Global Growth Partners, LLC · Nationwide Service

BOLTED STEEL TANK
OPERATOR'S GUIDE

Design to ANSI/AWWA D103-19 · Operation · What-If Scenarios · Issue Checklists · Maintenance · Annual, Biennial and Five-Year Inspection Programs

Glass-fused-to-steel bolted tank with exterior caged ladder and roof handrail

Prepared by Andrew Feucht, Founder & Principal

Global Growth Partners, LLC · 8258 Gentry St NW, Massillon, OH 44646

(330) 265-1776 · Andy@TanksandCovers.com · TanksandCovers.com

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About This Guide

This Operator's Guide was prepared by TanksandCovers.com — the nationwide single-source supplier of bolted steel tanks, aluminum covers, coatings and process equipment operated by Global Growth Partners, LLC — as a reference for owners and operators of factory-coated bolted steel water storage tanks. It draws on ANSI/AWWA D103-19, the related AWWA standards and manuals, manufacturer practice, and field experience with bolted-tank specification, inspection and failure analysis across municipal water, wastewater and industrial service.

Copyright and standards. ANSI/AWWA D103 and the other standards cited are copyrighted publications of their issuing bodies. This guide paraphrases and summarizes their provisions for operators and does not reproduce them; it is not a substitute for the standards, which should be purchased and consulted directly. Section numbers refer to D103-19 unless stated otherwise.

Reference material. Where this guide reproduces the substance of manufacturer documents — a design-basis sheet, a hydrostatic test procedure, an inspection and maintenance manual, an insulation system — it does so in generic, anonymized form and **for reference only**, to show operators what such documents contain and how to read them. No manufacturer, project, owner or site is identified, and none of those values apply to any tank other than the one they were prepared for.

Limitations. This guide provides general information and is not engineering, legal or regulatory advice for any specific tank or system. Tank-specific requirements are set by the manufacturer's drawings, calculations and operation and maintenance manual, by the contract documents, and by the applicable federal, state and local regulations, all of which govern over this guide. Structural findings and water-quality events should be referred to the tank manufacturer, a licensed engineer experienced in bolted tanks, and the regulator as appropriate. Global Growth Partners, LLC and TanksandCovers.com accept no liability for decisions made on the basis of this document.

Feedback and updates. Corrections, field experiences and suggested additions are welcome at Andy@TanksandCovers.com. This is Revision 1.0, September 2026.

Conventions used in this guide

- **Figures** (numbered in blue) are original diagrams drawn for this guide. **Photos** (orange) are field photographs of bolted tanks under construction and in service. **Details** (green) are manufacturers' standard drawings and submittal sheets, reproduced with all identifying information removed, for reference only. **Tables** carry their own numbering.
- **Section references** such as 'Sec. 13.6.1' refer to ANSI/AWWA D103-19 unless another document is named; 'Chapter' and 'Checklist' references refer to this guide.
- **Severity codes** A / B / C — used in the checklists, scenarios and defect log — mean: A, structural or water-quality, act now; B, will worsen, schedule within the year; C, cosmetic or monitor.
- **Locations** on the tank are given by ring (course) number counted from the bottom, by degrees clockwise from the 0° reference when viewed from above, and by bolt count from the nearest vertical seam.
- **Units** are US customary with metric equivalents where the standard gives them; sheet thickness is given in inches and gauge; pressures in psi or ounces per square inch as on the drawings.
- **'Typical', 'commonly' and 'representative'** signal manufacturer practice rather than a requirement of the standard; the drawings and O&M manual for your tank govern.

Revision	Date	Description
1.0	September 2026	Initial issue.

Contents

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Part I — Understanding Your Bolted Tank

1. Purpose and How to Use This Guide

This guide is written for the people who live with a bolted steel water tank after the contractor leaves: plant and distribution operators, maintenance staff, utility managers, and the consultants and inspectors they hire. It gathers, in one place, the parts of ANSI/AWWA D103 that shape how the tank behaves, the field experience of what goes wrong with bolted tanks and why, and a practical inspection and maintenance program built around three rhythms — the annual audit, the two-year detailed audit, and the five-year comprehensive inspection.

It covers every construction type recognized by the standard: factory-applied thermoset powder (fusion-bonded epoxy) and liquid coatings, glass-fused-to-steel (vitreous enamel), hot-dip galvanized panels, and bolted stainless steel panels. Where the tank types differ — and in the field they differ mostly in how the coating fails and how it is repaired — the guide says so.

How the guide is organized

- **Part I** explains what a bolted tank is, how the joint works, and how each coating system behaves.
- **Part II** is an operator's digest of ANSI/AWWA D103-19 — the design, materials, accessories, coating, foundation, seismic and wind provisions — organized by section so you can find the requirement behind what you see on the tank.
- **Part III** covers operating the tank: commissioning records, level and turnover management, water quality, cold-weather operation, and cathodic protection.
- **Part IV** is a set of what-if scenarios — leaks, overflows, storms, earthquakes, ice, contamination, structural findings — each with symptoms, likely causes, immediate actions, things not to do, and follow-up.
- **Part V** gives component-by-component issue checklists for use in the field.
- **Part VI** is the maintenance program: the ten-year calendar, routine tasks, the annual audit, the biennial audit, the five-year comprehensive inspection, repair procedures, cleaning and disinfection, and record-keeping.
- **Appendices** provide a glossary, a D103 section map with key numbers, referenced standards, log and data-sheet templates, and unit conversions.

Read this first — what this guide is and is not

This guide summarizes and paraphrases AWWA D103-19 for operators. It is **not** the standard, and it is not a substitute for it. Numeric values quoted here are taken from the standard and its predecessors or from common specification practice; some minimums have changed between editions. Always verify a requirement against the edition named in your tank's contract documents and against your manufacturer's drawings and O&M manual, which govern your specific tank.

Nothing in this guide is engineering advice for a specific structure. Structural findings — bulging, sheared bolts, settlement, anchor distress, roof damage — call for the manufacturer or a licensed structural engineer experienced in bolted tanks. Water-quality events call for your regulator's requirements first.

2. What a Bolted Tank Is — and Why It Behaves Differently

A bolted steel tank is a cylinder assembled in the field from factory-coated sheets (panels) that overlap and are bolted together, rather than plates that are field-welded. Every structural joint in the shell, bottom, and (for a bolted steel roof) the roof is a **lap joint**: two coated sheets overlapping with a continuous sealant or gasket between them, clamped by rows of high-strength bolts. This single fact drives almost everything an operator needs to know:

- **The coating is finished before the tank exists.** Sheets are blasted, coated, cured or fired, holiday-tested and inspected in a controlled plant. Field work should never touch the coating other than to repair the small damage that handling and bolting cause. That is why D103 is titled *factory-coated* — the coating is the product, not an afterthought.

- **Watertightness lives in the sealant and the bolt clamp**, not in fusion of metal. The joint is designed to be slightly flexible; it accommodates thermal movement and small foundation movement that would crack a weld. It also means sealant condition, bolt torque and bolt-hole coating integrity are the things that determine whether the tank leaks.
- **Every bolt hole is a coating edge.** Holes are punched or drilled before coating, and the coating wraps the hole edge, but the hole is still the most vulnerable spot on every sheet. Bolts on the wet side are therefore encapsulated or capped, and sealant covers the hole.
- **The tank can be taken apart.** Panels can be replaced, tanks can be raised by adding a course, and a well-kept bolted tank can be relocated. Repairs are local — a sheet, a seam, a bolt row — not a full re-lining campaign.
- **Design is by course.** Sheet thickness, bolt count and bolt spacing change ring by ring as hydrostatic pressure increases toward the bottom. The lowest courses are the thickest, the most heavily bolted, and the ones where a leak matters most.

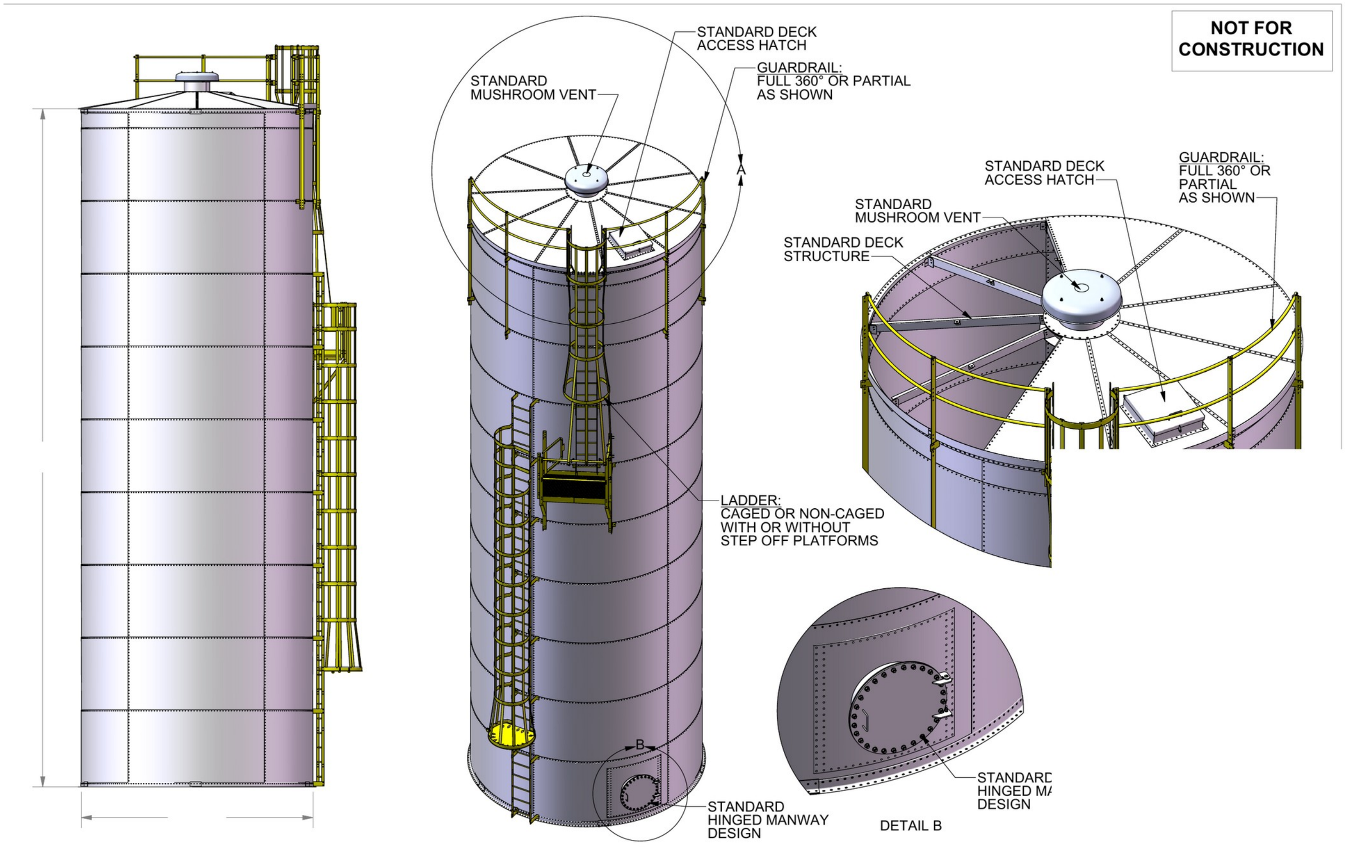
Photo 1 — Factory-coated (FBE) bolted shell during erection, before the roof and appurtenances are set. Note the staggered vertical seams and the temporary door sheet left out at the base for access.

Photo 2 — Glass-fused-to-steel tank being jacked: the completed upper courses are raised and the next course is bolted in beneath them — the reverse of welded-tank erection.

A short history

Bolted steel tanks began in the oilfields of the 1920s and 1930s, where a tank that could be trucked in as flat sheets, bolted together by a small crew in a few days, and taken down and moved when the lease ran dry had obvious advantages over field-welded plate. Those tanks — built to API 12B — were galvanized or field-painted, and their reputation for weeping seams was earned. Two developments in the 1960s and 1970s changed the product: vitreous-enamel (glass-fused-to-steel) coatings fired onto the sheets in the factory, first applied to farm silos and then to liquid tanks, and fusion-bonded epoxy powder coatings that could be applied and cured on both sides of a sheet before it left the plant. With the coating finished before erection and the joint sealed with a synthetic elastomer rather than a fibrous gasket, the bolted tank became a genuine competitor to welded steel and concrete for potable water, and AWWA issued the first edition of D103 in 1980 with the Bolted Tank Manufacturers' Association. Successive editions (1987, 1997, 2009 and 2019) have tightened the design method, added seismic and wind provisions aligned with ASCE 7, and formalized the coating systems and NSF/ANSI 61 requirements described in this guide.

Today bolted tanks are built in diameters from about 10 ft to more than 200 ft and heights past 60 ft, in factory-coated carbon steel and in stainless steel, for potable water, wastewater, fire protection, industrial process liquids and dry bulk. The features that made the oilfield tank practical — flat-pack shipping, erection from the ground with jacks, and joints that can be opened — remain the reasons a utility chooses one, and the maintenance program in Part VI exists because those same joints are its consumable parts.



Detail 1 — Manufacturer's standard general-arrangement sketch of a self-supporting-roof bolted tank: caged exterior ladder with step-off platforms, deck access hatch, mushroom vent, full or partial guardrail, and the hinged shell manway (Details A and B). Standard drawing, for reference only.

Terms you will see on the drawings

Table 1 — Bolted-tank vocabulary used in this guide and on manufacturer drawings.

Term	Meaning	Why it matters to the operator
Course (ring)	One horizontal row of shell sheets. Courses are numbered from the bottom.	Defect logs, bolt-row references and repair scopes are written by course and seam.
Sheet / panel	One factory-coated steel piece. Rolled to the tank radius and typically tapered so vertical seams stagger.	Sheets are the replacement unit; the manufacturer keeps the die/pattern for your tank.
Lap joint	The overlap between adjacent sheets, sealed and bolted. Horizontal laps join courses; vertical laps join sheets in a course.	The only path water can take out of the tank other than a breached sheet.

Term	Meaning	Why it matters to the operator
MWL — maximum water level	The highest normal operating level, set by the overflow. Design hydrostatic loads are computed from MWL.	Running above MWL (overflow blocked, level control failed) loads the top course beyond design and floods the freeboard.
BCL — bottom capacity level	The level of the outlet or the lowest point that can be drained through the piping.	Usable volume = MWL to BCL, not tank height.
Freeboard	Height from MWL to the top of the shell / underside of the roof. Sized for the seismic sloshing wave (Sec. 14.4) and for the overflow.	It is not spare capacity; filling into the freeboard defeats seismic and roof design.
Stiffener / wind girder	Horizontal rings on the shell (interior or exterior) that resist wind buckling and, on open-top tanks, hold the shell round.	Corrosion traps and inspection points; never used as anchor points for rigging unless the manufacturer says so.
Tension ring / top angle	The ring at the top of the shell that carries the roof (or dome) reaction and keeps the shell circular.	Roof-to-shell leaks, galvanic couples (aluminum dome on steel) and fastener corrosion show up here.
Base-setting (starter) ring	For concrete-bottom (Type 6) tanks, the coated ring cast into the floor that the first course bolts to.	It cannot be re-levelled after the pour; floor-to-shell leaks on these tanks are the hardest to fix.
Anchor chair	The gusseted bracket on the shell that transfers anchor-bolt uplift into the shell.	Anchors are only present when wind or seismic overturning requires them — do not assume every tank is anchored.
Ring schedule	The table on the elevation drawing giving, for each course (ring), the sheet thickness and grade and the bolt-row notation (e.g. '1/4 in. Gr 50, 1RV').	The quickest way to know where the thick, heavily bolted courses are and what a replacement sheet must be.
Coverage	Manufacturer's shorthand for the number of sheets per ring and the sheet width (e.g. '15 @ 112' = fifteen 112-in.-wide sheets per course).	Locates a defect: seams are counted from the 0° reference, and the sheet count per ring fixes their spacing.

How a submittal drawing set is organized

Every bolted-tank manufacturer issues its drawings in much the same order, and an operator who knows the order can find any fact about the tank in a minute. A typical approval or record set contains:

- **General-notes sheet (S-00 or similar).** Design notes — site, standard and edition, risk category, wind, seismic values, live/snow load, pressure/vacuum, temperature, specific gravity, corrosion allowance, freeboard, minimum operating level, usable capacity, and the base reactions the foundation designer used. Then materials of construction (sheet and shape grades, bolts, nuts, gaskets, sealant), material sizing (angles, rafters, sheet gauges) and general notes such as the bolt-tightening specification and the bolt pitch. Chapter 7 walks through one.
- **Elevation view (S-01/S-02).** The shell seen from the 0° and 180° sides with the **ring schedule** down one margin — thickness, grade and bolt-row notation for each ring — plus freeboard, roof slope, overall height from top of concrete to top of eave angle, and the note giving the number of sheet spaces from 0° to the first vertical seam.
- **Shell orientation / plan (S-03).** The tank in plan with every shell appurtenance located by degrees clockwise from 0°, with a schedule giving mark, size, description, orientation and elevation above the bottom of the base angle; standard nozzle and manway details with projections and flange ratings.

- **Roof orientation (S-04).** The same for the deck: hillside nozzles, hatches and vents by degrees and plan radius from the tank centerline; deck sheet gauge and nozzle projection.
- **Capacity sketch (S-05).** The definitions of nominal, maximum, design-liquid, minimum-fill and net-working capacity and the heel (Chapter 8).
- **Standard details.** The manufacturer's library sheets — bolting details, base angle, deck structure, manway, hatch, vent, ladder, guardrail, flanges — most of which appear in this guide as Details 4–19.
- **Approval block and revision table.** Who approved what, when. A drawing marked 'preliminary' or 'not for construction' is not the record set; ask for the issued-for-construction or as-built revision.

Keep two copies

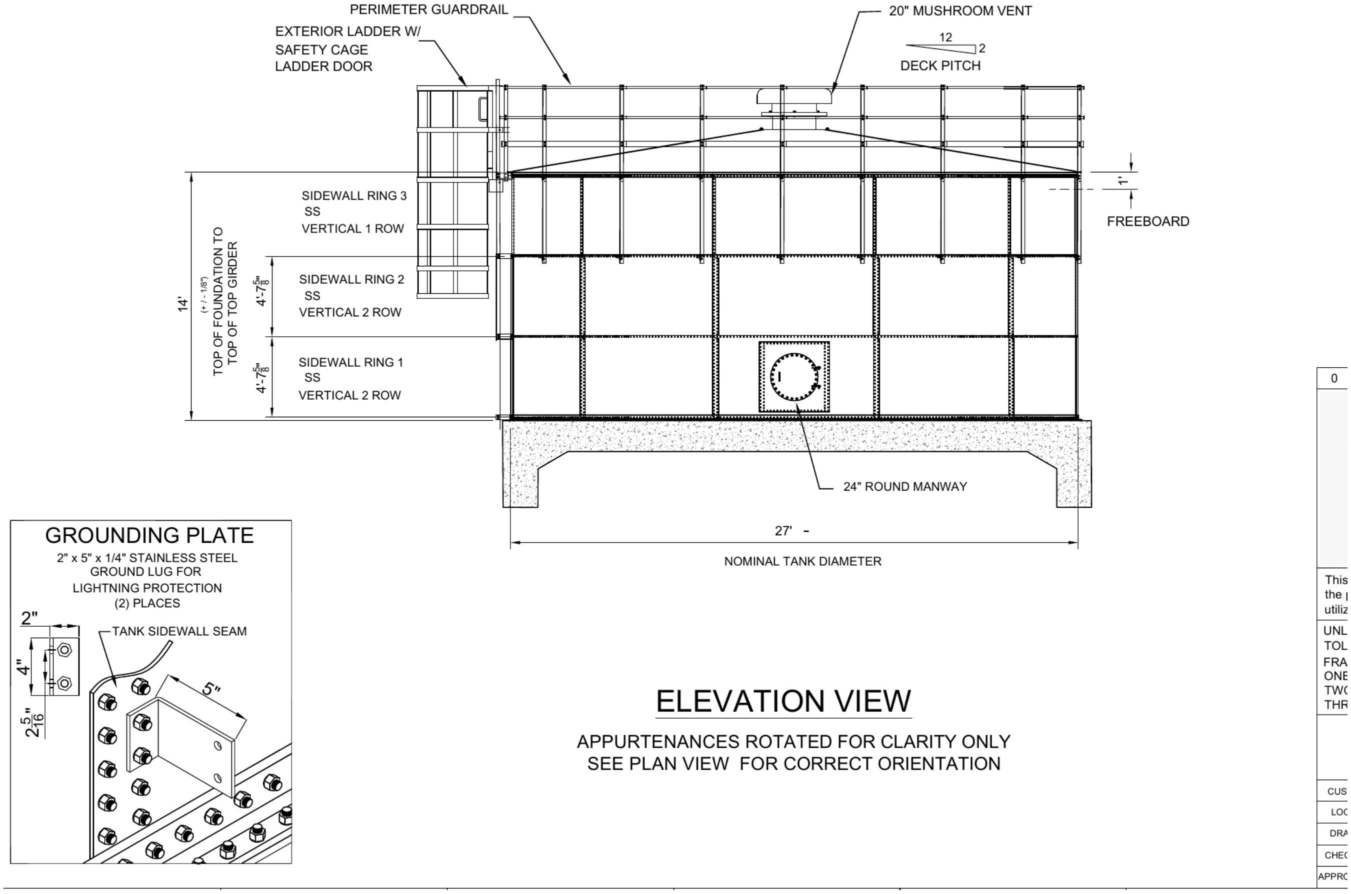
One set lives in the office file; a second, laminated set of the general-notes sheet, the elevation and the two orientation drawings lives in the tank's control building or the operator's truck. Most field questions — where is the 90° nozzle, what gauge is ring 2, is the tank anchored — are answered from those four sheets.

Reviewing a submittal as an owner

Operators are often asked to review a tank submittal alongside the engineer. The engineer checks the structure; the operator is the only reviewer who knows how the tank will actually be run. The items worth an operator's signature are:

- Nozzle sizes, orientations and elevations match the yard piping and the valves that will be bought; the inlet and outlet are far enough apart (or a diffuser is provided) to avoid short-circuiting.
- The overflow discharges where the site can take the water, above a splash pad, with an air gap — and is not aimed at the ladder, the electrical panel or the neighbor.
- The ladder, hatch and platform are on the side of the tank the operator will approach from, with the level indicator readable from the parking area.
- Freeboard, MWL and minimum operating level agree with the SCADA set-points the utility intends to use; the high-level switch sits below the weir and the low-level switch above the outlet.
- The vent capacity covers the largest pump that could ever fill or drain the tank, including fire flow and future pumps.
- The coating, sealant, bolt caps and gaskets are listed with NSF/ANSI 61 certifications by product name.
- The drawing states the tightening specification and shows the ring schedule, sheet count and 0° reference — the three things the defect log will depend on.
- Foundation type, frost depth and anchorage match the geotechnical report and the seismic risk category the utility's emergency plan assumes.

The findings that most often come out of an operator's review are small and expensive to fix later: a manway on the side away from the access road; an overflow that discharges onto the ladder; a level indicator facing the woods; a vent sized for the original well pump and not the booster station that came later; a target board that ices in the prevailing wind; and set-points in the SCADA spreadsheet that do not match the freeboard on the drawing. None of them is a structural matter, all of them are cheaper to change on paper than in steel, and the engineer will rarely catch them without the operator in the room.



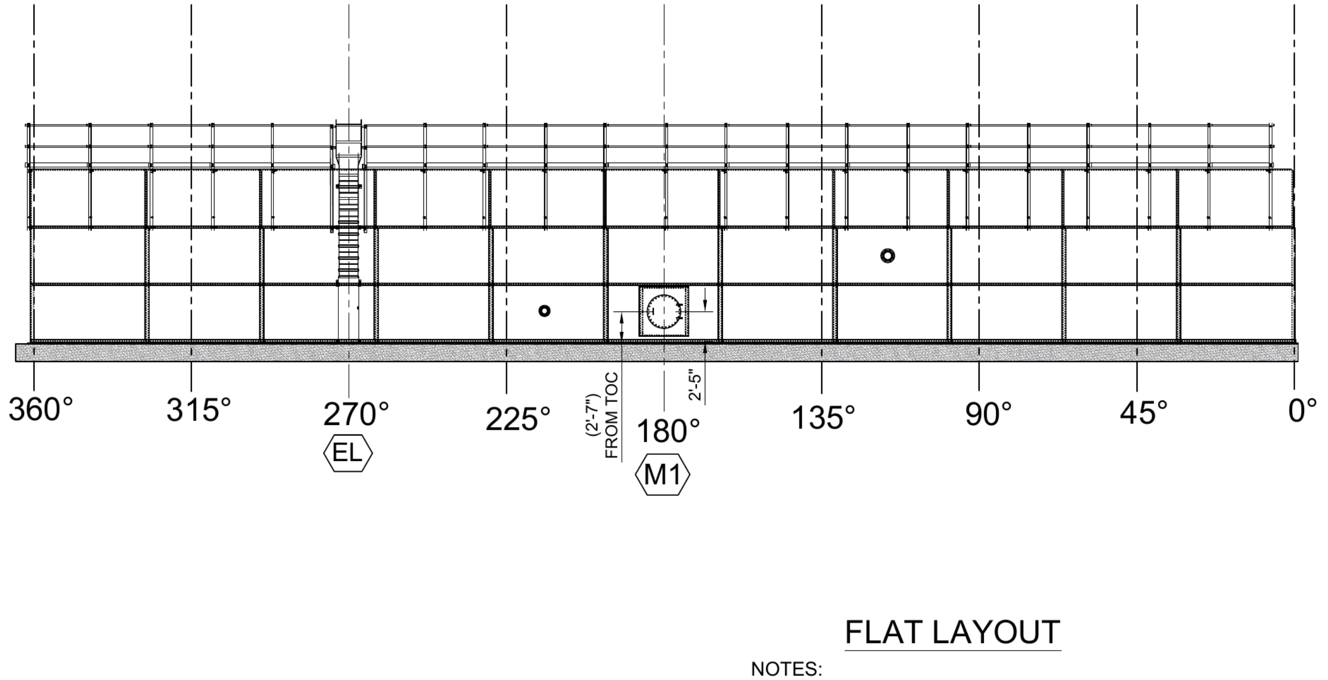
Detail 2 — Submittal elevation view of a small three-ring bolted tank: ring schedule at left (material and bolt rows per ring — 'vertical 2 row' on the lower rings, '1 row' on the top ring), freeboard, deck pitch, appurtenances rotated into view, and the grounding-plate detail at the sidewall seam. Project identifiers removed.

Locating anything on the shell — the 0° convention

Bolted-tank drawings locate every shell item by an angle measured **clockwise from a 0° reference when viewed from above**, and by an elevation measured from the top of the foundation (or the bottom of the base angle — the drawing will say which). The 0° point is usually marked on the shell during erection and is often the location of the exterior ladder or a principal nozzle. The 'flat layout' (Detail 3) unrolls the shell so that the whole circumference can be seen at once, viewed from the outside, with 0° at the right and the angles increasing to the left.

The same convention should be used in the defect log. A finding written as *'weep at ring 2 / ring 3 horizontal lap, 12 bolts clockwise of the vertical seam nearest 135°'* can be found by anyone with the drawings, years later, in the rain. A finding written as *'leak on the north side about halfway up'* cannot. Where the 0° mark has been painted over, re-establish it from a fixed appurtenance on the orientation drawing — the manway or the ladder — and re-mark it.

Because every ring has the same number of sheets (the 'coverage'), the vertical seams fall at a fixed angular pitch — 360° divided by the sheet count, 24° for fifteen sheets, 30° for twelve — and the seams of adjacent rings are offset by a whole number of bolt spaces, so a seam can also be identified by counting from the 0° seam in the ring below.



Detail 3 — The same tank's 'flat layout' — the shell unrolled and viewed from outside, with appurtenances located by degrees from the 0° reference and by elevation from the top of foundation. This is how nozzles, manways and ladders are located on every bolted-tank drawing and how a defect should be logged.

Nominal and actual dimensions

The diameter on a drawing is a **nominal** value — the diameter to the centerline of the shell sheets, or to the inside of the base angle, depending on the manufacturer. Sheet coverage times sheet count gives the circumference: fifteen sheets of 112 in. coverage make a 1,680-in. circumference and a 44.56-ft nominal diameter, which is why bolted-tank diameters are rarely round numbers. Shell height is given from the top of the concrete to the top of the eave angle; usable water depth is from the floor to the overflow, which is less by the freeboard. When a replacement sheet, a mixer bracket or an insulation jacket is ordered, the manufacturer needs the nominal diameter, the ring count and coverage, and the ring schedule — not a tape-measured circumference.

Table 2 — Illustrative relationship between sheet count, coverage, circumference and nominal diameter for a 112-in. sheet system (other manufacturers use other coverages; check the drawings).

Sheet count per ring	Coverage per sheet (in.)	Circumference (ft)	Nominal diameter (ft)	Vertical-seam pitch
9	112	84.0	26.7	40°
11	112	102.7	32.7	32.7°
12	112	112.0	35.7	30°
15	112	140.0	44.6	24°
18	112	168.0	53.5	20°
24	112	224.0	71.3	15°
30	112	280.0	89.1	12°

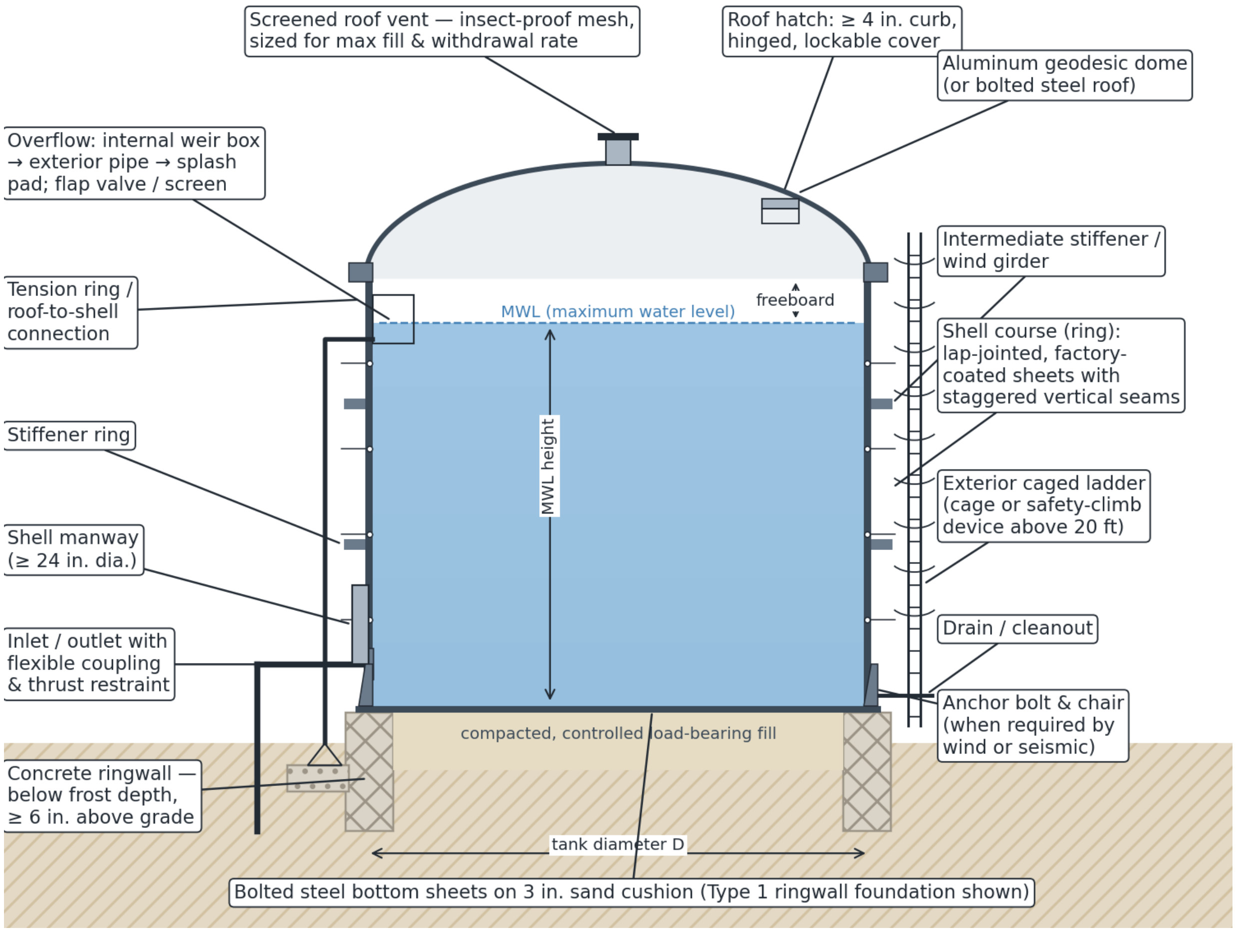


Figure 1 — Anatomy of a ground-supported bolted steel tank in section, with the appurtenances and terms used throughout this guide (Type 1 concrete-ringwall foundation with a bolted steel bottom shown).

