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

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Dale Berner studied Civil Engineering at the University of California at Berkeley, earning his BS in 1978, his M. Eng. in 1982, and his PhD in 1984 under the direction of Ben C. Gerwick, Jr. He joined Ben's structural engineering firm, Ben C. Gerwick, Inc., in 1983 and currently serves as the company's CEO. During his 27 years with Gerwick, Dr. Berner has worked in most of the company's design sectors including locks and dams, offshore fixed and floating platforms, flood barriers, concrete technology, and deep foundations. Notable design projects that Dr. Berner has made significant contributions to include: (a) the Olmsted Dam on the Ohio River; (b) the Inner Harbor Navigation Lake Borgne Hurricane Barrier in New Orleans; (c) the Troll Concrete Gravity Base Structure (GBS) in the North Sea; and (d) the Hibernia GBS platform offshore of Newfoundland.

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Design & Construction of Concrete Tanks for Refrigerated Liquefied Gas Containment

ACI 376 Code & Commentary: Material Requirements

Dale Berner
President
Ben C. Gerwick, Inc.

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Purpose of this Presentation

- A detailed discussion on the materials provisions (Chapter 4) of the new ACI 376 Code. This includes concrete, steel and accessories for the containment of extremely low temperature liquids.

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Overview

- Test of Materials
- Cementitious Materials
- Aggregates
- Water
- Admixtures
- Fibers
- Deformed Reinforcement

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Overview

- Plate Steel Composite with Concrete
- Prestressed Reinforcement
  - Prestressing Anchorages
- Post-tensioning Ducts
  - Grout
- Metal Liners and Non-Structural Components
- Insulation
- Coating Requirements

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Test of Materials

- Tests shall conform to applicable building codes and shall be approved by the Engineer.
- Tests shall be made in accordance with the applicable ACI or ASTM (or comparable) standards as listed in this code and shall be performed at ambient temperature unless indicated otherwise by this Code.
- The complete record of material tests 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.

Test of Materials

- Tests performed concrete at low temperature can be significantly influenced by:
  - a) the history of specimen (cooling/heating),
  - b) the cooling/heating rate,
  - c) the temperature range.
- 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.

Cementitious Materials

- Portland cement ASTM C150,
- Fly ash ASTM C618,
- Slag cement ASTM C989,
- Silica fume ASTM C1240.
- Fly ash, slag cement, or silica fume increase the durability due to increase in impermeability.
- Fly ash or slag cement reduce the heat development.
- Fly ash or silica fume mitigate the alkali-aggregate reaction.

Aggregates

- Aggregates, including lightweight aggregates, shall conform to ACI 350.
- Aggregates shall produce a concrete that meets the cryogenic performance requirements given in this Code with regard to cracking, thermal conductivity, and permeability.
- Aggregates for use in concrete for primary containment should have a low coefficient of thermal expansion, but not so low that incompatibility with the cement matrix can lead to cracking at the aggregate/matrix interface and consequent increased permeability.

Water

- Water shall conform to ACI 350 requirements.
- ASTM C1602 can be used for the mixing water requirements.

Admixtures

- Water reduction and setting time modification ASTM C494
- Flowing concrete ASTM C1017
- Air-entraining admixture ASTM C260
- Compatibility checked with ASTM C1679
- Calcium chloride shall not be used in in prestressed concrete, in concrete containing embedded aluminum, or in concrete cast against stay-in-place galvanized steel forms.

Fibers

- Use of fiber-reinforced concrete or fiber-reinforced shotcrete shall be permitted.
- Steel fibers improve:
  - Compressive ductility
  - Tensile strength and ductility/toughness
  - Shear strength and ductility
  - Crack control
  - Fatigue resistance
- Polypropylene or other synthetic fibers used to improve resistance to spalling of concrete in fire shall have documented evidence from the producer of satisfactory performance in the service temperature range of concrete.

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Deformed Reinforcement

1. Deformed reinforcement at service temperatures down to 0 °F (or -4 °F?)

   Deformed reinforcing bars used when design temperature is equal to or greater than 0 °F (or -4 °F?) shall be uncoated deformed bar conforming to the requirements of ASTM A615, Grade 60, ASTM A706, or BS 4449, Grade 460, with a yield strength not less than 60,000 lb/in^2.

- Deformed reinforcement conforming to ASTM A615, Grade 60, has been used on a number of RLG storage tanks to accommodate the following:
  - In concrete exponents not below 0 °F
  - Accidental conditions
  - Temporary stresses during construction
  - In concrete components exposed to either service or cryogenic conditions when the steel stresses do not exceed the allowable stresses in 4.7.2 mentioned in the next slide.

