# Tank Inspection, Repair, Alteration, and Reconstruction (Selected Section from API 653)

# SECTION 1 - SCOPE

**Introduction:** Summary from API 653 copied here for reading. Recommend reading API 653 latest edition before going for full examination. Note, this note is directly taken from API. Portion deleted and readjusted for easy reading of inspectors.

API 653 standard covers steel storage tanks built to API 650 and its predecessor API 12C. It provides minimum requirements for maintaining the integrity of such tanks after they have been placed in service and addresses inspection, repair, alteration, relocation, and reconstruction.

The scope is limited to the tank foundation, bottom, shell, structure, roof, attached appurtenances, and nozzles to the face of the first flange, first threaded joint, or first welding-end connection. Many of the design, welding, examination, and material requirements of API 650 can be applied in the maintenance inspection, rating, repair, and alteration of in-service tanks. In the case of apparent conflicts between the requirements of this standard and API 650 or its predecessor API 12C, this standard shall govern for tanks that have been placed in service.

This standard employs the principles of API 650; however, storage tank owner/operators, based on consideration of specific construction and operating details, may apply this standard to any steel tank constructed in accordance with a tank specification.

This standard is intended for use by organizations that maintain or have access to engineering and inspection personnel technically trained and experienced in tank design, fabrication, repair, construction, and inspection.

This standard does not contain rules or guidelines to cover all the varied conditions which may occur in an existing tank. When design and construction details are not given and are not available in the as-built standard, details that will provide a level of integrity equal to the level provided by the current edition of API 650 must be used.

This standard recognizes fitness-for-service assessment concepts for evaluating in-service degradation of pressure containing components. API 579-1/ASME FFS-1, Fitness-For-Service, provides detailed assessment procedures or acceptance criteria for specific types of degradation referenced in this standard. When this standard does not provide specific evaluation procedures or acceptance criteria for a specific type of degradation or when this standard explicitly allows the use of fitness-for-service criteria, API 579-1/ASME FFS-1 may be used to evaluate the various types of degradation or test requirements addressed in this standard.

**Compliance with This Standard:** The owner/operator has ultimate responsibility for complying with the provisions of this standard. The application of this standard is restricted to organizations that employ or have access to an authorized inspection agency as defined in 3.3. Should a party other than the owner/operator be assigned certain tasks, such as relocating and reconstructing a tank, the limits of responsibility for each party shall be defined by the owner/operator prior to commencing work.

**Jurisdiction:** If any provision of this standard presents a direct or implied conflict with any statutory regulation, the regulation shall govern. However, if the requirements of this standard are more stringent than the requirements of the regulation, then the requirements of this standard shall govern.

# Section 2 - References

1. API Recommended Practice 579-1/ASME FFS-1 – Fitness for Service (See our API 579 course, available from Dec. 2022)
2. API Recommended Practice 580 – Risk Based Inspection
3. API Standard 620 – Design and Construction of Large, Low-pressure Storage Tanks
4. API Standard 650 – Welded Tank for Oil Storage
5. API Recommended Practice 651 – Cathodic Protection of Aboveground Storage Tanks
6. API Recommended Practice 652 – Large and Aboveground Storage Tank Bottoms

Plus, various other standards, refer API 653 for details

# Section 3 - Terms and Definitions

Following are select terms and definition from API 653

**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.

**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.

**Breakover Point:** The area on a tank bottom where settlement begins.

**Candidate Tank:** The tank(s) for which corrosion rates are not known.

**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.

**Control Tank:** The tank(s) for which corrosion rates and service history are known and documented.

**Corrosion Rate:** The total metal loss divided by the period of time over which the metal loss occurred.

**Critical Zone:** The portion of the tank bottom or annular plate within 3 in. of the inside edge of the shell, measured radially inward.

**Current Applicable Standard:** The current edition of the standard (such as API standard or UL standard) that applies if the tank were built today.

**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.

**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/operator.

**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 API 6.3.2).

**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.

**Hot Tap:** Identifies a procedure for installing a nozzle in the shell of a tank that is in service.

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

**Insert Plate:** A steel plate that replaces part of a shell plate with a nominal thickness that is equivalent to, or no more than, **$^1/_8$ in.** greater than the nominal thickness of the adjoining material. When an insert plate is equal to the full height of a shell ring, it is considered to be a shell plate.

**Inspection Activities:** Any activity relating to the performance of inspection of aboveground storage tanks while employed by or under contract with an authorized inspection agency.

