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**American Water Works  
Association**

ANSI/AWWA D121-12  
(First Edition)

The Authoritative Resource on Safe Water®

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## *AWWA Standard*

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# Bolted Aboveground Thermosetting Fiberglass- Reinforced Plastic Panel-Type Tanks for Water Storage



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# Foreword

*This foreword is for information only and is not a part of ANSI<sup>\*</sup>/AWWA D121.*

## I. Introduction.

I.A. *Background.* This standard covers bolted aboveground thermosetting fiberglass-reinforced plastic (FRP) panel-type tanks for water storage and is based on more than a decade of accumulated knowledge and experience from installations worldwide, as well as engineering procedures and analyses generally accepted in the tank industry. Bolted FRP panel-type tanks are typically field assembled from factory-produced modular panel units. Tanks ranging in size from 260 gal to 2.5 mil gal have been constructed.

I.B. *History.* This is the first edition of ANSI/AWWA D121. In June 2007, the Standards Council approved this new standard and assigned it to Standards Committee 370, Thermosetting Fiberglass-Reinforced Plastic Tanks. A subcommittee was formed to prepare this standard. Applicable publications, such as ANSI/AWWA D120, ANSI/AWWA D103, BS EN 13280:2001, SS245:1995, and JIS R3411-3417 were consulted in forming this standard, and seismic design procedures are based on current practice as reflected in ASCE/SEI 7-05, ANSI/AWWA D110-04, ACI 350.3-06, and Technical Information Document TID 7024, chapter 6 and appendix F, US Atomic Energy Commission.

This first edition was approved by the AWWA Board of Directors on Jan. 22, 2012.

I.C. *Acceptance.* In May 1985, the US Environmental Protection Agency (USEPA) entered into a cooperative agreement with a consortium led by NSF International (NSF) to develop voluntary third-party consensus standards and a certification program for direct and indirect drinking water additives. Other members of the original consortium included the Water Research Foundation (formerly AwwaRF) and the Conference of State Health and Environmental Managers (COSHEM). The American Water Works Association and the Association of State Drinking Water Administrators (ASDWA) joined later.

In the United States, authority to regulate products for use in, or in contact with, drinking water rests with individual states.<sup>†</sup> Local agencies may choose to impose requirements more stringent than those required by the state. To evaluate the health

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\* American National Standards Institute, 25 West 43rd Street, Fourth Floor, New York, NY 10036.

† Persons outside the United States should contact the appropriate authority having jurisdiction.

effects of products and drinking water additives from such products, state and local agencies may use various references, including

1. An advisory program formerly administered by USEPA, Office of Drinking Water, discontinued on Apr. 7, 1990.
2. Specific policies of the state or local agency.
3. Two standards developed under the direction of NSF, NSF\*/ANSI 60, Drinking Water Treatment Chemicals—Health Effects, and NSF/ANSI 61, Drinking Water System Components—Health Effects.
4. Other references, including AWWA standards, *Food Chemicals Codex*, *Water Chemicals Codex*,<sup>†</sup> and other standards considered appropriate by the state or local agency.

Various certification organizations may be involved in certifying products in accordance with NSF/ANSI 61. Individual states or local agencies have authority to accept or accredit certification organizations within their jurisdiction. Accreditation of certification organizations may vary from jurisdiction to jurisdiction.

Annex A, “Toxicology Review and Evaluation Procedures,” to NSF/ANSI 61 does not stipulate a maximum allowable level (MAL) of a contaminant for substances not regulated by a USEPA final maximum contaminant level (MCL). The MALs of an unspecified list of “unregulated contaminants” are based on toxicity testing guidelines (noncarcinogens) and risk characterization methodology (carcinogens). Use of Annex A procedures may not always be identical, depending on the certifier.

ANSI/AWWA D121 does not address additives requirements. Users of this standard should consult the appropriate state or local agency having jurisdiction in order to

1. Determine additives requirements, including applicable standards.
2. Determine the status of certifications by all parties offering to certify products for contact with, or treatment of, drinking water.
3. Determine current information on product certification.

## **II. Special Issues.**

II.A. *Purchase.* When tanks are purchased using this standard, the purchaser must specify certain basic requirements. The purchaser may desire to modify, delete, or amplify sections of this standard to suit special conditions. It is strongly recommended that such modifications, deletions, or amplifications be made by supplementing this

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\* NSF International, 789 N. Dixboro Road, Ann Arbor, MI 48105.

† Both publications available from National Academy of Sciences, 500 Fifth Street, NW, Washington, DC 20001.

standard rather than by rewriting or incorporating sections from this standard into a separate specification.

II.B. *Design and Construction.* The details of design and construction covered by this standard are minimum requirements. A tank cannot be represented as adhering to the provisions of ANSI/AWWA D121 if it does not meet the minimum requirements of this standard.

II.C. *Manufacturing Method.* Tanks covered by this standard shall be manufactured by compression molding with SMC (sheet mold compound) using the hot press method. Tanks requiring no internal or external coating and bolted construction have a long life expectancy. Regular inspection and repair of damaged or deteriorated areas may be the determining factors in the length of tank life.

II.D. *Foundations.* Tank foundations are one of the more important aspects of tank design. Detailed requirements for tank foundations are covered in Sec. 5.8 of this standard. This standard does not require the manufacturer or constructor to be responsible for the design of the tank foundation unless otherwise specified by the purchaser. Unless otherwise specified by the purchaser, the purchaser must obtain an adequate soil investigation at the tank site, including recommendations of the type of foundation to be used, the depth of foundation required, and the design soil-bearing pressure. This information, as well as specifications for an adequate soil investigation, should be established by a qualified geotechnical engineer. The top of the foundation strips should be 20 in. (500 mm) minimum above the finished grade, unless otherwise specified by the purchaser. The tank manufacturer shall provide the loads that the foundation beams will have to support.

A drainage inlet structure or suitable erosion protection should be provided to receive the discharge from the tank overflow. The overflow shall not be connected directly to a sewer or a storm drain without an air break.

II.E. *Annual Inspection and Maintenance.* Inspection and maintenance is important if maximum tank life is to be attained. Inspections should be performed annually.

II.F. *Disinfection Procedures.* This standard does not cover tank disinfection procedures. ANSI/AWWA C652, Standard for Disinfection of Water-Storage Facilities, should be consulted for recommended procedures for disinfection of water-storage facilities. If the disinfecting is to be done by the tank constructor, the purchaser must specify how such disinfecting is to be done.

II.G. *Recommended Items to Be Furnished by the Purchaser and Manufacturer.* The following recommendations on items to be furnished by both the

purchaser and the manufacturer are considered good practice, but are not requirements of ANSI/AWWA D121.

When a bolted FRP panel-type tank is to be purchased under the provisions of this standard, the purchaser should provide the following:

1. The site on which the tank is to be built, including sufficient space to permit the structure to be erected by customary methods.
2. Foundation design and construction unless otherwise specified.
3. Water at the proper pressure for testing, as required, and facilities for disposal of waste water after testing.
4. A suitable right-of-way from the nearest public road to the erection site.
5. Materials furnished by the purchaser to be used by the constructor for construction of the tank.

The manufacturer should furnish the following:

1. Foundation layout and loads to be supported for the intended tank.
2. Anchor bolts, if required, for wind, earthquake, or other lateral loads, or if specified to be furnished.
3. All materials, except materials furnished by the purchaser that are necessary to assemble the structure components, including the accessories required by this standard.

Variations in the responsibilities of both the purchaser and the manufacturer as previously outlined may be made by contractual agreement. The purchaser and the bidder should each furnish information identified in the sections that follow.

**III. Use of This Standard.** It is the responsibility of the user of an AWWA standard to determine that the products described in that standard are suitable for use in the particular application being considered.

**III.A. Purchaser Options and Alternatives.** The following information should be furnished by the purchaser when taking bids for a tank:

1. Standard used—that is, ANSI/AWWA D121, Bolted Aboveground Thermosetting Fiberglass-Reinforced Plastic Panel-Type Tanks for Water Storage, of latest revision.
2. Whether compliance with NSF/ANSI 61, Drinking Water System Components—Health Effects, is required.
3. Affidavit of compliance, if required.
4. Tank capacity and dimensional restrictions if any.
5. Maximum flow rate, either in or out.
6. Desired time for completion.

7. Site location.
8. Type of road available for access to the site, and whether the road is public or private.
9. Name of and distance to the nearest town.
10. Name of and distance to the nearest railroad siding.
11. Availability of electric power; who furnishes it and at what fee, if any; what voltage is available; whether direct or alternating current; and, if alternating current, what cycle and phase.
12. Availability of compressed air and at what pressure, volume, and fee, if any.
13. The bottom capacity level of the tank when empty if different from the level when the tank would be emptied through the specified discharge piping.
14. The type of pipe and fittings for fluid conductors and the type of pipe joint.
15. The required freeboard.
16. Details of other federal, state or provincial, and local requirements (Sec. 4.1).
17. Any additional accessories required (Section 7).
18. The number and location of pipe connections, and type and size of pipe to be accommodated.

NOTE: Connections to the piping furnished by the constructor are to be made by the purchaser (Sec. 7.2).

19. If the roof ladder for providing access to roof hatches and vents is to be omitted (Sec. 7.4.3).
20. If safety cages, rest platforms, or other safety devices are required, and on which ladders (Sec. 7.5).

III.B. *Information to Be Furnished by the Manufacturer or Constructor.* The following information shall be furnished by the manufacturer or constructor for a tank:

1. Dimensions of the tank, including the vertical load, lateral loads, and overturning moments imparted to the foundation by all loads should also be identified at the time of the bid.
2. The number, names, and sizes of all accessories. This includes the type of roof ladder if an alternative method from that required in Sec. 7.4.3 is proposed.

III.C. *Items for Consideration by the Purchaser.* The design, construction, and final placement of a storage tank into service require cooperation between the purchaser, manufacturer, and constructor of the tank. Various practices are used to ensure successful tank placement. The following items are suggested for inclusion in the purchaser's requirements, unless local practice dictates otherwise.

Please note that this material is not stipulated in the text of ANSI/AWWA D121.

1. The purchaser may want to provide for field inspection to be performed either by the purchaser or by a commercial inspection agency, the cost of which shall be paid by the purchaser. As an option, the purchaser may require the manufacturer or constructor to perform the inspection work and, at the conclusion of the work, to submit a written report. The report should include a statement indicating that the tank has been erected according to the manufacturer's instructions, that the required testing has been performed, and that any leaks have been repaired.

2. This standard assumes that the purchaser (owner) provides sufficient water replacement and circulation to prevent freezing in the tank and riser pipe. Where low usage may result in the possibility of freezing, the purchaser shall waste water or provide heat to prevent freezing. The purchaser is referred to National Fire Protection Association (NFPA) document NFPA 22, *Water Tanks for Private Fire Protection*, for heater sizing. Purchasers are cautioned against allowing ice to build up for use as insulation because the ice may break loose and damage the tank. Where reference to ice damage is discussed in the standard, it is in anticipation of improper operation rather than approval of an icing condition.

3. On completion of the tank erection, it is recommended that the constructor dispose of all rubbish and other unsightly material caused by the operations and leave the premises in as good a condition as found at the start of the tank erection. It is recommended that the purchaser provide appropriate containers for placement and removal of disposed materials. Sec. 9.10 of ANSI/AWWA D121 does not list requirements for cleanup.

4. ANSI/AWWA D121 does not require the manufacturer or constructor to blind (i.e., temporarily seal all openings) and fill the tank to top capacity level. It is common practice for the purchaser to provide this effort. Should the purchaser require that the constructor provide this service and a supply of water, this must be provided for in the purchaser's requirements.

5. ANSI/AWWA D121 does not require the constructor to furnish foundation plans (only foundation layout drawings with directional details to support the tank). Should the purchaser specify submission of foundation plans; the purchaser must furnish adequate information relative to the type of foundation, foundation depth, and allowable soil-bearing pressure. (*see* Sec. II.D of the foreword and Sec. 5.8, *Foundation Design*, for further information.)

6. ANSI/AWWA D121 does not require the manufacturer or constructor to construct and install a foundation. Should the purchaser require that a foundation be

provided by the constructor, any information other than that contained in Sec. 5.8 of this standard must also be provided by the purchaser.

7. It is recommended that the purchaser retain a qualified geotechnical consultant to conduct a proper soil investigation. Unless otherwise specified by the purchaser, ANSI/AWWA D121 does not require that the manufacturer or constructor provide this service (see Sec. 5.8.5).

8. The purchaser may want to provide for shop inspection, to be performed either by the purchaser or by a commercial inspection agency, the cost of which shall be paid by the purchaser.

III.D. *Modification to Standard.* Any modification to the provisions, definitions, or terminology in this standard must be provided in the purchaser's documents.

**IV. Major Revisions.** This is the first edition of this standard.

**V. Comments.** If you have any comments or questions about this standard, please call AWWA Engineering and Technical Services at 303.794.7711, FAX at 303.795.7603, write to the department at 6666 West Quincy Avenue, Denver, CO 80235-3098, or email at standards@awwa.org.

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*AWWA Standard*

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# **Bolted Aboveground Thermosetting Fiberglass-Reinforced Plastic Panel- Type Tanks for Water Storage**

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## **SECTION 1: GENERAL**

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### **Sec. 1.1 Scope**

This standard describes the design, fabrication, installation, inspection, and testing of bolted aboveground thermosetting fiberglass-reinforced plastic (FRP) panel-type tanks for potable water storage. Requirements for the fabrication, handling, construction, and testing of FRP panels, concrete and steel foundation structure, foundation, and accessories are included. Site elevation and procurement, tank sizing; post-commissioning inspection and maintenance; and the design, operation, and control of the water distribution system that connects to the bolted aboveground FRP panel-type tank are beyond the scope of this standard.

1.1.1 *Tank roofs.* Tanks storing domestic or potable water shall have roofs conforming to the requirements of this standard. Tanks storing nonpotable water may be constructed without roofs.

1.1.2 *Items not covered.* This standard does not cover all details of design and construction. Details that are not addressed shall be designed and constructed to be as adequate and as safe as those that would otherwise be provided under this standard.

1.1.3 *Local requirements.* This standard is not intended to cover storage tanks erected in areas subject to regulations more stringent than the requirements contained within this standard. In such cases, this standard should be followed where it does not conflict with more stringent requirements. Where more stringent federal, state, provincial and local government requirements exist, such requirements shall be specified, and this standard shall be interpreted to supplement them.

**Sec. 1.2 Purpose**

The purpose of this standard is to provide minimum requirements for the design, manufacture, installation, and inspection of bolted, aboveground thermoset fiberglass-reinforced plastic (FRP) panel-type tanks for the storage of water. This standard is only applicable to tanks with a base elevation substantially at ground level.

**Sec. 1.3 Application**

This standard can be referenced in project documents that address the design, fabrication, construction, inspection, and testing of bolted aboveground FRP panel-type tanks for water storage. The stipulations of this standard apply when this document has been referenced and then only to bolted aboveground FRP panel-type tanks.

**Sec. 1.4 Drawings to Be Furnished**

Construction drawings for the bolted aboveground FRP panel-type tank and foundation shall be provided. Drawings shall show all features of the work, including the size and position of structural components, the required length or grade of materials, and construction tolerances. Where foundation and tank designs are performed by separate parties, each party shall provide construction drawings. Details of bolted joints shall be referenced on the drawings.

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## SECTION 2: REFERENCES

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This standard references the following documents. In their latest editions, they form a part of this standard to the extent specified within the standard. In any case of conflict, the requirements of this standard shall prevail.

ACI\* 301—Specifications for Structural Concrete.

ACI 318—Building Code Requirements for Structural Concrete.

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\* American Concrete Institute, 38800 Country Club Dr., Farmington Hills, MI 48331.

AISC\* 360, Specification for Structural Steel Buildings.

ANSI†/AWWA C652—Disinfection of Water-Storage Facilities.

ASCE‡/SEI 7-05—Minimum Design Loads for Buildings and Other Structures.

ASTM§ A36/A36M—Standard Specification for Carbon Structural Steel.

ASTM A48/A48M—Standard Specification for Gray Iron Castings.

ASTM A123/A123M—Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products.

ASTM A153/A153M—Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware.

ASTM A194/A194M—Standard Specification for Carbon and Alloy Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both.

ASTM A216/A216M—Standard Specification for Steel Castings, Carbon, Suitable for Fusion Welding, for High-Temperature Service.

ASTM A307—Standard Specification for Carbon Steel Bolts and Studs, 60,000 psi Tensile Strength.

ASTM A325—Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength.

ASTM A490—Standard Specification for Steel Structural Bolts, Alloy Steel, Heat-Treated, 150 ksi Minimum Tensile Strength.

ASTM A563—Standard Specification for Carbon and Alloy Steel Nuts.

ASTM A572/A572M—Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel.

ASTM A668/A668M—Standard Specification for Steel Forgings, Carbon and Alloy, for General Industrial Use.

ASTM C581—Standard Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass-Fiber-Reinforced Structures Intended for Liquid Service.

ASTM D395—Standard Test Methods for Rubber Property—Compression Set.

ASTM D412—Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension.

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\* American Institute of Steel Construction, One East Wacker Drive, Suite 700, Chicago, IL 60601.

† American National Standards Institute, 25 West 43rd Street, Fourth Floor, New York, NY 10036.

‡ American Society of Civil Engineers, 1801 Alexander Bell Drive, Reston, VA 20191.

§ ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

ASTM D573—Standard Test Method for Rubber—Deterioration in an Air Oven.

ASTM D638—Standard Test Method for Tensile Properties of Plastics.

ASTM D695—Standard Test Method for Compressive Properties of Rigid Plastics.

ASTM D732—Standard Test Method for Shear Strength of Plastics by Punch Tool.

ASTM D790—Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials.

ASTM D792—Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement.

ASTM D883, Standard Terminology Relating to Plastics.

ASTM D953—Standard Test Method for Bearing Strength of Plastics.

ASTM D1056—Standard Specification for Flexible Cellular Materials—Sponge or Expanded Rubber.

ASTM D1171—Standard Test Method for Rubber Deterioration—Surface Ozone Cracking Outdoors or Chamber (Triangular Specimens).

ASTM D2240—Standard Test Method for Rubber Property—Durometer Hardness.

ASTM D2290—Standard Test Method for Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe by Split Disk Method.

ASTM D2563—Standard Practice for Classifying Visual Defects in Glass-Reinforced Plastic Laminate Parts.

ASTM D2583—Standard Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor.

ASTM D2584—Standard Test Method for Ignition Loss of Cured Reinforced Resins.

ASTM D3567—Standard Practice for Determining Dimensions of “Fiber-glass” (Glass-Fiber-Reinforced Thermosetting Resin) Pipe and Fittings.

ASTM F593—Standard Specification for Stainless Steel Bolts, Hex Cap Screws, and Studs.

ASTM F594—Standard Specification for Stainless Steel Nuts.

ASTM F1554—Standard Specification for Anchor Bolts, Steel, 36, 55, and 105-ksi Yield Strength.

ASTM G152—Standard Practice for Operating Open Flame Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials.

ASTM G153—Standard Practice for Operating Enclosed Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials.

ASTM SI10 IEEE/ASTM SI 10—American National Standard for Metric Practice.

AWS\* A5.1—Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding.

AWS D1.1/D1.1M-2010—Structural Welding Code—Steel.

FTPI† 2007-1—Recommended Practice for the In-service Inspection of Aboveground Atmospheric Fiberglass Reinforced Plastic (FRP) Tanks and Vessels.

FTPI RP T-95-02—Remanufacturing of Fiberglass Reinforced Plastic (FRP) Underground Storage Tanks.

ISO‡ 9001:2008—Quality Management Systems – Requirements.

NFPA§ 22—Standard for Water Tanks for Private Fire Protection.

NSF¶/ANSI 61—Drinking Water System Components—Health Effects.

OSHA\*\* 29 CFR 1910—Occupational Safety and Health Standards—General Industry.

RCSC†† (Research Council on Structural Connections)—Specification for Structural Joints Using ASTM A325 or A490 Bolts.

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## SECTION 3: DEFINITIONS

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Unless otherwise indicated, the plastics terminology used in this standard is in accordance with ASTM D883. The following definitions shall apply in this standard:

1. *Capacity*: The net tank volume measured as the difference between the total tank volume and volume of the freeboard. (NOTE: The usable volume of water may be less than the capacity depending on the location of the tank discharge.)

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\* American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126..

† Fiberglass Tank and Pipe Institute, 11150 South Wilcrest Dr., Suite 101, Houston, TX 77099.

‡ International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, Case postale 56, CH-1211 Geneva 20, Switzerland.

§ National Fire Protection Association, One Batterymarch Park, Quincy, MA 02169.

¶ NSF International, 789 N. Dixboro Road, Ann Arbor, MI 48105.

\*\* US Department of Labor, Occupational Safety and Health Administration, 200 Constitution Avenue, Washington, D.C. 20210

†† Research Council on Structural Connections, One East Wacker Dr., Suite 3100, Chicago, IL 60601.

2. *Constructor:* The party that provides the work and materials for placement or installation.
3. *Freeboard:* The difference between the top of the tank and the top of the water surface.
4. *Manufacturer:* The party that manufactures, fabricates, or produces materials or products.
5. *Purchaser:* The person, company, or organization that purchases any materials or work to be performed.
6. *Resin:* A thermosetting polyester or vinyl ester that is crosslinked with styrene. The physical and chemical properties of resins vary greatly. Each type of resin has particular strengths and weaknesses for a given application, which require evaluation.
7. *Sloshing:* The movement of water in the tank that is attributable to external forces, such as earthquakes, that cause dynamic loading on the tank.
8. *Supplier:* The party that supplies materials or services. A supplier may or may not be the manufacturer.
9. *Surface veil:* A fine reinforcement-mat layer applied to the laminate surface.
10. *Tank:* A chamber used for water storage. Tanks covered by this standard are typically square, rectangular, U, or L-shaped.

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## SECTION 4: MATERIALS

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### Sec. 4.1 General

Materials to be incorporated in any structure to meet the provisions of this standard shall be new, previously unused, and in first-class condition, and shall comply with the requirements of this standard.

Material shall comply with the requirements of the Safe Drinking Water Act and other federal regulations for potable water, wastewater, and reclaimed water systems as applicable.

### Sec. 4.2 Bolts for Panel Connections

4.2.1 *Bolts.* Bolts for joining tank panels shall conform to the requirements of ASTM A307, ASTM A325, ASTM A490, or ASTM F593 and shall comply with the requirements of AISC 360. Nuts for these bolts shall conform to ASTM A194, ASTM A563, and ASTM F594.

4.2.2 *Anchor bolts.* Anchor bolts shall conform to the requirements of ASTM A36, ASTM A307, or ASTM A572, grade 50.

### Sec. 4.3 Foundation-Reinforcing Steel

Reinforcing steel in foundations shall comply with the requirements of ACI 318.

