite and re-order the book, while retaining its special character. This decision coincided with the formation of the Steel Construction Institute and it was given the task of co-ordinating this activity.

A complete restructuring of the book was undertaken for the fifth edition, with more material on overall design and a new section on construction. The analytical material was condensed because it is now widely available elsewhere, but all the design data were retained in order to maintain the practical usefulness of the book as a day-to-day design manual. Allowable stress design concepts were replaced by limit state design encompassing BS 5950 for buildings and BS 5400 for bridges. Design examples are to the more appropriate of these two codes for each particular application.



The fifth edition was published in 1992 and proved to be a very worthy successor to its antecedents. It also ran to several printings in both hard and soft covers; an international edition was also printed and proved to be very popular in overseas markets.

This sixth edition maintains the broad structure introduced in 1992, reflecting its target readership of designers of structural steelwork of all kinds.

- Design synthesis
- Steel technology
- Design theory
- Element design
- Connection design
- Other elements
- Construction.

### **Design synthesis: Chapters 1–5**

A description of the nature of the process by which design solutions are arrived at for a wide range of steel structures including:

- Single- and multi-storey buildings (Chapters 1 and 2)
- Heavy industrial frames (Chapter 3)
- Bridges (Chapter 4)
- Other diverse structures such as space frames, cable structures, towers and masts, atria and steel in housing (Chapter 5).

### **Steel technology: Chapters 6–8**

Background material sufficient to inform designers of the important problems inherent in the production and use of steel, and methods of overcoming them in practical design.

- Applied metallurgy (Chapter 6)
- Fatigue and Fracture (Chapter 7)
- Sustainability and steel construction (Chapter 8).

### **Design theory: Chapters 9–12**

A résumé of analytical methods for determining the forces and moments in structures subject to static or dynamic loads, both manual and computer-based.

Comprehensive tables for a wide variety of beams and frames are given in the Appendix.

- Manual and computer analysis (Chapter 9)
- Beam analysis (Chapter 10)
- Frame analysis (Chapter 11)
- Applicable dynamics (Chapter 12).

### **Element design: Chapters 13–22**

A comprehensive treatment of the design of steel elements, singly, in combination or acting compositely with concrete.

- Local buckling and cross-section classification (Chapter 13)
- Tension members (Chapter 14)
- Columns and struts (Chapter 15)
- Beams (Chapter 16)
- Plate girders (Chapter 17)
- Members with compression and moments (Chapter 18)
- Trusses (Chapter 19)
- Composite floors (Chapter 20)
- Composite beams (Chapter 21)
- Composite columns (Chapter 22).

### **Connection design: Chapters 23–27**

The general basis of design of connections is surveyed and amplified by consideration of specific connection methods.

- Bolts (Chapter 23)
- Welds and design for welding (Chapter 24)
- Plate and stiffener elements in connections (Chapter 25)
- Design of connections (Chapter 26)
- Foundations and holding-down systems (Chapter 27).

### **Other elements: Chapters 28–30**

- Bearings and joints (Chapter 28)
- Piles (Chapter 29)
- Floors and orthotropic decks (Chapter 30).

**Construction: Chapters 31–35**

Important aspects of steel construction about which a designer must be informed if he is to produce structures which can be economically fabricated, and erected and which will have a long and safe life.

- Tolerances (Chapter 31)
- Fabrication (Chapter 32)
- Erection (Chapter 33)
- Fire protection and fire engineering (Chapter 34)
- Corrosion resistance (Chapter 35).

Finally, Chapter 36 summarizes the state of progress on the Eurocodes, which will begin to influence our design approaches from 2003 onwards.

A comprehensive collection of data of direct use to the practising designer is compiled into a series of appendices.

By kind permission of the British Standards Institution, references are made to British Standards throughout the manual. The tables of fabrication and erection tolerances in Chapter 31 are taken from the *National Structural Steelwork Specification*, second edition. Much of the text and illustrations for Chapter 33 are taken from *Steelwork Erection* by Harry Arch. Both these sources are used by kind permission of the British Constructional Steelwork Association, the publishers. These permissions are gratefully acknowledged.

Finally I would like to pay tribute both to the 38 authors who have contributed to the sixth edition and to my hard-working principal editor, Dr Buick Davison. All steelwork designers are indebted to their efforts in enabling this text book to be maintained as the most important single source of information on steel design.

