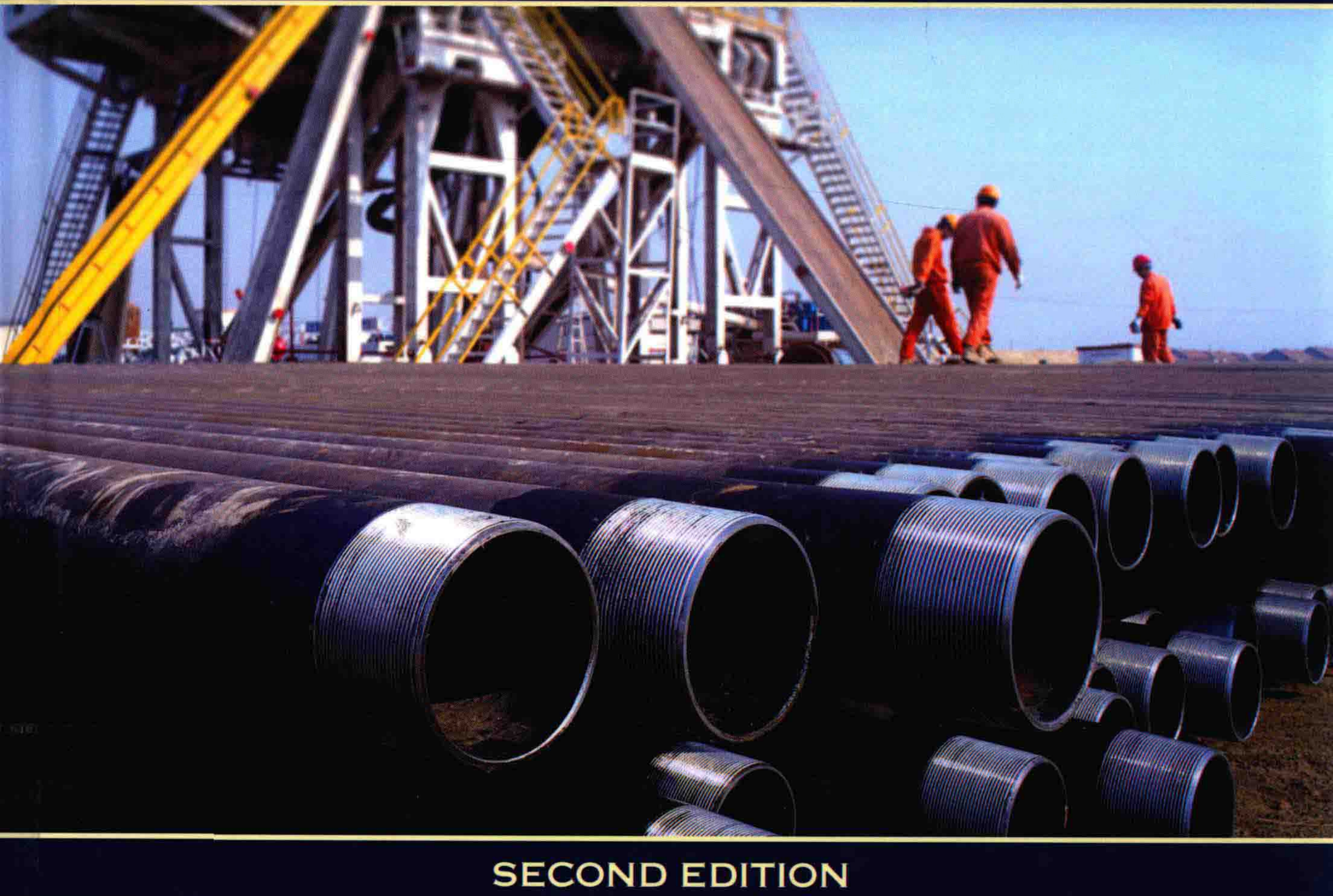
GULF DRILLING GUIDES

CASING AND LINERS FOR DRILLING AND COMPLETION

DESIGN AND APPLICATION



SECOND EDITION

TED G. BYROM

Casing and Liners for Drilling and Completion

Design and Application

Second Edition

Ted G. Byrom

ELSEVIER

AMSTERDAM • BOSTON • HEIDELBERG • LONDON
NEW YORK • OXFORD • PARIS • SAN DIEGO
SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO
Gulf Professional Publishing is an imprint of Elsevier