### Sec. 4.4 FRP Panels

Panels shall be manufactured using Sheet Molding Compound (SMC) in accordance with Sec. 4.4.1, 4.4.2, and 4.4.3 by compression molding using a hot-pressed method with a minimum molding pressure of 2,470 psi (17 MPa) and a curing temperature of 284°F (140°C). SMC used in the manufacture shall be from an approved NSF/ANSI 61 supplier, manufactured panels shall conform to ASTM: D638, D695, D790, D792, D953, D2563, D2583 and have greater than 40 percent glass content.

4.4.1 *Resin.* The resin shall be a commercial grade, thermosetting plastic resin that has been evaluated in a laminate by test in accordance with Sec. 4.4. The resin shall not contain fillers or pigments except as specified in Sec. 4.4.1.1, 4.4.1.2, 4.4.1.3, 4.4.1.4, and 4.4.1.5.

4.4.1.1 *Thixotropic agent.* Up to 5 percent (by weight) thixotropic agent that will not interfere with visual inspection may be added for viscosity control. Resin pastes used to fill crevices before overlay shall not be subject to this limitation.

4.4.1.2 *Ultraviolet absorbers.* Ultraviolet absorbers may be added to the final resin coating to improve weather resistance.

4.4.1.3 *Pigments.* Resins, catalyst, and other additives may contain pigments, dyes, or colorants, provided their concentration does not prevent detection of visual defects or adversely affect performance of the FRP panel.

4.4.1.4 *Fire-retardants.* Fire-retardant agents may be added for improved fire resistance.

4.4.1.5 *Fillers.* The structural filler may contain particular fillers, provided that the fillers are compatible with other laminate constituents and do not adversely affect the performance of the laminate. The glass volume fraction in the filled laminate shall be no less than the glass volume fraction in an unfilled laminate based on the glass content requirements.

#### 4.4.2 *Reinforcing materials.*

4.4.2.1 *Fiberglass.* The reinforcing material shall be a commercial-grade glass fiber having a coupling agent; it shall be compatible with the resin used and

suitable for the particular fabrication technique. The reinforcing material used to fabricate the tank shall be comparable to that used to generate environmental-resistance and physical-property design data.

4.4.3 *Surfacing materials.*

4.4.3.1 Surfacing veil. The surfacing veil, when used in the interior layer, shall be commercial grade and chemical resistant, having a coupling agent.

4.4.4 *Physical and mechanical properties.*

4.4.4.1 Wall thickness. The average wall thickness of the FRP panel shall be measured in accordance of ASTM D3567. No FRP panel shall have a thickness of less than 0.1181 in. (3 mm).

4.4.4.2 Surface hardness. The surface hardness (interior and exterior) shall be at least 90 percent of the resin manufacturer's minimum specified hardness for the cured resin, when tested in accordance with ASTM D2583.

4.4.4.3 Glass content. The glass content of the structural layer, when measured in accordance with Sec. 8.7.1.2 shall be no less than 90 percent of the design glass content.

4.4.4.4 Modulus of elasticity. The modulus of elasticity of the FRP panel measured in either tension or flexure in accordance with Sec. 8.7.1.3 and Sec. 8.7.1.4 shall be no less than 1,200,000 psi (8,274 MPa). The initial, unaged flexural modulus of elasticity shall be determined for evaluating the laminate for environmental exposure and quality control.

4.4.4.5 Tensile strength. The initial, unaged ultimate tensile strength of the FRP panel in the weakest direction when measured in accordance with Sec. 8.7.1.3 shall be no less than 14,500 psi (100 MPa).

4.4.4.6 Flexural strength. The initial, unaged ultimate flexural strength of the FRP panel in the weakest direction when measured in accordance with Sec. 8.7.1.4 shall be no less than 23,900 psi (165 MPa).

4.4.4.7 Shear strength. The initial, unaged ultimate shear strength of the FRP panel in the weakest direction when measured in accordance with Sec. 8.7.1.5 shall be no less than 13,500 psi (93 MPa).

4.4.4.8 Compressive strength. The initial, unaged ultimate compressive strength of the FRP panel in the weakest direction when measured in accordance with Sec. 8.7.1.6 shall be no less than 23,200 psi (160 MPa).

4.4.4.9 Bearing strength. The initial, unaged ultimate bearing strength of the FRP panel in the weakest direction when measured in accordance with Sec. 8.7.1.7 shall be no less than 29,000 psi (200 MPa).



**Sec. 4.5 Structural Shapes**

Hot-rolled structural shapes for use under the provisions of this standard shall conform to AISC 360. Material shall conform to ASTM A36.

**Sec. 4.6 Castings**

Iron castings shall conform to ASTM A48, class 30. Steel castings shall conform to ASTM A216, grade WCB.

**Sec. 4.7 Forgings**

Forgings from plate and sheet materials shall conform to ASTM A668.

**Sec. 4.8 Galvanized Coatings**

When hot-dip galvanized coatings are to be supplied, they can only be used on external steel footings, reinforcements, and/or external ladders in accordance with the recommended practice of the American Hot Dip Galvanizers Association in compliance with ASTM A123 and ASTM A153.

**Sec. 4.9 Structural Bolts for Steel Footing Connection**

4.9.1 *Bolts.* Steel bolts shall be ASTM A325 or ASTM A490, meeting the requirements of RCSC Specification for Structural Joints Using ASTM A325 or A490 Bolts.

4.9.2 *Foundation anchor bolts.* Foundation anchor bolts shall conform to ASTM F1554, Grade 36, 55, or 105. Unless otherwise specified, anchor bolts shall be supplied with unified coarse (UNC) threads with a Class 2a tolerance, as permitted in ASTM F1554. Nuts for anchor bolts shall be furnished as heavy hex nuts, ASTM A563 Grade A (for Grade 36 and 55 bolts) or Grade DH (for Grade 105 bolts).

**Sec. 4.10 Electrodes**

Manual, shielded-metal, arc-welding electrodes shall conform to the requirements of AWS A5.1. Welding electrodes shall be of any E60XX or E70XX classification suitable for the electric current characteristics, the position of welding, and other conditions of intended use.

**Sec. 4.11 Gaskets and Sealants**

The manufacturer shall use gaskets, sealants, and patches, or any combination, in accordance with the following requirements.

4.11.1 *Gaskets.* EPDM roof gasket material shall be of adequate tensile strength and resilience to obtain a leak proof seal at seams and joints. Gasket material shall be resistant to weather and ozone exposure as designated by ASTM D1171 and comply with ASTM D412 (Die A) and D1056.

**Table 1 Physical requirement for sealant material**

Description	Strip and Extruded Sealant Material
Tensile strength, initial, psi minimum, ASTM D412 longitudinal direction	1,030 psi (7,100 kPa)
Tensile strength, initial, psi minimum, ASTM D412 cross direction	1,348 psi (9,300 kPa)
Ultimate elongation, initial, percent of minimum, ASTM D412 longitudinal direction	430%
Ultimate elongation, initial, percent of minimum, ASTM D412 cross direction	675%
Hardness, Shore A, ASTM D2240	75 ± 5
Hardness change, Shore A, after oven aging, ASTM D573	7

4.11.2 *Sealants.* Sealants shall be SEBS (styrene-ethylene-butylene-styrene) an elastomer with enhanced performance and excellent resistance to aging and NSF/ANSI 61 approved. SEBS shall comply with the following: ASTM D395 Method B, D412, D792, and D2240. Physical requirements are described in Table 1.

4.11.3 *Patches.* Patches shall be self-adhesive EPDM cellular rubber, a sealant used at main SEBS sealant intersections. EPDM resists aging from weather, ozone, and water with superior UV resistance and complies with ASTM D412 (Die A) and D1056.

1. Resistance to temperature. The sealant shall remain flexible when in continuous operation over a temperature range of  $-4^{\circ}\text{F}$  to  $+212^{\circ}\text{F}$  ( $-40^{\circ}\text{C}$  to  $+100^{\circ}\text{C}$ ).

2. Weatherability. The sealant shall be resistant to hardening and cracking. The sealant shall be essentially solid and contain no plasticizers or extenders that could cause shrinkage caused by weathering. The sealant shall be resistant to ozone and ultraviolet light.

3. Chemical resistance. The sealant shall be chemically resistant without extraction to water and shall not swell or degrade under normal water-storage conditions.

4. Material specification. The sealant shall be NSF/ANSI 61 approved.

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## SECTION 5: TANK DESIGN

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### Sec. 5.1 Design Methodology

Structural elements for the tank shall be designed for all imposed loads based on accepted structural engineering practice. Specified factored resistances shall exceed the response resulting from specified factored loads. Loads and load factors

shall be as specified in Sec. 5.2. Seismic loads due to earthquake shall be as specified in Sec. 5.3. Strengths and resistance factors for FRP panels and connections shall be as specified in Sec. 5.4.

## Sec. 5.2 Design Loads

The following loads shall be considered in the design of tank structures and foundations and shall be used in Load and Resistance Factor Design (LRFD) load combinations of Sec. 5.2.7.

5.2.1 *Water load (F)*. Water load shall be the weight of water when the tank is filled to its capacity. The static water pressure is to be treated as a long period load. Unit weight used for water shall be 62.4 lb/ft<sup>3</sup> (1,000 kg/m<sup>3</sup>).

5.2.2 *Dead load (D)*. Dead load is a gravity load due to the weight of permanent components of the bolted FRP panel-type water tank and is to be treated as a long period load.

5.2.3 *Roof live load (L<sub>r</sub>)*. Roof live load is the load attributable to weight of the persons during maintenance and is in accordance with ASCE/SEI 7-05. The minimum roof live load shall be 12 lb/ft<sup>2</sup> (0.58 kN/m<sup>2</sup>) and is to be treated as a short-period load.

5.2.4 *Snow load (S)*. Snow load shall be in accordance to ASCE/SEI 7-05 chapter 7 and Table 1.1 of chapter 1.

5.2.5 *Wind load (W)*. Wind load is the wind pressure acting on the wall and roof of the tank and is in accordance with ASCE/SEI 7-05, chapter 6.

5.2.6 *Earthquake load (E)*. Earthquake load takes into account the impulsive and convective (sloshing) actions of the liquid. Tanks shall be analyzed for earthquake loads in accordance with Sec. 5.3 of this standard.

5.2.7 *Load combinations*. The tank shall be provided with strength adequate to resist the critical effect resulting from the following combination of loads:

$$1.4 ( D + F ) \quad (\text{Eq 5-1})$$

$$1.2 ( D + F ) + 0.50 L_r \quad (\text{Eq 5-2})$$

$$1.2 ( D + F ) + 0.50 S \quad (\text{Eq 5-3})$$

$$1.2 D + 1.6 L_r + 0.80 W \quad (\text{Eq 5-4})$$

$$1.2 D + 1.6 S + 0.80 W \quad (\text{Eq 5-5})$$

$$1.2 D + 1.6 W + 0.50 L_r \quad (\text{Eq 5-6})$$

$$1.2 D + 1.6 W + 0.50 S \quad (\text{Eq 5-7})$$

$$1.2 D + 1.0 E + 0.20 S \quad (\text{Eq 5-8})$$

$$0.90 D + 1.6 W \quad (\text{Eq 5-9})$$

$$0.90 D + 1.0 E \quad (\text{Eq 5-10})$$

**Table 2 Load Duration for Loading Types**

Load Duration	Load Condition	Types of Loading					Remarks
		<i>F</i>	<i>D</i>	<i>L<sub>r</sub></i>	<i>S</i>	<i>W</i>	
Long Period	Normal						
Short Period	At time of maintenance						
	At time of storm						*
	At time of earthquake						
	At time of snow						*

\*Will not be considered when the tank is enclosed by other structure.

Where:

*D* = dead load

*E* = earthquake load

*F* = load due to water

*L<sub>r</sub>* = roof live load

*S* = snow load

*W* = wind load

5.2.8 *Duration of load.* The duration of load shall be considered in the design, as shown in Table 2.

5.2.9 *Temperature load.* Where applicable, the structural effects of temperature change shall be considered in combination with other loads. The load factor on temperature effects shall not be less than 1.0.

### Sec. 5.3 Seismic Design

5.3.1 *Scope.* The seismic design of bolted FRP panel-type (BFRPP) water-storage tanks subjected to seismic loads includes two aspects: the “loading side,” which is the determination of seismic loads based on earthquake spectral response accelerations and the geometry of the tank; and the “resistance side,” which is the detailed design of the tank structure to resist the seismic loads. This section describes procedures for determining the “loading side.”

The seismic loads for the design of a BFRPP water-storage tank are based on ASCE/SEI 7-05. Seismic loads of the building code, with jurisdiction over the area where the BFRPP tank will be located, shall be used if they exceed the requirements of ASCE/SEI 7-05.

The “resistance side” is covered in Sec. 5.3.8, 5.4, 5.5, 5.6, 5.7, and 5.8 of this standard.

5.3.2 *Notation.*

- $B$  = inside dimension (length or width) of a rectangular tank, perpendicular to the direction of the ground motion being investigated, ft (m)
- $C_o$ ,  $C_i$ , and  $C_t$  = period-dependent seismic response coefficients
- $d_{max}$  = required freeboard (sloshing height) measured from the water surface at rest, ft (m)
- EBP = excluding base pressure (datum line just above the base of the tank wall)
- $F_a$  = short-period site coefficient (at 0.2-sec period) from ASCE/SEI 7-05, Table 11.4-1
- $F_v$  = long-period site coefficient (at 1.0-sec period) from ASCE/SEI 7-05, Table 11.4-2
- $g$  = acceleration due to gravity [32.17 ft/s<sup>2</sup> (9.807 m/s<sup>2</sup>)]
- $h_c$  = height above the base of the wall to the center of gravity of convective lateral force for the case, excluding base pressure (EBP), ft (m)
- $h'_c$  = height above the base of the wall to the center of gravity of the convective lateral force for the case, including base pressure (IBP), ft (m)
- $h_i$  = height above the base of the wall to the center of gravity of the impulsive lateral force for the case, excluding base pressure (EBP), ft (m)
- $h'_i$  = height above the base of the wall to the center of gravity of the impulsive lateral force for the case, including base pressure (IBP), ft (m)
- $h_r$  = height from the base of the wall to the center of gravity of the tank roof, ft (m)
- $h_w$  = height from the base of the wall to the center of gravity of the wall, ft (m)
- $H_L$  = design depth of stored water (i.e., tank height less freeboard), ft (m)
- $H_w$  = wall height (inside dimension), ft (m)
- $k$  = stiffness of the wall, lb/ft (kN/m)
- $I$  = importance factor
- IBP = including base pressure (datum line at the base of the tank including the effects of the tank bottom and supporting structure)

- $L$  = inside dimension of a rectangular tank, parallel to the direction of the ground motion being investigated, ft (m)
- $M_b$  = bending moment on the entire tank cross section just above the base of the tank wall, ft-lb (kN-m)
- $M_c$  = bending moment of the entire tank cross section just above the base of the tank wall (EBP) due to the convective force  $V_c$ , ft-lb (kN-m)
- $M'_c$  = overturning moment at the base of the tank, including the tank bottom and supporting structure (IBP), due to the convective force  $V_c$ , ft-lb (kN-m)
- $M_i$  = bending moment of the entire tank cross section just above the base of the tank wall (EBP) due to the impulsive force  $V_i$ , ft-lb (kN-m)
- $M'_i$  = overturning moment at the base of the tank, including the tank bottom and supporting structure (IBP), due to the impulsive force  $V_i$ , ft-lb (kN-m)
- $M_o$  = overturning moment at the base of the tank, including the tank bottom and supporting structure (IBP), ft-lb (kN-m)
- $M_r$  = bending moment of the entire tank cross section just above the base of the tank wall (EBP) due to the roof inertia force  $V_r$ , ft-lb (kN-m)
- $M_w$  = bending moment of the entire tank cross section just above the base of the tank wall (EBP) due to the wall inertia force  $V_w$ , ft-lb (kN-m)
- $p_{fL}$  = hydrodynamic pressure on the floor due to lateral acceleration, lb/ft<sup>2</sup> (kPa)
- $p_{fv}$  = hydrodynamic pressure on the floor due to vertical acceleration, lb/ft<sup>2</sup> (kPa)
- $p_{vy}$  = hydrodynamic pressure due to the effect of vertical acceleration, at water level  $y$ , above the base of the tank, lb/ft<sup>2</sup> (kPa)
- $P$  = total vertical dynamic force at the base, lb (kN)
- $P_{rv}$  = vertical inertia force of roof, lb (kN)
- $P_{wv}$  = vertical inertia force of walls, lb (kN)
- $P_{fv}$  = vertical dynamic force acting on the floor due to vertical acceleration, lb (kN)

$R$  = response modification factor, a numerical coefficient representing the combined effect of the structure's ductility, energy-dissipating capacity, and structural redundancy ( $R_c$  for the convective component of the stored water;  $R_i$  for the impulsive component)

$S_1$  = mapped maximum considered earthquake 5 percent damped spectral response acceleration; parameter at a period of 1 sec, expressed as a fraction of the acceleration due to gravity  $g$ , from ASCE/SEI 7-05, Figures 22-1 through 22-14

$S_{D1}$  = design spectral response acceleration, 5 percent damped, at a period of 1 sec, as defined in Sec. 5.3.7.4, expressed as a fraction of the acceleration due to gravity  $g$ .

$S_{DS}$  = design spectral response acceleration, 5 percent damped, at short periods, as defined in Sec. 5.3.7.4, expressed as a fraction of the acceleration due to gravity  $g$ .

$S_s$  = mapped maximum considered earthquake 5 percent damped spectral response acceleration parameter at short periods, expressed as a fraction of the acceleration due to gravity  $g$ , from ASCE/SEI 7-05, Figures 22-1 through 22-14

$t_w$  = average wall thickness, in. (mm)

$T_c$  = natural period of the first (convective) mode of sloshing, sec

$T_i$  = fundamental period of oscillation of the tank (plus the impulsive component of the stored water), sec

$T_S = S_{D1}/S_{DS}$

$T_v$  = natural period of vibration of stored water in the vertical direction, sec

$\ddot{u}_v$  = effective vertical spectral acceleration defined by Eq 5-31 that is derived by scaling an elastic horizontal response spectrum, expressed as a fraction of the acceleration due to gravity  $g$ .

$V$  = total horizontal base shear, lb (kN)

$V_c$  = total lateral convective force associated with  $W_c$ , lb (kN)

$V_{cy}$  = lateral convective force due to  $W_c$ , per unit height of the tank wall, occurring at water level  $y$ , lb/ft of wall height (kN/m)

$V_{fL}$  = lateral inertia force of floor, lb (kN)

$V_i$  = total lateral impulsive force associated with  $W_i$ , lb (kN)

$V_{iy}$  = lateral impulsive force due to  $W_i$ , per unit height of the tank wall, occurring at water level  $y$ , lb/ft of wall height (kN/m)

- $V_{rL}$  = lateral inertia force of roof  $W_r$ , lb (kN)  
 $V_{wL}$  = lateral inertia force of wall  $W_w$ , lb (kN)  
 $V'_{wL}$  = lateral inertia force of one wall ( $W'_w$ ), perpendicular to the direction of the earthquake force, lb (kN)  
 $V_{wy}$  = lateral inertia force due to  $W_w$ , per unit height of the tank wall, occurring at level  $y$  above the tank base, lb/ft of wall height (kN/m)  
 $V_y$  = combined horizontal force (due to the impulsive and convective components of the stored water, and the wall's inertia) at a height  $y$  above the tank base, lb/ft of wall height (kN/m)  
 $W_c$  = equivalent weight of the convective component of the stored water, lb (kN)  
 $W_f$  = weight of the floor, lb (kN)  
 $W_i$  = equivalent weight of the impulsive component of the stored water, lb (kN)  
 $W_L$  = total weight of the stored water, lb (kN)  
 $W_r$  = equivalent weight of the tank roof, plus superimposed load, plus applicable portion of snow load considered as dead load, lb (kN)  
 $W_t$  = total weight of the tank, including the tank bottom and supporting structure; does not include the weight of stored water, lb (kN)  
 $W_w$  = weight of all walls, lb (kN)  
 $W'_w$  = weight of one wall perpendicular to the direction of horizontal ground acceleration being investigated  
 $y$  = water level at which the wall is being investigated (measured from tank floor), ft (m)  
 $\gamma_w$  = density of water, 62.4 lb/ft<sup>3</sup> (9.807 kN/m<sup>3</sup>)  
 $\epsilon$  = effective mass coefficient (ratio of equivalent dynamic mass of the BFRPP wall to its actual total mass), Eq 5-47  
 $\lambda$  = coefficient as defined in Eq 5-49

### 5.3.3 *General criteria for analysis and design.*

5.3.3.1 **Dynamic characteristics.** The dynamic characteristics of a BFRPP water-storage tank shall be derived in accordance with Sec. 5.3.7. Alternatively, a more rigorous dynamic analysis that accounts for the interaction between the structure and the stored water may be used. However, the total base shear and base overturning moment determined from a more rigorous dynamic analysis shall not be less than 80 percent of the values obtained from Sec. 5.3.4.



5.3.3.2 Design loads. The loads generated by the design earthquake shall be computed in accordance with Sec. 5.3.4.

5.3.3.3 Design requirements.

5.3.3.3.1 The walls, floor, and roof of a BFRPP water-storage tank shall be designed to withstand the effects of both the design horizontal acceleration and the design vertical acceleration combined with the effects of the applicable static loads.

5.3.3.3.2 Regarding the effect of horizontal acceleration, the design shall take into account the effects of the transfer of shear between the adjacent walls, the roof and the walls, the floor and the wall, and the wall and the base; and the dynamic pressure acting on the walls and the floor.

5.3.3.3.3 Regarding the vertical acceleration, the design shall take into account the transfer of the vertical inertia force of the roof to the walls and columns, the vertical inertia force of the walls, and the accelerated weight of the stored water acting on the floor. The design shall take into account the lateral pressure of the vertically accelerated stored water acting on the walls.

5.3.3.3.4 The effects of horizontal and vertical acceleration shall be combined as follows:

$$E = 1.0 \times (\text{horizontal acceleration effects}) + 0.3 \times (\text{vertical acceleration effects});$$

and

$$E = 0.3 \times (\text{horizontal acceleration effects}) + 1.0 \times (\text{vertical acceleration effects});$$

Where:

$E$  = the earthquake load in combinations with other design loads used in strength design

5.3.4 *Earthquake design loads.*

5.3.4.1 Earthquake loads. The BFRPP water-storage tank shall be designed for the following dynamic forces in addition to static pressures and loads:

1. Horizontal inertia forces of the roof  $V_{rL}$ , walls  $V_{wL}$ , and floor  $V_{fL}$ ;
2. Hydrodynamic impulsive force  $V_i$  of the stored water;
3. Hydrodynamic convective (sloshing) force  $V_c$  of the stored water;
4. Hydrodynamic pressure of the horizontally accelerated stored water acting on the floor  $p_{fL}$ ;
5. Vertical inertia forces of the roof  $P_{rv}$ , walls  $P_{wv}$ , and floor  $P_{fv}$ ;
6. Hydrodynamic pressure of the vertically accelerated stored water acting on the floor and the walls  $p_{fv}$ .

