

ACI 376-11

**Code Requirements for Design
and Construction of Concrete
Structures for the Containment of
Refrigerated Liquefied Gases and
Commentary**

An ACI Standard

Reported by ACI Committee 376



American Concrete Institute®



First Printing
May 2013

American Concrete Institute®
Advancing concrete knowledge

Code Requirements for Design and Construction of Concrete Structures for the Containment of Refrigerated Liquefied Gases and Commentary

Copyright by the American Concrete Institute, Farmington Hills, MI. All rights reserved. This material may not be reproduced or copied, in whole or part, in any printed, mechanical, electronic, film, or other distribution and storage media, without the written consent of ACI.

The technical committees responsible for ACI committee reports and standards strive to avoid ambiguities, omissions, and errors in these documents. In spite of these efforts, the users of ACI documents occasionally find information or requirements that may be subject to more than one interpretation or may be incomplete or incorrect. Users who have suggestions for the improvement of ACI documents are requested to contact ACI via the errata website at www.concrete.org/committees/errata.asp. Proper use of this document includes periodically checking for errata for the most up-to-date revisions.

ACI committee documents are intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. Individuals who use this publication in any way assume all risk and accept total responsibility for the application and use of this information.

All information in this publication is provided “as is” without warranty of any kind, either express or implied, including but not limited to, the implied warranties of merchantability, fitness for a particular purpose or non-infringement.

ACI and its members disclaim liability for damages of any kind, including any special, indirect, incidental, or consequential damages, including without limitation, lost revenues or lost profits, which may result from the use of this publication.

It is the responsibility of the user of this document to establish health and safety practices appropriate to the specific circumstances involved with its use. ACI does not make any representations with regard to health and safety issues and the use of this document. The user must determine the applicability of all regulatory limitations before applying the document and must comply with all applicable laws and regulations, including but not limited to, United States Occupational Safety and Health Administration (OSHA) health and safety standards.

Participation by governmental representatives in the work of the American Concrete Institute and in the development of Institute standards does not constitute governmental endorsement of ACI or the standards that it develops.

Order information: ACI documents are available in print, by download, on CD-ROM, through electronic subscription, or reprint and may be obtained by contacting ACI.

Most ACI standards and committee reports are gathered together in the annually revised ACI Manual of Concrete Practice (MCP).

American Concrete Institute
3880 Country Club Drive
Farmington Hills, MI 48331
U.S.A.
Phone: 248-848-3700
Fax: 248-848-3701

www.concrete.org

ISBN-13: 978-0-87031-814-6
ISBN: 0-87031-814-4

Code Requirements for Design and Construction of Concrete Structures for the Containment of Refrigerated Liquefied Gases (ACI 376-11) and Commentary

An ACI Standard

Reported by ACI Committee 376

Neven Krstulovic-Opara, Chair

Piotr D. Moncarz, Secretary

| | | | |
|--------------------|---------------------|------------------------|---------------------------|
| Junius Allen | George C. Hoff | Praveen K. Malhotra | Eric S. Thompson |
| Dale Berner | Richard A. Hoffmann | Keith A. Mash | Sheng-Chi Wu |
| Mike S. Brannan | John Holleyoak | Stephen Meier | |
| Hamish Douglas | Joseph Hoptay | Robert W. Nussmeier | <i>Consulting members</i> |
| Charles S. Hanskat | Thomas R. Howe | Rolf P. Pawski | Robert Arvedlund |
| Humayun Hashmi | Dajiu Jiang | Ramachandran S. Rajan | James P. Lewis |
| Alan D. Hatfield | Jameel U. Khalifa | William L. Rushing Jr. | Terry Turpin |
| Kare Hjortset | Nicholas A. Legatos | Robert W. Sward | |

Note: Special acknowledgment to Jeffrey Garrison for his contributions to this document.

Keywords: bund wall; commissioning; cryogenic; damage stability; decommissioning; earthquake design levels; fatigue; float out; floating storage unit; foundation heating; gravity base structure; impact loads; liners; liquefied natural gas; liquid stratification; permanent ballast; purging; refrigerated liquefied gas; reinforcement (cryogenic); tanks; thermal corner protection.

CONTENTS

INTRODUCTION 3

CHAPTER 1—GENERAL 5

1.1—Scope 5

1.2—Quality assurance 6

CHAPTER 2—NOTATION AND DEFINITIONS 7

2.1—Notation 7

2.2—Definitions 8

CHAPTER 3—REFERENCED STANDARDS 14

CHAPTER 4—MATERIALS 18

4.1—Testing of materials 18

4.2—Cementitious materials 18

4.3—Aggregates 18

4.4—Water 19

4.5—Admixtures 19

4.6—Fibers 19

4.7—Deformed reinforcement 19

4.8—Plate steel composite with concrete 20

4.9—Prestressed reinforcement 21

4.10—Prestressing anchorages 21

4.11—Post-tensioning ducts 22

4.12—Grout 22

4.13—Metal liners and nonstructural metal components 22

4.14—Insulation 23

4.15—Coating requirements 23

ACI Committee Reports, Guides, and Commentaries are intended for guidance in planning, designing, executing, and inspecting construction. This document is intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. The American Concrete Institute disclaims any and all responsibility for the stated principles. The Institute shall not be liable for any loss or damage arising therefrom.

