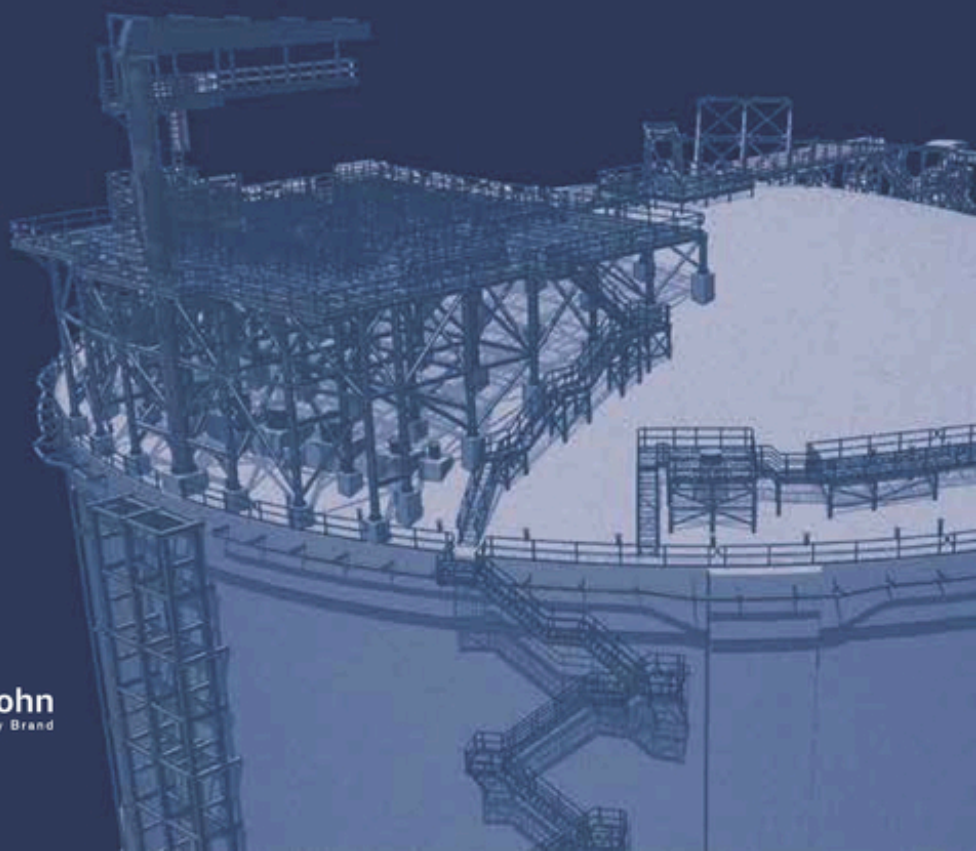


BetonKalender

Design and Construction of LNG Storage Tanks

Josef Rötzer



WILEY

 Ernst & Sohn
A Wiley Brand

Design and Construction of LNG Storage Tanks

Design and Construction of LNG Storage Tanks

Josef Rötzer

Author

Dr. Josef Rötzer

TGE Gas Engineering GmbH
Leopoldstraße 175
80804 Munich
Germany

Cover: LNG tank with typical steel structure

Photo courtesy: Günther Sell, TGE Gas Engineering GmbH, Munich

Editors of *Beton-Kalender*

Prof. Dipl.-Ing. Dr.-Ing. Konrad Bergmeister

Ingwien.at engineering GmbH
Rotenturmstr. 1
1010 Vienna
Austria

Prof. Dr.-Ing. Frank Fingerloos

German Society for Concrete and Construction Technology
Kurfürstenstr. 129
10178 Berlin
Germany

Prof. Dr.-Ing. Dr. h.c. mult.

Johann-Dietrich Wörner

ESA – European Space Agency
Headquarters
8-10, rue Mario Nikis
75738 Paris cedex 15
France

English Translation: Philip Thrift,
Hannover, Germany

■ All books published by **Ernst & Sohn** are carefully produced. Nevertheless, authors, editors, and publisher do not warrant the information contained in these books, including this book, to be free of errors. Readers are advised to keep in mind that statements, data, illustrations, procedural details or other items may inadvertently be inaccurate.

The original German text is published in *Beton-Kalender* 2016, ISBN 978-3-433-03074-5, titled "Planung und Auslegung von Flüssigerdgastanks". This book is the revised English translation of the mentioned contribution.

Library of Congress Card No.:
applied for

British Library Cataloguing-in-Publication Data

A catalogue record for this book is available from the British Library.

Bibliographic information published by the Deutsche Nationalbibliothek

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at <<http://dnb.d-nb.de>>.