5.3.4.2 Lateral inertia forces due to horizontal ground motion.

5.3.4.2.1 Lateral inertia forces acting above the foundation due to horizontal ground motion shall be determined as follows:

**Roof:**

Lateral inertia force of roof due to self-weight of roof, plus 25 percent of the design live load, and 20 percent of the design snow load where the flat roof snow load exceeds 30 lb/ft<sup>2</sup>:

$$V_{rL} = C_i I (W_r / R_i) \quad (\text{Eq 5-11})$$

**Walls:**

Lateral inertia force of walls due to self-weight of walls:

$$V_{wL} = C_i I (\epsilon W_w / R_i) \quad (\text{Eq 5-12})$$

$$V'_{wL} = C_i I (\epsilon W'_w / R_i) \quad (\text{Eq 5-13})$$

**Stored water:**

Lateral inertia force of stored water due to impulsive component of stored water:

$$V_i = C_i I (W_i / R_i) \quad (\text{Eq 5-14})$$

Lateral inertia force of stored water due to convective component of the stored water:

$$V_c = C_c I (W_c / R_c) \quad (\text{Eq 5-15})$$

**Floor:**

Lateral inertia force of floor due to self-weight of the floor:

$$V_{fL} = C_i I (W_f / R_i) \quad (\text{Eq 5-16})$$

Where:

$C_i$  and  $C_c$  = the horizontal seismic response coefficients determined in accordance with Sec. 5.3.7.4.

$I$  = is the importance factor

$I$  = 1.25 for BFRPP tanks that are part of lifeline systems, or in accordance with applicable building code;

$I$  = 1.0 for all other BFRPP tanks.

$W_r$ ,  $W_w$ , and  $W_f$  = the weights of the BFRPP tank roof, walls, and floor, respectively.

$W'_w$  = the weight of one wall of the BFRPP tank that is perpendicular to the direction of horizontal ground acceleration being investigated.

$\varepsilon$  = the effective weight coefficient of the BFRPP tank walls determined in accordance with Sec. 5.3.7.2.4.

$W_i$  and  $W_c$  = the weights corresponding to impulsive and convective (sloshing) components of the stored water, respectively, determined in accordance with Sec. 5.3.7.2.1.

$R_i$  = the impulsive response modification factor = 2.0.

$R_c$  = the convective response modification factor = 1.0.

5.3.4.2.2 Total base shear. At the base of the BFRPP tank walls, the total shear due to horizontal earthquake forces shall be determined by

$$V = [(V_i + V_{wL} + V_{rL} + V_{fL})^2 + V_c^2]^{1/2} \quad (\text{Eq 5-17})$$

5.3.4.3 Dynamic vertical forces and moments due to horizontal ground motion.

5.3.4.3.1 Moments at base. The bending moment  $M_b$  on the entire BFRPP tank cross section at the base of the walls, excluding floor pressure (EBP), shall be determined by

$$M_w = V_w L h_w \quad (\text{Eq 5-18})$$

$$M_r = V_r L h_r \quad (\text{Eq 5-19})$$

$$M_i = V_i h_i \quad (\text{Eq 5-20})$$

$$M_c = V_c h_c \quad (\text{Eq 5-21})$$

$$M_b = [(M_i + M_w + M_r)^2 + M_c^2]^{1/2} \quad (\text{Eq 5-22})$$

The overturning moment  $M_o$  at the base of the BFRPP tank, including the BFRPP tank floor pressure (IBP), shall be determined by

$$M'_i = V_i h'_i \quad (\text{Eq 5-23})$$

$$M'_c = V_c h'_c \quad (\text{Eq 5-24})$$

$$M_o = [(M'_i + M_w + M_r)^2 + M_c'^2]^{1/2} \quad (\text{Eq 5-25})$$

Where:

Base = elevation at the top of the supporting steel members.

$h_w$  = height from the base of the wall to the center of gravity of the wall.

$h_r$  = height from the base of the wall to the center of gravity of the tank roof.

$h_i$  and  $h'_i$  = respectively, the height above the base of the wall to the center of gravity of the impulsive lateral force for the case excluding base pressure (EBP) and for the case including base pressure (IBP) determined in accordance with Sec. 5.3.7.2.

$h_c$  and  $h'_c$  = respectively, the height above the base of the wall to the center of gravity of the convective lateral force for the case excluding base pressure (EBP) and for the case including base pressure (IBP) determined in accordance with Sec. 5.3.7.2.

5.3.4.3.2 Dynamic pressure on the floor due to horizontal ground motion.

$$p_{fL} = 6[(M'_i - M_i)^2 + (M'_c - M_c)^2]^{1/2} / BL^2 \quad (\text{Eq 5-26})$$

5.3.4.4 Dynamic vertical forces due to horizontal ground motion.

5.3.4.4.1 The dynamic vertical forces acting above the foundation due to vertical ground motion shall be determined as follows:

**Roof:**

Due to self-weight of roof, plus 25 percent of the design live load, and 20 percent of the design snow load where the flat roof snow load exceeds 30 lb/ft<sup>2</sup>:

$$P_{rv} = C_t I (W_r / R_i) \quad (\text{Eq 5-27})$$

Where:

$C_t$  = the seismic response coefficient determined in accordance with Sec. 5.3.7.4.

**Walls:**

Due to self-weight of walls:

$$P_{wv} = C_t I (\epsilon W_w / R_i) \quad (\text{Eq 5-28})$$

**Floor:**

Due to self-weight of the floor:

$$P_{fv} = C_t I (W_f / R_i) \quad (\text{Eq 5-29})$$

**Stored water:**

Due to vertically accelerated stored water, the pressure above the base shall be determined by

$$p_{fv} = \gamma_w H_L \ddot{u}_v \quad (\text{Eq 5-30})$$

Where:

$$\ddot{u}_v = C_t I / R_i \quad (\text{Eq 5-31})$$

5.3.4.4.2 Total dynamic vertical force on the base.

$$P = P_{rv} + P_{wv} + P_{fv} + p_{fv} BL \quad (\text{Eq 5-32})$$

5.3.4.4.3 Dynamic horizontal force due to vertical ground motion. Due to vertical ground motion, the dynamic pressure acting on the wall above the base shall be determined by Eq 5-30.

### 5.3.5 *Earthquake and load distribution.*

5.3.5.1 General. The walls of a BFRPP tank shall be designed for dynamic shear forces and dynamic pressure distributions in accordance with Sec. 5.3.5.2. The floor of a BFRPP tank shall be designed for the dynamic pressure distribution in accordance with Sec. 5.3.5.2. The roof of a BFRPP tank shall be designed for the dynamic pressure distribution in accordance with Sec. 5.3.5.4. Alternatively, a BFRPP water-storage tank may be designed for shears and pressures determined from a rigorous analysis that takes into account the complex vertical and horizontal variations in hydrodynamic pressures.

5.3.5.2 Shear transfer. The wall-to-base, wall-to-wall, and wall-to-roof joints of a BFRPP tank shall be designed for earthquake shear forces using the following shear-force transfer mechanism:

1. Frame-reinforced walls perpendicular to the direction of the horizontal ground motion being investigated shall be analyzed as plates supported by the frames and subjected to the horizontal pressures determined in Sec. 5.3.5.2.1. The shears along the wall-to-floor and wall-to-roof joints shall correspond to the plate reactions. The distributed loading on the frames shall correspond to the reactions of the plate.

2. Walls not reinforced with frames that are perpendicular to the direction of the horizontal ground motion being investigated shall be analyzed as plates subjected to the horizontal pressures determined in Sec. 5.3.5.2.1. Shears along the wall-to-base, wall-to-wall, and wall-to-roof joints shall correspond to the plate reactions.

3. Walls parallel to the direction of the horizontal ground motion being investigated shall be analyzed as plates subjected to in-plane and out-of plane forces determined in Sec. 5.3.5.2.2.

5.3.5.2.1 Shear in walls perpendicular to the direction of ground motion. Leading and trailing halves of a BFRPP tank wall perpendicular to the direction of ground motion being investigated shall be loaded perpendicular to its plane by the wall's own inertia force  $V_{wL}$ , one-half the impulsive force of the water  $V_i$ , and one-half the convective (sloshing) force of the water  $V_c$ .

The dynamic force on the wall, due to horizontal ground motion, at any given height  $y$  above the base shall be determined by

$$V_y = [(V_{iy} + V_{wy})^2 + V_{cy}^2]^{1/2} \quad (\text{Eq 5-33})$$

Where:

$$V_{iy} = (V_i/2)[4H_L - 6h_i - (6H_L - 12h_i)(y/H_L)]/H_L^2 \quad (\text{Eq 5-34})$$

$$V_{cy} = (V_c/2)[4H_L - 6h_c - (6H_L - 12h_c)(y/H_L)]/H_L^2 \quad (\text{Eq 5-35})$$

$$V_{wy} = V'_{wL} (H_w - y)/H_w \quad (\text{Eq 5-36})$$

The dynamic pressure on the wall, due to vertical ground motion, at any given height  $y$  above the base shall be determined by

$$p_{vy} = \gamma_w(H_L - y)\ddot{u}_v \quad (\text{Eq 5-37})$$

The effects of the horizontal and vertical ground motions shall be combined in accordance with Sec. 5.3.3.3.4.

5.3.5.2.2 Shear in walls parallel to the direction of ground motion. A wall parallel to the direction of the ground motion being investigated shall be loaded in its plane by the wall's own in-plane inertial force  $V'_{wL}$ , the in-plane forces corresponding to the edge reactions from the abutting walls (*see* Sec. 5.3.5.2, Items 1 and 2), and roof shear force  $V_{rL}$ .

The dynamic pressure on the wall, due to vertical ground motion, at any given height  $y$  above the base shall be determined by Eq 5-37.

The effects of the horizontal and vertical ground motions shall be combined in accordance with Sec. 5.3.3.3.4.

5.3.5.3 Dynamic vertical force distribution on floor. The dynamic vertical force on the floor due to roof inertial force  $P_{rv}$ , floor inertial forces  $P_{fv}$ , and accelerated stored water pressure  $p_{fv}$ , due to vertical ground motion, shall be uniformly distributed over the area of the floor.

The effects of vertical ground motion shall be combined with effect of  $p_{fi}$  due to horizontal ground motion in accordance with Sec. 5.3.3.3.4.

5.3.5.4 Dynamic vertical force distribution on roof. The dynamic vertical force  $P_{rv}$  shall be uniformly distributed over the area of the roof.

5.3.6 *Freeboard.* Provisions shall be made to accommodate the maximum oscillation of the free surface of the stored water generated by the earthquake. The maximum vertical displacement of the oscillation  $d_{max}$  shall be determined by

$$d_{max} = 0.50L C_c I \quad (\text{Eq 5-38})$$

### 5.3.7 *Dynamic model.*

5.3.7.1 General. The dynamic characteristics of BFRPP water-storage tanks subjected to earthquake acceleration shall be computed in accordance with Sec. 5.3.7.2, 5.3.7.3, and 5.3.7.4.

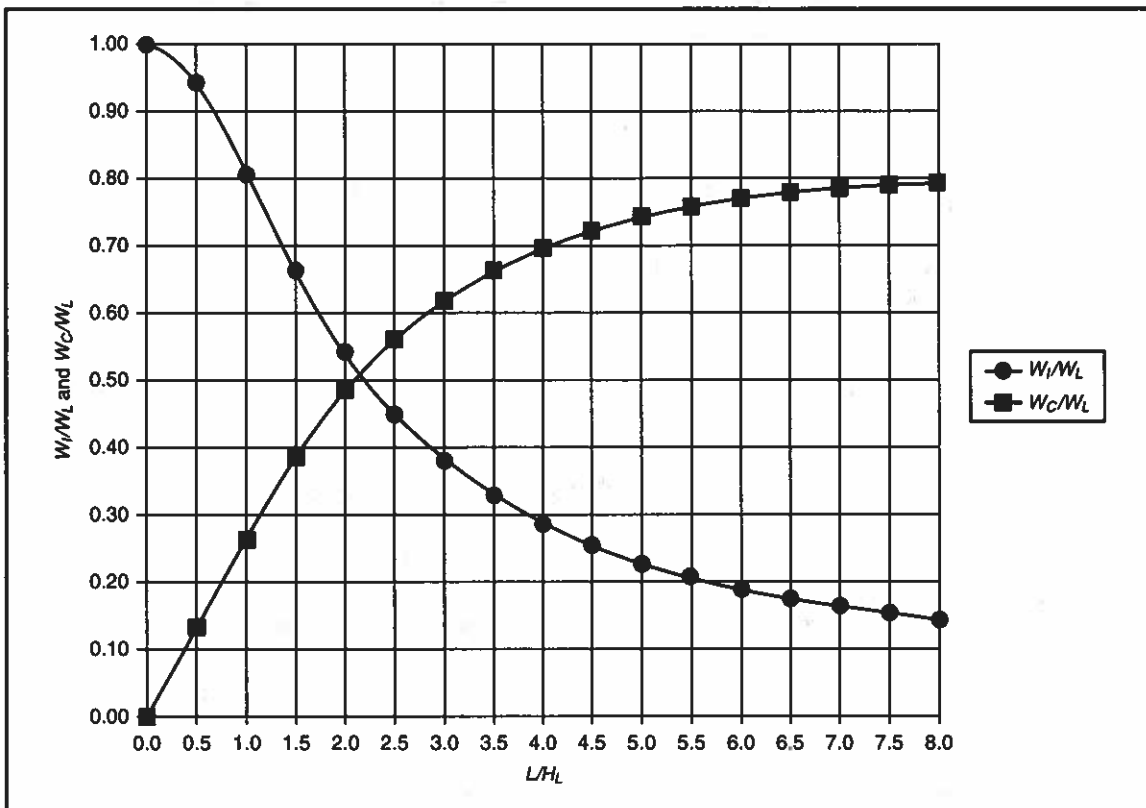


Figure 1 Curves for obtaining factors  $W_i/W_L$  and  $W_c/W_L$  for the ratio  $L/H_L$

5.3.7.2 Dynamic characteristics of the impulsive and convective actions of stored water.

5.3.7.2.1 Equivalent weights of the accelerated stored water. The impulsive fraction of the stored water shall be determined from Figure 1 or from the following equation

$$W_i/W_L = \tanh[0.866(L/H_L)] / [0.866(L/H_L)] \quad (\text{Eq 5-39})$$

The convective (sloshing) fraction of the stored water shall be determined from Figure 1 or from the following equation

$$W_c/W_L = 0.264(L/H_L) \tanh [3.16(H_L/L)] \quad (\text{Eq 5-40})$$

5.3.7.2.2 Height to centers of gravity EBP of the stored water. The height of the center of gravity of the impulsive part of the stored water, excluding pressure on the floor (EBP), shall be determined from Figure 2 or from the following equations.

For a BFRPP tank with  $L/H_L < 1.333$

$$h_i/H_L = 0.5 - 0.09375 (L/H_L) \quad (\text{Eq 5-41})$$

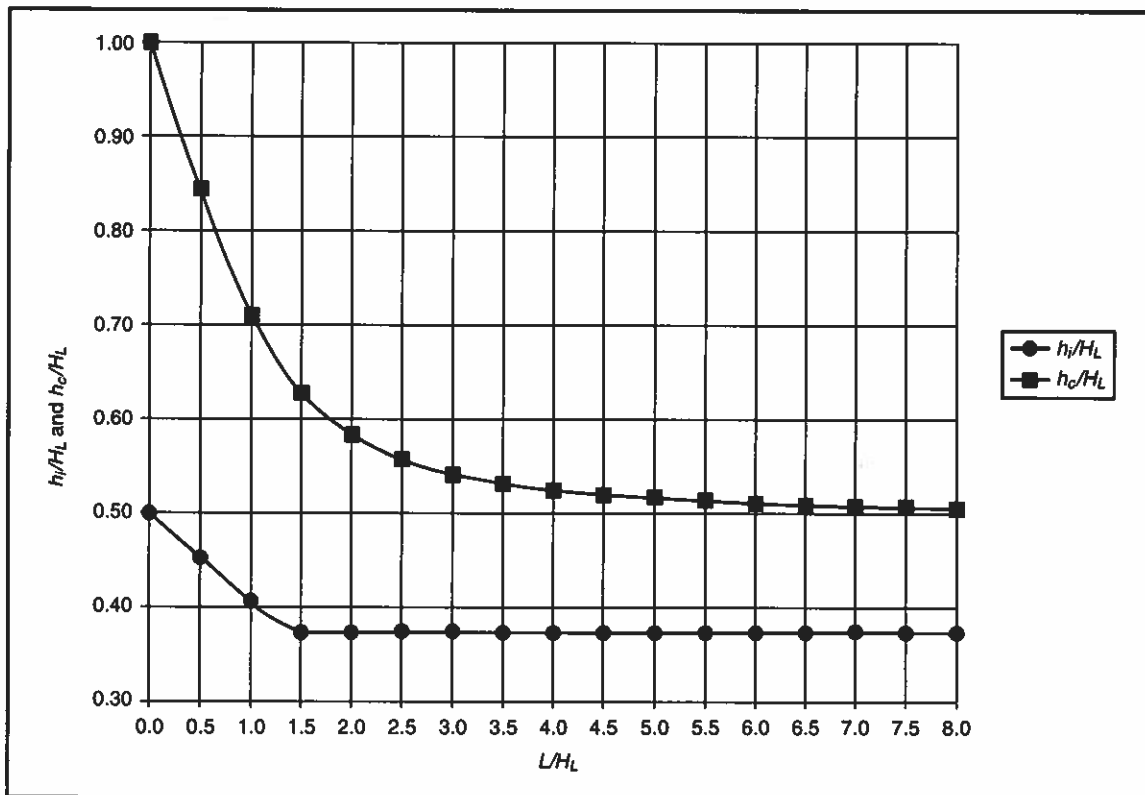


Figure 2 Curves for obtaining factors  $h_i/H_L$  and  $h_c/H_L$  for the ratio  $L/H_L$  (EBP)

For a BFRPP tank with  $L/H_L \geq 1.333$

$$h_i/H_L = 0.375 \quad (\text{Eq 5-42})$$

For all BFRPP tanks, the height of the center of gravity of the convective (sloshing) part of the stored water, excluding pressure on the floor (EBP), shall be determined from Figure 2 or from the following

$$h_c/H_L = 1 - \{\cosh[3.16(H_L/L)] - 1\} / \{3.16(H_L/L) \sinh [3.16(H_L/L)]\} \quad (\text{Eq 5-43})$$

5.3.7.2.3 Height to centers of gravity IBP of the stored water. The height of the center of gravity of the impulsive part of the stored water, including pressure on the floor (IBP), shall be determined from Figure 3 or from the following equations.

For a BFRPP tank with  $L/H_L < 0.75$

$$h_i/H_L = 0.45 \quad (\text{Eq 5-44})$$

For a BFRPP tank with  $L/H_L \geq 0.75$

$$h_i/H_L = [0.866(L/H_L) / \{2 \tanh[0.866(L/H_L)]\}] - 1/8 \quad (\text{Eq 5-45})$$



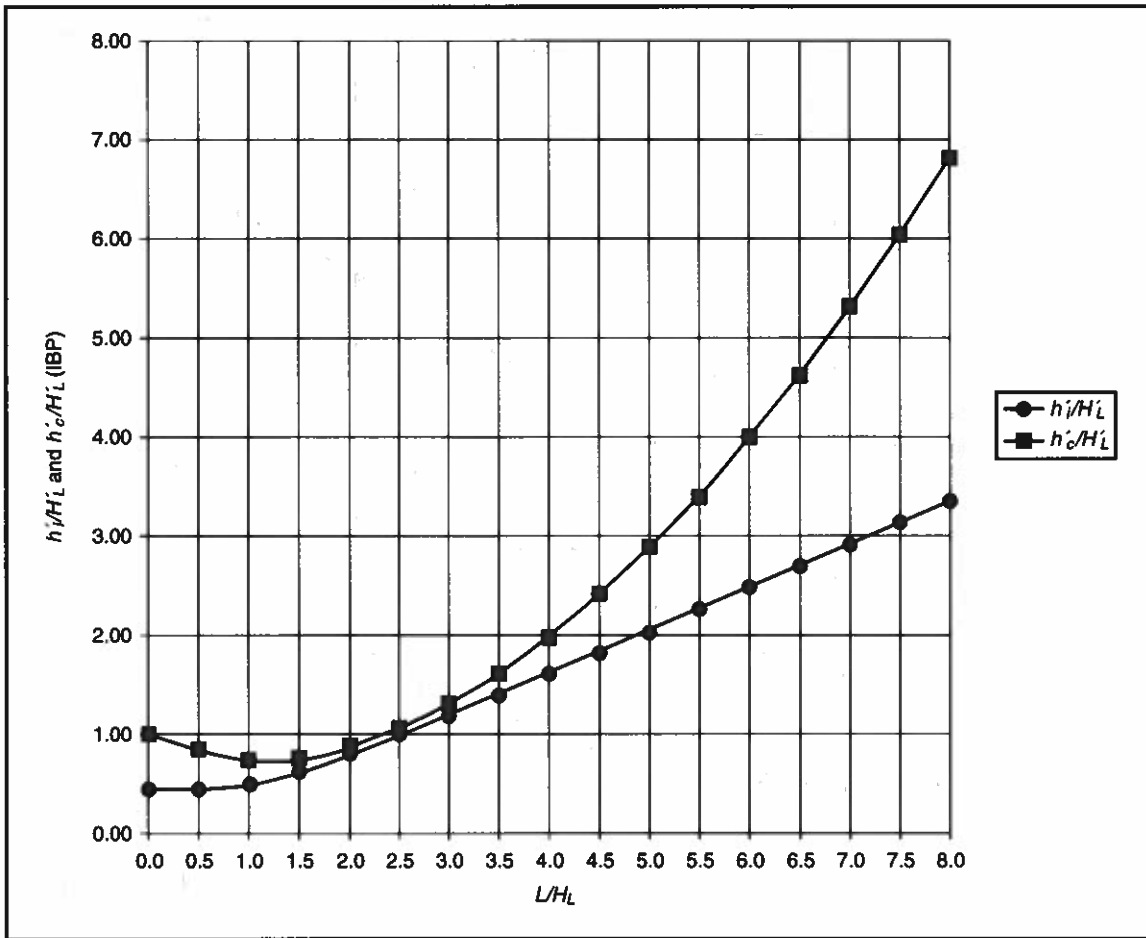


Figure 3 Curves for obtaining factors  $h_i/H_L$  and  $h_c/H_L$  for the ratio  $L/H_L$  (IBP)

For all BFRPP tanks, the height of the center of gravity of the convective (sloshing) part of the stored water, including pressure on the floor (IBP), shall be determined from Figure 3 or from

$$h_c/H_L = 1 - \{ \cosh [3.16(H_L/L) - 2.01] / [3.16(H_L/L) \sinh [3.16(H_L/L)]] \} \quad (\text{Eq 5-46})$$

5.3.7.2.4 Effective mass coefficient  $\epsilon$  for wall. The effective mass coefficient  $\epsilon$  shall be determined by

$$\epsilon = [0.0151(L/H_L)^2 - 0.1908(L/H_L) + 1.021] \leq 1.0 \quad (\text{Eq 5-47})$$

5.3.7.3 Periods of vibration. For use in determining the seismic response coefficient  $C_i$ , determine the period of lateral vibration of the BFRPP structure and impulsive part of the stored water using a generally acceptable method of dynamic analysis. As an alternate to computing the natural period of vibration, the structure of the BFRPP tank may be, conservatively, considered rigid and  $C_i$  determined in accordance with Sec. 5.3.7.4.