*Graham Owens*

# Contributors

## **Harry Arch**

Harry Arch graduated from Manchester Faculty of Technology. For many years he worked for Sir William Arrol, where he became a director, responsible for all outside construction activities including major bridges, power stations and steelworks construction. In 1970 he joined Redpath Dorman Long International, working on off-shore developments.

## **Mike Banfi**

Mike Banfi joined Arup from Cambridge University in 1976. He has been involved in the design of various major projects, including: Cummins Engine Plant, Shotts; The Hong Kong and Shanghai Bank, Hong Kong; Usine L'Oreal, Paris; roofs for the TGV stations, Lille and Roissy; roofs for the Rad-und Schwimmsportshalle, Berlin; and various office blocks. He is now based in Arup Research & Development where he provides advice on projects; examples include: Wellcome Wing to the Science Museum, London; City Hall, London; T5, Heathrow. He is UK National Technical Contact for Eurocode 4 part 1.1 and was on the steering committee for the 4th edition of the NSSS. He is an Associate Director.

## **Hubert Barber**

Hubert Barber joined Redpath Brown in 1948 and for five years gained a wide experience in steel construction. The remainder of his working life was spent in local government, first at Manchester and then in Yorkshire where he became chief structural engineer of West Yorkshire. He also lectured part-time for fourteen years at the University of Bradford.

## **Tony Biddle**

Tony Biddle graduated in civil engineering from City University in 1966 and spent the early part of his career in contractors, designing in steel and reinforced concrete

before specializing in soil mechanics and foundation design in 1970. Between 1974 and 1993 he worked in the offshore industry, becoming a specialist in steel piling. He joined SCI in 1994 as manager for civil engineering and has developed the R&D research project work in steel piling related topics. He has been a drafting member for Eurocode 3 part 5, contributor to BS 8002 amendments, and author of several SCI publications.

### **Michael Burdekin**

Michael Burdekin graduated from Cambridge University in 1959. After fifteen years of industrial research and design experience he went to UMIST, where he is now Professor of Civil and Structural Engineering. His specific expertise is the field of welded steel structures, particularly in the application of fracture mechanics to fracture and fatigue failure.

### **Brian Cheal**

Brian Cheal graduated from Brighton Technical College in 1951 with an External Degree of the University of London. He was employed with W.S. Atkins and Partners from 1951 to 1986, becoming a technical director in 1979, and specialized in the analysis and design of steel-framed structures, including heavy structural framing for power stations and steelworks. He has written design guides and given lectures on various aspects of connection design and is co-author of *Structural Steelwork Connections*.

### **David Dobb-Fuller**

David Dobb-Fuller started his career with the Cleveland Bridge and Engineering Company in London. His early bridge related work gave a strong emphasis to heavy fabrication; in later years he moved on to building structures. As technical director for Conder Southern in Winchester his strategy was to develop close links between design for strength and design for production. Currently he is a partner with Gifford and Partners in Southampton where he continues to exercise his skills in the design of steel structures.

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Ian Duncan joined the London office of Ove Arup and Partners in 1966 after graduating from Surrey University. From 1975 he taught for four years at Univer-



sity College Cardiff before joining Buro Happold. He now runs his own practice in Bristol.

### **Michael Green**

Michael Green graduated from Liverpool University in 1971. After an early career in general civil engineering, he joined Buro Happold, where he is now an executive partner. He has worked on a wide variety of building projects, developing a specialist expertise in atria and large-span structures.

### **Alan Hart**

Alan Hart graduated from the University of Newcastle upon Tyne in 1968 and joined Ove Arup and Partners. During his career he has been involved in the design of a number of major award-winning buildings, including Carlsberg Brewery, Northampton; Cummins Engine Plant, Shotts, Lanarkshire; and the Hongkong and Shanghai Bank, Hong Kong. He is a project director of Ove Arup and Partners.

### **Alan Hayward**

Alan Hayward is a bridge specialist and is principal consultant of Cass Hayward and Partners, who design and devise the erection methodology for all kinds of steel bridges, many built on a design:construct basis. Projects include London Docklands Light Railway viaducts, the M25/M4 interchange, the Centenary Lift bridge at Trafford Park and the Newark Dyke rail bridge reconstruction. Movable bridges and roll-on/roll-off linkspans are also a speciality. He is a former chief examiner for the Institution of Structural Engineers and was invited to become a Fellow of the Royal Academy of Engineers in 2001.

