Date: November 2013
Re: Addendum 3

This package contains Addendum 3 of API Std 653, *Tank Inspection, Repair, Alteration, and Reconstruction*, Fourth Edition. This package consists of the pages that have changed since the April 2009 printing the Fourth Edition, the August 2010 Addendum 1, and the January 2012 Addendum 2.

To update your copy of API Std 653, replace, delete, or add the following pages as indicated:

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Tank Inspection, Repair, Alteration, and Reconstruction

Downstream Segment

API STANDARD 653
FOURTH EDITION, APRIL 2009

ADDENDUM 1, AUGUST 2010
ADDENDUM 2, JANUARY 2012
ADDENDUM 3, NOVEMBER 2013
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Section 3—Definitions

For the purposes of this standard, the following definitions apply.

3.1 alteration
Any work on a tank that changes its physical dimensions or configuration.

3.2 as-built standard
The standard (such as API standard or UL 5 standard) used for the construction of the tank component in question. If this standard is not known, the as-built standard is the standard that was in effect at the date of the installation of the component. If the date of the installation of the component is unknown, then the current applicable standard shall be considered to be the as-built standard. See Annex A for a list of API welded storage tank standards. The standard used for repairs or alterations made after original construction is the as-built standard only for those repairs or alterations, so there may be more than one as-built standard for a tank.

3.3 authorized inspection agency
One of the following organizations that employ an aboveground storage tank inspector certified by API.

a) The inspection organization of the jurisdiction in which the aboveground storage tank is operated.

b) The inspection organization of an insurance company which is licensed or registered to and does write aboveground storage tank insurance.

c) An owner/operator of one or more aboveground storage tank(s) who maintains an inspection organization for activities relating only to his/her equipment and not for aboveground storage tanks intended for sale or resale.

d) An independent organization or individual under contract to and under the direction of an owner/operator and recognized or otherwise not prohibited by the jurisdiction in which the aboveground storage tank is operated. The owner/operator’s inspection program shall provide the controls necessary for use by authorized inspectors contracted to inspect aboveground storage tanks.

3.4 authorized inspector
An employee of an authorized inspection agency who is qualified and certified to perform inspections under this inspection standard. Whenever the term inspector is used in API 653, it refers to an authorized API Standard 653 inspector.

3.5 breakover point
The area on a tank bottom where settlement begins.

3.6 candidate tank
The tank(s) for which corrosion rates are not known.

3.7 change in service
A change from previous operating conditions involving different properties of the stored product such as specific gravity or corrosivity and/or different service conditions of temperature and/or pressure.

3.8 **control tank**
The tank(s) for which corrosion rates and service history are known and documented.

3.9 **corrosion rate**
The total metal loss divided by the period of time over which the metal loss occurred.

3.10 **critical zone**
The portion of the tank bottom or annular plate within 3 in. of the inside edge of the shell, measured radially inward.

3.11 **current applicable standard**
The current edition of the standard (such as API standard or UL standard) that applies if the tank were built today.

3.12 **door sheet**
A plate (or plates) cut from an existing tank shell to create a temporary access opening. After planned work is completed, the door sheet(s) shall be reinstalled or replaced.

3.13 **examiner**
A person who assists the inspector by performing specific nondestructive examination (NDE) on aboveground storage tanks and evaluates to the applicable acceptance criteria, but does not interpret the results of those examinations in accordance with API 653, unless specifically trained and authorized to do so by the owner/user.

3.14 **external inspection**
A formal visual inspection, conducted or supervised by an authorized inspector, to assess all aspects of the tank as possible without suspending operations or requiring tank shutdown (see 6.3.2).

3.15 **fitness-for-service assessment**
A methodology whereby flaws contained within a structure are assessed in order to determine the adequacy of the flawed structure for continued service without imminent failure.

3.16 **hot tap**
Identifies a procedure for installing a nozzle in the shell of a tank that is in service.

3.17 **hydrotest**
A test performed with water, in which static fluid head is used to produce test loads.

3.18 **inspector**
A shortened title for an authorized tank inspector qualified and certified in accordance with this standard.

3.19 **internal inspection**
A formal, complete inspection, as supervised by an authorized inspector, of all accessible internal tank surfaces (see 6.4.1).
3.20 major alteration/or major repair
An alteration or repair that includes any of the following:

a) installing a shell penetration larger than NPS 12 beneath the design liquid level;
b) installing a bottom penetration within 12 in. of the shell;
c) removing and replacing or adding a shell plate beneath the design liquid level where the longest dimension of the replacement plate exceeds 12 in.;
d) removing or replacing annular plate ring material where the longest dimension of the replacement plate exceeds 12 in.;
e) complete or partial (more than one-half of the weld thickness) removal and replacement of more than 12 in. of vertical weld joining shell plates or radial weld joining the annular plate ring;
f) installing a new bottom;

NOTE Installation of a portion of a new bottom as described in 12.3.3.3 is not defined as a major repair.
g) removing and replacing part of the weld attaching the shell to the bottom, or to the annular plate ring, in excess of the amounts listed in 12.3.2.5.1 a);
h) jacking a tank shell.

3.21 owner/operator
The legal entity having both control of and/or responsibility for the operation and maintenance of an existing storage tank.

3.22 product-side
The side of the tank that is in contact with the stored liquid product.

3.23 recognized toughness
A condition that exists when the material of a component is deemed acceptable for use by the provisions of any of the following sections of this standard:

a) Section 5.3.2 (based on edition of standard of tank’s original construction, or by coupon testing);
b) Section 5.3.5 (based on thickness);
c) Section 5.3.6 (based on lowest design metal temperature);
d) Section 5.3.8 (based on exemption curves).

3.24 reconstruction
Any work necessary to reassemble a tank that has been dismantled and relocated to a new site.

3.25 reconstruction organization
The organization having assigned responsibility by the owner/operator to design and/or reconstruct a tank.
3.26 repair
Work necessary to maintain or restore a tank to a condition suitable for safe operation. Repairs include both major repairs (see 3.20) and repairs that are not major repairs. Examples of repairs include:

a) removal and replacement of material (such as roof, shell, or bottom material, including weld metal) to maintain tank integrity;

b) re-leveling and/or jacking of a tank shell, bottom, or roof;

c) adding or replacing reinforcing plates (or portions thereof) to existing shell penetrations;

d) repair of flaws, such as tears or gouges, by grinding and/or gouging followed by welding.

3.27 repair organization
An organization that meets any of the following:

a) an owner/operator of aboveground storage tanks who repairs or alters his/her own equipment in accordance with this standard;

b) a contractor whose qualifications are acceptable to the owner/operator of aboveground storage tanks and who makes repairs or alterations in accordance with this standard;

c) one who is authorized by, acceptable to, or otherwise not prohibited by the jurisdiction, and who makes repairs in accordance with this standard.

3.28 similar service assessment
The process by which corrosion rates and inspection intervals are established for a candidate tank using corrosion rates and service history from a control tank for the purpose of establishing the next inspection date.

3.29 soil-side
The side of the tank bottom that is in contact with the ground.

3.30 storage tank engineer
One or more persons or organizations acceptable to the owner/operator who are knowledgeable and experienced in the engineering disciplines associated with evaluating mechanical and material characteristics that affect the integrity and reliability of aboveground storage tanks. The storage tank engineer, by consulting with appropriate specialists, should be regarded as a composite of all entities needed to properly assess the technical requirements.

3.31 unknown toughness
A condition that exists when it cannot be demonstrated that the material of a component satisfies the definition of recognized toughness.
Section 4—Suitability for Service

4.1 General

4.1.1 When the results of a tank inspection show that a change has occurred from the original physical condition of that tank, an evaluation shall be made to determine its suitability for continued use.

4.1.2 This section provides an evaluation of the suitability of an existing tank for continued service, or for a change of service, or when making decisions involving repairs, alterations, dismantling, relocating, or reconstructing an existing tank.

4.1.3 The following list of factors for consideration is not all-inclusive for all situations, nor is it intended to be a substitute for the engineering analysis and judgment required for each situation:

- a) internal corrosion due to the product stored or water bottoms;
- b) external corrosion due to environmental exposure;
- c) stress levels and allowable stress levels;
- d) properties of the stored product such as specific gravity, temperature, and corrosivity;
- e) metal design temperatures at the service location of the tank;
- f) external roof live load, wind, and seismic loadings;
- g) tank foundation, soil, and settlement conditions;
- h) chemical analysis and mechanical properties of the materials of construction;
- i) distortions of the existing tank;
- j) operating conditions such as filling/emptying rates and frequency.

4.2 Tank Roof Evaluation

4.2.1 General

4.2.1.1 The structural integrity of the roof and roof support system shall be verified.

4.2.1.2 Roof plates corroded to an average thickness of less than 0.09 in. in any 100 in.² area or roof plates with any holes through the roof plate shall be repaired or replaced.

4.2.2 Fixed Roofs

4.2.2.1 Roof support members (rafters, girders, columns, and bases) shall be inspected for soundness by a method acceptable to the responsible inspector. Distorted (such as out-of-plumb columns), corroded, and damaged members shall be evaluated and repaired or replaced if necessary. Particular attention must be given to the possibility of severe internal corrosion of pipe columns (corrosion may not be evidenced by external visual inspection).

4.2.2.2 When a frangible roof-to-shell joint is required, evaluate for items impacting compliance with requirements under API 650, Section 5.10.2.6. Examples of some items to evaluate include tank bottom-to-shell joint corrosion or...
tank roof-to-shell joint modification (such as reinforcement of the joint, attachment of handrail, or other frangible joint area change).

**4.2.3 Floating Roofs**

4.2.3.1 Areas of roof plates and pontoons exhibiting cracks or punctures shall be repaired or the affected sections replaced. Holes through roof plates shall be repaired or replaced.

4.2.3.2 Areas that are pitted shall be evaluated to determine the likelihood of through-pitting occurring prior to the next scheduled internal inspection. If so, the affected areas shall be repaired or replaced.

4.2.3.3 Roof support systems, perimeter seal systems, appurtenances such as a roof rolling ladder, anti-rotation devices, water drain systems, and venting systems shall be evaluated for needed repairs or replacements.

4.2.3.4 Guidance for the evaluation of existing floating roofs shall be based on the criteria of API 650, Annex C, for external floating roofs, and Annex H for internal floating roofs. However, upgrading to meet this standard is not mandatory.

**4.2.4 Change of Service**

4.2.4.1 Internal Pressure

All requirements of the current applicable standard (e.g. API 650, Annex F) shall be considered in the evaluation and subsequent alterations to the tank roof and roof-to-shell junction.

4.2.4.2 External Pressure

As applicable, the roof support structure (if any), and the roof-to-shell junction shall be evaluated for the effects of a design partial vacuum. The criteria outlined in API 650, Annex V shall be used.

4.2.4.3 Operation at Elevated Temperature

All requirements of API 650, Annex M, shall be considered before changing the service of a tank to operation at temperatures above 200 °F.

4.2.4.4 Operation at Lower Temperature Than Original Design

If the operating temperature is changed to a lower temperature than the original design, the requirements of the current applicable standard for the lower temperature shall be met.

4.2.4.5 Normal and Emergency Venting

4.2.4.5.1 Effects of change in operating conditions (including product service and pumping rates) on normal and emergency venting shall be considered.

4.2.4.5.2 Vents shall be inspected for proper operation and screens shall be verified to be clear of obstruction.

**4.3 Tank Shell Evaluation**

4.3.1 General

4.3.1.1 Flaws, deterioration, or other conditions (e.g. change of service, relocation, corrosion greater than the original corrosion allowance) that might adversely affect the performance or structural integrity of the shell of an existing tank must be evaluated and a determination made regarding suitability for intended service.
Table 4.1—Maximum Allowable Shell Stresses (Not for Use for Reconstructed Tanks, See Note 6)

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<th>Minimum Specified Tensile Strength, $T$ (lbf/in.$^2$)</th>
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<th>Upper Courses</th>
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<td><strong>Riveted Tanks:</strong></td>
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<td>A7, A9 or A10 (Note 1, Note 3)</td>
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<td>$T$</td>
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<td>Note 4</td>
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</table>

**NOTE 1** ASTM A7, ASTM A9, ASTM A10 and ASTM A442 are obsolete ASTM material specifications previously listed in API 12C and API 650.

**NOTE 2** The yield stress and tensile strength values shown are per API 653 for welded ASTM material of unknown origin.

**NOTE 3** This provision is for riveted tanks, constructed of any grade of material, evaluated per 4.3.4.1 of this standard.

**NOTE 4** This provision is for riveted tanks, constructed of known grades of material, evaluated per 4.3.4.2 of this standard. For all courses, the maximum allowable shell stress for both product and hydrostatic test conditions are listed under column for allowable product stress, $s$.

**NOTE 5** This provision is for riveted tanks, constructed of unknown grades of material, evaluated per 4.3.4.2 of this standard.

**NOTE 6** The allowable stresses for reconstructed tanks are tabulated in API 650, Table 5-2a or 5-2b or calculated per 8.4 of this standard.

**NOTE 7** The allowable stresses are calculated per 4.3.3.1 and 4.3.3.2 of this standard, unless otherwise noted. The calculated allowable stresses are rounded to the nearest 100 lbf/in.$^2$. 
4.3.3.5 The thickness determinations of 4.3.3.1, 4.3.3.2, and 4.3.3.3 consider liquid loading only. All other loads shall also be evaluated according to the original standard of construction; and engineering judgment shall be used to evaluate different conditions or new information. As applicable, the following loadings shall be taken into account:

a) wind-induced buckling;

b) seismic loads;

c) operation at temperatures over 200 °F;

d) vacuum-induced external pressure;

e) external loads caused by piping, tank-mounted equipment, hold down lugs, etc.;

f) wind-induced overturning;

g) loads due to settlement.

---

**Table 4.2—Joint Efficiencies for Welded Joints**

<table>
<thead>
<tr>
<th>Standard</th>
<th>Edition and Year</th>
<th>Type of Joint</th>
<th>Joint Efficiency $E$</th>
<th>Applicability or Limits</th>
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</thead>
<tbody>
<tr>
<td>API 650</td>
<td>Seventh and Later (1980 to Present)</td>
<td>Butt</td>
<td>1.00</td>
<td>Basic Standard</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Butt</td>
<td>0.85</td>
<td>Annex A Spot RT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Butt</td>
<td>0.70</td>
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</tr>
<tr>
<td></td>
<td>First to Sixth (1961 to 1978)</td>
<td>Butt</td>
<td>0.85</td>
<td>Basic Standard</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Butt</td>
<td>1.00</td>
<td>Annexes D and G</td>
</tr>
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<td>API 12C</td>
<td>14th and 15th (1957 to 1958)</td>
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</tr>
<tr>
<td></td>
<td>3rd to 13th (1940 to 1956)</td>
<td>Lap $^a$</td>
<td>0.75</td>
<td>$\frac{3}{8}$ in. max. $t$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Butt $^c$</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td></td>
<td>First and Second (1936 to 1939)</td>
<td>Lap $^a$</td>
<td>0.70</td>
<td>$\frac{1}{16}$ in. max. $t$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lap $^b$</td>
<td>0.50 + $k/5$</td>
<td>$\frac{1}{4}$ in. max. $t$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Butt $^c$</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td>Unknown</td>
<td></td>
<td>Lap $^a$</td>
<td>0.70</td>
<td>$\frac{1}{16}$ in. max. $t$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lap $^b$</td>
<td>0.50 + $k/5$</td>
<td>$\frac{1}{4}$ in. max. $t$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Butt</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Lap $^d$</td>
<td>0.35</td>
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</table>

$^a$ Full double lap-welded.

$^b$ Full fillet weld with at least 25% intermittent full fillet opposite side; $k$ = percent of intermittent weld expressed in decimal form.

$^c$ Single butt-welded joints with a back-up bar were permitted from the years of 1936 to 1940 and 1948 to 1954.

$^d$ Single lap-welded only.
4.3.3.6 As an alternative to the procedures described above, any thinning of the tank shell below minimum required wall thickness due to corrosion or other wastage may be evaluated to determine the adequacy for continued service by employing the design by analysis methods defined in Section VIII, Division 2, Appendix 4 of the ASME Code; or API 579-1/ASME FFS-1, Section 4, Section 5 or Section 6, as applicable. When using the ASME criteria, the stress value used in the original tank design shall be substituted for the $S_m$ value of Division 2, if the design stress is less than or equal to the lesser of $\frac{2}{3}Y$ (specified minimum yield strength) or $\frac{1}{3}T$ (specified minimum tensile strength). If the original design stress is greater than $\frac{2}{3}Y$ or $\frac{1}{3}T$, then the lesser of $\frac{2}{3}Y$ or $\frac{1}{3}T$ shall be substituted for $S_m$.

4.3.4 Minimum Thickness Calculation for Riveted Tank Shell

4.3.4.1 The minimum acceptable thickness for riveted tank shells shall be calculated using the equation in 4.3.3.1 except that the following allowable stress criteria and joint efficiencies shall be used:

- $S$ is 21,000 lbf/in.$^2$;
- $E$ is 1.0 for shell plate 6 in. or more away from rivets. See Table 4.3 for joint efficiencies for locations within 6 in. of rivets.

4.3.4.2 The rivet joint efficiencies given in Table 4.3 are conservative minimums for riveted tank construction details and are included to simplify riveted tank evaluations. However, in some cases it may be advantageous to calculate the actual rivet joint efficiencies using computational methods applicable to lap and butt type riveted joints. When this alternative of calculated joint efficiencies is used, the following maximum allowable stresses shall apply:

a) for the maximum tensile stress in net section of plate, use the lesser of 0.80$Y$ or 0.429$T$; use 21,000 lbf/in.$^2$ if $T$ or $Y$ is unknown;

b) for the maximum shear in net section of rivet, use 16,000 lbf/in.$^2$;

c) for the maximum bearing stress on plates or rivets, use 32,000 lbf/in.$^2$ for rivets in single shear, and 35,000 lbf/in.$^2$ for rivets in double shear.

4.3.4.3 For tanks with riveted joints, consideration shall be given to whether, and to what extent, corrosion affects such joints. If calculations show that excess thickness exists, this excess may be taken as corrosion allowance.