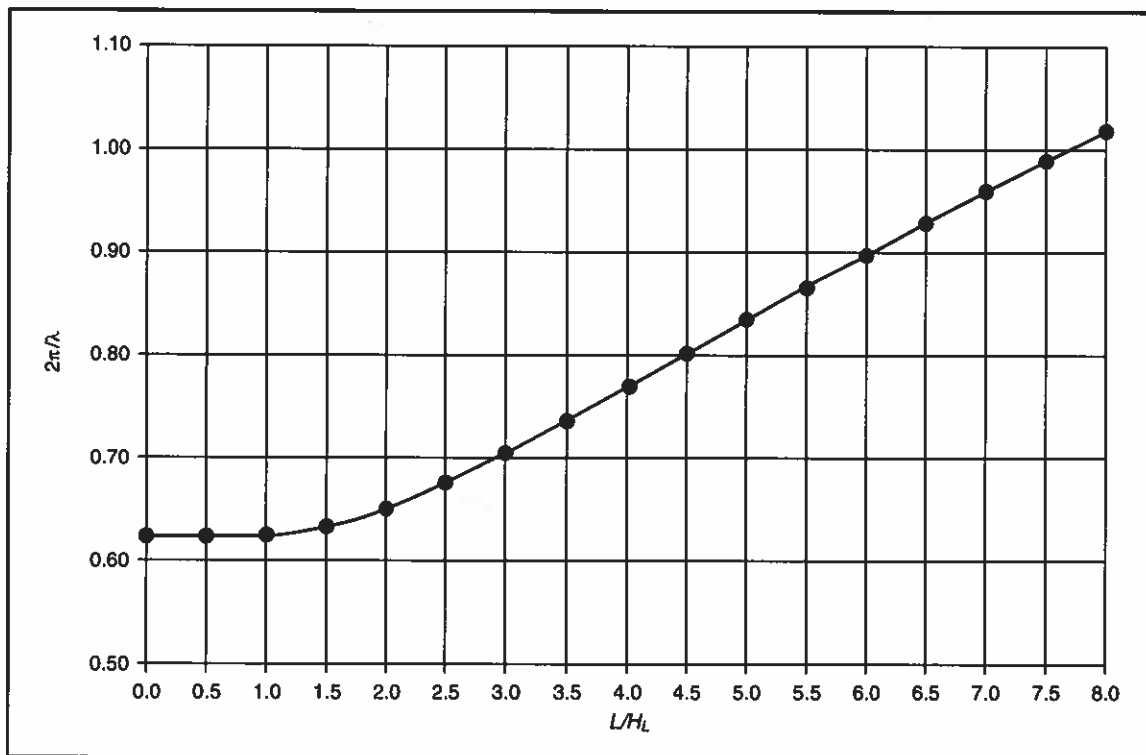


Figure 4 Curve for obtaining the factor  $2\pi/\lambda$  for the ratio  $L/H_L$

The natural period of the oscillating free surface of the stored water shall be determined from

$$T_c = (2\pi/\lambda)L^{1/2} \quad (\text{Eq 5-48})$$

Where:

$$\lambda = \{3.16g \tanh [3.16(H_L/L)]\}^{1/2} \quad (\text{Eq 5-49})$$

or  $(2\pi/\lambda)$  may be determined from Figure 4, and  $L$  must be in feet.

Fundamental period of oscillation of the tank (plus the impulsive component of the stored water).

$$T_i = 2\pi [(W_i + W'_w) / (gk)]^{1/2} \quad (\text{Eq 5-50})$$

#### 5.3.7.4 Seismic response coefficients $C_i$ , $C_c$ , and $C_f$ .

5.3.7.4.1 Design response spectrum. Construct the design response spectrum in accordance with ASCE/SEI 7-05 as follows:

1. Classify the site in accordance with site class definitions of ASCE/SEI 7-05, Sec. 11.4.2;
2. Determine the maximum considered earthquake spectral response acceleration at short periods  $S_s$  and at 1 sec  $S_1$  from ASCE/SEI 7-05, Figure 22-1 through Figure 22-14;

3. Determine the acceleration-based site coefficient  $F_a$  and the velocity-based site coefficient  $F_v$  from ASCE/SEI 7-05, Table 11.4-1 and Table 11.4-2, respectively;

4. Calculate the design spectral response accelerations for short periods  $S_s$  and for 1-sec period  $S_1$  from

$$S_{DS} = (2/3) F_a S_s \quad (\text{Eq 5-51})$$

$$S_{D1} = (2/3) F_v S_1 \quad (\text{Eq 5-52})$$

5. Construct the design response spectrum for lateral acceleration in accordance with ASCE/SEI 7-05, Sec. 11.4.5;

6. For the design spectrum for vertical acceleration, use  $2/3$  of the design response spectrum for horizontal acceleration.

5.3.7.4.2 Determine  $C_i$  as follows:

For  $T_i \leq T_s$

$$C_i = S_{DS} \quad (\text{Eq 5-53})$$

For  $T_i > T_s$

$$C_i = S_{D1}/T_i \leq S_{DS} \quad (\text{Eq 5-54})$$

Where:

$$T_s = S_{D1}/S_{DS} \quad (\text{Eq 5-55})$$

5.3.7.4.3 Determine  $C_c$  as follows:

For  $T_c \leq 1.6/T_s$

$$C_c = 1.5S_{D1}/T_c \leq 1.5S_{DS} \quad (\text{Eq 5-56})$$

For  $T_c > 1.6/T_s$

$$C_c = 2.4S_{DS}/T_c^2 \quad (\text{Eq 5-57})$$

5.3.7.4.4 Determine  $C_t$  as follows:

$$C_t = S_{DS} \quad (\text{Eq 5-58})$$

Alternatively,  $C_t$  may be determined from the vertical response spectrum at the vertical period  $T_v$ .  $T_v$  may be calculated by a generally accepted rational method considering the vertical stiffness of the floor, roof support columns, and the roof; and the mass of the floor, roof support columns, roof, and stored water.

5.3.8 *Resistance due to sliding and overturning.*

5.3.8.1 **Overturning.** The resistance to the overturning moment about the edge of the tank at the bottom may be provided by the weight of the tank and its contents and shall have a minimum safety factor of 1.50.

$$M = L/2 (W_t + W_L) \quad (\text{Eq 5-59})$$

5.3.8.2 *Sliding.* The resistance to sliding shall be determined by the shear stress of anchored bolts against the actual shear at base of the tank and shall provide a minimum safety factor of 1.50.

## Sec. 5.4 Strength and Resistance of FRP Panels and Connections

5.4.1 *Nominal FRP panel strength.* The nominal FRP strength for panels and connections shall be determined in accordance with Sec. 4.4.4.5, 4.4.4.6, 4.4.4.7, 4.4.4.8, and 4.4.4.9 of this standard.

5.4.2 *Resistance factors for FRP.* Unless otherwise specified in this standard, Resistance Factors  $\phi$ , for the FRP in panels and connections shall be as follows:

Short-Term Loads only:  $\phi = 0.50$

Long-Term Loads or Combinations of Long- and Short-term Loads:  $\phi = 0.25$

5.4.3 *Stiffness for FRP.* The short-term modulus for the FRP in panels and connections shall be determined in accordance with Sec. 4.4.4.4 of this standard. Unless otherwise determined by tests, the modulus of elasticity for long-term loads shall be taken as 50 percent of the short-term value. Where applicable, the modulus values shall account for the anticipated service exposure and temperature in accordance with Sec. 8.7.2.2.

5.4.4 *Deflections of FRP panels.* Panel deflections due to both short-term and long-term loads shall be limited to  $L/360$ , where  $L$  is the span between points of support or fixity.

5.4.5 *Bolt strength.* Design strengths for steel bolts shall be based on the nominal strengths in AISC, Table J3.2, multiplied by the Resistance Factor  $\phi$ , specified as follows:

Bolt in tension:  $\phi = 0.75$

Bolt in shear:  $\phi = 0.65$

5.4.6 *Effect of gasket and sealant in bolted joints.* In the design of bolted joints, the effect of the gasket and sealant shall be neglected, provided the compressed thickness of the gasket or sealant does not exceed  $1/16$  in. (1.6 mm) and shall conform to the requirements of Sec. 4.11 of this standard.

5.4.7 *Minimum spacing.* The center-to-center distance between bolts shall not be less than 5 in. (125 mm).

## Sec. 5.5 Strength of Welds

Welds shall be designed in accordance with AISC 360, Table J2.5.

## Sec. 5.6 Foundation Anchor Bolts

5.6.1 *Tension in anchor bolts.* The anchor bolts shall be designed in accordance with ACI 318 appendix D for the factored load demands of Sec. 3.2.1b,

augmented by the overstrength factor  $\Omega_o = 2$  in accordance with ASCE/SEI 7-05, Sec. 15.7.3a.

The tensile strength of an anchor rod is equal to the breakout strength of the concrete anchorage of the anchor bolt group (or those anchor bolts participating in tension in the case of tension due to moment) or the sum of the steel tensile strengths of the contributing anchors bolt. For anchor bolt connections in tension, the design tensile strength of contributing anchor bolt is taken as the smallest of the sum of the steel tensile strengths of the contributing individual anchor bolts or the concrete tensile strength of the anchor group. Breakout and pull-out strength of anchors in tension are calculated in D.5.2 and D.5.3 of ACI 318.

**5.6.2 Shear in anchor bolts.** For the typical cast-in-place anchor group used, the shear capacity determined by concrete breakout is evaluated and calculated in D.6.1 of the ACI 318.

**5.6.3 Development by lapping with concrete reinforcement.** If an anchor is designed to lap with reinforcement, the anchor strength can be taken as  $\phi A_{se,N} F_{ya}$  as the lap splice length will ensure that ductile behavior will occur.  $A_{se,N} A_{sc}$  is the effective cross-sectional area, which is the tensile stress area for threaded rods.  $\phi = 0.90$ , as prescribed in ACI 318.

## Sec. 5.7 Roof Panels

**5.7.1 General.** This section establishes design standard criteria of the roof panels.

**5.7.2 Definition.** The roof panels shall be supported by side panels and pipes as per the instruction and drawings supplied by the manufacturer conforming to the dimensions of the tanks. The roof surface shall be designed as a watertight system under design load conditions.

### 5.7.3 Notation.

$B$  = inside dimension (length or width) of a rectangular tank, perpendicular to the direction of the ground motion being investigated, ft (m)

$B_a$  = bearing stress due to critical load combination, lb/ft<sup>2</sup> (N/m<sup>2</sup>)

$B_r$  = bearing strength of panels, lb/ft<sup>2</sup> (N/m<sup>2</sup>)

$d_a$  = actual freeboard, ft (m)

$d_{max}$  = required freeboard, ft (m)

$E$  = modulus of elasticity, psi (N/mm<sup>2</sup>)

$F_a$  = bending stress due to  $M$ , lb/ft<sup>2</sup> (N/m<sup>2</sup>)

$F_r$  = flexural resistance of roof support plate, lb/ft<sup>2</sup> (N/m<sup>2</sup>)

- $I$  = moment of inertia, in.<sup>4</sup> (mm<sup>4</sup>)
- $M$  = bending moment, lb·ft (N·m)
- $P_{cr}$  = critical compressive load, lb (N)
- $P_u$  = compressive load due to critical load combination, lb (N)
- $S_{Ac}$  = convective spectral acceleration, g
- $P_{max}$  = maximum uplift pressure on the roof panel, lb (N)
- $W_{cm}$  = convective (sloshing) mass within the portion confined by the roof
- $\rho$  = mass density of water, lb/ft<sup>3</sup> (kg/m<sup>3</sup>)
- $X_f$  = wetted width
- $Z$  = section modulus, in.<sup>3</sup> (mm<sup>3</sup>)
- $\gamma_w$  = density of water, 62.4 lb/ft<sup>3</sup> (9.807 kN/m<sup>3</sup>)

5.7.4 Roof loads.

5.7.4.1 Roof. Roof load is determined in Sec. 5.2 and roof pressure due to convective (sloshing) mass will be the basis for the design load.

5.7.4.2 Wetted width. When the actual freeboard,  $d_a$  is smaller than the required freeboard,  $d_{max}$ , a portion of the roof panel will be wetted by the sloshing wave which will cause uplift forces on the tank roof panels. The normalized wetted width,  $X_f/0.50 L$  is read from Figure 5 as a function of the ratio between the actual and the required freeboard,  $d_a/d_{max}$ .

5.7.4.3 Uplift pressure. The maximum uplift pressure on the roof panel due to sloshing wave is determined a follows:

$$P_{max} = \rho X_f S_{Ac} \tag{Eq 5-60}$$

5.7.4.4 Convective (sloshing) mass. The convective (sloshing) mass within the portion confined by the roof should be considered in the design of the

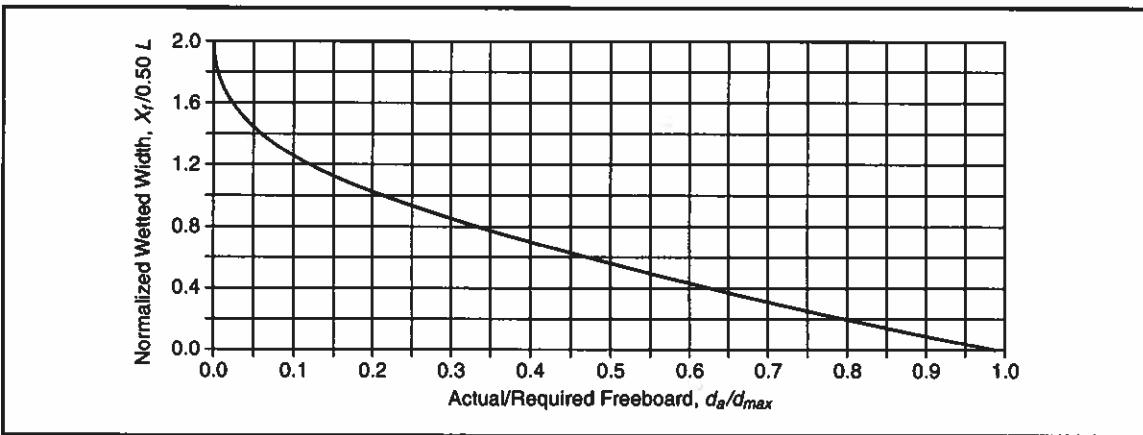


Figure 5 Curve for obtaining the normalized wetted width,  $X_f/0.50 L$ , for the ratio  $d_a/d_{max}$

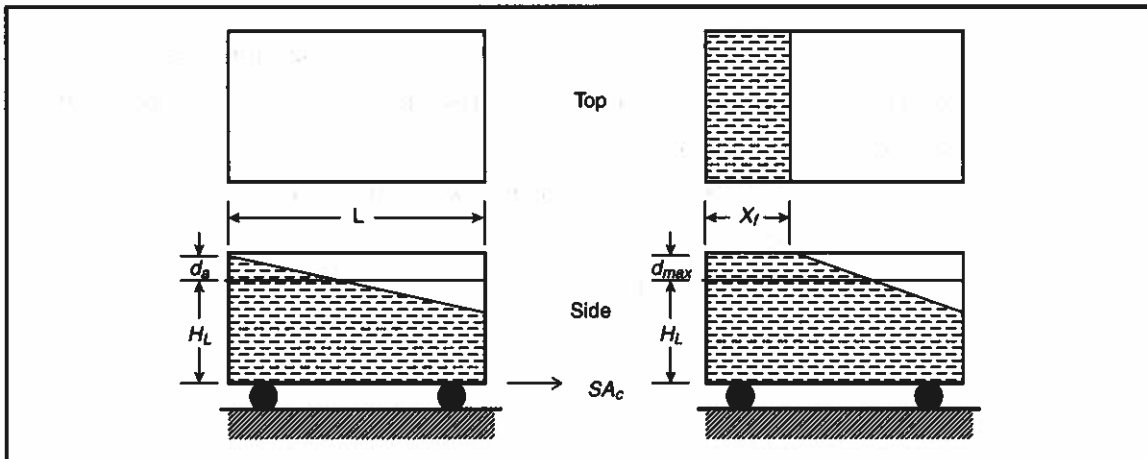


Figure 6 Wetted width on the roof when the required freeboard is greater than the actual freeboard

roof and supporting structure and becomes part of the impulsive mass. The hydrostatic head is equal to the required freeboard less the actual freeboard.

$$W_{cm} = \gamma_w X_f B (d_{max} - d_a) \quad (\text{Eq 5-61})$$

5.7.5 Method of analysis.

5.7.5.1 Roof panel. A roof panel restrained at its roof support assumes no rotation. The roof panel strength is compared with the applied load in accordance with Sec. 5.2 of this standard and with the sloshing effect when the actual freeboard is less than the required freeboard, as seen in Figure 6.

5.7.5.2 Roof panel and panel connections. In computing the actual strength of the roof panel and panel connections, computations below will be adopted.

Flexural Strength

$$\phi F_r \geq F_a$$

where:

$\phi$  = strength reduction factor, 0.90 for bending

$$F_a = M / Z$$

Bearing Strength

$$\phi B_r \geq B_a$$

where:

$\phi$  = strength reduction factor, 0.70 for bearing

5.7.5.3 Roof support pipe. The roof support pipe should be designed in accordance with AISC 360 for factored loads of Sec. 5.2.7 of this standard.

The roof support pipe is subject to lateral load computed as the sum of the weight of the pipe and the virtual weight of water surrounding of the pipe times the impulsive acceleration at the period of the pipe from the response spectrum and axial load in Sec. 5.2.7 of this standard.

Design of Support Pipe (Combined Axial and Bending Loads)

a. For  $Pu/\phi P_n \geq 0.20$

$$Pu/\phi P_n + 8/9 (Mu_x/\phi_b Mn_x + Mu_y/\phi_b Mn_y) \leq 1.0$$

b. For  $Pu/\phi P_n < 0.20$

$$Pu/2\phi_c P_n + (Mu_x/\phi_b Mn_x + Mu_y/\phi_b Mn_y) \leq 1.0$$

where:

$Pu$  = required axial compressive load from LRFD load combination, kips (N)

$Mu$  = required moment using LRFD load combination, kip-in. (N-mm)

$P_n$  = nominal axial compressive strength, kip (N)

$$P_n = F_{cr} A_g$$

(a) when  $KL/r \leq 4.71 (E/F_y)^{1/2}$  (or  $F_e \geq 0.44F_y$ );

$$F_{cr} = [0.658 F_y/F_e] F_y$$

(b) when  $KL/r > 4.74 (E/F_y)^{1/2}$  (or  $F_e < 0.44F_y$ );

$$F_{cr} = 0.877 F_e$$

where:

$$F_e = \pi^2 E / (KL/r)^2$$

$A_g$  = gross area, in.<sup>2</sup> (mm<sup>2</sup>)

$F_{cr}$  = flexural buckling stress, ksi (N/mm<sup>2</sup>)

$F_y$  = yield strength of material used, ksi (N/mm<sup>2</sup>)

$K$  = effective length factor

$L$  = laterally unbraced length, in. (mm)

$r$  = governing radius of gyration, in. (mm)

$M_n$  = nominal flexural strength, kip-in. (N-mm)

$$M_n = F_y Z$$

$Z$ , ( $Z_x$ ,  $Z_y$ ), = section modulus, in.<sup>3</sup> (mm<sup>3</sup>)

$x$  = subscript relating symbol to strong axis

$y$  = subscript relating symbol to weak axis

(NOTE: for pipe or tubular section,  $x$  and  $y$  axis are reversible, i.e.,  $x = y$ )

$\phi_C$  = resistance factor for compression (0.90)

$\phi_b$  = resistance factor for flexure/bending (0.90)



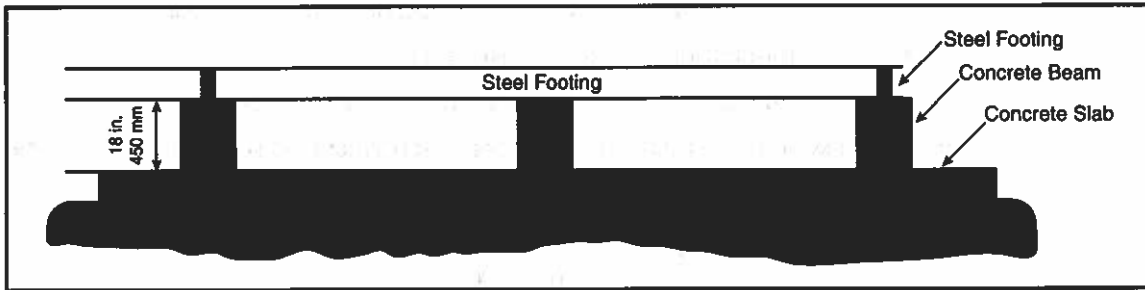


Figure 7 Elevation of concrete foundation

## Sec. 5.8 Foundation Design

5.8.1 *Foundations.* Tanks shall be supported on a concrete slab with integral concrete beams at a maximum interval of 6.5 ft (2 m). The top of the concrete beams shall be a minimum of 18 in. (450 mm) above the top of the concrete slab, unless otherwise specified by the purchaser. (See Figure 7.)

5.8.2 *Concrete design, materials, and construction.* The design of the concrete foundations, the specifications for the cement and aggregate shall be in accordance with ACI 318, except as may be modified by agreement between the purchaser and constructor.

5.8.3 *Water load.* Water load, as defined in Sec. 5.2.1, shall be considered as dead load.

5.8.4 *Soil bearing value.* The purchaser shall specify the allowable soil-bearing pressure using an appropriate factor of safety as defined in Sec. 5.8.6. However, in no case shall the specified bearing pressure exceed that which would cause intolerable settlements and impair the structural integrity of the tank.

5.8.5 *Soil investigation.* A soil investigation shall be provided by the purchaser to determine the following:

1. The presence or absence of rock, old excavation, or fill.
2. Whether the site is a suitable place on which to build the structure.
3. The classification of soil strata, after appropriate sampling.
4. The type of foundation that will be required at the site.
5. The elevation of groundwater, and whether dewatering is required.
6. The bearing capacity of the soil, and the depth at which the foundation must be founded.
7. Whether piling will be required for support of foundations, and the length of such piling.

8. The elevations of the existing grade and other topographical features that may affect the foundation design or construction.

9. The homogeneity and compressibility of the soils across the tank site, so that the possibility of total and differential settlement of the structure may be evaluated.

5.8.6 *Factor of safety.* The following minimum factors of safety shall be used in determining the allowable soil-bearing pressure. The ultimate bearing capacity should be based on sound principles of geotechnical engineering. See the foreword, Section III.C, item 7, for additional information.