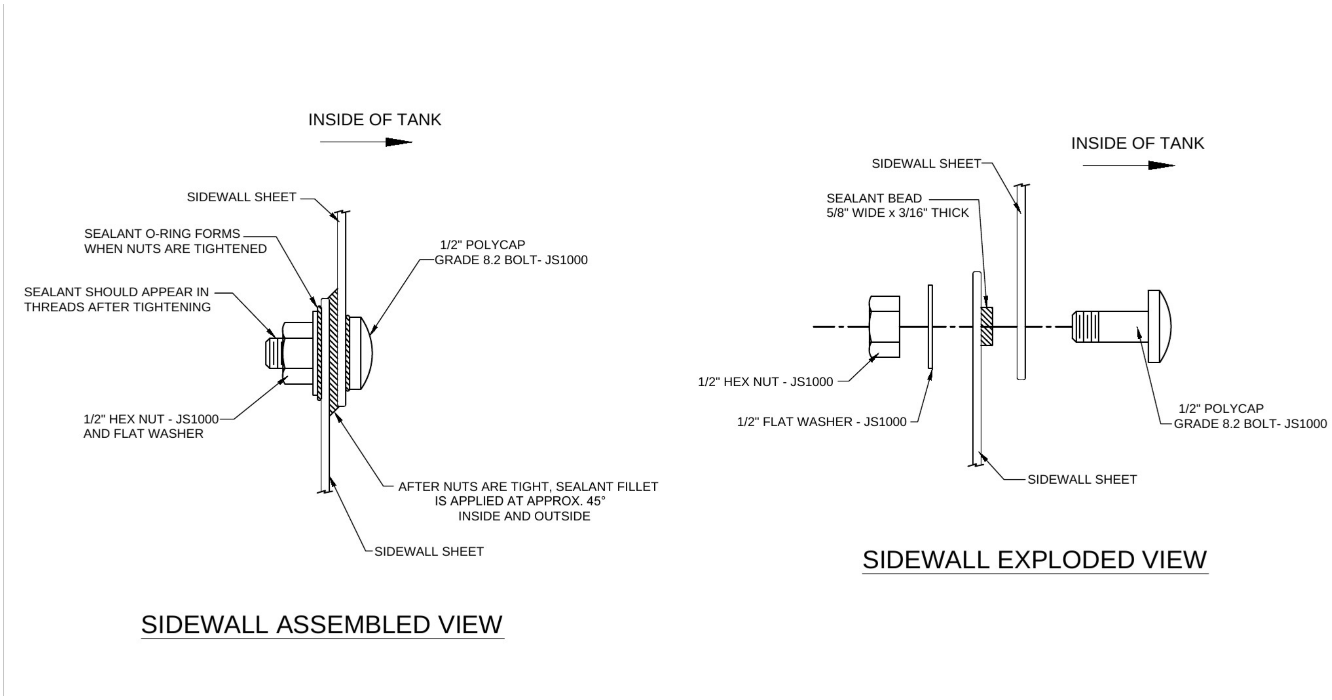
3. The Bolted Joint — What Actually Holds the Water In

Everything about bolted-tank maintenance comes back to the lap joint, so it is worth understanding it in detail. Detail 4 is a manufacturer's standard bolting detail for a sidewall lap; Detail 5 shows the floor and deck versions. Which sheet is inside at a horizontal lap varies between manufacturers — check your drawings before assuming.

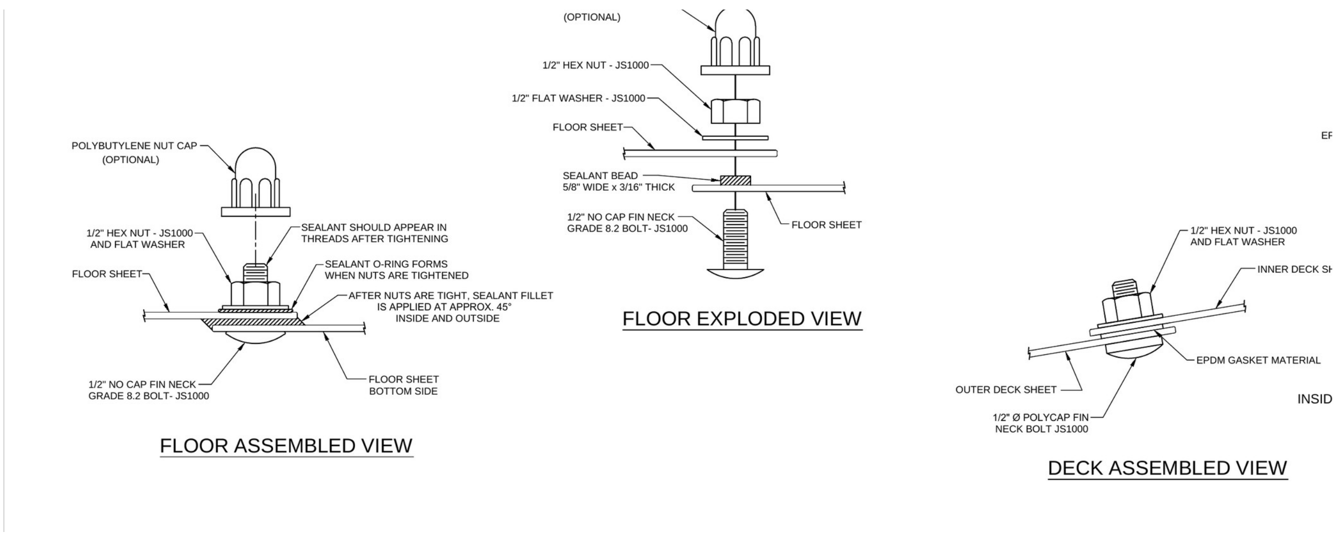
Why a bolted lap joint rather than a weld

A field weld fuses two plates into one; a bolted lap clamps two coated sheets together with a sealant between them. The bolted joint gives up some strength — the holes remove section, and the joint efficiency used in design (Sec. 5) reflects that — in exchange for four things that matter to a water utility: the coating is never damaged by heat, erection needs no welders, no field radiography and no post-weld coating repair, the tank can be erected in weeks by a small crew working at grade with jacks, and the joint can be opened again. The trade-off is that the sealant and the bolt clamp are consumable, inspectable items with a service life, where a sound weld is not. Everything in Parts V and VI about seams, fillets, caps and torque follows from that one trade-off.

Bolted lap joints in factory-coated tanks have been in service in the United States since the 1930s, first in oilfield tanks built to API 12B and, since the 1980s, in water tanks built to D103. The design method is the same one used for bolted steel connections generally — bolt shear, bearing on the sheet, and net-section tension — with allowable stresses and joint efficiencies calibrated by the manufacturers' testing and set out in the standard. A properly bolted and sealed lap, in a sheet of the specified thickness and grade, is not the weak point of a bolted tank; a lap whose sealant has aged or whose bolts have been disturbed is.



Detail 4 — Manufacturer's standard sidewall bolting detail, assembled (left) and exploded (right): ½-in. polymer-capped Grade 8.2 fin-neck bolt with the encapsulated head inside the tank, sealant bead ⅝ in. wide × 3/16 in. thick in the lap, hex nut and flat washer outside; sealant forms an O-ring under the head when the nut is tightened, and a fillet is applied at the sheet edge inside and out. Standard detail, for reference only.



Detail 5 — The matching floor and deck (roof) bolting details. On the floor the polymer-capped bolt head is on the bottom side and an optional polyethylene nut cap covers the threads on the wet side; on the deck an EPDM gasket replaces the sealant between the outer and inner deck sheets.

Photo 3 — Sealant being gunned along a horizontal lap during erection. The continuous bead is laid before the next sheet is set, then tooled into a fillet at the exposed edge.

Photo 4 — Bolted steel floor with every radial and circumferential lap sealed and every bolt capped before the shell is raised; the base angle and hold-down clips are visible at the perimeter.

Bolts

D103 Sec. 4.2 covers bolts, nuts and anchor bolts. The fastener details below are typical of current factory-coated bolted tank designs and are given **for reference only** — the bolt, nut, cap and tightening specification for your tank are on the manufacturer's general-notes sheet and in the erection manual.

- **Bolt type and grade.** Lap-joint bolts are commonly ½-13 UNC **fin-neck bolts to SAE J429 Grade 8 / 8.2** (150 ksi tensile, 120 ksi proof) with at least four splines under the head; ⅝- and ¾-in. bolts appear on larger tanks (some manufacturers use Grade 5 or the ASTM F3125 equivalents). The fins under the head bite into the punched hole so the bolt cannot spin while the nut is run down from the other side — a one-person operation. Plain hex bolts to ASTM A325 / F3125 are used for structural attachments (rafters, angles, platforms) rather than in the sealed laps.
- **Orientation, finish and encapsulation.** In a typical potable-water design the **encapsulated bolt head is inside the tank** and the washer and nut are outside (Detail 4); on the floor the head is on the underside and a polyethylene nut cap covers the threads on the wet side. Bolts carry a mechanically deposited zinc or zinc-flake coating certified to NSF/ANSI 61, and the head is encapsulated up to the splines in a UV-stabilized, black, high-impact polypropylene copolymer that is itself NSF 61 certified. Bolt length is chosen so that 0–4 threads show beyond the nut and no threads sit in the shear plane between sheets thicker than ¼ in. Check your own drawings — some designs reverse the orientation.
- **Nuts.** SAE J995 Grade 5 or 8, with ASTM A563 or A194 nuts as acceptable substitutes; washers as the design calls for.
- **Pattern and pitch.** Bolt rows per seam and the bolt pitch are set course by course by the joint-efficiency design (Sec. 5). A common configuration on a mid-size tank is a **single row at both vertical and horizontal seams — noted '1RV' on the ring schedule — at a uniform pitch of about 2.3 inches in both directions**, with two or three rows added at the lower courses of larger or taller tanks. Vertical seams are offset from the seam in the

course below by a whole number of bolt spaces, never aligned. Detail 2 shows the ring-schedule notation on a real elevation, and Detail 4 the joint itself.

- **Tightening.** Many fin-neck systems specify **AISC 'snug-tight'** (the full effort of a worker with an ordinary spud wrench, or a few impacts of an impact wrench, bringing the plies into firm contact) rather than a measured torque; others give a torque value. Whichever applies is on the general-notes sheet. Over-tightening crushes the sealant, cracks glass coatings and yields the sheet at the hole; under-tightening lets the lap breathe. Never substitute a value from a generic bolt chart.
- **Anchor bolts.** Present only when the wind or seismic check requires them (Sec. 5.9, 15.2, 14.3) or the owner specifies them. Many self-anchored tanks have none — the general-notes sheet will say 'anchor bolts = none'. Where used: ASTM F1554 Grade 36 (A36 acceptable), minimum ¾ in., galvanized.
- A missing or sheared bolt is a structural finding, not a cosmetic one, particularly in the bottom two courses where the pitch and row count were set by the highest hoop load.

Photo 5 — Interior (wet) side: fin-neck bolt heads fully encapsulated in black UV-stabilized polypropylene up to the splines, so no fastener steel touches the water. In the typical potable design (Detail 4) the head is inside the tank.

Photo 6 — Exterior (dry) side: hex nut and flat washer under a snap-on polyethylene cap over the threads. The cap must be present and uncracked on every bolt.

Sealants and gaskets

- D103 Sec. 4.10 and Table 1 set requirements for sealants and gasket materials. In potable service every sealant, gasket and bolt cap that touches the water must be certified to **NSF/ANSI 61** (and NSF/ANSI 372 for lead content) as a product, not merely as a chemistry.
- The lap sealant is a gun-applied elastomer — typically a one-component **polyurethane** construction sealant — laid in a continuous bead inside the lap and at every bolt hole before the sheets are bolted, then finished as a fillet along the exposed sheet edge on the wet side and usually on the exterior too. Flanged connections, manway covers and blind flanges use **EPDM gaskets**. Some glass-fused systems use a pre-formed gasket strip in the laps, others a bead — the erection manual says which.

- Polyurethane lap sealants are one-component, moisture-cured products certified to NSF/ANSI 61; typical data sheets give a tack-free time of 6–8 hours and a minimum cure of 24 hours at 73 °F / 50 % RH, while manufacturers' hydrotest procedures commonly wait **seven days** before filling so that the whole tank's sealant — including the last, coldest, thickest beads — has cured. Disinfection follows the same rule (Chapter 9).
- Sealant is the wear item of a bolted tank. It ages by UV, ozone, disinfectant, and mechanical working of the lap. Expect a service life measured in decades in the lap itself but considerably less for the exposed fillet, which is why the fillet is the first thing an inspection looks at.
- Disinfection should not begin until the sealant has cured for the period the manufacturer specifies; chlorinating uncured sealant is a classic cause of early seam weeping.

Field rule of thumb

A bolted tank that weeps at a seam in its first year almost always has a bolting or sealant workmanship cause (uneven torque, gaps in the bead, cold application). A tank that starts weeping after fifteen dry years almost always has a sealant-aging or coating-undercutting cause. The response differs: the first is a warranty conversation, the second is a maintenance program.

4. Coating Systems Recognized by D103

Section 12 of D103-19 defines the factory coating systems permitted: galvanized coatings (Sec. 12.3), glass coatings (Sec. 12.4), thermoset liquid suspension coatings (Sec. 12.5) and thermoset powder coatings (Sec. 12.6), plus common provisions on marking (12.7), protection during shipping and erection (12.8) and holiday testing (12.9). Stainless steel bolted tanks have no applied coating; they rely on the alloy's passive film and are covered by the materials provisions.

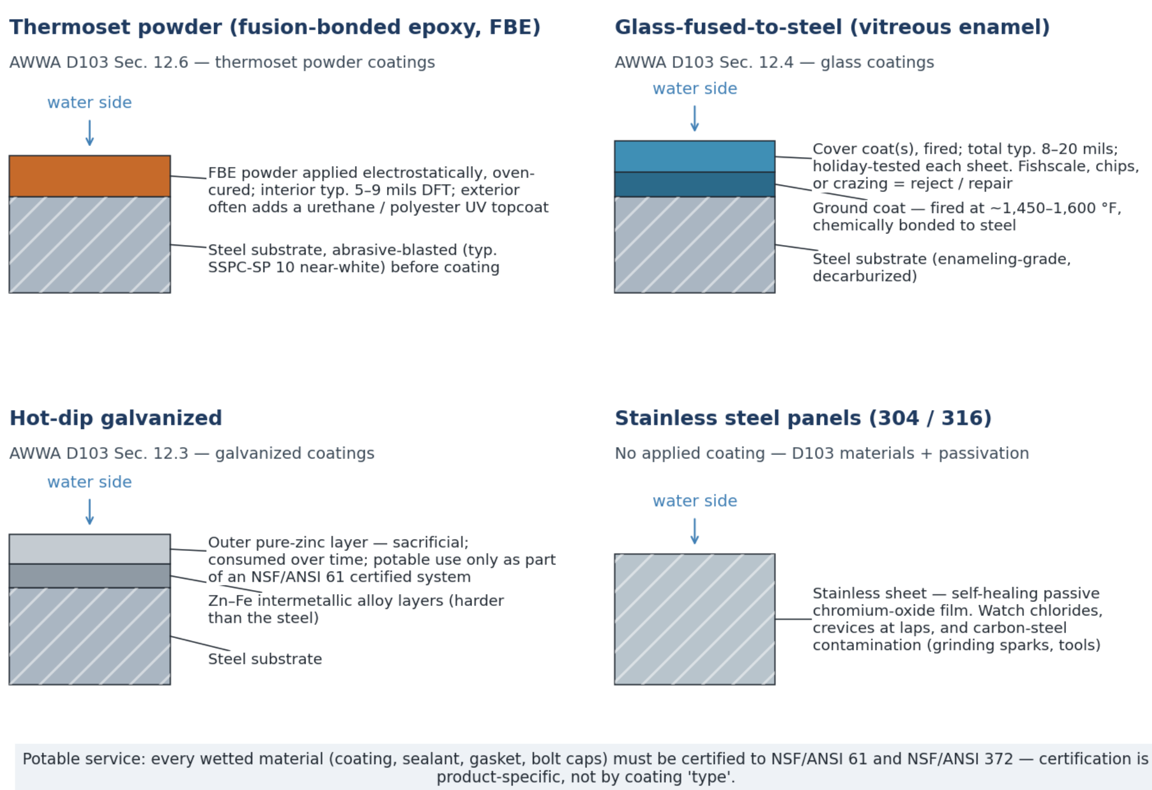


Figure 2 — Schematic cross-sections of the coating systems recognized by D103 (not to scale). The steel is the same; what differs is how the barrier is made, how it fails, and how it is repaired.

Table 3 — Coating systems compared from the operator's point of view.

System	How it is made	Strengths	Weak points / failure modes	Field repair
Thermoset powder (fusion-bonded epoxy, FBE)	Sheet blasted both sides to near-white (SSPC-SP 10, ≥ 1.0 mil profile), washed, RO-rinsed and given a zirconium conversion pretreatment, then electrostatically powder-coated and oven-cured. A representative potable system: interior thermoset epoxy 8 mils nominal (8–10); exterior epoxy primer 5 mils plus a super-durable polyester topcoat 3 mils (3–5) for UV. Each sheet is checked for cure (MEK rub), adhesion (ASTM D3359), DFT (SSPC-PA 2) and holidays (low-voltage wet sponge, ASTM D5162).	Tough, flexible, tolerant of torque and handling; readily patched; wide manufacturer base; economical.	Chalking and fading of exterior topcoat; undercutting from holidays and bolt-hole edges; chemical attack by high-strength disinfectant; softening at high temperature.	Sand, feather, solvent-wipe and apply the manufacturer's NSF 61 two-part epoxy patch; holiday-test the patch.
Thermoset liquid suspension	Similar substrate preparation; liquid epoxy applied in the plant and oven-cured.	As for powder; good edge coverage.	As for powder.	As for powder.
Glass-fused-to-steel (vitreous enamel)	Enameling-grade steel, ground coat and cover coat(s) sprayed and fired at roughly 1,450–1,600 °F so the glass bonds chemically to the steel. Total typically 8–20 mils; every sheet holiday-tested.	Hardest, most chemically inert barrier; no UV degradation; no chalking; exceptional life in aggressive (wastewater, high-chlorine, brine) service.	Brittle: chips at impact points and at bolt holes; hydrogen 'fishscale' and crazing are manufacturing defects that appear later; cannot be re-fired in the field; edge chips are the classic origin of bolt-hole corrosion.	Clean, degrease and patch with the manufacturer's NSF 61 epoxy or urethane repair compound; larger damage means a replacement sheet.
Hot-dip galvanized	Sheet dipped in molten zinc after fabrication; zinc-iron alloy layers plus an outer pure-zinc layer.	Sacrificial protection of small bare spots; low cost; robust exterior in rural / non-coastal atmospheres.	Zinc is consumed — life depends on water chemistry (soft, low-alkalinity water is aggressive); white rust; not suitable for most potable interiors unless part of an NSF 61 certified duplex system.	Zinc-rich primer or cold-galvanizing compound on the exterior; interior repair usually means a liquid epoxy system and a decision about the whole surface.
Stainless steel (304 / 316)	No coating; sheets and bolts of the same alloy family, passivated after fabrication.	No coating to fail; no disinfectant sensitivity; long life in most municipal waters.	Chloride pitting and crevice corrosion in the laps and under gaskets (316 far better than 304); carbon-steel contamination (tools, grinding sparks) rusts on the surface; galvanic attack of any carbon-steel fitting bolted to it.	Remove contamination, re-passivate; replace pitted sheets. No 'patch' exists for pitting.

Photo 7 — Glass-fused-to-steel tank with exterior caged ladder, roof handrail and shell manway. The high-gloss cobalt finish is the fired glass itself; note the sealant fillets visible at every lap.

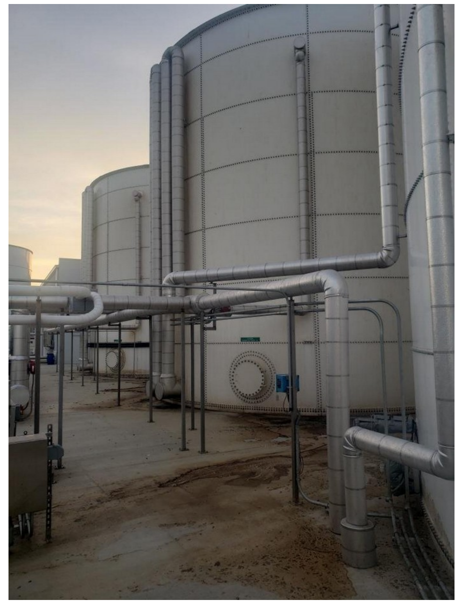


Photo 8 — FBE-coated bolted tanks in process service with insulated stainless piping; the shell manway and nozzle reinforcing pads are visible in the first course.

Whatever the system, the potable-water requirement is the same: **every material in contact with the water must be certified to NSF/ANSI 61**, and the certification must be for the product actually used — the specific coating, the specific sealant, the specific bolt cap — not for a generic type. Ask for the certification listings at commissioning and keep them in the tank file; a coating repair with an uncertified product is a compliance problem regardless of how well it sticks.

Part II — ANSI/AWWA D103-19: The Design Provisions, Section by Section

5. About the Standard

ANSI/AWWA D103, *Factory-Coated Bolted Carbon Steel Tanks for Water Storage*, provides the minimum requirements for the design, construction, inspection and testing of new, cylindrical, factory-coated bolted carbon steel tanks for water storage that stand at or near grade. It was first issued in 1980 in cooperation with the Bolted Tank Manufacturers' Association, revised in 1987, 1997 and 2009, and the current fifth edition, D103-19, was approved in June 2019 with an effective date of January 1, 2020. Corrugated tanks and tanks built of stacked or laminated sheets are outside its scope; welded tanks are covered by AWWA D100 and aluminum dome roofs by AWWA D108.

Two points about the standard's philosophy matter for operators. First, D103 is a **purchaser's standard**: it presumes the purchaser (the owner or its engineer) will specify the things the standard leaves open — capacity, geometry, site loads, coating system, foundation type, accessories, NSF 61 compliance, and any state requirements — and it lists those items in its foreword. If your contract documents did not specify something, the manufacturer's standard practice applied. Second, the standard divides responsibility: the purchaser is responsible for the foundation design and for the geotechnical investigation, the manufacturer for the tank design, materials, shop fabrication and coating, and the constructor (often the manufacturer's own crew) for erection, testing and coating repair. Knowing who owned what is the first step in any warranty or failure conversation.

Table 4 — Section map of ANSI/AWWA D103-19 with the provisions most relevant to operations.

Section	Title (D103-19)	What it governs — operator relevance
1	General	Scope, purpose, items not described, permits and regulations; purchaser responsibilities.
2	References	The ASTM, ASCE, ACI, AWWA, NSF and SAE documents the standard relies on.
3	Definitions	Terms — including MWL, BCL, purchaser, manufacturer, constructor.
4	Materials	Steel sheets and plates, bolts and anchor bolts (4.2), gaskets and sealants (4.10, Table 1), roof materials.
5	General Design	Loads, risk category (5.2.1), design criteria and allowable stresses (5.3), sheet thickness limits, roof supports (5.7), foundation anchor bolts (5.9).
6	Sizing of Tanks	Capacity and standard dimensions; how MWL and BCL define usable volume.
7	Accessories for Tanks	Shell manholes (7.1), pipe connections (7.2), overflow (7.3), ladders (7.4), safety devices (7.5), roof openings (7.6), vent (7.7), galvanic corrosion (7.8).
8–10	Welding; Shop Fabrication; Erection	Where welding is permitted (shop only, before coating, except by prior agreement), sheet edge preparation, tolerances, field bolting, gasketing and sealants, field coating repair, cleanup.
11	Inspection and Testing	Shop inspection, the hydrostatic test, disposal of test water, disinfection (AWWA C652).
12	Coatings	12.3 galvanized, 12.4 glass, 12.5 thermoset liquid, 12.6 thermoset powder, 12.7 marking, 12.8 protection, 12.9 holiday testing.
13	Foundation Design and Construction	13.2 geotechnical, 13.3 safety factors, 13.4 foundation types (1–6), 13.5 design details (height above grade, frost depth, top projection, deep foundations), 13.6 concrete and tolerances, 13.7 backfill and pipe cover.
14	Seismic Design	Ground motion (14.2), seismic loads (14.3), freeboard (14.4), piping connections (14.5), foundation considerations (14.6), tensile straps (14.7).
15	Wind Design of Flat-Bottom Tanks	Wind pressure (15.1), anchor check (15.2), sliding check (15.3), top and intermediate girders (15.4), tensile straps (15.5).
App. A	Commentary	Explanatory material keyed to each section — not mandatory, but the best plain-language explanation of intent.

What the purchaser was supposed to specify

The foreword to D103-19 lists the information the purchaser should provide. Reading this list against your original contract documents tells you what design basis your tank actually has — and what is simply 'manufacturer's standard'. The principal items are:

- The standard and edition, and whether **NSF/ANSI 61** compliance is required.

- Federal, state and local requirements (Sec. 1.1.3) — for most utilities the state sanitary code and the Ten States Standards or their equivalent.
- Tank geometry: diameter, capacity, **MWL above top of foundation**, BCL if different from the outlet level, type of roof (bolted steel or aluminum dome), and type of bottom (steel bottom or concrete bottom with embedded base-setting ring).
- Site data: risk category, basic wind speed and exposure, ground snow load, seismic parameters (S_S, S_1, site class) or the geotechnical report that lets the manufacturer derive them, frost depth, and allowable soil bearing.
- The coating system (which of Sec. 12.3–12.6) for interior and exterior, colors, and any additional exterior topcoat.
- Foundation type (Sec. 13.4) and who designs it; whether anchors are required by the owner regardless of calculation.
- Accessories: manhole size and number, pipe connection sizes and orientations, overflow type and discharge, vent, ladder and fall protection, roof hatch, level indicator, cathodic protection provisions, mixing, sampling taps, lightning protection, and any insulation or heating.
- Testing and disinfection requirements, test-water disposal, and the drawings, calculations and records to be delivered.

Where to find your tank's design basis

The manufacturer's approved erection drawings and design calculations (sealed by an engineer registered in the state, when the contract required it) are the authoritative record of the design loads, sheet thicknesses by course, bolt schedule, foundation loads, anchorage, freeboard and the seismic overturning ratio J. If the utility does not have them, request them from the manufacturer now — before there is a problem — and file them with the O&M manual, coating certifications and hydrostatic test record. Appendix G provides a tank data-sheet template to capture the key values in one page.

6. Materials (D103 Section 4)

Steel sheets and plates

Shell, bottom and roof sheets are carbon steel to ASTM specifications named in the standard — typically ASTM A1011 (hot-rolled sheet, grades 36 to 60 and higher), A36, A572 (grades 50 and 60) and A656 for higher-strength sheets, with plates to the same families for thicker courses and reinforcing pads. Glass-fused tanks use enameling-grade steels selected for firing. Allowable stresses depend on the specified minimum yield strength, so **a higher-strength sheet is thinner for the same course** — a point to remember when comparing an old tank with a new one or evaluating a replacement sheet.

The standard sets both minimum and maximum sheet thicknesses. Historically the minimum thickness of shell, bottom and low-slope roof sheets has been **0.094 in. (about 2.4 mm)**, and early editions capped the maximum shell thickness at ⅜ in. because thicker material could not then be reliably rolled, punched and factory-coated. That limit no longer reflects practice: with plate-rolling, CNC punching or drilling of plate, and coating lines built for it, **½-in. plate is now standard in bolted-tank design for the lowest rings of tall and large-diameter tanks**, with 7/16-in. and ⅜-in. plate on the rings above. Where a design needs more than ½ in. at the bottom ring, manufacturers normally move to a higher-strength grade (A572 Gr 60–65, A1011 Gr 70–80) or add a bolt row rather than go thicker, because bolt shear and bearing — not sheet tension — start to govern the lap joint. The design thickness for each course is set by hydrostatic hoop tension, wind and seismic loads, and the efficiency of the bolted joint. Sheets carry no corrosion allowance in the usual sense — the coating is the corrosion protection — which is why coating condition, not wall thickness, is the primary measure of remaining life in a bolted tank.

Bolts, nuts and anchor bolts (Sec. 4.2)

- Lap-joint bolts and nuts: high-strength grades as described in Chapter 3, with a specified corrosion-resistant finish and encapsulation on the wet side. Bolt material, finish and cap material should be listed in the submittals.
- Anchor bolts (Sec. 5.9 for design): historically a **minimum ¾-in. diameter, galvanized**, upset or plain, designed for the maximum net uplift and installed to the tolerances in Sec. 13.6.3 (±¼ in. location, projection and embedment; ±3° plumb).
- Stainless bolts in carbon-steel tanks and carbon-steel bolts in stainless tanks are galvanic couples; the standard's galvanic-corrosion provision (Sec. 7.8) requires dissimilar metals to be isolated.

Gaskets and sealants (Sec. 4.10, Table 1)

Table 1 of the standard lists acceptable gasket and sealant material properties. For the operator the essentials are: the product used must be the one in the submittals; it must be NSF/ANSI 61 certified for potable service; it must be applied within its temperature window; and it must be allowed to cure before the tank is filled and disinfected. Keep a tube of the manufacturer's sealant in date in the shop — a seam repair with a hardware-store product voids more than the warranty.

