Composite structures
of steel and concrete
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This volume provides an introduction to the theory and design of composite structures of steel and concrete. Readers are assumed to be familiar with the elastic and plastic theories for the analysis for bending and shear of cross-sections of beams and columns of a single material, such as structural steel, and to have some knowledge of reinforced concrete. No previous knowledge is assumed of the concept of shear connection within a member composed of concrete and structural steel, nor of the use of profiled steel sheeting in composite slabs. Shear connection is covered in depth in Chapter 2 and Appendix A, and the principal types of composite member in Chapters 3, 4 and 5.

All material of a fundamental nature that is applicable to structures for both buildings and bridges is included, plus more detailed information and a fully worked example relating to buildings. The design methods are illustrated by calculations. For this purpose a single problem, or variations of it, has been used throughout the volume. The reader will find that the dimensions for this structure, its loadings, and the strengths of the materials soon remain in the memory. The design is not optimal, because one object here has been to encounter a wide range of design problems, whereas in practice one seeks to avoid them.

This volume is intended for undergraduate and graduate students, for university teachers, and for engineers in professional practice who seek familiarity with composite structures. Most readers will seek to develop the skills needed both to design new structures and to predict the behaviour of existing ones. This is now always done using guidance from a code of practice. The British code for composite beams, BS 5950:Part 3, Section 3.1, is associated with BS 5950:Part 1 for steel structures and BS 8100 for concrete structures. These are all being superseded by the new European codes (‘Eurocodes’), and will be withdrawn within a few years. The Eurocodes are being published by the standards institutions for most European countries as EN 1990 to EN 1999, each of which has several Parts. These have been available as ENV (preliminary) codes for several years.
In the UK, their numbers are BS EN 1990, etc., and in Germany (for example) DIN EN 1990, etc. Each code includes a National Annex, for use for design of structures to be built in the country concerned. Apart from these annexes and the language used, the codes will be identical in all countries that are members of the European Committee for Standardization, CEN.

The Eurocode for composite structures, EN 1994, is based on recent research and current practice, particularly that of Western Europe. It has much in common with the latest national codes in this region, but its scope is far wider. It has many cross-references to other Eurocodes, particularly:

- EN 1990, Basis of Structural Design,
- EN 1991, Actions on Structures,
- EN 1992, Design of Concrete Structures and
- EN 1993, Design of Steel Structures.

All the design methods explained and used in this volume are those of the Eurocodes. The worked example, a multi-storey framed structure for a building, includes design for resistance to fire. Foundations are not included.

The Eurocodes refer to other European (EN) and International (ISO) standards, for subjects such as products made from steel and execution. ‘Execution’ is an example of a word used in Eurocodes with a particular meaning, which is replacing the word in current usage, construction. Other examples will be explained as they occur.

Some of these standards may not yet be widely available, so this volume is self-contained. Readers do not need access to any of them; and should not assume that the worked examples here are fully in accordance with the Eurocodes as implemented in any particular country. This is because Eurocodes give only ‘recommended’ values for some numerical values, especially the $\gamma$ and $\psi$ factors. The recommended values, which are used here, are subject to revision in National Annexes. However, very few of them are being changed.

Engineers who need to use a Eurocode in professional practice should also consult the relevant Designers’ Guide. These are being published in the UK for each Eurocode, and are suitable only for use with the code and those to which it refers. They are essentially commentaries on a clause-by-clause basis, and start from a higher level of prior knowledge than is assumed here. The Guide to EN 1994-1-1, Design of composite steel and concrete structures – General rules and rules for buildings is consistent with this book, being written by the present author and D. Anderson. Corresponding publications in other languages are appearing, each relating the Eurocodes to the national codes of the country concerned.
The previous edition of this volume was based on the ENV Eurocodes. The many changes made in the EN versions have led to extensive revision and a complete re-working of the examples.

The author has for several decades shared the challenge of drafting the General, Buildings and Bridges parts of EN 1994 with other members of multi-national committees, particularly Henri Mathieu, Karlheinz Roik, Jan Stark, Gerhard Hanswille, Bernt Johansson, Jean-Paul Lebet, Joel Raoul, Basil Kolas and David Anderson. The substantial contributions made by these friends and colleagues to the author’s understanding of the subject are gratefully acknowledged. However, responsibility for what is presented here rests with the writer, who would be glad to be informed of any errors that may be found.

Thanks are due also to the School of Engineering, University of Warwick, for facilities provided, and most of all to the writer’s wife Diana, for her unfailing support.

R.P. Johnson

Cover photograph shows composite decking prior to concreting (courtesy of The Steel Construction Institute).
Symbols, terminology and units

The symbols used in this volume are, wherever possible, the same as those in EN 1994 and in the Designers’ Guide to EN 1994-1-1. They are based on ISO 3898:1987, Bases for design of structures – Notation – General symbols. They are more consistent than those used in the British codes, and more informative. For example, in design one often compares an applied ultimate bending moment (an ‘action effect’ or ‘effect of action’) with a bending resistance, since the former must not exceed the latter. This is written

\[ M_{Ed} \leq M_{Rd} \]

where the subscripts E, d and R mean ‘effect of action’, ‘design’ and ‘resistance’, respectively.

For longitudinal shear, the following should be noted:

- \( v \), a shear stress (shear force per unit area), with \( \tau \) used for a vertical shear stress;
- \( v_L \), a shear force per unit length of member, known as ‘shear flow’;
- \( V \), a shear force (used also for a vertical shear force).

For subscripts, the presence of three types of steel leads to the use of ‘s’ for reinforcement, ‘a’ (from the French ‘acier’) for structural steel, and ‘p’ or ‘ap’ for profiled steel sheeting. Another key subscript is \( k \), as in

\[ M_{Ed} = \gamma_f M_{Ek} \]

Here, the partial factor \( \gamma_f \) is applied to a characteristic bending action effect to obtain a design value, for use in a verification for an ultimate limit state. Thus ‘k’ implies that a partial factor (\( \gamma \)) has not been applied, and ‘d’ implies that it has been. This distinction is made for actions and resistances, as well as for the action effect shown here.