### **Eric Hindhaugh**

Eric Hindhaugh trained as a structural engineer in design and constructional steelwork, timber and lightweight roll-formed sections. He then branched into promotional and marketing activities. He was a market development manager in construction for British Steel Strip Products, where he was involved in Colorcoat and the widening use of lightweight steel sections for structural steel products. He is now retired.

**Roger Hudson**

Roger Hudson studied metallurgy at Sheffield Polytechnic whilst employed by BISRA. He also has a Masters degree from the University of Sheffield. In 1968, he joined the United Steel Companies at Swinden Laboratories in Rotherham to work on the corrosion of stainless steels. The laboratories later became part of British Steel where he was responsible for the Corrosion Laboratory and several research projects. He is now principal technologist in the recently formed Corus company. He is a member of several technical and international standards committees, has written technical publications, and has lectured widely on the corrosion and protection of steel in structures. He is a long serving professional member of the Institute of Corrosion and is currently chairman of the Yorkshire branch and chairman of the Training and Certification Governing Board.

**Ken Johnson**

Ken Johnson was head of corrosion and coatings at British Steel's Swinden Laboratories. His early experience was in the paint industry but he then worked in steel for over twenty-five years, dealing with the corrosion and protection aspects of the whole range of British Steel's products, including plates, section, piling, strip products, tubes, stainless steels, etc. He represented the steel industry on several BSI and European Committees and was a council member of the Paint Research Association. He is now retired.

**Alan Kwan**

Alan Kwan graduated from the University of Sheffield and Cambridge University. He is a lecturer in structural engineering at Cardiff University, specializing in light-weight, deployable, tension and space structures, and numerical methods for their analysis.

**Mark Lawson**

A graduate of Imperial College, and the University of Salford, where he worked in the field of cold-formed steel, Mark Lawson spent his early career at Ove Arup and Partners and the Construction Industry Research and Information Association. In 1987 he joined the newly formed Steel Construction Institute as research manager for steel in buildings, with particular reference to composite construction, fire engineering and cold-formed steel. He is a member of the Eurocode 4 project team on fire-resistant design.

**Ian Liddell**

After leaving Cambridge, Ian Liddell joined Ove Arup and Partners to work on the roof of the Sydney Opera House and on the South Bank Art Centre. His early career encompassed a wide range of projects, with particular emphasis on shell structures and lightweight tension and fabric structures. Since 1976 he has been a partner of Buro Happold and has been responsible for a wide range of projects, many with special structural engineering features, including mosques, auditoriums, mobile and temporary structures, stadiums and retail atria.

**Matthew Lovell**

Matthew Lovell studied civil engineering at University College, London. After graduation Matthew worked for Arup on the Chur Station roof project. He is now senior associate at Buro Happold and has worked on many steel structures, including Thames Valley University LRC, the National Centre for Popular Music, and St David's RF Hotel. He has recently completed an MSc in Interdisciplinary Design at Cambridge University.

**Stephen Matthews**

Stephen Matthews graduated from the University of Nottingham in 1974 and completed postgraduate studies at Imperial College in 1976–77. His early professional experience was gained with Rendel Palmer and Tritton. During subsequent employment with Fairfield Mabey and Cass Hayward and Partners he worked on the design of several large composite bridges, including the Simon de Montfort Bridge Evesham, M25/M4 interchange, Poyle, and viaducts on the Docklands Light Railway. He is a director of WSP (Civils), where he has been manager of the Bridges Division since 1990. Work has included a number of major bridge repair schemes and drafting of the UK National Application Document for Eurocode 3 part 2 (steel bridges).

**David Moore**

David Moore graduated from the University of Bradford in 1981 and joined the Building Research Establishment (BRE) where he has completed over twenty years of research and specialist advisory work in the area of structural steelwork. He is the author of over 70 technical papers on a wide range of subjects. He has also made a significant contribution to a number of specialist steel and composite connection design guides, many of which are used daily by practising structural engineers and

steelwork fabricators. Currently he is the director of the Centre for Structural Engineering at BRE.

### **Rangachari Narayanan**

Rangachari Narayanan graduated in civil engineering from Annamalai University (India) in 1951. In a varied professional career spanning over forty years, he has held senior academic positions at the Universities of Delhi, Manchester and Cardiff. He is the recipient of several awards including the Benjamin Baker Gold Medal and George Stephenson Gold Medal, both from the Institution of Civil Engineers. For many years he headed the Education and Publication Divisions at the Steel Construction Institute.