Roof materials

Bolted steel roofs use the same sheet and coating provisions as the shell. Aluminum geodesic domes are designed and furnished under **AWWA D108**, with the shell-to-dome interface (tension ring, isolation from the steel, and the roof reaction) coordinated under D103 Sec. 5.7. The aluminum alloys, isolation gaskets and stainless fasteners of the dome have their own maintenance needs, addressed in Part V and Chapter 17.

Sheet thickness: gauges, decimals and weights

Ring schedules mix gauge numbers and fractions — '10 ga', '3/16 in.', '¼ in.' — because sheet below about 3/16 in. is bought by gauge and plate above it by fraction. The table converts the values that appear on bolted-tank drawings and gives the steel weight, which is what the foundation and the jacks are carrying.

Table 5 — Sheet and plate designations used on bolted-tank ring schedules (Manufacturers' Standard Gauge for sheet; weights at 40.8 lb/ft² per inch).

Designation	Thickness (in.)	Thickness (mm)	Weight (lb/ft²)	Where it typically appears
12 gauge	0.1046	2.66	4.27	Floor and roof (deck) sheets; upper rings of small tanks
10 gauge	0.1345	3.42	5.49	Upper shell rings
8 gauge	0.1644	4.18	6.71	Mid-height rings
3/16 in.	0.1875	4.76	7.65	Middle and lower rings
¼ in.	0.2500	6.35	10.20	Bottom ring of mid-size tanks
5/16 in.	0.3125	7.94	12.75	Bottom rings of tall or large tanks

Designation	Thickness (in.)	Thickness (mm)	Weight (lb/ft²)	Where it typically appears
3/8 in.	0.3750	9.53	15.30	Bottom rings of large tanks; the maximum shell thickness in early editions of D103
7/16 in.	0.4375	11.11	17.85	Bottom rings of tall, large-diameter tanks
½ in.	0.5000	12.70	20.40	Standard in current bolted-tank design for the bottom rings of tall or large-diameter tanks (typically 100 ft diameter and above, or 40 ft and taller); rolled, punched and coated as plate

D103's historic minimum of 0.094 in. corresponds to about 13 gauge, and the standard limits how thin a roof sheet may be on low-slope roofs because a walking inspector, not the water, governs. At the other end, a ½-in. bottom ring on a large tank behaves as plate, not sheet: it is rolled to radius in a plate roll, its holes are drilled or punched with heavy tooling, its edges are machined rather than sheared, and its laps carry two or three bolt rows. For the operator the practical differences are weight — a ½-in. sheet of 112-in. coverage and 57-in. height weighs close to 900 lb, so replacement is a crane and manufacturer-crew job — and stiffness, which makes a bulge or flat spot in a ½-in. ring a far more serious finding than the same shape in a 10-gauge ring. High-strength grades (A572 Gr 50 and above, A1011 Gr 50–80) allow thinner rings for the same hoop load, which is why two tanks of the same size and age can have different ring schedules.

Photo 9 — Bolted steel roof on a completed FBE tank (rear) with the bolted floor of a second tank laid out on its foundation pad (front). Both roof and floor are assembled from sealed, bolted lap joints exactly like the shell.

7. General Design (D103 Section 5)

Section 5 is the heart of the standard: it tells the manufacturer how to size every part of the tank. The operator does not need the equations, but does need to know what loads the tank was designed for, because operating outside them — overfilling, storing a heavier liquid, adding roof equipment, or losing foundation support — is how well-built tanks get into trouble.

Loads and load combinations

- **Dead load** — the weight of the tank, roof, insulation and all attached equipment.
- **Hydrostatic load** — water at 62.4 lb/ft^3 to the MWL (0.433 psi per foot of depth). Hoop tension in each course is proportional to depth times diameter, so the bottom course of a tall, large tank sees by far the greatest demand. If a tank stores anything other than clean water (sludge, brine, process liquid) the specific gravity must have been specified.
- **Roof live / snow load** — the standard requires a minimum roof live load, historically **15 psf**, or the snow load derived from the site's ground snow load per ASCE 7 where that governs. Drifting against a taller adjacent structure, ice build-up on a dome, and equipment added later all eat into this margin.
- **Wind** — velocity pressure from the basic wind speed and exposure in ASCE 7, applied to the shell and roof (Sec. 15). Wind governs the number and size of intermediate stiffeners on tall or open-top tanks, and the anchor and sliding checks when the tank is empty.
- **Seismic** — impulsive and convective (sloshing) forces per Sec. 14, governing anchorage, freeboard, and the flexibility required of piping connections.
- Load combinations pair the water at MWL with wind or seismic at reduced factors, and check the **empty tank** separately — an empty bolted tank in a windstorm is the governing case for uplift and sliding on many sites.

Table 6 — Design load cases and their operational meaning.

Load case	What it governs on the tank	What it means for operation
Water at MWL (hydrostatic)	Shell thickness and bolt rows by ring; base angle; floor-to-shell joint.	Never exceed MWL; a heavier liquid than the design specific gravity overloads every ring.
Dead load + roof live / snow	Rafters, deck sheets, tension ring, shell top; foundation bearing with the tank full.	Snow beyond the design value and any equipment added to the roof reduce the margin.
Empty tank + wind	Overturning and sliding of the empty shell; anchorage decision; stiffener spacing.	A drained tank in a windstorm is a design case — check with the manufacturer before leaving a tank empty in storm season.
Full tank + wind	Shell buckling between stiffeners; roof uplift.	Loose stiffener or roof fasteners reduce capacity.
Full tank + seismic	Base shear and overturning (impulsive), sloshing wave and freeboard (convective), piping flexibility, anchorage.	Keep the freeboard; keep flexible couplings free; anchor bolts, where fitted, must be sound.
Internal pressure / vacuum	Roof-to-shell joint and deck sheets (small design values, typically an ounce or two per square inch).	A blocked vent or a plugged overflow exceeds these within minutes of a fast fill or draw.

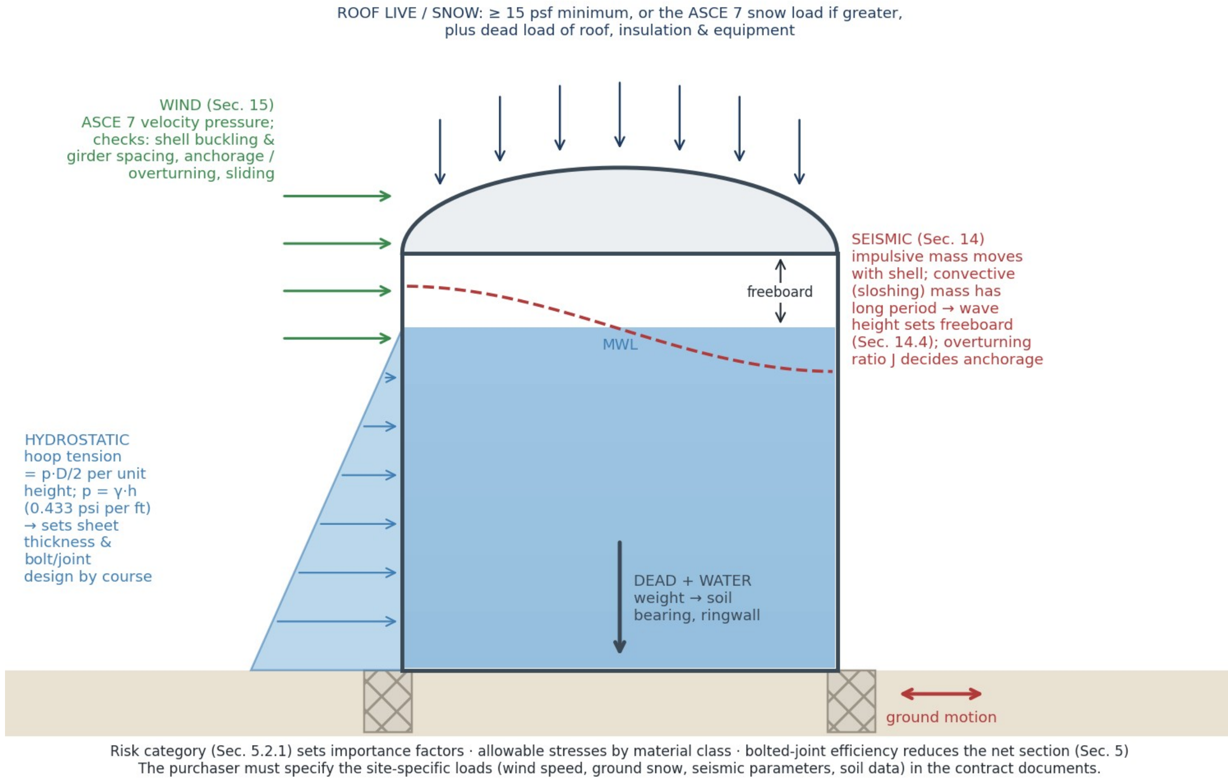


Figure 3 — The loads D103 designs for. Hydrostatic pressure sets the shell by course; roof live/snow, wind and seismic loads set the roof, stiffeners, anchorage and freeboard; the whole assembly must be carried by the foundation.

Risk category and importance factors (Sec. 5.2.1)

The tank is assigned a risk category (II, III or IV in the ASCE 7 sense) reflecting the consequences of failure. Category IV — tanks that serve fire suppression or facilities essential after an earthquake — carries a seismic importance factor of 1.50 versus 1.00 for an ordinary tank (Table 2 of the standard) and higher wind importance. If your utility's emergency plan depends on a tank, its design should reflect that; if the plan changed after the tank was built, the design basis may now be wrong.

Allowable stresses and joint efficiency (Sec. 5.3)

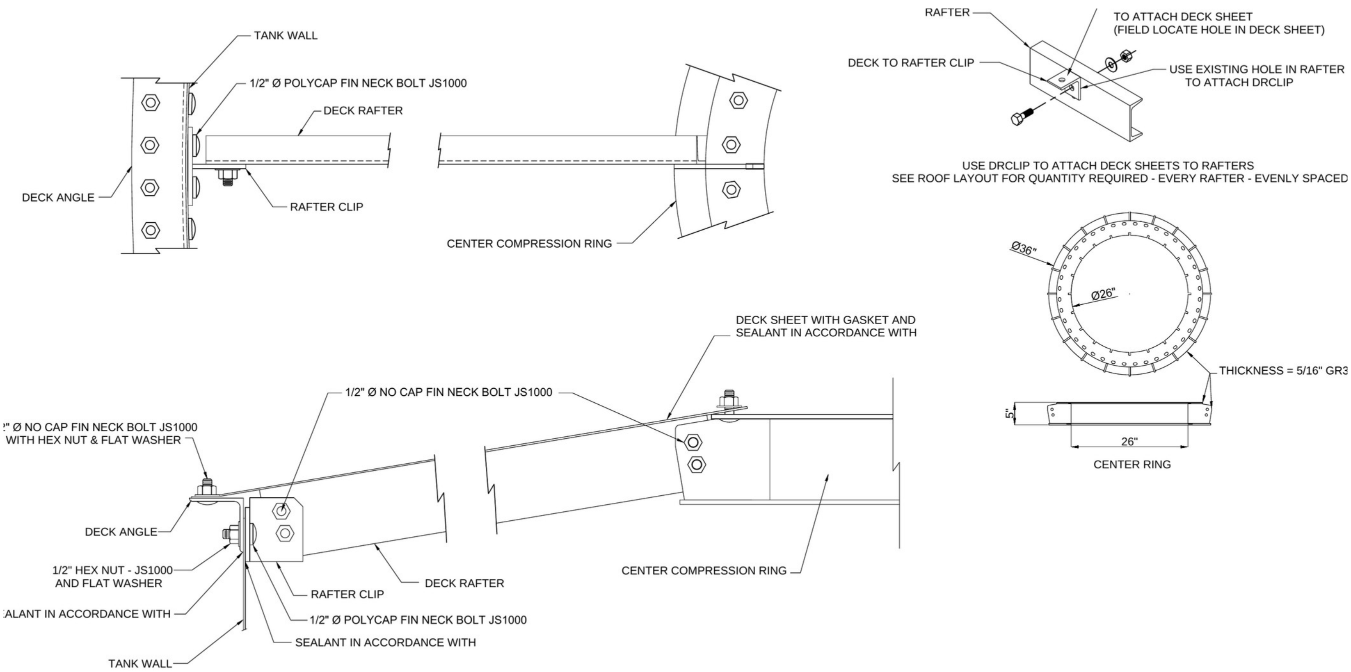
D103 is an allowable-stress standard: sheet tension, bolt shear, bolt bearing on the sheet, and net-section tension at the bolt holes are each limited to a fraction of the material strength, with the fractions depending on the material class and the bolted-joint efficiency. Joint efficiency accounts for the loss of sheet cross-section at the holes and for how the load is shared among bolts; it is why bolt rows, spacing and edge distance are structural, not cosmetic. Allowable stresses may be increased by a stated factor for load combinations that include wind or seismic.

Shell thickness and stiffening

- Thickness is computed course by course for hoop tension at the bottom of each course, then checked against the minimum thickness, the wind-buckling requirement and any manufacturer's standard gauges. Sheets in the same course are the same thickness; sheets get thinner going up.
- Where the shell is too thin for wind buckling over its unstiffened height, intermediate stiffeners (wind girders) are added at calculated spacings (Sec. 15.4). Open-top tanks also need a top girder to keep the shell round.
- Tensile straps (Sec. 14.7 and 15.5) are a bolted-tank-specific detail: straps that tie courses together across horizontal laps to carry longitudinal (vertical) tension from overturning that the lap bolts alone cannot.

Roofs and roof supports (Sec. 5.7)

Every potable-water tank must have a roof. Roofs may be column-supported bolted steel, self-supporting bolted steel (cone or shallow dome), or an aluminum geodesic dome to AWWA D108. The roof and its support are designed for the dead load plus the roof live or snow load, wind uplift, and — for a dome — the horizontal thrust at the tension ring. A common operator mistake is to treat the roof as a platform: the design live load is for snow and maintenance access, not for mounting antennas, mixers or solar arrays without an engineering check.



DECK STRUCTURE ASSEMBLY
RAFTER AND DECK SHEET TO SIDEWALL CONNECTION

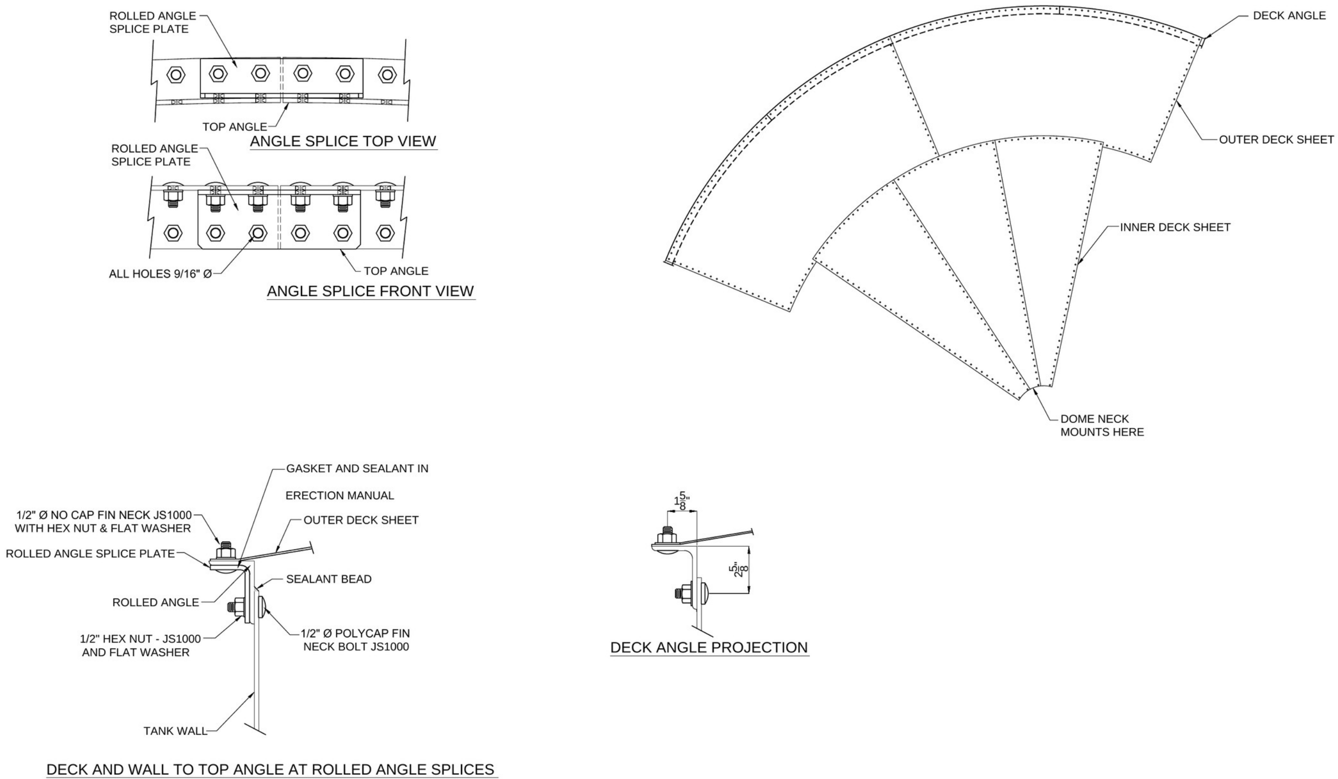
Detail 6 — Standard deck (roof) structure for a rafter-supported bolted steel roof: rafters clipped to the deck angle at the shell and to a center compression ring, deck sheets attached with polymer-capped fin-neck bolts and drclips, gasket and sealant at the deck-to-shell joint. Standard detail, for reference only.

Roof types compared

Table 7 — Roof systems used on bolted tanks.

Roof type	How it works	Where it is used	Operator notes
Rafter-supported bolted steel deck (Detail 6)	Coated steel deck sheets on radial rafters (channels) spanning from the deck angle to a center compression ring; 2:12 slope is common.	Most potable and fire tanks up to roughly 60–80 ft diameter without columns; larger with a center column or trusses.	Rafter-to-shell clips, the compression ring and the drclips are the structural items; deck laps use gaskets; inspect the underside at drain-down.
Self-supporting bolted steel cone	Deck sheets stiffened to carry their own load to the tension ring without rafters.	Small and mid-size tanks.	Ponding indicates a deflected sheet; do not add point loads.
Column-supported steel roof	Rafters carried on interior columns; flatter slopes.	Large-diameter tanks.	Column bases on the floor are corrosion points; check plumb after settlement.

Roof type	How it works	Where it is used	Operator notes
Aluminum geodesic dome (AWWA D108)	Triangulated aluminum space truss with clamped panels, self-supporting from an integral tension ring; dead weight about 3 psf.	Large diameters, high snow, corrosive atmospheres, and where a maintenance-free roof is wanted.	Dissimilar-metal isolation at the shell; batten gaskets and stainless fasteners; keep it electrically isolated from cathodic protection.
Open top (with top wind girder)	No roof; a heavy top ring holds the shell round.	Non-potable process and some wastewater tanks only — D103 requires roofs on potable tanks.	Girder corrosion and ice loading at the rim.



Detail 7 — Deck angle (top angle) bolting and splice details, with the deck-and-wall-to-top-angle section at a rolled-angle splice. The top angle is the tension ring of a self-supporting roof; its splice plates and bolts are structural.

Foundation anchor bolts (Sec. 5.9)

Anchor bolts are required only when the wind or seismic overturning or sliding check (Sec. 15.2, 15.3, 14.3) cannot be satisfied by the weight of the tank and its contents — but the purchaser may specify them regardless. When required they are designed for the net uplift with the stated allowable stress increase, set in chairs on the shell, and installed to the tolerances in Sec. 13.6.3. Corroded, bent or loose anchor bolts on a tank that needs them are a structural defect.

Reading a manufacturer's design-basis sheet — a representative example

Every bolted-tank submittal begins with a general-notes sheet that states the design basis in a page. Learning to read it is the fastest way to understand what your tank was built for. The values below are taken from a representative, recent D103-19 fire-protection tank design and are **for reference only** — they are one manufacturer's numbers for one site and are not requirements or defaults for any other tank.

Table 8 — Representative design-basis values from a recent D103-19 bolted-tank submittal (for reference only — not applicable to any other tank).

Item	Representative value	What it tells the operator
Tank	44.6 ft diameter × 28.1 ft shell (6 rings); flat steel floor; 2:12 cone roof with compression / tension ring and internal rafters; ~205,000 gal usable	Geometry and roof type. Usable capacity, not nominal, is what the fire-flow or storage calculation should use.
Standard / risk	AWWA D103-19; ASCE 7-16 Risk Category III; seismic importance factor I_E = 1.25	A fire-protection tank was assigned the higher category; its seismic and wind design forces are 25 % above an ordinary tank.
Wind	117 mph basic wind speed, Exposure C, I_w = 1.0	The design storm. Compare with the site's actual ASCE 7 map value if the site or surroundings change.
Seismic	S_S = 0.142 g, S_1 = 0.048 g, Site Class D, F_a = 1.60, F_v = 2.40, S_{DS} = 0.151, S_{D1} = 0.077, T_L = 6 s; impulsive coefficient 0.227, convective 0.115; R_i = 2.5, R_c = 1.5	Just above the 'no seismic design' threshold ($S_S \le 0.15$ and $S_1 \le 0.04$), so a full Sec. 14 design was run. R_i = 2.5 means the tank is self-anchored — and the sheet confirms 'anchor bolts: none'.
Roof live / snow	40 psf	Well above the 15 psf minimum; the site's ground-snow load governed. Roof design load is the number to check against drifted snow (Scenario S6).
Pressure / vacuum	1.16 oz/in² internal, 0.5 oz/in² vacuum	The roof and vent were designed for these small pressures — a blocked vent exceeds them quickly.
Design temperature / pH / SG	180 °F maximum; pH 7; specific gravity 1.0	Storing anything hotter, more aggressive or denser than this is outside the design basis.
Corrosion allowance	0 in.	Normal for a factory-coated bolted tank: the coating is the corrosion protection, so coating condition — not wall thickness — is the life indicator.
Freeboard / minimum level	120 in. freeboard; 6 in. minimum operating level	The overflow sits 10 ft below the eave on this tank; the level instrument's low alarm should respect the 6 in. heel.
Shell ring schedule	Ring 1: ¼ in.; Rings 2–4: 3/16 in.; Rings 5–6: 10 ga (0.135 in.) — all ASTM A572 Gr 50; single bolt row ('1RV') at every seam, 2.32 in. pitch horizontally and vertically; 15 sheets of 112 in. coverage per ring	Thickness steps down with height as hoop load falls. A replacement sheet must match the ring's thickness and grade; a bolt survey is referenced to this pitch.
Floor and roof sheets	12 ga (0.1046 in.) A572 Gr 50; encapsulated nuts required on the floor	The floor is the thinnest steel in the tank and sits on the foundation — hence the emphasis on bottom inspection.
Structural members	Top eave angle L3½×3½×⅜; bottom angle L3½×2½×⅜; roof rafters C8×11.5 with three rows of lateral bracing — all Gr 50	The tension ring and bottom angle are the two structural rings an inspector must see; rafter bracing is checked at the interior inspection.
Fasteners	SAE J429 Gr 8 fin-neck bolts, zinc-flake coated, polyethylene caps; SAE J995 Gr 5/8 nuts; A325 hex bolts for structure; tightening = AISC snug-tight	There is no torque value on this design — 'snug-tight' is the specification. Re-tightening with a torque wrench to a chart value would be wrong.
Gaskets / sealant	EPDM gaskets; one-component polyurethane lap sealant	The repair kit must match these; potable service would additionally require NSF/ANSI 61 listings.
Nozzles	Shell nozzles 150-lb raised-face slip-on flanges on stainless spools; projections 8 in. (≤ 8 in. pipe), 10 in. (10–14 in.), 14 in. (16–24 in.); deck nozzles 12 in. projection; backing plate where required; all flanges factory-located	Projections leave room for insulation and for flange bolting; a field-added nozzle would not be factory-located and needs the manufacturer's approval.

Item	Representative value	What it tells the operator
Base reactions	Empty ≈ 68 kips; full ≈ 1,890 kips; empty + wind: 22.5 kips shear, 316 kip-ft moment; full + seismic: 49 kips shear, 386 kip-ft moment (854 kip-ft on a mat or piles); shell line load 0.49–1.04 kip/ft	The numbers the foundation designer worked to. The empty-tank wind case is a real load case — relevant when the tank is drained for inspection.
Platforms	60 psf design live load, if applicable	Do not stage material or equipment on roof platforms beyond this.

Why 'for reference only' matters

The example shows the *shape* of a design basis — the questions a submittal answers — so that an operator can find the same items on their own tank's drawings. It is not a template for design and not a benchmark for another site: change the diameter, the height, the ground snow, the soil class or the risk category and every number changes.

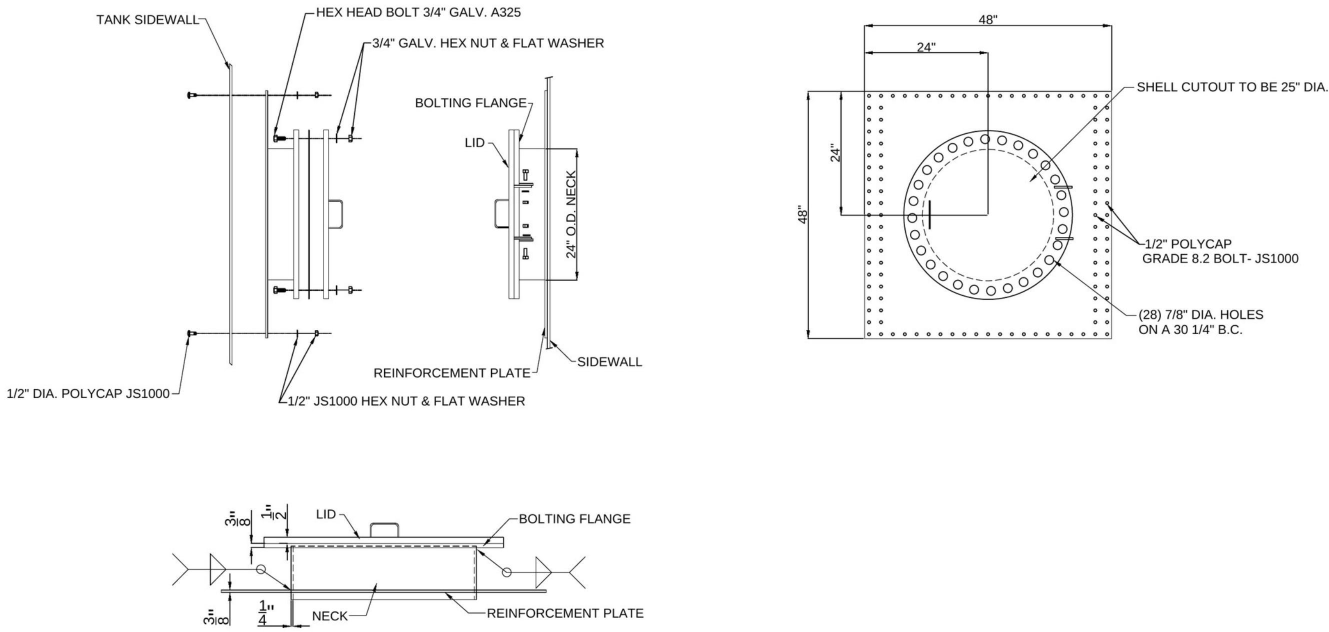
8. Sizing and Accessories (D103 Sections 6 and 7)

Section 6 covers capacity and standard dimensions. Manufacturers' capacity sketches use a consistent set of terms, and knowing them avoids the commonest sizing mistake — quoting the nominal cylinder volume as if it were usable storage:

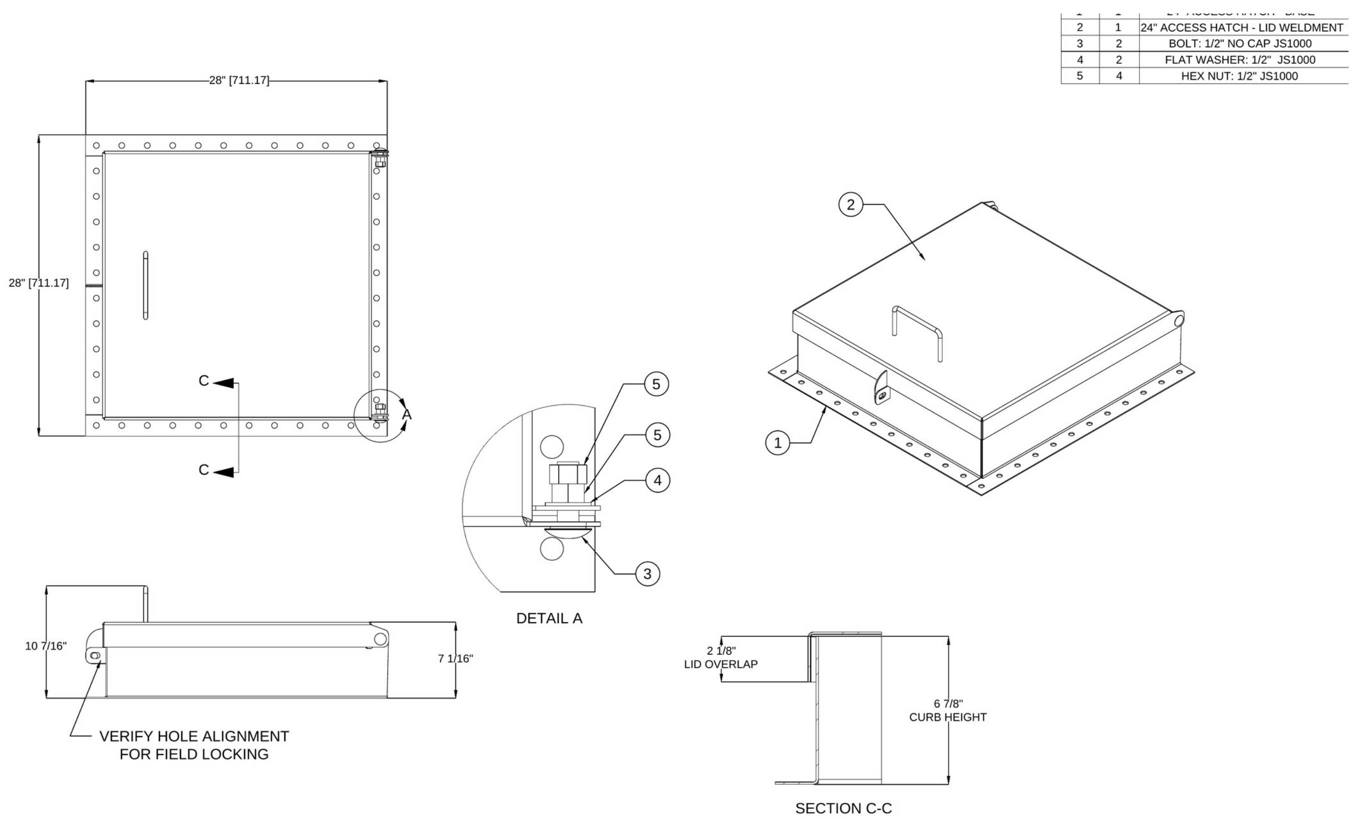
- **Nominal capacity** — the full cylindrical volume of the shell (adjusted for a cone-up or cone-down bottom). A brochure number, not an operating one.
- **Design liquid level (DLL) / maximum water level (MWL)** — the level of the overflow.
- **Maximum capacity** — the volume to the shut-off level (high-level switch), which sits below the DLL by the pump shut-off time allowance.
- **Minimum fill level / bottom capacity limit (BCL)** — the top of the suction nozzle (or the elbow inlet if fitted); the pump loses suction below it.
- **Heel** — the non-usable volume below the minimum fill level. A center sump drain eliminates the heel.
- **Net working capacity** — maximum capacity minus the heel: the only number that belongs in a fire-flow or storage calculation.
- **Freeboard** — from the DLL to the top of the shell; where no level switches exist the freeboard is taken to the top of the overflow weir.