4.3.4.4 Non-liquid loads (see 4.3.3.5) shall also be considered in the analysis of riveted tanks.

4.3.5 Distortions

4.3.5.1 Shell distortions include out-of-roundness, buckled areas, flat spots, and peaking and banding at welded joints.

4.3.5.2 Shell distortions can be caused by many conditions such as foundation settlement, over- or under-pressuring, high wind, poor shell fabrication, or repair techniques, and so forth.

4.3.5.3 Shell distortions shall be evaluated on an individual basis to determine if specific conditions are considered acceptable for continuing tank service and/or the extent of corrective action.

4.3.6 Flaws

Flaws such as cracks or laminations shall be thoroughly examined and evaluated to determine their nature and extent and need for repair. If a repair is needed, a repair procedure shall be developed and implemented. The requirement for repairing scars such as arc strikes, gouges, or tears from temporary attachment welds must be evaluated on a case-by-case basis. Cracks in the shell-to-bottom weld shall be removed.
4.3.7 Wind Girders and Shell Stiffeners

The evaluation of an existing tank shell for suitability for service must also consider the details and condition of any wind girders or shell stiffeners. Degradation by corrosion of these structural elements or their attachment welds to the shell may render these elements inadequate for the design conditions.

4.3.8 Shell Welds

The condition of the tank shell welds shall be evaluated for suitability for service using criteria from this standard, the as-built standard, or fitness-for-service assessment. Any flaws or deterioration such as corrosion or pitting of the existing welds shall be evaluated. If necessary, appropriate repair procedures shall be established or the tank safe fill height reassessed. Some typical shell butt-welded flaws and recommended procedures for repairs are given in 9.6.

4.3.9 Shell Penetrations

4.3.9.1 The condition and details of existing shell penetrations (nozzles, manways, cleanout openings, etc.) shall be reviewed when assessing the integrity of an existing tank shell. Details such as type and extent of reinforcement, weld spacing, and thickness of components (reinforcing plate, nozzle neck, bolting flange, and cover plate), are important considerations and shall be reviewed for structural adequacy and compliance with the as-built standard. Existing welds on the tank shell that are not to be modified or affected by repairs and are closer than required by API 650 (Seventh Edition or later) are acceptable for continued service if the welds are examined by the magnetic particle method and have no rejectable defects or indications. Grinding to eliminate weld defects is permissible if the resulting profile satisfies base thickness and weld size requirements. Weld repairs may not be used to accept weld spacings closer than permitted by API 650 (Seventh Edition or later) except as permitted by 9.10.2.7. Any other noncompliance, or deterioration due to corrosion, must be assessed and repair procedures established where appropriate or the tank re-rated, as necessary.

4.3.9.2 Nozzle wall thickness shall be evaluated for pressure and all other loads.

4.3.10 Operation at Elevated Temperatures

Tanks of welded construction that operate at elevated temperatures (exceeding 200 °F, but less than 500 °F) shall be evaluated for suitability of service. The requirements of this section are based in part on the requirements of API 650, Annex M.
4.3.10.1 Continued Operation at Elevated Temperatures

4.3.10.1.1 Existing tanks that were originally designed and constructed to the requirements of API 650, Annex M-1a or M-1b, shall be evaluated for continued service, as follows.

a) The tank shell shall be evaluated in conformance with 4.3.3, except that the allowable stress ($S$) for all shell courses shall not exceed 0.80 $Y$. The value of $Y$ shall be taken as the minimum specified yield strength of the shell material multiplied by the yield strength reduction factor in of API 650, Table M-1. When the minimum specified yield strength of the shell material is not known, the evaluation shall be based upon an assumed value of 30,000 lbf/in.$^2$.

b) If the bottom plate material in the critical zone has been reduced in thickness beyond the provisions of the original tank bottom corrosion allowance, if any, the shell-to-bottom joint shall be evaluated for elevated temperature, liquid head and thermal cycles. The simplified analysis technique recommended in API 650, Section M.4, may be used to satisfy this requirement.

4.3.10.1.2 Existing elevated temperature service tanks that were not originally designed and constructed to the requirements of API 650, Annex M, but have a successful service history of operation shall be evaluated for continued service as noted in 4.3.10.1.1. If the tank diameter exceeds 100 ft and the tank was not constructed with a butt-welded annular ring, an analysis of the critical zone is required [see 4.3.10.1.1 b)]. In addition, the maximum operating temperature shall not exceed the temperatures at which the tank has operated successfully in the past.

4.3.10.2 Conversion to Operation at Elevated Temperatures

Existing tanks that were not originally designed and constructed to the requirements of API 650, Annex M shall be evaluated for a change to service to elevated temperatures as follows.

a) The tank shell shall be evaluated in conformance with API 650, Annex M. The allowable shell stresses of this standard (API 653) shall not be used.

b) The need for a butt-welded annular ring shall be determined in conformance with API 650, Annex M and installed if required.

c) The shell-to-bottom joint shall be evaluated for fatigue conditions. In addition, the adequacy of the bottom plate material in the critical zone shall be based upon the requirements of this standard.

4.4 Tank Bottom Evaluation

4.4.1 General

Tank bottom inspection strategies shall provide suitable data which, when used with the procedures in this standard, will determine the tank bottom integrity necessary to prevent leakage of fluids that may cause environmental damage. Each aspect of corrosion phenomena, and other potential leak or failure mechanism must be examined. Periodic assessment of tank bottom integrity shall be performed in addition to the internal inspections specified in 6.4. The assessment period shall be less than or equal to the appropriate internal inspection interval given in 6.4.2. The use of leak detection tests or monitoring systems (such as double bottoms or liners under tank bottoms with leak detection pipes) will satisfy the requirement for periodic assessment between internal inspections.

Excessive foundation settlement of storage tanks can affect the integrity of tank shells and bottoms. Therefore, monitoring the settlement behavior of tanks is a recognized practice to assess the integrity of tank bottoms. See Annex B for techniques for evaluating tank bottom settlement.
4.4.2 Causes of Bottom Failure

The following list gives some historical causes of tank bottom leakage or failure that shall be considered in the decision to line, repair, or replace a tank bottom:

a) internal pitting and pitting rates in the anticipated service;

b) corrosion of weld joints (weld and heat affected zone);

c) weld joint cracking history;

d) stresses placed on the bottom plates by roof support loads and shell settlement;

e) underside corrosion (normally in the form of pitting);

f) inadequate drainage resulting in surface water flowing under the tank bottom;

g) the lack of an annular plate ring when required;

h) uneven settlement that results in high localized stresses in the bottom plates;

i) roof support columns or other supports welded to the tank bottom where adequate allowance for movement was not made;

j) rock or gravel foundation pads with inadequately filled-in surface voids;

k) nonhomogeneous fill under the tank bottom (e.g. a lump of clay in a sand foundation pad);

l) inadequately supported sumps.

4.4.3 Tank Bottom Release Prevention Systems (RPSs)

API supports the use of a release prevention system (RPS) to maintain the integrity of tank bottoms. The term RPS refers to the suite of API standards and recommended practices that are designed to maintain tank integrity and thus protect the environment. With respect to tank bottoms, these include: internal inspection of the tank bottom; leak detection systems and leak testing of the tank; installing cathodic protection for the underside of the tank bottom; lining the bottom of the tank interior; providing a release prevention barrier (RPB) under the tank bottom; or some combination of these measures, depending on the operating environment and service of the tank.

4.4.3.1 Internal Inspection

Internal inspection of the tank bottom is intended to assess the current bottom integrity and identify problem conditions that may lead to future loss of integrity. Internal inspection techniques, such as bottom settlement monitoring, and considerations for determining appropriate inspection frequency, are found in 4.4.6, Section 6, Annex B, Annex C, and elsewhere.

4.4.3.2 Leak Detection Systems and Leak Testing

Tank leak detection systems and leak testing are intended to identify, quantify, and/or locate a tank bottom integrity failure that is not detectable visually or through inventory reconciliation. Leak detection may be integral to the tank design, either as constructed or as modified (e.g. RPB with interstitial monitoring) or may operate separately (e.g. soil vapor monitoring and chemical marker); may be operated by the tank owner or as a third party test or service; and may detect leaks continuously or on a periodic basis. Tank leak detection systems and testing methods are listed and discussed in API 575.
4.4.3.3 Cathodic Protection

Cathodic protection systems are intended to mitigate corrosion of steel surfaces in contact with soil, such as the underside of tank bottoms. A selection basis for cathodic protection systems is covered by API 651.

4.4.3.4 Internal Lining Protection

Internal linings and coatings for the top side of the tank bottom are intended to mitigate corrosion by providing a barrier between the tank bottom and corrosion sources. Applied linings and coatings for internal surfaces of tank bottoms are covered by API 652.

4.4.3.5 Release Prevention Barriers (RPBs)

An RPB includes steel bottoms, synthetic materials, clay liners, concrete pads, and all other barriers or combinations of barriers placed in the bottom of or under a tank, which have the function of:

1) preventing the escape of released material, and
2) containing or channeling released material for leak detection.

RPB design is covered in detail in Annex I of API 650. Replacement of tank bottoms is covered in 9.10.2.

If a decision is made to replace an existing bottom, API supports the evaluation of installing an RPB or continued use of an RPS. The evaluation should consider the effectiveness of other RPS controls, the product stored, the location of the tank, and environmental sensitivities.

4.4.4 Bottom Plate Thickness Measurements

Various methods for determining tank bottom plate soils-side corrosion are available. The methods vary to the extent by which they can reliably measure general corrosion and pitting. A combination of these methods may be required along with extrapolation techniques and analysis to establish the probable conditions of the entire tank bottom. Magnetic flux leakage (MFL) tools are commonly used, along with ultrasonic (UT) thickness measurement tools, to examine tank bottoms. Ultrasonic thickness measurement techniques are often used to confirm and further quantify data obtained by MFL examination, but these techniques may not be required depending on the specific procedure and application. The quality of data obtained from both MFL and ultrasonic thickness techniques is dependent on personnel, equipment and procedures. Annex G may be used to provide guidance in qualifying personnel and procedures for obtaining thickness data.

4.4.5 Minimum Thickness for Tank Bottom Plate

Quantifying the minimum remaining thickness of tank bottoms based on the results of measurement can be done by the method outlined in 4.4.5.1. Other approaches such as the probabilistic method in 4.4.5.2 may be used.

4.4.5.1 An acceptable method for calculating the minimum acceptable bottom thickness for the entire bottom or portions thereof is as follows:

\[
MRT = (\text{Minimum of } RT_{bc} \text{ or } RT_{ip}) - O_r (StP_r + UP_r)
\]

where

- \( MRT \) is the minimum remaining thickness at the end of interval \( O_r \). This value must meet the requirements of Table 4.4 and 4.4.5.4 and 4.4.6;
- \( O_r \) is the in-service interval of operation (years to next internal inspection) not to exceed that allowed by 6.4.2;
4.4.5.2 For the probabilistic method, a statistical analysis is made of thickness data from measurements (see 4.4.6) projecting remaining thickness, based on sample scanning of the bottom.

4.4.5.3 If the minimum bottom thicknesses, at the end of the in-service period of operation, are calculated to be less than the minimum bottom renewal thicknesses given in Table 4.4, or less than the minimum bottom renewal thicknesses providing acceptable risk as determined by an RBI assessment per 6.4.2.4, the bottom shall be lined, repaired, replaced, or the interval to the next internal inspection shortened.

4.4.5.4 Unless a stress analysis is performed, the minimum bottom plate thickness in the critical zone of the tank bottom defined in 9.10.1.2 shall be the smaller of one-half the original bottom plate thickness (not including the original corrosion allowance) or 50% of \( t_{\text{min}} \) of the lower shell course per 4.3.3.1 but not less than 0.1 in. Isolated pitting will not appreciably affect the strength of the plate.

4.4.5.5 The repair of internal pitting, when performed to extend the in-service period of operation, shall be by pit welding, overlay welding, or lap patching, followed by inspection and testing. The extent of weld repairs is limited in the critical zone in accordance with 9.10.1.2.

4.4.5.6 The treatment of bottom pitting by the use of non-welded repairs (e.g. coatings, caulking) can not be used to increase \( RT_{\text{ip}} \) for calculating \( MRT \).

4.4.5.7 The thickness of the projection of the bottom plate beyond the shell as measured at the toe of the outside bottom-to-shell fillet weld shall not be less than 0.1 in. The projection of the bottom plate beyond the outside toe of the shell-to-bottom weld shell shall be at least 3/8 in.

4.4.6 Minimum Thickness for Annular Plate Ring

4.4.6.1 Due to strength requirements, the minimum thickness of annular plate ring is usually greater than 0.10 in. Isolated pitting will not appreciably affect the strength of the plate. Unless a stress analysis is performed, the annular plate thickness shall be in accordance with 4.4.6.2 or 4.4.6.3, as applicable.

4.4.6.2 For tanks in service with a product specific gravity less than 1.0, which require annular plates for other than seismic loading considerations, the thickness of the annular plates shall be not less than the thicknesses given in Table 4.5, plus any specified corrosion allowance. Interpolation is allowed within Table 4.5 based on shell stress determined per Note b of Table 4.5.
4.4.6.3 For tanks in service with a product specific gravity of 1.0 or greater, which require annular plates for other than seismic loading considerations, the thickness of the annular plates shall be in accordance with API 650, Table 5-1a or 5-1b, plus any specified corrosion allowance. Interpolation is allowed within API 650, Table 5-1a or 5-1b based on shell stress determined per Note b of API 650, Table 5-1.

4.4.6.4 For tanks that utilize thickened annular plates for seismic considerations, a seismic evaluation shall be performed in accordance with the requirements of the as built standard, using the actual thickness of the existing annular plate.

4.4.6.5 For the thickness and projection of the annular plate beyond the shell, see 4.4.5.7.

<table>
<thead>
<tr>
<th>Minimum Bottom Plate Thickness at Next Inspection (in.)</th>
<th>Tank Bottom/Foundation Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>Tank bottom/foundation design with no means for detection and containment of a bottom leak.</td>
</tr>
<tr>
<td>0.05</td>
<td>Tank bottom/foundation design with means to provide detection and containment of a bottom leak.</td>
</tr>
<tr>
<td>0.05</td>
<td>Applied tank bottom reinforced lining, &gt; 0.05 in. thick, in accordance with API 652.</td>
</tr>
</tbody>
</table>

Table 4.4—Bottom Plate Minimum Thickness

Table 4.5—Annular Bottom Plate Thicknesses (in.) (Product Specific Gravity < 1.0)

<table>
<thead>
<tr>
<th>Plate Thickness $a$ of First Shell Course (in.)</th>
<th>Stress $b$ in First Shell Course (lbf/in.$^2$)</th>
<th>$&lt; 24,300$</th>
<th>$&lt; 27,000$</th>
<th>$&lt; 29,700$</th>
<th>$&lt; 32,400$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t \leq 0.75$</td>
<td>0.17</td>
<td>0.20</td>
<td>0.23</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>$0.75 &lt; t \leq 1.00$</td>
<td>0.17</td>
<td>0.22</td>
<td>0.31</td>
<td>0.38</td>
<td></td>
</tr>
<tr>
<td>$1.00 &lt; t \leq 1.25$</td>
<td>0.17</td>
<td>0.26</td>
<td>0.38</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>$1.25 &lt; t \leq 1.50$</td>
<td>0.22</td>
<td>0.34</td>
<td>0.47</td>
<td>0.59</td>
<td></td>
</tr>
<tr>
<td>$t &gt; 1.50$</td>
<td>0.27</td>
<td>0.40</td>
<td>0.53</td>
<td>0.68</td>
<td></td>
</tr>
</tbody>
</table>

NOTE: The thicknesses specified in the table are based on the foundation providing a uniform support under the full width of the annular plate. Unless the foundation is properly compacted, particularly at the inside of a concrete ringwall, settlement will produce additional stresses in the annular plate.

$^a$ Plate thickness refers to the tank shell as constructed.

$^b$ Stresses are calculated from $[2.34D((H-1))/t]$.

4.5 Tank Foundation Evaluation

4.5.1 General

4.5.1.1 The principal causes of foundation deterioration are settlement, erosion, cracking, and deterioration of concrete initiated by: calcining, attack by underground water, attack by frost, and attack by alkalies and acids. To ensure suitability for service, all tank foundations shall be inspected periodically (see 6.3).
4.5.1.2 Some mechanisms of concrete deterioration are briefly described below.

a) calcining (loss of water of hydration) can occur when concrete has been exposed to sufficiently high temperature for a period of time. During intermediate cooling periods, the concrete can absorb moisture, swell, lose its strength, and crack;

b) deterioration of concrete exposed to underground water can be caused by chemical attack, by cyclic changes in temperature, and by freezing moisture;

c) expansion of freezing moisture in porous concrete, or in concrete with minor settlement cracks or temperature cracks, can result in spalling and/or the development of serious structural cracks;

d) sulfate-type alkanes, and to a lesser extent, chlorides, can act corrosively to destroy the bond of the concrete;

e) temperature cracks (hairline cracks of uniform width) do not seriously affect the strength of the concrete foundation structure; however, these cracks can be potential access points for moisture or water seepage that could eventually result in corrosion of the reinforcing steel.

4.5.1.3 When a tank is to be used in elevated temperature [> 93 °C (200 °F)] service, the provisions of API 650, Section B.6 shall be considered in the evaluation of the suitability for service of the tank foundation.

4.5.2 Foundation Repair or Replacement

4.5.2.1 If there is a need for foundation replacement or installation, the new foundation elevation profile must meet the tolerance in 10.5.6. Alternatively, if the new foundation is to be constructed up to the bottom, changing the levelness of the tank is not required if reviewed and approved by a storage tank engineer considering the plumbness of the shell, presence, or absence of shell distortion, and original construction levelness which warrant leaving the tank at the current state of levelness.

4.5.2.2 Concrete pads, ringwalls, and piers, showing evidence of spalling, structural cracks, or general deterioration, shall be repaired to prevent water from entering the concrete structure and corroding the reinforcing steel.

4.5.3 Anchor Bolts

Distortion of anchor bolts and excessive cracking of the concrete structures in which they are embedded may be indications of either serious foundation settlement or a tank overpressure uplift condition.
Section 6—Inspection

6.1 General

Periodic in-service inspection of tanks shall be performed as defined herein. The purpose of this inspection is to assure continued tank integrity. Inspections, other than those defined in 6.3 shall be directed by an authorized inspector.

