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Design and Construction of Concrete Tanks for Refrigerated Liquefied Gas Containment, Part 1

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ACI WEB SESSIONS

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Overview

- History of concrete structures in RLG
- Why Code is required
- Committee membership
- Document outline
- Current status

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ACI 376 Code

- "Code Requirements for Design and Construction of Concrete Structures for Containment of Refrigerated Liquefied Gases (ACI 376-10) and Commentary"
- Complete standalone Code and Commentary
- Liquefied Natural Gas is the predominate refrigerated liquefied gas (RLG)

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Liquefied Natural Gas (LNG)

- cold colorless liquid
- lighter than water
- boils at approx. -260ºF (at atmospheric pressure)
- when liquefied shrinks approx. 620 times
- essentially all methane - CH_4 (liquefaction process strips most higher freezing-point products)

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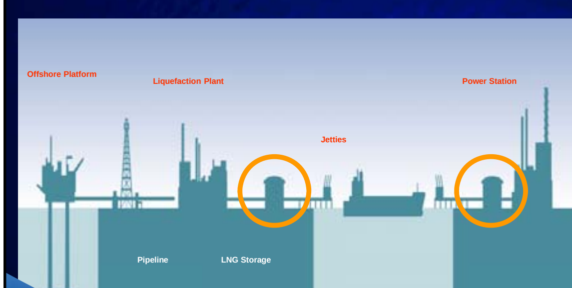
LNG Tanks



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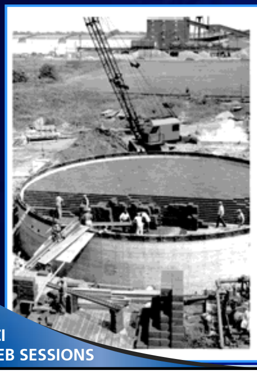
LNG Tanks



- First Prestressed Concrete RLG Tank
- 950 m³ Liquid Oxygen Tank (250,000-gallons) East Chicago, IN
- 1953 – Preload Inc. Jack Closner Nicholas Legatos

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LNG Tanks

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Full-Containment LNG Tank

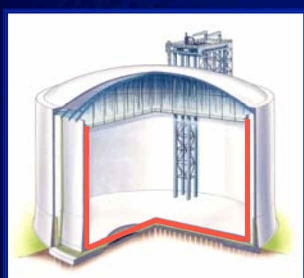

Photo courtesy Arup

- 9% Ni Steel

or

- Prestressed Concrete

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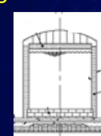
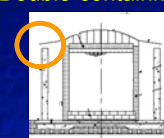
LNG Tank Types

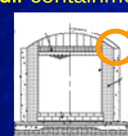
Single containment



Double-containment



Full-containment



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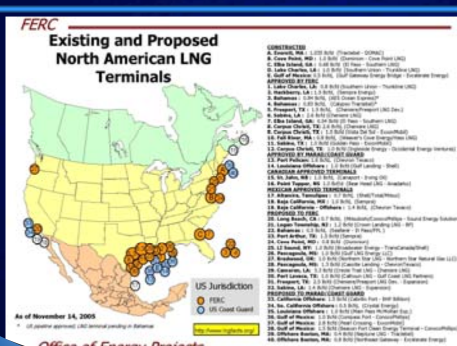
Market for LNG Tanks



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Current Practice

- LNG tanks containments are predominantly
  - 9% nickel steel
  - 5083 aluminum (not currently used)
- Both these metals are extremely tough at service temperatures of -260°F.
- Outer vessels are usually carbon steels.
- Diking or product spillage containment has been mounded earth to form dikes

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Concrete LNG Tanks

- **Unlined concrete tanks** → liquid oxygen **1952**

- **Precast** (lined) **concrete tanks:**
  - Barcelona 1969
    - (Two at 40,000 m^3)
  - Philadelphia 1974
    - (Two at 94,000 m^3)
  - Staten Island 1974
    - (Two at 143,000 m^3)
  - Cumberland, RI (#1) 1975
    - (One at 4,000 m^3)
  - Barcelona (#2) 1981
    - (One at 80,000 m^3)

1 m3 = 6.25 Bbl = 264 US gallons
80,000 m3 = 21,000,000 Gallons

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Concrete Advantages

- Concrete construction produces inherently robust structures
- Concrete provides corrosion and fire protection to the embedded reinforcement
- Concrete structures are the most resistant to fires, explosions and terrorist actions.

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Metal Shell Considerations

- Thin metal shells are efficient liquid containment structures.
- Cost requirements mandate that these structures be made as thin as possible.
- Corrosion protection is a concern with environmental exposures
- With “thinness”, additional protection needed for fire protection and resistance to terrorism or explosion.

