Analysis and Design of Steel and Composite Structures

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This book is dedicated to the memory of my parents, Bo Fen Liang (1928–1981) and Xing Zi He (1936–1987), and to my wife, Xiao Dan Cai, and my sons, Samuel Zhi De Liang, Matthew Zhi Cheng Liang and John Zhi Guo Liang.

Preface

Steel and composite steel–concrete structures are widely used in modern bridges, buildings, sport stadia, towers and offshore structures. The analysis and design of steel and composite structures require a sound understanding of the behaviour of structural members and systems. This book provides an integrated and comprehensive introduction to the analysis and design of steel and composite structures. It describes the fundamental behaviour of steel and composite members and structures and the latest design criteria and procedures given in Australian Standards AS/NZS 1170, AS 4100, AS 2327.1, Eurocode 4 and AISC-LRFD specifications. The latest research findings on composite members by the author's research teams are also incorporated in the book. Emphasis is placed on a sound understanding of the fundamental behaviour and design principles of steel and composite members and connections. Numerous step-by-step examples are provided to illustrate the detailed analysis and design of steel and composite members and connections.

This book is an ideal course textbook on steel and composite structures for undergraduate and postgraduate students of structural and civil engineering, and it is a comprehensive and indispensable resource for practising structural and civil engineers and academic researchers.

Chapter 1 introduces the limit state design philosophy, the design process and material properties of steels and concrete. The estimation of design actions on steel and composite structures in accordance with AS/NZS 1170 is described in Chapter 2. Chapter 3 presents the local and post-local buckling behaviour of thin steel plates under in-plane actions, including compression, shear and bending of steel plates in contact with concrete. The design of steel members under bending is treated in Chapter 4, which includes the design for bending moments and the shear and bearing of webs to AS 4100. Chapter 5 is devoted to steel members under axial load and bending. The analysis and design of steel members under axial compression, axial tension and combined axial load and bending to AS 4100 are covered. In Chapter 6, the design of bolted and welded steel connections, including bolted moment end plate connections and pinned column base plate connections, is presented. Chapter 7 introduces the plastic analysis and design of steel beams and frames.

The behaviour and design of composite slabs for strength and serviceability to Eurocode 4 and Australian practice are treated in Chapter 8. Chapter 9 presents the behaviour and design of simply supported composite beams for strength and serviceability to AS 2327.1. The design method for continuous composite beams is also covered. The behaviour and design of short and slender composite columns under axial load and bending in accordance with Eurocode 4 are given in Chapter 10. This chapter also presents the nonlinear inelastic analysis of thin-walled concrete-filled steel tubular short and slender beam-columns under axial load and biaxial bending. Chapter 11 introduces the behaviour and design of composite connections in accordance with AISC-LRFD specifications, including single-plate and tee shear connections, beam-to-composite column moment connections and semi-rigid composite connections.

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Contents

Chapter 1

Introduction

1.1 STEEL AND COMPOSITE STRUCTURES

Steel and composite steel–concrete structures are widely used in modern bridges, buildings, sport stadia, towers and offshore structures. According to their intended functions, buildings can be classified into industrial, residential, commercial and institutional buildings. A steel structure is composed of steel members joined together by bolted or welded connections, which may be in the form of a pin-connected truss or a rigid frame. In comparison with reinforced concrete structures, steel structures have the advantages of lightweight, large-span, high ductility and rapid construction. The rapid steel construction attributes to the fact that steel members and connection components can be prefabricated in a shop. As a result, significant savings in construction time and costs can be achieved. Perhaps, steel portal frames as depicted in Figure 1.1 are the most commonly used steel structures in industrial buildings. They are constructed by columns, roof rafters and bracings, which are joined together by knee, ridge and column base connections. The design of steel portal frames is treated in this book.

The advantages of the rapid and economical steel construction of multistorey buildings can only be utilised by composite steel–concrete structures, which are efficient and cost-effective structural systems. Composite structures are usually constructed by composite columns or steel columns and steel beams supporting composite slabs or concrete slabs. It is noted that steel is the most effective in carrying tension and concrete is the most effective in resisting compression. Composite members make the best use of the effective material properties of both steel and concrete. A composite beam is formed by attaching a concrete slab to the top flange of a steel beam as shown in Figure 1.2. By the composite action achieved by welding shear connectors to the top flange of the steel beam, the steel beam and the concrete slab works together as one structural member to resist design actions. In a composite beam under bending, the concrete slab is subjected to compression, while the steel beam is in tension, which utilises the effective material properties of both steel and concrete. The common types of composite columns include concrete encased composite columns, rectangular concrete-filled steel tubular columns and circular concrete-filled steel tubular columns as presented in Figure 1.3. High-strength composite columns have increasingly been used in high-rise composite buildings due to their high structural performance such as high strength and high stiffness. The fundamental behaviour and the state-of-the-art analysis and design of composite slabs, composite beams, composite columns and composite connections are covered in this book.

The design of steel and composite structures is driven by the limited material resources, environmental impacts and technological competition which demand lightweight, low-cost and high-performance structures. These demands require that structural designers must have a sound understanding of the fundamental behaviour of steel and composite