6.2 Inspection Frequency Considerations

6.2.1 Several factors must be considered to determine inspection intervals for storage tanks. These include, but are not limited to, the following:

a) the nature of the product stored;

b) the results of visual maintenance checks;

c) corrosion allowances and corrosion rates;

d) corrosion prevention systems;

e) conditions at previous inspections;

f) the methods and materials of construction and repair;

g) the location of tanks, such as those in isolated or high risk areas;

h) the potential risk of air or water pollution;

i) leak detection systems;

j) change in operating mode (e.g. frequency of fill cycling, frequent grounding of floating roof support legs);

k) jurisdictional requirements;

l) changes in service (including changes in water bottoms);

m) the existence of a double bottom or a release prevention barrier.

6.2.2 The interval between inspections of a tank (both internal and external) should be determined by its service history unless special reasons indicate that an earlier inspection must be made. A history of the service of a given tank or a tank in similar service (preferably at the same site) should be available so that complete inspections can be scheduled with a frequency commensurate with the corrosion rate of the tank. On-stream, nondestructive examination methods shall be considered when establishing inspection frequencies.

6.2.3 Jurisdictional regulations, in some cases, control the frequency and interval of the inspections. These regulations may include vapor loss requirements, seal condition, leakage, proper diking, and repair procedures. Knowledge of such regulations is necessary to ensure compliance with scheduling and inspection requirements.

6.3 Inspections from the Outside of the Tank

6.3.1 Routine In-service Inspections

6.3.1.1 The external condition of the tank shall be monitored by close visual inspection from the ground on a routine basis. This inspection may be done by owner/operator personnel, and can be done by other than authorized
inspectors as defined in 3.4. Personnel performing this inspection should be knowledgeable of the storage facility operations, the tank, and the characteristics of the product stored.

6.3.1.2 The interval of such inspections shall be consistent with conditions at the particular site, but shall not exceed one month.

6.3.1.3 This routine in-service inspection shall include a visual inspection of the tank’s exterior surfaces. Evidence of leaks; shell distortions; signs of settlement; corrosion; and condition of the foundation, paint coatings, insulation systems, and appurtenances should be documented for follow-up action by an authorized inspector.

6.3.2 External Inspection

6.3.2.1 All tanks shall be given a visual external inspection by an authorized inspector. This inspection shall be called the external inspection and must be conducted at least every five years or \( \frac{RCA}{4N} \) years (where \( RCA \) is the difference between the measured shell thickness and the minimum required thickness in mils, and \( N \) is the shell corrosion rate in mils per year) whichever is less. Tanks may be in operation during this inspection.

6.3.2.2 Insulated tanks need to have insulation removed only to the extent necessary to determine the condition of the exterior wall of the tank or the roof.

6.3.2.3 Tank grounding system components such as shunts or mechanical connections of cables shall be visually checked. Recommended practices dealing with the prevention of hydrocarbon ignition are covered by API 2003.

6.3.3 Ultrasonic Thickness Inspection

6.3.3.1 External, ultrasonic thickness measurements of the shell can be a means of determining a rate of uniform general corrosion while the tank is in service, and can provide an indication of the integrity of the shell. The extent of such measurements shall be determined by the owner/operator.

6.3.3.2 When used, the ultrasonic thickness measurements shall be made at intervals not to exceed the following.

a) When the corrosion rate is not known, the maximum interval shall be five years. Corrosion rates may be estimated from tanks in similar service based on thickness measurements taken at an interval not exceeding five years.

b) When the corrosion rate is known, the maximum interval shall be the smaller of \( \frac{RCA}{2N} \) years (where \( RCA \) is the difference between the measured shell thickness and the minimum required thickness in mils, and \( N \) is the shell corrosion rate in mils per year) or 15 years.

6.3.3.3 Internal inspection of the tank shell, when the tank is out of service, can be substituted for a program of external ultrasonic thickness measurement if the internal inspection interval is equal to or less than the interval required in 6.3.3.2 b).

6.3.4 Cathodic Protection Surveys

6.3.4.1 Where exterior tank bottom corrosion is controlled by a cathodic protection system, periodic surveys of the system shall be conducted in accordance with API 651. The owner/operator shall review the survey results.

6.3.4.2 The owner/operator shall assure competency of personnel performing surveys.

6.4 Internal Inspection

6.4.1 General

6.4.1.1 Internal inspection is primarily required to do as follows.

a) Ensure that the bottom is not severely corroded and leaking.
b) Gather the data necessary for the minimum bottom and shell thickness assessments detailed in Section 6. As applicable, these data shall also take into account external ultrasonic thickness measurements made during in-service inspections (see 6.3.3).

c) Identify and evaluate any tank bottom settlement.

6.4.1.2 All tanks shall have a formal internal inspection conducted at the intervals defined by 6.4.2. The authorized inspector shall supervise or conduct a visual examination and assure the quality and completeness of the nondestructive examination (NDE) results. If the internal inspection is required solely for the purpose of determining the condition and integrity of the tank bottom, the internal inspection may be accomplished with the tank in-service utilizing various ultrasonic robotic thickness measurement and other on-stream inspection methods capable of assessing the thickness of the tank bottom, in combination with methods capable of assessing tank bottom integrity as described in 4.4.1. Electromagnetic methods may be used to supplement the on-stream ultrasonic inspection. If an in-service inspection is selected, the data and information collected shall be sufficient to evaluate the thickness, corrosion rate, and integrity of the tank bottom and establish the internal inspection interval, based on tank bottom thickness, corrosion rate, and integrity, utilizing the methods included in this standard.

6.4.2 Inspection Intervals

Initial and subsequent inspection intervals shall be in compliance with the requirements of 6.4.2.1 and 6.4.2.2.

For existing tanks, tank owner/operators shall review the internal inspection interval and be in compliance with this section within 5 years from date of first publication of API Standard 653, Fourth Edition, Addendum 3.

6.4.2.1 Initial Internal Inspection Interval

The initial internal inspection intervals for newly constructed tanks and/or refurbished tanks shall be established either per 6.4.2.1.1 or 6.4.2.1.2.

6.4.2.1.1 The interval from initial service date until the first internal inspection shall not exceed 10 years unless a tank has one or more of the leak prevention, detection, corrosion mitigation, or containment safeguards listed in Table 6.1. The initial internal inspection date shall be based on incremental credits for the additional safeguards in Table 6.1 which are cumulative.

For example, the maximum interval for a ¼ in. bottom that has a release prevention barrier and a fiberglass lining would be determined as follows:

10 years (initial) + 5 years (fiberglass lining) + 10 years (release prevention barrier) = 25 years.

The initial inspection interval shall not exceed 20 years for tanks without a Release Prevention Barrier, or 30 years for tanks with a Release Prevention Barrier.

Table 6.1—Tank Safeguard

<table>
<thead>
<tr>
<th>Tank Safeguard</th>
<th>Add to Initial Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. Fiberglass-reinforced lining of the product-side of the tank bottom installed per API RP 652.</td>
<td>5 yrs</td>
</tr>
<tr>
<td>i. Installation of an internal thin-film coating as installed per API RP 652.</td>
<td>2 yrs</td>
</tr>
<tr>
<td>iii. Cathodic protection of the soil-side of the tank bottom installed, maintained, and inspected per API RP 651.</td>
<td>5 yrs</td>
</tr>
<tr>
<td>iv. Release prevention barrier installed per API Std 650, Annex I.</td>
<td>10 yrs</td>
</tr>
<tr>
<td>v. Bottom corrosion allowance greater than 0.150 in.</td>
<td>(Actual corrosion allowance - 150 mils) / 15 mpy</td>
</tr>
</tbody>
</table>
6.4.2.1.2 As an alternative to establishing the initial interval in accordance with Section 6.4.2.1 and Table 6.1, the initial internal inspection date and reassessment can be established using Risk Based Inspection (RBI) assessment per 6.4.2.2.2.

These assessments may establish an initial inspection interval exceeding 10 years but shall not exceed 20 years for tanks without a Release Prevention Barrier, or 30 years for tanks with a Release Prevention Barrier except as follows.

If an RBI assessment has been performed, the maximum initial internal inspection interval does not apply to tanks storing the following.

1) Highly viscous substances which solidify at temperatures below 110 °F, (some examples of these substances are: asphalt, roofing flux, residuum, vacuum bottoms and reduced crude), or;

2) Any substance or mixture that is:
   a) not identified or regulated either as a hazardous chemical or material under the applicable laws of the jurisdiction; and
   b) that the owner/operator has determined will not adversely impact surface or groundwater beyond the facility or affect human health or the environment.

6.4.2.2 Subsequent Internal Inspection Interval

The interval between subsequent internal inspections shall be determined in accordance with either the corrosion rate procedures of 6.4.2.2.1 or the risk based inspection procedures as outlined in 6.4.2.2.2.

6.4.2.2.1 The subsequent inspection interval (beyond the initial inspection) can be determined using the measured tank bottom corrosion rate and the minimum remaining thickness in accordance with 4.4.5. During any examination to determine corrosion rates the owner/operator should ensure they understand the effectiveness of the inspection techniques employed for detecting and measuring potential damage mechanisms.

When changing service, an owner/operator may decide to use internal corrosion rates obtained from similar service assessment (performed per Annex H of API 653) when setting subsequent internal inspection dates.

When using the corrosion rate procedures of 6.4.2.2.1 the maximum subsequent internal inspection interval shall be 20 years for tanks without a Release Prevention Barrier, or 30 years for tanks with a Release Prevention Barrier.

6.4.2.2.2 An owner/operator can establish the subsequent internal inspection interval using risk based inspection (RBI) procedures in accordance with API RP 580 and the additional requirements of this section.

The results of the RBI assessment shall be used to establish a tank inspection strategy that defines the most appropriate inspection methods, appropriate frequency for internal, external and in-service inspections, and prevention and mitigation steps to reduce the likelihood and consequence of tank leakage or failure.

An RBI assessment shall consist of a systematic evaluation of both the likelihood of failure and the associated consequences of failure, in accordance with API RP 580. The RBI assessment shall be thoroughly documented, clearly defining all factors contributing to both likelihood and consequence of tank leakage or failure.

The RBI assessment shall be performed by a team including inspection and engineering expertise knowledgeable in the proper application of API RP 580 principles, tank design, construction, and modes of deterioration. The RBI assessment shall be reviewed and approved by a team as above at intervals not to exceed 10 years or more often if warranted by process, equipment, or consequence changes.
The applied RBI methodology (not every individual assessment) shall have a documented validation review to demonstrate that it has all the key elements defined in API 580 and this section. The validation should be performed by an entity external to the RBI assessment team.

If corrosion rates are based on prior inspections, they shall be derived from either high or medium inspection effectiveness as defined by the owner-user procedures. Refer to API RP 581 for examples of high and medium inspection effectiveness. Corrosion rates from low inspection effectiveness such as spot UT shall not be used in the RBI process.

A tank shall be removed from service when the risk exceeds the acceptable risk criteria established per the owner-user procedure.

NOTE API does not recommend running tank bottoms to failure, or operating tanks indefinitely with known or suspected bottom leaks.

6.4.2.2.2.1 Likelihood factors that shall be evaluated in tank RBI assessments, in addition to the likelihood factors in API RP 580 include, but are not limited to, the following:

a) original thickness, weld type, and age of bottom plates;

b) analysis methods used to determine the product-side, soil-side and external corrosion rates for both shell and bottom and the accuracy of the methods used;

c) inspection history, including tank failure data;

d) soil resistivity;

e) type and design quality of tank pad/cushion including quality control at construction;

f) water drainage from berm area;

g) type/effectiveness of cathodic protection system and maintenance history;

h) operating temperatures;

i) effects on internal corrosion rates due to product service;

j) internal coating/lining/liner type, age and condition;

k) use of steam coils and water draw-off details;

l) quality of tank maintenance, including previous repairs and alterations;

m) design codes and standards and the details utilized in the tank construction, repair, and alteration (including tank bottoms);

n) materials of construction;

o) effectiveness of an inspection includes examination methods and scope which are to be determined by the inspector;

p) functional failures, such as floating roof seals, roof drain systems, etc.;

q) settlement data;

r) quality assurance/control during tank construction, including pad cleanliness, slope of bottom, foundation installation, document/records to show how the tank was built, etc.
6.4.2.2.2 Consequence factors that shall be evaluated in tank RBI assessments include, but are not limited to, the following:

a) tank bottom with a Release Prevention Barrier (RPB) details (single, double, RPB, internal reinforced linings, etc.);

b) product type and volume;

c) mode of failure, (i.e. slow leak to the environment, tank bottom rupture or tank shell brittle fracture);

d) identification of environmental receptors such as wetlands, surface waters, ground waters, drinking water aquifers, and bedrock;

e) distance to environmental receptors;

f) effectiveness of leak detection systems and time to detection;

g) mobility of the product in the environment, including, for releases to soil, product viscosity and soil permeability;

h) sensitivity characteristics of the environmental receptors to the product;

i) cost to remediate potential contamination;

j) cost to clean tank and repair;

k) cost associated with loss of use;

l) impact on public safety and health;

m) dike containment capabilities (volume and leak tightness).

6.5 Alternative to Internal Inspection to Determine Bottom Thickness

In cases where construction, size, or other aspects allow external access to the tank bottom to determine bottom thickness, an external inspection in lieu of an internal inspection is allowed to meet the data requirements of Table 4.4. However, in these cases, consideration of other maintenance items may dictate internal inspection intervals. This alternative approach shall be documented and made part of the permanent record of the tank.

6.6 Preparatory Work for Internal Inspection

Specific work procedures shall be prepared and followed when conducting inspections that will assure personnel safety and health and prevent property damage in the workplace (see 1.4).

6.7 Inspection Checklists

Annex C provides sample checklists of items for consideration when conducting in-service and out-of-service inspections.

6.8 Records

6.8.1 General

Inspection records form the basis of a scheduled inspection/maintenance program. (It is recognized that records may not exist for older tanks, and judgments must be based on experience with tanks in similar services.) The owner/operator shall maintain a complete record file consisting of three types of records, namely: construction records, inspection history, and repair/alteration history.
Section 7—Materials

7.1 General

This section provides general requirements for the selection of materials for the repair, alteration, and reconstruction of existing tanks. Specific requirements for repairs and alterations are covered in Section 9.

7.2 New Materials

All new materials used for repair, alterations, or reconstruction shall conform to the current applicable standard.

7.3 Original Materials for Reconstructed Tanks

7.3.1 Shell and Bottom Plates Welded to the Shell

7.3.1.1 All shell plate materials and bottom plates welded to the shell shall be identified. Materials identified by original contract drawings, API nameplates, or other suitable documentation do not require further identification. Material not identified shall be tested and identified by the requirements as outlined in 7.3.1.2. After identification, determination shall be made as to suitability of the material for intended service.

7.3.1.2 Each individual plate for which adequate identification does not exist shall be subjected to chemical analysis and mechanical tests as required in ASTM A6 and ASTM A370 including Charpy V-notch. Impact values shall satisfy the requirements of API 650, Section 4.2.9, Section 4.2.10, Section 4.2.11, and Table 4-4a or Table 4-4b. When the direction of rolling is not definitely known, two tension specimens shall be taken at right angles to each other from a corner of each plate, and one of those test specimens must meet the specification requirements.

7.3.1.3 For known materials, all shell plates and bottom plates welded to the shell shall meet, as a minimum, the chemistry and mechanical properties of material specified for the application with regard to thickness and design metal temperature given in API 650, Figure 4-1a or Figure 4-1b.

7.3.2 Structural

Existing rolled structural shapes that are to be reused shall meet the requirement of ASTM A7 as a minimum. New structural material shall meet the requirements of ASTM A36 or ASTM A992 as a minimum.

NOTE ASTM A7 was a steel specification that was discontinued in the Fourth Edition of API 650, 1970.

7.3.3 Flanges and Fasteners

7.3.3.1 Flange material shall meet the minimum requirements of the material specifications in the as-built standard.

7.3.3.2 Fasteners shall meet the material specifications of the current applicable standard.

7.3.4 Roof, Bottom, and Plate Windgirders

If existing plates are to be used to reconstruct the tank, they shall be checked for excessive corrosion and pitting (see Section 4 and Section 6).

7.4 Welding Consumables

Welding consumables shall conform to the AWS classification that is applicable to the intended use.
Section 8—Design Considerations for Reconstructed Tanks

8.1 General

Any specific design considerations other than normal product loading shall be specified by the owner/operator. See 4.4.3 for release prevention systems and release prevention barrier definition.

8.2 New Weld Joints

8.2.1 Weld joint details shall meet the welding requirements of the current applicable standard.

8.2.2 All new shell joints shall be butt-welded joints with complete penetration and complete fusion.

8.3 Existing Weld Joints

Existing weld joints shall meet the requirements of the as-built standard.

8.4 Shell Design

8.4.1 Thickness to be used for each shell course when checking tank design shall be based on measurements taken within 180 days prior to relocation. (See 4.3.2 for measuring procedure, number, and locations of measured thicknesses.)

8.4.2 The maximum design liquid level for product shall be determined by calculating the maximum design liquid level for each shell course based on the specific gravity of the product, the actual thickness measured for each shell course, the allowable stress for the material in each course, and the design method to be used. The allowable stress for the material shall be determined using API 650, Table 5-2a or Table 5-2b. For material not listed in Table 5-2a or Table 5-2b, an allowable stress value of the lesser of 2/3 yield strength or 2/5 tensile strength shall be used.

8.4.3 The maximum liquid level for hydrostatic test shall be determined by using the actual thickness measured for each shell course, the allowable stress for the material in each course, and the design method to be used. The allowable stress for the material shall be determined using API 650, Table 5-2a or Table 5-2b. For material not listed in Table 5-2a or Table 5-2b, an allowable stress value of the lesser of 3/4 yield strength or 3/7 tensile strength shall be used.

8.4.4 If a corrosion allowance is required for the reconstructed tank, the required corrosion allowance shall be deducted from the actual thickness before calculating the maximum liquid level. If the actual thickness is greater than that necessary to allow the liquid level required, the extra thickness can be considered as corrosion allowance.

8.4.5 The joint efficiency and allowable stress levels used for the design liquid level calculations shall be consistent with the design method used and with the degree and type of examination made on welded joints. The joint efficiency and allowable stress levels for existing welded joints that are not to be removed and replaced shall be based on the original degree and type of examination.