A worked example shows how far apart the numbers can be. A 44.6-ft-diameter tank with a 28-ft shell has a nominal cylinder volume of about 328,000 gal. With a 10-ft freeboard the design liquid level is 18 ft above the floor, so the volume to the overflow is about 211,000 gal; a high-level shut-off 6 in. below the weir takes maximum capacity to roughly 205,000 gal; and a 6-in. minimum operating level over a horizontal suction nozzle leaves a heel of about 6,000 gal — a net working capacity near 199,000 gal, or 61 percent of the nominal figure. Fire-flow and storage calculations that use the nominal number overstate the tank by more than a third.

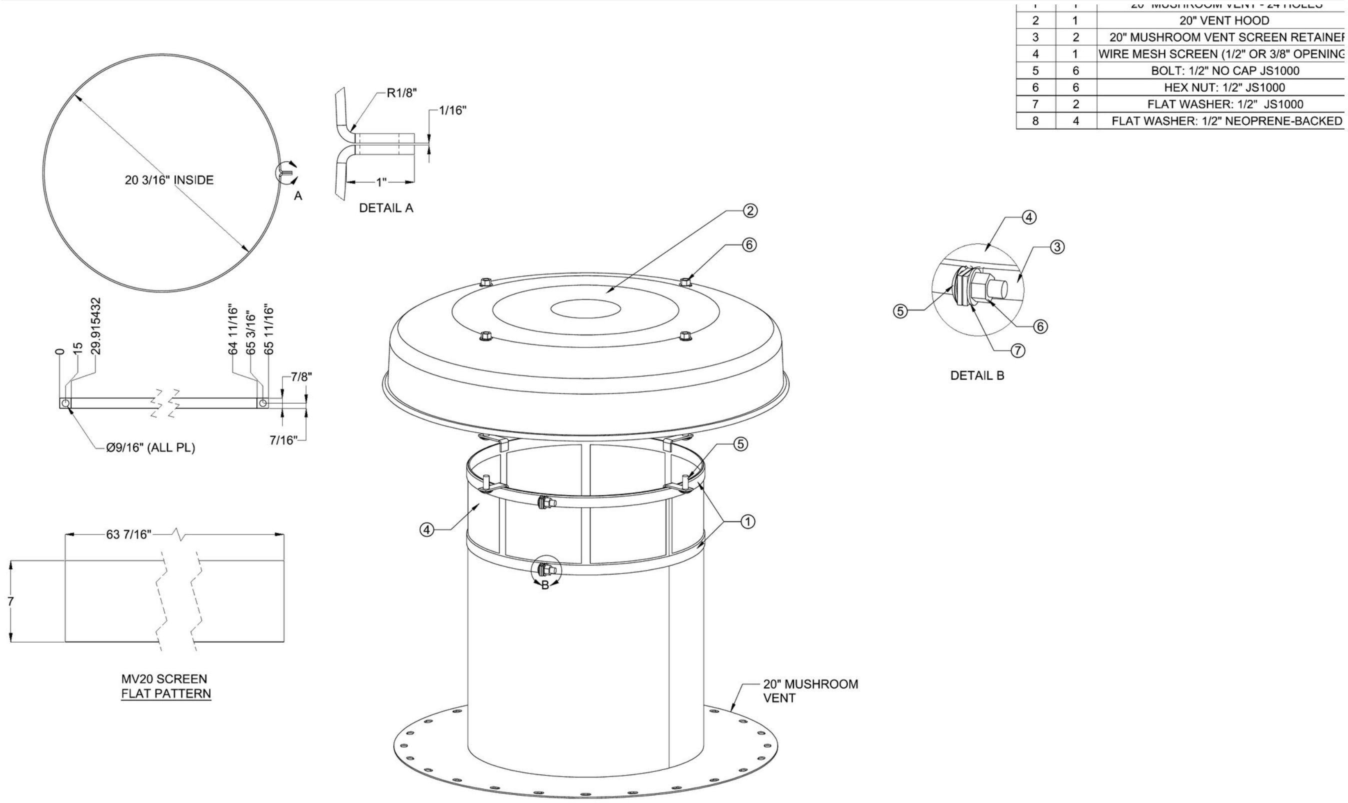
Standard dimensions follow the sheet system: ring heights are fixed by the sheet (commonly 4 to 5 ft), so shell heights come in whole rings, and diameters come in whole sheets of coverage (Chapter 2). A purchaser who specifies '200,000 gallons' will be offered the nearest combination of diameter and ring count that gives at least that working volume, and the freeboard is then set by the seismic wave height and the overflow, not chosen to round the capacity.



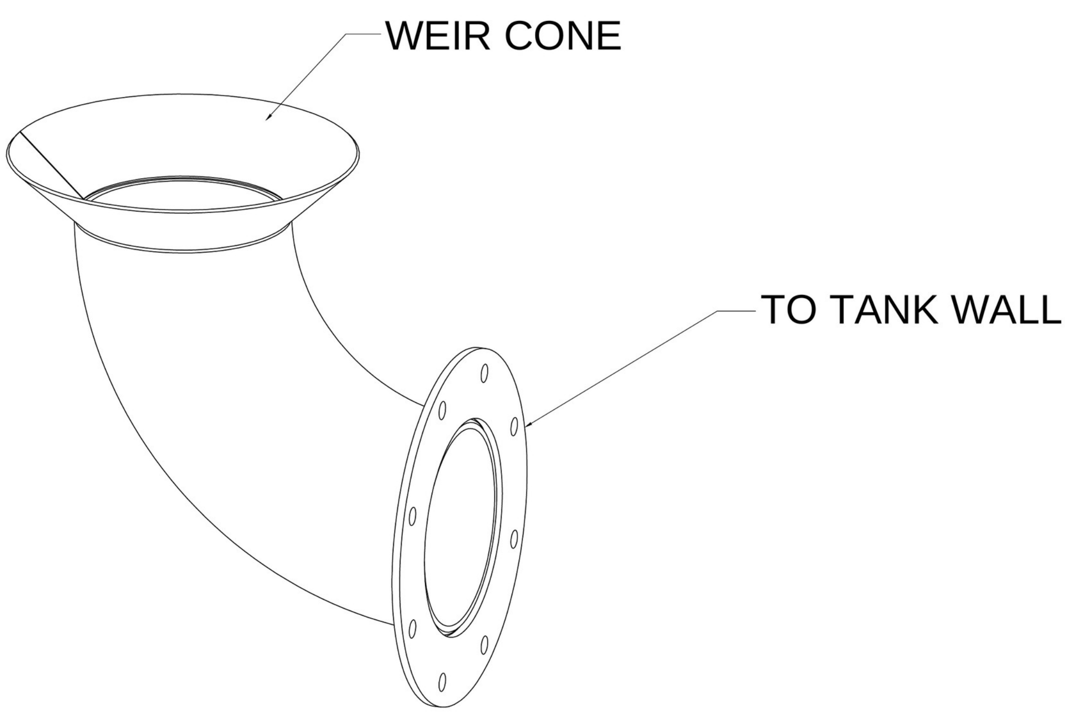
Detail 8 — Standard 24-in. shell manway for a bolted steel tank: neck and bolting flange through the sidewall with an interior reinforcement plate, ½-in. polymer-capped Grade 8.2 bolts through the plate, ¾-in. galvanized A325 hex bolts on the lid, and the 25-in. shell cut-out. Standard detail, for reference only.



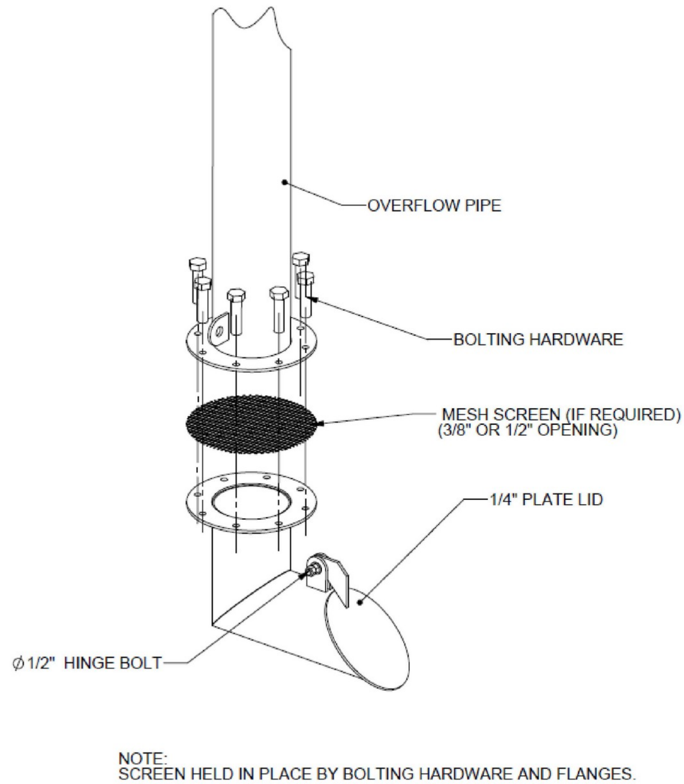
Detail 9 — Standard 24-in. square deck access hatch: 6⅞-in. curb, hinged lid with 2⅛-in. overlap, hasp for locking — the D103 Sec. 7.6 requirements in hardware.



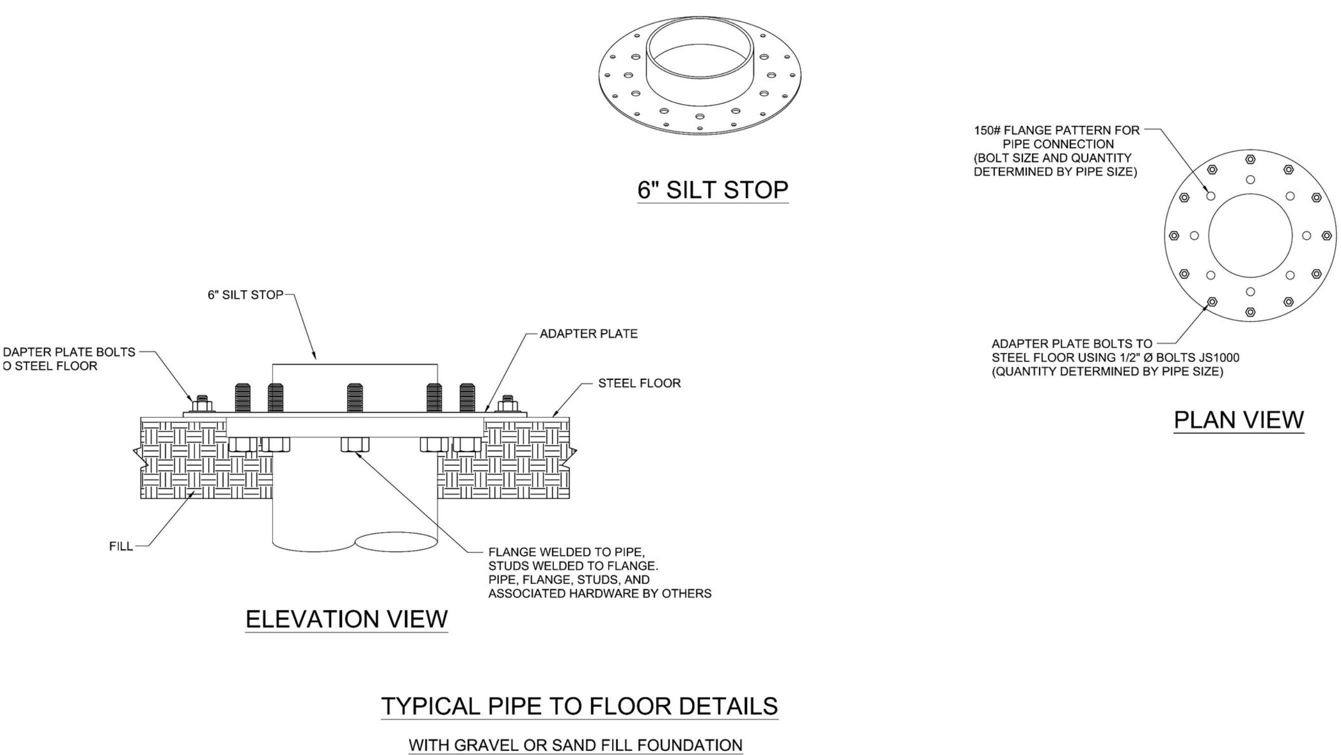
Detail 10 — Hood-and-screen assembly for a 20-in. mushroom vent on an extended neck: screen retainer, wire mesh screen (½-in. or ⅜-in. openings) and neoprene-backed washers. The screen is what the operator inspects.



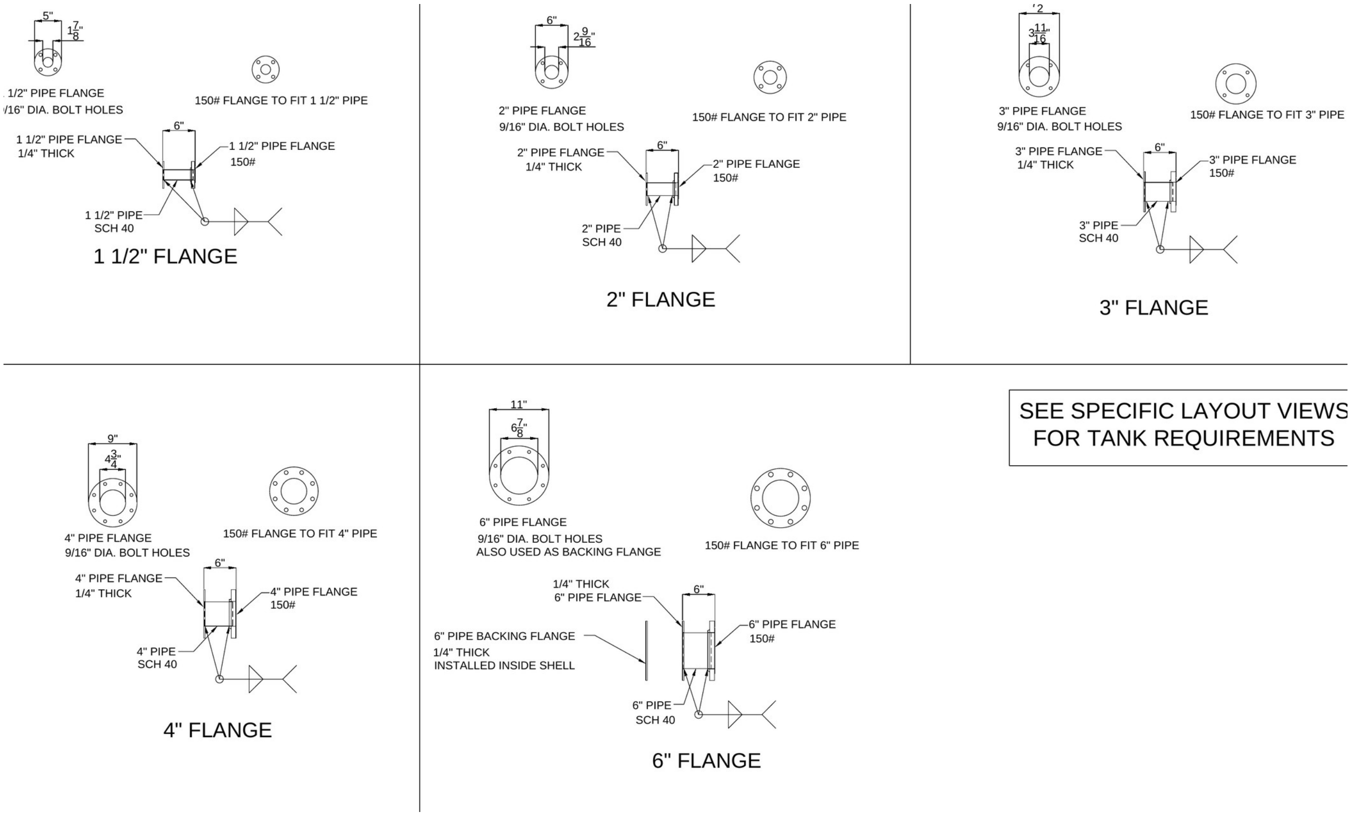
Detail 11 — Overflow weir-cone assembly — a 90° internal weir elbow that bolts to the tank wall and feeds an external downcomer. The lip of the cone sets the design liquid level.



Detail 12 — Typical overflow mesh-screen detail at the downcomer discharge: ⅜- or ½-in. mesh held between flanges, with a hinged ¼-in. plate lid (flap) — the vermin barrier that D103 Sec. 7.3 requires and that Scenario S4 asks you to check.



Detail 13 — Typical pipe-to-floor connection on a gravel or sand-fill foundation: flange and studs welded to the pipe by others, adapter plate bolted to the steel floor with ½-in. bolts, and a 6-in. silt stop above the floor.



Detail 14 — Typical small shell flanges (1½ in. to 6 in.): 150-lb pattern, pipe stub through the sidewall, backing flange installed inside the shell for the larger sizes. Nozzles are factory-located and saw-cut — never torch-cut or welded in the field.

Table 9 — Accessory requirements of D103 Section 7 and the operator checkpoints that follow from them.

Accessory (D103 Sec.)	What the standard requires (paraphrased)	Operator checkpoints
Shell manhole (7.1)	At least one shell manway, minimum 24-in. diameter (or an equivalent 24 × 18-in. elliptical or rectangular opening), with a bolted, gasketed cover and a reinforcing pad that restores the shell strength lost at the opening; hinged or davited covers on large openings.	Gasket condition; bolts all present and torqued; reinforcing pad seams for weeping; cover not used as a shelf for equipment; confined-space signage.
Pipe connections (7.2)	Flanged or grooved nozzles through the shell or bottom with reinforcing as required; flexibility and restraint at the shell to accommodate settlement and seismic movement (Sec. 14.5); bottom connections through concrete bottoms detailed to remain watertight.	Flexible couplings present and free to move; thrust restraint on the pipe, not the tank; no weeping around nozzle reinforcing pads; pipe supported so its weight does not hang on the shell.
Overflow (7.3)	Sized for the maximum fill rate; internal weir box or external pipe; discharge to a splash pad or drain with an air gap; screened (typically 24-mesh corrosion-resistant) or fitted with a flap valve; the overflow is not a vent.	Free discharge, screen intact, flap closes, no standing water in the pipe, no evidence of continuous overflow (erosion, algae); overflow level vs. actual MWL alarm settings. A common configuration is a 90° internal weir elbow (weir cone) with an external downcomer and flap valve (Details 11–12).

Accessory (D103 Sec.)	What the standard requires (paraphrased)	Operator checkpoints
Ladders (7.4)	Exterior and interior ladders of stated dimensions and clearances, with a cage, safety-climb device or other fall protection above the height OSHA requires (cages alone no longer satisfy OSHA 1910.28 for new installations); interior ladders extend to the floor.	Rung corrosion at the shell brackets; safety-climb cable tension and top anchorage; rest platforms; ladder guard locked; interior ladder isolated from the coating with proper brackets.
Safety devices (7.5)	Roof handrails, hatch guards, and other devices the purchaser specifies; the standard's commentary references OSHA and state requirements.	Handrail integrity on domes (aluminum), hatch fall-through guards, tie-off points rated and labeled.
Roof openings (7.6)	A hatch near the ladder with a curb at least 4 in. high, a hinged cover overlapping the curb by at least 2 in., a hasp for locking, and a clear opening of at least 24 in.; additional openings for equipment as specified.	Curb height, gasket, overlap, lock present and used, screen on any open-bottom equipment penetration, no ponding around the curb.
Vent (7.7)	A vent above the MWL sized so that the maximum fill and withdrawal rates do not pressurize or collapse the roof; screened against birds and insects with corrosion-resistant mesh; provided with a means (frangible panel, pressure–vacuum feature) to relieve if the screen ices or clogs.	Screen intact and clean; ice in winter; vent not painted shut; capacity not reduced by a retrofit screen finer than designed; overflow not counted as the vent. Potable specifications commonly call for an expanded-aluminum or wire-mesh screen with ½-in. (sometimes ⅜-in.) openings on a mushroom vent (Detail 11).
Galvanic corrosion (7.8)	Dissimilar metals — aluminum dome to steel shell, stainless fittings and hardware, copper or brass in contact with the steel — must be electrically isolated by gaskets, sleeves and washers.	White corrosion on aluminum at the tension ring; rust bleed at stainless bolts; missing isolation washers after any repair; CP system unintentionally bonded to the dome.
Nameplate and level indicator (spec items)	Specifications typically add a manufacturer's nameplate (serial number, diameter, height, maximum design capacity) on the exterior shell about 5 ft above grade, a liquid-level indicator with stainless float, number board and high-visibility target, and high/low level sensors.	Nameplate legible — it is the key to the tank file; target board and float cable per the manufacturer's annual checks (Chapter 25).

9. Fabrication, Erection, Inspection and Testing (D103 Sections 8–11)

- **Welding (Sec. 8)** is a shop operation done before coating — attachments, reinforcing pads, nozzle necks. Field welding on a factory-coated bolted tank is prohibited unless the manufacturer and purchaser agree in advance and the coating is repaired to the standard, because heat destroys the coating on both faces of the sheet. An operator should treat any proposal to weld on the tank (a bracket, an antenna mount, a pipe support) as a change to the design basis that needs the manufacturer's written approval.
- **Shop fabrication (Sec. 9)** covers sheet edge preparation, rolling, hole punching or drilling before coating, manufacturing tolerances, and shop inspection of the coating (film thickness, holiday testing, cure). The shop inspection records are part of the tank's birth certificate; ask for them.
- **Erection (Sec. 10)** is normally done from the top down with synchronized hydraulic jacks (Photo 2) — the roof and top ring are assembled at grade, raised, and each lower ring bolted in beneath, keeping the crew on the ground. Specifications prohibit any backfill against the sidewall during or after construction without the manufacturer's design review. The section requires field bolting per the manufacturer's procedure, continuous gasketing and sealant, repair of coating damage caused by handling or bolting with the manufacturer's

approved system, and cleanup — including removal of every stray bolt, washer and drill chip from the interior before filling. Carbon-steel debris left on a stainless or glass floor becomes a corrosion site.

- **Inspection and testing (Sec. 11)** — after erection the tank is filled for a **hydrostatic test**; the standard requires the tank to be watertight, with weeping at bolts or seams corrected (by re-torquing or re-sealing) and the test repeated. Test water is disposed of in compliance with local requirements (AWWA C655 for dechlorination if the water is chlorinated). **Disinfection** follows AWWA C652 — chlorination by one of its three methods, then bacteriological sampling before the tank goes into service — and must not begin until the sealant has cured. Manufacturer-modified specifications commonly accept liquid chlorine or sodium hypochlorite but **not calcium hypochlorite (HTH) tablets or granules**, which can damage the coating where they sit, and recommend Method 3 (partial-volume 50 mg/L, then fill).

A representative hydrostatic test procedure

D103 requires the tank to be filled and shown watertight; the manufacturer's procedure fills in the how. The steps below are typical of current bolted-tank manufacturers' hydrotest procedures and are given **for reference only** — follow the procedure issued for your tank.

1. Test after the sealant cure period (commonly **seven days**) but within about **30 days** of tank completion, so that the erector is still available and the warranty clock is unambiguous.
2. Visually inspect the whole tank for loose or missing bolts, nuts and washers before any water goes in.
3. Every opening must be piped, valved or blind-flanged; every shell manway installed and tight.
4. Fill with **clean potable water** (never wastewater or process liquid) through a valved connection or a hose tied off through the roof manway.
5. Fill to **2 ft and hold for at least 12 hours** — this is the bottom test. Walk the base for weeping at the floor laps and the shell-to-bottom joint before going further.
6. If the bottom is tight, resume filling until water runs into the overflow (or to the design freeboard level if there is no overflow). **Do not overfill**; shut the supply off the moment the overflow runs.
7. Map every seep. After all repairs, hold the full level for a **minimum of 24 hours** with no further weeping.
8. Any leak from the bottom or a sidewall seam is reported to the manufacturer, who dispatches a service technician; the erector does the repairs. Manufacturers generally do not guarantee a leak-free first fill and do not bear the cost of draining, refilling, vacuum trucks or confined-space gear for the test — build that into the contract and schedule.
9. On an **insulated tank, the hydrotest is completed and accepted before the insulation is installed** — once the jacket is on, the seams cannot be watched.

What to keep from the hydrotest

Date and duration of the test, water level held, ambient temperature, the leak map (every seep and what was done about it), and photographs. Ten years later, a weep at the same bolt row is a very different finding if the record shows it wept at hydrotest too.

10. Coatings (D103 Section 12)

Section 12 sets, for each coating system, the surface preparation, application, cure or firing, film thickness, inspection and holiday-testing requirements that the plant must meet, together with marking, protection and repair. Chapter 4 described how each system behaves; this section notes the provisions an operator most often needs.

- **Galvanized coatings (12.3):** hot-dip galvanizing to the referenced ASTM specification after fabrication, with a stated minimum coating weight; sheet edges and holes coated; a passivation or chromate treatment against white rust in storage; potable use only where the system is NSF 61 certified.
- **Glass coatings (12.4):** enameling-grade steel; ground and cover coats fired to a specified thickness range; each sheet holiday-tested at a stated voltage on the water side; fishscale, crazing and chipping are rejection criteria; repair of edge damage with an approved compound.
- **Thermoset liquid suspension (12.5) and thermoset powder (12.6):** abrasive-blast surface preparation to a specified cleanliness and profile; application and cure per the coating manufacturer; minimum and maximum dry film thickness verified per SSPC-PA 2; holiday testing per the standard's method; interior systems NSF 61 certified.
- **Marking (12.7):** sheets are marked so the coating system, batch and position can be identified — useful when tracing a defect across several sheets.
- **Protection (12.8):** coated sheets are handled, shipped and stored so the coating is not damaged; field damage is repaired before the affected area is bolted where possible.
- **Holiday testing (12.9):** the electrical test — low-voltage wet sponge for thin films, high-voltage spark for thick — that finds pinholes in the coating. It is a shop operation for the sheets and a field operation for repairs. The same test, at the manufacturer's voltage, is the objective way to survey coating condition at the five-year inspection.

Field coating repair is the one coating activity the standard expects to happen on site. The rule is simple: use the manufacturer's approved repair material, apply it to a properly prepared surface within its temperature and humidity window, and holiday-test it. Bolted-tank warranties commonly require that only the manufacturer's repair kit be used; keep the kit and its NSF listing in the tank file.

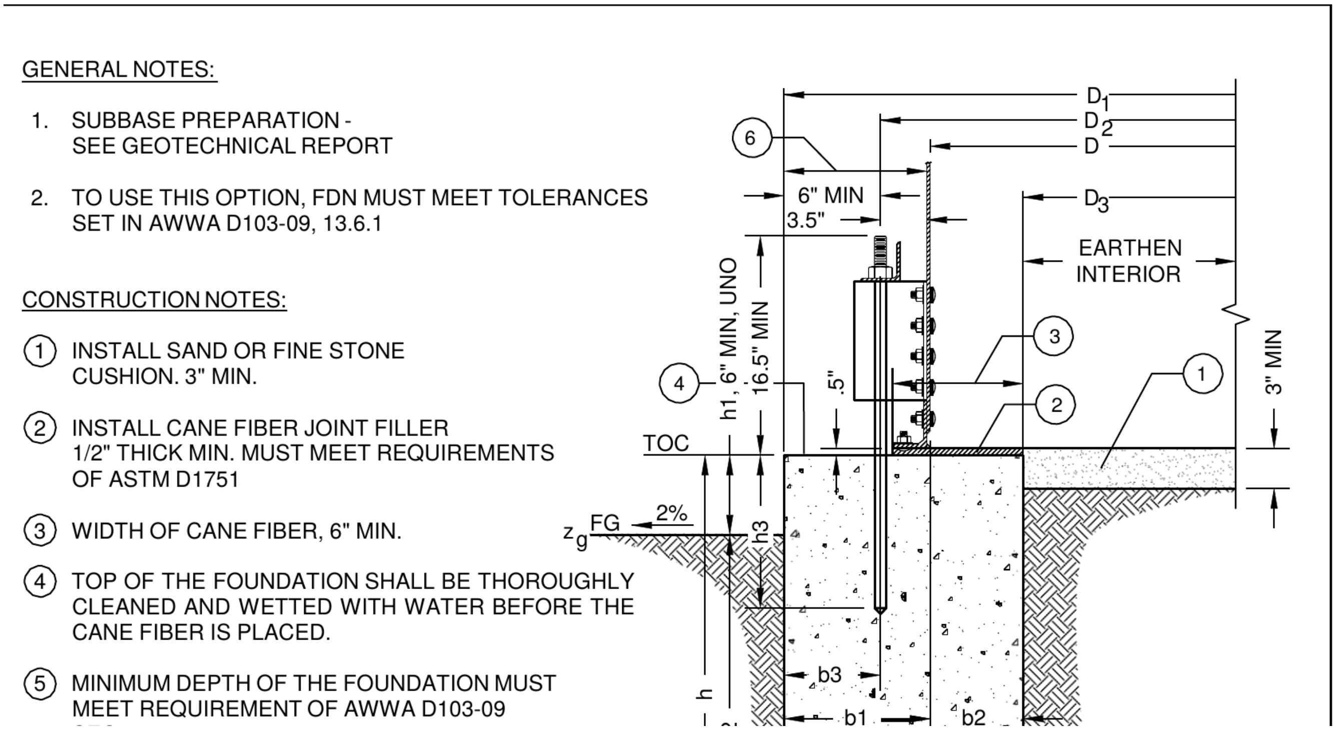
11. Foundations (D103 Section 13)

The purchaser is responsible for the foundation, and most bolted-tank problems that are not coating problems are foundation problems. Section 13 requires a geotechnical investigation (13.2), sets safety factors for bearing and stability (13.3), defines six foundation types (13.4), gives design details (13.5), concrete requirements and tolerances (13.6), and backfill and pipe cover requirements (13.7).

Geotechnical investigation and safety factors (Sec. 13.2, 13.3)

The standard requires a geotechnical investigation of the site before the foundation is designed, and it is the purchaser's job to commission it and to give the report to the tank manufacturer. The report establishes the allowable soil bearing, the depth to competent material and to groundwater, the frost penetration, the expected total and differential settlement under the full tank, and the seismic site class. Bolted tanks are light structures when empty and very heavy when full — the representative tank in Chapter 7 goes from 68 kips to 1,890 kips — so the soil sees almost the whole load only after the tank is filled, and a foundation designed on assumed bearing values can settle differentially in the first year of service.