Reference to this document shall not be made in contract documents. If items found in this document are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

ACI 376-11 was adopted November 11, 2011, and was published May 2013.
 Copyright © 2013, American Concrete Institute.
 All rights reserved including rights of reproduction and use in any form or by any means, including the making of copies by any photo process, or by electronic or mechanical device, printed, written, or oral, or recording for sound or visual reproduction or for use in any knowledge or retrieval system or device, unless permission in writing is obtained from the copyright proprietors.

CHAPTER 5—DESIGN LOADS.24
 5.1—Design loads24
 5.2—Loading conditions28

CHAPTER 6—MINIMUM PERFORMANCE REQUIREMENTS.31
 6.1—General31
 6.2—Primary concrete container31
 6.3—Secondary concrete container34
 6.4—Roof performance criteria35
 6.5—Other performance criteria35
 6.6—Concrete quality36
 6.7—Shotcrete40
 6.8—Coating design40
 6.9—Metal components41

CHAPTER 7—LOAD FACTORS42
 7.1—General42
 7.2—Load factors for ultimate limit state of primary container42
 7.3—Load factors for ultimate limit state of secondary container45

CHAPTER 8—ANALYSIS AND DESIGN.49
 8.1—Methods of analysis49
 8.2—Design basis54
 8.3—Foundation design54
 8.4—Wall design55
 8.5—Roof design58

CHAPTER 9—DETAILING60
 9.1—General60
 9.2—Reinforcement details60
 9.3—Internal prestressing systems61
 9.4—External prestressing systems63
 9.5—Concrete containment wall63
 9.6—Metal components65
 9.7—Anchorage to concrete66
 9.8—Liners and coatings67

CHAPTER 10—FOUNDATIONS69
 10.1—General69
 10.2—Geotechnical investigation69
 10.3—Design requirements for shallow foundations72
 10.4—Design requirements for deep foundations76
 10.5—Ground improvement80
 10.6—Foundation details80
 10.7—Foundation performance monitoring details82
 10.8—Monitoring frequency84
 10.9—Inspection and testing85

CHAPTER 11—CONSTRUCTION REQUIREMENTS.87
 11.1—Construction plan87
 11.2—Tolerances87

11.3—Shotcrete for external prestressing systems90
 11.4—Post-tensioning91
 11.5—Winding of prestressed reinforcement: wire or strand95
 11.6—Forming95
 11.7—Construction joints97
 11.8—Concrete embedments97
 11.9—Coatings98
 11.10—Welding98

CHAPTER 12—COMMISSIONING/ DECOMMISSIONING.99
 12.1—Scope99
 12.2—Testing99
 12.3—Pressure and vacuum testing104
 12.4—Purging into service105
 12.5—Cool-down106
 12.6—Settlement and movement monitoring108
 12.7—Liquefied natural gas containment methods109
 12.8—Decommissioning: purging out of service and warm-up109
 12.9—Recordkeeping111
 12.10—Nomenclature111

APPENDIX A—TANK CONFIGURATIONS, DETAILS, AND EXAMPLES.113
 RA.1—Tank configurations113
 RA.2—Full-containment tanks: typical details113
 RA.3—Examples of base joint details113

APPENDIX B—OFFSHORE CONCRETE TERMINALS.124
 B.1—Scope124
 B.2—General124
 B.3—Loads and load combinations125
 B.4—Concrete and reinforcement materials128
 B.5—Global and local structural analysis129
 B.6—Criteria and methodology of concrete sectional design131
 B.7—Fatigue performance criteria132
 B.8—Design considerations during construction, transportation, and installation132
 B.9—Decommissioning135
 B.10—Design for accidents135

APPENDIX C—FATIGUE PERFORMANCE139
 C.1—Scope139
 C.2—General139
 C.3—Fatigue performance criteria139

COMMENTARY REFERENCES142

INTRODUCTION

ACI Committee 376 was formed and subsequently ACI 376-11 was drafted in response to a request from the National Fire Protection Association (NFPA) Technical Committee 59A on liquefied natural gas (LNG). That committee is responsible for NFPA 59A, which is an internationally recognized standard governing the production, storage, and handling of LNG at an operating temperature of -270°F .

NFPA 59A contains provisions for the use of reinforced concrete and prestressed concrete for two principal applications: 1) impoundment—secondary containment in conjunction with a metallic primary container; and 2) storage—primary containment. NFPA 59A is somewhat limited; it does not provide guidelines specifically tailored to concrete use at cryogenic temperatures. This limitation was the impetus for Committee 59A's request. Although the request was related specifically to containment of LNG, this code addresses concrete use for other refrigerated liquefied gas (RLG) as well, ranging in operating temperatures from $+40$ to -325°F . This makes the code and commentary analogous to the American Petroleum Institute's API 620, which governs design and construction of steel and aluminum RLG storage tanks to -270°F .