G | P
P |

Gulf Professional Publishing is an imprint of Elsevier
225 Wyman Street, Waltham, MA 02451, USA
The Boulevard, Langford Lane, Kidlington, Oxford, OX5 1GB, UK

Second Edition 2015

First Edition 2007

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the Library of Congress

British Library Cataloguing in Publication Data
Byrom, Ted G.
Casing and liners for drilling and completion : design and application / by Ted G. Byrom. – Second edition.
pages cm
Includes bibliographical references and index.
ISBN 978-0-12-800570-5
1. Oil well casing–Design and construction. I. Title.
TN871.22.B97 2014
622′.3381–dc23

2014014250

For information on all Gulf Professional publications
visit our web site at store.elsevier.com

This book has been manufactured using Print On Demand technology. Each copy is produced to order and is limited to black ink. The online version of this book will show color figures where appropriate.

ISBN: 978-0-12-800570-5

Acknowledgments

I owe very special thanks to Leon Robinson who encouraged the first edition of this textbook as the first in a series of textbooks that he envisioned as an encyclopedia of drilling technology. Simply put, his goal was to publish a record of current drilling technology before the "old timers" all retired and faded away. He recognized that a trend in more frequent personnel turnover was resulting in an industry cycle of having to continually reinvent drilling practices and technology that have been well known by earlier generations of engineers. His encouragement was invaluable to the first edition, and he continues to be an inspiration for this second edition.

Thanks also to Marc Summers for his valuable suggestions on additional load cases and their systematic organization, and so too, the many helpful suggestions of others who used the first edition in teaching casing design.

Finally, and especially, I extend my grateful appreciation to my editors, Katie Hammon, Kattie Washington, and Anusha Sambamoorthy whose enthusiasm and tireless efforts made this the smoothest publishing experience of my career.

Preface

This second edition represents a significantly revised and improved version of the first edition, and in many respects it is a new book. I have taught various aspects of casing design over more than twenty years, and for the past six I taught a 5-day basic casing design course from the first edition of this book. I felt that some changes in organization and approach would greatly enhance its value for engineers learning casing design. Hence, the present focus is on a clear and logical progression through the design/selection sequence and related practices followed by material on more advanced topics of casing performance mechanics and casing in directional and horizontal wells.

I have added some new material on loading cases and some additional perspective on approaches to design. Especially topical is the addition of a section on casing performance in hydraulic fracturing of horizontal wells, a relatively new application and one in which I have been consulting in the past few years. Along these lines, I have also added a brief overview of some aspects of rock mechanics as it relates to fracturing and horizontal wells in a separate appendix.

While the first edition contained much foundational matter such as units of measure, hydrostatics, and so forth, it was all interspersed throughout the main body of text. That order of presentation works well for an introduction to casing design, but once an engineer is past the fundamentals it makes for an amount of clutter for someone wanting to refer back specifically to the design/selection process. Consequently, I have moved most of the foundational material from the body of the text into appendices for easy study and reference. One might question the necessity for including such foundational material in a text like this, but having taught specific industry training courses for engineers over the past eighteen years, I can assure you that most of this material is essential. Engineers who approach casing design for the first time typically come from various disciplines and may or may not have any previous exposure to solid mechanics, but more importantly, it is an inescapable fact that we forget what we were taught if we are not using it on a regular basis. Those new to the topic of casing design should devote serious study to these appendices, and I highly encourage all to at least review them. In the appendices I have gone into greater depth and detail on some of the peripheral issues of casing than might seem necessary for those whose only interest is in basic level casing design, but I did so to enhance the value of the book as a fairly complete reference on the topic.