Section 13.3 sets minimum safety factors for bearing capacity and for overturning and sliding, and requires the foundation to be designed for the base reactions the manufacturer reports on the general-notes sheet — including the empty-plus-wind and full-plus-seismic cases, and the higher seismic moment that applies when the tank sits on a mat or on piles. Where soils are poor, the choices are a deeper ringwall, a slab, ground improvement, or piles with a structural mat; the manufacturer's tank design does not change, but its anchorage might.



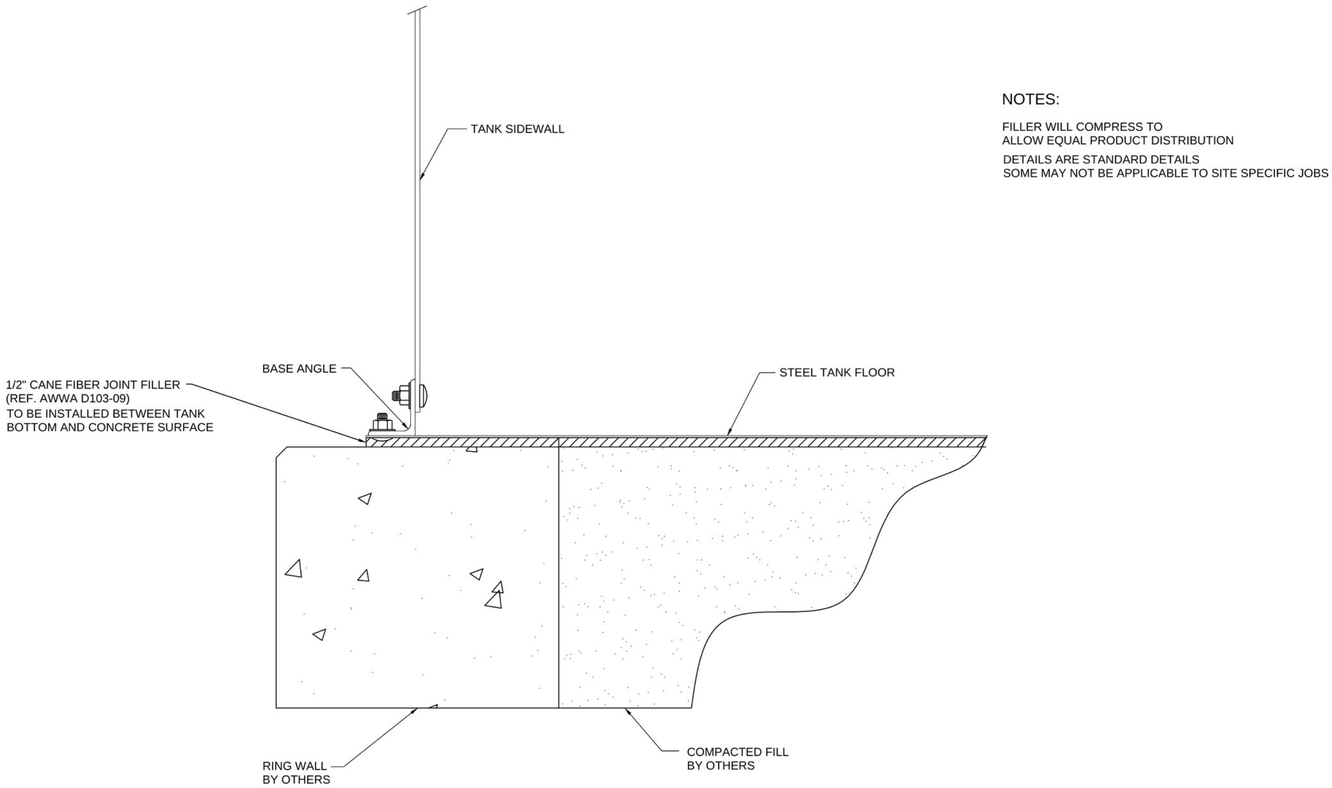
Detail 15 — Type 1 foundation standard detail — steel-bottom tank on a concrete ringwall with cane-fiber joint filler under the shell: 3-in. minimum sand or fine-stone cushion, ½-in. × 6-in. ASTM D1751 filler on a cleaned and wetted foundation top, 2 % slope away from the shell, ringwall depth to the D103 frost requirement, and the levelness tolerances of Sec. 13.6.1 as a condition of using the option. Standard detail, for reference only.

What a good ringwall installation looks like

- **Concrete.** Reinforced ringwall to ACI 318 / ACI 301, typically 3,000–4,000 psi, with continuous hoop reinforcement top and bottom and vertical ties; a width of 12–18 in. is common for mid-size tanks, set by bearing and by the 3-in. (or 8–9 in.) projection rule of Sec. 13.5.3. Top corners rounded or beveled; the exposed band smooth-formed to 6 in. below grade.
- **Depth.** Below the extreme frost line for the site and never less than 12 in. below finished grade; the ringwall is what keeps frost from reaching the fill under the floor.
- **Interior fill.** All topsoil and organics removed; controlled granular fill placed and compacted in lifts to the density the foundation designer specifies (95 % of modified Proctor is a common requirement); the surface crowned or level as the manufacturer's drawings show, then the 3-in. sand or fine-stone cushion screeded flat so the floor sheets bear evenly.
- **Levelness.** Top of ringwall within ±⅛ in. in any 30 ft and ±¼ in. from a plane — measured and recorded before the tank arrives, because the erector will refuse a foundation that is out of tolerance and the schedule slips a month.

- **Joint filler.** ½-in. ASTM D1751 cane-fiber (or equivalent non-extruding, resilient) filler, 6 in. wide, on a cleaned and wetted surface, under the full circumference of the shell; it compresses under the shell load and spreads the bearing, and it is what the operator sees at the base joint for the life of the tank.
- **Drainage.** Finished grade 6 in. below the top of the concrete and sloped at least 2 % away; a gravel or paved apron where mowing would otherwise throw soil against the shell.

Poor fill, not poor concrete, is the commonest ringwall problem: settlement of the interior fill leaves the floor spanning a void while the shell is still firmly supported, and the first sign is a floor that drums when tapped or a bottom-course lap that begins to weep.

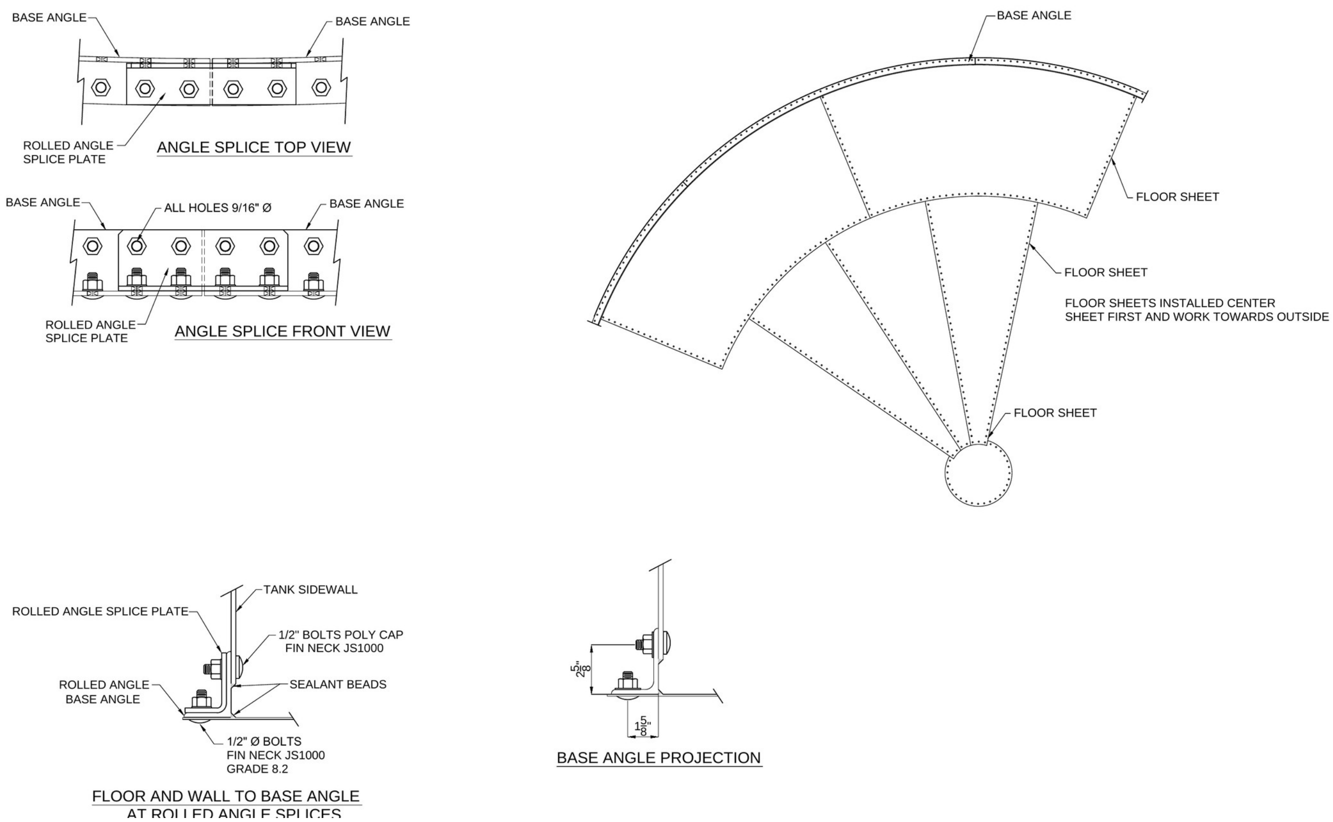


Detail 16 — The same joint as built: base angle bolted to the first shell course and the steel floor, sitting on the cane-fiber filler over the ringwall, floor on compacted fill. The filler compresses so the floor load spreads evenly; the ringwall and fill are by others.

The base angle — the joint that carries everything

On a steel-bottom bolted tank the shell does not sit on the foundation directly; it bolts to a rolled **base angle** (Detail 16), whose horizontal leg bolts to the floor sheets and whose vertical leg forms the first course lap. The angle does three jobs at once: it transfers the shell's dead load and the roof reaction into the ringwall through the joint filler, it makes the floor-to-shell corner watertight through two sealed bolted laps, and — on a self-anchored tank — its connection to the floor sheets is what resists the seismic uplift that would otherwise lift the shell edge. Base angles are supplied in rolled segments spliced with plates (Detail 17), and the splice bolts are structural in the same sense as the lap bolts.

For the inspector the base angle is the lowest, wettest, most highly loaded metal on the tank, and it is partly hidden: the horizontal leg is under the water, the vertical lap is behind the first course, and the bearing surface is on the filler. Weeping at the toe of the shell, staining of the joint filler, or filler that has been squeezed out or has disappeared are its warning signs. Interior inspections should include the floor-to-angle bolts and the fillet along the whole perimeter, and any repair to the angle itself is a manufacturer job.



Detail 17 — Base-angle bolting detail: floor and wall to base angle at rolled-angle splices, splice plates with 9/16-in. holes, sealant beads at every faying surface, and the base-angle projection section. The shell-to-bottom joint is the highest-load joint in the tank.

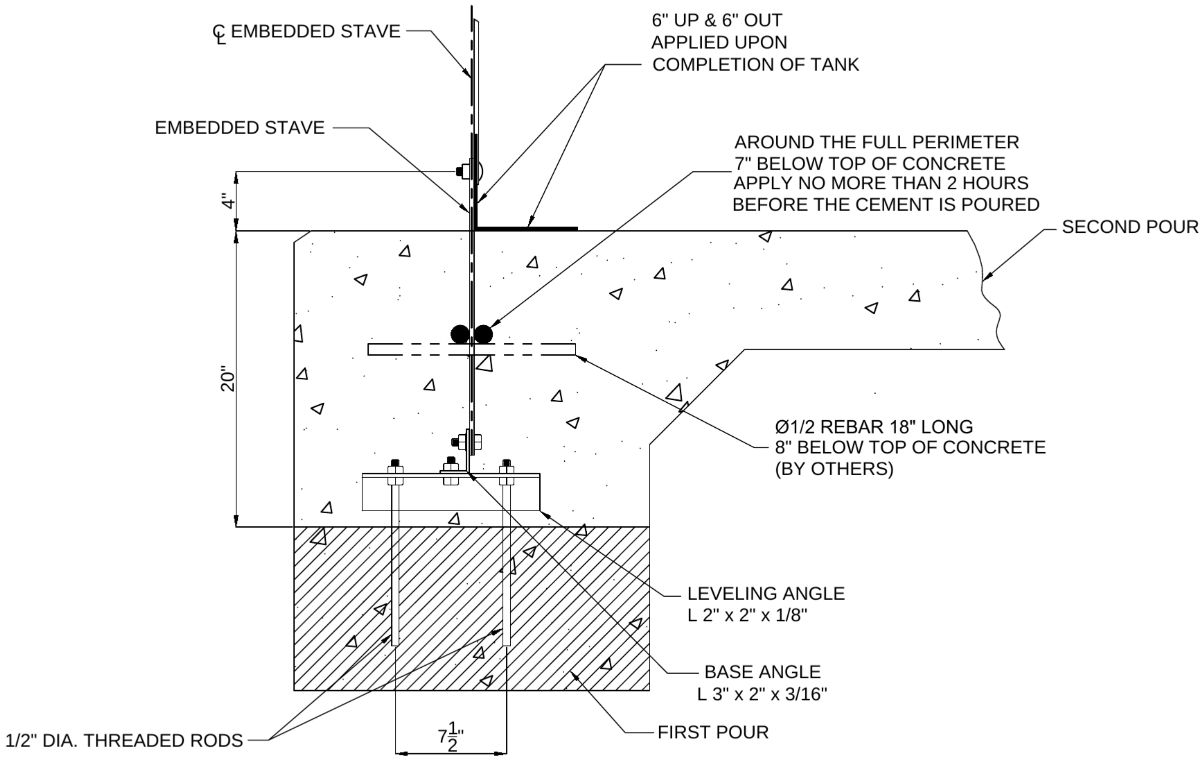
Steel bottom or concrete bottom?

Most water tanks are built with a bolted steel bottom on a ringwall or slab (Types 1–5). The concrete-bottom, embedded-ring design (Type 6) is chosen where a flat concrete floor is wanted for process reasons, where the tank must be drained dry to a floor drain, or where a slab is being poured anyway. The two behave differently in service:

Table 10 — Operational differences between steel-bottom and concrete-bottom bolted tanks.

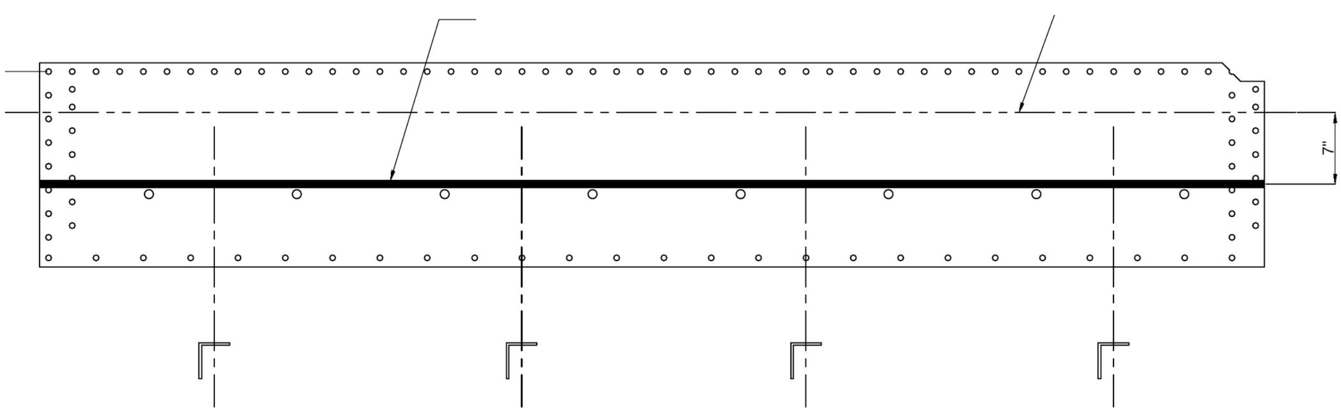
Aspect	Bolted steel bottom (Types 1–5)	Concrete bottom with embedded ring (Type 6)
Watertightness	Sealed bolted laps in the floor and at the base angle; leaks show as weeping at the shell toe or as fines washing from under the ringwall.	Depends on concrete quality, the waterstop bead at the stave and the ring-to-concrete bond; leaks show as damp concrete outside the wall or as water at the stave.
Seismic behavior	The floor annulus resists uplift; self-anchoring possible up to J = 1.54 with checks.	No steel annulus; ASCE 7-16 limits self-anchored use to J ≤ 0.785 — anchorage or a different type elsewhere.
Settlement	Tolerates modest differential settlement of the interior fill; a void under the floor is detectable by tap test.	Slab and ring settle together; cracks in the floor are the concern and are hard to see under water.
Repair	Floor sheets can be re-sealed, re-bolted or replaced; the base angle can be re-sealed from inside.	Concrete floor repairs and stave-to-concrete leaks need epoxy injection or a liner; the stave cannot be re-levelled.
Cleaning	Sediment collects along the base angle and in the floor laps; vacuum cleaning around the perimeter is slow.	Smooth floor, often sloped to a sump — easiest to clean; no heel if a center sump drain is fitted.

Aspect	Bolted steel bottom (Types 1–5)	Concrete bottom with embedded ring (Type 6)
Inspection	Floor laps, bolts and caps are inspected at drain-down; ultrasonic thickness readings are possible.	Concrete condition, crack mapping, and the stave coating above the floor; the embedded steel cannot be inspected.



WALL TO EMBEDDED BASE RING CONNECTION

Detail 18 — Type 6 wall-to-embedded-base-ring connection (standard detail): base angle L3×2×3/16 set on ½-in. threaded rods with an L2×2×⅛ leveling angle in the first pour; embedded starter stave cast into the 20-in. second-pour floor with ½-in. × 18-in. rebar dowels 8 in. below the top of concrete; a swellable waterstop bead inside and outside around the full perimeter 7 in. below the top of concrete, placed no more than two hours before the pour; and a protective coating applied 6 in. up the stave and 6 in. out over the concrete when the tank is complete. Product names removed; for reference only.



Detail 19 — Plan / elevation of the embedded stave showing the continuous waterstop bead and the ½-in. rebar dowels through the stave — the two features that keep a concrete-bottom tank tight at the ring.

Foundation types (Sec. 13.4)

- **Type 1 — concrete ringwall with a steel bottom.** The bottom sheets bear on compacted, controlled load-bearing fill inside the ringwall with a sand or fine-stone cushion of at least 3 in. under the sheets; the shell bears on the ringwall over a ½-in. resilient joint filler (ASTM D1751). The ringwall carries the shell and roof line load, confines the fill, and keeps water and frost away from the bottom.
- **Type 2 — concrete slab with a steel bottom.** A reinforced slab supports the whole tank; the same joint filler sits between steel and concrete. Common for smaller tanks, weak soils and fire-protection tanks under NFPA 22.
- **Types 3, 4 and 5** are further steel-bottom variants defined in the standard (consult Sec. 13.4 of your edition for the exact configurations). All steel-bottom types have the structural advantage that the bottom sheets tie into the shell and act as the annulus that resists seismic uplift.
- **Type 6 — concrete bottom with an embedded base-setting ring (Sec. 13.4.6).** There are no steel bottom sheets; a coated starter ring (stave) is set on a leveling assembly — never on blocks, bricks or shims — levelled to within ¼ in. overall and ⅛ in. in any 30 ft, fitted with an elastomer waterstop strip below the floor line, and cast into the reinforced concrete floor, which is the tank bottom; the first course bolts to it (Details 18–19). Because there is no steel annulus, ASCE 7-16 limits this type to sites where the seismic overturning ratio J (D103 Eq. 14-32) does not exceed 0.785 unless the connection is specifically engineered. Floor cracks and the ring-to-concrete interface are the leak paths to watch on these tanks.

Design details and tolerances (Sec. 13.5, 13.6)

Table 11 — Foundation design details and tolerances of D103-19 Sections 13.5–13.7.

Requirement	D103-19 provision	Why it matters in service
Height above grade	Top of concrete foundation at least 6 in. above adjacent grade unless otherwise specified.	Keeps the shell base out of standing water and snowmelt; grade that has crept up against the shell is a maintenance finding.
Minimum depth	Bottom of the foundation below the extreme frost penetration for the locality (the standard's Figure 1), and never less than 12 in. below finished grade; deeper where soils or uplift require, shallower only on rock.	Frost heave under a shallow ringwall lifts the shell unevenly and shears sealant in the first course.
Top projection	Foundation top extends at least 3 in. beyond the shell (8 in. recommended for base-setting-ring tanks; 9 in. or more where anchor bolts are used); top corners rounded or beveled.	Room for the joint filler, the sealant fillet, and anchor chairs; a narrow projection lets water sit against the shell.
Levelness	Ringwalls and slabs level within ±⅛ in. in any 30 ft of circumference under the shell and within ±¼ in. of an established plane; ±1 in. before grouting.	Out-of-level foundations put the first course into bending and are the commonest cause of early bottom-course weeping; a settlement survey uses these tolerances as its benchmark.
Anchor bolts	Location, projection and embedment within ±¼ in.; plumb within ±3°.	Bent or offset bolts overload chairs and crack the concrete.
Base-setting rings	Level within ±1/16 in. and concentric within ±¼ in., set with a levelling assembly (not on shims or bricks), before concrete placement.	The ring cannot be corrected after the pour; any error is permanent.
Concrete	ACI 318 design, ACI 301 construction; smooth form finish on the exposed top portion to 6 in. below grade.	Honeycomb and cold joints at the exposed band are entry points for water and freeze-thaw spalling.

Requirement	D103-19 provision	Why it matters in service
Backfill (13.7)	All topsoil and organic material inside a ringwall removed and replaced with controlled load-bearing fill compacted in lifts; degree of compaction set by the water load and ringwall height; pipe cover per the standard's Figure 2 unless local conditions dictate otherwise.	Poorly compacted fill settles under the water load, leaving the bottom sheets spanning voids; a bottom that 'drums' when tapped is telling you this.

12. Seismic Design (D103 Section 14)

Section 14 derives design ground motion from ASCE 7 — the risk-adjusted maximum considered earthquake with a 2 percent probability of exceedance in 50 years, reduced by two-thirds to the design earthquake and by importance and response-modification factors to service-level forces. Tanks at sites where the mapped one-second acceleration S_1 is 0.04 g or less **and** the short-period acceleration S_S is 0.15 g or less need no seismic design at all; everywhere else the manufacturer must run the numbers.

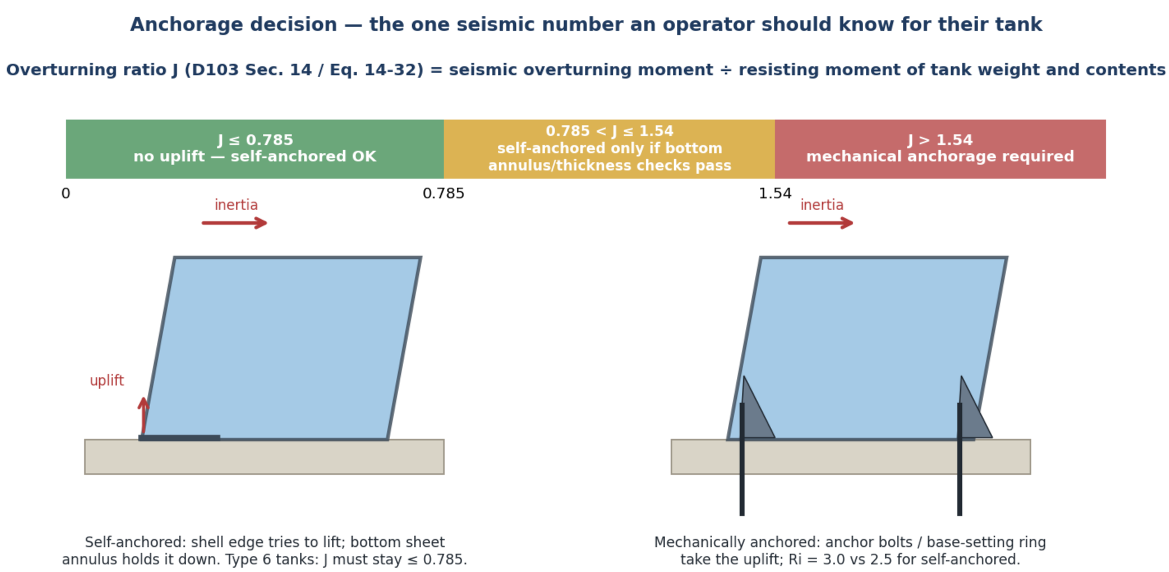


Figure 4 — The seismic anchorage decision. The overturning ratio J from the design calculations tells you whether the tank relies on its own weight, on its bottom sheets, or on mechanical anchors — and therefore what an inspector must look at after an earthquake.

- **Site class (14.2.3)** comes from the geotechnical investigation; where it is unknown the standard defaults to Site Class D unless E or F soils are present, and Site Class F requires a site-specific study. Site coefficients F_a and F_v (Tables 3 and 4) can more than double the ground motion on soft soils.
- **Response modification factors (Table 5):** R_i = 3.0 for mechanically anchored tanks and 2.5 for self-anchored, R_c = 1.5 for the convective component in both cases. Anchoring a tank is therefore rewarded with lower impulsive design forces.
- **Impulsive and convective components (14.3):** part of the water moves rigidly with the shell (impulsive, short period); the rest sloshes (convective, long period, 0.5 percent damping). The sloshing wave height sets the required **freeboard (14.4)**; where insufficient freeboard is provided the roof must be designed for the wave pressure. This is why the freeboard is not spare storage.

- **Overturning ratio J (Eq. 14-32):** $J \le 0.785$ — no uplift, the tank is stable on its weight; $0.785 < J \le 1.54$ — the tank is self-anchored only if the bottom-sheet annulus checks pass; $J > 1.54$ — mechanical anchorage is required. For Type 6 (embedded-ring) tanks ASCE 7-16 caps J at 0.785. Ask the manufacturer for the J value and write it on the tank data sheet (Appendix G).
- **Piping connections (14.5):** inlet, outlet and drain connections must accommodate the vertical uplift and horizontal displacement the design earthquake produces, using flexible couplings or expansion joints located and restrained so that the pipe, not the tank shell, takes the thrust. Rigidly piped tanks fail at the nozzle in earthquakes.
- **Foundation considerations (14.6)** and **tensile straps (14.7)** address the transfer of overturning forces into the ringwall and across horizontal laps.

The representative design basis in Chapter 7 illustrates a low-seismic site: with $S_S = 0.142$ g and $S_1 = 0.048$ g the tank fell just outside the exemption, Site Class D coefficients raised the design accelerations to $S_{DS} = 0.151$ and $S_{D1} = 0.077$, and the overturning check allowed a self-anchored tank ($R_i = 2.5$) with no anchor bolts. On a Site Class D or E site in the central or western states the same tank would very likely be anchored.

13. Wind Design (D103 Section 15)

Section 15 applies ASCE 7 velocity pressures to the shell and roof, then requires four checks: shell stability under the design wind pressure (15.1), overturning of the empty tank with an anchor check if the resisting moment is insufficient (15.2), sliding of the empty tank (15.3), and the sizing and spacing of top and intermediate girders (15.4), with tensile straps where needed (15.5). Two operating consequences follow: **an empty bolted tank in high wind is a real load case**, so a tank drained for inspection or repair in storm season should be evaluated and, if the manufacturer advises, partially filled or temporarily restrained; and stiffener rings are structural members — corrosion at their attachment to the shell, or damage from rigging, reduces the wind capacity of the tank.

Part III — Operating the Tank

14. Commissioning and the Tank File

A bolted tank's first year sets the pattern for the next thirty. The commissioning file is the baseline every later inspection is compared against; if you are inheriting a tank without one, assembling it is the first maintenance task. The file should contain:

✓	Commissioning record — items to have on file	What to look for / acceptance
☐	Approved erection drawings and sealed design calculations	Sheet thickness by course, bolt schedule, roof design, stiffener locations, anchorage, foundation loads, freeboard, seismic J ratio, design wind speed and snow load.
☐	Geotechnical report and foundation design	Bearing values, frost depth, site class, settlement estimates, compaction requirements.

✓	Commissioning record — items to have on file	What to look for / acceptance
☐	Foundation as-built survey	Levelness readings around the circumference (against the ±⅛ in. / 30 ft and ±¼ in. tolerances), anchor-bolt survey, base-setting-ring survey.
☐	Material certifications	Mill certificates for sheets; bolt grade and finish certifications; sealant and gasket data sheets; NSF/ANSI 61 and 372 listings for every wetted product.
☐	Shop coating records	Surface-profile and DFT readings by sheet, holiday-test results, cure/firing records, sheet marking key (Sec. 12.7).
☐	Erection records	Bolt torque procedure and verification, field coating-repair log with locations, sealant cure log, cleanup sign-off.
☐	Hydrostatic test record	Date, duration, level, leak map, corrective actions, re-test, photographs.
☐	Disinfection and sampling record	AWWA C652 method used, chlorine dose and contact time, dechlorination (C655), bacteriological results, regulator approval to place in service.
☐	Manufacturer O&M manual and warranty	Torque values, repair kit and procedure, inspection intervals required to keep the warranty, contacts.
☐	Accessory data	Level instrument calibration, mixer and CP rectifier manuals, vent capacity, overflow rating, hatch and ladder details, lightning protection.
☐	Baseline photographs	Exterior all around, roof, interior before first fill, each nozzle, the base joint, and the overflow discharge.

Appendix G is a one-page tank data sheet to summarize the values an operator needs at hand — diameter, MWL, BCL, freeboard, coating system and repair kit, foundation type, anchorage, J ratio, torque value, vent and overflow capacities.

15. Routine Operation

Levels, alarms and the overflow

- Operate between BCL and MWL. Set the high-level alarm **below** the overflow lip with enough margin for the fill pump to stop; set the high-high alarm at the overflow. A tank that overflows regularly is wasting water, eroding the splash pad, icing the overflow in winter, and telling you the level control needs attention.
- Trend the level signal against the target-board or float gauge monthly; drifting transducers are common and a wrong level reading hides both overfilling and low-level problems.

- Never operate above MWL to gain storage. The design hydrostatic load, the freeboard and the roof loading all assume MWL as the ceiling.
- Watch the daily level swing. A tank that barely cycles has a water-age problem; a tank that cycles to the bottom every day may be pulling sediment and exposing the lower shell to wet-dry cycling.

Turnover and water quality

- Aim for complete turnover in **three to five days** — roughly 20–30 percent of the volume exchanged daily — and more in warm months. Where demand does not provide it, use an inlet diffuser, a mixer, or a recirculation loop, or operate the tank on a deeper daily cycle.
- Sample at the outlet and, if the tank has one, at a top sample tap; a widening gap in residual or temperature between the two is stratification. Track water age with a simple volume-over-demand calculation or a tracer study.
- Sediment accumulates on the floor regardless of water quality; it shelters biofilm and consumes disinfectant. Plan cleaning on the calendar (Part VI) rather than waiting for complaints.
- Nitrification in chloraminated systems, taste-and-odor events, and coliform hits are the classic symptoms of poor turnover; each has a storage-tank cause more often than a source cause.