The most common use of reinforced concrete and prestressed concrete in cryogenic storage applications is for secondary containment around metal primary storage tanks. Prestressed concrete primary containment tanks were built in North America and Europe from the 1960s through the 1980s. Renewed interest in the use of concrete for primary containment and the need for a code that addressed secondary concrete containment led to the development of this code, which includes pertinent excerpts from ACI 318-11 and ACI 350-06. The commentary includes considerations by the committee in developing the code.

The commentary is not intended to provide a complete historical background concerning development of the code, nor is it intended to provide a detailed summary of the studies and research data reviewed by the committee in formulating its provisions. References to specific research

data are provided for more in-depth study of the background materials.

ACI 376 may be used as a part of a legally adopted code and, as such, must differ in form and substance from documents that provide detailed specifications, recommended practice, complete design procedures, or design aids.

Requirements more stringent than the code provisions are desirable for unusual structures. This code and commentary cannot replace sound engineering knowledge, experience, and judgment. A code for design and construction states the minimum requirements necessary to provide for public health and safety. ACI 376 is based on this principle. For any structure, the owner and engineer may require the quality of materials and construction to be higher than the minimum requirements necessary to provide serviceability and to protect the public as stated in the code. Lower standards, however, are not permitted.

ACI 376 has no legal status unless it is adopted by regulatory bodies. Where the code has not been adopted, it may serve as a reference to good practice. The code provides a means of establishing minimum standards for acceptance of design and construction by a legally appointed official or designated representative. The code and commentary are not intended for use in settling disputes between the owner, engineer, contractor, or their agents, subcontractors, material suppliers, or testing agencies. Therefore, the code cannot define the contract responsibility of each of the parties in typical construction. General references requiring compliance with ACI 376 in the job specifications should be avoided because the contractor is rarely in a position to accept responsibility for design details or construction requirements that depend on a detailed knowledge of the design. Generally, the contract documents should contain all of the necessary requirements to ensure compliance with the code. In part, this can be accomplished by reference to specific code sections in the job specifications. Other ACI publications, such as ACI 301, are written specifically for use as contract documents for construction.

Currently in preview, click buy full version

CODE

COMMENTARY

CHAPTER 1—GENERAL

1.1—Scope

This code provides minimum requirements for design and construction of reinforced concrete and prestressed concrete structures for the storage and containment of refrigerated liquefied gases (RLG) with service temperatures between +40 and -325°F. Notwithstanding, the principals listed herein are applicable to concrete foundations of double-steel tanks subject to the approval of the owner.

Container design shall include the design of the container wall, its foundation (footing and floor slab), the concrete portions of its roof, and the bund wall, whenever applicable.

R1.1—Scope

Typically, reinforced concrete and prestressed concrete structures for the containment of RLGs are classified into two main categories:

- a) Secondary containment, which represents the most widespread use of such structures
- b) Primary containment

Henceforth in this document, the term “concrete” is used to denote both conventionally reinforced and prestressed concrete. This code is not applicable to the design of membrane tanks because construction and detailing requirements are not included. A membrane tank has a non-self-supporting thin layer (membrane) inner tank that is supported through insulation by an outer tank. With appropriate additional engineering analysis and justification, portions of this code may be applied to the design of a concrete outer tank of a membrane tank using both primary and secondary tank criteria. This code does not address the materials, design, or construction of steel primary or secondary tanks. Such information is further described in API 620.

This code has been developed with the lowest operating temperature of -325°F. Lower product temperatures could also be used, however, provided appropriate additional engineering analysis and justification is performed for each proposed application. Single containment, double containment, and full containment concepts are covered by this code.

A concrete bund wall is an open-top cylindrical wall serving as the outer boundary of an impounding area surrounding a single-containment RLG storage tank.

In a double-containment tank system, the primary container is normally a single-containment RLG storage tank with a vapor-tight shell and roof designed to contain both refrigerated liquid and the associated vapors under normal operating conditions. In this system, the secondary container is often an open-top concrete wall that serves two basic functions:

- a) Provides protection to the primary container from external loads under normal operating conditions
- b) Contains the leakage from the primary container (but not the vapor generated from such leakage) under accidental-spill conditions

In a full-containment tank system, the primary container is designed to contain the refrigerated liquid under normal operating conditions. In this system, the secondary container is a vapor-tight wall with a vapor-tight roof that spans over the inner tank. The roof may be metal, concrete, or a composite of the two materials.

Under normal operating conditions, the secondary container provides protection to the primary container from external loads. Under accidental-spill conditions, the secondary container also contains the leakage from the primary container and contains or controls the vapor generated from such leakage.