I have included scant material on pipe standards and specifications, especially in regard to connections, only what is essential to understand the process of casing design. The reasons for this are twofold, one is that standards and specifications change periodically and a book based heavily on them is out of date as soon as a new specification or standard is published, and the other is that most of the meager published data on oilfield tubulars is of a nominal or minimal performance nature and readily available elsewhere. My focus in this book is on the fundamental mechanics that will not change over time.

Finally and importantly, as with the first edition, I have tried to maintain a conversational style so that it may be easily read and understood by those seeking self education without the necessity of an instructor. There are many precautions and opinions sprinkled throughout, sometime homiletic in tone, but all based in real case histories, most of which could never find their way into print. I hope these add to the content. Overall, the reader should find this edition to be a much improved and more useful textbook.

Ted G. Byrom
Mount Vernon, Indiana
January, 2014

Preface to the First Edition

Hardly anyone reads a Preface. Please read this one, because this book is a bit different and what is written here is the actual introduction to the book. I never read a textbook that I really liked when I was a student. The main reason is that most authors seemed more interested in presenting the information with the goal of impressing colleagues rather than instructing the reader as a student of the subject. For a long time, I thought they were so smart that they could not relate to the ordinary student. I now know that is rarely true. You should know that I have reached a point in my career where no one is important enough that I need to impress, and certainly no money is to be made writing a textbook. My reason for accepting the task of writing this text is that I truly wanted to attempt to explain this subject in an understandable manner to the many petroleum engineers who need or want to understand it but at best received a couple of classroom lectures and a homework assignment on the subject from someone who never designed or ran a real string of casing in his life. I was in that same position some 44 years ago. This book is also intended for those coming into the oilfield from other disciplines and needing to understand casing design.

This book is not written in the style of most textbooks. That is because it its main purpose is to teach you, the reader, about casing and casing design without need of an instructor to "explain" it to you. I would like you to read this as if you and I were sitting down together as I explain the material to you. While some of the material requires a little formality, I have tried to put it on a readable level that progresses through the various processes in a logical manner. I have also tried to anticipate, pose, and answer some of the questions you might ask in the process of our discussion.

The first five chapters of this book lay a foundation in basic casing design. It is, if you will, a recipe book for basic casing design. It does go into some detail at times, but overall its purpose is to actually teach an understanding of basic casing design. If you are not an engineer, and many casing strings are designed by nonengineers, do not be discouraged by the many equations you see. The information in this part should be sufficient to design adequate casing strings for the vast majority of the wells drilled in the world, and although the chapter on hydrostatics contains some calculus, none of it is beyond the capabilities of a second-year engineering student. The sixth chapter is about running and landing casing. Most of it is common sense, but there are some practical insights that are worth the time it takes to read.

Chapter 6 begins the discussion of slightly more advanced material. Some of this material is not covered in universities, except on a graduate level, but I have tried to present it so that any undergraduate engineering student should be able to understand it. The remaining chapters continue in the same vein.

I have not tried to cover everything about casing or casing design in this book. I have never had any aspirations of writing the definitive text on casing or any other subject, mostly because some aspects hold no interest at all for me. I have personally run and cemented close to a couple of hundred casing strings as a field drilling engineer, designed several hundred more, and been involved with several thousand casing strings over my career. These have ranged from very shallow strings to a few over 23,000 ft. Never have I designed a string for a geothermal well, and my corrosion and sour gas experience is limited. Consequently, little is said about those subjects in this book. There are much better sources for that than what I could write on those particular topics.

Ted G. Byrom
Mount Vernon, Indiana
September, 2006

Acronyms

AEUB	Alberta Energy and Utilities Board
API	American Petroleum Institute
IADC	International Association of Drilling Contractors
ISO	International Organization for Standardization
SPE	Society of Petroleum Engineers

See Glossary for technical acronyms.

