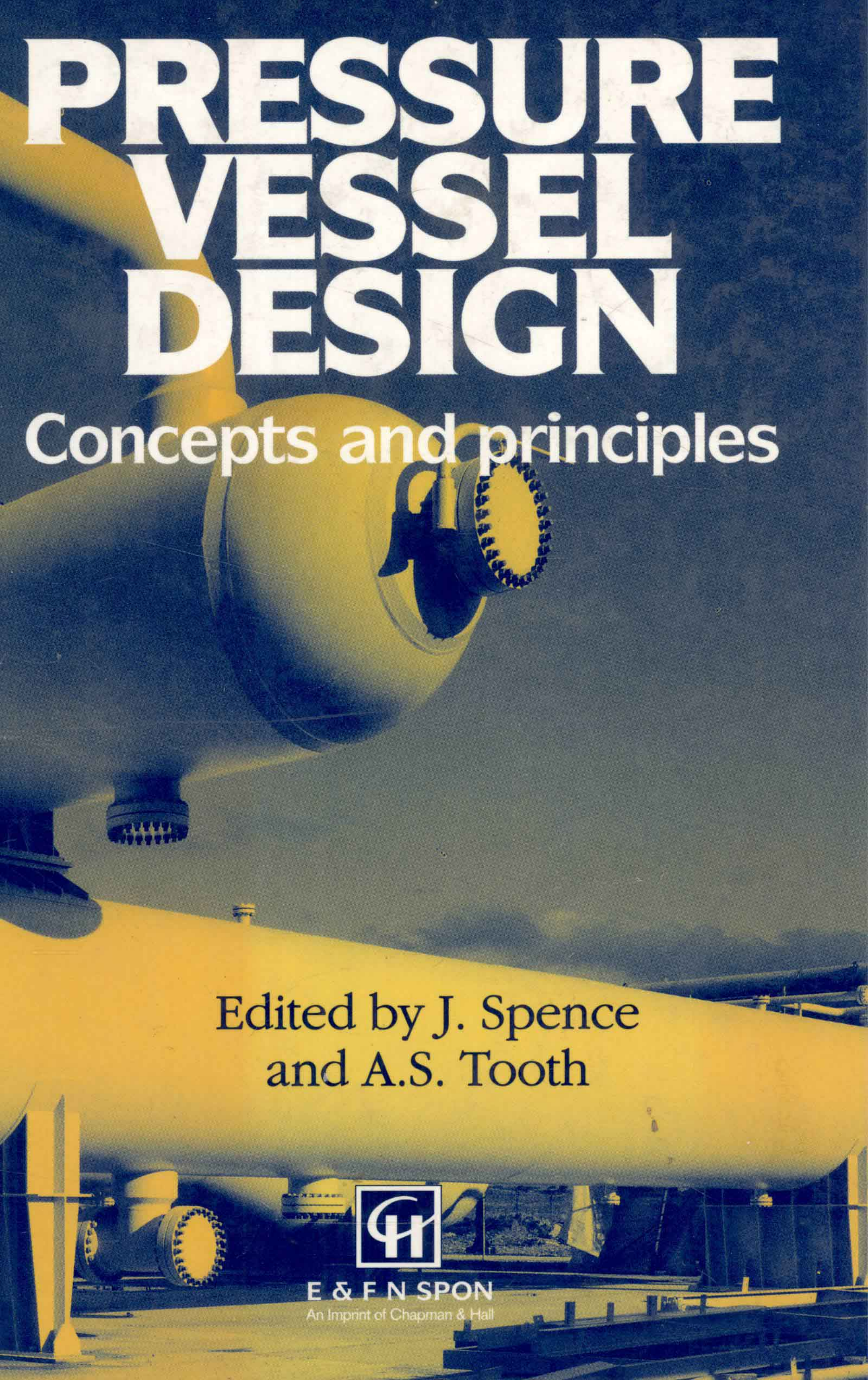

PRESSURE VESSEL DESIGN

Concepts and principles

Edited by J. Spence and A.S. Tooth

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PRESSURE VESSEL DESIGN

Preface

Pressurised equipment is required in a wide range of industrial plant for storage and manufacturing processes. The size and geometric form of the 'vessels' used varies greatly from the large cylindrical vessels required for high-pressure gas storage to the small purpose-built vessels used in the aeronautics industry. Petrochemical plant and offshore oil and gas rigs bristle with pressure vessels. In each case the vessels have to be carefully designed to cope with the operating temperatures and pressures. Plant safety and integrity are paramount and depend initially on the adequacy of the design methods.