### **David Nethercot**

Since graduating from the University of Wales, Cardiff, David Nethercot has completed thirty years of teaching, research and specialist advisory work in the area of structural steelwork. The author of over 300 technical papers, he has lectured frequently on post-experience courses; he is chairman of the BSI Committee responsible for BS 5950, and is a frequent contributor to technical initiatives associated with the structural steelwork industry. Since 1999 he has been head of the Department of Civil and Environmental Engineering at Imperial College.

### **Gerard Parke**

Gerry Parke is a lecturer in structural engineering at the University of Surrey specializing in the analysis and design of steel structures. His particular interests lie in assessing the collapse behaviour of both steel industrial buildings and large-span steel space structures.

### **Phil Peacock**

Phil Peacock is a member of the Corus Construction Centre. He started his career in 1965 at steelwork fabricators Ward Bros. Ltd., gained an HND at Teesside Polytechnic and moved to White Young Consulting Engineers in 1973 before joining British Steel (now Corus) in 1988. His experience covers the design management of a wide range of projects: heavy plant buildings and structures for the steel, petrochemical and coal industries, commercial offices, leisure and retail developments. He serves on several industry committees and is a past chairman of the Institution of Structural Engineers Scottish Branch.

**Alan Pottage**

Alan Pottage graduated from the University of Newcastle upon Tyne in 1976 and gained a Masters degree in structural steel design from Imperial College in 1984. He has gained experience in all forms of steel construction, particularly portal frame and multi-rise structures, and has contributed to various code committees, and SCI guides on composite design and connections.

**Graham Raven**

Graham Raven graduated from King's College, London in 1963 and joined Ove Arup and Partners. Following thirteen years with consulting engineers working on a variety of building structures he joined a software house pioneering work in structural steel design and detailing systems. In 1980 this experience took him to Ward Building Systems where he became technical director and was closely associated with the development of a range of building components and increased use of welded sections in buildings. Since 1991, with the exception of a year with a software house specialising in 3D detailing systems, he has been employed at the Steel Construction Institute, where he is the senior manager responsible for the Sustainability Group.

**John Righiniotis**

John Righiniotis graduated from the University of Thessalonika in 1987 and obtained an MSc in structural steel design from Imperial College in 1988. He worked at the Steel Construction Institute on a wide range of projects until June 1990 when he was required to return to Greece to carry out his military service.

**John Roberts**

John Roberts graduated from the University of Sheffield in 1969 and was awarded a PhD there in 1972 for research on the impact loading of steel structures. His professional career includes a period of site work with Alfred McAlpine, following which he has worked as a consulting engineer, since 1981 with Allott & Lomax/Babtie Group. He is a director of Babtie Group where he heads up the Structures and Buildings Teams that have designed many major steelwork structures. He was president of the Institution of Structural Engineers in 1999–2000 and is a council member of both the Steel Construction Institute and the BCSA.



**Terry Roberts**

Terry Roberts graduated in civil and structural engineering from the University of Wales Cardiff in 1967, and following three years of postgraduate study was awarded a PhD in 1971. His early professional experience was gained in bridge design and site investigation for several sections of the M4 motorway in Wales. He returned to academic life in 1975. He is the author of over 100 technical papers on various aspects of structural engineering, for which he received a DSc from the University of Wales and the Moisseiff Award from the Structural Engineering Institute of the American Society of Civil Engineers in 1997. Since 1996 he has been head of the Division of Structural Engineering in the Cardiff School of Engineering.

**Jef Robinson**

Jef Robinson graduated in metallurgy from Durham University in 1962. His early career in the steel industry included formulating high ductility steels for automotive applications and high-strength notch ductile steels for super tankers, drilling platforms and bridges. Later as market development manager for the structural division of British Steel (now Corus) he chaired the BSI committee that formulated BS 5950 Part 8: *Fire Resistant Design* for structural steelwork and served on a number of international fire related committees. He was appointed honorary professor at the University of Sheffield in 2000.

**Alan Rogan**

Alan Rogan is a leading consultant to the steel industry, working with prestigious clients such as Corus and Cleveland Bridge Engineering Group. Alan has been involved in the construction of many buildings, such as Canary Wharf, Gatwick Airport extension and many bridges from simple footbridges to complex multi-spans, in the UK and overseas.