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

**Internal Inspection:** A formal, complete inspection, as supervised by an authorized inspector, of all accessible internal tank surfaces.

**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) a non-metallic repair that contributes more than one-half the strength of the shell in an area more than **12 in.** high
g) installing a new bottom
h) 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 API 653 clause 12.3.3.5.1
i) jacking a tank shell.

**Owner / Operator:** The legal entity having control of and/or responsibility for the operation and maintenance of an existing storage tank.

**Product-Side:** The side of the tank that is in contact with the stored liquid product.

**Reconstruction:** Any work necessary to reassemble a tank that has been dismantled and relocated to a new site.

**Reconstruction Organization:** The organization having assigned responsibility by the owner/operator to design and/or reconstruct a tank.

**Repair:** Work necessary to maintain or restore a tank to a condition suitable for safe operation. Repairs include both major repairs (see API 652 clause 3.22) 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-levelling 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.

**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.

**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.

**Soil-Side:** The side of the tank bottom that is in contact with the ground.

**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.

**Structural Discontinuity:** An abrupt change in shape or cross-section that affects stress or strain distribution through the entire wall thickness.

**Thickened Insert Plate:** A steel plate that replaces part of a shell plate with a nominal thickness that is greater than the nominal thickness of the adjoining material by more than **$^1/_8$ in.**

**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

**General:** 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. 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.

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.

## Tank Roof Evaluation

**General:** The structural integrity of the roof and roof support system shall be verified. 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.

### Fixed Roofs

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). 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).

### Floating Roofs

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. 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. 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. 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.

**Change of Service:**

**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.

**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.

**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**.

**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.

**Normal and Emergency Venting:** Effects of change in operating conditions (including product service and pumping rates) on normal and emergency venting shall be considered. Vents shall be inspected for proper operation and screens shall be verified to be clear of obstruction.

## Tank Shell Evaluation

**General:** 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.

The evaluation of the existing tank shell shall be conducted by a storage tank engineer and shall include an analysis of the shell for the intended design conditions, based on existing shell plate thickness and material. The analysis shall take into consideration all anticipated loading conditions and combinations, including pressure due to fluid static head, internal and external pressure, wind loads, seismic loads, roof live loads, nozzle loads, settlement, and attachment loads.

Shell corrosion occurs in many forms and varying degrees of severity and may result in a generally uniform loss of metal over a large surface area or in localized areas. Pitting may also occur. Each case must be treated as a unique situation and a thorough inspection conducted to determine the nature and extent of corrosion prior to developing a repair procedure. Pitting does not normally represent a significant threat to the overall structural integrity of a shell unless present in a severe form with pits in close proximity to one another. Criteria for evaluating both general corrosion and pitting are defined below.

If the requirements of welded or riveted repair cannot be satisfied, the corroded or damaged areas shall be repaired, or the allowable liquid level of the tank reduced, or the tank retired. The allowable liquid level for the continued use of a tank may be established by using the equations for a minimum acceptable thickness and solving for height. The actual thickness, as determined by inspection, minus the corrosion allowance shall be used to establish the liquid level limit. The maximum design liquid level shall not be exceeded.

**Actual Thickness Determination:** For determining the controlling thicknesses in each shell course when there are corroded areas of considerable size, measured thicknesses shall be averaged in accordance with the following procedure.

For each area, the authorized inspector shall determine the minimum thickness $t_2$, at any point in the corroded area, excluding widely scattered pits.

Calculate the critical length **L**, where $L = 3.7 \sqrt{(Dt_2)}$, where

**L** is the maximum vertical length, in inches, over which hoop stresses are assumed to "average out" around local discontinuities.

**D** is the tank diameter in feet

$t_2$ is the latest thickness, in inches, in an area of corrosion, exclusive of pits

The authorized inspector shall visually or otherwise decide which vertical plane(s) in the area is likely to be the most affected by corrosion. Profile measurements shall be taken along each vertical plane for a distance. In the plane(s), determine the lowest average thickness, $t_1$, averaged over a length of **L**, using at least five equally spaced measurements over length **L**.