Contents

Introduction to casing design

1

Chapter outline head

1.1 Introduction

In this textbook, we will explore the fundamentals and practices of basic casing design with some introduction to more advanced ideas and techniques. We will use a simple process that involves manual calculations and graphical plots. This is the historical method of learning casing design and will instill a depth of understanding. For the vast majority of casing strings run in the world this is still the method

Casing and Liners for Drilling and Completion. http://dx.doi.org/10.1016/B978-0-12-800570-5.00001-2

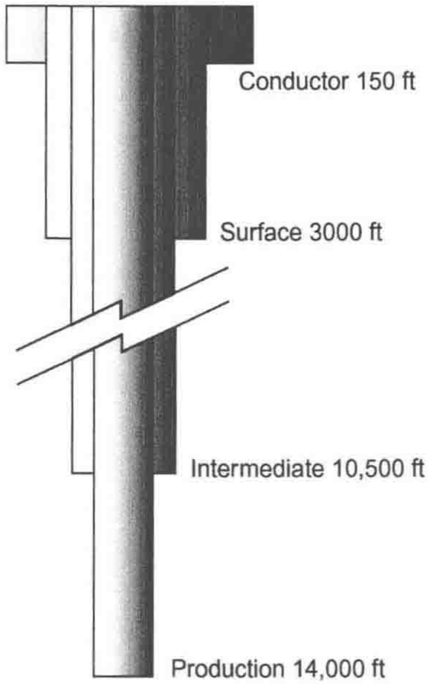


Figure 1.1 Casing string design for a typical well.

employed. Those engineers already well founded in the process may use more advanced techniques and specific software. While there is some excellent software on the market that does casing design, one cannot really learn the process using software. This is not by any means a harangue about casing design software; some of it is excellent and quite sophisticated especially compared to the crude first attempts that hit the market. But the unwelcome fact is that many who are using it are overwhelmed by multipage, detailed printouts, half of which they do not even pretend to understand. And truth be told, many of the "support" personnel experience the same problem. Information is not knowledge if you do not understand it.

1.2 Design basics

Casing design is a bit different from most structural design processes in engineering because the "structure" being designed is a single tubular monolith of given outside diameter primarily supported from the top end. There is nothing to actually "design" in the conventional sense of structural engineering. Geometrically speaking, our structure is already designed. The available tubular sizes and strengths are standardized, so the design process maybe thought of as a two-step process:

1. Calculate the anticipated loads.
2. Selecting from the available standard tubes those with adequate strength to safely sustain those loads.

As simple as that may sound, casing design is still not a linear process. It is not a matter of calculating the anticipated loads and then selecting the casing. The selected casing itself is part of the load. Hence, the process must be iterated to account for that fact. Still, it is quite an easy process in the vast majority of cases.

The basic design/selection sequence in its iterative form might be listed in steps:

1. Determine depths and sizes of casing.
2. Determine pressure loads.
3. Apply design factors and make preliminary selection.
4. Determine axial loads and apply design factors.
5. Adjust preliminary selection for axial design loads.
6. Adjust for combined tension/collapse loading.

Some might not consider Step 1 a part of casing design, and technically that is true. That step might be done by someone other than the casing designer and not in conjunction with the actual design process. However, we are going to include it in our treatment because it is essential for us to understand how it is done and how the results affect our design process.

The actual design process starts with Step 2, where we calculate the pressure loads for various scenarios using basic hydrostatics. We do this for all the strings in the well.

In Step 3 we select the worst case pressure loading from the previous step and apply a design factor which gives us a margin to account for uncertainty in the loads and pipe strengths. The results of that are design pressure-load plots for each string of casing in the well. From these plots, we make preliminary selections of casing, which will safely sustain those design loads.

Because the axial load (weight) of the string is a function of the casing itself, we must then calculate it from the preliminary pressure-load selection. We then apply a design factor to the axial load and check to see if our preliminary selection has sufficient axial strength. If it does, Step 4 is complete and we skip Step 5. If it does not, then in Step 5, we must modify the preliminary selection so that it also satisfies the axial design load. When we modify the preliminary selection, we must recalculate the axial load for the modified string and apply our axial design factor again. We must also check to ascertain that the modified string still meets our pressure-load design requirements. So in this step, the process becomes iterative. It is not difficult though, because in the manual process, it is easy to visually see the values and minimize the iterations. Seldom are more than two iterations required.