© 2020 Wilhelm Ernst & Sohn, Verlag für Architektur und technische Wissenschaften GmbH & Co. KG, Rotherstraße 21, 10245 Berlin, Germany

All rights reserved (including those of translation into other languages). No part of this book may be reproduced in any form – by photoprinting, microfilm, or any other means – nor transmitted or translated into a machine language without written permission from the publishers. Registered names, trademarks, etc. used in this book, even when not specifically marked as such, are not to be considered unprotected by law.

Print ISBN: 978-3-433-03277-0

ePDF ISBN: 978-3-433-60997-2

ePub ISBN: 978-3-433-60996-5

oBook ISBN: 978-3-433-60998-9

Cover Design: Hans Baltzer, Berlin, Germany

Typesetting: SPi Global, Chennai, India

Printing and Binding: Printed in the Federal Republic of Germany

Printed on acid-free paper

Contents

Editorial *vii*

About the Author *ix*

- 1 Introduction** *1*
 - Reference *3*

- 2 History of Natural Gas Liquefaction** *5*
 - 2.1 Industrialisation and Energy Demand *5*
 - 2.2 The Beginnings of Gas Liquefaction *6*
 - 2.3 The First Steps Towards Transport in Ships *9*
 - 2.4 Algeria Becomes the First Exporter *11*
 - 2.5 Further Development with Peak-Shaving Plants *12*
 - 2.6 The First German LNG Tank in Stuttgart *13*
 - 2.7 Wilhelmshaven – the Attempt to Establish a German Receiving Terminal *14*
 - 2.8 The Liquefaction of Gas in Australia *15*
 - 2.9 Pollutant Emissions Limits in the EU *21*
 - References *23*

- 3 Regulations and their Scope of Applicability** *25*
 - 3.1 History of the Regulations *25*
 - 3.2 EEMUA Publication No. 147 and BS 7777 *26*
 - 3.3 LNG Installations and Equipment – EN 1473 *28*
 - 3.4 Design and Construction of LNG Tanks – EN 14620 *29*
 - 3.5 API 620 – the American Standard for Steel Tanks *32*
 - 3.6 API 625 – Combining Concrete and Steel *33*
 - 3.7 ACI 376 – the American Standard for Concrete Tanks *33*
 - References *34*

- 4 Definitions of the Different Tank Types** *37*
 - 4.1 Definitions and Development of the Different Types of Tank *37*
 - 4.2 Single Containment Tank System *38*
 - 4.3 Double Containment Tank System *40*
 - 4.4 Full Containment Tank System *40*

4.5	Membrane Tank System	44
	References	47
5	Performance Requirements and Design	49
5.1	Performance Requirements for Normal Operation	49
5.2	Thermal Design	51
5.3	Hydrostatic and Pneumatic Tests	52
5.4	Soil Survey, Soil Parameters and Permissible Settlement	54
5.5	Susceptibility to Soil Liquefaction	56
	References	58
6	Tank Analysis	59
6.1	Requirements for the Analysis of the Concrete Structure	59
6.2	Requirements for the Model of the Concrete Structure	60
6.3	Strut-and-Tie Models for Discontinuity Regions	62
6.4	Liquid Spill	65
6.5	Fire Load Cases	68
6.6	Explosion and Impact	72
	References	74
7	Dynamic Analysis	77
7.1	Theory of Sloshing Fluid	77
7.2	Housner's Method	79
7.3	Veletsos' Method	81
7.4	Provisions in EN 1998-4, Annex A	82
7.4.1	Hydrodynamic Pressure on Tank	83
7.4.2	Masses and Associated Lever Arms	85
7.5	Seismic Design of LNG Tanks	88
	References	92
8	Construction	93
8.1	Construction Phases and Procedures	93
8.1.1	Base Slab	93
8.1.2	Tank Wall	94
8.1.3	Ring Beam	97
8.1.4	Tank Roof	97
8.1.5	Concrete Roof	100
8.2	Wall Formwork	102
8.3	Reinforcement	105
8.4	Prestressing	108
8.5	Tank Equipment (Inclinometers, Heating)	111
8.6	Construction Joints	114
8.7	Curing of Concrete Surfaces	115
	References	115
9	Summary	117
	Index	119

Editorial

The *Concrete Yearbook* is a very important source of information for engineers involved in the planning, design, analysis and construction of concrete structures. It is published on a yearly basis and offers chapters devoted to various, highly topical subjects. Every chapter provides extensive, up-to-date information written by renowned experts in the areas concerned. The subjects change every year and may return in later years for an updated treatment. This publication strategy guarantees that not only is the latest knowledge presented, but that the choice of topics itself meets readers' demands for up-to-date news.

For decades, the themes chosen have been treated in such a way that, on the one hand, the reader gets background information and, on the other, becomes familiar with the practical experience, methods and rules needed to put this knowledge into practice. For practising engineers, this is an optimum combination. In order to find adequate solutions for the wide scope of everyday or special problems, engineering practice requires knowledge of the rules and recommendations as well as an understanding of the theories or assumptions behind them.