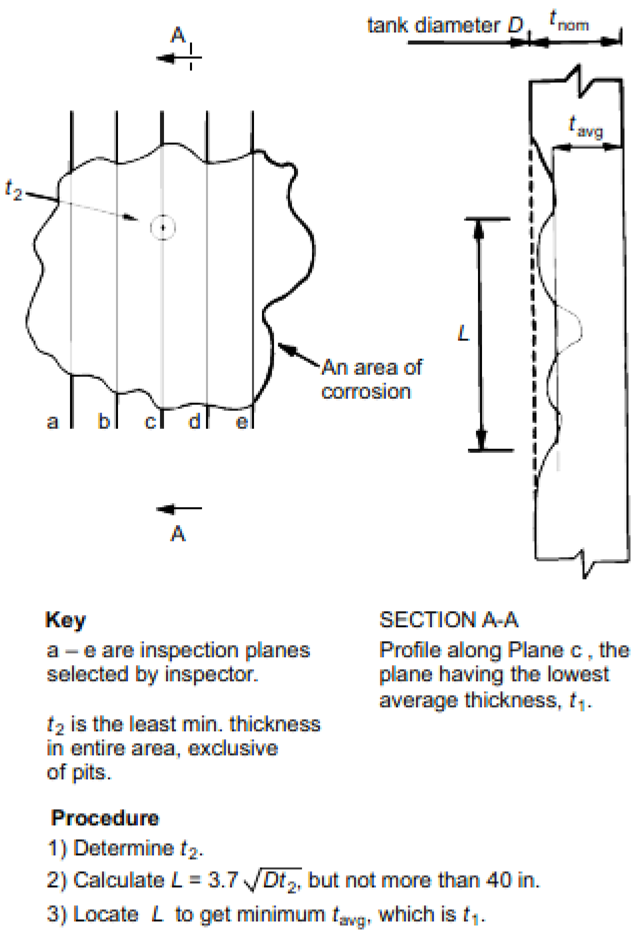


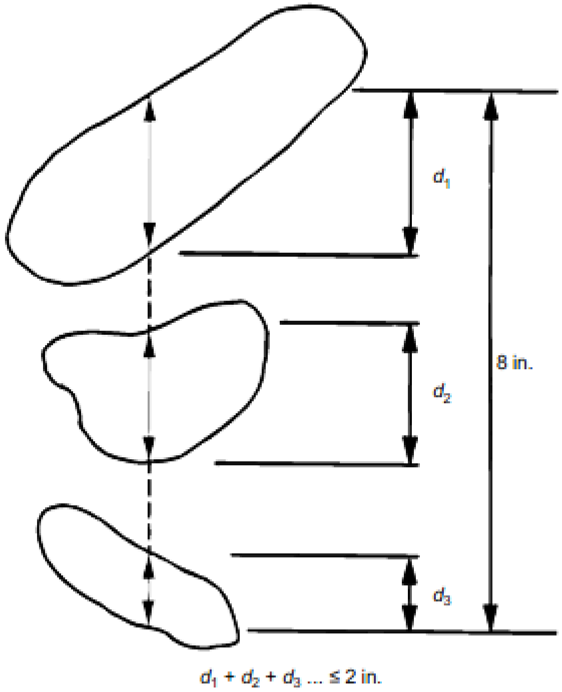

**Figure: Inspection of Corrosion Areas**

<u>The criteria for continued operation is as follows:</u>

- the value **1** shall be greater than or equal to $t_{min}$, subject to verification of all other loadings
- listed in API 653 Claus 4.3.3.5
- the value **2** shall be greater than or equal to **60 %** of min; and
- any corrosion allowance required for service until the time of the next inspection shall be added to min and **60 %** of min

Widely scattered pits may be ignored provided that:

- no pit depth results in the remaining shell thickness being less than one-half the minimum acceptable tank shell thickness exclusive of the corrosion allowance; and
- the sum of their dimensions along any vertical line does not exceed **2 in.** in an **8 in.** length, see following figure




**Figure**

**Minimum Thickness Calculation for Welded Tank Shell**

## Minimum Thickness Calculation for Riveted Tank Shell

The minimum acceptable thickness for riveted tank shells shall be calculated using the equation in API 653 clause 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 below for joint efficiencies for locations within **6 in.** of rivets.

The rivet joint efficiencies given in Table below 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:

- for the maximum tensile stress in net section of plate, use the lesser of **0.80 or 0.429**; use **21,000 lbf/in.$^2$** if **T** or **Y** is unknown
- for the maximum shear in net section of rivet, use **16,000 lbf/in.$^2$**
- 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.

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. Non-liquid loads shall also be considered in the analysis of riveted tanks.

| Type of Joint | Number of Rivet Rows | Joint Efficiency, *E* |
|---|---|---|
| Lap | 1 | 0.45 |
| Lap | 2 | 0.60 |

| | | |
|---|---|---|
| **Lap** | **3** | **0.70** |
| **Lap** | **4** | **0.75** |
| **Butt** a | **2** b | **0.75** |
| **Butt** | **3** b | **0.85** |
| | | |
| a. All butt joints listed have butt straps both inside and outside. | | |
| b. Number of rows on each side of joint centre line. | | |

**Distortions**

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

**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.

**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.

**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. Typical shell weld conditions are listed below with their required evaluation and/or repair actions.