Over the last century the design of equipment has developed in a progressive way. In the early days many components were designed on the basis of a 'stress concentration factor' (SCF) applied to the basic membrane stress. The technical basis of this SCF was often somewhat inadequate — perhaps a few strain gauge results or the avoidance of gross distortion of a critical region. At times one could be forgiven in thinking that the SCF was a 'fudge factor'.

A considerable boost was provided to the understanding of the basic behaviour of these components following the development of the nuclear power programme both in the USA and in Europe in the late 1950s and early 1960s. Minds were 'concentrated wonderfully'. A wide range of applied mechanics problems were solved at this time many of which were relevant to pressure vessel design. Terms such as 'limit analysis' and 'shakedown' became part of the design vocabulary. In time, these concepts were incorporated into the design philosophy of many pressure vessel standards. However, their inclusion was somewhat piecemeal and with the passage of time to some extent were shrouded in mystery.

More recently, with the advent of increased service demands, quality requirements and safety legislation it has become more important for engineers to understand the fundamental principles underlying the methodologies within the standards.

Partly with this in mind in 1986 the Pressurised Systems Group of the Institution of Mechanical Engineers, London, UK, with the support of the British Standards Institution (BSI) and in collaboration with the University of Strathclyde, planned a series of seminars and a course related to pressure vessel design. The course was held at the Department of Mechanical Engineering, University of Strathclyde, Glasgow, UK, in June 1986. The respective chairmen of the BSI Specialist Working Parties of the PVE/-/5 Pressure Vessel Design Committee were invited to speak at the course (and the seminars). The course numbers were restricted to approximately 50 but the course was oversubscribed and an overflow course was therefore held in September of the same year. The pattern of seminars and course(s) established in 1986 has been repeated each year. While a different theme has been selected for the seminars in London, the basic philosophy course has been held each year, with a full complement of delegates.

In response to industrial demand the range of courses has been extended progressively to cover basic and advanced examples, piping design, the use of finite elements in pressure vessel design and GRP pipes and vessels. To date, the original philosophy course has been held eight times in Glasgow and, also variants thereof, in Singapore, Poland, Brazil, the Republic of South Africa, Australia and Egypt with a total attendance approaching 1000 delegates. It is considered that a key element in the continuing success of the course is that the lecturers are drawn primarily from the appropriate BSI Pressure Vessel Design Committee. The delegates, therefore, had the advantage of listening to and questioning the Standard writers face to face. The interaction with the large number of participants has provided an excellent opportunity for constantly revising and updating the contents of the course. For example, a section on the European scene was introduced in 1991, in an effort to prepare the industry for a more active entry into Europe from 1993.

Over the years it has been our pleasure to host these courses at Strathclyde and to meet the many delegates who have spent a few days with us. The lecturing team has remained the same since the beginning. Throughout, they have given their time and efforts unstintingly and the editors would like to record their indebtedness to them. It has been, and continues to be, a pleasure and a stimulating experience to work together with them on this endeavour.

With our educational background in engineering we have always believed that knowledge was best transferred in the atmosphere of open discussion. The course suited that concept. In view of this we were initially somewhat reluctant to provide the course notes to anyone other than the delegates or to provide the material in book form. However, it has become apparent that many colleagues would welcome a book on this topic. Each author has, therefore, completely revised and rewritten their contributions in a format more suitable for book form. While the British Standard (BS 5500) has been used extensively in the text, the concepts and principles are appropriate to other national standards. The move to develop a European Standard, referred to in Chapter 12, means that changes will take place in the approach used to design various components. It is the hope of the editors that the fundamental philosophy, which is outlined herein, will not only assist those engineers currently involved in design but will also help provide a solid base to understand the alternative design approaches which will no doubt appear in the next decade.

This book will be of interest to the designers and fabricators, to users and plant operators, to inspection bodies, academics, senior students and researchers who are involved with pressurised systems. We trust that both newcomers to the field and experienced practitioners will find this book stimulating and rewarding.

J. Spence and A.S. Tooth, 1992

Acknowledgements

The editors and authors of this volume would like to acknowledge the help and cooperation of colleagues past and present and their respective employers and organisations. Scientific information and engineering 'know-how' has been made available in the hope that this will lead to improved plant safety and integrity. They also acknowledge the help given by the British Standards Institution, who have made available diagrams and charts from BS 5500 to illustrate the text.