**Dick Stainsby**

Dick Stainsby's career training started with an HNC and went on to include post-graduate studies at Imperial College London. His experience has encompassed steel structures of all kinds including bridgework. He was for many years chief designer with Redpath Dorman Long Middlesbrough. Since retiring from mainstream industry he has assisted the British Constructional Steelwork Association, the Steel Construction Institute and the Institution of Structural Engineers in the production of

technical publications relating to steelwork connections. He also compiled the National Structural Steelwork Specification for Building Construction, which is now in its 4th Edition.

**Paul Tasou**

Paul Tasou graduated from Queen Mary College, London in 1978 and subsequently obtained an MSc in structural steel design from Imperial College, London. He spent eleven years at Rendel Palmer and Tritton working on a wide range of bridge, building and civil engineering projects. He is now principal partner in Tasou Associates.

**Colin Taylor**

Colin Taylor graduated from Cambridge in 1959. He started his professional career in steel fabrication, initially in the West Midlands and subsequently in South India. After eleven years he moved into consultancy where, besides practical design, he became involved with graduate training, the use of computers for design and drafting, company technical standards and drafting work for British Standards and for Eurocodes as editorial secretary for Eurocode 3. Moving to the Steel Construction Institute on its formation as manager of the Codes and Advisory Division, he also became involved with the European standard for steel fabrication and erection *Execution of Steel Structures*.

**John Tyrrell**

John Tyrrell graduated from Aston University in 1965 and immediately joined Ove Arup and Partners. He has worked for them on a variety of projects in the UK, Australia and West Africa; he is now a project director. He has been responsible for the design of a wide range of towers and guyed masts. He currently leads the Industrial Structures Group covering diverse fields of engineering from telecommunications and broadcasting to the power industry.

**Peter Wickens**

Having graduated from Nottingham University in 1971, Peter Wickens spent much of his early career in civil engineering, designing bridges and Metro stations. In 1980,

he changed to the building structures field and was project engineer for the Billingsgate Development, one of the first of the new generation of steel composite buildings. He is currently manager of the Structural Division and head of discipline for Building Structures at Mott MacDonald.

### **Michael Willford**

Michael Willford joined Arup in 1975, having graduated from Cambridge University. He has been a specialist in the design of structures subjected to dynamic actions for over twenty years. His design and analysis experience covers a wide variety of projects including buildings, bridges and offshore structures. He is currently a director of Arup and the leader of a team of specialists working in these fields based in London and San Francisco.

### **John Yates**

John Yates was appointed to a personal chair in mechanical engineering at the University of Sheffield in 2000 after five years as a reader in the department. He graduated from Pembroke College, Cambridge in 1981 in metallurgy and materials science and then undertook research degrees at Cranfield and the University of Sheffield before several years of postdoctoral engineering and materials research. His particular interests are in developing structural integrity assessment tools based on the physical mechanisms of fatigue and fracture. He is the honorary editor of *Engineering Integrity* and an editor of the international journal *Fatigue and Fracture of Engineering Materials and Structures*.

### **Ralph Yeo**

Ralph Yeo graduated in metallurgy at Cardiff and Birmingham and lectured at The University of the Witwatersrand. In the USA he worked on the development of weldable high-strength and alloy steels with International Nickel and US Steel and on industrial gases and the development of welding consumables and processes at Union Carbide's Linde Division. Commercial and general management activities in the UK, mainly with The Lincoln Electric Company, were followed by twelve years as a consultant and expert witness, with special interest in improved designs for welding.

# Notation

Several different notations are adopted in steel design; different specializations frequently give different meanings to the same symbol. These differences have been maintained in this book. To do otherwise would be to separate this text both from other literature on a particular subject and from common practice. The principal definitions for symbols are given below. For conciseness, only the most commonly adopted subscripts are given; others are defined adjacent to their usage.