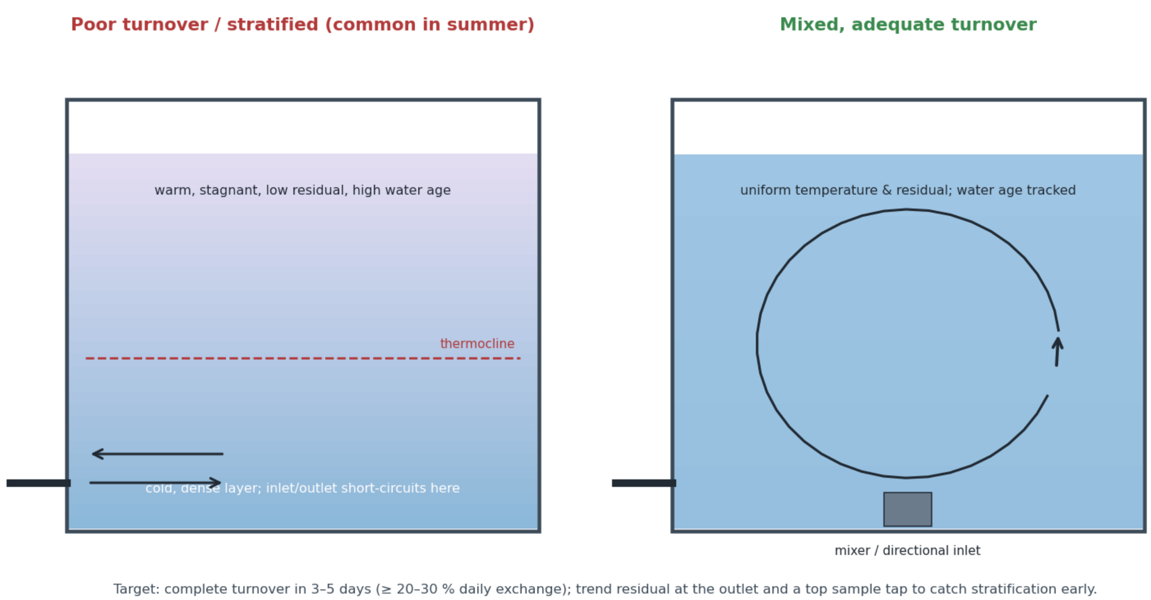


Figure 5 — Stratification is the commonest water-quality mechanism in a storage tank: warm, stagnant water at the top loses disinfectant residual while the inlet and outlet short-circuit through the cold bottom layer.

Security and access

- Lock the hatch, the ladder guard and the site fence; alarm the hatch if the site is remote. An open hatch is a contamination event under most state rules and triggers sampling.
- Keep vegetation, debris and stored materials away from the base; nothing should lean on the shell or sit on the ringwall.
- Control who may climb: confined-space and fall-protection rules apply to every entry and every roof visit. The roof hatch and the manway are the only sanctioned openings; do not open dome panels for access.

Things an operator should never do to a bolted tank

Prohibited without the manufacturer's written approval

Weld, cut or drill anything on the tank; mount equipment to the roof, shell or dome; hang loads from stiffeners or the tension ring; use the shell as an anchor point for rigging.

Store any liquid other than the design liquid; fill above MWL; pressurize or evacuate the tank (closing the vent, plugging the overflow, filling or draining faster than the vent can pass).

Apply a coating, sealant, cleaner or disinfectant product not approved by the manufacturer and NSF 61-certified for the service.

Torque bolts to a value taken from a generic chart, or replace bolts with hardware-store fasteners.

Use high-pressure abrasive or dry-ice blasting on the coating, or hydro-blasting above the pressure the coating manufacturer allows, during cleaning.

Drain the tank in high-wind season, or leave it empty for extended periods, without checking the empty-tank wind case and freeze exposure with the manufacturer.

16. Cold-Weather Operation

Ice is the load case the standard does not explicitly design for, and it is the mechanism behind a large share of bolted-tank damage in northern climates. Water in the freeboard and at the wall freezes first; a floating ice cap forms, bonded to an ice collar on the shell. As the level falls the cap hangs on the collar, loading the shell in bending and shearing the sealant; as the level rises, the cap is lifted against the roof structure. Ice in the vent screen blocks breathing; frost heave under a shallow ringwall lifts the first course.

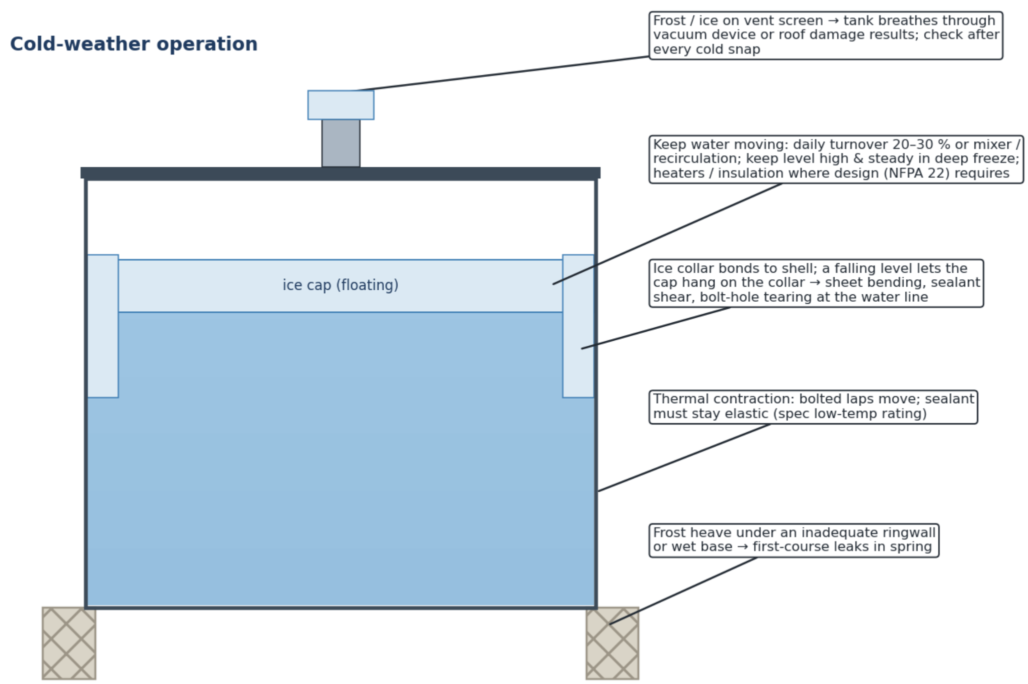


Figure 6 — Cold-weather mechanisms: ice collar and cap, vent icing, thermal contraction of the laps, frost heave at the base, and the operating measures that reduce them.

- **Keep the water moving.** Turnover of 20–30 percent a day, a mixer, or a recirculation loop prevents the cap from forming in most climates. Where the design (NFPA 22 fire tanks, very cold sites) includes heaters or insulation, keep them working and inspect them before freeze-up.
- **Keep the level high and steady** during deep-freeze periods rather than cycling deeply; a small daily swing under a thin cap does far less damage than a large one.
- **Check the vent after every cold snap.** A frost-plugged screen turns the tank into a vacuum vessel on the next draw-down; roof damage from vacuum is a common winter finding. Confirm the vent's frangible or pressure–vacuum feature is intact.
- **Watch the overflow.** An iced overflow pipe means the overflow is not available; ice on the splash pad means the tank is overflowing in freezing weather.
- **Inspect in spring** for the winter's damage: new weeping at the water-line courses, cracked sealant fillets, bent or displaced ladder brackets at the ice line, ice damage to the interior ladder and level float, and heave cracks in the ringwall.
- **Sealant work has a temperature window** (commonly above 40 °F and rising). Winter leak repairs are usually temporary; schedule the permanent repair for the shoulder season.

17. Insulated Tanks

Fire-protection tanks in freezing climates, process tanks holding warm liquid, and some potable tanks are insulated. The common bolted-tank system is a **panelized metal-jacketed insulation**: rigid foam board against the shell, an outer aluminum jacket, and a cable-and-band attachment that avoids drilling the tank. The description below is typical of current systems and is **for reference only**; the insulation manufacturer's drawings govern your tank.

- **Insulation.** Polyisocyanurate foam board, commonly 2–4 in. thick (3 in. is typical), with a double foil facer as a moisture barrier, on both shell and roof.
- **Jacket.** 0.024-in. stucco-embossed aluminum, factory-painted (siliconized polyester) in a standard color, formed with double-folded standing seams; roof panels in a 'parallel' layout to the roof slope; 0.016-in. aluminum on trim and beauty rings.
- **Attachment.** ¼-in. 7×19 stainless steel cables around the shell at about 3 ft centers, secured to the shell and jam-cleated at the roof; ½-in. × 0.020-in. stainless bands wrapped around the cables and locked into the panel seams; 3/16-in. bulb-type blind rivets at about 4 in. centers along laps and flashings; zinc-coated hardware; unpainted mill-finish rivets.
- **Flashings and seals.** Z-flashing and edge flashing at the roof edge; ridge cap at the roof peak; two-piece 'beauty rings' with down-weather overlaps at every nozzle, manway and roof penetration; polyurethane caulk / adhesive sealing the full perimeter of every flashing and penetration.
- **Sequence.** The tank is hydrotested and accepted first; then insulation; jacket coating damaged in handling is touched up with the jacket manufacturer's approved materials before acceptance.

Operationally, insulation changes the inspection problem: the shell seams, bolts and coating that Part V asks you to look at are hidden. The inspector's attention shifts to the things that let water reach the steel behind the jacket.

✓	Insulated-tank exterior — additional checks	What to look for / acceptance
☐	Jacket panels: seams locked, no lifted or wind-loosened panels, no dents holding water, no missing rivets	A lifted seam is a water path to the foam; re-seat and re-rivet in kind.

✓	Insulated-tank exterior — additional checks	What to look for / acceptance
☐	Base of jacket: bottom flashing / drip edge intact and clear of grade; no soil, mulch or snow banked against it; weep path open	Water trapped at the base of the foam sits against the first course — the highest-load steel in the tank.
☐	Roof edge Z-flashing, ridge cap and all penetration beauty rings: caulk continuous, no cracking or separation, overlaps facing down-weather	Re-caulk with the specified polyurethane; do not use silicone over polyurethane.
☐	Cables and bands: no broken or slack cables, no corroded band clips; panels not sagging	
☐	Staining or icicles emerging from the jacket; jacket panels warm/cold in a pattern (thermal camera) suggesting wet insulation	Wet foam has lost its R-value and is holding water against the shell — open the jacket locally and inspect the coating (CUI check).
☐	Penetrations added after insulation (conduit, instruments): sealed with a proper collar and caulk, not foamed or taped	
☐	Interior inspection interval: because the exterior seams cannot be seen, treat the interior inspection as the primary seam inspection and do not extend its interval	

18. Cathodic Protection

Cathodic protection (CP) protects the small areas of steel exposed at coating holidays, bolt-hole edges and damaged spots below the water line by making the steel the cathode of an electrochemical cell. It is a supplement to the factory coating, not a replacement for it, and it does nothing above the water line. Two systems are used in water tanks: sacrificial (galvanic) anode systems under **AWWA D106**, and automatically controlled impressed-current systems under **AWWA D104**.

Does a factory-coated bolted tank need cathodic protection?

Not always, and the standard does not require it. A new tank with an intact factory coating has almost no bare steel for a CP system to protect, and many bolted tanks — particularly glass-fused tanks and tanks in low-conductivity water — run their whole life without it. CP earns its cost where the coating is expected to develop holidays faster than the maintenance program will find them: aggressive or high-chloride water, chloraminated systems with elevated conductivity, high-turnover tanks with wet-dry cycling, epoxy tanks reaching mid-life, and any tank where the owner wants insurance against bolt-hole corrosion at the water line. Where a state regulator or a specification calls for CP, the design should be done to AWWA D104 or D106 by a corrosion specialist, sized for the coating's expected holiday area, and — critically — set so that it does not over-protect and blister the coating it is meant to supplement.

For the operator, the practical rules are simple: read and log the rectifier monthly; do not let a rectifier stay off for a season; keep anode strings clear of the ladder, the dome and any stainless fittings; and have the system surveyed by a specialist annually and inspected physically at every interior inspection. A CP system nobody reads is a set of consumable anodes and an electric bill.

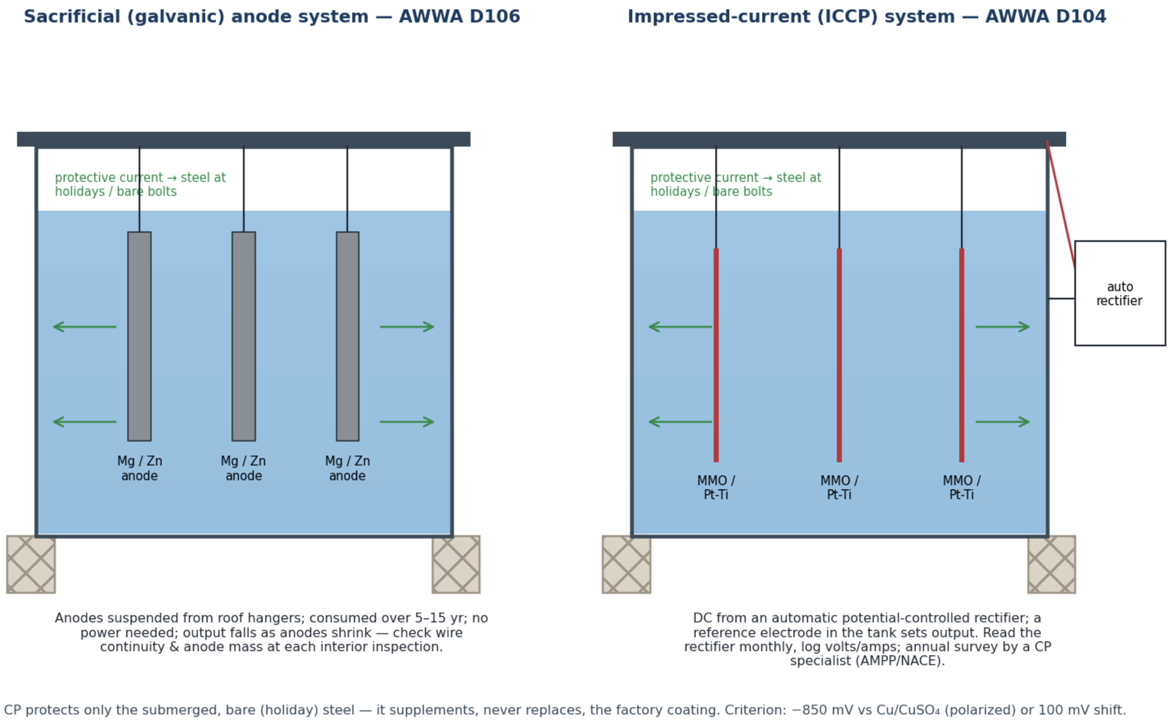


Figure 7 — Sacrificial-anode and impressed-current cathodic protection for the submerged interior. Both protect only bare steel below the water line and both need routine reading and periodic survey.

Table 12 — Cathodic protection systems compared.

Aspect	Sacrificial anodes (D106)	Impressed current (D104)
How it works	Magnesium or zinc anodes hung from the roof corrode preferentially and drive current to the steel.	A rectifier drives DC from inert (MMO or platinized-titanium) anodes to the steel; a reference electrode controls output automatically.
Best suited to	Small tanks, good coatings, low-conductivity water where little current is needed.	Larger tanks, older or damaged coatings, higher-conductivity water, ice-prone tanks (anodes can be raised).
Operator tasks	Visual check of hanger wires and continuity at each interior inspection; record anode consumption; replace at 50–75 % consumed (typically 5–15 years).	Read and log rectifier volts/amps monthly; annual potential survey by a CP specialist (AMPP/NACE); check reference cell and anode strings at interior inspections; raise anodes before freeze-up if the system is so equipped.
Criterion	Polarized potential of −850 mV vs. $Cu/CuSO_4$, or 100 mV polarization shift.	Same.
Watch for	Anodes consumed without anyone noticing; broken hanger wires lying on the floor; calcareous deposits on the coating (normal in moderation).	Over-protection (blistering of epoxy, hydrogen at glass) from an uncontrolled rectifier; rectifier off for months; anode strings shorted to the ladder or dome.

Stainless steel and galvanized tanks generally do not use interior CP; aluminum domes must be electrically isolated from any CP system, and CP current must never be allowed to find the dome.

Part IV — What-If Scenarios

Each scenario below follows the same structure: what you see, what it usually means, what to do now, what not to do, and what to do afterwards. The scenarios are written for the person on site with a radio, a flashlight and a camera. Where a scenario involves a structural or water-quality decision, the guidance is to stabilize, record and escalate — not to diagnose alone.

Triage: the first five minutes

Most of the scenarios begin the same way. Before working through the specific one, the person on site should settle three questions:

Table 13 — Three questions that come before every scenario.

Question	If yes	If no
Is anyone at risk? (structural movement, energized equipment, a roof that has moved, an open hatch above a full tank)	Clear the area, barricade, and call the supervisor before anything else.	Continue.
Is water leaving the tank faster than the system can tolerate, or is the tank's contents at risk of contamination?	Isolate the tank (close the outlet, stop the fill) and notify the supervisor and, if contamination is possible, the regulator.	Continue.
Can the condition be documented without climbing or entering?	Photograph with a scale reference, note level, temperature and weather, log by course / seam / degrees, and proceed with the scenario.	Do not climb or enter alone; arrange the access, fall-protection and confined-space controls first.

Severity in the scenarios follows the defect-log convention used throughout the guide: **A** — structural or water-quality, act now; **B** — will worsen, schedule within the year; **C** — cosmetic or monitor. Every scenario ends with a record entry, because the pattern of small findings over years is what tells an inspector whether a tank is aging normally or failing.

Table 14 — Notification matrix for tank events.

Who to notify	When	What they need from you
Supervisor / on-call operator	Immediately for any A finding; same day for B.	Location by ring/degrees, photographs, water level, what you have already done.
Tank manufacturer (service line)	Any active leak, structural sign, bolt cluster failure, coating question, before any repair beyond the manufacturer's touch-up procedure.	Tank serial number (nameplate), drawings revision, photographs, defect log entry, water level and temperature.
State drinking-water program	Open hatch or vent breach, suspected contamination, any event that takes a potable tank out of service, before re-disinfection and return to service.	Event description, samples taken, actions, proposed disinfection method (C652) and sampling plan.
Licensed structural engineer	Uplift, buckling, settlement out of tolerance, roof deformation, anchor distress, any change to loads on the tank.	Drawings and calculations, survey readings, photographs, the design-basis sheet.

Who to notify	When	What they need from you
Law enforcement / security	Evidence of entry, vandalism, gunshot damage.	Preserve the scene; photographs; times.
Insurer	Storm, earthquake, vehicle or vandalism damage.	Photographs before cleanup; the inspection report.

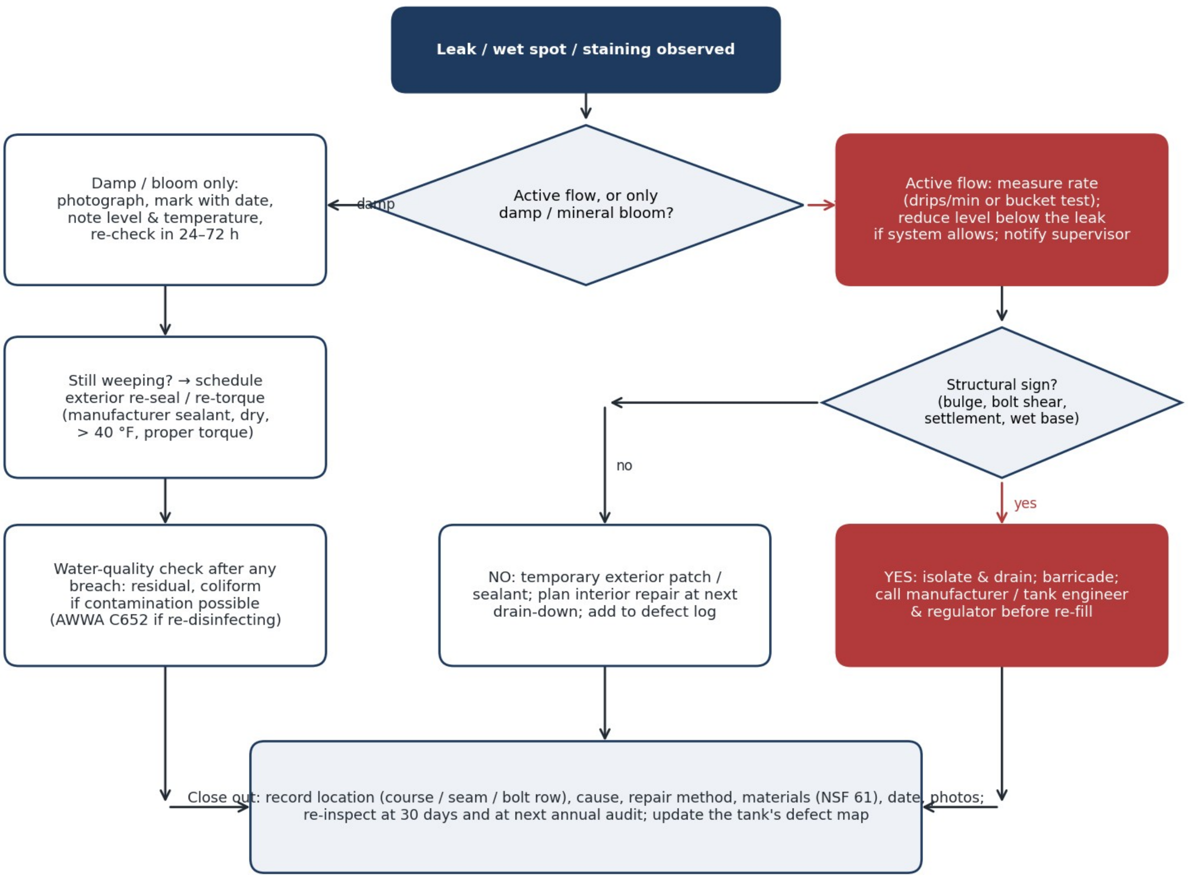


Figure 8 — Response flowchart for a leak, wet spot or stain. Most bolted-tank leaks are sealant or bolt-cap problems that can wait for a planned repair; the flowchart separates those from the few that cannot.

S1. A wet streak or mineral bloom below a horizontal seam

What you see	A damp line or a white/orange bloom on the exterior below a lap, usually at one or a few bolts, worse when the tank is full. No measurable flow.
What it usually means	Sealant has locally lost adhesion or the exposed fillet has cracked; on older tanks, coating undercutting at a bolt hole; on a new tank, uneven torque or a gap in the bead. Almost never structural.
Do now	Photograph with a scale; mark the location by course, seam and bolt count from a reference (the ladder); note level, temperature and weather; re-check in 24–72 h; add to the defect log.
Do not	Do not tighten the bolt with an impact wrench or 'just a bit more' — over-torque cracks glass and crushes sealant. Do not smear a hardware-store caulk over it.
Afterwards	Schedule an exterior re-seal (Part VI, Chapter 30) in a dry window above the sealant's minimum temperature; if several seams weep, plan an interior re-seal at the next drain-down and look for the systemic cause.

References	D103 Sec. 4.10, 10; manufacturer erection manual (torque, sealant).

S2. Active leak — a steady drip or stream

What you see	Water running from a bolt, a seam, a nozzle pad or the base joint; flow you can measure.
What it usually means	A failed bolt cap or bolt, a torn or missing sealant section, a sheared bolt, a corroded-through hole on an old tank, or a failed nozzle gasket. At the base of a Type 6 tank, a floor crack or ring interface.
Do now	Measure the rate (drips per minute or a bucket test); if the system allows, lower the level below the leak; notify the supervisor; barricade the area if the flow is eroding the base or icing; inspect the surroundings for other leaks. Apply a temporary exterior patch only if you can do it safely from the ground or a lift.
Do not	Do not enter the tank; do not climb a wet ladder to reach a leak; do not drain the tank in high wind without checking the empty-tank case; do not remove a leaking bolt while the tank is full above it.
Afterwards	Diagnose the cause (not just the symptom) at repair — if the bolt hole is corroded, the sheet may need replacement; if a bolt sheared, ask why. Re-inspect the repair at 30 days.
References	D103 Sec. 4.2, 10, 11; Chapter 30 repair procedures.

S3. Wet base — water at the shell-to-foundation joint

What you see	Dampness or flow at the joint filler line, the anchor chairs or the top of the ringwall; efflorescence or washed fines beside the foundation; the bottom 'drums' when tapped.
What it usually means	On steel-bottom tanks: a leaking bottom sheet or the shell-to-bottom lap, or surface water from grade sloping toward the tank. On Type 6 tanks: a floor crack or the ring-to-concrete interface. Loss of fill under the bottom if fines are washing out.
Do now	Distinguish rain/snowmelt from tank water (chlorine test strip or conductivity); photograph; mark the extent; check the overflow discharge is not the source; check grade and drainage.
Do not	Do not ignore washed-out fines — a bottom spanning a void is a structural condition; do not pump grout under the bottom without engineering.
Afterwards	If tank water: plan an interior bottom inspection (drain-down) and a settlement survey; if surface water: regrade and drain. Either way re-survey the ringwall level.
References	D103 Sec. 13.5, 13.7, 14.6.

S4. The tank is overflowing

What you see	Water discharging from the overflow; splash-pad erosion, algae or ice at the discharge; high-high alarm.
What it usually means	Level transducer drift or failure; altitude valve or pump control failure; a closed outlet; or an inlet flow greater than the overflow can pass (rising level above the overflow lip).
Do now	Stop or throttle the inflow at the source; verify the actual level by target board or float; confirm the overflow is discharging freely and the screen or flap is not restricting it; check the roof for ponding or vent discharge (a sign the overflow cannot keep up).
Do not	Do not close the overflow to stop the waste — that turns a nuisance into a pressurized-roof event; do not chlorinate the discharge area to 'sanitize' it.

Afterwards	Repair the control cause; recalibrate the level instrument; inspect the overflow pipe, screen and flap; repair the splash pad; check the top course and roof-to-shell joint for weeping after operating above MWL.
References	D103 Sec. 7.3, 7.7; Chapter 15.

S5. Vent screen blocked, iced or damaged

What you see	Frost or ice on the screen; a screen torn or missing; birds or insects inside; roof panels dished (vacuum) or lifted (pressure) after a large fill or draw.
What it usually means	Winter icing; screen corrosion; a retrofit screen finer than designed; vent capacity below the current pump rates after a pump upgrade.
Do now	Stop large fills and draws until the vent is clear; clear ice by hand (never with a torch on a coated or aluminum roof); inspect the roof for deformation; if the roof has moved, keep people off it and call the manufacturer.
Do not	Do not remove the screen 'until spring'; do not enlarge the vent opening yourself.
Afterwards	Confirm the vent's frangible or pressure–vacuum feature works; compare vent capacity with the maximum fill and withdrawal rates now in use; replace the screen with the specified mesh in a corrosion-resistant material; add the vent to the cold-snap check list.
References	D103 Sec. 7.7; Chapter 16.

S6. Heavy snow or ice on the roof

What you see	Snow depth beyond what the site usually sees; drifting against a taller structure or the ladder; ice on a dome; roof panels or dome members visibly deflected.
What it usually means	Roof live/snow load approaching the design value (a minimum of 15 psf is common where no higher snow load was specified — about 12 in. of settled snow or 3 in. of ice).
Do now	Estimate the load (measure depth and take a density sample); keep people off the roof; if the estimate approaches the design load, remove snow from the ground with a roof rake or by a contractor with a plan; monitor deflection.
Do not	Do not send staff onto a snow-loaded roof; do not chip ice off a coated or aluminum roof; do not use salt on a steel roof.
Afterwards	Compare the site's ASCE 7 ground snow load with the roof design load in the calculations; if the design is marginal for the site, get an engineering evaluation; inspect roof-to-shell joints and dome members in spring.
References	D103 Sec. 5, 5.7; AWWA D108 for domes.

S7. After a high-wind event

What you see	Lifted or missing dome panels; loose roof sheets; bent ladder cage; tank rotated or shifted (misaligned nozzles, cracked joint filler); debris impact marks; a partially empty tank that was in storm season.
What it usually means	Wind pressure on the shell and uplift on the roof; on an empty or near-empty tank, overturning or sliding at the base.
Do now	Keep clear of loose panels; check for leaks and for movement at the base and at every pipe connection; photograph everything before any cleanup; fill the tank to a normal level if it was low and the shell is sound.

Do not	Do not re-fasten dome panels or roof sheets with generic hardware; do not climb until the ladder and roof are checked.
Afterwards	Have the manufacturer or an engineer assess any movement or panel loss; verify anchor bolts and chairs; document as a storm claim if applicable.
References	D103 Sec. 15; AWWA D108.

S8. After an earthquake

What you see	Water on the ground around the base; wet streaks at the lower courses; buckling ('elephant foot') at the bottom course; bent or pulled anchor bolts; cracked ringwall; nozzle or piping displacement; overflow discharge from sloshing; dome damage from the wave.
What it usually means	Impulsive shear and overturning at the base, convective wave impact on the roof, and piping that could not accommodate the movement.
Do now	Isolate the tank if there is any sign of base uplift, buckling or nozzle damage; check the outlet and drain piping for leaks; sample the water if the roof or hatch was breached; photograph everything.
Do not	Do not refill a tank that has uplifted or buckled; do not tighten pulled anchor bolts.
Afterwards	Engineering inspection before return to service; compare observed behavior with the design J ratio and freeboard; check flexible couplings; if the tank performed poorly, the site seismic parameters or site class may need review.
References	D103 Sec. 14, 14.4, 14.5; Chapter 12.

S9. Settlement, out-of-round, or a bulge

What you see	The ladder no longer plumb; a horizontal seam that dips; cracked joint filler on one side; a bulge or flat spot in a course; bolts working loose along one seam; a pipe connection under strain.
What it usually means	Differential settlement of the foundation (poor fill, wet subgrade, washout), or a local overload; a bulge in the bottom courses is a structural finding.
Do now	Measure and record — level survey of the ringwall against the commissioning survey, plumb of the shell at several points, seam elevations; reduce the level if the manufacturer advises; check every pipe connection.
Do not	Do not add water or load to 'push it back'; do not shim or grout without engineering.
Afterwards	Engineering evaluation; monitoring points and a survey schedule; repair of drainage or fill; possible re-levelling (bolted tanks can sometimes be jacked and re-set).
References	D103 Sec. 13.2, 13.3, 13.6.1.

S10. Hatch found open, lock cut, or evidence of entry

What you see	Open or damaged hatch; footprints, tools or debris on the roof; foreign material visible in the water.
What it usually means	Vandalism, trespass, or a crew that forgot to lock up. In every case a potential contamination event.
Do now	Close and secure the hatch; do not disturb evidence; notify the supervisor and, per your plan, law enforcement; take samples per your emergency response plan (residual, coliform, and anything the situation suggests); consider isolating the tank until results are in.