8.5 Shell Penetrations

8.5.1 Replacement and new penetrations shall be designed, detailed, welded, and examined to meet the requirements of the current applicable standard.

8.5.2 Existing penetrations shall be evaluated for compliance with the as-built standard.
8.6 Windgirders and Shell Stability

8.6.1 Top and intermediate windgirders for open top tanks shall meet the requirements of the current applicable standard.

8.6.2 Tanks to be reconstructed shall be checked for wind-induced buckling in accordance with the procedures of the current applicable standard, using the wind requirements for the location where the tank will be reconstructed.

8.7 Roofs

8.7.1 Roof designs shall meet the requirements of the as-built standard.

8.7.2 If the new site requires a larger design load than the original site, the adequacy of the existing roof shall be evaluated using the current applicable standard.

8.8 Seismic Design

Tanks that will be reconstructed shall be checked for seismic stability based on the rules of the current applicable standard using the dimensions and thicknesses of the reconstructed tank. Reconstructed tanks shall be built to meet the stability requirements of the current applicable standard. Thickened bottom plates under the bottom shell course or anchoring of the tank may be required even if not used on the original tank.
NOTES:
1. See table in Figure 9-1 for minimum weld spacing and dimensions H, R, and V.
2. Detail shown for door sheet that utilizes removed section of tank shell. If new material is utilized, see Figure 9-1 for requirements.
3. Prior to welding new vertical weld seam which intersects the bottom plate, cut existing shell-to-bottom weld for a minimum of 12 in. beyond the new vertical weld seam. The cut shall extend past or stop short of existing bottom plate welds by at least 3 in. or 5t. Weld the shell-to-bottom weld last.
4. Door sheets need not extend to shell-to-bottom weld provided that weld spacing and corner radii are in accordance with Figure 9-1.

**Figure 9-4**—Details for Door Sheet in Butt Weld Shell Seam Tank—No Vertical Seam Offset

NOTES:
1. See table in Figure 9-1 for minimum weld spacing and dimensions H, R, and V.
2. Prior to welding new vertical joints, cut the existing horizontal weld for a minimum of 12 in. beyond the new vertical weld seam. Weld the horizontal seam last.
3. Prior to welding new vertical joints which intersect the bottom plate, cut the existing shell-to-bottom weld for a minimum of 12 in. beyond the new vertical weld joint. The cut shall extend past or stop short of existing bottom plate welds by at least 3 in. or 5t. Weld the shell-to-bottom weld last.
4. Door sheets need not extend to shell-to-bottom weld provided that weld spacing and corner radii are in accordance with Figure 9-1.

**Figure 9-5**—Details for Door Sheet in Butt Welds Shell Seam Tank—Tank-Vertical Seam Offset
9.3 Shell Repairs Using Lap-welded Patch Plates

9.3.1 Lapped patch shell repairs are an acceptable form of repair for butt-welded, lap-welded, and riveted tank shells, under the conditions outlined in 9.3.2, 9.3.3, and 9.3.4; only when specified by the owner. In addition, the repair details shall comply with the requirements of 9.3.1.1 through 9.3.1.10. These repairs are permanent repairs subject to an ongoing inspection and maintenance program. These requirements may be used to evaluate existing lapped patch shell repairs; however, the plate thickness limits need not apply.

9.3.1.1 All repair material shall comply with the requirements of the current applicable standard of construction and API 653.

9.3.1.2 Lapped patch shell repairs shall not be used on any shell course thickness (original construction) that exceeds $\frac{1}{2}$ in., nor to replace doorsheets or shell plates.

9.3.1.3 Except as permitted in 9.3.3.2 and 9.3.4.3, the repair plate material shall be the smaller of $\frac{1}{2}$ in. or the thickness of the shell plate adjacent to the repairs, but not less than $\frac{3}{16}$ in.

9.3.1.4 The shape of the repair plate may be circular, oblong, square, or rectangular. All corners, except at the shell-to-bottom joint, shall be rounded to a minimum radius of 2 in. The nozzle reinforcing plate shapes of API 650, Figure 5-8, are also acceptable.

9.3.1.5 The repair plate may cross any butt-welded vertical or horizontal shell seams that have been ground flush, but must overlap a minimum of 6 in. beyond the shell seam. The weld spacing requirements of Figure 9.1 shall be used as a basis for locating repair plates relative to butt-welded, fillet-welded, and riveted seams and other repair plates.

9.3.1.6 Repair plates may extend to and intersect with the external shell-to-bottom joint if the vertical sides intersect the tank bottom at a 90° angle and the shell-to-bottom weld is in conformance with Figure 9.6. Repair plates positioned on the shell interior shall be located such that the toe-to-toe weld clearances are a minimum of 6 in. to the shell-to-bottom weld.

9.3.1.7 The maximum vertical and horizontal dimension of the repair plate is 48 in. and 72 in., respectively. The minimum repair plate dimension is 4 in. The repair plate shall be formed to the shell radius.

9.3.1.8 Shell openings and their reinforcements shall not be positioned within a lapped patch shell repair.

9.3.1.9 Prior to application of a lapped patch shell repair, the areas to be welded shall be ultrasonically examined for plate defects and remaining thickness.

9.3.1.10 Repair plates shall not be lapped onto lap-welded shell seams, riveted shell seams, other lapped patch repair plates, distorted areas, or unrepaired cracks or defects.

9.3.2 Lapped patch repair plates may be used for the closure of holes caused by the removal of existing shell openings or the removal of severely corroded or eroded areas. In addition, the following requirements shall be satisfied.

9.3.2.1 The welding shall be continuous on the outer perimeter of the repair plate and the inner perimeter of the hole in the shell plate. The minimum hole diameter is 2 in. Shell openings due to plate removal shall have a minimum corner radius of 2 in.

9.3.2.2 Nozzle necks and reinforcing plates shall be entirely removed prior to installation of a repair plate.

9.3.2.3 The repair plate thickness selection shall be based on a design that conforms to the as-built standard and API 653, using a joint efficiency not exceeding 0.70. The welds of the repair plate shall be full fillet welds. The minimum repair plate dimension shall be 4 in. with a minimum overlap of 1 in. and a maximum overlap of 8 times the shell thickness ($8t$).

9.3.2.4 The repair plate thickness shall not exceed the nominal thickness of the shell plate adjacent to the repair.
c) Welded-on patch plates shall not be placed over areas of the tank bottom that have global dishing, local dishing [except as allowed by 9.10.1.1 d)], settlement, or distortion greater than the limits of Annex B.

NOTE If the tank is still undergoing settlement, the addition of welded-on patch plate may not be advisable.

d) A welded-on patch plate may be placed over a mechanical dent or local dishing if: its unsupported dimension does not exceed 12 in. in any direction; it is at least 1 1/4 in. thick; it is at least as thick as the existing bottom; and does not overlap seams or other patches, except for tanks designed in accordance with API 650, Annex M, which shall have welded-on patch plates at least 3/8 in. thick.

e) These repairs are permanent repairs subject to an on-going inspection and maintenance program.

f) Installation of a new sump shall conform to API Standard 650 Section 5, paragraph 5.8.7 (Water Drawoff Sumps), Tables 5-16a and 5-16b and Figure 5-21.

9.10.1.2 Repairs within the Critical Zone

The use of welded-on patch plates is permitted for repairing a portion of tank bottoms within the critical zone (see 3.10 for definition) provided 9.10.1.1 requirements and the following additional requirements are met.

a) Maximum plate thickness for welded-on patch plates within the critical zone is 1/4-in. and must meet the toughness requirements of API 650, Section 4.2.10.

b) When a welded-on patch plate is within 6 in. of the shell, the welded-on patch plate shall be tombstone shaped. The sides of the tombstone shaped welded-on patch plate shall intersect the shell-to-bottom joint at approximately 90°.

c) Perimeter welds on welded-on patch plates within the critical zone shall be two-pass, minimum, and examined per 12.1.1.3 and 12.1.7.2.

d) Installation of a welded-on patch plate by butt-welding to an adjacent existing patch is not permitted in the critical zone.

e) Welded-on patch plates over existing patches are not allowed in the critical zone.

f) The bottom plate under the perimeter of a welded-on patch plate shall meet the thickness requirements in 4.4.

g) For tanks with shell plate of unknown toughness as defined in Section 3, new fillet welds utilized to install a tombstone patch plate in the critical zone shall be spaced at least the greater of 3 in. or 5r from existing vertical weld joints in the bottom shell course, where r is the thickness of the bottom shell course, in inches. See Figure 9.13 for further guidance on weld spacing.

NOTE The bottom plate thickness at the attachment weld must be at least 0.1-in. thick before welding the welded-on patch plate to the bottom plate. Refer to API 2207 for further information.

9.10.1.2.1 No welding or weld overlays are permitted within the critical zone except for the welding of: widely scattered pits (see 4.3.2.2), pinholes, cracks in the bottom plates, the shell-to-bottom weld, welded-on patch plates, or where the bottom plate welded to the shell is being replaced.

9.10.1.2.2 A welded-on patch plate shall not be used if the covered bottom plate minimum remaining thickness at the toe of the internal shell-to-bottom weld will be less than the minimum thickness required by 4.4.5 and 4.4.6 at the next internal inspection.

9.10.1.2.3 Welded-on patch plates are not permitted in the critical zone on a tank bottom with an operating temperature exceeding 200 °F for carbon steel or 100 °F for stainless steel.

9.10.1.2.4 If more extensive repairs are required within the critical zone than those listed in 9.10.1.2, the bottom plate welded to the shell shall be cut out and a new plate shall be installed. Weld spacing requirements shall be in accordance with 9.10.2.4, and API 650, Section 5.1.5.4 and Section 5.1.5.5. The shell-to-bottom weld shall be removed and replaced for a minimum distance of 12 in. on each side of the new bottom plate.
Figure 9.13—Typical Welded-on Patch Plates on Tank Bottom Plates
9.10.1.3 The use of welded-on patch plates that do not meet the requirements of 9.10.1.1 or 9.10.1.2 is permitted if the repair method has been reviewed and approved by an engineer experienced in storage tank design in accordance with API 650. The review shall consider brittle fracture, stress due to settlement, stress due to shell-bottom discontinuity, metal temperature, fracture mechanics, and the extent and quality of NDE.

9.10.1.4 Unacceptable indications such as cracks, gouges, tears, and corroded areas discovered in bottom plates, located outside the critical zone, may be repaired by deposition of weld metal followed by examination and testing in accordance with 12.1.7.3. Surface irregularities and contamination within the area to be repaired shall be removed before welding.

9.10.1.5 The repair of sumps located within the critical zone shall be in accordance with 9.10.1.2.

9.10.1.6 The repair of corroded plates in the critical zone is limited to pit welding or overlay welding as noted in this section. The weld repair of bottom plate corrosion is permitted if all of the following conditions are satisfied.

a) The sum of the pit dimensions along an arc parallel to the shell-to-bottom joint does not exceed 2 in. in an 8-in. length.

b) There must be sufficient remaining bottom plate thickness for completion of a sound weld and to avoid burn-through. The minimum acceptable bottom plate thickness for weld repairs is 0.10 in. A lesser thickness is permitted for weld repairs only if reviewed and approved by an engineer experienced in storage tank design and repair.

c) All weld repairs shall be ground flush with the surrounding plate material and be examined in accordance with 12.3.2.4.

9.10.2 Replacement of Tank Bottom Plates

9.10.2.1 Requirements governing the installation of a replacement bottom over an existing bottom are given in 9.10.2.1.1 through 9.10.2.1.5.

9.10.2.1.1 Suitable noncorrosive material cushion such as sand, gravel, or concrete shall be used between the old bottom and the new bottom.

9.10.2.1.2 The shell shall be slotted with a uniform cut made parallel to the tank bottom. The cut edges in the slot shall be ground to remove all slag and burrs from cutting operations. The new bottom plate shall extend outside the shell as required by API 650, Section 5.4.2. All rules for weld spacing shall be followed.

9.10.2.1.3 Voids in the foundation below the old bottom shall be filled with sand, crushed limestone, grout, or concrete.

9.10.2.1.4 Except as permitted in 9.10.2.7, existing shell penetrations shall be raised or their reinforcing plates modified if the elevation of the new bottom results in inadequate nozzle reinforcement details (see Figure 9.8 and API 650, Section 5.7.2) or if the weld space requirements given in API 650, Section 5.7.3 are not met.

9.10.2.1.5 For floating roof tanks, the new bottom profile must keep the roof level when it is resting on its support legs. The levelness of the floating roof can be adjusted by changing the length of the support legs. The support legs can either remain the same length to maintain the original height above the bottom or be shortened by the same amount as the thickness of the cushion and new bottom plate.

9.10.2.2 New bearing plates for fixed roof support columns shall be installed. For steel floating roof legs, steel pads or other means shall be used to distribute the loads on the bottom of the tank and provide a wear surface. If pads are used, they shall be continuously welded to the tank bottom. For aluminum floating roofs, the pads may be omitted if the owner/operator approves and new austenitic stainless steel or acceptable non-metallic (e.g., Teflon) spacers are installed to isolate legs from the carbon steel bottom. For aluminum floating roofs, austenitic stainless steel or acceptable non-
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metallic (e.g., Teflon) spacers may installed to isolate legs from the carbon steel bottom instead of welded pads if the spacers will not damage bottom coatings, there is no evidence of corrosion damage from such spacers on the previous bottom, and if the owner/operator approves.

9.10.2.3 When removing an existing tank bottom, the tank shell shall be separated from tank bottom either by:

a) cutting the shell parallel to the tank bottom a minimum of \( \frac{1}{2} \) in. above the bottom-to-shell weld (cut line B-B as shown in Figure 10.1), or

b) removing the entire shell-to-bottom attachment weld, including any penetration and heat affected zone by suitable methods such as arc gouging and/or grinding.

All arc-gouged areas of the tank shell-to-bottom weld shall be magnetic particle examined, and defective areas repaired and re-examined.

9.10.2.4 Installation of a new tank bottom, after removal of the existing tank bottom, shall meet all requirements of API 650. Except as permitted in 9.10.2.7, existing shell penetrations shall be raised or their penetration reinforcing plates modified if the elevation of the new bottom results in inadequate nozzle reinforcement (see Figure 9.8 and API 650, Section 5.7.2) or if the weld spacing requirements given in API 650, Section 5.7.3 are not met. For tanks with shell plate of unknown toughness as defined in Section 3, new weld joints in the bottom or annular ring shall be spaced at least the greater of 3 in. or \( 5 \, \sqrt{t} \) from existing vertical weld joints in the bottom shell course, where \( t \) is the thickness of the bottom shell course, in inches.

9.10.2.5 Replacement of portions of an existing tank bottom (entire rectangular plates or large segments of plates) not within the critical zone (see 3.10 for definition) are permitted under the same rules that govern installation of bottoms in new tank construction per API 650, Sections 5.4 and 5.5.

9.10.2.6 The following shall be considered for tanks with cathodic protection and under-bottom leak detection.

a) For tanks having cathodic protection (CP) installed under the existing bottom, consideration shall be given to removal of the entire bottom and unused dead shell to prevent shielding of CP current to the new bottom. Removal of the old bottom is also important in preventing galvanic corrosion (refer to API 651). Where this is possible, removal of the entire old bottom, except the unused dead shell and not more than 18 in. of bottom annulus attached to the shell, shall be considered.

b) Consideration shall be given to installing under-bottom leak detection at this time (such as a RPB) to contain and channel any bottom leak to a location where it can readily be observed from outside of the tank. See 4.4.3.5 and Annex I.

9.10.2.7 For tanks constructed from materials having 50,000 lbf/in.\(^2\) yield strength or less, existing shell penetrations need not be raised if the following conditions are met.

a) For reinforced penetrations, including low-types, a minimum of 4 in. shall be maintained between the shell-to-bottom weld toe and the nearest penetration attachment weld toe (reinforcing plate periphery weld, or nozzle neck weld to low type reinforcing plate and shell welds).

b) For self-reinforced penetrations, the greater of 3 in. or \( 2 \frac{1}{2} \, \sqrt{t} \) shall be maintained between the shell-to-bottom weld toe and the nearest penetration attachment weld toe.

c) The shell-to-bottom weld is to be welded with low hydrogen electrodes and with welding procedures that are designed to limit distortion and residual stress.

d) The toes of the welds shall be blend-ground to minimize stress concentrations as follows.
i) For circular reinforcing plates, blend-grind the periphery attachment weld from the “four o'clock” position to the “eight o'clock” position. Blend-grind the inside and outside of the shell-to-bottom weld a minimum of one penetration diameter length on either side of the penetration centerline.

ii) For diamond-shaped reinforcing plates, blend-grind the lower horizontal length of the diamond shaped attachment weld. Blend-grind the inside and outside of the shell-to-bottom weld a minimum of one penetration diameter length on either side of the penetration centerline.

iii) For low-type penetrations, blend-grind the nozzle attachment weld (shell and reinforcing plate) from the “four o'clock” position to the “eight o'clock” position. Blend-grind the inside and outside of the shell-to-bottom weld a minimum of one penetration diameter length on either side of the penetration centerline.

e) The blend-ground lengths of welds listed in 9.10.2.1.7 d) shall be magnetic particle examined before and after hydrostatic test.

9.10.3 Additional Welded-on Plates

9.10.3.1 If other welded-on plates such as wear, isolation, striker, and bearing plates, are to be added to tank bottoms, they shall be installed in accordance with 9.10.1, and examined in accordance with 12.1.7. For these additional welded-on plates, if the lap weld spacing requirements as set forth in Figure 9.13 are not met, magnetic particle (MT) or liquid penetrant (PT) examination is required for the exposed welds or portions of welds failing to meet minimum spacing criteria. See Section 12 for acceptance requirements.

9.10.3.2 Welded-on plates that fall within the critical zone (see 3.10 for definition) shall be installed in accordance with 9.10.1.2 and comply with all of its requirements.

9.11 Repair of Fixed Roofs

9.11.1 Repairs

9.11.1.1 Roof repairs involving tank venting shall be made such that normal and emergency venting meet the requirements of API 650, Section 5.8.5.

9.11.1.2 Roof repairs involving modification of the roof structure and the frangible joint (if applicable) shall be in compliance with the requirements of API 650, Section 5.10.