$A$	Area
	or End area of pile
	or Constant in fatigue equations
$A_e$	Effective area
$A_g$	Gross area
$A_s$	Shear area of a bolt
$A_t$	Tensile stress area of a bolt
$A_v$	Shear area of a section
$a$	Spacing of transverse stiffeners
	or Effective throat size of weld
	or Crack depth
	or Distance from central line of bolt to edge of plate
	or Shaft area of pile
$B$	Breadth
$\mathbf{B}$	Transformation matrix
$b$	Outstand
	or Width of panel
	or Distance from centreline of bolt to toe of fillet weld or to half of root radius as appropriate
$b_e$	Effective breadth or effective width
$b_1$	Stiff bearing length
$C$	Crack growth constant
$\mathbf{C}$	Transformation matrix
$C_v$	Charpy impact value
$C_y$	Damping coefficient
$c$	Bolt cross-centres
	or Cohesion of clay soils

$D$	Depth of section Diameter of section or hole
$\mathbf{D}$	Elasticity matrix
$D_r$	Profile height for metal deck
$D_s$	Slab depth
$d$	Depth of web or Nominal diameter of fastener or Depth
$d_e$	Effective depth of slab
$E$	Modulus of elasticity of steel (Young's modulus)
$e$	End distance
$e_y$	Material yield strain
$F_c$	Compressive force due to axial load
$F_s$	Shear force (bolts)
$F_t$	Tensile force
$F_v$	Shear force (sections)
$f$	Flexibility coefficient
$f_a$	Longitudinal stress in flange
$f_c$	Compressive stress due to axial load
$f_{cu}$	Cube strength of concrete
$f_m$	Force per unit length on weld group from moment
$f_r$	Resultant force per unit length on weld group from applied concentric load
$f_v$	Force per unit length on weld group from shear or Shear stress
$G$	Shear modulus of steel
$g$	Gravitational acceleration
$H$	Warping constant of section or Horizontal reaction
$h$	Height or Stud height or Depth of overburden
$I_o$	Polar second moment of area of bolt group
$I_{oo}$	Polar second moment of area of weld group of unit throat about polar axis
$I_x$	Second moment of area about major axis
$I_{xx}$	Polar second moment of area of weld group of unit throat about $xx$ axis
$I_y$	Second moment of area about minor axis
$I_{yy}$	Polar second moment of area of weld group of unit throat about $yy$ axis
$K$	Degree of shear connection or Stiffness
$\mathbf{K}$	Stiffness matrix
$K_s$	Curvature of composite section from shrinkage or Constant in determining slip resistance of HSFG bolts
$K_1, K_2, K_3$	Empirical constants defining the strength of composite columns



$k_a$	Coefficient of active pressure
$k_d$	Empirical constant in composite slab design
$k_p$	Coefficient of passive resistance
$L$	Length of span or cable
$L_y$	Shear span length of composite slab
$M$	Moment
or	Larger end moment
$M_{ax}, M_{ay}$	Maximum buckling moment about major or minor axis in presence of axial load
$M_b$	Buckling resistance moment (lateral – torsional)
$M_E$	Elastic critical moment
$M_o$	Mid-length moment on a simply-supported span equal to unrestrained length
$M_{pc}$	Plastic moment capacity of composite section
$M_{rx}, M_{ry}$	Reduced moment capacity of section about major or minor axis in the presence of axial load
$M_x, M_y$	Applied moment about major or minor axis
$\bar{M}_x, \bar{M}_y$	Equivalent uniform moment about major or minor axis
$M_1, M_2$	End moments for a span of a continuous composite beam
$m$	Equivalent uniform moment factor
or	Empirical constant in fatigue equation
or	Number of vertical rows of bolts
$m_d$	Empirical constant in composite slab design
$N$	Number of cycles to failure
$N_c, N_q, N_\gamma$	Constants in Terzaghi's equation for the bearing resistance of clay soils
$n$	Crack growth constant
or	Number of shear studs per trough in metal deck
or	Number of horizontal rows of bolts
or	Distance from bolt centreline to plate edge
$P$	Force in structural analysis
or	Load per unit surface area on cable net
or	Crushing resistance of web
$P_{bb}$	Bearing capacity of a bolt
$P_{bg}$	Bearing capacity of parts connected by friction-grip fasteners
$P_{bs}$	Bearing capacity of parts connected by ordinary bolts
$P_c$	Compression resistance
$P_{cx}, P_{cy}$	Compression resistance considering buckling about major or minor axis only
$P_o$	Minimum shank tension for preloaded bolt
$P_s$	Shear capacity of a bolt
$P_{sL}$	Slip resistance provided by a friction-grip fastener
$P_t$	Tension capacity of a member or fastener
$P_u$	Compressive strength of stocky composite column
$P_v$	Shear capacity of a section