5.8.6.1 A factor of safety of 3 shall be provided, based on calculated ultimate bearing capacity when direct loads and wind are considered.

5.8.6.2 A factor of safety of 2.25 shall be provided, based on calculated ultimate bearing capacity when direct loads and earthquake loads are considered.

5.8.6.3 A factor of safety of 1.5 shall be provided, based on calculations for sliding and overturning as determined in Sec. 5.3.8.

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## SECTION 6: SIZING OF TANKS

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The standard capacities for tanks shall be as published by the manufacturer and shall be calculated to the nearest 1,000 gal (3.8 m<sup>3</sup>).

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## SECTION 7: ACCESSORIES FOR TANKS

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### Sec. 7.1 Manways

1. The roof manway panel shall have a minimum 24-in. (610-mm) diameter opening and access door fixed with stainless steel hinges and lock device.
2. The access door shall be designed to be nondetachable and opened to 135°.
3. The access door shall be hermetically closed and light-, dust-, and insect-proof.

### Sec. 7.2 Pipe Connections

7.2.1 *Connections.* The pipe connections shall be of the size specified by the purchaser. They are usually attached to the tank bottom and sides. Point of attachment shall be designated by the purchaser.

7.2.2 *Flexibility.* Sufficient piping flexibility to accommodate seismic movements and settlement in the piping system shall be provided to protect the connections.

### Sec. 7.3 **Overflow**

The tank shall be equipped with an overflow of the type and size specified by the purchaser. If an overflow to ground is required, it shall be brought down the outside of the tank wall and supported at proper intervals with suitable brackets. The overflow to the ground shall discharge over a drainage inlet structure or a splash block. The intake shall have a capacity at least equal to the pumping rate as specified by the purchaser and overflow pipe at least twice the capacity.

### Sec. 7.4 **Ladders**

7.4.1 *Outside tank ladder.* The manufacturer and/or constructor shall furnish a tank ladder on the outside of the wall beginning 8 ft (2.4 m), or as specified, above the level of the tank bottom, and located to provide access to the roof manhole. The minimum clear width of step surface for rungs shall be 16 in. (406.4 mm), and rungs shall be equally spaced not less than 11 in. (279.4 mm), nor more than 15 in. (381 mm), on center. The perpendicular distance from the centerline of the rungs to the tank wall shall not be less than 7 in. (177.8 mm). Rung size shall not be less than  $\frac{3}{4}$  in. (1 mm) in diameter, or equivalent section.

The maximum spacing of supports attaching the ladder to the tank shall not exceed 10 ft (3 m). The minimum design live load shall be 2 loads of 250 lb (113.4 kg), each concentrated between any two consecutive attachments to the tank. Each rung in the ladder shall be designed for a single concentrated load of 250 lb (113.4 kg), minimum. The design loads shall be concentrated at such a point or points as will cause the maximum stress in the structural ladder member being considered. Side rails may be of any shape having section properties adequate to support the design loads and providing a means of securely fastening each rung to the side rail to lock each rung to the side rails.

7.4.2 *Inside tank ladder.* Inside tank ladders are recommended and shall comply with the requirements of Sec. 7.4.1.

7.4.3 *Minimum requirements.* Minimum requirements for ladders and hatches can be found in OSHA 29 CFR Part 1910. NOTE: Regardless of the access protection provided to tank roof hatches and vents, weather conditions on tank roofs are extremely variable, and workers and their supervisors are expected to exercise good judgment in matters of safety. Among other things, this may include the use of safety lines when windy, icing, or other hazardous conditions exist.

### **Sec. 7.5 Safety Devices**

If a safety cage, rest platforms, roof-ladder handrails, ladder lock, anti-climb device, or other safety devices are required by federal or local laws or regulations, the purchaser shall so specify. None of these are recommended for use inside the tank.

### **Sec. 7.6 Vents**

If the tank roof is of tight construction, a suitable vent shall be furnished above the maximum water level. The vent shall have a capacity to pass air so excessive positive or negative pressure will not develop and the maximum rate of the water, either entering or leaving the tank is possible. The overflow pipe shall not be considered a tank vent.

**WARNING:** An improperly vented tank may cause external pressures to act on the tank, which will cause deformation even at a low pressure differential.

**7.6.1 Location.** Even if more than one vent is required, one tank vent shall always be located near the center of the roof; the vent shall be designed and constructed to prevent the ingress of birds or animals.

**7.6.2 Screening.** Screens shall be provided when governing health authorities require screening against insects.

### **Sec. 7.7 Additional Accessories and Exceptions**

Any additional accessories required to be furnished shall be specified by the purchaser. Exceptions to the provisions of this section may be specified by the purchaser to suit special situations.

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## **SECTION 8: FABRICATION**

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### **Sec. 8.1 Compression Molding**

FRP panels shall be formed in matched metal molds by compression molding using the hot-pressed method with a minimum molding pressure of 2,470 psi (17 MPa) and a minimum curing temperature of 284°F (140°C).

### **Sec. 8.2 Steel Footings—Welded Work**

The steel footings may be prepared by shearing, machining, chipping, or oxygen or plasma arc cutting.

**8.2.1 Oxygen or plasma arc cutting.** When edges of plates are oxygen or plasma arc cut, the surface obtained shall be uniform and smooth and shall be

cleaned of slag accumulations before welding. Cutting shall follow closely the prescribed lines.

8.2.2 *Shearing.* Shearing may be used for material  $\frac{3}{8}$  in. (9.5 mm) or less in thickness.

### **Sec. 8.3 Assembly and Subassemblies**

The field assembly of tank panels shall be by bolting. Welding shall be limited to the shop fabrication of steel footings in subassemblies.

### **Sec. 8.4 Welds**

Welds in the structural members shall be made according to the minimum requirements of AWS. Manufacturers shall maintain a welder training program and shall be able to certify, if requested, that these welds were made by AWS-qualified welders and inspected according to AWS standards. These welds are to be made to ensure complete fusion with the base metal, within the limits specified for each joint.

### **Sec. 8.5 Manufacturing Tolerances**

8.5.1 *FRP panel tolerance.* FRP panels shall have dimensional tolerance of not more than  $\frac{1}{32}$  in. (0.8 mm) from their intended design dimension.

8.5.2 *Top surface welds.* Welds on the top surface of steel footings should be ground flat and the top surfaces of the beams shall be within  $\frac{1}{64}$  in. (0.4 mm).

8.5.3 *Steel footings.* The steel footing framework shall be level within  $\frac{1}{200}$  in. and shall be supported on concrete beams with a maximum span between beams of 6.5 ft (2 m) to ensure maximum deflection of the steel footing is no more than  $\frac{3}{16}$  in. (5 mm).

### **Sec. 8.6 Shipping**

Material shall be loaded, transported to the site, unloaded, and stored in such a manner as to prevent damage.

### **Sec. 8.7 Quality Standards and Control**

The tank manufacturer's quality management system shall comply with the international standard ISO 9001:2008.

FRP panels used in the assembly of a tank shall be individually bar-coded and information such as manufacturing parameters, raw material batches used in manufacture, etc., recorded and maintained.

8.7.1 *Physical and mechanical properties of FRP panel.* Physical and mechanical tests shall be conducted in accordance with Sec. 8.7.1.1 to 8.7.1.4. Tests shall be conducted at temperatures representative of the anticipated service

conditions. Additional tests may be required by the manufacturer's third-party quality control and quality assurance program or the purchaser.

8.7.1.1 Specimens. Physical and mechanical tests shall be conducted on specimens cut from any FRP panels determined by the engineer to be representative of the materials and methods of fabrication used in the tank.

8.7.1.2 Glass content. Determine the glass content of the structural layer of the FRP panel in accordance with ASTM D2584. The specimen shall be prepared by cutting or grinding away the inner surface and exterior surface. Test a minimum of three sets of three specimens each. Sample sets shall be taken from separate, representative locations on the panel.

8.7.1.3 Tensile properties. Determine tensile strength and modulus of elasticity in accordance with one or more of the following methods: ASTM D638 or ASTM D2290. The test specimens shall be the actual thickness of the fabricated FRP panel and shall not be machined on the surface except at the ends to facilitate uniform gripping. Tensile properties shall be determined in at least two orthogonal directions. Test five specimens in each direction unless otherwise specified.

8.7.1.4 Flexural properties. Determine flexural strength and tangent modulus of elasticity in accordance with ASTM D790. The test specimens shall be the actual thickness of the fabricated FRP panel and shall not be machined on the surface. Flexural properties shall be determined in at least two orthogonal directions. Test five specimens in each direction unless otherwise specified.

8.7.1.5 Shear properties. Determine shear strength and tangent modulus of elasticity in accordance with ASTM D732. The test specimens shall be the actual thickness of the fabricated FRP panel and shall not be machined on the surface. Shear properties shall be determined in at least two orthogonal directions. Test five specimens in each direction unless otherwise specified.

8.7.1.6 Compressive properties. Determine compressive strength and tangent modulus of elasticity in accordance with ASTM D695. The test specimens shall be the actual thickness of the fabricated FRP panel and shall not be machined on the surface. Compressive properties shall be determined in at least two orthogonal directions. Test five specimens in each direction unless otherwise specified.

8.7.1.7 Bearing properties. Determine bearing strength and tangent modulus of elasticity in accordance with ASTM D953. The test specimens shall be the actual thickness of the fabricated FRP panel and shall not be machined on the surface. Bearing properties shall be determined in at least two orthogonal directions. Test five specimens in each direction unless otherwise specified.

8.7.2 *Environmental resistance.* Environmental resistance tests shall be conducted in accordance with Sec. 8.7.2.1 to 8.7.2.2.4. Additional tests may be required by the manufacturer's third-party quality control and quality assurance program or by the purchaser. If deemed acceptable by the engineer, tests conducted in accordance with ASTM C581 may be used to meet the requirements of this section.

8.7.2.1 *Specimens.* Resistance to environmental exposure of the FRP panel laminate shall be determined on specimens cut from laminates that are determined by the engineer to be representative of the materials and methods of fabrication used in the tank. Specimens for testing of mechanical properties after exposure may be cut either before or after exposure in the test media. The edges of all exposure specimens shall be coated with paraffinated resin. When tests are conducted in liquids intended for internal containment only, a corrosion-resistant barrier may be added to the exterior surface of the specimens. The number of specimens for exposure testing shall be as specified for the required mechanical tests.

8.7.2.2 *Immersion tests.* The FRP panel shall be evaluated by immersion tests in accordance Sec. 8.7.2.2.1 to 8.7.2.2.9. The laminate shall exhibit no loss of color, erosion of resin, or surface defects as the result of immersion. The thickness, weight, and hardness shall exhibit no change greater than 10 percent. The extrapolated flexural properties (strength and modulus of elasticity) at 100,000 hr shall not be less than 50 percent of the initial properties.

8.7.2.2.1 *Immersion periods.* Immerse specimens for 30, 90, and 180 days, and 1 year in the required test media. Also prepare and obtain initial test properties on a control set of specimens immediately following fabrication and cure of test laminates.

8.7.2.2.2 *Immersion media.* Immersion media shall be representative of the anticipated service environment(s).

8.7.2.2.3 *Immersion temperature.* Immersion temperature shall be representative of the anticipated service environment(s).

8.7.2.2.4 *Immersion procedures.* Specimens must remain completely immersed during the test interval. Specimens shall not be stacked. Maintain a minimum  $\frac{1}{8}$  in. (3.175 mm) between specimens and between specimen and the container wall. Change test media as often as needed to maintain the original composition and concentration. Use methods to maintain test temperature within 5°F (3°C) of the specified value during the test. At the end of the immersion interval, remove specimens, clean and dry them by blotting with a paper towel. Cold tap water may be used to facilitate cleaning. Unless otherwise specified, allow specimens

to cool to room temperature before conducting required mechanical tests. All tests shall be completed within 4 hr after removal from the test media.

8.7.2.2.5 *Physical examination.* Examine all specimens prior to immersion and at the end of each immersion interval. Record visual appearance, including color, texture, and surface features.

8.7.2.2.6 *Thickness change.* Measure and record the thickness to the nearest 0.001 in. (0.0254 mm) at two locations on each specimen before and after immersion.

8.7.2.2.7 *Weight change.* Measure and record weight to the nearest gram before and after immersion.

8.7.2.2.8 *Hardness.* Measure and record Barcol hardness at five locations on each specimen.

8.7.2.2.9 *Flexural properties.* Conduct flexural tests for strength and modulus in accordance with Sec. 8.7.1.4. Plot the test results with respect to time for each immersion interval on a semi-log time plot. Extrapolate flexural strength and modulus to 100,000 hr and report the values as a percentage of initial properties.

8.7.3 *Light and water exposure.* Expose ten specimens to 360 days of light and water exposure in accordance with ASTM G152 and ASTM G153, Method I, Type D or DH apparatus. During each operating cycle of 120 min, the specimens are to be exposed to light alone for 102 min and light and water for 18 min. After exposure, test five specimens for flexural properties in accordance with Sec. 8.7.1.4., exterior surface in tension. The flexural properties (strength and modulus of elasticity) shall be at least 80 percent of initial properties.

8.7.4 *Impact and cold exposure.* Condition five specimens for 16 hr in a cold box at  $-20^{\circ}\text{F}$  ( $-29^{\circ}\text{C}$ ). After conditioning, remove each specimen one at a time and immediately clamp between two steel rings having an inside diameter of  $4\frac{1}{4}$  in. (108 mm). Drop a 1.18-lb (0.536-kg) steel ball from a height of 6 ft (1.83 m) to strike the exterior surface of the specimen. Specimen shall exhibit no visible signs of cracking or fracture.

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## SECTION 9: CONSTRUCTION

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### Sec. 9.1 General

The manufacturer shall provide instructions for the assembly of the tank, and the tank shall be assembled in accordance with these instructions. Special care shall be taken to ensure correct panel's placement, for its intended position.



## Sec. 9.2 Foundation Installation

The earth around the foundation shall be sufficiently graded to permit efficient work during tank erection and to prevent ponding of water in the foundation area. The tops of the foundation beams shall be accurately located at the proper elevation.

9.2.1 *Tolerances on concrete foundations.* Slabs and beams, after grouting, and before placing the steel footing, shall be level within  $\frac{1}{16}$  in. (2 mm).

9.2.2 *Finish.* The top portions of foundation concrete beams shall be finished to a smooth form finish in compliance with ACI 301. Any small holes may be troweled over with mortar as soon as possible after the forms are removed.

## Sec. 9.3 Anchor Bolts

It is the responsibility of the constructor to locate the anchor bolts between the steel footing and the concrete beams within  $\frac{1}{4}$  in. (6.35 mm) of the manufacturer's anchor bolt layout design.

## Sec. 9.4 Anchor Bolt Placement and Tolerance

a. The variation in dimension between the centers of any two anchor bolts within an anchor-bolt group shall be equal to or less than 3 in. (7.62 cm).

b. The variation in dimension between the centers of adjacent anchor-bolt groups shall be equal to or less than 4 in. (10.16 cm).

c. The variation in elevation of the tops of anchor bolts shall be equal to or less than plus or minus 2 in. (5.08 cm).

d. The accumulated variation in dimension between centers of anchor-bolt groups along the established column line through multiple anchor-bolt groups shall be equal to or less than 4 in. (10.16 cm) per 100 ft (38.48 m), but not to exceed a total of 1 in. (2.54 cm).

e. The variation in dimension from the center of any anchor-bolt group to the established column line through that group shall be equal to or less than 4 in. (10.16 cm).

## Sec. 9.5 Steel Footing

It is the responsibility of the constructor to level the steel-footing framework within  $\frac{1}{16}$  in. (2 mm) in conformance with the manufacturer's design.

9.5.1 *Welded joints.* Welding may be used to join shop-fabricated steel footing subassemblies that are subsequently bolted into place in the field. Welds shall meet the design requirements of Sec. 5.5.

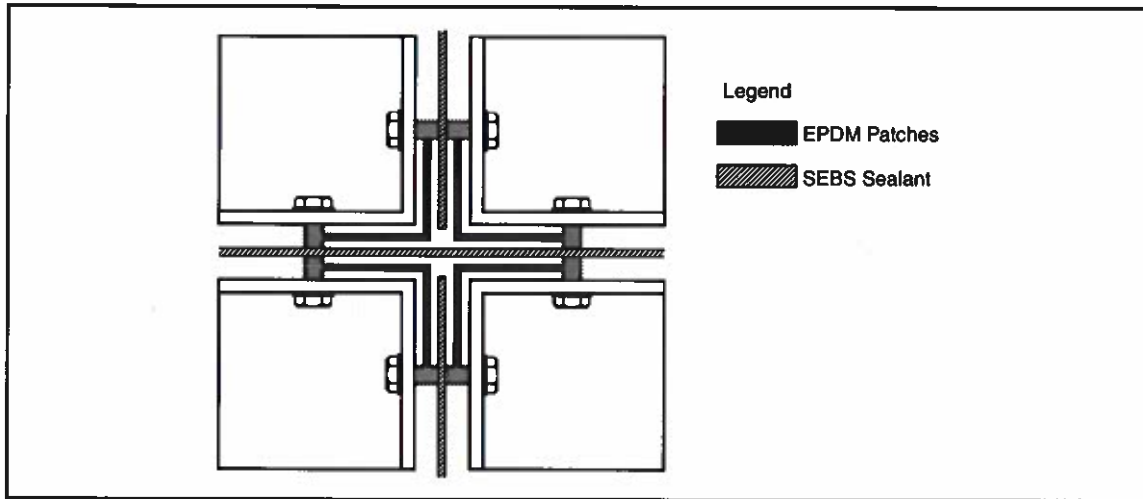


Figure 8 Sealant detail at panel intersections

## Sec. 9.6 Types of Joint

9.6.1 *Bolted joints.* Vertical and horizontal panel joints shall be field bolted. Bolt holes shall be shop drilled for field assembly. The bolted joints that are required to be watertight shall be sealed with suitable gasket material, sealant, or gasket material and sealant (see Sec. 9.6.3 and Figure 8).

9.6.2 *Alignments.* It is standard practice for field-assembled tanks to require fit-up alignments of a panel according to a panel layout chart provided by the manufacturer. The manufacturer's erection procedures shall be followed.

9.6.3 *Sealant requirements.* Main SEBS sealant shall have 4 ribs (O-ring type compression strips) and pre-punched holes that align with the tank panel bolt holes. Sealant is to be placed between the panels, and panels shall be bolted to the required torque setting as specified by the manufacturer's assembly guide to provide leak-free connections. Bottom and sidewall panels shall be fitted with the combination of main SEBS sealant and EPDM patches at intersections to provide leak-free joints. A roof panel will have EPDM gaskets all around the panels to provide weatherproof joints.

## Sec. 9.7 Bolting

Bolts, nuts, and washers shall be located and installed in accordance with the instructions on assembling the tank provided by the manufacturer.

## Sec. 9.8 Bolt Tightening Requirements

See Table 3.

**Table 3 Nut rotation\* from snug-tight condition**

Bolt Length, <i>in.</i> (as measured from underside of head to extreme end of point)	Both Faces Normal to Bolt Axis	One Face Normal to Bolt Axis and Other Face Sloped Not More Than 1:20	Both Faces Sloped Not More Than 1:20 From Normal to Bolt Axis
Up to and including 4 diameters	1/3 turn	1/2 turn	2/3 turn
Over 4 diameters but not exceeding 8 diameters	1/2 turn	2/3 turn	5/6 turn
Over 8 diameters but not exceeding 12 diameters	2/3 turn	5/6 turn	1 turn

\*Nut rotation is relative to bolt, regardless of the element (nut or bolt) being turned. For bolts installed by 1/2 turn and less, the tolerance should be  $\pm 30$  degrees; for bolts installed by 2/3 turn or more, the tolerance should be  $\pm 45$  degrees. All materials within the grip of the bolt must be steel.

### Sec. 9.9 Gaskets and Sealants

Gaskets and sealants or both shall be supplied by the manufacturer and installed between all joints in compliance with the assembly instructions. The constructor shall exercise care in properly locating and installing any gaskets supplied by the manufacturer.

### Sec. 9.10 Cleanup

On completion of the assembly, the constructor shall, if required by the purchaser's documents, dispose of rubbish and other unsightly material and shall leave the premises in as good a condition as found at the start of the tank construction.

### Sec. 9.11 Marking

Tank components shall be given a piece mark number for ease of assembly, in lieu of marking, the tank manufacturer's standard practice may be used.

### Sec. 9.12 Protection

Coated parts shall be protected from damage during shipment and storage.

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## SECTION 10: INSPECTION AND TESTING

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### Sec. 10.1 FRP Panel Damage

FRP panels shall be visually inspected before assembly and shall be free of cracks or crazes to the surfaces. If found, the panel should be replaced by the manufacturer and/or contractor before assembly.

### **Sec. 10.2 Testing**

Once assembled the tank should be slowly filled with water to just beyond the first horizontal joint line, which is normally at 3.3 ft (1 m). A walk-around shall be performed and all joints and penetrations inspected for leakage. The tank shall continue to be filled slowly and the process of a walk-around visual inspection repeated at each horizontal joint level until the tank is full. The tank shall be left full for a period of at least 24 hr and a final leakage/general conditions walk-around inspection shall be done.

### **Sec. 10.3 Disposal of Test Water**

The constructor shall provide a means of disposing of test water with a connection to the inlet pipe or drain pipe.

### **Sec. 10.4 Repair of Leaks**

Leaks or damage to bolted, aboveground FRP panel-type tanks are to be repaired by replacing an affected panel or component through unbolting the affected part and replacing it with a new part by the manufacturer and/or contractor, taking general safety and entry considerations of FTPI RP T-95-02 into consideration.

### **Sec. 10.5 Disinfecting**

Regardless of the sequence used for testing the tank, the tank shall be disinfected after the final test and it may then be filled with potable water and placed into service. Disinfection shall not be the responsibility of the constructor or manufacturer unless otherwise specified by the purchaser (Refer to ANSI/AWWA C652).

### **Sec. 10.6 Inspection and Maintenance**

Tanks should be inspected and maintained as prescribed in FTPI 2007-1, taking notable exceptions into consideration, such as the manufacturing method being compression molding. In addition to inspection procedures described, the tightness/torque of the over-roof tie-rods should also be checked annually for slackness and adjusted if required.

# APPENDIX A

## Metric (SI) Equivalents

*This appendix is for information only and is not a part of ANSI/AWWA D121.*

Metric units used are those of the International System of Units (SI), which is officially recognized by all industrial nations. This document may be supplemented by ASTM\* SI 10, Metric Practice Guide.

Table A.1 lists selected SI conversions for the convenience of users of this standard.