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Governing Documents

- DOT 49CFR193 - Rules for LNG facilities connected to pipelines (pipelines are governed by 49CFR192)
- NFPA 59A (2009) – current standard which governs the LNG industry

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Regulatory Structure

Department of Transportation (DOT)
Pipeline and Hazardous Materials Safety Administration
49CFR193

↓ DOT incorporates through reference

NFPA 59A
“Standard for the Production, Storage & Handling of LNG”

- Also referenced by FERC & other agencies
- Used worldwide as the “final word” on siting, design, construction & fire protection

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NFPA 59A: Structure

NFPA 59A

Covers:
- Plant Siting and Layout
- Process Equipment
- Stationary LNG Storage Containers
- Vaporization Facilities
- Piping Systems and Components
- Instrumentation and Electrical Services
- Transfer of LNG and Refrigerants
- Fire Protection, Safety, and Security
- Operating, Maintenance, and Personnel Training
- Seismic Design of LNG Plants
- Security

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NFPA 59A: Current

NFPA 59A

R.C. & PSC Tanks

For Steel Tanks:
API Standard 620
"Design and Construction of Large, Welded, Low-Pressure Storage Tanks"

- ACI 318
- ACI 372
- ACI 373

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NFPA 59A: Future

NFPA 59A

For Steel Tanks:
API Standard 620
API Standard 625
Tank Systems for RLG Storage

For R.C. & PSC Tanks:
ACI 376

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Primary Reasons for ACI 376

- Give the LNG industry a comprehensive, mandatory document for use of concrete in LNG tanks
- Allows NFPA 59A to make direct reference to the Code for Concrete LNG tanks
- Concrete in LNG tanks produces a system that is inherently fire and terrorist resistant.

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ACI 376: History

- *February 2003* – NFPA 59A requests ACI to develop a code specifically addressing cryogenic concrete tanks
- *August 2003* – TAC (ACI) requests interested parties to propose & justify formation of a committee on LNG tanks
- *June 2004* – formation of an LNG tank CODE committee **approved**
- *October 2004* – **First** ACI 376 committee **meeting** in SF
- *Jan 2009* – **target** for ACI 376 Code **release** to TAC (ACI)
- *Feb 2010* – release of Provisional Code
- *Spring 2012* – release of Final Version of Code

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ACI 376: Objectives & Scope

- **OBJECTIVE:** Use of reinforced and prestressed concrete tanks for primary and secondary containment.
- **SCOPE:** Encompasses all members that are a physical part of these two types of containers

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ACI 376 Membership

Major International Companies Represented on ACI 376		
Arup	ConocoPhillips	Philadelphia Gas Works
Baker Concrete Construction	Dywidag International	Preload
Bechtel Corp	Exponent	Shell
Ben C Gerwick Inc	ExxonMobil	Tank Industry Consultants
BERGER/ABAM Engineers	Factory Mutual Global Research	US Fed Energy Regulatory Commission
BP America	Hoffmann & Feige	V Structural
Chevron Energy Technology	KBR	Zachry Industrial
Chicago Bridge & Iron	Landmark Structures	Independent consultants

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ACI 376: Content

A. **Materials and Tests**

B. **Design Loads**

C. **Minimum Performance Criteria**
- Primary Concrete Container
- Secondary Concrete Container
- Roof Performance Criteria
- Fatigue Performance Criteria
- Other Performance Criteria

ACI 376: Content

D. **Load Factors and Strength Reduction Factors**

E. **Analysis and Design**
- Design Basis
- Foundation Design
- Roof Design

F. **Detailing**
- Reinforcement
- Prestressing systems
- Concrete containment wall
- Anchorage to concrete
- Liners and coatings

ACI 376: Content

G. **Foundations**
- Geotechnical Investigation
- Design Requirements for Shallow & Deep Foundations
- Ground Improvement
- Foundation Monitoring
- Inspection and Testing

H. **Construction Requirements**
- Mockups
- Tolerances
- Shotcrete
- Prestressing
- Forming
- Joints, Embeds and Coatings

ACI 376: Content

I. **Commissioning/Decommissioning**
- Hydrostatic Testing
- Pressure and Vacuum Testing
- Purging into Service
- Cooldown
- Settlement and movement monitoring
- LNG tank fill methods
- Decommissioning: Purging out of service and warm up