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Deformed Reinforcement

2. Deformed reinforcement at service temperatures below 0 °F (or -4 °F?)

   For the design of reinforced concrete components exposed to either service or accidental cryogenic conditions, the selection of the nonprestressed steel reinforcement shall be based on ductility and toughness complying with one of:

a) For carbon steel reinforcement mentioned in the previous slides, the resulting stresses shall not exceed the following:

Bar diameter †	Maximum allowable stresses (lb/in.^{2})*
0.500 in. and smaller (No. 3 and 4)	12,000
0.625 in. to 0.875 in. (No. 5, 6 and 7)	10,000
1.000 and larger (No. 8 and larger)	8000

*For ASTM A706 and Grades 400W and 500W of CAN/CSA G30.18.

†U.S. customary bar designations in parentheses. The limits of this table are applicable to soft metric conversion of ASTM A706 and nominal metric sizes of CAN/CSA G30.18.

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Deformed Reinforcement

b) Steel that satisfies the requirements of EN 14620-3:2006, Annex A.

c) Fully austenitic stainless steel high-yield deformed reinforcing bars conforming to the requirements of ASTM A955, Grade 60, or BS 6744, Grade 500, with a yield strength not less than 60,000 psi.

- Generally, the effect of low service temperatures on nonprestressed reinforcement is to increase the yield and tensile strength, and reduce the ductility and fracture toughness. Selection of cryogenic reinforcement should, therefore, take account of these fundamental property changes.

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Plate Steel Composite with Concrete

- Selection of plate steel used as reinforcement acting in composite action with concrete shall be based on the requirements of API 620, Appendix Q or R, as applicable for the design metal temperature corresponding to minimum service temperature at surface of the plate.
- API 620 Appendices Q and R depends on design metal temperature (DMT) as follows:

a) Appendix Q is applicable to product temperatures to –270 °F; and

b) Appendix R is applicable to product temperatures at +40 to –60 °F.

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Prestressed Reinforcement

- Provisions of this Section shall apply to single strands and wires, multi-strand tendons, and bars.
- The strand for internal circumferential prestressing systems shall comply with the provisions of ASTM A416 and ACI 350, Chapters 3 and 18 Prestressing strands that do not comply with these provisions shall comply with other National or International Codes with the approval of the Engineer.
- Steel for wire-wound prestressing shall comply with the provisions of ASTM A421 and ACI 350, Appendix G, for both field die-drawn and other wire-wound systems; or with BS 4486 or BS 5896.