Do not	Do not assume the water is fine because it looks fine; do not enter the tank.
Afterwards	Follow the state's requirements for a security breach; inspect the interior when the tank is next drained or by camera; upgrade locks, add a hatch alarm and camera; review the site's security assessment.
References	State drinking-water rules; AWWA J100 / G430 security guidance; AWWA C652 if re-disinfection is required.

S11. A coating chip, scratch or holiday is found

What you see	A chip at a bolt hole or sheet edge (glass); a scratch through to steel (epoxy); rust spots; blisters; a 'rust tear' below a bolt.
What it usually means	Handling or impact damage, undercutting from an old holiday, over-torque cracking (glass), or a wear point (ladder brackets, float guides).
Do now	Photograph and measure; note the location by course/sheet; if interior and the tank is full, log it for the next drain-down; if exterior, clean and patch with the manufacturer's kit within its application window.
Do not	Do not use a general-purpose epoxy or a spray can on an interior surface; do not grind glass; do not blast.
Afterwards	Track the defect count by zone over time — a rising count in the splash zone is the trigger for a coating condition survey at the next five-year inspection.
References	D103 Sec. 12.8, 12.9; Chapter 30.

S12. Low disinfectant residual, taste-and-odor, or a coliform hit traced to the tank

What you see	Residual at the tank outlet well below the inlet; complaints on the tank's pressure zone; positive samples; nitrification indicators in chloraminated systems.
What it usually means	Long water age from poor turnover; stratification; sediment and biofilm; an open or breached hatch or vent; a dead-leg overflow pipe with standing water.
Do now	Increase turnover (deeper cycle, mixer, flush the zone); sample top and bottom; inspect hatch, vent and overflow immediately; follow the regulator's notification and repeat-sample rules.
Do not	Do not dose chlorine into the tank through the hatch as a fix; do not exceed the coating manufacturer's disinfectant limits.
Afterwards	Clean the tank; evaluate a mixing system; correct the operating pattern; consider a tracer or CFD study for persistent problems.
References	AWWA G200; AWWA C652; state rules; Chapter 15.

S13. Ice damage discovered in spring

What you see	New weeping at the courses that were at the winter water line; sealant fillet shredded; bolts loose in a band; interior ladder bent; level float damaged; dome members bent near the wall.
What it usually means	Ice cap and collar loading the shell during level swings; ice lifted against the roof structure.
Do now	Photograph and log by course; re-check torque of the affected band with the manufacturer's value; re-seal the fillet; check the dome and interior ladder from the hatch with a camera.
Do not	Do not torque bolts on a glass-fused tank without confirming the value; do not assume a single dry season means the seam is fine.

Afterwards	Change the winter operating pattern (Chapter 16): higher, steadier levels and mixing; consider insulation or a heater if the design allows; schedule an interior inspection if the damage band is extensive.
References	Chapter 16; manufacturer O&M manual.

S14. Level instrument fails or reads wrong

What you see	Level frozen, jumping, or inconsistent with the target board or float; pumps cycling strangely; overflow or low-pressure complaints.
What it usually means	Transducer drift, plugged sensing line, frozen float, condensation in a radar/ultrasonic unit, wiring or SCADA scaling error.
Do now	Verify the level manually (target board, float, or a tape from the hatch with confined-space precautions); run the fill pumps in manual with someone watching the level until the instrument is repaired.
Do not	Do not run automatic fill on an instrument you cannot verify.
Afterwards	Repair and recalibrate; add a second, independent level indication if the tank has none; review alarm set-points against MWL and BCL.
References	Chapter 15.

S15. Gunshot, impact, or other penetration of the shell

What you see	A hole or dent; water jetting; a dent on a glass-fused tank surrounded by radial cracks.
What it usually means	Vandalism or accident. A penetration in a lower course is also a stress concentration in a highly loaded sheet.
Do now	Treat as an active leak (S2); if the hole is small, a temporary plug (a rubber-gasketed toggle bolt or a manufacturer's emergency patch) from outside is acceptable; secure the site; report to law enforcement.
Do not	Do not weld a patch; do not leave a dented glass-fused sheet unrepaired — the cracks propagate.
Afterwards	Sheet replacement is the usual permanent repair; check the neighboring sheets; interior coating repair around the hole.
References	D103 Sec. 8, 10, 12.8.

S16. Pipe break at or near the tank, or thrust at a nozzle

What you see	Water from a nozzle flange or pad; a flexible coupling extended or bent; a pipe pulled off its supports; frost heave lifting the pipe.
What it usually means	Thrust not restrained on the pipe; settlement; frost; a coupling that was never free to move; water hammer from a pump trip.
Do now	Isolate at the nearest valve; drain the pipe, not the tank, if possible; support the pipe so its weight is off the nozzle; photograph the coupling positions.
Do not	Do not restrain the pipe to the tank shell; do not weld on the nozzle.
Afterwards	Restore restraint on the pipe side; check the nozzle reinforcing pad seams for weeping; review the seismic and settlement flexibility requirements (Sec. 14.5) for the connection.
References	D103 Sec. 7.2, 14.5, 13.7.2.

S17. Rapid draw-down (fire flow, main break) and the tank 'pops'

What you see	A loud bang or oil-canning during a fast draw; a dished roof or dome; an inward dent in a top course.
What it usually means	Withdrawal faster than the vent can admit air — a vacuum. Common where pump capacity was added after the tank was built, or the vent was partially blocked.
Do now	Stop or slow the withdrawal; open the hatch (with precautions) to relieve vacuum if the roof is deforming; keep people off the roof.
Do not	Do not refill fast — the reverse (pressure) case is just as bad.
Afterwards	Compare vent capacity with the maximum system withdrawal rate; have the roof inspected; add vacuum relief if warranted; brief fire-flow operations on the limit.
References	D103 Sec. 7.7; Chapter 8.

S18. Missing, sheared or corroded bolts

What you see	A bolt hole with no bolt; a bolt head or nut lying at the base; a row of bolts with rust tears; a bolt that turns freely.
What it usually means	Corrosion of unprotected threads, over-torque, hydrogen embrittlement of high-strength bolts in a corrosive environment, ice loading, or bolts omitted at erection.
Do now	Count and map missing or damaged bolts by course and seam; if any are in the bottom two courses or along one seam in a cluster, report the same day; replace only with the manufacturer's bolts, sealant and caps.
Do not	Do not run the tank full with a cluster of missing bolts in a lower course; do not substitute a longer or different-grade bolt.
Afterwards	Sample bolts for the manufacturer; check the encapsulation and plating spec against the environment; consider a bolt survey across the tank if more than a handful are affected.
References	D103 Sec. 4.2, 5.3, 10.

S19. Aluminum dome or roof-to-shell joint leaking into the tank

What you see	Rain water streaks inside below the tension ring; white corrosion products on aluminum members; dripping at batten bars; birds inside.
What it usually means	Failed batten-bar gaskets or perimeter flashing; galvanic attack at the dome-to-steel interface where isolation has failed; loose or missing fasteners.
Do now	Photograph from the hatch; check the tension ring and perimeter flashing from the roof (with fall protection); confirm the hatch and vent are not the entry point.
Do not	Do not seal the dome perimeter with a sealant that traps water against the aluminum; do not use dissimilar-metal fasteners.
Afterwards	Dome manufacturer's inspection; replace gaskets and fasteners in kind; verify isolation and that the dome is not bonded to the CP system.
References	AWWA D108; D103 Sec. 5.7, 7.8.

S20. Lightning strike or electrical fault

What you see	Scorched coating spots; arc marks at the base, ladder or grounding; instrument or rectifier failure; a dome fastener blown.
What it usually means	Lightning attachment to the tank or a strike on the site wiring; a CP rectifier ground fault.
Do now	Check the grounding and bonding; inspect the strike point for coating damage (holiday) and repair; verify the rectifier and level instrument.
Do not	Do not assume the dome or ladder is a designed lightning path.
Afterwards	Review lightning protection (NFPA 780) and bonding of the dome, ladder, piping and CP system.
References	NFPA 780; AWWA D104.

Part V — Issue Checklists by Component

These checklists are written to be printed and carried. Each line names a condition; the right-hand column says what acceptable looks like or what a finding means. Findings go into the defect log (Appendix F) with a location, a photograph and a severity: **A** — structural or water-quality, act now; **B** — will worsen, schedule within the year; **C** — cosmetic or monitor. The inspection zones in Figure 5 are used throughout.

Using the checklists in the field

- **Walk the same route every time** — base circuit clockwise from the 0° mark, then each course line with binoculars, then the roof — so that omissions are obvious and photographs are comparable year to year.
- **Carry the elevation and orientation drawings**, a tape, a camera with a scale card, a flashlight, binoculars, chalk or a paint stick for marking, a clean rag for the touch test on sealant, and the defect log.
- **Tick every line**, including the ones with no finding; an unticked line is an uninspected item, not a clean one.
- **Photograph before touching.** A wet spot dries, a loose cap falls off, a crack fills with rain; the record is the first photograph.
- **Give every finding a severity the same day**, and escalate every A finding the same day. Deferring the severity decision to the report is how urgent items get lost.
- **Never climb or enter alone.** Roof visits need fall protection and a second person; interior entry needs the confined-space program, atmospheric testing and a rescue plan — even on an empty, open tank.
- **Close the loop.** A checklist that does not end with entries in the defect log and a date for each repair has recorded conditions without managing them.

Photographs that are worth keeping

A finding photograph should answer three questions without a caption: where on the tank, how big, and what does it look like up close. Take a wide shot that includes a fixed reference (the ladder, a nozzle, the 0° mark), a medium shot showing the course and seam, and a close-up with a scale card or a tape in frame. Name the files by date, ring and degrees. The annual reference-point photographs (Appendix F) are taken from marked spots at the same focal length so that a chalking patch or a rust bloom can be measured year over year by laying the frames side by side.

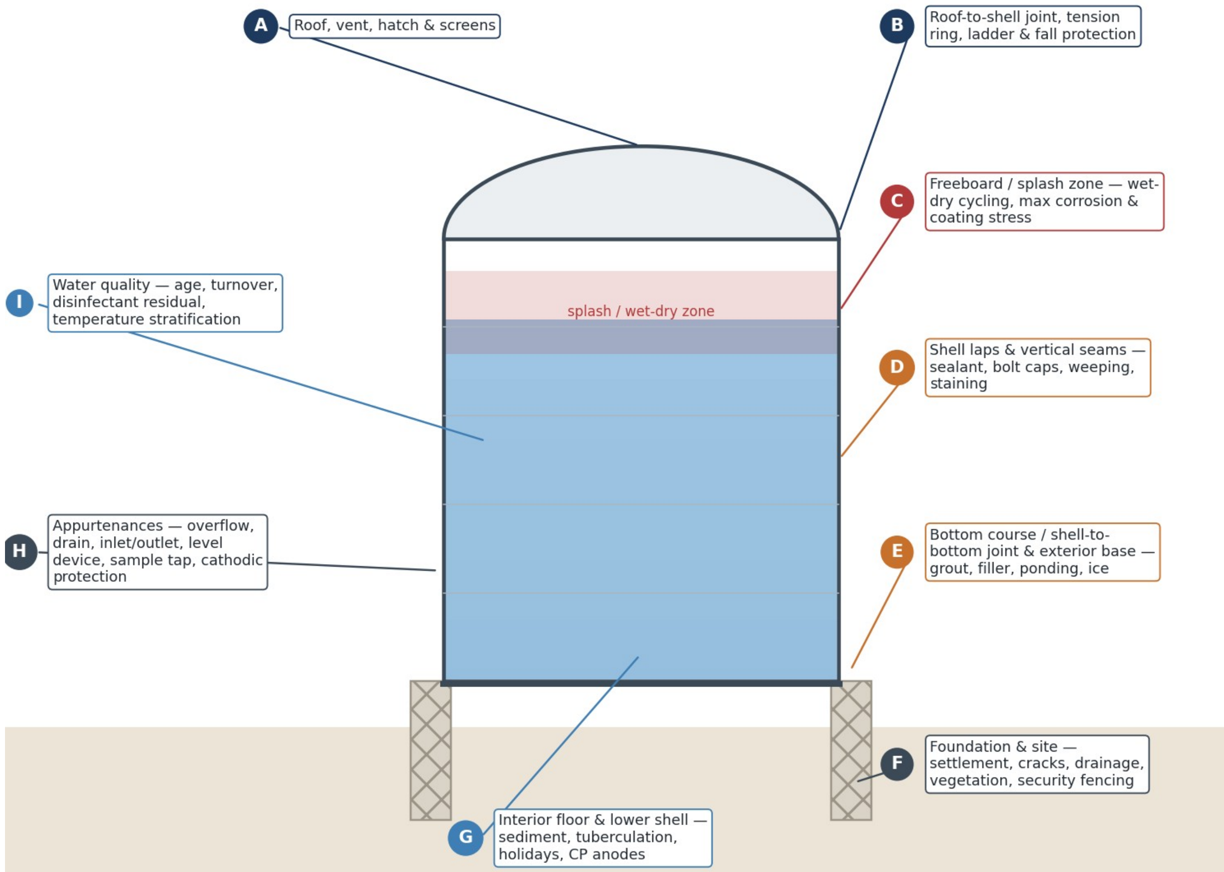


Figure 9 — Inspection zones A–I used in the checklists and audit forms. The splash zone (C) and the base (E, F) are where most findings originate.

19. Foundation and Site (Zone F)

✓	Foundation and site	What to look for / acceptance
☐	Grade slopes away from the tank on all sides; no ponding within 10 ft	Standing water against the ringwall or slab is a B finding; ponding at the shell is an A finding on Type 6 tanks.
☐	Top of foundation at least 6 in. above grade all around	Grade creep, mulch, gravel or paving raised against the shell must be cut back.
☐	Ringwall / slab free of structural cracks, spalls, exposed rebar	Hairline shrinkage cracks are normal; cracks wider than 1/16 in., offset cracks, or cracks aligned with anchor bolts are B; any displacement is A.
☐	Joint filler intact around the full circumference; no gaps, no extrusion, no vegetation	Missing filler lets water sit under the shell; replace in kind.
☐	No fines washed out, no voids under the bottom (tap test / probe at the ringwall)	Drumming bottom or visible voids: A finding — void under a loaded bottom.
☐	Anchor bolts: present, plumb, nuts tight, no corrosion loss, chairs sound, no concrete cracking at bolts	Corrosion loss of section, bent bolts or cracked chairs on an anchored tank are A.

✓	Foundation and site	What to look for / acceptance
☐	Settlement survey points readable; readings within tolerance of the baseline	Change > ¼ in. from plane or > ⅛ in. in 30 ft since baseline triggers an engineering review.
☐	Overflow splash pad intact; discharge point free; no erosion channel	Erosion means chronic overflow — fix the control cause.
☐	Pipe cover and trench backfill not settled; valve boxes at grade	Settled trench beside the ringwall may be undermining it.
☐	Site fence, gate, signage, lighting; vegetation cleared 3 ft from the shell; no stored materials against the tank	Security and fire-access finding; vegetation traps moisture against the base.
☐	Lightning protection and grounding conductors intact and bonded	Corroded or cut down-conductors.

20. Shell Exterior, Seams and Bolts (Zones D, E, C)

✓	Shell exterior	What to look for / acceptance
☐	Walk the full circumference at the base and at each course line; note every wet spot, streak, bloom or stain by course/seam/bolt	Any active flow = S2; damp spots = S1. Map them — a pattern along one seam differs from scattered spots.
☐	Exposed sealant fillets continuous, adhered, pliable; no cracking, chalking, gaps or extrusion	Cracked or missing fillet on a dry seam is C; on a wet seam B; along a whole course B–A.
☐	Bolt heads / caps: all present; caps not cracked, faded to chalk, or missing; no rust bleeding from under caps	Missing or split caps are B (they become S18); rust tears from many bolts in a zone indicate plating failure — sample for the manufacturer.
☐	No missing, loose or sheared bolts (sight along each seam; tap suspect bolts)	Any missing bolt in the bottom two courses is A.
☐	Sheets flat and true; no bulges, flat spots, dents or oil-canning	Bulge in a lower course A; dent with cracked glass B; cosmetic dent above the water line C.
☐	Coating: chalking, fading, checking, blistering, peeling, rust spots; measure and map	Exterior epoxy chalking is normal aging (C); blistering or peeling to steel is B; rust at bolt holes in the splash zone is the first sign of undercutting (B).
☐	Stiffener rings and tension ring: attachment bolts tight; no corrosion at the ring-to-shell contact; no ponding on top of exterior rings	Corrosion at the ring attachments is a wind-capacity finding (B).
☐	Nozzle reinforcing pads: no weeping at pad seams; flanges tight; couplings free; pipe supported independently	Weeping at a pad is B; a coupling bottomed out or a pipe hanging on the nozzle is A.
☐	Manway: cover bolts all present and tight; gasket not extruded; no weeping; davit or hinge functional	

✓	Shell exterior	What to look for / acceptance
☐	Level indicator, sample tap, drain valve: operable, no leaks, drain valve locked closed	
☐	Dissimilar-metal contacts (SS fittings, aluminum, brass) isolated; no galvanic corrosion products	White or rust bleed at a dissimilar joint is B.
☐	Splash-zone band (about 2 ft either side of normal top level): closer look for rust spots, blister rows, sealant condition	The zone with the highest defect count; trend it year over year.

21. Coating-Specific Checks

Table 15 — Coating and material-specific inspection points.

System	Look for	Finding / action
Thermoset powder / liquid epoxy	Chalking and color fade (exterior); checking; blisters (interior at holidays); rust spots at bolt holes and sheet edges; soft or discolored coating near chlorine injection or high-strength disinfectant contact; undercutting at old repairs.	Chalking: C, plan an exterior overcoat when gloss and film are gone. Blisters or rust: B, patch per manufacturer; a rising count in the splash zone triggers a DFT and holiday survey at the 5-year inspection. Softening: check disinfectant practices.
Glass-fused-to-steel	Chips at bolt holes and sheet edges; fishscale (half-moon flakes) anywhere; crazing (fine crack network); rust at chips; impact stars; failed epoxy patches (edges lifting).	Chip with bare steel: B, patch. Fishscale appearing on several sheets: B, notify manufacturer (a manufacturing defect); map sheet marks (Sec. 12.7). Many chips in one area: look for the cause (ice, rigging, ladder contact).
Hot-dip galvanized	White rust (zinc corrosion) especially at laps and low spots; red rust (zinc consumed); thin or missing coating at cut edges; runs and drips holding water.	Red rust: B — the sacrificial layer is gone there; interior red rust in a potable tank: A for water quality review and a lining decision.
Stainless steel	Pitting (small dark pits) especially in laps, under gaskets and at the water line; rust staining from carbon-steel contamination; crevice corrosion at bolts; tea staining in coastal air.	Contamination staining: B, clean and re-passivate. Pitting: B–A depending on depth; measure and trend; consider chloride levels and 316 upgrade for replacement sheets.
Aluminum dome	White corrosion powder; pitting at batten bars and the tension ring; galvanic attack where isolation failed; loose or missing stainless fasteners; sealant failure at battens; skylight or hatch panel cracking.	Galvanic attack at the steel interface: B; missing fasteners: B; leaks into the tank: B–A (water quality).

22. Roof, Dome, Vent, Hatch and Overflow (Zones A, B)

✓	Roof and appurtenances	What to look for / acceptance
☐	Roof surface: no ponding, no deflected panels, no loose or missing fasteners, no debris	Ponding on a bolted steel roof means a slope or support problem (B).
☐	Roof-to-shell joint / tension ring: no gaps, no weeping into the tank, sealant intact, isolation gaskets present under an aluminum dome	
☐	Vent: screen intact, correct mesh, clean; free of paint, ice, nests; frangible or vacuum feature intact; capacity adequate for current pump rates	Any breach in the screen is a water-quality finding (A under most state rules).

✓	Roof and appurtenances	What to look for / acceptance
☐	Roof hatch: curb ≥ 4 in.; cover overlaps ≥ 2 in.; gasket intact; hinge and hasp functional; locked; no ponding at the curb	
☐	Other roof penetrations (mixer, CP, level, antenna): sealed, screened, gasketed; no unauthorized additions	Unauthorized equipment on the roof is B until the manufacturer approves it.
☐	Overflow: weir box clear; pipe unobstructed; screen or flap present and functional; discharge free with air gap; no standing water in the pipe	A blocked or unscreened overflow is a water-quality finding.
☐	Handrails and fall-protection anchors on the roof: sound, rated, labeled; dome handrail posts not corroded at the base	
☐	Lightning air terminals and conductors intact	

23. Ladders, Access and Safety (Zone B)

✓	Ladders and safety	What to look for / acceptance
☐	Exterior ladder: rungs and rails sound; brackets not corroded at the shell; ladder guard fitted and locked	Corrosion at brackets is common — the coating is breached there.
☐	Fall protection: cage or safety-climb device present and serviceable; cable tension, top bracket and sleeve inspected per the device manufacturer; OSHA 1910.28 compliance for the installation date	Cages alone do not satisfy current OSHA for new installations; existing cages must be maintained.
☐	Rest platforms and roof landing: sound; toe boards; no trip hazards	
☐	Interior ladder (from the hatch by camera or at inspection): brackets sound, not bent by ice, isolated from the coating	
☐	Confined-space signage, entry permit program, rescue plan for the tank; atmospheric monitor calibrated	
☐	Site hazards: overhead lines near the ladder, guy wires, uneven ground at the base	

24. Interior (Zones G, C, H) — Drained or by ROV / Diver

✓	Interior condition	What to look for / acceptance
☐	Floor: sediment depth (measure at several points); debris; standing water after drain; coating condition under sediment; drumming or flexing sheets; bottom laps and sealant	Sediment > 1 in. justifies cleaning; flexing sheets: void under the bottom (A).
☐	Shell-to-bottom joint: sealant fillet, bolt caps, corrosion, weeping marks	The highest-load joint in the tank — any corrosion is B–A.
☐	Lower courses: bolt caps, sealant, coating holidays, rust nodules (tuberculation) on carbon steel, pitting on stainless	
☐	Splash / wet-dry zone: blister rows, rust spots at bolt holes, sealant embrittlement, ice damage	Typically the worst zone; DFT and holiday-test a sample area here.

✓	Interior condition	What to look for / acceptance
☐	Upper shell and underside of roof: condensation corrosion, coating condition, roof support corrosion, dome underside, tension-ring corrosion, bird or insect intrusion	
☐	Nozzles, overflow weir, drain sump, level float and stilling well, mixer, sample lines: condition, gaskets, corrosion, fouling	
☐	Cathodic protection: anode condition and consumption, hanger wires, reference cell, insulation of lead wires, evidence of over-protection (blisters, calcareous deposits)	
☐	Interior ladder and any platforms: brackets, corrosion, ice damage	
☐	Foreign objects: bolts, tools, debris, biofilm mats	Carbon-steel debris on a stainless or glass floor is B — remove and check for staining.
☐	Coating survey: DFT readings (SSPC-PA 2) and holiday test on representative areas by zone; adhesion test if lining replacement is being considered	Trend against commissioning values; a systemic loss of film in the splash zone is the trigger for re-lining planning.

Part VI — The Maintenance Program

25. Philosophy and the Ten-Year Calendar

Bolted tanks are low-maintenance structures, not no-maintenance structures. Their maintenance is almost entirely **inspection and small, timely repair**: a sealant fillet renewed before it lets water under the coating; a bolt cap replaced before the bolt rusts; a chip patched before it undercuts; a vent screen replaced before a bird finds it. Left alone for twenty years the same tank needs sheet replacement and a re-lining campaign. The program below is built on three audits of increasing depth, on a fixed calendar, with a defect log that carries findings from one to the next.

What a bolted-tank maintenance program costs — and saves

Because a bolted tank's coating is applied in the factory, the two largest costs in a welded tank's life — periodic abrasive blasting and field recoating of the interior and exterior, with the containment, lost storage and water-quality disruption that go with them — are largely absent. In their place is a steady, predictable program of small items. In relative terms:

Table 16 — Relative cost picture of a bolted-tank maintenance program (orders of magnitude only; site conditions govern).

Activity	Typical interval	Relative cost	What it avoids
Routine and quarterly visits	Weekly–quarterly	Staff time only	Missing an active leak, an open hatch or a blocked vent.
Annual exterior audit with minor re-sealing and cap replacement	Yearly	Low — a day or two of labor plus sealant and caps	Undercutting at seams and bolt holes, which becomes sheet replacement.
Biennial detailed audit (lift or rope access, torque sampling, survey)	Every 2 years	Low–moderate	Systemic torque loss, settlement, coating loss found late.

Activity	Typical interval	Relative cost	What it avoids
Interior drain-down inspection and cleaning	Every 2–5 years	Moderate — outage, cleaning, disinfection, inspector	Sediment-driven water-quality events; floor and base-angle corrosion.
Exterior overcoat (epoxy / polyester systems)	15–25 years, when chalking and film loss are general	Moderate — a fraction of a welded tank's recoat, no interior work	Exterior undercutting; appearance complaints.
Sheet replacement	As needed	Low per sheet; manufacturer crew	The alternative to a lining campaign for localized damage.
Interior re-lining	Rarely required if the program above is kept	High — the welded-tank-style outage	—

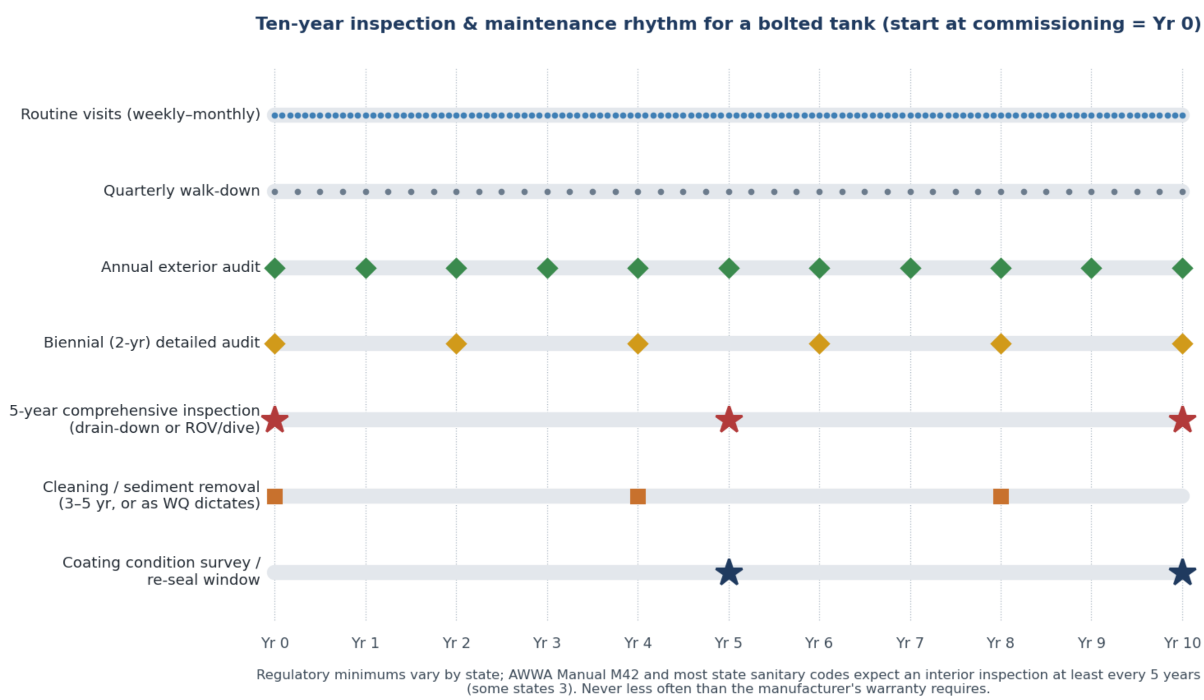


Figure 10 — The ten-year inspection and maintenance rhythm: routine visits, quarterly walk-downs, the annual exterior audit, the biennial detailed audit, the five-year comprehensive inspection, cleaning, and the coating condition survey.

Table 17 — The maintenance program at a glance.

Activity	Frequency	Who	Scope in brief
Routine visit	Weekly to monthly, per site	Operator	Walk the base, glance at the overflow and vent, verify level and alarms, check the hatch lock, read the CP rectifier, note anything new.
Quarterly walk-down	Every 3 months (and after any storm, freeze or earthquake)	Operator	Full exterior circuit at base level with a camera; roof visit if safe; overflow test; vent check; sealant and bolt cap scan of the lower courses.

Activity	Frequency	Who	Scope in brief
Annual exterior audit	Every 12 months, shoulder season	Utility maintenance lead (or consultant)	Part V checklists 19–23 in full; roof and dome; ladder and fall protection; instrument calibration; CP; defect log review; report.
Biennial detailed audit	Every 24 months (replaces that year's annual)	Consultant or trained utility inspector	Annual audit plus torque sampling, exterior coating DFT and adhesion spot checks, settlement survey, drone/photo survey, interior look from the hatch, CP potential survey, records and design-basis review.
Five-year comprehensive inspection	Every 60 months (some states 36)	Qualified tank inspector; ROV/diver contractor or drain-down crew	Everything above plus the full interior (checklist 24), coating survey, sediment, structural review, and a condition report with a repair plan and a re-lining outlook.
Cleaning	3–5 years or as water quality dictates	Contractor / utility	Sediment removal, floor and lower-shell wash-down within coating limits, disinfection (C652), return to service.
Coating condition survey	At the 5-year inspection; annually once the survey shows systemic loss	Coating inspector (SSPC/AMPP certified)	DFT, holiday and adhesion testing by zone with a remaining-life estimate.

Timing

Do the annual audit in the shoulder season (spring or fall) when the sealant can be repaired the same week if needed and the tank is neither iced nor at peak demand. Do the five-year inspection in the low-demand season and plan the drain-down with the wind case and freeze exposure in mind.

What the manufacturer's own manual typically requires

Most bolted-tank manufacturers issue a short customer inspection and maintenance manual, and its intervals are usually **conditions of the warranty**. The program in this guide is built to satisfy a typical manual and add to it; the manual's own requirements are summarized here **for reference only** — read the one issued with your tank.

Table 18 — Typical manufacturer inspection and maintenance requirements (for reference only).

Item	Typical manufacturer requirement	Where it sits in this guide
Site	Remove debris that has accumulated against the shell or appurtenances.	Routine visit; Checklist 19.
Concrete ringwall / slab	Annually examine for fractures or distortion that could load the shell eccentrically; check for voids or gaps between tank bottom and foundation from settlement; confirm anchor bolts (if any) are snug-tight.	Annual audit; Checklist 19.
Granular berm foundation	Annually check for wash-outs; maintain drainage away from the tank; keep vegetation clear within 5 ft and trees within 30 ft of the tank.	Annual audit; Checklist 19.
Shell seams	Monthly: check all seams for distortion from structural stress (consult the manufacturer if found) and for any sign of leaks.	Routine visit (monthly); Checklist 20.
Roof and exterior	Check the exterior roof for corrosion, loose connections and coating damage; inspect the tank generally for corrosion.	Quarterly walk-down; Checklists 20–22.