J. **Tank Details** *(Appendix A)*

K. **Offshore Concrete Terminals** *(Appendix B)*

L. **Fatigue Performance** *(Appendix C)*

Page 2-2 CHAPTER 2 376/376R-XX
Editing Version #6 - 2008.10.24

CODE	COMMENTARY
	reduced coefficient of thermal expansion.
2.1.1 – Structural Portland cement (see also Section 2.3), "concrete", shall have a specified 28-day compressive strength, f'_c, of not less than 4,000 lb/in^2 for reinforced concrete and not less than 5,000 lb/in^2 for liquid-containment concrete when tested on cylinders at ambient temperature in accordance with 2.1.5.6.	
2.1.2 – The maximum water to cementitious material ratio shall be 0.45.	
2.1.3 – Concrete shall conform to the other applicable requirements of ACI 350 regarding: constituents, testing, durability, concrete quality, mixing and placing.	**R2.1.3** – These requirements can be found in Chapters 3, 4 and 5 of ACI 350[2.1].
2.1.4 – The concrete shall be designed to have acceptable properties with respect to the following: a) Impermeability (see 2.1.5.8) b) Fire resistance (see 2.1.5.10) c) Behavior at cryogenic temperature (2.1.5) d) Durability (see 2.1.5.9)	
2.1.5 – Cryogenic Response of Concrete The behavior of concrete at cryogenic temperature shall be considered in the determination of the performance and integrity of the structure.	**R2.1.5** See References 2.2 to 2.40 for information on the cryogenic behavior of reinforced/ prestressed concrete. The values of the material properties listed in the commentary are typical values provided for reference. The engineer may use different values if verified by tests on the specific mix, or base on prior test data.
2.1.5.1 – Moisture Content of Concrete The influence of the moisture content of the concrete shall be considered in the assessment of: thermal conductivity, thermal deformation, permeability, specific heat, moisture migration and the risk of freeze-thaw attack.	**R2.1.5.1** – Properties of concrete under cryogenic conditions are greatly affected by the moisture content. Saturated concrete can degrade due to expansion of water on freezing. Nevertheless, many properties of moist concrete can be enhanced at low temperatures but generally these should not be used in design except where listed. For the primary container, thermal gradients in

ACI 376 Refrigerated Liquefied Gas Structures Code and Commentary

2008.10.27 printing

ACI 376-10 Provisional Standard

CHAPTER 4—MATERIALS

4.1—Tests of materials

4.1.1—Testing of materials used in concrete construction shall conform to applicable building codes and the licensed design professional.

4.1.2—Tests of materials shall be made in accordance with the applicable ACI and ASTM (or comparable) standards listed or referenced by this Code except where indicated.

4.1.3—Tests shall be performed at ambient temperature except where indicated by this Code that they shall be performed at cryogenic temperature appropriate to the liquid to be stored.

4.1.4—The complete record of material tests in accordance with Section 4.14.3 shall be available for inspection during the progress of the work, and a complete set of these documents shall be preserved by the licensed design professional or Owner for at least 2 years after completion of the work.

4.1.5—Records of all performance related tests shall be maintained for the life of the structure.

R4.1—Tests of materials

R4.1.1—Acceptable standard material tests at ambient temperatures are referenced in:
a) ACI 350 and ACI 318 for concrete and conventional reinforcing steel;
b) ACI 349 for metallic liners
c) ASTM (or comparable) for general materials.
Other tests are listed in this Code.

R4.1.3—Results from low temperature tests performed on concrete can be significantly influenced by:
a) the history of specimen (cooling/heating),
b) the cooling/heating rate,
c) the temperature range.
The physical properties of non-prestressed reinforcement and prestressing steels are almost independent of the test specimen's thermal history; however, care should be taken when testing massive steel specimens to ensure that thermally induced internal stresses do not influence the test results.

R4.1.4—All tests need to be carefully controlled and reported.

4.2—Cementitious materials

Portland cement, fly ash, slag cement, and silica fume shall conform to ASTM C150, ASTM C618, ASTM C989, and ASTM C1240, respectively.

R4.2—Cementitious materials

Impermeability and durability of concrete may be increased by the use of fly ash, slag cement, or silica fume as part of the cementitious materials. The use of fly ash or slag cement can assist in the reduction of heat development in large sections during hydration, and hence reduce the risk of thermal cracking. The use of fly ash or silica fume can also mitigate the effects of alkali-aggregate reactivity and can be verified using ASTM C441 and ASTM C311.

4.3—Aggregates

Aggregates, including lightweight aggregates, used in making concrete shall conform to ACI 350 and the aggregate shall be selected so that the concrete meets the cryogenic

Resources

- World's LNG Plants & Terminals
  - *www.globallnginfo.com*
- LNG Terminals-status of proposed and existing facilities
  - *www.intelligencepress.com/features/lng*
- Introduction to LNG" (Good "primer“)
  - *www.beg.utexas.edu/energycon/lng*

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Thank You

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