$p$	Ratio of cross-sectional area of profile to that of concrete in a composite slab
$p_b$	Bending strength
$p_{bb}$	Bearing strength of a bolt
$p_{bg}$	Bearing strength of parts connected by friction-grip fasteners
$p_{bs}$	Bearing strength of parts connected by ordinary bolts
$p_c$	Compressive strength
$p_E$	Euler strength
$p_o$	Minimum proof stress of a bolt
$p_s$	Shear strength of a bolt
$p_t$	Tension strength of a bolt
$p_w$	Design strength of a fillet weld
$p_y$	Design strength of steel
$Q$	Prying force
$q$	Ultimate bearing capacity
$q_b$	Basic shear strength of a web panel
$q_{cr}$	Critical shear strength of a web panel
$q_e$	Elastic critical shear strength of a web panel
$q_f$	Flange-dependent shear strength factor
$R$	Reaction
or	Load applied to bolt group
or	Radius of curvature
$R_c$	Compressive capacity of concrete section in composite construction
$R_q$	Capacity of shear connectors between point of contraflexure and point of maximum negative moment in composite construction
$R_r$	Tensile capacity in reinforcement in composite construction
$R_s$	Tensile capacity in steel section in composite construction
$R_w$	Compression in web section in composite construction
$r$	Root radius in rolled section
$r_r$	Reduction factor in composite construction
$r_x, r_y$	Radius of gyration of a member about its major or minor axis
$S$	Span of cable
$S_R$	Applied stress range
$S_x, S_y$	Plastic modulus about major or minor axis
$s$	Spacing
or	Leg length of a fillet weld
$T$	Thickness of a flange or leg
or	Tension in cable
$t$	Thickness of web
$U$	Elastic energy
$U_s$	Specified minimum ultimate tensile strength of steel
$u$	Buckling parameter of the section
$V$	Shear force
or	Shear resistance per unit length of beam in composite construction
$V_b$	Shear buckling resistance of stiffened web utilizing tension field action

$V_{cr}$	Shear buckling resistance of stiffened or unstiffened web without utilizing tension field action
$\nu$	Slenderness factor for beam
$W$	Point load
	or Foundation mass
	or Load per unit length on a cable
	or Energy required for crack growth
$w$	Lateral displacement
	or Effective width of flange per bolt
	or Uniformly distributed load on plate
$X_e$	Elastic neutral axis depth in composite section
$x$	Torsion index of section
$x_p$	Plastic neutral axis depth in composite section
$Y$	Correction factor in fracture mechanics
$Y_s$	Specified minimum yield stress of steel
$Z_c$	Elastic section modulus for compression
$Z_{oo}$	Elastic modulus for weld group of unit throat subject to torsional load
$Z_x, Z_y$	Elastic modulus about major or minor axis
$z$	Depth of foundation
$\alpha$	Coefficient of linear thermal expansion
$\alpha_e$	Modular ratio
$\beta$	Ratio of smaller to larger end moment
	or Coefficient in determination of prying force
$\gamma$	Ratio $M/M_o$ , i.e. ratio of larger end moment to mid-length moment on simply-supported span equal to unrestrained length
	or Bulk density of soil
	or Coefficient in determination of prying force
$\gamma_f$	Overall load factor
$\gamma_m$	Material strength factor
$\Delta$	Displacements in vector
$\delta$	Deflection
	or Elongation
$\delta_c$	Deflection of composite beam at serviceability limit state
$\delta_{ic}$	Deflection of composite beam at serviceability limit state in presence of partial shear connection
$\delta_o$	Deflection of steel beam at serviceability limit state
$\delta_{oo}$	Deflection in continuous composite beam at serviceability limit state
$\varepsilon$	Constant $(275/p_y)^{1/2}$
	or Strain
$\eta$	Load ratio for composite columns
$\lambda$	Slenderness, i.e. effective length divided by radius of gyration
$\lambda_{cr}$	Elastic critical load factor
$\lambda_{LO}$	Limiting equivalent slenderness
$\lambda_{LT}$	Equivalent slenderness

$\lambda_0$	Limiting slenderness
$\mu$	Slip factor
$\mu_x, \mu_y$	Reduction factors on moment resistance considering axial load
$\sigma$	Stress
$\sigma_\varepsilon$	Tensile stress
$\phi$	Diameter of composite column
or	Angle of friction in granular soil