Item	Typical manufacturer requirement	Where it sits in this guide
Pressure-relief manway / PV vent	Inspect and wipe the seat ring and gasket; check for free movement; in cold climates inspect often for condensation icing; clean the screen and replace if deteriorated.	Routine visit; Checklist 22; Scenario S5.
Free-flowing vent	Clean the screen as required; check the wire for deterioration; watch for icing in cold climates.	Routine visit; Checklist 22.
Nozzles and piping	Check for distortion of the shell at pipe attachments caused by differential settlement between tank and piping; remove it by adjusting the pipe supports.	Checklist 20; Scenario S16.
Target-board level indicator	Annually: indicator rides freely; board clean; sheave rollers turn smoothly (remove the inspection plate); float cable free of wear or broken strands; do not lubricate any part; bolts tight against wind; keep the board clear of ice.	Annual audit.
Valves, sample boxes, sight glass, gauges	Annually inspect for smooth operation; clean and repair as required.	Annual audit.
Ladder, cage, handrails	Inspect coatings for corrosion or damage; report corrosion with photographs to the manufacturer; repair coating damage with the manufacturer's touch-up procedure.	Annual audit; Checklist 23.
Lightning protection	Annually inspect rods, conductors and clamps for good electrical connection.	Annual audit.
Interior	Every two years (or as the tank dictates): drain, remove sediment and flush; check the interior and roof support structure for corrosion and distortion; check the coating for wear from liquid movement; inspect the nuts on the bottom; check interior appurtenances; confirm all materials, tools and equipment are removed before return to service; disinfect potable tanks per local code.	Biennial audit — see note below; Checklist 24; Chapter 31.
Added equipment	Installing any appurtenance or equipment that overstresses the tank voids the warranty; obtain the manufacturer's recommendation before adding loads.	Chapter 15 'never do' list; biennial design-basis review.

Interior interval — the manufacturer's manual may be stricter than the state

Where the manufacturer's manual calls for the interior to be drained and inspected **every two years**, that interval governs for the life of the warranty and is good practice afterwards; the five-year comprehensive inspection in this guide is then the deeper, documented version of every second or third interior look, not a substitute for the two-year one. On an insulated tank, or a tank whose exterior seams cannot be seen for any reason, treat the interior interval as fixed.

26. Routine and Quarterly Tasks

✓	Routine visit (weekly–monthly)	Notes
☐	Level, alarms and pump status consistent; no overflow discharge	
☐	Base walk: any new wet spot, stain or bloom; anything leaning on the tank	

✓	Routine visit (weekly–monthly)	Notes
☐	Monthly seam check (manufacturer requirement): sight along every visible seam for distortion and for any sign of leakage	Report seam distortion to the manufacturer the same week.
☐	Vent screen visible and clear (binoculars); no birds around the roof	
☐	Hatch locked; ladder guard locked; fence and gate secure; no signs of entry	
☐	CP rectifier on; volts/amps logged; within the specialist's range	
☐	Mixer running (if fitted); sample-tap residual within range	
☐	Weather note: freeze, storm, high wind since last visit → trigger the quarterly walk-down	

✓	Quarterly walk-down (and after any storm, freeze or earthquake)	Notes
☐	Full circumference at the base with a camera; photograph each new finding with a reference	
☐	Scan every seam and bolt row visible from the ground with binoculars; count missing caps and loose bolts	
☐	Overflow: pour test or observe a controlled fill to the lip; screen and flap operate; discharge free	
☐	Vent: screen condition, ice, nests, relief feature	
☐	Sealant fillet condition on the lower two courses (touch test at reachable height)	
☐	Joint filler and foundation top; grade; splash pad; drainage	
☐	Roof visit if conditions allow: hatch, vent, penetrations, panels, handrails, dome fasteners	
☐	Instrument check: level vs. target board	
☐	Update the defect log; escalate any A finding the same day	

27. The Annual Exterior Audit

The annual audit is a full application of checklists 19 through 23, carried out by someone with the authority to schedule repairs, and closed with a short written report. The audit form below adds the items that are specific to the yearly cycle.

✓	Annual audit — additional items	What to look for / acceptance
☐	Review the defect log: every open B item has a repair date; every A item is closed	The log is the audit's starting point, not its output.
☐	Compare this year's photographs with last year's at the fixed reference points (Appendix F)	Change, not condition, is what an annual audit detects.

✓	Annual audit — additional items	What to look for / acceptance
☐	Sealant: touch-test reachable fillets at every course; renew any section that is cracked, chalked or non-adherent	Plan lift access for upper courses every second year.
☐	Bolt caps: replace all missing or split caps found within reach; count and locate those above reach	
☐	Exterior coating: map new rust spots, blisters and chalking by zone; measure DFT at the same 12 reference points each year	A reference grid makes the trend meaningful.
☐	Level instrument: calibrate against a physical measurement; verify alarm set-points against MWL and BCL	
☐	Overflow: confirm capacity ≥ maximum current fill rate (pump upgrades change this); flap valve seats; screen mesh correct	
☐	Vent: confirm capacity ≥ maximum fill and withdrawal rates; replace screen if corroded	
☐	Ladder and fall protection: device inspected per its manufacturer; cage and brackets; document	
☐	Cathodic protection: annual potential survey (ICCP) or rectifier and reference check; anode plan	
☐	Foundation: settlement survey readings at the fixed points; joint filler renewed where missing	
☐	Roof and dome: full checklist 22 with roof visit	
☐	Water quality: review the year's residual, temperature and sampling data for the tank; turnover adequate?	
☐	Security: locks, hatch alarm, camera, fence; review the site's vulnerability assessment	
☐	Records: update the tank data sheet; file the report, photographs and DFT readings	
☐	Warranty: confirm the inspection satisfies the manufacturer's warranty conditions; notify the manufacturer of any warrantable finding in writing	

28. The Biennial Detailed Audit

Every second year the annual audit is extended to include measured checks that need equipment, access or outside expertise. The intent is to catch the slow processes — torque relaxation, coating thinning, settlement, CP drift — before the five-year inspection has to deal with their consequences.

✓	Biennial audit — additional items	What to look for / acceptance
☐	Bolt torque sampling: check a statistically useful sample (e.g., 5 % of bolts on the lower two courses and at every nozzle pad) with a calibrated wrench at the manufacturer's value; record and map	Systematic low torque on a course is a B finding and a re-torque program.

✓	Biennial audit — additional items	What to look for / acceptance
☐	Exterior coating: DFT at the reference grid plus 20 random points per zone; adhesion (ASTM D3359 or D4541) at two non-critical exterior spots; holiday test of any patch made in the last two years	
☐	Lift or rope-access inspection of upper-course seams, stiffeners, tension ring and roof-to-shell joint at close range	
☐	Drone or pole-camera photographic survey of the full exterior and roof for the record	
☐	Settlement survey by a surveyor against the commissioning benchmarks; plumb of the shell at four points	
☐	Interior look from the hatch with a camera or ROV without draining: water line band, ladder, float, anodes, sediment depth by pole	Where the manufacturer's manual requires a two-year drain-down, do the drain-down instead: remove sediment and flush, inspect the roof support structure for corrosion and distortion, inspect the floor nuts and caps, check coating wear, and confirm all tools and materials are removed before return to service.
☐	CP: full potential survey and anode condition estimate (ICCP and galvanic); rectifier calibration	
☐	Overflow and vent capacity recalculated against current maximum flows; alarm set-points reviewed	
☐	Design-basis review: any change in risk category, added equipment, new adjacent structures (snow drift, wind), changed stored liquid, new pump capacity, site development affecting drainage	Changes to the design basis need the manufacturer's or an engineer's concurrence.
☐	Records review: are drawings, calculations, coating certifications, NSF listings and the repair kit on file and in date?	
☐	Written report with repair plan and budget for the next two years	

29. The Five-Year Comprehensive Inspection

The five-year inspection is the one in which the interior is seen, measured and reported by someone qualified to judge coating and structural condition, and in which the tank's remaining life is estimated. State sanitary codes commonly require an interior inspection at this interval (some at three years); AWWA Manual M42 describes the practice. It is either a **drain-down inspection** (the tank emptied, cleaned, entered under confined-space controls, then disinfected and returned to service) or an **in-service inspection** by a remotely operated vehicle or a certified potable-water diver. Drain-down gives the better inspection and allows repair; in-service inspection avoids the outage and the empty-tank wind exposure but cannot repair sealant or coating.

Planning

✓	Five-year inspection — planning	What to look for / acceptance
☐	Choose drain-down vs. ROV/diver based on: system redundancy, season, wind exposure of the empty tank, known defects needing repair, and the last drain-down date (do a drain-down at least every other cycle)	
☐	Regulator notification and any required approvals for out-of-service and return-to-service	
☐	Inspector qualifications: tank inspection experience with bolted tanks; coating inspector certification (AMPP/SSPC); confined-space and fall-protection program; diver certification for potable work if used	
☐	Manufacturer engaged for repair materials, torque values and, if wanted, a representative on site	
☐	Drain plan: discharge point, dechlorination (AWWA C655), rate, empty-tank wind check with the manufacturer	
☐	Cleaning plan within coating limits (pressure, no abrasives); sediment disposal	
☐	Return-to-service plan: repairs, sealant cure time, disinfection method (AWWA C652), sampling, refill rate within vent capacity	
☐	Baseline documents on site: drawings, previous reports, defect log, DFT records, sheet marking key	

Interior inspection scope

Checklist 24 (Chapter 24) is the field checklist. The inspection report must additionally contain:

1. **Structural condition** — floor sheets and laps, shell-to-bottom joint, lower-course bolting and sealant, any deformation, nozzle pads, roof supports, tension ring and dome interface, ladder and platforms, anchor chairs; a statement whether any A-level structural finding requires engineering review before return to service.
2. **Coating condition by zone** — a mapped survey of defects; DFT readings by zone against commissioning values (SSPC-PA 2); holiday testing of representative areas and of every repair; adhesion where re-lining is under consideration; a classification of each zone (sound / localized repair / general deterioration) and an estimate of remaining coating life.
3. **Bolts and sealant** — count and map of missing, corroded or capped-failed bolts; sealant condition by course; torque sample results; recommendation on a re-seal or re-torque program.
4. **Sediment and water quality** — sediment depth and character, biofilm, evidence of stratification (staining lines), condition of the overflow weir, vent and hatch from inside.
5. **Cathodic protection** — anode condition and consumption, hanger wires, reference cell, potential readings, over-protection evidence.
6. **Appurtenances** — level instruments, mixer, sample lines, drain sump, interior ladder, roof penetrations.
7. **Repairs made during the outage** — location, material (with NSF 61 listing), method, holiday test result, photographs.
8. **Return-to-service record** — cleaning, sealant cure, disinfection method and dose, dechlorination, bacteriological results, refill rate, first-fill leak check.

9. **Condition rating and outlook** — an overall rating; the five-year repair plan with budget; the projected timing of the next major intervention (re-seal campaign, exterior overcoat, sheet replacement, re-lining) and its rough cost.

The two questions the five-year report must answer

Is the coating still protecting the steel? Bolted-tank life is coating life. Wall thickness measurements are useful only where the coating has already failed; the survey should be framed around holidays, DFT trend and undercutting, not just ultrasonic thickness.

Are the joints still watertight and structurally sound? Sealant condition, bolt condition and torque at the lowest courses and the shell-to-bottom joint are the structural pulse of a bolted tank.

30. Repair Procedures

Exterior seam re-seal (weeping seam, cracked fillet)

1. Confirm the conditions: dry surface, ambient and steel temperature within the sealant manufacturer's window (commonly above 40 °F and rising), no rain expected during cure.
2. Remove the failed fillet with a plastic scraper; do not use a grinder or wire wheel on the coating. Clean the sheet edge and adjacent coating with the manufacturer's recommended solvent; let it flash off.
3. Check the bolts in the affected run with a calibrated wrench at the manufacturer's torque; replace any missing or split caps. On glass-fused tanks, do not exceed the specified torque under any circumstances.
4. Apply the manufacturer's NSF 61 sealant in a continuous fillet along the sheet edge, tooling it into the lap and around each bolt head; the bead must bridge the sheet edge to the sheet below with no voids.
5. Allow the full cure before the seam is submerged (if interior) or before rain (if exterior). Record the location, material batch, date, temperature and applicator; photograph.

Interior re-seal (at drain-down)

1. Confined-space entry under the utility's program; ventilation for sealant solvents; lighting.
2. Same surface preparation and application as above, working from the bottom laps and the shell-to-bottom joint upward; replace every failed bolt cap; renew the fillet around every nozzle and manway pad.
3. Holiday-test the coating along the re-sealed laps before sealing (the sealant hides holidays).
4. Cure fully before disinfection — chlorinating uncured sealant is the commonest cause of a re-sealed tank weeping again within the year.

Coating repair

Table 19 — Coating repair by system.

System	Procedure (manufacturer's kit and instructions govern)
Epoxy (powder or liquid)	Remove loose coating and rust to sound, tight material (hand or power tool cleaning to SSPC-SP 2/3; small areas only — no blasting); feather the edges; solvent-wipe; apply the two-part NSF 61 repair epoxy to the specified DFT in the specified coats; holiday-test after cure. Exterior: match with the manufacturer's topcoat.

System	Procedure (manufacturer's kit and instructions govern)
Glass-fused-to-steel	Never grind or blast the glass. Remove rust and loose glass at the chip with hand tools; clean with the recommended solvent; apply the manufacturer's NSF 61 patch compound (typically a two-part epoxy or urethane) feathered onto the glass; holiday-test. Chips larger than the manufacturer's limit, or fishscale over a sheet, mean sheet replacement.
Galvanized	Exterior: clean and apply zinc-rich primer or cold-galvanizing compound to the specified thickness. Interior potable: the repair must itself be NSF 61 certified — usually an epoxy patch; widespread loss of zinc is a lining decision, not a patch.
Stainless	No coating repair; remove contamination with a stainless brush or pickling paste and re-passivate per ASTM A380/A967; pitted sheets are replaced.

Bolt replacement

1. Use only the manufacturer's bolt, nut, washer, cap and sealant for the tank — grade, finish, head style and length are all design items.
2. Replace bolts one at a time, with the water level below the bolt where possible; on a full tank, a single bolt in an upper course may be replaced with the manufacturer's procedure, never a cluster.
3. Apply sealant to the hole and under the head; install; torque to the specified value; cap the wet side; fillet the exterior.
4. Send a sample of any failed bolt to the manufacturer with photographs; a pattern of failures is a materials question, not a maintenance one.

Sheet replacement

A sheet can be replaced in the field by the manufacturer's crew or a qualified bolted-tank contractor: the tank is drained below the sheet, neighboring bolts are removed, the sheet is withdrawn and a new factory-coated sheet installed with new sealant and bolts. It is the correct repair for a corroded-through hole, a dented glass sheet, a bullet hole, or a sheet with extensive fishscale, and is normally far cheaper than any lining alternative. The replacement must match the course's thickness and grade — the manufacturer will have the pattern.

31. Cleaning and Disinfection

- **Cleaning:** drain, remove sediment (vacuum or shovel — never a steel shovel on a coated floor), wash down with low-pressure water within the coating manufacturer's pressure limit, no abrasives or dry ice, remove debris. Inspect the floor while it is clean; this is the only time it is seen.
- **Disinfection:** AWWA C652 provides three methods — chlorinating the full tank to 10 mg/L for 6 hours (or 6 mg/L for 24 hours) then draining or diluting; spraying or brushing a 200 mg/L solution on all interior surfaces and holding 30 minutes; or chlorinating a partial volume to 50 mg/L for 6 hours then filling. The method should respect the coating manufacturer's limits on disinfectant concentration and contact time (glass and epoxy differ) and the sealant's cure.
- **Dechlorination:** AWWA C655 for the discharge of chlorinated water; local discharge rules govern.
- **Sampling:** bacteriological samples per the regulator (typically two consecutive negative results) before return to service.
- **Refill:** at a rate within the vent capacity; watch every seam during the first fill and at 24 hours; record the first-fill leak check as the new baseline.

32. Records and Documentation

A bolted tank rewards good records more than most structures because its defects are discrete and mappable — by course, seam and bolt. The minimum record set is:

- The **tank file** (Chapter 14) with drawings, calculations, certifications, warranty and the O&M manual.
- The **tank data sheet** (Appendix G), updated at every audit.
- The **defect log** (Appendix F): every finding with location, date, photograph, severity, action and closure.
- The **repair log**: every repair with location, material and batch, applicator, conditions, test result and photograph.
- The **photograph archive** at fixed reference points, organized by year.
- The **inspection reports** — quarterly walk-down notes, annual and biennial audit reports, five-year inspection reports — filed with the utility's asset-management system.
- The **operating record** — level history, overflow events, cold-weather events, water-quality data for the tank, CP readings, instrument calibrations.

Appendix A — Glossary

Table 20 — Glossary.

Term	Definition
Annulus	The ring of bottom sheets just inside the shell that resists seismic uplift on a self-anchored tank.
BCL	Bottom capacity level — the lowest level that can be drawn through the outlet piping.
Base-setting ring	The coated steel ring embedded in a concrete tank bottom (Type 6) to which the first course bolts.
Convective component	The sloshing portion of the water in an earthquake; long period, sets the freeboard.
Course	One horizontal ring of shell sheets.
DFT	Dry film thickness of a coating, in mils (thousandths of an inch).
Encapsulation	The molded polymer covering of a bolt head (or cap over a nut) that isolates the bolt from the water.
Fishscale	Half-moon flakes of glass coating that pop off after firing due to hydrogen in the steel; a manufacturing defect.
Fin-neck bolt	A bolt with splines (fins) under the head that lock into the punched hole so the nut can be run down from one side; the standard lap-joint bolt of most bolted-tank systems.
Freeboard	Height from MWL to the top of the shell / underside of the roof.
Heel	The non-usable volume below the minimum fill level (top of the suction nozzle).
Net working capacity	Maximum capacity (to the shut-off level) minus the heel — the usable storage.
1RV / 2RV	Ring-schedule notation for the number of bolt rows at the vertical seams of a course.
Snug-tight	AISC bolt-tightening condition: plies in firm contact, achieved with the full effort of a worker on an ordinary wrench or a few impacts of an impact wrench; no measured torque.

Term	Definition
GFS	Glass-fused-to-steel; vitreous enamel coating fired onto steel sheets.
Holiday	A pinhole, void or thin spot in a coating that exposes steel; found by electrical holiday testing.
Impulsive component	The portion of the water that moves rigidly with the shell in an earthquake.
J (overturning ratio)	D103's seismic ratio of overturning moment to resisting moment; determines whether a tank needs anchorage.
Joint efficiency	The fraction of a sheet's strength available across a bolted joint after allowing for holes and load sharing.
Lap joint	The overlapping, sealed, bolted joint between two sheets.
MWL	Maximum water level — the highest normal operating level, set by the overflow.
NSF/ANSI 61	The health-effects standard for drinking-water system components; product-specific certification required for wetted materials.
Ringwall	A concrete ring foundation under the shell, with fill inside supporting the bottom.
Self-anchored	A tank that resists overturning by its own weight and the weight of water on its bottom annulus, without anchor bolts.
Site class	The ASCE 7 classification of the soil at a site (A–F) that scales seismic ground motion.
Splash zone	The band of shell around the normal operating water level that is alternately wet and dry.
Stiffener / wind girder	A horizontal ring on the shell resisting wind buckling.
Tension ring	The ring at the top of the shell carrying the roof or dome reaction.
Tensile strap	A strap across a horizontal lap carrying vertical tension from overturning.
Type 1–6 foundation	The foundation configurations defined in D103 Sec. 13.4; Types 1–5 have steel bottoms, Type 6 a concrete bottom with an embedded base-setting ring.

Appendix B — D103-19 Key Numbers Quick Reference

Values below are those cited in this guide. Confirm each against the edition governing your tank; several minimums originated in earlier editions and manufacturer practice and are given for orientation.

Table 21 — Key numbers referenced in this guide.

Item	Value	Where
Minimum sheet thickness (shell, bottom, low-slope roof)	0.094 in. (2.4 mm)	Sec. 5 (historic value)
Maximum shell sheet thickness	⅜ in. in early editions; ½-in. plate is standard for the bottom rings of tall / large tanks in current design — verify against your edition	Sec. 5
Minimum roof live load	15 psf (or ASCE 7 snow if greater)	Sec. 5

Item	Value	Where
Minimum anchor bolt diameter	¾ in., galvanized	Sec. 5.9 (historic value)
Shell manway	≥ 24 in. dia. or equivalent	Sec. 7.1
Roof hatch	≥ 24 in. clear; curb ≥ 4 in.; cover overlap ≥ 2 in.	Sec. 7.6
Foundation top above grade	≥ 6 in.	Sec. 13.5.1
Foundation depth	Below extreme frost penetration; never < 12 in.	Sec. 13.5.2
Foundation top projection beyond shell	≥ 3 in.; 8 in. recommended with base-setting ring; ≥ 9 in. with anchor bolts	Sec. 13.5.3
Foundation levelness	±⅛ in. in any 30 ft; ±¼ in. from plane; ±1 in. before grout	Sec. 13.6.1
Anchor bolt tolerances	±¼ in. location / projection / embedment; ±3° plumb	Sec. 13.6.3
Base-setting ring tolerances	Level ±1/16 in.; concentric ±¼ in.	Sec. 13.6.4
Sand cushion under steel bottom (Type 1)	≥ 3 in.	Sec. 13.4
Joint filler under shell	½ in. resilient, ASTM D1751	Sec. 13.4
Seismic design not required when	S_1 ≤ 0.04 g and S_S ≤ 0.15 g	Sec. 14.1.1
Seismic importance factor I_E	1.00 / 1.25 / 1.50 for Risk Category II / III / IV	Table 2
Response modification R_i / R_c	3.0 / 1.5 anchored; 2.5 / 1.5 self-anchored	Table 5
Design spectrum scaling	U = ⅔ of MCE_R; K = 1.5 (5 % → 0.5 % damping) for convective	Sec. 14.2.6
Overturning ratio J thresholds	≤ 0.785 no uplift; 0.785–1.54 self-anchored with checks; > 1.54 anchor. Type 6: ≤ 0.785 (ASCE 7-16)	Eq. 14-32
Default site class when unknown	D (unless E or F present)	Sec. 14.2.3
Hydrostatic pressure	0.433 psi per ft of water depth (62.4 lb/ft^3)	—
Cathodic protection criterion	−850 mV vs. $Cu/CuSO_4$ polarized, or 100 mV shift	AWWA D104 / D106
Typical hydrotest sequence (reference)	≥ 7-day sealant cure; ≤ 30 days after completion; 2 ft hold ≥ 12 h; fill to overflow; hold ≥ 24 h after repairs	Manufacturer procedure
Typical lap bolt (reference)	½ in. SAE J429 Gr 8 fin-neck, zinc-flake coated, PE cap; ~2.3 in. pitch; AISC snug-tight	Manufacturer general notes
Typical manufacturer inspection intervals (reference)	Seams monthly; foundation & appurtenances annually; interior every 2 years	Manufacturer O&M manual
C652 disinfection (Method 1)	10 mg/L free chlorine for 6 h (or 6 mg/L for 24 h)	AWWA C652

Appendix C — Referenced Standards and Guidance

Table 22 — Standards and guidance documents cited.

Document	Subject
ANSI/AWWA D103-19	Factory-Coated Bolted Carbon Steel Tanks for Water Storage — the governing standard for the tank.
ANSI/AWWA D100	Welded Carbon Steel Tanks for Water Storage — the welded-tank counterpart; source of much shared design methodology.
ANSI/AWWA D102	Coating Steel Water-Storage Tanks — field-applied coating systems (used when a bolted tank is re-lined or overcoated).
ANSI/AWWA D104	Automatically Controlled, Impressed-Current Cathodic Protection for the Interior Submerged Surfaces of Steel Water Storage Tanks.
ANSI/AWWA D106	Sacrificial Anode Cathodic Protection Systems for the Interior Submerged Surfaces of Steel Water Storage Tanks.
ANSI/AWWA D108	Aluminum Dome Roofs for Water Storage Facilities.
ANSI/AWWA C652	Disinfection of Water-Storage Facilities.
ANSI/AWWA C655	Field Dechlorination.
AWWA Manual M42	Steel Water-Storage Tanks — design, construction, operation, maintenance, inspection and repair practice.
AWWA G200	Distribution Systems Operation and Management — storage-facility water-quality management.
NSF/ANSI 61 and 372	Drinking Water System Components — Health Effects; Lead Content.
ASCE/SEI 7	Minimum Design Loads and Associated Criteria for Buildings and Other Structures — wind, snow and seismic ground motion.
ACI 318 / ACI 301	Building Code Requirements for Structural Concrete / Specifications for Concrete Construction — foundations.
ASTM D1751	Preformed Expansion Joint Filler for Concrete Paving and Structural Construction (Nonextruding and Resilient Bituminous Types) — the shell joint filler.
ASTM F3125; SAE J429	High-strength structural bolts; mechanical and material requirements for externally threaded fasteners.
SSPC-SP 10 / NACE No. 2; SSPC-PA 2; ASTM D5162	Near-white blast cleaning; measurement of dry coating thickness; discontinuity (holiday) testing of nonconductive coatings on metallic substrates.
ASTM A380 / A967	Cleaning, descaling and passivation of stainless steel.
NFPA 22	Water Tanks for Private Fire Protection — additional requirements for fire tanks (heating, foundations, capacity).
NFPA 780	Installation of Lightning Protection Systems.

Document	Subject
OSHA 29 CFR 1910.27 / 1910.28 / 1910.146	Fixed ladders and fall protection; permit-required confined spaces.
State sanitary code / Ten States Standards (GLUMRB)	State-specific storage-facility requirements: inspection intervals, security, overflow and vent details, disinfection.

Appendix D — Hydrostatic Pressure and Unit Conversions

Table 23 — Hydrostatic pressure vs. depth. *Hoop load per foot of height = p·D/2 with p in lb/ft² (62.4 × depth) and D = 50 ft; illustrates why the bottom course is the critical one.

Water depth above point (ft)	Pressure (psi)	Pressure (ft head)	Hoop load per ft of course on a 50-ft-dia tank (lb/ft)*
10	4.33	10	15,600
20	8.66	20	31,200
30	12.99	30	46,800
40	17.32	40	62,400
50	21.65	50	78,000
60	25.98	60	93,600

Table 24 — Unit conversions.

Quantity	Conversion
1 mil	0.001 in. = 25.4 µm
1 psi	2.31 ft of water = 6.895 kPa
1 psf	0.0479 kPa; 15 psf ≈ 12 in. of settled snow (10 lb/ft³) or 3 in. of ice
1 ft³ of water	7.48 US gal = 62.4 lb
Tank volume	V (gal) = 5.874 × D² × H (D and H in ft)
1 in.	25.4 mm; ⅛ in. = 3.2 mm; ¼ in. = 6.4 mm
Torque	1 ft·lb = 1.356 N·m

Appendix E — Inspection Log Template

Table 25 — Inspection log (R routine, Q quarterly, A annual, B biennial, 5 five-year).

Date	Type (R/Q/A/B/5)	Inspector	Level (ft)	Weather / temp	Findings (ref. defect log #)	Actions / escalation	Sign-off

Appendix F — Defect Log and Reference Photo Points

Table 26 — Defect log.

Defect #	Date found	Zone (A–I)	Location (course / seam / bolt from ladder)	Description	Severity (A/B/C)	Photo #	Action & date	Closed by / date

Reference photo points. Establish and mark twelve fixed exterior points at the base (every 30° starting at the ladder), four roof points (hatch, vent, opposite the ladder, dome perimeter at the overflow) and four interior points (from the hatch: down the ladder, toward the overflow, toward the inlet, straight down). Photograph each point at every annual audit from the same spot and angle; file by year. The comparison is the audit.

Appendix G — Tank Data Sheet

Table 27 — Tank data sheet.

Item	Value	Source / date
Tank name / asset ID		
Owner / site address		
Manufacturer / model / serial		
Year built; erector		
Governing standard and edition		
Coating system — interior (Sec. 12.x) / repair kit / NSF 61 listing		
Coating system — exterior / topcoat		
Diameter (ft) / shell height (ft) / number of courses		
Nominal capacity / usable capacity (gal)		
MWL (ft above foundation) / BCL (ft)		
Freeboard (ft) — design sloshing wave height		
Roof type (bolted steel / aluminum dome, D108)		
Roof design live/snow load (psf)		
Design wind speed (mph) / exposure / risk category		
Seismic: S_S / S_1 / site class / S_DS / S_D1 / I_E		
Overturning ratio J; anchorage (self / mechanical; bolt size and count)		
Foundation type (Sec. 13.4) / designer / frost depth / bearing		
Bolt grade, finish, size; torque value (ft·lb)		
Sealant product / batch / NSF listing		
Vent capacity (cfm) vs. max fill and draw (gpm)		

Item	Value	Source / date
Overflow size and capacity (gpm) / discharge point		
Manway size(s) / hatch size		
Level instrument type / alarms (high, high-high, low)		
Mixer / recirculation		
Cathodic protection type / rectifier / anode date		
Ladder / fall-protection device / last inspection		
Lightning protection		
Hydrotest date / disinfection date / in-service date		
Warranty expiry and conditions		
Last annual / biennial / 5-year inspection dates		
Next due: annual / biennial / 5-year / cleaning		

Appendix H — Ten Rules for Living with a Bolted Tank

A one-page summary to post in the control building.

1. **The coating is the tank.** Corrosion protection is a factory film a few thousandths of an inch thick; every inspection is first a coating inspection.
2. **Every bolt hole is a coating edge and every lap is a sealant joint.** Caps, fillets and tightness are the maintenance items; wall thickness is not.
3. **Follow the manufacturer's tightening specification** — snug-tight or a stated torque — never a generic chart.
4. **Use only the manufacturer's sealant, bolts, caps and repair kit,** and only products certified to NSF/ANSI 61 in potable service.
5. **Never weld, cut, drill or hang anything on the tank** without the manufacturer's written approval; added load voids the warranty and may exceed the design.
6. **Operate between BCL and MWL.** The freeboard is for the seismic wave and the overflow, not for storage.
7. **Keep the vent breathing and the overflow flowing.** A blocked screen collapses a roof; a blocked overflow floods one.
8. **Log every finding by ring, seam and degrees** from the 0° mark, with a photograph and a severity. The trend is the diagnosis.
9. **Inspect on the calendar, not on complaint:** seams monthly, exterior annually, interior every two years where the manufacturer requires it and never less than every five.
10. **Read the general-notes sheet once a year.** Wind, snow, seismic, capacity, anchorage and the ring schedule are all on one page; if the site or the service has changed, the design basis may no longer fit.

Where to get help

Tank manufacturer — drawings, torque or tightening specification, repair kit, warranty, service technicians.

State drinking-water program — inspection intervals, security and contamination reporting, disinfection approval.

A licensed structural engineer experienced in bolted tanks — settlement, bulging, seismic or wind reassessment, added loads.

AMPP/SSPC-certified coating inspector — five-year coating survey and re-lining decisions.

AWWA — the standards (D103, D104, D106, D108, C652) and Manual M42.

Site-Specific Notes

Use this space for the items that are unique to this tank and site: gate and hatch key numbers, SCADA tag names for the level and alarms, the location of the 0° mark, the manufacturer's service contact, the regulator's contact, and any standing instructions from the utility.

Item	Note
Location of 0° reference mark	
SCADA tags — level / high / high-high / low	
Alarm set-points (ft above floor)	
Manufacturer service contact	
Regulator contact for tank events	
Confined-space rescue arrangement	
Standing instructions	