IN-LB Inch-Pound Units

An ACI Standard

Refrigerated Liquefied Gas Containment for Concrete Structures—Code Requirements and Commentary

Reported by ACI Committee 376

ACI CODE-376-23

American Concrete Institute
Always advancing

First Printing: July 2023
ISBN: 978-1-64195-221-7

**Refrigerated Liquefied Gas Containment for Concrete Structures—
Code Requirements and Commentary**

The technical committees responsible for ACI committee reports and standards strive to avoid ambiguities, omissions, and errors in these documents. Despite 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 http://concrete.org/Publications/DocumentErrata.aspx. 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 regarding 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.

ACI documents are written via a consensus-based process. The characteristics of ACI technical committee operations include:
(a) Open committee membership
(b) Balance/lack of dominance
(c) Coordination and harmonization of information
(d) Transparency of committee activities to public
(e) Consideration of views and objections
(f) Resolution through consensus process

The technical committee documents of the American Concrete Institute represent the consensus of the committee and ACI. Technical committee members are individuals who volunteer their services to ACI and specific technical committees.

American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
Phone: +1.248.848.3700
Fax: +1.248.848.3701

www.concrete.org

ACI CODE-376-23

Refrigerated Liquefied Gas Containment for Concrete Structures—Code Requirements and Commentary

An ACI Standard

Reported by ACI Committee 376

Kare Hjorteset, Chair | Rolf P. Pawski, Vice Chair | Jeffrey C. Garrison, Secretary

Junius Allen
Thomas A. Ballard
Catherine Boucard
Hamish Douglas
Humayun Hashmi
Richard A. Hoffmann
Joseph Hoptay
Thomas R. Howe
Dajiu Jiang
Jameel U. Khalifa
Neven Krstulovic-Opara
Keith A. Mash
Sanjay S. Mehta
Piotr D. Moncarz
Praveen K. Malhotra
Robert W. Nussmeier
William H. Oliver
John Powell
Ramanujam S. Rajan
Josef Roetzer
William E. Rushing Jr.
Eric S. Thompson
Fariborz Vossoughi
Markus Wernli

Consulting Members

Robert Arvedlund
Dale Berner
Mike S. Brannan
Alex Cooperman
Charles S. Hanskat
Alan D. Hatfield
Nicholas A. Legatos
James P. Lewis
Stephen Meier
Robert W. Sward
Terry Turpin

Note: The committee would like to thank T. Shi for her contribution to this code. The first version of ACI CODE-376 was published in 2011.

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

ACI CODE-376-23 supersedes ACI 376-11, and was approved by the ACI Standards Board for publication in March 2023 and published July 2023.

INTRODUCTION

ACI CODE-376, "Refrigerated Liquefied Gas Containment for Concrete Structures—Code Requirements and Commentary," hereinafter called the Code or the 2023 Code and Commentary, are presented in a side by-side column format. These are two separate but coordinated documents, with Code text placed in the left column and the corresponding Commentary text aligned in the right column. Commentary section numbers are preceded by an "R" to further distinguish them from Code section numbers. The two documents are bound together solely for the user's convenience. Each document carries a separate enforceable and distinct copyright.

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 –325°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 318-19 and ACI 350-20. 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 CODE-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 CODE-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 CODE-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 CODE-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. The contract documents should contain all the necessary requirements to ensure compliance with the Code, except in cases where the contractor acts as a specialty engineer that is responsible for all or part of the design and construction details. In this case, inclusion of the Code, in whole or in part, by reference in the project documents is acceptable. Other ACI publications, such as ACI 301, are written specifically for use as contract documents for construction and can be included in the project documents by reference.

CODE

CHAPTER 1—GENERAL REQUIREMENTS

1.1—Scope

1.1.1 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 (RLGs) with service temperatures between +40 and –325°F.

1.1.2 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, if applicable.

COMMENTARY

R1.1—Scope

R1.1.1 Typically, reinforced concrete and prestresssed 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

In this Code, the term "concrete" is used to denote both concrete reinforced with nonprestressed reinforcement and prestressed concrete.

Appendix D has been added in this version of the Code that includes design and detailing requirements for membrane tanks. A membrane tank has a non-self-supporting thin layer (membrane) that is supported through insulation by an outer concrete tank that structurally is the primary container and secondary container.

This Code does not address the materials, design, or construction of steel primary or secondary tanks. Such information is further described in API 620.

R1.1.2 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:

1. Provides protection to the primary container from external loads under normal operating conditions.
2. 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 constructed of 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.

CODE

COMMENTARY

New design and detailing requirements have been added for the thermal corner protection (TCP) embedment plate and secondary containment wall in the vicinity of the TCP embedment plate.

1.1.3 Design and detailing requirements not specifically covered by this Code shall comply with ACI 350 and national design standards as specified in the project documents. In case of conflict between the requirements of ACI 350 and national standards, the more stringent requirements shall apply.

R1.1.3 ACI 350 is intended to be used for those aspects of concrete design not specifically covered by this Code such as reinforcement development length, calculation of prestress losses, and strength design procedures. The user should be familiar with ACI 350 provisions and implement appropriate provisions as applicable. It is noted that the properties and operating temperature range of the liquid products stored in RLG tank structures covered by this Code are fundamentally different from that of liquids covered by the provisions of ACI 350. To consider this, specific references to ACI 350 together with appropriate modifications are provided in this Code.

Although like concrete liquid-containing structures in ACI 350, the design and construction of concrete RLG containers are more complex due to cold storage temperatures and safety associated with preventing release of gas or liquid into the environment. For an overview of the design and construction topics covered by the Code, refer to Bruggeling (1978) and Roetzer (2020).

1.2—Quality assurance

1.2.1 *Plan*—The project specifications shall include provisions for developing a quality assurance plan to verify that materials, fabrication, and construction conform to the design. The plan shall include:

(a) Procedures for exercising control of fabrication and construction
(b) Required inspections and tests
(c) Inspection and test procedures

R1.2—Quality assurance

R1.2.1 *Plan*—For the design-build approach typically used for RLG tank construction, the project specifications will provide only an outline of the quality assurance requirements. The design-build contractor is typically responsible for developing details of the quality assurance plan and quality control with review by the owner or other responsible party.

1.2.2 *Traceability*—The location of all permanent materials in the structure shall be traceable to source documents demonstrating compliance with specifications, standards, tests, and quality assurance and quality control requirements. The quality assurance/quality control system documents shall identify which component or material in the structure was tested or certified.

R1.2.2 *Traceability*—Source documents should include:

(a) Manufacturer's certificates demonstrating conformity with ASTM or other applicable standards for concrete and grout materials, reinforcement, and metal plate
(b) Certification of conformance to standards and specifications from material suppliers
(c) Truck batch tickets for ready mixed concrete, and results of field and laboratory tests for concrete and grout placed at the site
(d) Welding procedure specifications (WPSs) used for welding of reinforcing bars, plate, and structural steel
(e) Qualifications of welders, shotcrete nozzlemen, and inspectors or other personnel performing tests and inspections

1.2.3 *Documentation*

R1.2.3 *Documentation*

1.2.3.1 Documentation of materials, testing, and performance measurements and results shall be provided in a quality assurance/quality control system specified in the project specifications.

R1.2.3.1 All certifications, quality assurance/quality control records, design drawings, specifications, and construction records of any kind should be assembled by the owner in a logical manner that facilitates later recovery and