9.11.2 Supported Cone Roofs

9.11.2.1 The minimum thickness of new roof plates shall be $\frac{3}{16}$ in. plus any corrosion allowance as specified in the repair specifications. In the event roof live loads in excess of 25 lbf/ft$^2$ are specified (such as insulation, operating vacuum, high snow loads), the plate thickness shall be based on analysis using the allowable stresses in conformance with API 650, Section 5.10.3 (see 9.11.2.2).

9.11.2.2 The roof supports (rafters, girders, columns, and bases) shall be repaired or altered such that under design conditions the resulting stresses do not exceed the stress levels given in API 650, Section 5.10.3.

9.11.3 Self-supporting Roofs

9.11.3.1 The nominal thickness of new roof plate shall be $\frac{3}{16}$ in. or the required plate thickness given in API 650, Section 5.10.5 or Section 5.10.6, plus any specified corrosion allowance, whichever is greater.

9.11.3.2 The details of the roof-to-shell junction shall meet the requirements of API 650, Section 5.10.5, Section 5.10.6, or Annex F of this standard, as applicable, for the intended service.
9.12 Repair of Floating Roofs

9.12.1 External Floating Roofs

Any method of repair is acceptable that will restore the roof to a condition enabling it to perform as required.

9.12.2 Internal Floating Roofs

Repairs to internal floating roofs shall be made in accordance with the original construction drawings, if available. If the original construction drawings are not available, the roof repairs shall be in compliance with the requirements of API 650, Annex H.

9.12.3 Repair of Leaks in Pontoons

All leaks in pontoons or compartments of double deck floating roofs shall be repaired by rewelding the leaking joints and/or use of patch plates.

9.13 Repair or Replacement of Floating Roof Perimeter Seals

9.13.1 Primary Seals

Rim-mounted primary shoe seals and toroidal seal systems can be removed, repaired, or replaced. To minimize evaporation losses and reduce potential hazard to the workers, no more than one-fourth of the roof seal system should be out of an in-service tank at one time. Temporary spacers to keep the roof centered shall be used during the repairs. Primary seal systems mounted partly or fully below the bolting bar or top of the rim usually cannot be reached to allow removal in service. In this case, in-service repairs are limited to replacement of the primary seal fabric.

9.13.2 Secondary Seals

Rim-mounted and shoe-mounted secondary seals may be readily installed, repaired, or replaced while the tank is in service.

9.13.3 Seal-to-shell Gap

Repair and other corrective actions to maintain seal-to-shell gap requirements, include the following.

a) Adjusting the hanger system on primary shoe seals, and adding foam filler in toroidal seals.

b) Increasing the length of rim mounted secondary seals in the problem area.

c) Replacing all or part of the primary seal system along with possible installation of a rim extension for a secondary seal. This step shall be taken only after checking the annular space variation at several levels from low pump out to high liquid level.

9.13.4 Mechanical Damage

Damaged parts shall be repaired or replaced. Prior to taking this action, the cause of the damage shall be identified and corrected. Buckled parts shall be replaced, not straightened. Torn seal fabric shall be replaced.

9.13.5 Deterioration of Seal Material

Material deterioration results from wear and corrosion on metallic elements, and chemical and weather deterioration of seal fabric. The service life and inspection information shall be used to determine whether a change of material is warranted.
10.5 Dimensional Tolerances

10.5.1 General

10.5.1.1 The tolerances given in this section have been established to produce a reconstructed tank of acceptable appearance and structural integrity and to permit proper functioning of floating roofs and seals.

10.5.1.2 Measurements to verify these tolerances shall be taken before the hydrostatic test of the reconstructed tank.

10.5.2 Plumbness

10.5.2.1 The maximum out-of-plumbness of the top of the shell relative to the bottom of the shell shall not exceed 1/100 of the total tank height, with a maximum of 5 in. The 1/100 criteria, with a maximum of 5 in., shall also apply to fixed roof columns. For tanks with internal floating roofs, apply the criteria of this section or API 650, Section 7.5.2 and Annex H, Section H.4.1.1, whichever is more stringent.

10.5.2.2 The out-of-plumbness in one shell course shall not exceed the values specified for mill tolerances in ASTM A6 or ASTM A20, whichever is applicable.

10.5.3 Roundness

Radii measured at 1 ft above the shell-to-bottom weld shall not exceed the tolerances shown in Table 10.2.

Radius tolerances measured higher than one foot above the shell-to-bottom weld shall not exceed three times the tolerances given in Table 10.2.

10.5.4 Peaking

With a horizontal sweep board 36-in. long, peaking shall not exceed 1/2 in. The sweep board shall be made to the true outside radius of the tank.

10.5.5 Banding

With a vertical sweep board 36-in. long, banding shall not exceed 1 in.

Table 10.2—Radii Tolerances

<table>
<thead>
<tr>
<th>Tank Diameter (ft)</th>
<th>Radius Tolerances (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 40</td>
<td>±1/2</td>
</tr>
<tr>
<td>40 to &lt; 150</td>
<td>±3/4</td>
</tr>
<tr>
<td>150 to &lt; 250</td>
<td>±1</td>
</tr>
<tr>
<td>≥ 250</td>
<td>±1 1/4</td>
</tr>
</tbody>
</table>
10.5.6 Foundations

10.5.6.1 To achieve the tolerances specified in 10.5.1 through 10.5.5, it is essential that foundations true to a plane be provided for the tank reconstruction. The foundation shall have adequate bearing capacity to maintain the trueness of the foundation.

10.5.6.2 Where foundations true to a horizontal plane are specified, tolerances shall be as follows:

a) where concrete ringwalls are provided under the shell, the top of the ringwall shall be level within $\pm{\frac{1}{8}}$ inches in any 30 ft of the circumference and within $\pm{\frac{1}{4}}$ inches in the total circumference measured from the average elevation;

b) where concrete ringwalls are not provided, the foundation under the shell shall be level within $\pm{\frac{1}{8}}$ in. in any 10 ft of circumference and within $\pm{\frac{1}{2}}$ in. in the total circumference measured from the average elevation.

10.5.6.3 For foundations specified to be sloped from a horizontal plan, elevation differences about the circumference shall be calculated from the specified high point. Actual elevation differences about the circumference shall be determined from the actual elevation of the specified high point. The actual elevation differences shall not deviate from the calculated differences by more than the following tolerances:

a) where concrete ringwalls are provided $\pm{\frac{1}{8}}$ inches in any 30 ft of circumference and $\pm{\frac{1}{4}}$ inches in the total circumference;

b) where concrete ringwalls are not provided, $\pm{\frac{1}{8}}$ inches in any 10 ft of circumference and $\pm{\frac{1}{2}}$ inches in the total circumference.
Section 11—Welding

11.1 Welding Qualifications

11.1.1 Welding procedure specifications (WPSs) and welders and welding operators shall be qualified in accordance with Section IX of the ASME Code, the additional requirements of API 650, Section 9, and this standard. Welding procedures for ladder and platform assemblies, handrails, stairways, and other miscellaneous assemblies, but not their attachments to the tank, shall comply with either AWS D1.1, AWS D1.6, or Section IX of the ASME Code, including the use of SWPSs.

11.1.2 Weldability of steel from existing tanks shall be verified. If the material specification for the steel from an existing tank is unknown or obsolete, test coupons for the welding procedure qualification shall be taken from the actual plate to be used.

11.2 Identification and Records

11.2.1 Each welder and welding operator shall be assigned an identifying number, letter, or symbol. Records of this identification, along with the date and results of the welder’s qualification tests shall be accessible to the inspector.

11.2.2 The welder or welding operator’s identification mark shall be hand- or machine-stamped adjacent to and at intervals not exceeding 3 ft along the completed welds. In lieu of stamping, a record may be kept that identifies the welder or welding operator employed for each welded joint; these records shall be accessible to the inspector. Roof plate welds and flange-to-nozzle-neck welds do not require welder identification.

11.3 Preheat or Controlled Deposition Welding Methods as Alternatives to Post-weld Heat Treatment (PWHT)

Preheat and controlled deposition welding, as described in 11.3.1 and 11.3.2, may be used in lieu of PWHT for repairs to existing nozzles where PWHT is required by API 653 or was performed in the original construction but is inadvisable or mechanically unnecessary for the repair. Prior to using any alternative method, a metallurgical review conducted by a storage tank engineer shall be performed to assess whether the proposed alternative is suitable for the application. The review shall consider the reason for the original PWHT of the equipment, susceptibility of the service to promote stress corrosion cracking, stresses in or near the weld, etc.

If materials are of unknown toughness and fall under the Figure 5.2 exemption curve, follow the requirements of 11.3.2. The storage tank engineer must concur in writing with the PWHT exemption. Also, the tank owner/operator must authorize the exemption in writing.

Selection of the welding method used shall be based on technical consideration of the adequacy of the weld in the as-welded condition at operating and hydrotest conditions.

11.3.1 Preheating Method (Impact Testing Not Required)

If impact testing is not required, the following additional preheat requirements apply.

a) This method is limited to use on P-1 materials that were not required to be impact tested as part of the original construction or under current requirements of API 650, Section 9.2.

b) The welding shall be limited to the shielded-metal-arc welding (SMAW), gas-metal-arc welding (GMAW), flux-cored arc welding (FCAW) and gas-tungsten-arc welding (GTAW) processes.

c) The welders and welding procedures shall be qualified in accordance with the applicable rules of the original code of construction, except that the PWHT of the test coupon used to qualify the procedure shall be omitted.
d) The weld area shall be preheated and maintained at a minimum temperature of 150 °C (300 °F) during welding. The 150 °C (300 °F) temperature shall be checked to assure that 100 mm (4 in.) of the material or four times the material thickness (whichever is greater) on each side of the groove is maintained at the minimum temperature during welding. The maximum inter-pass temperature shall not exceed 315 °C (600 °F). When the weld does not penetrate through the full thickness of the material, the minimum preheat and maximum inter-pass temperatures need only be maintained at a distance of 100 mm (4 in.) or four times the depth of the repair weld (whichever is greater) on each side of the joint.

11.3.2 Controlled-deposition Welding Method (Impact Testing Required)

If impact testing is required, the following welding requirements apply.

a) This method may be used when welding is to be performed on materials that were required to be impact tested per 4.2.9 and 4.2.10 of API 650 as part of the original construction or under current requirements of API 650, Section 9.2, and is limited to P-1, P-3 and P-4 steels.

b) The welding shall be limited to the shielded-metal-arc welding (SMAW), gas-metal-arc welding (GMAW), flux-cored arc welding (FCAW) and gas-tungsten-arc welding (GTAW) processes.

c) A weld procedure specification shall be developed and qualified for each application. The welding procedure shall define the preheat temperature, the inter-pass temperature and the post heating temperature requirement in Item e), §) below. The qualification thickness for the test plates and repair grooves shall be in accordance with Table 11.1.

Table 11.1—Welding Methods as Alternatives to Post-weld Heat Treatment (PWHT)
Qualification Thicknesses for Test Plates and Repair Grooves

<table>
<thead>
<tr>
<th>Depth of Test Groove Welded $t$</th>
<th>Repair Groove Depth Qualified</th>
<th>Thickness $T$ of Test Coupon Welded</th>
<th>Thickness of Base Metal Qualified</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t &lt; t$</td>
<td>$&lt; 50$ mm (2 in.)</td>
<td>$&lt; T$</td>
<td></td>
</tr>
<tr>
<td>$t ≥ t$</td>
<td>$≥ 50$ mm (2 in.)</td>
<td>50 mm (2 in.) to unlimited</td>
<td></td>
</tr>
</tbody>
</table>

The test material for the welding procedure qualification shall be of the same material specification (including specification type, grade, class and condition of heat treatment) as the original material specification for the repair. If the original material specification is obsolete, the test material used should conform as much as possible to the material used for construction, but in no case shall the material be lower in strength or have a carbon content of more than 0.35 %.

d) When impact tests are required by the construction code applicable to the work planned, the PQR shall include sufficient tests to determine if the toughness of the weld metal and the heat-affected zone of the base metal in the as-welded condition are adequate at the minimum design metal temperature. If special hardness limits are necessary for corrosion resistance (e.g. those set forth in NACE RP 0472, NACE MR 0103 and NACE MR 0175), the PQR shall include hardness test results.

e) The WPS shall include the following additional requirements.

1) The supplementary essential variables of ASME Code, Section IX, Paragraph QW-250, shall be required.

2) The maximum weld heat input for each layer shall not exceed that used in the procedure qualification test.
Section 12—Examination and Testing

12.1 NDE

12.1.1 General

12.1.1.1 NDE shall be performed in accordance with API 650, Section 8, and any supplemental requirements given herein.

12.1.1.2 Personnel performing NDE shall be qualified in accordance with API 650, Section 8, and any supplemental requirements given herein.

12.1.1.3 Acceptance criteria shall be in accordance with API 650, Section 8, and any supplemental requirements given herein.

12.1.1.4 Each newly deposited weld or any cavity resulting from gouging or grinding operations shall be visually examined over its full length. Additional NDE of these welds may be required as described in the following relevant sections.

12.1.1.5 Annex G may be used to provide additional guidance in qualifying personnel and procedures when magnetic flux leakage (MFL) tools are used to examine tank bottoms. Owner/operators should determine specific requirements to meet their tank bottom integrity needs.

12.1.2 Shell Penetrations

12.1.2.1 Ultrasonic examination of shell plate for laminations shall be made in the immediate area affected when:

a) adding a reinforcing plate to an existing unreinforced penetration,

b) adding a hot tap connection.

12.1.2.2 Cavities resulting from gouging or grinding operations to remove attachment welds of existing reinforcing plates shall be examined by magnetic particle or liquid penetrant methods.

12.1.2.3 Completed welds attaching nozzle neck to shell, and reinforcing plate to shell and to nozzle neck, shall be examined by the magnetic particle or liquid penetrant methods. Consider additional examination (e.g. fluorescent magnetic particle examination and/or ultrasonic examination) for hot tap connections to shell plates of unknown toughness as defined in Section 3.

12.1.2.4 Completed welds of stress-relieved assemblies shall be examined by the magnetic particle or liquid penetrant methods after stress relief, but before hydrostatic testing.

12.1.3 Repaired Weld Flaws

12.1.3.1 Cavities resulting from gouging or grinding operations to remove weld defects shall be examined by the magnetic particle or liquid penetrant methods.

12.1.3.2 Completed repairs of butt-welds shall be examined over their full length by radiographic or ultrasonic methods.

12.1.3.3 Completed repairs of fillet welds shall be examined over their full length by the appropriate NDE method listed herein.
12.1.4 Temporary and Permanent Attachments to Shell Plates

12.1.4.1 The welds of permanent attachments (not including shell-to-bottom welds) and, areas where temporary attachments are removed and the remaining weld projections have been removed, shall be examined visually.

12.1.4.2 Completed welds of new permanent attachments (not including shell-to-bottom welds) and areas where temporary attachments have been removed (API 650 tank shell materials of Groups IV, IVA, V, or VI), shall be examined by either the magnetic particle method (or, at the option of the purchaser, by the liquid penetrant method).

12.1.5 Shell Plate to Shell Plate Welds

12.1.5.1 New welds attaching existing shell plate to existing or new shell plate shall be examined by radiographic methods (see 12.2). In addition, for plate thicknesses greater than 1 in., the back-gouged surface of the root pass and final pass (each side) shall be examined for its complete length by magnetic particle or liquid penetrant methods.

12.1.5.2 New welds joining new shell plate material to new shell plate material (partial or full shell course replacement or addition) need only be examined radiographically in accordance with API 650, Section 8.1.

12.1.6 Shell-to-bottom Weld

12.1.6.1 New welding on the shell-to-bottom joint shall be examined for its entire length by using a right-angle vacuum box and a solution film, or by applying light diesel oil. Additionally, the first weld pass shall be examined by applying light diesel oil to the side opposite the first weld pass made. The oil shall be allowed to stand at least 4 hours (preferably overnight) and then the weld examined for wicking action. The oil shall be removed before the weld is completed.

12.1.6.2 As an alternative to 12.1.6.1, the initial weld passes, inside and outside of the shell, shall have all slag and non-metals removed from the surface of the welds and examined visually. Additionally, after completion of the inside and outside fillet or partial penetration welds, the welds shall be tested by pressurizing the volume between the inside and outside welds with air pressure to 15 psig and applying a solution film to both welds. To assure that the air pressure reaches all parts of the welds, a sealed blockage in the annular passage between the inside and outside welds must be provided by welding at one or more points. Additionally, a small pipe coupling communicating with the volume between the welds must be welded on each side of and adjacent to the blockages. The air supply must be connected at one end and a pressure gauge connected to a coupling on the other end of the segment under test.

12.1.6.3 The existing weld at the shell-to-bottom joint shall be examined by visual, as well as by magnetic particle or liquid penetrant methods, for the full length under a welded-on patch plate. An additional 6 in. of the shell-to-bottom joint on each side of the welded-on patch plate shall be examined similarly before placement of the repair plate to assure weld integrity and to confirm the absence of weld cracks.

12.1.7 Bottoms

12.1.7.1 Upon completion of welding on a tank bottom, the plates and the entire length of new welds for tank bottom plates shall be examined visually for any potential defects and leaks. Particular attention shall apply to areas such as sumps, dents, gouges, three-plate laps, bottom plate breakdowns, arc strikes, temporary attachment removal areas, and welding lead arc burns. Visual examination acceptance and repair criteria are specified in API 650, Section 8.5. In addition, all new welds, including the weld attaching a patch plate to the bottom, the areas of bottom plate restored by welding, and the restoration of welds found with defects during an internal inspection shall be examined by one of the methods specified in API 650, Section 7.3.3. Leaking areas shall be repaired by grinding and rewelding as required, and the repaired area shall be retested.

12.1.7.2 In addition to the requirements in 12.1.7.1, the root and final pass of a welded-on patch plate weld in the critical zone (see 3.10 for definition) shall be visually examined and examined by either magnetic particle or liquid penetrant method over its full length.
12.1.7.3  In addition to the requirements in 12.1.7.1, areas of bottom plate repaired by welding shall be examined by the magnetic particle method or the liquid penetrant method. In addition, the repaired area shall also be tested using a vacuum box and solution or a tracer gas and detector.