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James Boyle is a Professor in the Department of Mechanical Engineering at the University of Strathclyde where he has been on the academic staff for the past 10 years. Previous to that he held a number of research posts. His research interests include solid mechanics, inelasticity (plasticity and creep), high-temperature design, finite element methods and composite materials. Particular emphasis has been placed on applications to pressure vessel design and on problems of design by analysis. He is the author of Chapter 3 – 'Plastic design concepts'.

R. Fawcett

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Richard Fawcett has been working with ICI on the design of vessels, especially catalytic reactors since 1966. He is a graduate of Cambridge and MIT. He became a member of the BSI pressure vessel design methods sub-committee in 1978 and its chairman in 1989. He considers that his role there has been to make the Standard (BS5500) more usable and useful to the practicing designer. He is presently the leader of the UK delegation on the design committee to provide a European Pressure Vessel Standard. He is the author of Chapter 12 – 'Progress towards a European standard'.

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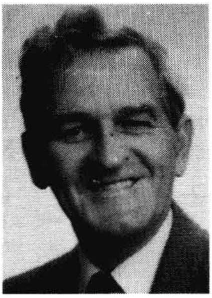

Gerry Galletly is a graduate of both Liverpool University and MIT. He spent 12 years in government/industry (working for the US Navy, Shell Development Corporation and Pratt & Whitney Aircraft) and has been Professor of Applied Mechanics at Liverpool since 1964. He has published more than 100 papers on shell structures, many on buckling problems related to torispherical shells. Several of the papers have been awarded prizes by IMechE and ASME. He was elected to the Royal Academy of Engineering (FEng) in 1989. He is a co-author of Chapter 7 — 'Design rules for dished ends'.

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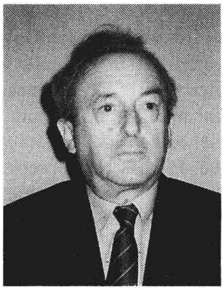

After a short spell in the aircraft industry, Bill Kendrick joined the Naval Construction Research Establishment in 1950. He retired in 1986 as Head of the Structures Division of the Admiralty Research Establishment. He was awarded an OBE for his work on the Structural Design of Supertankers. He was responsible for the technical aspects of the External Pressure section of BS5500 and presently acts as a consultant to the industry. He is a graduate of the Universities of Nottingham and Glasgow and the author of Chapter 8 – 'The design of externally pressurised vessels with BS 5500'.

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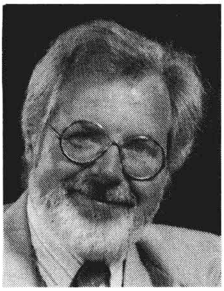

Steve Maddox was educated at the University of Southampton and Imperial College of Science and Technology, London from which he gained his PhD on 'A fracture mechanics analysis of the fatigue strength of welded joints' in 1972. He is a Chartered Engineer and Fellow of the Welding Institute. In 1983 he received the Leslie Lidstone ESAB Gold Medal for his contribution to welding technology. After working as a Scientific Officer in the Fatigue Section of the Engineering Department of The Welding Institute he joined the Mechanical Engineering Department at Southampton University as Technical Manager of the Wolfson Materials Advisory Service in 1974. In 1977 he returned to The Welding Institute and became Head of the Fatigue Laboratory. He has published over 50 papers in the area of fracture mechanics and fatigue in welded structures and is currently Principal Fatigue Consultant to the Engineering and Materials Group at The Welding Institute. He is Chairman of Commission XIII 'Fatigue of welded components and structures' of the International Institute of Welding and a member of working groups producing fatigue rules. He is the author of Chapter 9 – 'Fatigue aspects of pressure vessel design'.

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Roderick McFarlane graduated from Cambridge University in 1970. He has always worked for BP, initially with BP Chemicals in Hull and latterly with BP Engineering in London. He has been a member of the BSI committee PVE/-/5 for 10 years and is the author of PD 6500, the four-part supplement to BS5500. He has twice presented papers at ASME Pressure Vessel and Piping Conference. He is the author of Chapter 10 – 'Tubesheet design'.