**Table A.1 Metric (SI) conversion factors**

Property	To Convert US Customary Units	To Metric (SI) Units	Multiply by*
Area	square inch (in. <sup>2</sup> )	millimeter squared (mm <sup>2</sup> )	6.451 600*E + 02
		meter squared (m <sup>2</sup> )	6.451 600*E – 04
	square foot (ft <sup>2</sup> )	meter squared (m <sup>2</sup> )	9.290 304*E – 02
Force	pound-force (lbf)	Newton (N)	4.448 222 E + 00
	kip (1,000 lbf)	Newton (N)	4.448 222 E + 03
Force/Area	pound-force/foot <sup>2</sup> (lbf/ft <sup>2</sup> )	newton/meter <sup>2</sup> (N/m <sup>2</sup> )	4.788 026 E + 01
Impact strength	foot-pound force (ft.lbf)	joule (J)	1.355 818 E + 00
Linear dimension	inch (in.)	millimeter (mm)	2.540 000*E + 01
	foot (ft)	millimeter (mm)	3.048 000*E + 02
Mass/Volume	pound-mass/cubic foot (lb/ft <sup>3</sup> )	kilogram/meter <sup>3</sup> (kg/m <sup>3</sup> )	1.601 846 E + 01
Temperature	degrees Fahrenheit (°F)	degrees Celsius (°C)	°C = (°F -32)/1.8
Tensile strength	pounds per inch <sup>2</sup> (psi) kips per inch <sup>2</sup> (ksi)	Pascal (Pa)	6.894 757 E + 03
		kilopascal (kPa)	6.894 757 E + 03
		megapascal (MPa)	6.894 757 E + 06
Velocity	miles per hour (mph) (US statute)	meter per second (m/s)	4.470 400*E – 01
Volume	gallon (gal) (US liquid)	meter cubed (m <sup>3</sup> )	3.785 412 E – 03

\*An asterisk (\*) after the sixth decimal place indicates that the conversion factor is exact and that all subsequent digits are zero. The number is followed by the letter E (exponent), a plus or a minus symbol, and two digits that indicate the power of 10 by which the number must be multiplied to obtain the correct value.

\* ASTM International, 100 Barr Harbor Dr., West Conshohocken, PA 19428.

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## APPENDIX B

### Seismic Analysis Example

*This appendix is for information only and is not a part of ANSI/AWWA D121.*

The following is a seismic analysis. For this example, the following information is provided (see Figures B.1A and B.1B):

Tank height	= 13.12 ft
Tank width, $B$	= 16.40 ft
Tank length, $L$	= 22.97 ft
Live load	= 16 lb/ft <sup>2</sup>
Snow load	= 20 lb/ft <sup>2</sup>
No. of roof panels	= 35

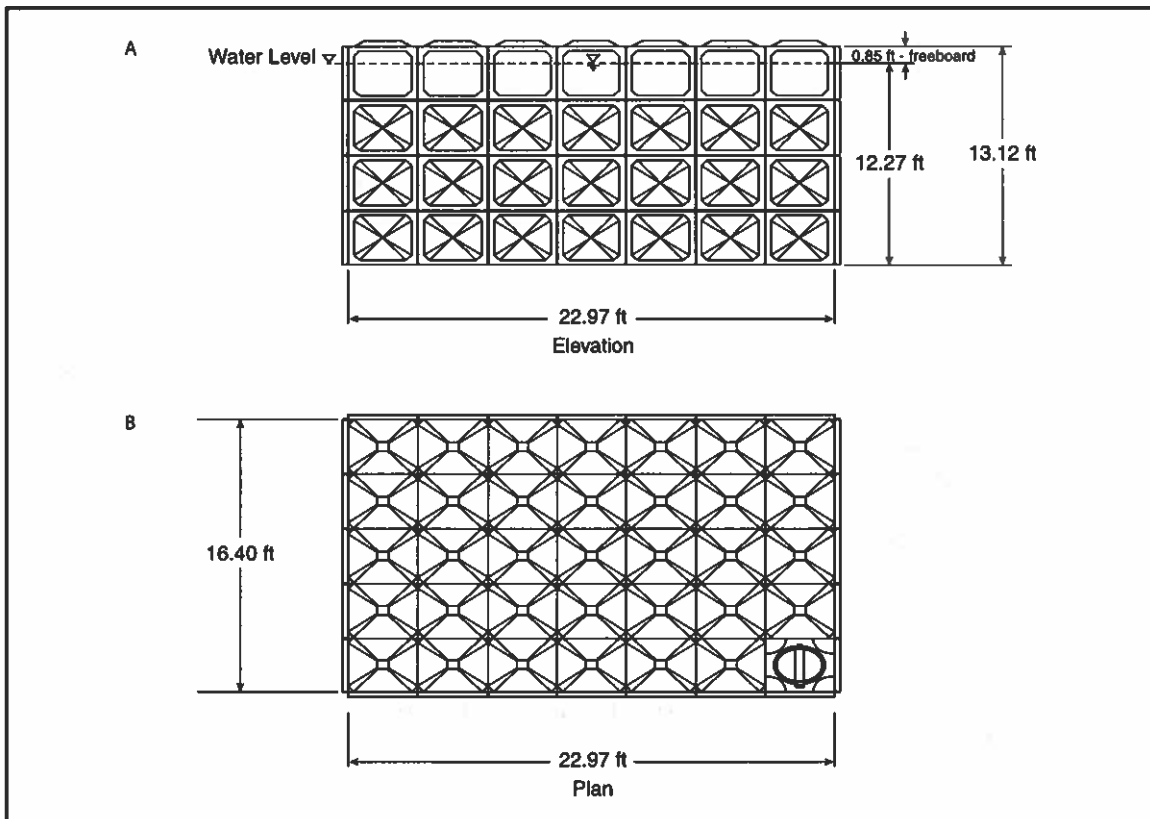


Figure B.1 Given tank dimensions

No. of side panels	= 96
No. of bottom panels	= 35
Freeboard provided	= 0.85 ft
Depth of stored water, $H_L$	= 12.27 ft
Total weight of the tank, $W_t$	= 17,397 lb
Tank content, $W_L$	= 288,684 lb
Weight of the floor, $W_f$	= 4,616 lb
Weight of the roof, $D$	= 761 lb
Weight of the wall, $W_w$	= 12,020 lb
Weight of the wall, $W'_w$	= 3506.50 lb (along B=22.97 ft)
Weight of the wall, $W'_w$	= 2503.50 lb (along B=16.40 ft)
Number of anchored bolts	= 12 pcs.
1-in. $\varnothing$ Bolt (A325)	= 48,000 psi (nominal shear strength)
Response modification factor, $R_i$	= 2.0
Response modification factor, $R_c$	= 1.0
Density of water, $\gamma_w$	= 62.43 lb/ft <sup>3</sup>

#### B.1 Determine the design response spectrum

Site Class = B	Sec. 5.3.7.4.1 (1)
$S_s = 1.974$ g	Sec. 5.3.7.4.1 (2)
$S_1 = 0.712$ g	Sec. 5.3.7.4.1 (2)
$F_a = 1.0$	Sec. 5.3.7.4.1 (3)
$F_v = 1.0$	Sec. 5.3.7.4.1 (3)

$$S_{DS} = {}^{2/3} F_a S_s = 1.316g \quad (5-51)$$

$$S_{D1} = {}^{2/3} F_v S_1 = 0.475g \quad (5-52)$$

#### Analysis for lengthwise shock ( $L = 22.97$ ft )

#### B.2 Determine $T_c$ , $T_i$ , and $T_s$

Determine  $T_c$ , based on the formula

$$T_c = (2\pi/\lambda)L^{1/2} \quad (5-48)$$

$$T_c = 0.64 (22.97)^{1/2} = 3.09 \text{ sec}$$

where:  $\lambda = \{3.16g \tanh [3.16(H_L / L)]\}^{1/2} \quad (5-49)$

$$\lambda = 9.745$$

$$2\pi/\lambda = 0.64$$



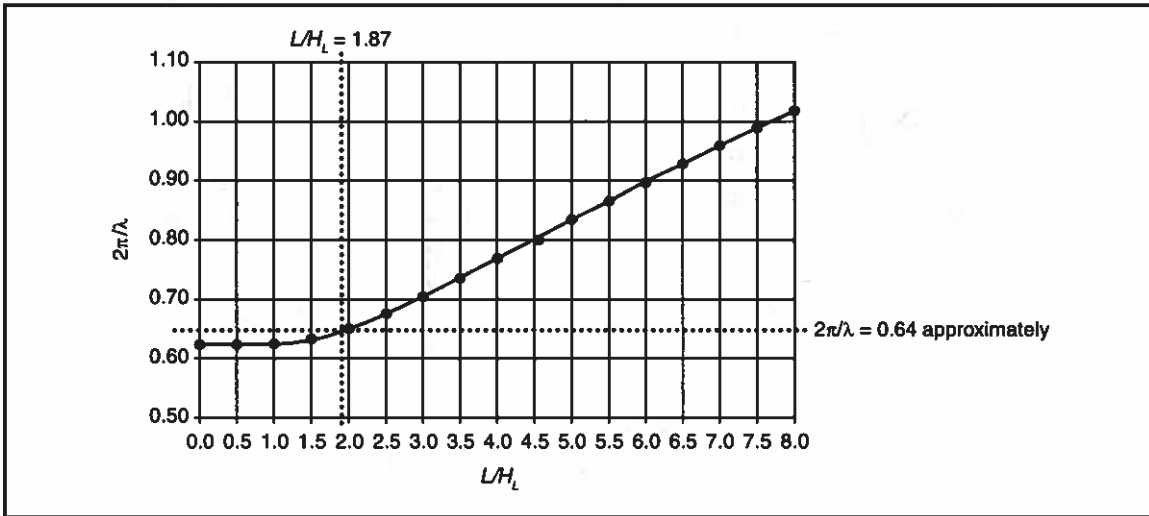


Figure B.2 Curve for obtaining the factor  $2\pi/\lambda$  for the ratio  $L/H_L$

Based on Figure B.2, when  $L/H_L$  is 1.87, then  $2\pi/\lambda = 0.64$  approximately

Determination of  $T_i$

$$T_i = 2\pi [(W_i + W_w) / (gk)]^{1/2} \tag{5-50}$$

$$T_i = 2\pi [(190,418.94 \text{ lb} + 2,503.50 \text{ lb}) / (32.17 \text{ ft/s}^2) (73,644 \text{ lb/ft})]^{1/2}$$

$$T_i = 1.79 \text{ sec}$$

For externally reinforced water tank with four members external bracing  
(Steel Section = W10 × 15)

where:

$$k = 3EI / L^3$$

$$k = [3 (29,000,000 \text{ psi}) (68.90 \text{ in.}^4) / (157.5 \text{ in.})^3] \times 4$$

$$k = 6,137 \text{ lb/in.} = 73,644 \text{ lb/ft}$$

Determination of  $T_s$

$$T_s = S_{D1} / S_{DS} \tag{5-55}$$

$$T_s = 0.475 / 1.316 = 0.36 \text{ sec}$$

B.3 Determine the  $C_c$ ,  $C_i$ , and  $C_t$

$$T_i > T_s$$

$$C_i = S_{D1} / T_i \tag{5-54}$$

$$C_i = 0.475 / 1.79$$

$$C_i = 0.27$$

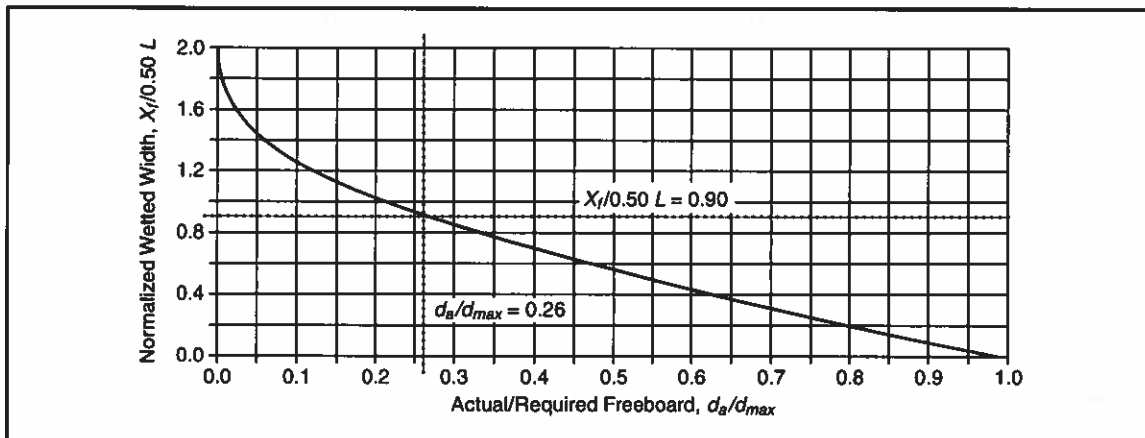


Figure B.3 Curve for obtaining the normalized wetted width,  $X_f/0.50 L$ , for the ratio  $d_a/d_{max}$

$$T_c < 1.6/T_s$$

$$C_c = 1.5 S_{D1}/T_c \quad (5-56)$$

$$C_c = 1.5 (0.475) / 3.09$$

$$C_c = 0.23$$

$$C_t = 2/3 (1.316) \quad \text{Sec. 5.3.7.4.1 (6)}$$

$$C_t = 0.877$$

#### B.4 Determine the sloshing wave height

$$d_{max} = 0.50L C_c I \quad (5-38)$$

$$d_{max} = 0.50 (22.97 \text{ ft}) (0.23) (1.25)$$

$$d_{max} = 3.30 \text{ ft}$$

The freeboard provided  $d_a = 0.85 \text{ ft} < d_{max}$

since  $d_{max} > d_a$ , convective (sloshing) mass must be considered (Figure B.3)

#### B.5 Convective (sloshing) mass within the portion confined by the roof, $W_{cm}$

$$W_{cm} = \gamma_w X_f B (d_{max} - d_a) \quad (5-61)$$

$$W_{cm} = (62.43) (10.34) (16.40) (3.30 - 0.85)$$

$$W_{cm} = 25,937.24 \text{ lb}$$

#### B.6 Determine the $W_i/W_L$ and $W_c/W_L$ based on the formula

$$W_i/W_L = 0.57 \quad (5-39)$$

$$W_c/W_L = 0.46 \quad (5-40)$$

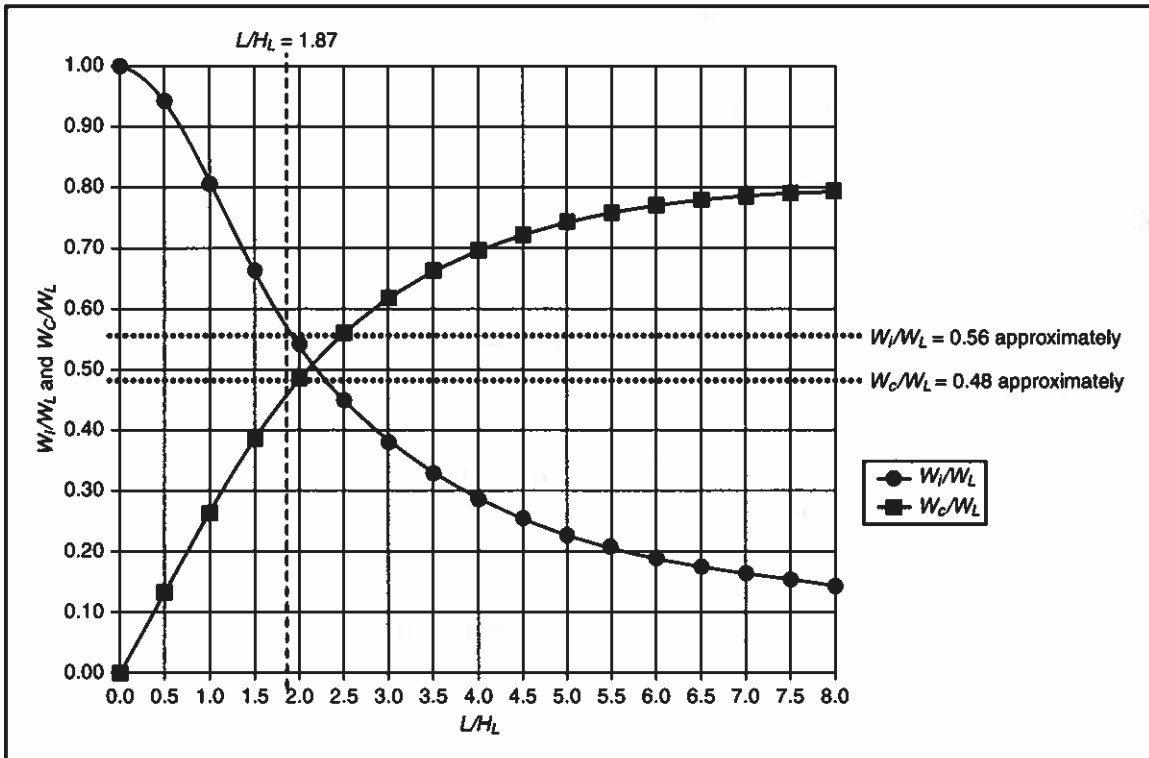


Figure B.4 Curves for obtaining factors  $W_i/W_L$  and  $W_c/W_L$  for ratio  $L/H_L$

Determine  $W_i/W_L$  and  $W_c/W_L$  from Figure B.4, when  $L/H_L$  is 1.87, then  
 $W_i/W_L$  is approximately 0.56  
 $W_c/W_L$  is approximately 0.48

B.7 Determine the  $W_i$  and  $W_c$

$$W_i = 0.57(288,564.39) + W_{cm} \quad \text{ASCE/SEI 7-05, section 15.7.6.1.2c}$$

$$W_i = 164,481.70 + 25,937.24$$

$$W_i = 190,418.94 \text{ lb}$$

$$W_c = 0.46 (288,564.39)$$

$$W_c = 132,739.62 \text{ lb}$$

B.8 Determine the weight of roof,  $W_r$ , plus 25 percent of design roof live load and 20 percent of design snow load where the flat snow load exceeds 30 lb/ft<sup>2</sup>.

$$W_r = D + 0.25 L_r + 0.20S$$

$$W_r = 761 \text{ lb} + 0.25 (16 \text{ lb/ft}^2 \times 16.40 \text{ ft} \times 22.97 \text{ ft})$$

$$W_r = 2,267.83 \text{ lb}$$

B.9 Determine the  $V_{rL}$ , due to self-weight of the roof

$$V_{rL} = C_i I (W_r / R_i) \quad (5-11)$$

$$V_{rL} = (0.27) (1.25) (2,267.83 / 2.0)$$

$$V_{rL} = 382.70 \text{ lb}$$

B.10 Determine the  $V_{wL}$ , due to self-weight of walls

$$V_{wL} = C_i I (\epsilon W_w / R_i) \quad (5-12)$$

$$V_{wL} = (0.27) (1.25) [(0.72) 12,020 / 2.0]$$

$$V_{wL} = 1,460.43 \text{ lb}$$

$$V'_{wL} = C_i I (\epsilon W'_w / R_i) \quad (5-13)$$

$$V'_{wL} = (0.29) (1.25) [(0.72) 2,503.50 \text{ lb} / 2.0]$$

$$V'_{wL} = 304.18 \text{ lb}$$

where:

$$\epsilon = [0.0151(L/H_L)^2 - 0.1908(L/H_L) + 1.021] \leq 1.0 \quad (5-47)$$

$$\epsilon = [0.0151(1.87)^2 - 0.1908(1.87) + 1.021] \leq 1.0$$

$$\epsilon = 0.72$$

Due to impulsive action of stored water

$$V_i = C_i I (W_i / R_i) \quad (5-14)$$

$$V_i = (0.27) (1.25) (190,418.94 / 2.0)$$

$$V_i = 32,133.20 \text{ lb}$$

Due to convective action of the stored water

$$V_c = C_c I (W_c / R_c) \quad (5-15)$$

$$V_c = (0.23) (1.25) (132,739.62 / 1.0)$$

$$V_c = 38,162.64 \text{ lb}$$

B.11 Determine the  $V_{fL}$ , due to self-weight of the floor

$$V_{fL} = C_i I (W_f / R_i) \quad (5-16)$$

$$V_{fL} = (0.27) (1.25) (4,616 / 2.0)$$

$$V_{fL} = 778.95 \text{ lb}$$

B.12 Determine the total horizontal base shear,  $V$

$$V = [(V_i + V_{wL} + V_{rL} + V_{fL})^2 + V_c^2]^{1/2} \quad (5-17)$$

$$V = [(32,133.20 + 1,460.43 + 382.70 + 778.95)^2 + (38,162.64)^2]^{1/2}$$

$$V = 51,617.02 \text{ lb}$$

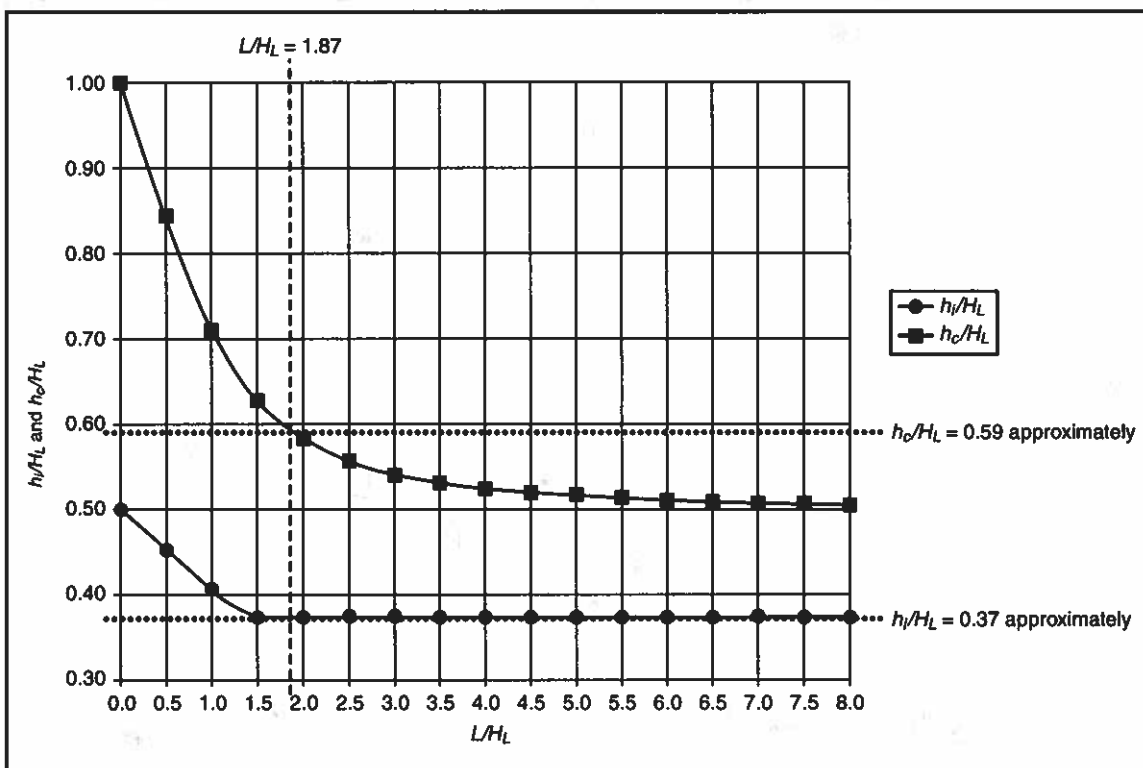


Figure B.5 Curves for obtaining factors  $h_i/H_L$  and  $h_c/H_L$  for the ratio  $L/H_L$