During the history of the *Concrete Yearbook*, an interesting development has taken place. In the early editions, themes of interest were chosen on an ad hoc basis. Meanwhile, however, the building industry has gone through a remarkable evolution. Whereas in the past attention focused predominantly on matters concerning structural safety and serviceability, nowadays there is an increasing awareness of our responsibility with regard to society in a broader sense. This is reflected, for example, in the wish to avoid problems related to the limited durability of structures. Expensive repairs to structures have been, and unfortunately still are, necessary because in the past our awareness of the deterioration processes affecting concrete and reinforcing steel was inadequate. Therefore, structural design should now focus on building structures with sufficient reliability and serviceability for a specified period of time, without substantial maintenance costs. Moreover, we are confronted by a legacy of older structures that must be assessed with regard to their suitability to carry safely the increased loads often applied to them today. In this respect, several aspects of structural engineering have to be considered in an interrelated way, such as risk, functionality, serviceability, deterioration processes, strengthening techniques, monitoring, dismantlement, adaptability and recycling of structures and structural materials plus the introduction of modern high-performance materials. The significance of sustainability has also been recognized. This must be added to the awareness that

design should focus not just on individual structures and their service lives, but on their function in a wider context as well, i.e. harmony with their environment, acceptance by society, responsible use of resources, low energy consumption and economy. Construction processes must also become cleaner, cause less environmental impact and pollution.

The editors of the *Concrete Yearbook* have clearly recognized these and other trends and now offer a selection of coherent subjects that reside under the common “umbrella” of a broader societal development of great relevance. In order to be able to cope with the corresponding challenges, the reader can find information on progress in technology, theoretical methods, new research findings, new ideas on design and construction, developments in production and assessment and conservation strategies. The current selection of topics and the way they are treated makes the *Concrete Yearbook* a splendid opportunity for engineers to find out about and stay abreast of developments in engineering knowledge, practical experience and concepts in the field of the design of concrete structures on an international level.

Prof. Dr. Ir. Dr.-Ing. h. c. *Joost Walraven*, TU Delft
Honorary president of the international concrete federation *fib*

About the Author

Dr.-Ing. Josef Rötzer (born in 1959) studied civil engineering at the Technical University of Munich and later obtained his PhD at the Bundeswehr University Munich. From 1995 onwards, he worked in the engineering head office of Dyckerhoff & Widmann (DYWIDAG) AG in Munich. His area of responsibility included the detailed design of industrial and power plant structures. The DYWIDAG LNG Technology competence area, focusing on the planning and worldwide construction of liquefied gas tanks, was integrated into STRABAG International in 2005.

Josef Rötzer is a member of the Working Group for Tanks for Cryogenic Liquefied Gases of the German Standards Committee and a member of the committee for the American code ACI 376.

1

Introduction

The use of natural gas as an independent branch of the global energy supply sector began in the early 1960s. Prior to that, natural gas had only been regarded as a by-product of crude oil production; there was no use for it and so it was either pumped back into the ground or flared. But all that has changed in the meantime – natural gas currently accounts for 22% of global energy supplies. Huge deposits in Australia are now being exploited and deposits in the USA will soon be coming online, which will increase that global share (Fig. 1.1). There are many reasons for this development – economic, political and ecological: Australia is close to the growing Asian economies, the USA is aiming to reduce its dependence on foreign oil and energy supplies by developing its own resources, and global efforts to replace fossil fuels by gas apply throughout the world.

The International Maritime Organisation (IMO), a specialised agency of the United Nations, has drawn up new rules that have been valid from 2015 and are particularly strict for the North Sea and Baltic Sea. Complying with emissions requirements is difficult when using diesel and heavy oil as marine fuel. But using liquefied natural gas (LNG) as a marine fuel results in – compared with diesel – about 90% less nitrogen oxide, up to 20% less carbon dioxide and the complete avoidance of sulphur dioxide and fine particles [1]. Det Norske Veritas (DNV), the Norwegian vessel classification body, therefore expects that there will be about 1000 new LNG-powered ships by 2020, which amounts to almost 15% of predicted new vessel orders. This change is heavily influenced by the huge drop in the price of natural gas, which has been brought about by the global production of shale gas (Fig. 1.2, Fig. 1.3).

The use of natural gas involves transport and storage difficulties. Transport via pipelines is economic up to a distance of 4000–5000 km, depending on the boundary conditions. In the case of difficult geographic circumstances, such as supplies to islands, e.g. Japan and Taiwan, or where it is necessary to cross mountain ranges, supplying gas via a pipeline is much more difficult and costly. Therefore, the method of liquefying natural gas and then transporting it over great distances in ships had already become established by the mid-20th century.

LNG technology takes advantage of the physical material behaviour of natural gas, the main constituent of which is methane. At the transition from the gaseous to the liquid state, the volume is reduced to 1/600. However, this requires the temperature of the gas to be lowered to -162°C . Only this extreme reduction