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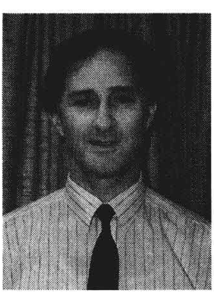

Doug Moffat is a graduate of Strathclyde University. Following 1 year of training with Rolls Royce Aero Engines and then 8 years in Babcock & Wilcox Ltd Research Department he joined the University of Liverpool Department of Mechanical Engineering in 1968 where he is now a Reader. His research interests have always been concerned with pressure vessel and piping problems, including aspects of elastic stress analysis, shakedown, buckling and collapse. He is a member of the IMechE Pressure Systems Group Committee. He is a co-author of Chapter 7 – 'Design rules for dished ends'.

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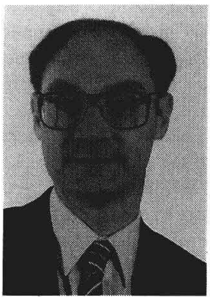

Howard Price was educated at William Hulme's Grammar School and Manchester University where he graduated in Mathematics. In 1968 he joined Rolls Royce (Aero Engine Division) in Derby as a trainee, and subsequently worked on heat transfer and stressing aspects of cooled turbine blades. In 1971 he moved to the Research Department of the Central Electricity Generating Board at Berkeley Nuclear Laboratories in Gloucestershire where he became part of a group carrying out theoretical and experimental studies on pressure vessels and boilers. He was soon involved with a British Standard working group revising the water-tube boiler code BS1113 and helping to implement the shakedown approach to the design of branches. Later he drafted the nozzle design section for BS5500 based on the most advanced approaches then available. He is now in the Structural Engineering Branch of Nuclear Electric plc, one of the CEGB's successor companies. He is the author of Chapter 6 – 'Nozzle design and branch connections'.

J. Spence
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John Spence holds degrees from the Royal College of Science and Technology (now the University of Strathclyde) and the University of Sheffield. His early career was spent with Stewarts & Lloyds and Babcock & Wilcox before moving to the University of Strathclyde where he is Head of Mechanical Engineering and holds the Trades House of Glasgow Chair of Mechanics of Materials. His main technical interest has been in Pressure Vessel and Piping Design associated with power generation plant. He has published widely with several books and about 100 technical papers. He presently serves on the British Standards Institution Master Pressure Vessels Standards Committee PVE/- and the Pressure Vessel Design Methods Committee PVE/-/5. He is currently Vice-President of the Institution of Mechanical Engineers and serves on various Institution committees including being chairman of the Research Committee, chairman of the International Affairs Committee and vice chairman of the Pressure Systems Group; he also serves on several other national committees. He is author of Chapters 1, 2 and 4 – dealing with basic shell analysis and design philosophy.

G. Thomson
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Gordon Thomson has a BSc in Mechanical Engineering (1977) and a PhD for research on pipework components (1981) from the University of Strathclyde. He began his career with Ferranti in Edinburgh as a stress engineer working on the design of electro-optic avionics before moving to become Design Manager for Motherwell Bridge in 1984, responsible for the design of pressure vessels and heat exchangers. In 1987, he moved to become Sales Manager for Babcock Energy in Renfrew, Scotland, primarily responsible for pressure vessel sales to the oil and petrochemical industries. Since 1988, Dr Thomson has been with GEC Ferranti and is currently Chief Engineer (Design) for the Navigation Systems Division. He is the author of Chapter 11 – 'Flange design'.

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Alwyn Tooth served an apprenticeship with the Simon Engineering Group before entering UMIST in 1948. He moved to Glasgow in 1952 to a lecturing post in the Royal College of Science and Technology (now University of Strathclyde). His early research work was stimulated by the need to establish design methods for nuclear containment buildings, then under consideration. This work was followed by a study of other pressurised containers and storage vessels with particular reference to the support of horizontal vessels. In 1972 he was invited to join the BSI specialist study working group on the support of horizontal vessels. He was appointed chairman of this group and joined the main BSI Pressure Vessel Design Committee PVE/-/5 in 1977. He has published extensively on these subjects and is the author of Chapter 5 – 'Local loads, supports and mounting'.

Contents

1

Introduction

J. Spence

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1.1 Preamble

Engineering design usually means design to ensure fitness for service. In the pressure vessel industry this will almost always involve strength considerations. What follows here is therefore not concerned with general or 'total design' which is a topic with far reaching ramifications; rather