David Blockley

STRUCTURAL ENGINEERING

A Very Short Introduction

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Preface

If you have ever wondered how a skyscraper, like the Shard in London, a big bridge, like the Golden Gate in San Francisco, a jumbo jet like the A380, or a cruise liner, like the *Queen Elizabeth*, stand tall: if you have ever wondered where the architecture stops and the engineering begins—then this is a book for you. We will explore in non-technical language how large man-made structures are created.

The purpose of the book is three-fold. First, I aim to help the general reader appreciate the nature of structure, the role of the structural engineer in man-made structures, and understand better the relationship between architecture and engineering. Second, I provide an overview of how structures work: how they stand up to the various demands made of them. Third, I give students and prospective students in engineering, architecture, and science access to perspectives and qualitative understanding of advanced modern structures—going well beyond the simple statics of most introductory texts.

Inevitably in such a short volume choices have to be made about what not to include. There will be gaps—in particular I have made no attempt to describe the everyday life and work of a structural engineer, the science of materials is limited, and I make only brief references as to how structures are actually put together. I have included some recommendations for further reading.

Everything has structure. The function of structure is to provide the form and shape on which other functions can operate. Natural structures vary from the very smallest part of an atom to the entire cosmology of the universe. Man-made structures include buildings, bridges, dams, ships, aeroplanes, rockets, trains, cars, and fairground rides, and all forms of artefacts—even large sculptures like the Angel of the North in the UK.

Structure is the difference between a random pile of components and a fully functional object. Through structure the parts connect to make the whole.

Engineering is the 'turning of ideas into reality'. Structural engineering is a critical part of the fulfilling of some of our most basic human needs—particularly for shelter, protection, and travel. It has evolved from the common-sense building of primitive huts, bridges, and weapons of ancient history, through the craft skills of medieval master masons who built castles, cathedrals, and country houses, to the latest and most sophisticated use of the science of structures and materials.

The wide range of different industries in which structural engineers work includes construction, transport, manufacturing, and aerospace. Each industry has its own particular ways of doing things. The book attempts to get behind those differences to the essential common core.

The work in a typical structural engineering design consultancy might be 30 per cent on design discussions; 30 per cent on structural analysis; 30 per cent on determining construction details; and 10 per cent on specifying, supervising, and checking the work. The structure of the book does not follow that pattern—instead we begin in Chapter 1 to trace the close and often controversial relationship between architectural and structural form and function. This clarification is important because so many people, including much of the media, see structure as architecture. We will see that architects rely on engineers to make their ideas work, in other words, to stand up safely and operate successfully. However, just as an architectural form may not function well structurally so an efficient structural form may not be good architecturally. The best structures are a harmony of architecture and engineering—where form and function are one and the flow of forces is logical. We also learn in Chapter 1 how you can develop your own understanding of structural form with some very simple experiments you can do at home. In Chapter 2 we examine the three requirements for good structure set by the Roman Vitruvius long ago: resilience, purpose, and delight. We see that force pathways are degrees of freedom and that so-called form-finding structures are exciting and innovative examples of the fusion of engineering and architecture. We find that structures are naturally lazy because they contain minimum potential energy. Chapter 3 gives us the historical perspective necessary to understand the modern controversies as we trace the story of the emergence of the master mason and the increasingly separate roles of the architect and the engineer. We see how, from the Renaissance onwards, specialisms grew through new scientific knowledge, new materials, and new demands for structures. We begin to understand how the engineering profession developed into a science based capability to create some very large and breathtaking structures. Chapter 4 then builds on that background to help us understand better the science of how structures work. By that I mean how they resist all of the demands made on them by forces of self-weight, people moving about, wind that may blow a hurricane and ground that may vibrate in an earthquake. These forces have to 'flow through' the components of the structure rather as water flows through a set of pipes. We introduce some of the major theoretical principles that are the basis for modern computer analysis methods. In Chapter 5 we examine the commonalities and differences between four types of very large impressive structures—a jumbo jet, a cruise ship, a long span bridge, and a skyscraper building. Finally in Chapter 6 we ask questions about risk because structures are safety critical—when they fail people may be killed. We recognize that no human activity is risk free. We ask how safe is safe enough. We identify a relatively new philosophy called 'systems-thinking' to examine how we might provide structures that will be resilient to the extreme weather events caused by changes in our climate should the worst scientific predictions come to pass.

Structural engineering is an important part of almost all undergraduate courses in engineering. This book is novel in the use of 'thought-experiments' as a straightforward way of explaining some of the important concepts that students often find the most difficult. These include virtual work, strain energy, and maximum and minimum energy principles, all of which are basic to modern computational techniques. The focus is on gaining understanding without the distraction of mathematical detail. The book is therefore particularly relevant for students of civil, mechanical, aeronautical, and aerospace engineering but, of course, it does not cover all of the theoretical detail necessary for completing such courses.

Structural engineering is a dominantly male profession. An increasing number of women are being recruited and rising to senior levels. Structural engineers, their professional bodies, the universities, and governments around the world are actively campaigning to recruit more women (see for example <http://www.wisecampaign.org.uk/> and <http://raeng.org.uk/news/publications/list/reports/Inspiring_Women_Engineers.pdf>). In this spirit I have used the feminine gender when needed.

I would like to thank a number of people who have helped me enormously. Anne Thorpe and Oksana Kasyutich have both read the whole book and made several suggestions to help make it

more accessible to the lay reader. My own specialism within structural engineering is in construction and so the invaluable help of a number of structural engineers in naval architecture and aerospace engineering has been crucial. In particular I am indebted to Emeritus Professor John Caldwell of the Department of Naval Architecture at the University of Newcastle for his close reading of my references to all things naval and for making many useful corrections and suggestions. Thanks to Vaughan Pomeroy, ex-Technical Director of Lloyd's Register and now Visiting Professor at the University of Southampton, who has read the whole book and made a number of corrections and suggestions. I am grateful to Danny Heaton, retired from Airbus, also for reading the entire book and particularly for helping me understand aircraft regulations. I thank Professor Paul Weaver of the Department of Aerospace at the University of Bristol for spotting at least one error and for checking out my references to aircraft structures. I am grateful for the close reading by Emeritus Professor Mike Barnes of the Department of Civil Engineering at the University of Bath and for making many pertinent and useful comments for improvements. I thank Michael Dickson for some useful advice and Simon Pitchers for valuable conversations about the relationships between structural engineering and architecture. Thanks go to David Elms for pointing me to the mathematical proof that you can find a stable position for a four-legged table on a rough floor and for consequent discussions that led to the explanation in the Reference Section to Chapter 4. I thank Robert Gregory for his reading of the text and permitting me to include his photograph of a spider's web.

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