12.1.8  Shell Plate

12.1.8.1  Shell Plate Repairs by Weld Metal Deposit

Areas of shell plate to be repaired by welding shall be examined visually. In addition, shell plate areas repaired by welding shall be examined by the magnetic particle method (or the liquid penetrant method).

12.1.8.2  Shell Plate Repairs by Lap-welded Patches

The attachment welds of new lap-welded shell patches shall be visually examined, and shall be examined by either the magnetic particle or liquid penetrant methods.

12.1.9  Fixed Roofs

Newly welded roof joints and repairs shall be examined in accordance with API 650, Section 7.3.2.2 and Section 7.3.7.

12.1.10  Floating Roofs

12.1.10.1  Repair Work to Steel Floating Roofs

After repair work is complete:

a) perform a visual examination from the top and bottom side of the floating roof;

b) perform an air leak, vacuum box, penetrating oil, tracer gas, or other applicable non destructive test of the repaired welds (see Annex F).

As an alternative to Item b), conduct a flotation test of the repaired roof.

Examination and acceptance criteria for NDT shall be in accordance with 12.1.

12.2  Radiographs

12.2.1  Number and Location of Radiographs

The number and location of radiographs shall be in accordance with API 650, Section 8.1.2 and the following additional requirements:

12.2.1.1  For vertical joints:

a) new replacement shell plates to new shell plates, no additional radiographs required, other than those required by API 650, Section 8.1.2.2 and Figure 8-1 for new construction;

b) new replacement shell plates to existing shell plates, one additional radiograph shall be taken in each joint;

c) repaired joints in existing shell plates shall have one additional radiograph taken in each joint.

12.2.1.2  For horizontal joints:

a) new replacement shell plates to new shell plates, no additional radiographs required, other than those required by API 650, Section 8.1.2.3 and Figure 8-11 for new construction;
b) new replacement shell plates to existing shell plates, one additional radiograph for each 50 ft of repaired horizontal weld;

c) repaired joints in existing shell plates shall have one additional radiograph taken for each 50 ft of repaired horizontal weld.

12.2.1.3 For intersections of vertical and horizontal joints:

a) new replacement shell plates to new shell plates, no additional radiographs required, other than those required by API 650, Section 8.1.2 and Figure 8-1 for new construction;

b) new replacement shell plates to existing shell plates, each intersection shall be radiographed;

c) all repaired intersections in existing shell plates shall be radiographed.

12.2.1.4 For reconstructed tanks, each butt-welded annular plate joint shall be radiographed in accordance with API 650, Section 8.1.2.9.

12.2.1.5 For reconstructed tanks, radiographic examination is required for 25% of all junctions of new welds over existing seams.

The owner/operator shall, with the consent of the contractor, determine the extent of further examination and repair that may be required.

Any further examination or repair of existing welds will be handled by contractual agreement between the owner/operator and tank reconstruction contractor.

12.2.1.6 New and replaced shell plate and door sheet welds shall be radiographed. All junctions between repair and existing welds shall be radiographed. If defects are found, 100% radiography shall be performed on the repaired weld.

12.2.1.6.1 For circular replacement plates, a minimum of one radiograph shall be taken regardless of thickness. When the circular replacement plate is located in a shell plate with thickness exceeding 1 in., the weld shall be fully radiographed.

12.2.1.6.2 For square and rectangular replacement plates, at least one radiograph shall be taken in a vertical joint, and at least one in a horizontal joint, and one in each corner. When the square or rectangular replacement plate is located in a shell plate with thickness exceeding 1 in., the vertical joints shall be fully radiographed.

12.2.1.7 The minimum diagnostic length of each radiograph shall be 6 in.

12.2.1.8 For penetrations installed using insert plates as described in 9.8.6, the completed butt welds between the insert plate and the shell plate shall be fully radiographed.

12.2.2 Acceptance Criteria for Existing Shell Plate to Shell Plate Welds

If the radiograph of an intersection between a new and old weld detects unacceptable welds by the current applicable standard, the existing welds shall be:

a) evaluated according to the as-built standard, or

b) evaluated using fitness-for-service assessment, or

c) repaired in accordance with 9.6.

12.2.3 Marking and Identification of Radiographs

12.2.3.1 Each film shall show an identification of the welder(s) making the weld. A weld map showing location of welds, weld number, radiograph number, welder identification, and grading of each weld is an acceptable alternative to this requirement.
12.2.3.2 Radiographs and radiograph records of all repaired welds shall be marked with the letter “R.”

12.3 Hydrostatic Testing

12.3.1 When Hydrostatic Testing is Required

A full hydrostatic test, held for 24 hours, shall be performed on the following.

a) A reconstructed tank.

b) Any tank that has undergone major repairs or major alterations (see Section 3) unless exempted by 12.3.2 for the applicable combination of materials, design, and construction features.

c) A tank where an engineering evaluation indicates the need for the hydrostatic test due to an increase in the severity of service. Examples of increased service severity are an increase in operating pressure (such as storing a product with a higher specific gravity), lowering the service temperature (see Figure 5.2), and using tanks that have been damaged.

12.3.2 When Hydrostatic Testing is Not Required

12.3.2.1 General

A full hydrostatic test of the tank is not required for major repairs and major alterations if 12.3.2.2 is satisfied plus either of the following:

a) appropriate parts of 12.3.2.3 through 12.3.2.6, or alternatively;

b) fitness-for-service evaluation per 12.3.2.7.

12.3.2.2 Review/Approval/Authorization Requirements

Items a) and b) below must be satisfied.

a) The repair has been reviewed and approved by an engineer experienced in storage tank design in accordance with API 650. The engineer must concur in writing with taking the hydrostatic testing exemption.

b) The tank owner/operator has authorized the exemption in writing.

12.3.2.3 Shell Repair

12.3.2.3.1 For welds to existing metal, develop welding procedure qualifications based on existing material chemistry, including strength requirements. Welding procedures shall be qualified with existing or similar materials, and shall include impact testing. Impact testing requirements shall follow appropriate portions of API 650, Section 9.2.2 and shall be specified in the repair procedure.

12.3.2.3.2 New materials used for the repair shall meet the current edition of API 650, Section 4 requirements.

12.3.2.3.3 Existing tank materials in the repair area shall meet at least one of the following requirements.

a) API 650 requirements (Seventh Edition or later).

b) Fall within the “safe for use” area on Figure 5.2.
c) Stress in the repair area shall not exceed 7000 lbf/in.\(^2\). This limiting stress shall be calculated as follows:

\[
S = \frac{2.6 \times H \times D \times G}{t}
\]

where

- \(S\) is the shell stress in pound force per square inch (lbf/in.\(^2\));
- \(H\) is the tank fill height above the bottom of repair or alteration in feet (ft);
- \(t\) is the shell thickness at area of interest in inches (in.);
- \(D\) is the tank mean diameter in feet (ft);
- \(G\) is the specific gravity of product.

12.3.2.3.4 New vertical and horizontal shell butt-welds shall have complete penetration and fusion.

12.3.2.3.5 The root pass and final pass examination shall be in accordance with 12.1.5. In addition, the finished weld shall be fully radiographed.

12.3.2.3.6 Shell welds for the reinforcing plate-to-nozzle neck and nozzle neck-to-shell joints shall have complete penetration and fusion. The root pass of the nozzle attachment weld shall be back-gouged and examined by magnetic particle or liquid penetrant methods. The completed weld shall be examined by magnetic particle or liquid penetrant methods and by the ultrasonic method. Examination and acceptance criteria for NDE shall be in accordance with 12.1.

12.3.2.3.7 See 12.3.2.5 for shell-to-bottom weld restrictions.

12.3.2.3.8 Door sheets shall comply with the requirements of this standard for shell plate installation, except they shall not extend to or intersect the bottom-to-shell joint.

12.3.2.4 Bottom Repair within the Critical Zone

12.3.2.4.1 Repairs to the annular ring or bottom plates, within the critical zone (see 3.10) shall comply with the following.

a) Meet the requirements of 12.3.2.3.1 through 12.3.2.3.3.

b) Be examined visually prior to welding, and examined after the root pass and the final pass by the magnetic particle or liquid penetrant methods. Annular plate butt-welds shall also be examined by ultrasonic methods after the final pass. Examination and acceptance criteria for NDE shall be in accordance with 12.1.

12.3.2.5 Shell-to-bottom Weld Repair

12.3.2.5.1 Repair of the weld attaching the shell to the annular ring or the shell to the bottom plate shall meet one of the following requirements.

a) A portion of the weld (of any length) may be removed and replaced as long as the replaced weld meets the size requirements of API 650, Section 5.1.5.7, and the portion replaced does not represent more than 50 % of the required weld cross-sectional area.

b) The weld on one side of the shell may be completely removed and replaced for a length not exceeding 12 in. Shell-to-bottom weld repairs replacing more than 50 % of the required weld cross-sectional area shall not be closer than 12 in. to each other, including repairs on the opposite side of the shell.
12.3.2.5.2 Repairs shall be examined prior to welding, after the root pass, and after the final pass by visual, as well as magnetic particle or liquid penetrant methods. Examination and acceptance criteria for NDE shall be in accordance with 12.1.

12.3.2.6 Minor Shell Jacking

12.3.2.6.1 Tank shell and critical zone materials shall meet one of the requirements of 12.3.2.3.3.

12.3.2.6.2 The engineer shall consider all pertinent variables when exempting a minor shell jacking repair from hydrostatic testing, including but not limited to: the magnitude of jacking required; material; toughness; quality control; inspection before and after repair; material temperature; future foundation stability; and jacking techniques (including controls and measurement). Careful consideration shall be given to potential stresses and damage that may result from jacking.

12.3.2.7 Fitness-for-service Evaluation

The owner/operator may utilize a fitness-for-service or other appropriate evaluation methodology based on established principles and practices to exempt a repair from hydrostatic testing. The procedures and acceptance criteria for conducting an alternative analysis are not included in this standard. This evaluation shall be performed by an engineer experienced in storage tank design and the evaluation methodologies used.

12.3.3 Other Cases Not Requiring Hydrostatic Testing

12.3.3.1 General

For clarity, the situations of 12.3.3.2 and 12.3.3.3 do not in themselves require a hydrostatic test because they are not major repairs or major alterations.

12.3.3.2 Repair or Alteration Made to a Floating Roof

No hydrotest is required.

12.3.3.3 Bottom Repair or Replacement Outside the Critical Zone

Portions of new bottoms (any or all rectangular plates or large segments of plates) in tanks may be replaced without a hydrotest when the subgrade under the new plates is found to be in a condition acceptable to the authorized inspector or is restored to such condition and either of the following conditions is met.

1) For tanks with annular rings, the annular ring and the area of support under the annular ring (concrete foundation or grade material) remains intact.

2) For tanks without annular rings, the bottom repair or replacement does not result in welding on the remaining bottom within the critical zone and the shell and bottom support in the critical zone remains intact. See 3.10 for a definition of the critical zone.

12.4 Leak Tests

New or altered reinforcing plates of shell penetrations shall be given an air leak test in accordance with API 650, Section 7.3.4.
### 12.5 Settlement Survey During Hydrostatic Testing

#### 12.5.1 When Settlement Survey is Required

A settlement survey shall be conducted for all existing tanks that undergo a hydrostatic test, except for tanks that have a documented service history of acceptable settlement values, **and** no settlement is anticipated to occur during the hydrotest.

#### 12.5.2 Initial Settlement Survey

When a settlement survey is required in accordance with 12.5.1, the tank settlement shall initially be surveyed with the tank empty, using an even number of elevation measurement points, \( N \), uniformly distributed around the circumference. An initial settlement survey, prior to the first hydrostatic test, provides baseline readings for future settlement evaluation. In the absence of this initial survey, the tank shall be assumed to be initially level.

The minimum number of elevation points shall be as indicated by the following equation:

\[
N = \frac{D}{10}
\]

where

\( D \) is the tank diameter, in feet (ft).

And

\( N \) is the minimum required number of settlement measurement points, but no less than eight. All values of \( N \) shall be rounded to the next higher even whole number. The maximum spacing between settlement measurement points shall be 32 ft.

#### 12.5.3 Settlement Survey During Hydrostatic Testing

When a settlement survey is required in accordance with 12.5.1, tank settlement shall be measured during filling and when the test water reaches 100% of the test level.
Section 13—Marking and Recordkeeping

13.1 Nameplates

13.1.1 Reconstructed Tanks

13.1.1.1 Tanks reconstructed in accordance with this standard shall be identified by a corrosion-resistant metal nameplate similar to that shown in Figure 13.1. Letters and numerals not less than \( \frac{5}{32} \) in. high shall be embossed, engraved, or stamped in the plate to indicate information as follows:

a) reconstructed to API 653;

b) edition and revision number;

c) year reconstruction was completed;

d) if known, the as-built standard and the year of original construction;

e) nominal diameter;

f) nominal shell height;

g) design specific gravity;

h) maximum permissible operating liquid level;

i) the name of the reconstruction contractor and the assigned serial number or contract number;

j) the owner/operator’s tank number;

k) shell material for each shell course;

l) maximum operating temperature;

m) allowable stress used in calculations of each shell course.

13.1.1.2 The new nameplate shall be attached to the tank shell adjacent to the existing nameplate, if any. An existing nameplate shall be left attached to the tank. Nameplates shall be attached as specified in API 650, Section 10.1 and Figure 10-1.

13.1.2 Tanks Without Nameplates

13.1.2.1 At the owner’s request a nameplate may be attached to a tank meeting the requirements in 13.1.2.2 through 13.1.2.4.

13.1.2.2 If information required to complete the nameplate as required by the as-built standard is available and traceable to the tank, a new Replacement Nameplate, similar to that shown in Figure 10-1 in API 650, may be attached under the direction of the Authorized inspector. The new nameplate shall contain all of the information required by the as-built standard and be marked ‘Replacement Nameplate.’

13.1.2.3 If information required to complete the nameplate as required by the as-built standard is not available, an ‘Assessment Nameplate’ may be attached under the direction of the Authorized inspector, provided a suitability for service assessment is performed per API 653, Sections 4 and 5. The new nameplate shall contain the following information:

a) API Standard 653, Assessment Nameplate;
b) Owner’s tank number;

c) the company performing the assessment;

d) the date the assessment was performed;

e) the date of the edition and the addendum number of API 653 used to perform the assessment;

f) the nominal diameter and nominal height, in meters (ft and in.);

g) the maximum capacity in m$^3$ (42-gallon barrels);

h) the liquid level in meters (ft. and in.) used to perform the assessment;

i) the specific gravity of the liquid used to perform the assessment;

j) the design metal temperature in °C (°F) used to perform the assessment;

k) the pressure and vacuum used to perform the assessment;

l) the maximum design temperature in °C (°F) used to perform the assessment;

m) the material specification, if known, for each shell course;

n) the allowable stress values in MPa (psi) used to perform the assessment;

o) the joint efficiency used to perform the assessment (see 4.3.3. or 4.3.4).

13.1.2.4 The nameplate shall be made of a corrosion resistant metal embossed, engraved, or stamped with letters and numerals not less than 4 mm ($\frac{5}{32}$ in.) high. Nameplates shall be attached as specified in API Std. 650. In addition, the nameplate shall be clearly marked as an API 653, *Assessment Nameplate*. Refer to Figure 13-2.

### 13.2 Recordkeeping

When a tank is evaluated, repaired, altered, or reconstructed in accordance with this standard, the following information, as applicable, shall be made a part of the owner/operator’s records for the tank (see 6.8).

#### 13.2.1 Calculations for:

a) component evaluation for integrity, including brittle fracture considerations (see Section 5);

b) re-rating (including liquid level);

c) repair and alteration considerations.

#### 13.2.2 Construction and repair drawings.

#### 13.2.3 Additional support data including, but not limited to, information pertaining to:

a) examinations (including thicknesses);

b) material test reports/certifications;

c) tests;
where

\[ S_{\text{max, ft}} \]

is permissible out-of-plane settlement, in feet (ft);

\[ L \]

is arc length between measurement points, in feet (ft);

\[ Y \]

is yield strength of the shell material, in pound force per square inch (lb/ft²);

\[ E \]

is Young's Modulus, in pound force per square inch (lb/ft²);

\[ H \]

is tank height, in feet (ft).


**B.3.2.2** When using the procedure in B.2.2.5 to determine out-of-plane settlement, the permissible out-of-plane settlement is given by the following equation (see Note):

\[ S_{\text{max, in}} = \min \left[ K \times S_{\text{arc}} \times \left( \frac{D}{H} \right) \times \left( \frac{Y}{E} \right), 4.0 \right] \]

<table>
<thead>
<tr>
<th>Tank Diameter</th>
<th>( K ), Open Top Tanks</th>
<th>( K ), Fixed Roof Tanks</th>
</tr>
</thead>
<tbody>
<tr>
<td>( D \leq 50 )</td>
<td>28.7</td>
<td>10.5</td>
</tr>
<tr>
<td>( 50 &lt; D \leq 80 )</td>
<td>7.8</td>
<td>5.8</td>
</tr>
<tr>
<td>( 80 &lt; D \leq 120 )</td>
<td>6.5</td>
<td>3.9</td>
</tr>
<tr>
<td>( 120 &lt; D \leq 180 )</td>
<td>4.0</td>
<td>2.3</td>
</tr>
<tr>
<td>( 180 &lt; D \leq 240 )</td>
<td>3.6</td>
<td>Not applicable</td>
</tr>
<tr>
<td>( 240 &lt; D \leq 300 )</td>
<td>2.4</td>
<td>Not applicable</td>
</tr>
<tr>
<td>( 300 &lt; D )</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

where

\[ S_{\text{max, in}} \]

is permissible out-of-plane settlement, in inches (in.);

\[ S_{\text{arc}} \]

is effective settlement arc, see B.2.2.5.1, in feet (ft);

\[ D \]

is tank diameter, in feet (ft);

\[ Y \]

is yield strength of the shell material, in pound force per square inch (lb/ft²);

\[ E \]

is Young's Modulus, in pound force per square inch (lb/ft²);

\[ H \]

is tank height, in feet (ft).


**B.3.2.3** Serviceability may also be a concern for tanks with significant out-of-plane settlement. Out-of-roundness can impede floating roof operation and also affect internal roof support structures. The out-of-roundness that a tank experiences with out-of-plane settlement is fairly sensitive to the actual pattern of settlement. The owner may wish to specify additional inspection or a more rigorous assessment of the tank's out-of-roundness.
B.3.2.4 If measured out-of-plane settlement exceeds the applicable limits described in B.3.2.1 or B.3.2.2, a more rigorous evaluation may be performed to determine the need for repairs. This evaluation should be done by an engineer experienced in tank settlement analysis.