- Cracks shall be removed. Removal areas shall be evaluated and repaired if necessary.
- Excessive weld reinforcement does not require rework if the tank has a satisfactory history of service. If the reinforcement will interfere with floating roof seal operation, it shall be ground as required.
- Undercut of shell butt welds resulting from original construction shall not require repair if the tank has been hydrotested or will not undergo a change of service.
- Weld corrosion shall be repaired if the corrosion pit cavity bottom is below the surface of the adjacent shell plate.
- Shell-to-bottom weld corrosion shall be repaired if the remaining fillet is less than the required weld size.
- Fillet weld size on existing nozzles shall be evaluated according to the original standard of construction.
- Surface defects, such as arc strikes, shall be acceptable if the tank has been hydrotested or will not undergo a change of service.

**Shell Penetrations:** 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 the minimum required spacings in API 650 (Seventh Edition or later) are acceptable for continued service if the welds are examined by the magnetic particle or **ACFM** (Alternating Current Field Measurement) methods 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. except as permitted by API 653 clause 9.11.2.7. Any other noncompliance, or deterioration due to corrosion, must be assessed and repair procedures established where appropriate or the tank re-rated, as necessary.

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

**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.

**Continued Operation at Elevated Temperatures:** Existing tanks that were originally designed and constructed to the requirements of API 650, Table M.1a or M.1b, shall be evaluated for continued service, as follows.

- 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.1a. 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.$^2$.**

- 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.

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. In addition, the maximum operating temperature shall not exceed the temperatures at which the tank has operated successfully in the past.

**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:

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

**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.

**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.

**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.

**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.

**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:

a) preventing the escape of released material, and
b) containing or channelling released material for leak detection.

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.

**Bottom Plate Thickness Measurements:** Various methods for determining tank bottom plate soil-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.

**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 of API 653.

## Minimum Thickness for Annular Plate Ring

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.

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 below, plus any specified corrosion allowance. Interpolation is allowed within Table based on shell stress determined per Note b of Table.

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.

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.

| Bottom Plate Thickness | |
|---|---|
| Minimum Bottom Plate Thickness at Next Inspection | Tank Bottom / Foundation Design |
| **0.10** | Tank bottom/foundation design with no means for detection and containment of a bottom leak. |

| | |
|---|---|
| **0.05** | Tank bottom/foundation design with means to provide detection and containment of a bottom leak. |
| **0.05** | Applied tank bottom reinforced lining, > 0.05 in. thick, in accordance with API 652. |

For the thickness and projection of the annular plate beyond the shell as follows:

| **Annular Bottom Plate Thicknesses (in.)<br>(Product Specific Gravity < 1.0)** | | | | |
|---|---|---|---|---|
| **Plate Thickness of First Shell Course** | **Stress [b] in First Shell Course** (lbf/in.$^2$) | | | |
| | **< 24,300** | **< 27,000** | **< 29,700** | **< 32,400** |
| **t <= 0.75** | 0.17 | 0.20 | 0.23 | 0.30 |
| **0.75 < t <= 1.00** | 0.17 | 0.22 | 0.31 | 0.38 |
| **1.00 < t <= 1.25** | 0.17 | 0.26 | 0.38 | 0.48 |
| **1.25 < t <= 1.50** | 0.22 | 0.34 | 0.47 | 0.59 |
| **T > 1.50** | 0.27 | 0.40 | 0.53 | 0.68 |
| 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 ring-wall, settlement will produce additional stresses in the annular plate. | | | | |
| (a) Plate thickness refers to the tank shell as constructed.<br>(b) Stresses are calculated from [**2.34 D (H** – 1/**t**] | | | | |
| Table | | | | |

## Tank Foundation Evaluation

**General:** 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 alkalis and acids. To ensure suitability for service, all tank foundations shall be inspected periodically.

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 alkalis, 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.

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.

**Foundation Repair or Replacement:** 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. Concrete pads, ring-walls, 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.

**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 5 - Brittle Fracture Considerations

**General:** This section provides a procedure for the assessment of existing tanks for suitability for continued operation or change of service with respect to the risk of brittle fracture and does not supplement or replace the requirements of Section 12 for the examination and testing for the hydrostatic testing of repaired, modified, or reconstructed tanks. The procedure applies to both welded and riveted tanks; however, the procedure is based primarily on experience and data obtained from welded tanks.