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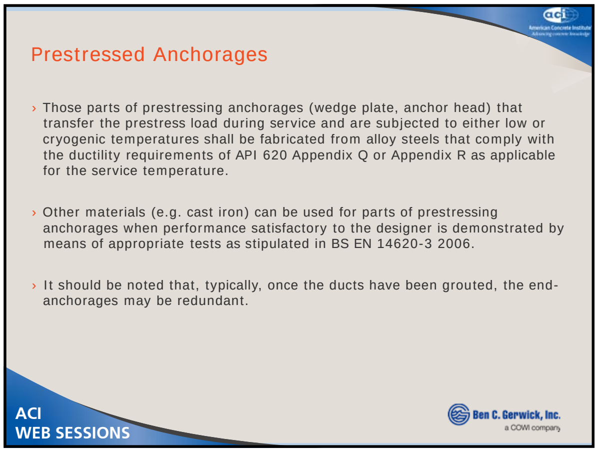
Prestressed Anchorages
› Those parts of prestressing anchorages (wedge plate, anchor head) that transfer the prestress load during service and are subjected to either low or cryogenic temperatures shall be fabricated from alloy steels that comply with the ductility requirements of API 620 Appendix Q or Appendix R as applicable for the service temperature.
› Other materials (e.g. cast iron) can be used for parts of prestressing anchorages when performance satisfactory to the designer is demonstrated by means of appropriate tests as stipulated in BS EN 14620-3 2006.
› It should be noted that, typically, once the ducts have been grouted, the end-anchorages may be redundant.
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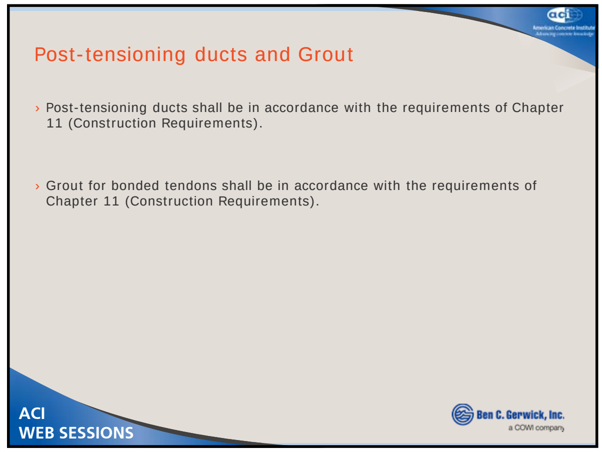
Post-tensioning ducts and Grout
› Post-tensioning ducts shall be in accordance with the requirements of Chapter 11 (Construction Requirements).
› Grout for bonded tendons shall be in accordance with the requirements of Chapter 11 (Construction Requirements).
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Metal liners and Non-structural Metal Components
› Plate steel used solely for primary or secondary containment of RLG shall conform to the requirements of API 620, Appendix Q or R, depending on the temperature range.
› Nonstructural metallic barriers incorporated in, and functioning compositely with, prestressed concrete subject to design temperatures between –60 and –270 °F during normal operation conditions shall be of metal classified for either "primary components" or "secondary components" in API 620, Appendix Q.
› All roof plate material and nonstructural metallic barriers in the concrete wall and the base slab shall be of carbon steel conforming to Appendix R of API 620. Roof liner plates and bottom vapor barrier plates shall be fine-grain carbon steel conforming at least to Group II ASTM A516, with the minimum design temperatures in accordance with the design requirements in API 620.
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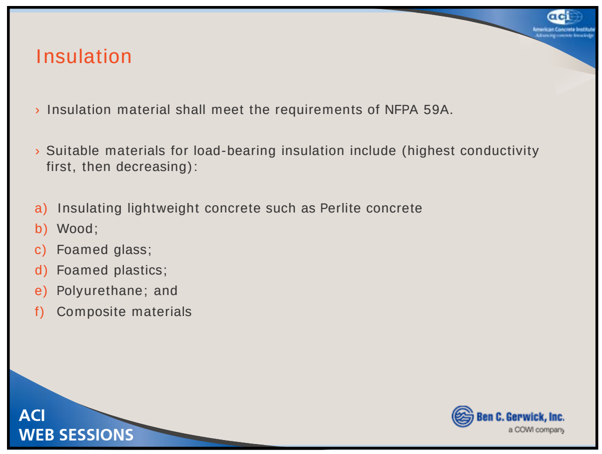
Insulation
› Insulation material shall meet the requirements of NFPA 59A.
› Suitable materials for load-bearing insulation include (highest conductivity first, then decreasing):
a) Insulating lightweight concrete such as Perlite concrete
b) Wood;
c) Foamed glass;
d) Foamed plastics;
e) Polyurethane; and
f) Composite materials
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Insulation
› Suitable materials for non-load-bearing insulation include (highest conductivity first, then decreasing):
a) Perlite;
b) Foamed plastics;
c) Fiberglass;
d) Mineral wool;
e) Polyurethane; and
f) Composite materials
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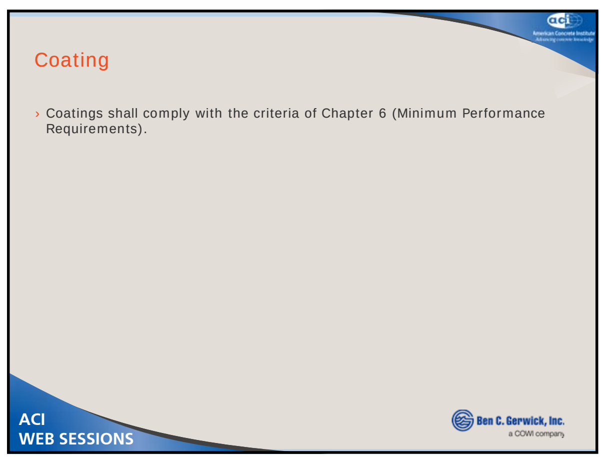
Coating
› Coatings shall comply with the criteria of Chapter 6 (Minimum Performance Requirements).
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Conclusions

- This Chapter of ACI 376 discusses the materials requirements of concrete for the containment of LNG and other refrigerated liquids, ranging in operating temperatures from +40 to –270 °F.
- Testing standards are mentioned together with design requirements to achieve the required performance.

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