B.3.3 Internal Bottom Settlements or Bulges

Measure the bulge or depression. The permissible bulge or depression is given by the following equation (see Note).

\[ B_B = 0.37R \]

where

- \( B_B \) is maximum height of bulge or depth of local depression, in inches;
- \( R \) is radius of inscribed circle in bulged area or local depression, in feet.

Figure B.10 is a graphical representation of this equation.


---

**Figure B.10—Localized Tank Bottom Settlement Limits for Single Pass Welds**

B.3.4 Edge Settlement

B.3.4.1 Maximum allowable settlement \( B_{ew} \) is shown in Figure B.11 for settled areas that include bottom lap welds essentially parallel to the shell (±20°). In settled areas where the measured settlement \( B \) exceeds 75% of allowed settlement \( B_{ew} \), all shell-to-bottom welds and bottom welds should be examined visually and with magnetic particle
or liquid penetrant methods. All indications should be repaired, or evaluated for risk of brittle fracture, and/or fatigue failure prior to returning the tank to service.

B.3.4.2 For settled areas where measured settlement $B$ exceeds 75% of $B_{ew}$, any welds within 12 in. of either side of the breakover area (see Figure B.6) should be examined visually. Any suspect areas should be examined with either magnetic particle examination or liquid penetrant examination. All indications should be repaired or evaluated for risk of fatigue prior to returning the tank to service.

B.3.4.3 Maximum allowable settlement $B_e$ is shown in Figure B.12 for areas of edge settlement with no welds, butt welds, or lap welds in the bottom that are essentially perpendicular to the shell ($\pm 20^\circ$). In settled areas where the measured settlement exceeds 75% of the allowed settlement, all shell-to-bottom welds and bottom welds should be examined visually and with magnetic particle or liquid penetrant methods. All indications should be repaired or evaluated for risk of brittle fracture and/or fatigue prior to returning the tank to service.

B.3.4.4 Maximum allowable settlement for areas of edge settlement with a lap weld at an arbitrary angle to the shell may be interpolated from $B_e$ and $B_{ew}$ from Figure B.11 and Figure B.12, and the following equation:

$$B_\alpha = B_e - (B_e - B_{ew}) \times \sin \alpha$$

Where $\alpha$ is the angle of the weld to a tank centerline and $B_\alpha$ is the allowable settlement for an area with a weld at that angle (see Figure B.13).

B.3.4.5 In general, settlement occurs slowly, and for most existing tanks, the majority of settlement is presumed to have occurred in the first few years of service. Significant additional settlement will not be expected after the initial inspections. Therefore, typical practice is to compare the measured edge settlement with the maximum allowable edge settlement $B_{ew}$ and $B_e$, and not include allowance for additional settlement during subsequent operation. Note that erosion of the pad adjacent to the tank may cause local settlement. In this case the settlement will continue unless the pad is repaired and future erosion prevented. For cases where significant additional settlement is expected, an engineer experienced in tank settlement evaluation should evaluate the settlement expected at the next inspection with the limits in B.3.4. This is analogous to a corrosion allowance for components expected to corrode.

B.3.4.6 The edge settlement limits described in B.2.3.1 through B.2.3.4 were developed for typical 1/4-in. thick tank bottoms with minimal corrosion.

a) Edge settlement limits can be applied with reasonable accuracy to 5/16- and 3/8-in. thick tank bottoms.

b) Edge settlement limits can be applied with reasonable accuracy to bottoms with general corrosion, as long as the areas near all welds are thicker than 3/16 in.

c) Edge settlement limits can be applied with reasonable accuracy to bottoms with local corrosion, if all locally thin areas in the settled area (closer than “R” to the shell) thinner than 3/16 in. are smaller than 12 in. in diameter and the thin area does not include a weld.

d) Settlement is presumed to be slow, and a small amount of additional settlement is expected to occur prior to the next inspection.

B.3.4.7 Edge settlement increases secondary stress at the bottom-to-shell weld. If weld repairs are made to the bottom-to-shell weld in an area where settlement exceeds 1/2 of $B_e$, these additional stresses should be evaluated by an engineer experienced in tank settlement evaluation before waiving a hydrostatic test per 12.3.

B.4 Repairs

B.4.1 If it is determined that settlements have occurred which are beyond the permissible limits established in the previous sections, then consideration should be given to making repairs or a rigorous stress analysis should be
performed to evaluate the deformed profile. Various repair techniques have been discussed above. The judgment on repairs should be tempered with knowledge of tank service history, previous repairs, previous inspections, tank foundation conditions, soil characteristics, the material of construction, and estimates of future settlement. See 9.10 for suggested repair details.

B.4.2 For tanks with edge settlement exceeding the limits and assumptions given in B.2.3.1 through B.2.3.7, the tank should be repaired. Any plate exceeding acceptable strains (typically 2 % to 3 %) should be replaced. Re-leveling the tank will not remove the plastic strain, so leveling the tank without replacing the strain may not be a sufficient repair. Welds in the area of the high strains should be removed and replaced, or be subjected to a fitness-for-service evaluation by an engineer experienced in tank settlement evaluation. The condition leading to the unacceptable settlement should be corrected. Depending on the severity and location of the settlement, required repairs may include regrading the soil under the tank bottom, and/or repairing the foundation. Jacking and re-leveling the shell may be required to prevent additional settlement damage. Jacking and leveling are usually done in conjunction with, not instead of, replacing damaged plate and welds. In lieu of repairs, a detailed analysis of the settled area may be performed by an engineer experienced in tank design and settlement evaluation. The analysis should consider primary and secondary stress and the risk of brittle fracture.

Figure B.11—Maximum Allowable Edge Settlement for Areas with Bottom Lap Welds Approximately Parallel to the Shell
Tanks with larger edge settlements are to be repaired, or have detailed analysis of bottom, and bottom-to-shell junction.

Welds in tanks with settlement greater than or equal 75% of \( B_{ew} \), and larger than 2 in., are to be examined with magnetic particle or liquid penetrant methods.

Tanks with settlement less than 75% of \( B_{ew} \) may be returned to service.

\[ R = \text{Radius of settled area, ft} \]

Figure B.12—Maximum Allowable Edge Settlement for Areas with Bottom Lap Welds Approximately Perpendicular to the Shell

Figure B.13—Edge Settlement with a Lap Weld at an Arbitrary Angle to the Shell
Annex F

NDE Requirements Summary

F.1 Introduction

This annex is a summary of all NDE requirements for repairs and reconstruction of tanks. It is provided only as a guide to assure that the proper examinations are performed and that the acceptance standards, examiner qualifications, and procedure requirements are followed.

F.2 Visual Examination

F.2.1 Visual examinations are required for:

a) cavities from removal of repads (see API 653, 12.1.2.2);

b) completed welds of stress-relieved assemblies after stress relief but before hydrostatic testing (see API 653, 12.1.2.4);

c) all fillet welds and completed repairs of fillet welds (see API 650, Section 7.3.2.2 and API 653, 12.1.3.3);

d) completed welds of new permanent attachments and areas of removed temporary attachments (see API 653, 12.1.4.2);

e) new shell plate-to-shell plate welds (see API 653, 12.1.5);

f) tack welds left in place (see API 650, Section 7.2.1.8);

g) bottom plate and all welds, including the weld attaching a patch plate to the bottom, for new bottom plates (see API 653, 12.1.7.1);

h) root and final weld pass of patch plate to bottom in the critical zone (see API 653, 12.1.7.2);

i) areas of a bottom plate repaired by welding (see API 653, 12.1.7.3);

j) areas of a shell plate to be repaired by welding (see API 653, 12.1.8);

k) cavities from removal of weld defects (see API 653, 12.1.3.1);

l) annular plate butt-welds root pass and final pass (see API 653, 12.3.2.4.1 b);

m) repaired areas of the shell-to-bottom weld (see API 653, 12.3.2.5.2).

F.2.2 The examination acceptance standard is API 650, Section 8.5.

F.2.3 The examiner’s employer shall determine and certify that each visual examiner meets the requirements of API Standard 650, Section 8.5.1.

F.3 Magnetic Particle and Liquid Penetrant Examination

F.3.1 Magnetic particle or liquid penetrant examinations are required for:

a) cavities from removing existing reinforcing pad welds (see API 653, 12.1.2.2);
b) new welds of nozzle neck-to-shell, nozzle neck-to-repad, and repad-to-shell (see API 653, 12.1.2.3);

c) completed welds of stress-relieved assemblies after stress relief, before hydrostatic testing (see API 653, 12.1.2.4);

d) cavities from removal of weld defects (see API 653, 12.1.3.1);

e) completed welds of new permanent attachments and areas of removed temporary attachments on API 650 material Groups IV, IVA, V, or VI (see API 653, 12.1.4.2);

f) the back-gouged surface of the root pass and the final surface of new shell plate welds where the shell is thicker than 1 in. (see API 653, 12.1.5);

g) existing shell-to-bottom welds that will be under a patch plate, plus 6 in. on each side (see API 653, 12.1.6.3);

h) root and final weld pass of patch plate to bottom in the critical zone (see API 653, 12.1.7.2);

i) bottom plate restored by welding (see API 653, 12.1.7.3);

j) areas of a shell plate repaired by welding (see API 653, 12.1.8);

k) MT or PT repairs to the annular plate or bottom plates within the critical zone after root and final pass [see API 653, 12.3.2.4.1 b]].

l) MT or PT repairs to the shell-to-bottom welds before and after root pass, and after final pass (see API 653, 12.3.2.5.2);

m) the back-gouged surface of the root pass of full penetration nozzle neck-to-shell and repad welds as required by API 653, 12.3.2.3.6, specific hydrostatic test exemption requirement;

n) the back-gouged surface of the root pass and final surface of new vertical and horizontal shell joints as required by API 653, 12.3.2.3.5, specific hydrostatic test exemption requirement.

F.3.2 Magnetic particle examination alone is required for weld removal areas of the bottom-to-shell welds when removing a bottom [see API 653, 9.10.2.2 b]].

F.3.3 The magnetic particle examination acceptance standard is ASME Section V, Article 7. The acceptance standards for the removal and repair of defects shall be in accordance with ASME Section VIII, Annex 6, Paragraphs 6-3, 6-4, and 6-5.

F.3.4 The liquid penetrant examination acceptance standards is ASME Section V, Article 6. The acceptance standards for the removal and repair of defects shall be in accordance with ASME Section VIII, Appendix 8, Paragraphs 8-3, 8-4, and 8-5.

F.3.5 The requirements for examiner qualifications shall follow API 650, Section 8.2.3, requiring an examiner with adequate vision and competent in the examination, interpretation, and evaluation of results.

F.3.6 Procedure requirements shall follow ASME Section V.

F.4 Ultrasonic Examination

F.4.1 Ultrasonic examinations are required for:

a) shell areas over which lap patch plates are to be welded (see API 653, 9.3.1.9);
Annex G

Qualification of Tank Bottom Examination Procedures and Personnel

G.1 Introduction

G.1.1 This annex provides guidance for qualifying both tank bottom examination procedures and individuals that perform tank bottom examinations. Owner/operators may elect to either apply this annex as written or modify it to meet their own applications and needs. Tank bottom examinations are an important factor in providing the owner/operator increased assurance of tank integrity. As a result, it is important that qualified examination procedures and personnel are used in these examinations. Specific agreements and requirements for qualification of tank bottom examination procedures and tank bottom examiners should be established between the owner/operator and the authorized inspection agency.

G.1.2 There have been many NDE tools developed for examining tank bottoms. Most of these tools are complex and require the operator to have a high level of knowledge and skill. The effectiveness of these examinations may vary greatly depending on the equipment used, the examination procedure, and the skill of the examiner.

Often the owner/operator will not have the ability to easily determine if the tank bottom examination has been effective in assessing the actual condition of the tank bottom. The requirements in this annex will provide the owner/operator additional assurance that the tank bottom examination will find significant metal loss.

G.2 Definitions

G.2.1 authorized inspection agency
Organizations that employ an aboveground storage tank inspector certified by API (see 3.3).

G.2.2 bottom scan
The use of equipment over large portions of the tank bottom to detect corrosion in a tank bottom. One common type of bottom-scanning equipment is the magnetic flux leakage (MFL) scanner.

G.2.3 essential variables
Variables in the procedure that cannot be changed without the procedure and scanning operators being re-qualified.

G.2.4 examiners
Scanning operators and NDE technicians who prove-up bottom indications.

G.2.5 non-essential variables
Variables in the procedure that can be changed without having to re-qualify the procedure and/or scanning operators.

G.2.6 qualification test
The demonstration test that is used to prove that a procedure or examiner can successfully find and prove-up tank bottom metal loss.
G.2.7
scanning operator
operator
The individual that operates bottom-scanning equipment.

G.2.8
sizing
prove-up
The activity that is used to accurately determine the remaining bottom thickness in areas where indications are found by the bottom scanning equipment. This is often accomplished using the UT method.

G.2.9
tank bottom examination
The examination of a tank bottom using special equipment to determine the remaining thickness of the tank bottom. It includes both the detection and prove-up of the indications. It does not include the visual examination that is included in the internal inspection.

G.2.10
tank bottom examination procedure
TBP
A qualified written procedure that addresses the essential and non-essential variables for the tank bottom examination. The procedure can include multiple methods and tools, i.e. bottom scanner, hand scanner, and UT prove-up.

G.2.11
tank bottom examiner qualification record
TBEQ
A record of the qualification test for a specific scanning operator. This record must contain the data for all essential variables and the results of the qualification test.

G.2.12
tank bottom procedure qualification record
TBPQ
A record of the qualification test for a tank bottom examination procedure. This record must contain the data for all essential variables and the results of the qualification test.

G.2.13
variables or procedure variables
The specific data in a procedure that provides direction and limitations to the scanning operator. Examples include: plate thickness, overlap of adjacent bottom scans, scanning speed, equipment settings, etc.

G.3 Tank Bottom Examination Procedures

G.3.1 Each authorized inspection agency performing tank bottom examinations is responsible to have and use TBPs. These procedures provide direction for examiners performing tank bottom examinations. A procedure also allows the owner/operator or authorized inspector to verify whether the examiners are correctly performing the examinations.

G.3.2 The authorized inspection agency that performs the tank bottom examinations should develop the TBPs.

G.3.3 Each TBP shall address essential and non-essential variables. Section G.5.4 provides guidance for determining appropriate TBP essential and non-essential variables. Each procedure should specify limits on appropriate variables, e.g. plate thickness range.
G.5.1.3 The minimum number and types of product side test pits located on the test plates are described below.

<table>
<thead>
<tr>
<th>Remaining Bottom Thickness (t) (in.)</th>
<th>Minimum Number of Pits</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.050 &lt; t &lt; (\frac{1}{2}T)</td>
<td>2</td>
</tr>
<tr>
<td>(\frac{1}{2}T) &lt; t &lt; (\frac{2}{3}T)</td>
<td>2</td>
</tr>
</tbody>
</table>

G.5.1.4 There should also be at least one area representing general soilside corrosion. This area should be at least 10 in.\(^2\) (64.52 cm\(^2\)) and have a remaining bottom thickness of about \(\frac{1}{2}T\) (nominal plate thickness).

G.5.2 Qualification Test Acceptance Standards

G.5.2.1 The following acceptance criteria must be met when qualifying either an examination procedure or an examiner. If all the acceptance criteria are met, the procedure or examiner shall be considered qualified. Owner/operators may substitute alternative acceptance criteria, either more or less conservative, based on their specific needs and requirements.

G.5.2.2 When qualifying either a procedure or a scanning operator, the operator must be able to detect the following flaws.

<table>
<thead>
<tr>
<th>Remaining Bottom Thickness (t) (in.)</th>
<th>Flaws That Must Be Found</th>
</tr>
</thead>
<tbody>
<tr>
<td>t &lt; 0.050</td>
<td>90 % to 100 %</td>
</tr>
<tr>
<td>0.050 in. &lt; t &lt; (\frac{1}{2}T)</td>
<td>70 % to 90 %</td>
</tr>
<tr>
<td>(\frac{1}{2}T) &lt; t &lt; (\frac{2}{3}T)</td>
<td>40 % to 60 %</td>
</tr>
<tr>
<td>Area of general corrosion</td>
<td>100 %</td>
</tr>
</tbody>
</table>

G.5.2.3 When qualifying either a procedure or an examiner, who proves up the indications, the examiner must be able to determine the flaw depth as follows:

<table>
<thead>
<tr>
<th>Type of Tank Bottom</th>
<th>Prove-up (Flaw Depth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not coated</td>
<td>±0.020 in.</td>
</tr>
<tr>
<td>Thin coating &lt; 0.030 in.</td>
<td>±0.030 in.</td>
</tr>
<tr>
<td>Thick coating &gt; 0.030 in.</td>
<td>Per agreement with owner/operator</td>
</tr>
</tbody>
</table>

The owner/operator should determine if additional flaw dimensions must be addressed in the qualification process.
G.5.2.4 While false calls, also referred to as over-calls, tend to be more of an examination efficiency issue than a tank bottom integrity issue, the owner/operator should determine if they should be addressed in the qualification process.

G.5.3 Qualification Test Variables

G.5.3.1 Essential variables are those items that may have a significant effect on the quality of the examination if they are changed from those used during the qualification test.