B.13 Determine  $h_i/H_L$ ,  $h_c/H_L$ ,  $h'_i/H_L$ ,  $h'_c/H_L$  based on the formula

when  $L/H_L > 1.333$ ;  $h_i/H_L = 0.375$  therefore,  $h_i = 4.60$  ft (5-42)

$h_c/H_L = 0.59$  therefore,  $h_c = 7.24$  ft (5-43)

when  $L/H_L > 0.75$ ;  $h'_i/H_L = 0.75$  therefore,  $h'_i = 9.20$  ft (5-45)

$h'_c/H_L = 0.82$  therefore,  $h'_c = 10.06$  ft (5-46)

Determine  $h_i/H_L$ ,  $h_c/H_L$ ,  $h'_i/H_L$ ,  $h'_c/H_L$  based on Figure B.5; when  $L/H_L$  is 1.87, then

$$h_i/H_L = 0.37$$

$$h_c/H_L = 0.59$$

Based on Figure B.6, when  $L/H_L$  is 1.87, then

$$h'_i/H_L = 0.75$$

$$h'_c/H_L = 0.80$$

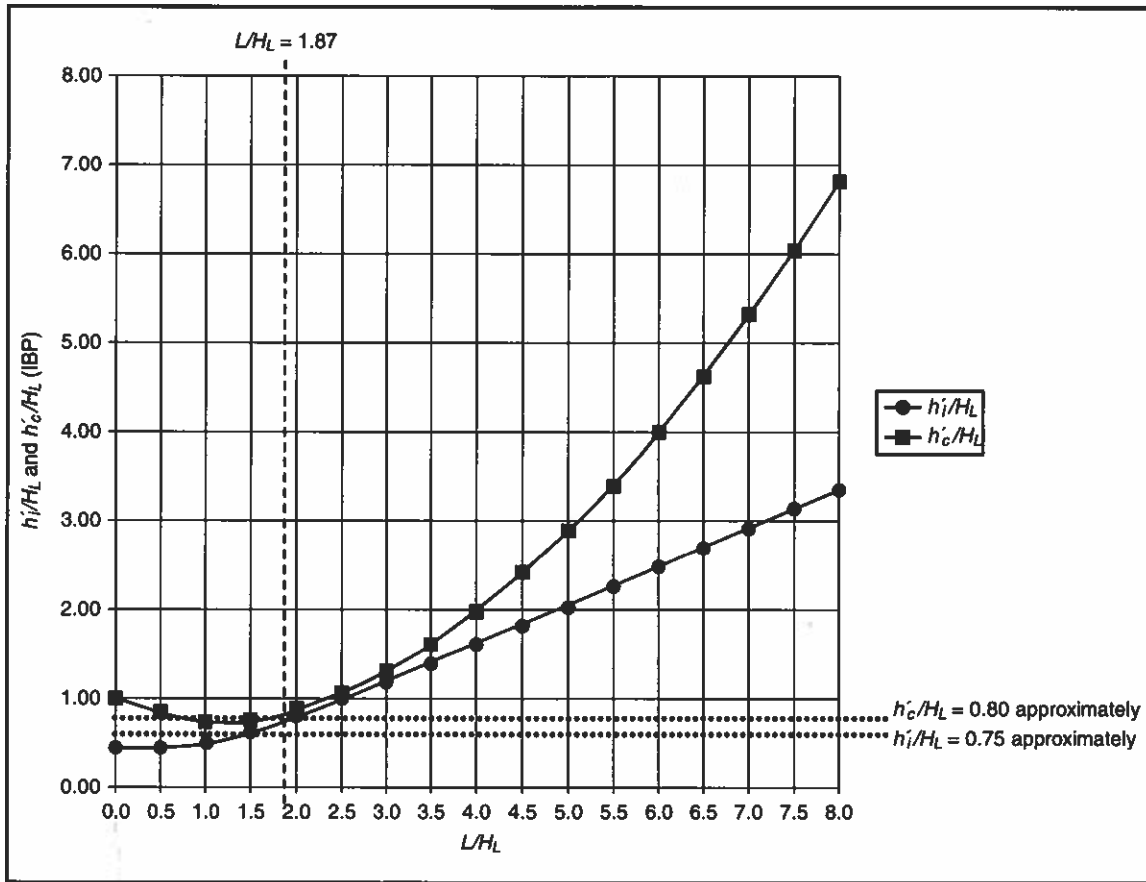


Figure B.6 Curves for obtaining factors  $h'_i/H_L$  and  $h'_c/H_L$  for the ratio  $L/H_L$

B.14 Determine moment at base,  $M_b$

Bending moment of the entire tank cross section just above the base of the tank wall (EBP) due to the wall inertia force,  $M_w$

$$M_w = V_w L h_w \tag{5-18}$$

$$M_w = (1,460.43) 13.12/2$$

$$M_w = 9,580.42 \text{ lb-ft}$$

Bending moment of the entire tank cross section just above the base of the tank wall (EBP) due to the roof inertia force,  $M_r$

$$M_r = V_r L h_r \tag{5-19}$$

$$M_r = (382.70) (13.12)$$

$$M_r = 5,021.02 \text{ lb-ft}$$

Bending moment of the entire tank cross section just above the base of the tank wall (EBP) due to the impulsive force,  $M_i$

$$M_i = V_i h_i \quad (5-20)$$

$$M_i = (32,133.20) (4.60)$$

$$M_i = 147,812.72 \text{ lb-ft}$$

Bending moment of the entire tank cross section just above the base of the tank wall (EBP) due to the convective force,  $M_c$

$$M_c = V_c h_c \quad (5-21)$$

$$M_c = (38,162.64) (7.24)$$

$$M_c = 276,297.51 \text{ lb-ft}$$

Bending moment of the entire tank cross section just above the base of the tank wall,  $M_b$

$$M_b = [(M_i + M_w + M_r)^2 + (M_c)^2]^{1/2} \quad (5-22)$$

$$M_b = [(147,812.72 + 9,580.42 + 5,021.01)^2 + (276,297.51)^2]^{1/2}$$

$$M_b = 320,497.54 \text{ lb-ft}$$

#### B.15 Determine the overturning moment, $M_o$

Overturning moment at the base of the tank, including the tank bottom and supporting structure (IBP), due to the impulsive force,  $M'_i$

$$M'_i = V_i h'_i \quad (5-23)$$

$$M'_i = (32,133.20) (9.20)$$

$$M'_i = 295,625.44 \text{ lb-ft}$$

Overturning moment at the base of the tank, including the tank bottom and supporting structure (IBP), due to the convective force,  $M'_c$

$$M'_c = V_c h'_c \quad (5-24)$$

$$M'_c = (38,162.64) (10.06)$$

$$M'_c = 383,916.16 \text{ lb-ft}$$

Overturning moment at the base of the tank, including the tank bottom and supporting structure,  $M_o$

$$M_o = [(M'_i + M_w + M_r)^2 + (M'_c)^2]^{1/2} \quad (5-25)$$

$$M_o = [(295,625.44 + 9,580.42 + 5,021.02)^2 + (383,916.16)^2]^{1/2}$$

$$M_o = 493,591.26 \text{ lb-ft}$$

#### B.16 Resistance to overturning moment

$$M = L/2 (W_t + W_D) \quad (5-59)$$

$$M = 22.97 / 2 (17,397 + 288,564.39)$$

$$M = 3,513,966.56 \text{ lb-ft}$$

Factor of safety:

$$F.S. = M/M_o$$

$$F.S. = 3,513,966.56 / 493,591.26$$

$$F.S. = 7.12 > 1.50 \text{ o.k.}$$

### B.17 Anchor bolts

12 pcs. × 1-in. diameter (ASTM 325)

$$\phi V_r \geq V$$

$$\phi = 0.75$$

$$\phi V_r = 0.75 [p (1)^2 / 4 (12) (48,000)] \geq 51,617.02 \text{ lb}$$

$$\phi V_r = 339,292 \text{ lb} \geq 51,617.02 \text{ lb}$$

Resistance to sliding

Factor of safety:

$$F.S. = V_r/V$$

$$F.S. = (339,292/0.75) / (51,617.02)$$

$$F.S. = 8.76 > 1.5 \text{ o.k.}$$

### B.18 Hydrodynamic pressure on the floor due to lateral acceleration

$$p_{fL} = 6 [(M'_i - M_i)^2 + (M'_c - M_c)^2]^{1/2} / BL^2 \quad (5-26)$$

$$p_{fL} = 6 [(295,625.44 - 147,812.72)^2 + (383,916.16 - 276,297.51)^2]^{1/2} /$$

$$(16.40) (22.97)^2$$

$$p_{fL} = 126.78 \text{ lb/ft}^2$$

### B.19 Dynamic vertical forces due to vertical ground motion

#### a. Roof

$$P_{rv} = C_t I (W_r / R_i) \quad (5-27)$$

$$P_{rv} = (0.877) (1.25) (2,267.83/2.0)$$

$$P_{rv} = 1,243.05 \text{ lb}$$

#### b. Wall

$$P_{wv} = C_t I (\epsilon W_w / R_i) \quad (5-28)$$

$$P_{wv} = (0.877)(1.25) (0.72) (12,020/2.0)$$

$$P_{wv} = 4,743.69 \text{ lb}$$

#### c. Floor

$$P_{fv} = C_t I (W_f / R_i) \quad (5-29)$$

$$P_{fv} = (0.877) (1.25) (4,616/2)$$

$$P_{fv} = 2,530.15 \text{ lb}$$



Due to vertically accelerated stored water:  $p_{fv} = \gamma_w H_L \ddot{u}_v$  (5-30)

where  $\ddot{u}_v = C_t I / R_i = (0.877) (1.25) / (2.0) = 0.55$  (5-31)

$p_{fv} = (62.43) (12.27) (0.55)$

$p_{fv} = 421.31 \text{ lb/ft}^2$

**B.20 Total dynamic vertical force on the base, due to vertical acceleration**

$P = P_{rv} + P_{wv} + P_{fv} + p_{fv} BL$  (5-32)

$P = 1,243.05 + 4,743.69 + 2,530.15 + 421.31 (16.40)(22.97)$

$P = 167,227.74 \text{ lb}$

**B.21 Dynamic pressure on wall force due to vertical ground motion, at  $y = 3.281 \text{ ft}$  (for example)**

$p_{vy} = \gamma_w (H_L - y) \ddot{u}_v$  (5-37)

where  $\ddot{u}_v = C_t I / R_i = (0.877) (1.25) / (2.0) = 0.55$  (5-31)

$p_{vy} = (62.43) (12.27 - 3.281) (0.55) = 308.65 \text{ lb/ft}^2$

**B.22 Dynamic force on the wall due to horizontal ground motion at the height of  $y = 3.281 \text{ ft}$**

$V_{iy} = (V_i/2) [4H_L - 6h_i - (6H_L - 12h_i)(y/H_L)]/H_L^2$  (5-34)

$V_{iy} = (32,133.20/2) [4(12.27) - 6(4.6) - (6(12.27) - 12(4.6))(3.281/12.27)]/12.27^2$

$V_{iy} = 1,766.65 \text{ lb/ft}$

$V_{cy} = (V_c/2)[4H_L - 6h_c - (6H_L - 12h_c)(y/H_L)]/H_L^2$  (5-35)

$V_{cy} = (38,162.64/2)[4(12.27) - 6(7.24) - (6(12.27) - 12(7.24))(3.281/12.27)]/12.27^2$

$V_{cy} = 1,164.21 \text{ lb/ft}$

$V_{wy} = V_w L / (H_w - y) / H_w$  (5-36)

$V_{wy} = 304.18(13.12 - 3.281) / 13.12$

$V_{wy} = 228.11 \text{ lb/ft}$

$V_y = [(V_{iy} + V_{wy})^2 + V_{cy}^2]^{1/2}$  (5-33)

$V_y = [(1,766.65 + 228.11)^2 + (1,164.21)^2]^{1/2}$

$V_y = 2,309.64 \text{ lb/ft}$

Pressure on wall at  $y = 3.281 \text{ ft}$

$V_y / B = 2,309.64 / 16.40 = 140.83 \text{ lb/ft}^2$

**B.23 Dynamic vertical force distribution on floor, due to vertical acceleration (Sec. 5.3.5.3)**

$P_{rv} + P_{fv} + p_{fv} = 1,243.05 + 2,530.15 + 421.31 (22.97) (16.40) = 162,484.05 \text{ lb}$

Dynamic pressure on floor =  $162,484.05 / (22.97) (16.40)$

=  $431.33 \text{ lb/ft}^2$

## B.24 Dynamic vertical force distribution on roof (Sec. 5.3.5.4)

$$P_{rv} = 1,243.05 \text{ lb}$$

$$\begin{aligned} \text{Dynamic pressure on roof} &= 1,243.05 / (16.40) (22.97) \\ &= 3.30 \text{ lb/ft}^2 \end{aligned}$$

## B.25 Effects of horizontal and vertical acceleration (Sec. 5.3.3.3.4)

$$E = 1.0 \times (\text{horizontal acceleration effects})$$

$$+ 0.3 \times (\text{vertical acceleration effects})$$

$$E = 0.3 \times (\text{horizontal acceleration effects})$$

$$+ 1.0 \times (\text{vertical acceleration effects})$$

Base shear:

$$E = 1.0 (51,617.02) + 0.3 \times (0) = 51,617.02 \text{ lb}$$

$$E = 0.3 \times (51,617.02) + 1.0 \times (0) = 15,485.11 \text{ lb}$$

Base moment:

$$E = 1.0 (320,497.54) + 0.3 \times (0) = 320,497.54 \text{ lb-ft}$$

$$E = 0.3 \times (320,497.54) + 1.0 \times (0) = 96,149.26 \text{ lb-ft}$$

Overturning moment:

$$E = 1.0 (493,591.26) + 0.3 \times (0) = 493,591.26 \text{ lb-ft}$$

$$E = 0.3 \times (493,591.26) + 1.0 \times (0) = 148,077.38 \text{ lb-ft}$$

Vertical force:

$$E = 1.0 (0) + 0.3 \times (167,227.74) = 50,168.32 \text{ lb}$$

$$E = 0.3 \times (0) + 1.0 \times (166,227.74) = 167,227.74 \text{ lb}$$

Dynamic pressure on floor:

$$E = 1.0 (126.78) + 0.3 \times (431.33) = 256.18 \text{ lb/ft}^2$$

$$E = 0.3 \times (126.78) + 1.0 \times (431.33) = 469.36 \text{ lb/ft}^2$$

Dynamic pressure on wall,  $y = 3.281$  ft:

$$E = 1.0 (130.19) + 0.3 \times (308.65) = 222.79 \text{ lb/ft}^2$$

$$E = 0.3 \times (130.19) + 1.0 \times (308.65) = 347.71 \text{ lb/ft}^2$$

Dynamic pressure on roof (without sloshing):

$$E = 1.0 (0) + 0.3 \times (3.30) = 0.99 \text{ lb/ft}^2$$

$$E = 0.3 \times (0) + 1.0 \times (3.30) = 3.30 \text{ lb/ft}^2$$

**Analysis for transverse shock (L=16.40 ft)**B.26 Determine  $T_c$ ,  $T_i$ , and  $T_s$ Determine  $T_c$ , based on the formula

$$T_c = (2\pi/\lambda) L^{1/2} \tag{5-48}$$

$$T_c = 0.63 (16.40)^{1/2} = 2.55 \text{ sec}$$

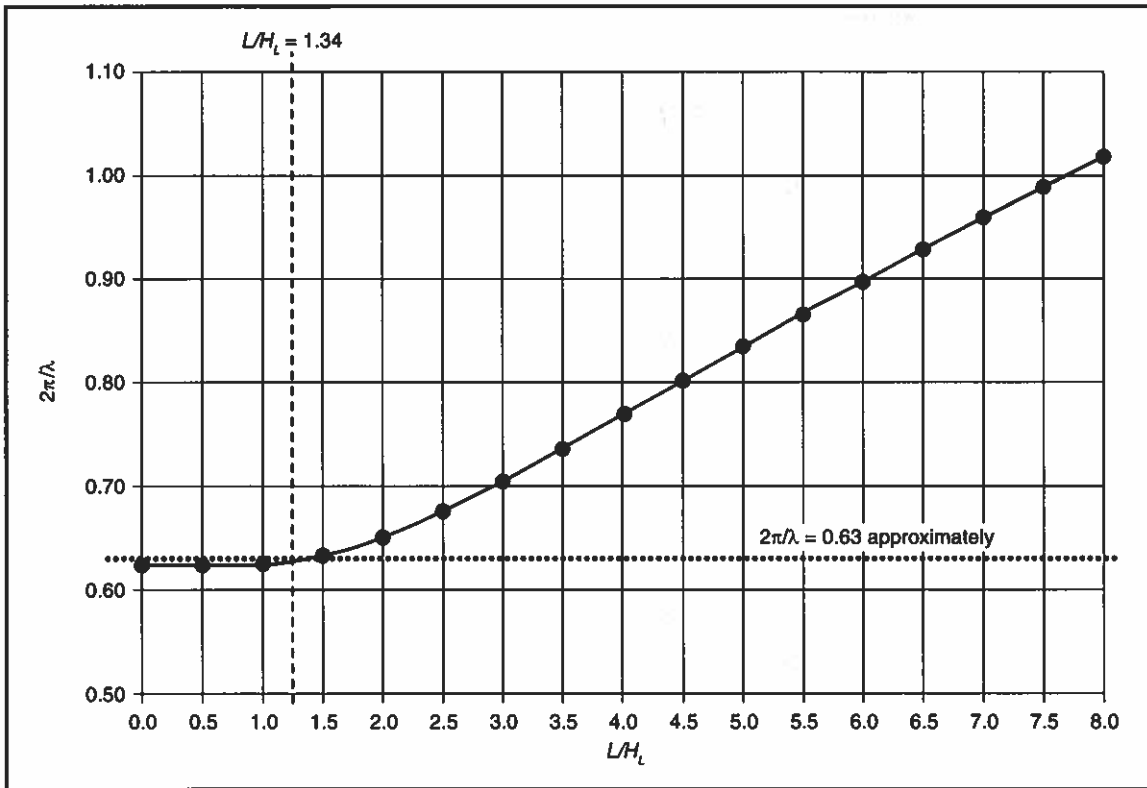


Figure B.7 Curve for obtaining the factor  $2\pi/\lambda$  for the ratio  $L/H_L$

where:  $\lambda = \{3.16g \tanh[3.16(H_L/L)]\}^{1/2}$  (5-49)

$\lambda = 9.99$

$2\pi/\lambda = 0.63$

Based on Figure B.7, when  $L/H_L$  is 1.34, then  $2\pi/\lambda = 0.63$  approximately

Determination of  $T_i$

$T_i = 2\pi[(W_i + W'_w) / (gk)]^{1/2}$  (5-50)

$T_i = 2\pi[(224,578.38 \text{ lb} + 3,506.50 \text{ lb}) / (32.17) (110,466.12 \text{ lb/ft})]^{1/2}$

$T_i = 1.59 \text{ sec}$

For externally reinforced water tank with external bracing (Steel Section = W10 x 15)

where:

$k = 3EI / L^3$

$k = [3 (29,000,000 \text{ psi}) (68.90 \text{ in.}^4) / (157.5 \text{ in.})^3] \times 6$

$k = 9,205.51 \text{ lb/in.} = 110,466.12 \text{ lb/ft}$

Determination of  $T_s$ 

$$T_s = S_{D1}/S_{DS} \quad (5-55)$$

$$T_s = 0.475 / 1.316 = 0.36 \text{ sec}$$

B.27 Determine  $C_c$ ,  $C_i$ , and  $C_t$ 

$$T_i > T_s$$

$$C_i = S_{D1}/T_i \quad (5-54)$$

$$C_i = 0.475/1.59$$

$$C_i = 0.30$$

$$T_c < 1.6/ T_s$$

$$C_c = 1.5 S_{D1}/T_c \quad (5-56)$$

$$C_c = 1.5 (0.475)/2.55$$

$$C_c = 0.28$$

$$C_t = \frac{2}{3} (1.316) \quad \text{Sec. 5.3.7.4.1 (6)}$$

$$C_t = 0.877$$

## B.28 Determine the sloshing wave height

$$d_{max} = 0.50 L C_c I \quad (5-38)$$

$$d_{max} = 0.50 (16.40) (0.28) (1.25)$$

$$d_{max} = 2.87 \text{ ft}$$

The freeboard provided  $d_a = 0.85 \text{ ft} < d_{max}$  since  $d_{max} > d_a$ , convective (sloshing) mass must be considered

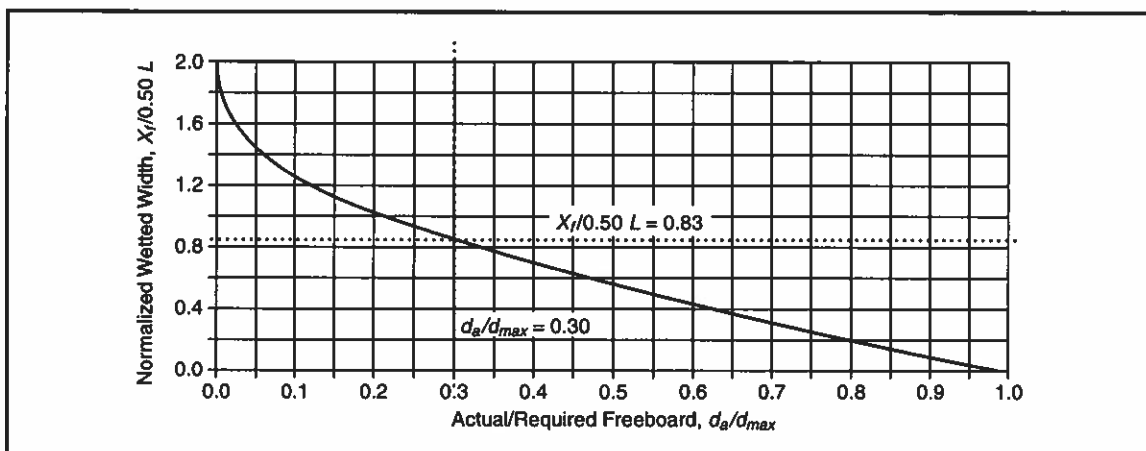


Figure B.8 Curve for obtaining the normalized wetted width,  $X_f/0.50 L$ , for the ratio  $d_a/d_{max}$