Finally, in Step 6, we check for the effects of combined axial tension and collapse loading, often referred to as *biaxial loading*. This is a critical step even in basic casing design, because tension in a string reduces the collapse resistance of the casing. This step too may require several iterations because any change or adjustment in the casing selection always requires that all the loads be rechecked.

For your early reference, Step 1 is covered in Chapter 2, Step 2 in Chapter 3, and Steps 3-6 in Chapter 4. Chapter 5 covers the casing installation process, and the remainder of the chapters covers more advanced topics.

1.3 Conventions used here

There is in the petroleum literature a virtual plethora of odd terminology, incoherent physical units, mathematical inconsistencies, and so forth. I have tried to adhere to several principles in this book:

- A readable text
- A progressive sequence for learning and self education
- Sufficient background material in appendices
- Adherence to ISO mathematics [1] and mechanics [2] standards
- Avoidance of acronyms except for organizational names (5) and those appearing in API/ISO standards (8) that you must necessarily understand plus only one other that is too common to not know (BOP)

Readability is essential for self-education, and I think, one of the most important features I have aimed for in this textbook. Perhaps I have oversimplified some concepts, but I prefer that to pedantic gibberish and superfluous acronyms that are more confusing than educational. And if the copy editor is successful at ironing out my convoluted sentence structure, you should find this book fairly readable.

1.3.1 Organization of book

The book is organized in a logical sequence that a beginner would follow to learn casing design, starting with the basics and proceeding to the more advanced topics. Chapters 2–4 illustrate basic casing design and Chapter 5 covers installation in the well. Having learned that material, the reader will have acquired the skills necessary for a fundamental level of casing design. That is the level of most who actually design the majority of casing strings in the world. Chapter 6 covers the details of casing strengths and performance, and Chapter 7 covers casing in deviated and horizontal wells. That latter chapter also contains materials on casing for hydraulic fracturing in horizontal wells.

Most of the referential and foundational materials on mechanics, hydrostatics, rock behavior, and so forth, have been moved to separate appendices so as not to clutter the logical progression of the design process and casing specific topics. Most of that material has been expanded in these appendices and should serve as handy reference or refresher for those needing it. I have also added an appendix with the most commonly used equations for easy access, rather than requiring a search through the text to locate them. Those equations that are boxed in the text are listed in this appendix along with their respective equation numbers from the text to facilitate locating the qualifications and discussions.

You will notice a number of redundancies in this text, and I can already imagine the number of times a reader may say, "He already said this!" While partly the result of my writing process, I have intentionally left some of these in place and added some. The reason is that it is seldom that anyone would read a text like this from beginning to end. More commonly one reads selectively those topics of concern or need, thus some of the pertinent precautions and qualifications mentioned elsewhere may be missed. I beg your patience when you encounter these.

1.3.2 Units and math

The problem with units in oilfield technology is that there are too many systems and hybrid systems in play, none of which use consistent units in oilfield applications. Here, I adhere to a simple underlying principle: *all physical phenomena are independent of any units used to measure them.* If we use consistent units from a coherent system, no conversion factors are necessary in properly stated physical formulas and equations. Importantly, *none of the formulas or equations in this book require conversion factors if you use consistent units*. There are no conversion factors included in any of the formulas, and it is left to you as a properly educated engineer to know when you need them. All that said, most of the global drilling and completion operations use the USC system (US Customary) of oilfield units, and we will bow to that custom here because it is the system of the vast majority of readers. The fundamental formulas will not require conversion factors, but our calculations will, and we will show them in the examples. Units of measure, physical constants, and material properties used in this text are covered in detail in Appendix B.

As in the first edition [3], I use specific gravity (specific density), $\hat{\rho}$, (SG) for liquid density, where specific gravity is defined as $\hat{\rho} \equiv \rho/\rho_{\text{wtr}}$, rather than the cumbersome lb/gal (ppg) of the USC system. This is done for ease of use in any unit system, where early in their education, every engineer committed