Table G.1—Suggested Essential Variables for Qualification Tests

<table>
<thead>
<tr>
<th>Essential Variable</th>
<th>Used During Test</th>
<th>Qualified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scanner Equipment</td>
<td>As tested</td>
<td>Same as tested</td>
</tr>
<tr>
<td>Prove-up Equipment</td>
<td>As tested</td>
<td>Same as tested</td>
</tr>
<tr>
<td>Prove-up Procedure</td>
<td>As tested</td>
<td>Same as tested</td>
</tr>
<tr>
<td>Plate Thickness ($T$)</td>
<td>$T$</td>
<td>$T +0.005$ in. – $T -0.130$ in.</td>
</tr>
<tr>
<td>Coating Thickness ($t_c$)</td>
<td>No coating used</td>
<td>0.000 in.</td>
</tr>
<tr>
<td></td>
<td>0.001 in. &lt; $t_c$ &lt; 0.030 in.</td>
<td>0.001 in. to 0.030 in.</td>
</tr>
<tr>
<td></td>
<td>0.031 in. &lt; $t_c$ &lt; 0.080 in.</td>
<td>0.031 in. to 0.080 in.</td>
</tr>
<tr>
<td></td>
<td>$t_c$ &gt; 0.080</td>
<td>0.081 in. to $t_c$</td>
</tr>
<tr>
<td>Distance from Shell ($d_s$)</td>
<td>$d_s$</td>
<td>Lesser of 8 in. or $d_s$</td>
</tr>
<tr>
<td>Critical Equipment Settings</td>
<td>As tested</td>
<td>Per manufacturer</td>
</tr>
<tr>
<td>Threshold Settings ($T_h$)</td>
<td>$T_h$</td>
<td>&lt; 10 %$T_h$</td>
</tr>
<tr>
<td>Calibration or Functional Check</td>
<td>As tested</td>
<td>Same as tested</td>
</tr>
</tbody>
</table>

G.5.3.2 Table G.1 lists suggested items that may be considered as essential variables for the qualification test when qualifying either a tank bottom examination procedure or a tank bottom examiner. Essential variables may be different for different types of tank bottom scanners. Authorized inspection agencies are responsible for determining what additional variables should be considered essential variables for each tank bottom scanner.

G.5.3.3 Essential variables and the values must be recorded on the TBP and on the TBEQ.

G.5.3.4 Non-essential variables are those items that will have a lesser affect on the quality of the examination. Non-essential variables may be different for different types of tank bottom scanners.

G.5.3.5 Non-essential variables must be listed on the TBP but need not be addressed on the TBPQ or the TBEQ. The following is a list of examples of items that might be considered as non-essential variables. Equipment
Annex I
(normative)

Inquiries and Suggestions for Change

I.1 Introduction

This annex describes the process established by API for submitting inquiries to API and for submitting suggestions for changes to this standard. Inquiries and suggestions for change are welcome and encouraged, however, submittals not complying with this annex and additional API policies will be returned unanswered. These submittals provide useful reader feedback to the responsible API Committee regarding technical accuracy, current technology use, clarity, consistency, and completeness of the standard. API will attempt to answer all valid inquiries.

I.2 Inquiry References

I.2.1 API maintains several websites that provide information that should be considered when considering submitting an inquiry.

I.2.2 Your inquiry may have been previously formally addressed by the Subcommittee and the resulting interpretation posted on the API web site at:

— For all Standards: http://mycommittees.api.org/standards/techinterp/default.aspx
— Refining only: http://mycommittees.api.org/standards/techinterp/refequip/default.aspx

For both links, click on the standard in question to download the file.

I.2.3 In addition, an addendum or errata, which may have addressed your issue, can be found on the API web site at:

— For all Standards: http://www.api.org/Standards/addenda/
— Refining only: http://www.api.org/Standards/addenda/add-ref.cfm

I.3 Definitions of Terms

I.3.1 inquiry
A question that asks what is the meaning of a specific paragraph, figure, or table in the standard; i.e., what do the words say. It is not a question that asks about the intention of the standard.

I.3.2 interpretation
The subcommittee’s answer to the inquiry. Typically, the answer is simply a “Yes” or “No” response, with a brief clarification if needed. This term is also used to refer to the combined question and answer.

I.3.3 suggestion for change
As opposed to an inquiry, a suggestion for change is a proposal to API for modifying the standard to make additions or to resolve apparent conflicts or omissions. API encourages both; however the submittal and handling procedures are different.
I.4 API Policy Regarding Inquiries

I.4.1 API has established the following limits on its activity in the handling of inquiries.

— API does not approve, certify, rate, or endorse any item, construction, proprietary device, or activity.

— API does not act as a consultant on specific engineering problems.

— API does not provide information on the general understanding, rationale or application of the Standard.

I.4.2 All inquiries that result in interpretations will therefore be made available to the general public on the API website.

I.5 Submission of Inquiries

I.5.1 All background and policies for submitting inquiries are stated in the following API web pages:


2) Then click on: “Technical Questions and Requests for Interpretation”

3) Then click on: “Click here for detailed information on Technical Questions and Requests for Interpretation”

4) Then click on: “RFI website here” to access the required electronic form for submitting an inquiry.

I.5.2 All inquiries must comply with the following:

a) be limited to a single subject or closely related subjects;

b) be stated as briefly and precisely as possible, including the applicable paragraph, figure, or table numbers;

c) providing a background explanation is optional, but is encouraged to assist the subcommittee in understanding the query;

d) be in the form of a “yes” or “no” question;

e) be technically and editorially correct and written in understandable English;

f) be related to the current edition/addendum of the document in question (Note: API will not issue interpretations of superseded or withdrawn documents);

g) The general format of the inquiry should be as follows: “Does Paragraph XXX of API-6XX require that ....?”. The inquirer shall also state the potential answer to the inquiry. In addition, if the inquirer believes a revision to the Standard is also needed, he or she shall provide recommended wording.

I.6 Typical Inquiry Process

I.6.1 The typical process of an inquiry is:

a) The Inquirer must prepare the inquiry, including any necessary background information, in full compliance with this Annex and submit via the API web page link.

b) API Standards Coordinator checks the inquiry to verify compliance with the requirements of submitting an inquiry.
c) If the inquiry cannot be answered for any reason, the Coordinator will issue the form letter to the inquirer advising the reason(s) for not answering the inquiry.

d) If the inquiry is valid, it will be forwarded to the Subcommittee for study, and the inquirer will be advised using the form letter.

e) The Subcommittee will evaluate the inquiry and either develop a response or determine that the inquiry cannot be answered, and advise the Coordinator accordingly. The Subcommittee will consider the need for modifying the standard to resolve technical issues, add new requirements, make editorial corrections, improve clarity, remove conflicts, etcetera.

f) The interpretation will be published on the API website when approved by the Subcommittee.

I.6.2 The time required to process a valid inquiry as described in I.6.1 may take as long as a year.

I.7 Responses to Inquiries

I.7.1 If the inquiry is properly phrased, the interpretation can be a one-word response. With many inquiries, there may be a need to provide clarifying statements, such as limits on the applicability.

I.7.2 The industry benefits as a whole when inquiries are utilized as a means to understand the technical requirements of the standard.

I.7.3 It is not possible to develop interpretations quickly to resolve immediate needs.

I.7.4 A form letter or email will be used to reply to inquirers indicating the action taken by API, and, if applicable, the reason(s) for not being able to accept the inquiry.

I.8 Suggestions for Changes

I.8.1 A Suggestion for Change is a communication (email preferred) from a reader to API proposing that a specific change be made to the standard.

I.8.2 Any format is acceptable, as long as the content is clear.

I.8.3 Submit suggestions to: pubweb@api.org.

I.8.4 The content of a suggestion should include the Standard number, edition, and addendum, and the relevant paragraph, table or figure numbers, etc. Provide as much explanation as necessary to be sure the reader understands the technical issues. Provide specific language that you think is needed to implement the change.

I.8.5 API will forward all suggestions that are suitably written to the Subcommittee for consideration. The Subcommittee will evaluate each suggestion and determine if a change is needed. The change may be included in a future edition or addendum.
Annex S

Austenitic Stainless Steel Storage Tanks

S.1 Scope

S.1.1 This annex covers the inspection, repair, alteration, and reconstruction of stainless steel tanks that were constructed in accordance with API 650, Annex S.

S.1.2 This annex states only the requirements that differ from the basic rules in this standard. For requirements not stated, the basic rules must be followed.

S.2 References

No changes to Section 2.

S.3 Definitions

No changes to Section 3.

S.4 Suitability for Service

S.4.1 In 4.2.4.1, the requirements of API 650, Section S.3.5 shall also be satisfied.

S.4.2 In 4.2.4.3, Annex M requirements shall be met for stainless steel tanks with design temperatures over 40 °C (100 °F) as modified by API 650, Sections S.3.6.2 thru S.3.6.7.

S.4.3 In 4.3.3.1, the maximum allowable stress \( S \) shall be modified as follows, for the design condition \( S_d \) and the hydrostatic test condition \( S_t \) the maximum allowable stress for all shell courses shall be the lesser of \( 0.95Y \) or \( 0.4T \).

S.4.4 Table 4.2 shall be in accordance with API 650, Table S-4. When the radiography schedule applied to the existing weld is unknown, the joint efficiency of 0.7 shall be used.

S.4.5 Section 4.3.3.5 c), shall be changed to read “Operation at temperatures over 40 °C (100 °F).”

S.4.6 In 4.3.3.6, the factor \( 2/3Y \) shall be replaced with \( 3/4Y \).

S.4.7 In 4.3.4, these rules do not cover stainless steel tanks.

S.5 Brittle Fracture

S.5.1 The tank is suitable for continued use in ambient temperature service.

S.6 Inspection

No changes to Section 6.

S.7 Materials

S.7.1 In 7.3.1.2, add reference to ASTM A480.

S.7.2 Structural may be shapes fabricated from plate. Plate and structural material shall meet API 650, Section S.2.
S.8 Design Considerations for Reconstructed Tanks

S.8.1 In 8.4.3, the allowable stress shall be revised to meet the allowable stresses of API 650, Section S.3.2.2.1.

S.9 Tank Repair and Alteration

S.9.1 In applying 9.1.1 to fabrication and construction requirements, API 650, Sections S.4.1 through S.4.9 shall be met as applicable.

S.9.2 Hot taps for stainless steels (reference Section 9.14) are not addressed by this annex.

S.10 Dismantling and Reconstruction

S.10.1 In 10.4.2, welding shall also meet the requirements of API 650, Section S.4.11.

S.10.2 Thermal cutting of stainless steel shall be by the iron powder burning, carbon arc, plasma-arc, water jet, or laser cutting methods.

S.10.3 The storage requirements of API 650, Section S.4.2 shall be met.

S.10.4 If specified by the owner/operator, the requirements of API 650, Section S.4.5 shall be met.

S.11 Welding

S.11.1 Welding shall also meet the requirements of API 650, Sections S.4.11 and S.4.12.

S.12 Examination and Testing

S.12.1 Any reference to magnetic particle method shall be replaced with the liquid penetrant method.

S.12.2 In 12.3, the quality of test water shall meet API 650, Section S.4.10.2.

S.13 Annexes

S.13.1 Annex F (NDE Requirements Summary)—any references to magnetic particle examination shall be disregarded.
Annex SC

Stainless and Carbon Steel Mixed Storage Tanks

SC.1 Scope

SC.1.1 This annex covers the inspection, repair, alteration and reconstruction of mixed material tanks constructed in accordance with API 650, Annex SC.

SC.1.2 This annex states only the requirements that differ from the basic rules in this standard, Annex S of this standard, Annex X of this standard and API 650, Annex SC. For requirements not stated, the basic rules shall be followed.

SC.1.3 In this annex the term “stainless steel” includes austenitic or duplex stainless steel unless noted otherwise.

SC.2 References

No changes to Section 2.

SC.3 Definitions

No changes to Section 3.

SC.4 Suitability for Service

SC.4.1 Add to 4.2.4.1: The requirements of API 650, Sections S.3.5 and API 650, and X.3.6, shall also be satisfied for the stainless steel components of the tank.

SC.4.2 Add to 4.2.4.3: This annex applies only to tanks in non-refrigerated services with a maximum design temperature not exceeding 93 °C (200 °F). Mixed material tanks operating at temperatures greater than 93 °C (200 °F) are not addressed in this annex except for tanks covered in SC.4.3 below. For the purposes of this annex, the design temperature shall be the maximum design temperature as specified by the owner/operator.

NOTE Exothermic reactions occurring inside unheated storage tanks can produce temperatures exceeding 40 °C (100 °F).

SC.4.3 Tanks containing mixed materials which do not meet the temperature limitations specified in SC.4.2, but have a successful service history of operation, shall be evaluated for thermal differential expansion at mixed material interface in order to remain in continued service. This analysis shall be performed in accordance with API 650 Annex SC, Section SC.3 and by an engineer experienced in storage tank design and evaluation methodologies. If no accounting for differential expansion effects in prior design work is documented, then such effects shall be evaluated at the time of existing tank assessment.

SC.4.4 Add to 4.3.3.1: The maximum allowable stress $S$ shall be modified as follows, for the design condition ($S_d$) and the hydrotest condition ($S_t$) the maximum allowable stress for austenitic stainless steel shell courses shall be the smaller of $0.95 \sigma$ or $0.4T$.

SC.4.5 Table 4-2—Joint efficiencies for welded joints shall be in accordance with API 650, Table S-4, or API 650, Table X-3. When the radiography schedule applied to the existing weld is unknown, then the joint efficiency of 0.7 shall be used.

SC.4.6 Revise 4.3.3.5.c to read ‘Operation at temperatures over 40 °C (100 °F).’

SC.4.7 Revise 4.3.3.6 by replacing the $2/3 \gamma$ factor with $3/4 \gamma$ for austenitic stainless steel components.
SC.4.8  The rules in 4.3.4 for riveted tanks do not cover mixed material tanks.

SC.5  Brittle Fracture Considerations
Evaluation of brittle fracture shall be done according to Section 5 of this standard for carbon steel, Section S.5 of this standard for austenitic stainless steel, and Section X.5 of this standard for duplex stainless steel components.

SC.6  Inspection
No Changes to Section 6.

SC.7  Materials
Materials requirements for mixed materials situations are unchanged from the base document except as modified by API 653 Appendices S and X (S.7 and X.7) for stainless steels.

SC.8  Design Considerations for Reconstructed Tanks
The allowable stress in 8.4.2 and 8.4.3 for stainless steel components shall be revised to meet the allowable stresses of API 650 Annex S or API 650 Annex X.

SC.9  Tank Repair and Alteration
SC.9.1  Revise 9.2 to read: Shell insert plates shall be made in accordance with API 650, Annex SC 3.2.2.
SC.9.2  Revise 9.3 to read: Lap patches shall be made carbon steel to carbon steel and stainless steel to stainless steel.
SC.9.3  Revise 9.8 to read: Shell penetrations and reinforcing shall be made in accordance with API 650, Annex SC 3.4.
SC.9.4  Revise 9.10 to read: Repair of tank bottoms shall be made in accordance with API 650, Annex SC 3.1.
SC.9.5  Revise 9.14 to read: Hot taps in stainless steel are not addressed by this annex.

SC.10  Other
For Dismantling and Reconstruction, Welding, Examination and Testing, and Annexes see the following sections of the basic document: S.10 through S.13 for austenitic stainless steel, and X.10 through X.13 for duplex stainless steel components.
Annex X

Duplex Stainless Steel Storage Tanks

X.1 Scope

X.1.1 This annex covers the inspection, repair, alteration and reconstruction of duplex stainless steel tanks that were constructed in accordance with API 650, Annex X.

X.1.2 This annex states only the requirements that differ from the basic rules in this Standard. For requirements not stated, the basic rules shall be followed.

X.2 References

No changes to Section 2.

X.3 Definitions

No changes to Section 3.

X.4 Suitability for Service

X.4.1 In 4.2.4.1, the requirements of API 650, Section X.3.6 shall also be satisfied.

X.4.2 In 4.2.4.3, the requirements of API 650, Annex M requirements shall be satisfied for duplex stainless steel tanks with design temperatures over 40 °C (100 °F) as modified by API 650, X.3.7.2 thru X.3.7.5.

X.4.3 In 4.3.3.1, the maximum allowable stress S shall be calculated the same way as for carbon steel.

X.4.3.1 \( Y = \text{specified minimum yield strength of the plate at design temperature; use material S32304 properties if duplex material/specification is not known.} \)

X.4.3.2 \( T = \text{specified minimum tensile strength of the plate at design temperature; use material S32304 properties if duplex material/specification is not known.} \)

X.4.4 Table 4-2 shall be in accordance with API 650, Table X-3. When the radiography schedule applied to the existing weld is unknown; the joint efficiency of 0.7 shall be used.

X.4.5 4.3.3.5c, shall be changed to read “Operation at temperatures over 40 °C (100 °F).”

X.4.6 The rules of 4.3.4 for riveted tanks do not cover duplex stainless steel tanks.

X.5 Brittle Fracture Considerations

X.5.1 In 5.3.2 the applicable API 650 edition and addendum for duplex stainless steel tanks is 11th edition, Addendum 1 or later.

X.5.2 5.3.5 does not apply to duplex stainless steel tanks.

X.5.3 The rules of 5.3.8 shall be replaced with the following: Tanks constructed of duplex stainless steels whose toughness testing or testing exemption conformed to API 650, X.2.3.2 may be considered to be adequately tough for continued operation.
X.6 Inspection

No Changes to Section 6.

X.7 Materials

X.7.1 In 7.3.1.2, add reference to ASTM A480 and A240.

X.7.2 Structural sections may be shapes fabricated from plate. Plate and structural material shall meet API 650, X.2.

X.8 Design Considerations for Reconstructed Tanks

In 8.4.2 and 8.4.3 the allowable stress shall be revised to meet the allowable stresses of API 650, Annex X.

X.9 Tank Repair and Alteration

X.9.1 In applying 9.1.1 to fabrication and construction requirements, API Standard 650, Sections X.4.1 through X.4.9 shall be met as applicable except as permitted in X.10.2 of this annex.

X.9.2 Hot taps for duplex stainless steels (reference section 9.14) are not addressed by this annex.

X.10 Dismantling and Reconstruction

X.10.1 In 10.4.2, welding shall also meet the requirements of API 650, Section X.4.11.

X.10.2 Carbon arc cutting shall not be used except when agreed to, in writing, by Purchaser as an exception to X.9.1, for certain dismantling operations.

X.10.3 The storage requirements of API 650, Section X.4.2 shall be met.

X.10.4 When specified by the Purchaser the requirements of API 650, Section X.4.5 shall be met.

X.11 Welding

Welding shall also meet the requirements of API 650, Sections X.4.11 and X.4.12.

X.12 Examination and Testing

X.12.1 Any reference to magnetic particle method shall be replaced with the liquid penetrant method.

X.12.2 In 12.3, the quality of test water shall meet API 650, Section X.4.10.

X.13 Annexes

Annex F, NDE Requirements Summary; any reference to magnetic particle method shall be replaced with the liquid penetrant method.