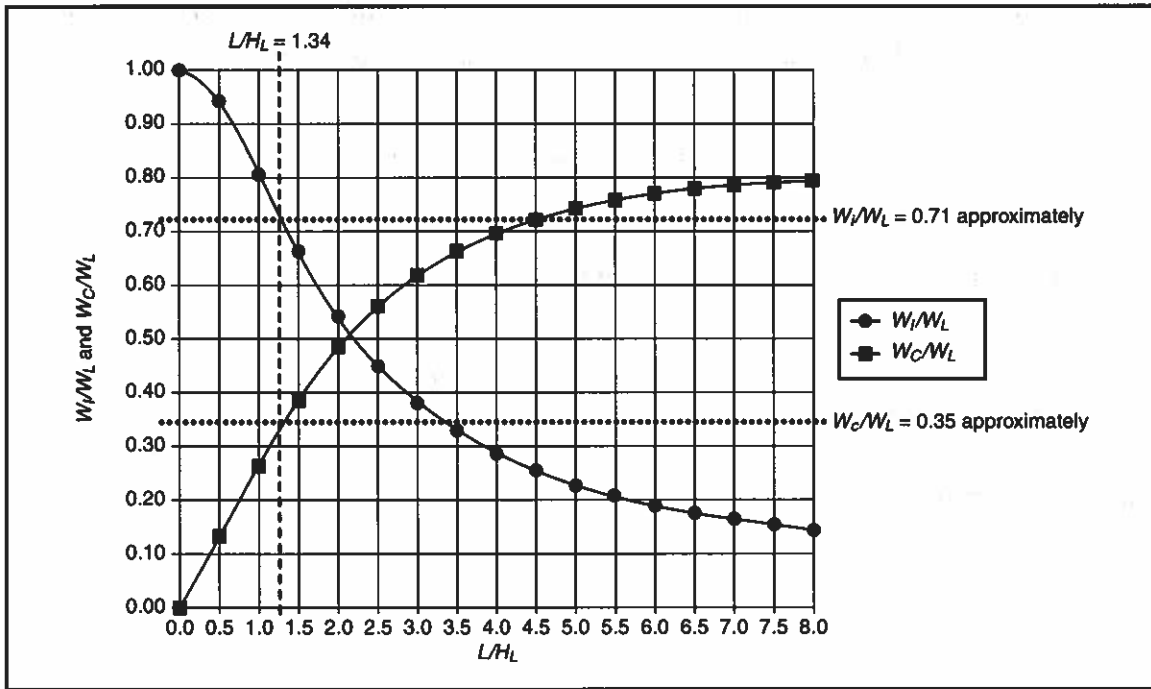


Figure B.9 Curves for obtaining factors  $W_i/W_L$  and  $W_c/W_L$  for the ratio  $L/H_L$

B.29 Convective (sloshing) mass within the portion confined by the roof,  $W_{cm}$

$$W_{cm} = \gamma_w X_f B (d_{max} - d_a) \tag{5-61}$$

$$W_{cm} = (62.43) (6.80) (22.97) (2.87 - 0.85)$$

$$W_{cm} = 19,697.66 \text{ lb}$$

B.30 Determine  $W_i/W_L$  and  $W_c/W_L$  based on the formula

$$W_i/W_L = 0.71 \tag{5-39}$$

$$W_c/W_L = 0.35 \tag{5-40}$$

Determine  $W_i/W_L$  and  $W_c/W_L$  based on Figure B.9; when  $L/H_L$  is 1.34, then

$W_i/W_L$  is approximately 0.71

$W_c/W_L$  is approximately 0.35

B.31 Determine  $W_i$  and  $W_c$

$$W_i = 0.71(288,564.39) + W_{cm} \quad \text{ASCE/SEI 7-05, Section 15.7.6.1.2c}$$

$$W_i = 204,880.72 + 19,697.66$$

$$W_i = 224,578.38 \text{ lb}$$

$$W_c = 0.35(288,564.39)$$

$$W_c = 100,997.54 \text{ lb}$$

- B.32 Determine the weight of roof,  $W_r$ , plus 25 percent of design roof live load and 20 percent of design snow load where the flat snow load exceeds 30 lb/ft<sup>2</sup>

$$W_r = D + 0.25 L_r + 0.20 S$$

$$W_r = 761 \text{ lb} + 0.25 (16 \text{ lb/ft}^2 \times 16.40' \times 22.97')$$

$$W_r = 2,267.83 \text{ lb}$$

- B.33 Determine  $V_{rL}$ , due to self-weight of the roof

$$V_{rL} = C_i I (W_r / R_i) \quad (5-11)$$

$$V_{rL} = (0.30) (1.25) (2,267.83 / 2.0)$$

$$V_{rL} = 425.22 \text{ lb}$$

- B.34 Determine  $V_{wL}$ , due to self-weight of walls

$$V_{wL} = C_i I (\epsilon W_w / R_i) \quad (5-12)$$

$$V_{wL} = (0.30) (1.25) [(0.79) 12,020 / 2.0]$$

$$V_{wL} = 1,780.46 \text{ lb}$$

$$V'_{wL} = C_i I (\epsilon W_w' / R_i) \quad (5-13)$$

$$V'_{wL} = (0.30) (1.25) [(0.79) 3,506.50 / 2.0]$$

$$V'_{wL} = 519.40 \text{ lb}$$

where:

$$\epsilon = [0.0151(L/H_L)^2 - 0.1908(L/H_L) + 1.021] \leq 1.0 \quad (5-47)$$

$$\epsilon = [0.0151(1.34)^2 - 0.1908(1.34) + 1.021] \leq 1.0$$

$$\epsilon = 0.79$$

Due to impulsive action of stored water

$$V_i = C_i I (W_i / R_i) \quad (5-14)$$

$$V_i = (0.30) (1.25) (224,578.38 / 2.0)$$

$$V_i = 42,108.45 \text{ lb}$$

Due to convective action of the stored water

$$V_c = C_c I (W_c / R_c) \quad (5-15)$$

$$V_c = (0.28) (1.25) (100,997.54 / 1.0)$$

$$V_c = 35,349.14 \text{ lb}$$

- B.35 Determine  $V_{fL}$ , due to self-weight of the floor

$$V_{fL} = C_i I (W_f / R_i) \quad (5-16)$$

$$V_{fL} = (0.30) (1.25) (4,616 / 2.0)$$

$$V_{fL} = 865.50 \text{ lb}$$

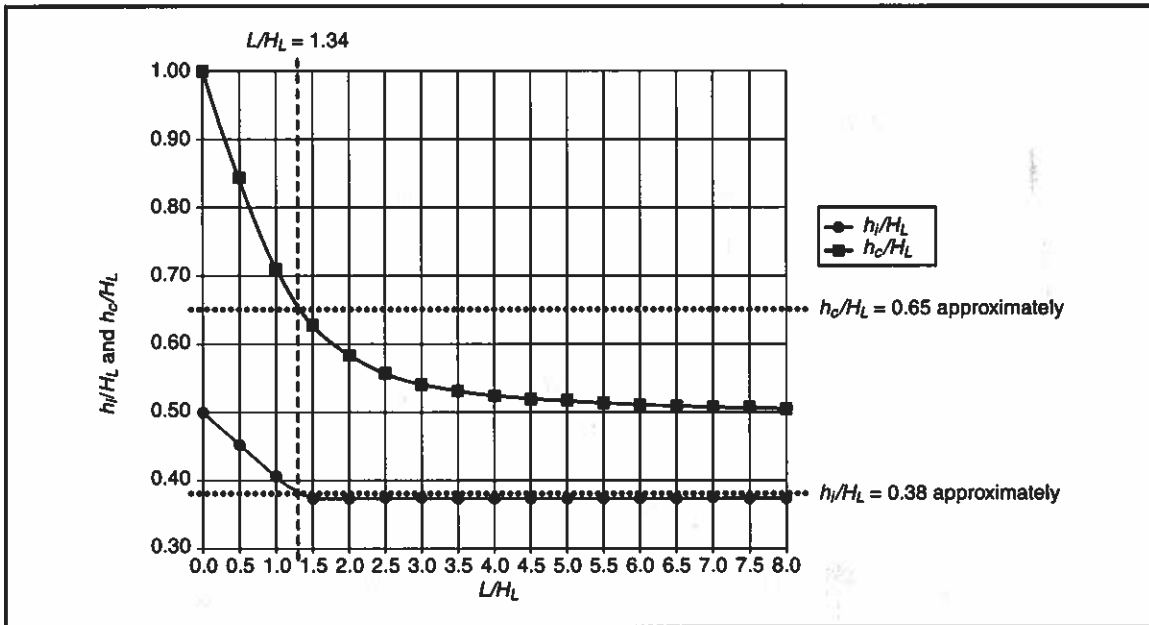


Figure B.10 Curves for obtaining factors  $h_i/H_L$  and  $h_c/H_L$  for the ratio  $L/H_L$

B.36 Determine the total horizontal base shear,  $V$

$$V = [(V_i + V_{wL} + V_{rL} + V_{fL})^2 + V_c^2]^{1/2} \tag{5-17}$$

$$V = [(42,108.45 + 1,780.46 + 425.22 + 865.50)^2 + 35,349.14^2]^{1/2}$$

$$V = 57,365.15 \text{ lb}$$

B.37 Determine  $h_i/H_L$ ,  $h_c/H_L$ ,  $h'_i/H_L$ ,  $h'_c/H_L$  based on the formula

when  $L/H_L > 1.333$ ;  $h_i/H_L = 0.375$  therefore,  $h_i = 4.60 \text{ ft}$  (5-42)

$h_c/H_L = 0.65$  therefore,  $h_c = 7.97 \text{ ft}$  (5-43)

when  $L/H_L > 0.75$ ;  $h'_i/H_L = 0.58$  therefore,  $h'_i = 7.12 \text{ ft}$  (5-45)

$h'_c/H_L = 0.73$  therefore,  $h'_c = 8.96 \text{ ft}$  (5-46)

Determine  $h_i/H_L$ ,  $h_c/H_L$ ,  $h'_i/H_L$ ,  $h'_c/H_L$  based on Figure B.10; when  $L/H_L$  is 1.34, then

$$h_i/H_L = 0.38$$

$$h_c/H_L = 0.65$$

Based on Figure B.11, when  $L/H_L$  is 1.34, then

$$h'_i/H_L = 0.75$$

$$h'_c/H_L = 0.80$$

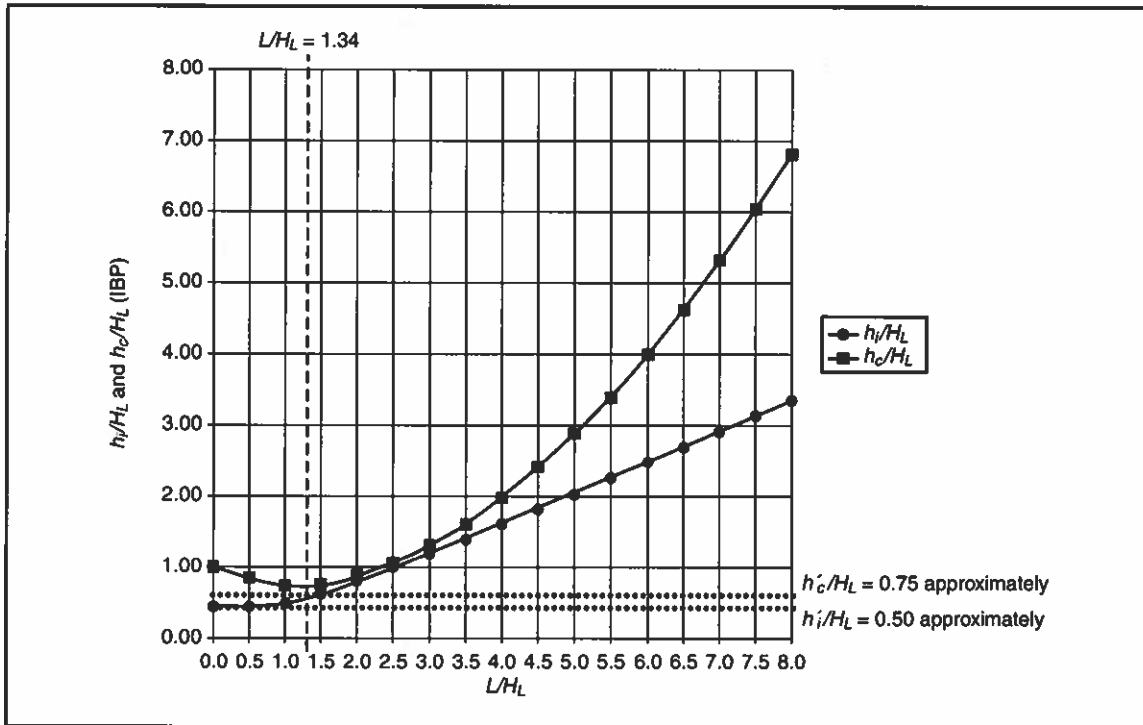


Figure B.11 Curves for obtaining factors  $h_i/H_L$  and  $h_c/H_L$  for the ratio  $L/H_L$

B.38 Determine moment at base,  $M_b$

Bending moment of the entire tank cross section just above the base of the tank wall (EBP) due to the wall inertia force,  $M_w$

$$M_w = V_w L h_w \tag{5-18}$$

$$M_w = (1,780.46) (13.12/2)$$

$$M_w = 11,679.82 \text{ lb-ft}$$

Bending moment of the entire tank cross section just above the base of the tank wall (EBP) due to the roof inertia force,  $M_r$

$$M_r = V_r L h_r \tag{5-19}$$

$$M_r = (425.22) (13.12)$$

$$M_r = 5,578.89 \text{ lb-ft}$$

Bending moment of the entire tank cross section just above the base of the tank wall (EBP) due to the impulsive force,  $M_i$

$$M_i = V_i h_i \tag{5-20}$$

$$M_i = (42,108.45) (4.60)$$

$$M_i = 193,698.87 \text{ lb-ft}$$



Bending moment of the entire tank cross section just above the base of the tank wall (EBP) due to the convective force,  $M_c$

$$M_c = V_c h_c \quad (5-21)$$

$$M_c = (35,349.14) (7.97)$$

$$M_c = 281,732.65 \text{ lb-ft}$$

Bending moment of the entire tank cross section just above the base of the tank wall,  $M_b$

$$M_b = [(M_i + M_w + M_r)^2 + (M_c)^2]^{1/2} \quad (5-22)$$

$$M_b = [(193,698.87 + 11,679.82 + 5,578.89)^2 + (281,732.65)^2]^{1/2}$$

$$M_b = 351,960.77 \text{ lb-ft}$$

### B.39 Determine the overturning moment, $M_o$

Overturning moment at the base of the tank, including the tank bottom and supporting structure (IBP), due to the impulsive force,  $M'_i$

$$M'_i = V_i h'_i \quad (5-23)$$

$$M'_i = (42,108.45) (7.12)$$

$$M'_i = 299,812.16 \text{ lb-ft}$$

Overturning moment at the base of the tank, including the tank bottom and supporting structure (IBP), due to the convective force,  $M'_c$

$$M'_c = V_c h'_c \quad (5-24)$$

$$M'_c = (35,349.14) (8.96)$$

$$M'_c = 316,728.29 \text{ lb-ft}$$

Overturning moment at the base of the tank, including the tank bottom and supporting structure,  $M_o$

$$M_o = [(M'_i + M_w + M_r)^2 + (M'_c)^2]^{1/2} \quad (5-25)$$

$$M_o = [(299,812.16 + 11,679.82 + 5,578.89)^2 + (316,728.29)^2]^{1/2}$$

$$M_o = 448,163.75 \text{ lb-ft}$$

### B.40 Resistance to overturning moment

$$M = L/2 (W_t + W_l) \quad (5-59)$$

$$M = 16.40 / 2 (17,397 + 288,564.39)$$

$$M = 2,508,883.40 \text{ lb-ft}$$

Factor of safety:

$$F.S. = M/M_o$$

$$F.S. = 2,508,883.40 / 448,163.75$$

$$F.S. = 5.60 > 1.50 \text{ o.k.}$$

## B.41 Anchor bolts

12 pcs × 1-in. diameter (ASTM 325)

$$\phi V_r \geq V$$

$$\phi = 0.75$$

$$\phi V_r = 0.75 [p (1)^2 / 4 (12) (48,000)]^3 57,365.15 \text{ lb}$$

$$\phi V_r = 339,292 \text{ lb} > 57,365.15 \text{ lb}$$

Resistance to sliding

Factor of safety:

$$F.S. = V_r / V$$

$$F.S. = (339,292 \text{ lb} / 0.75) / (57,365.15 \text{ lb})$$

$$F.S. = 7.89 > 1.5 \text{ o.k.}$$

## B.42 Hydrodynamic pressure on the floor due to lateral acceleration

$$p_{fL} = 6 [(M'_i - M_i)^2 + (M'_c - M_c)^2]^{1/2} / BL^2 \quad (5-26)$$

$$p_{fL} = 6 [(299,812.16 - 193,698.87)^2 + (316,728.29 - 281,732.65)^2]^{1/2} / (22.97) (16.40)^2$$

$$p_{fL} = 108.52 \text{ lb/ft}^2$$

## B.43 Dynamic vertical forces due to vertical ground motion

a. Roof

$$P_{rv} = C_t I (W_r / R_i) \quad (5-27)$$

$$P_{rv} = (0.877) (1.25) (2,267.83 / 2.0)$$

$$P_{rv} = 1,243.05 \text{ lb}$$

b. Wall

$$P_{wv} = C_t I (\epsilon W_w / R_i) \quad (5-28)$$

$$P_{wv} = (0.877) (1.25) (0.79) (12,020 / 2.0)$$

$$P_{wv} = 5,204.89 \text{ lb}$$

c. Floor

$$P_{fv} = C_t I (W_f / R_i) \quad (5-29)$$

$$P_{fv} = (0.877) (1.25) (4,616 / 2)$$

$$P_{fv} = 2,530.15 \text{ lb}$$

$$\text{Due to vertically accelerated stored water, } p_{fv} = \gamma_w H_L \ddot{u}_v \quad (5-30)$$

$$\text{where } \ddot{u}_v = C_t I / R_i = (0.877) (1.25) / (2.0) = 0.55 \quad (5-31)$$

$$p_{fv} = (62.43) (12.27) (0.55)$$

$$p_{fv} = 421.31 \text{ lb/ft}^2$$

B.44 Total dynamic vertical force on the base, due to vertical acceleration

$$P = P_{rv} + P_{wv} + P_{fv} + p_{fv} BL \quad (5-32)$$

$$P = 1,243.05 + 5,204.89 + 2,530.15 + 421.31 (22.97) (16.40)$$

$$P = 167,688.94 \text{ lb}$$

B.45 Dynamic pressure on wall due to vertical ground motion at  $y = 3.281$  ft

$$p_{vy} = \gamma_w (H_L - y) \ddot{u}_v \quad (5-37)$$

where:  $\ddot{u}_v = C_t I / R_i = (0.877)(1.25) / (2.0) = 0.55 \quad (5-31)$

$$p_{vy} = (62.43) (12.27 - 3.281)(0.55) = 308.65 \text{ lb/ft}^2$$

B.46 Dynamic force on the wall due to horizontal ground motion at the height of  $y = 3.281$  ft

$$V_{iy} = (V_i/2) [4H_L - 6h_i - 6H_L - 12h_i] (y/H_L)/H_L^2 \quad (5-34)$$

$$V_{iy} = (42,108.45/2) [4(12.27 - 6(4.60 - 6(12.27) - 12(4.60)) (3.281/12.27)]/12.27^2$$

$$V_{iy} = 2,315.08 \text{ lb/ft}$$

$$V_{cy} = (V_c/2)[4H_L - 6h_c - 6H_L - 12h_c](y/H_L)/H_L^2 \quad (5-35)$$

$$V_{cy} = (35,349.14/2)[4(12.27 - 6(7.97 - 6(12.27 - 126(7.97)))(3.281/12.27)]/12.27^2$$

$$V_{cy} = 839.18 \text{ lb/ft}$$

$$V_{wy} = V'_w L (H_w - y)/H_w \quad (5-36)$$

$$V_{wy} = 519.40 (13.12 - 3.281)/13.12$$

$$V_{wy} = 389.51 \text{ lb/ft}$$

$$V_y = [(V_{iy} + V_{wy})^2 + V_{cy}^2]^{1/2} \quad (5-33)$$

$$V_y = [(2,315.08 + 389.51)^2 + (839.18)^2]^{1/2}$$

$$V_y = 2,831.79 \text{ lb/ft}$$

Pressure on wall at  $y = 3.281$  ft

$$V_y/L = 2,831.79 / 22.97 = 123.28 \text{ lb/ft}^2$$

B.47 Dynamic vertical force distribution on floor Sec. 3.6.3

$$P_{rv} + P_{fv} + p_{fv} = 1,243.05 + 2,530.15 + 421.31 (22.97) (16.4) = 162,484.05 \text{ lb}$$

$$\text{Dynamic vertical force distribution on floor} = 162,484.05 / (22.97)(16.4)$$

$$= 431.33 \text{ lb/ft}^2$$

B.48 Dynamic vertical force distribution on roof Sec. 5.3.5.4

$$P_{rv} = 1,243.05 \text{ lb}$$

$$\text{Dynamic vertical force distribution on roof} = 1,243.05 / (16.4) (22.97)$$

$$= 3.30 \text{ lb/ft}^2$$

## B.49 Effects of horizontal and vertical acceleration      Sec. 5.3.3.3.4

$$E = 1.0 \times (\text{horizontal acceleration effects}) + 0.3 \times (\text{vertical acceleration effects})$$

$$E = 0.3 \times (\text{horizontal acceleration effects}) + 1.0 \times (\text{vertical acceleration effects})$$

Base shear:

$$E = 1.0 (57,365.15) + 0.3 \times (0) = 57,635.15 \text{ lb}$$

$$E = 0.3 \times (57,365.15) + 1.0 \times (0) = 17,209.55 \text{ lb}$$

Base moment:

$$E = 1.0 (351,960.77) + 0.3 \times (0) = 351,960.77 \text{ lb-ft}$$

$$E = 0.3 \times (351,960.77) + 1.0 \times (0) = 105,588.23 \text{ lb-ft}$$

Overturning moment:

$$E = 1.0 (448,163.75) + 0.3 \times (0) = 448,163.75 \text{ lb-ft}$$

$$E = 0.3 \times (448,163.75) + 1.0 \times (0) = 134,449.12 \text{ lb-ft}$$

Vertical force:

$$E = 1.0 (0) + 0.3 \times (167,688.94) = 50,306.68 \text{ lb}$$

$$E = 0.3 \times (0) + 1.0 \times (167,688.94) = 167,688.94 \text{ lb}$$

Dynamic pressure on floor:

$$E = 1.0 (108.52) + 0.3 \times (431.33) = 237.92 \text{ lb/ft}^2$$

$$E = 0.3 \times (108.52) + 1.0 \times (431.33) = 463.89 \text{ lb/ft}^2$$

Dynamic pressure on wall,  $y = 3.281 \text{ ft}$ :

$$E = 1.0 (108.83) + 0.3 \times (308.65) = 201.42 \text{ lb/ft}^2$$

$$E = 0.3 \times (108.83) + 1.0 \times (308.65) = 341.30 \text{ lb/ft}^2$$

Dynamic pressure on roof (without sloshing):

$$E = 1.0 (0) + 0.3 \times (3.30) = 0.99 \text{ lb/ft}^2$$

$$E = 0.3 \times (0) + 1.0 \times (3.30) = 3.30 \text{ lb/ft}^2$$

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