**Basic Considerations:** A decision tree is used to present the assessment procedure for failure due to brittle fracture. The decision tree is based on the following principles. In all reported incidents of tank failure due to brittle fracture, failure occurred either shortly after erection during hydrostatic testing or on the first filling in cold weather, after a change to lower temperature service, or after a repair/ alteration. This experience shows that once a tank has demonstrated the ability to withstand the combined effects of maximum liquid level (highest stresses) and lowest operating temperature without failing, the risk of failure due to brittle fracture with continued service is minimal.

Any change in service must be evaluated to determine if it increases the risk of failure due to brittle fracture. In the event of a change to a more severe service (such as operating at a lower temperature or handling product at a higher specific gravity) it is necessary to consider the need for a hydrostatic test to demonstrate fitness for a new more severe service. The following aspects should be considered:

a) the likelihood of repairs/alterations since the original hydrostatic test not meeting requirements of this standard
b) deterioration of the tank since original hydrostatic test.

# Section 6 - Inspection

**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.

**Inspection Frequency Considerations:** 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

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.

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.

## Inspections from the Outside of the Tank

**Routine In-service Inspections:** 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 API 653, clause 3.4. Personnel performing this inspection should be knowledgeable of the storage facility operations, the tank, and the characteristics of the product stored.

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

**External Inspection:** 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 as described by code.

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.

**Ultrasonic Thickness Inspection:** 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.

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 **RCA/2N** (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.

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).

**Cathodic Protection Surveys:** 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. The owner/operator shall assure competency of personnel performing surveys.

## Internal Inspection

General: 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 4. 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.

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.

**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 653, Fourth Edition, Addendum 2, January 2012.

**Initial Internal Inspection Interval:** The initial internal inspection intervals for newly constructed tanks or existing tanks with a newly installed bottom shall be established either per 6.4.2.1.1 or 6.4.2.1.2. Alternatively, the next internal inspection interval for existing tanks where a new bottom has been installed may be determined per 6.4.2.2, if all the following conditions are satisfied:

a) Inspection data has been obtained from the previous tank bottom.
b) Inspection data obtained is deemed applicable to the new tank bottom or corrosion rates (product or soil side) for the new tank bottom are not expected to be greater than the corrosion rates of the previous tank bottom.
c) Corrosion rate applicability to the new tank bottom shall be verified by a storage tank engineer experienced in materials or corrosion or by consulting with appropriate specialist.
d) The owner/operator shall agree and follow the guidelines in 6.4.2.2 in order to use the subsequent internal inspection interval as the next inspection interval for the new tank bottom.

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 preventions, detection, corrosion mitigation, or containment safeguards listed in Table 6.1. The maximum initial internal inspection interval shall be based on **10 years** plus incremental credits for the additional safeguards in Table 6.1, which are cumulative.

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

| **Tank Safeguard** | **Add to Initial Interval** |
|---|---|
| Fiberglass-reinforced lining of the product-side of the tank bottom installed per API RP 652. | **5 years** |
| Installation of an internal thin film coating as installed per API RP 652. | **2 years** |
| Cathodic protection of the soil-side of the tank bottom installed, maintained, and inspected per API RP 651. | **5 years** |
| Release prevention barrier installed per API 650, Annex I. | **10 years** |
| Initial bottom thickness > 0.25 in. | (Initial bottom thickness - 0.25 in.)/ corrosion rate* |
| Bottom constructed from stainless steel material that meets requirements of API 650, Annex SC, and either Annex S or Annex X; and internal and external environments have been determined by a qualified corrosion specialist to present very low risk of cracking or corrosion failure. | **10 years** |
| *Corrosion rate to be 15 mpy, or as determined from Annex H, Similar Service. | |

For example, the maximum initial internal inspection interval for a **$^{5}/_{16}$ in.** thick bottom that has a release prevention barrier, and a fiberglass-reinforced lining would be determined as follows:

Credit for initial bottom thickness **> 0.25 in. = (0.3125 in. - 0.25 in.) / 0.015 in./year = 4.2 years**
Maximum initial internal inspection interval = **10 years** (initial) + **5 years** (fiberglass-reinforced lining) + **10 years** (release prevention barrier) + **4.2 years** (credit for initial bottom thickness > **0.25 in.**) = **29.2 years**.

## Subsequent Internal Inspection Interval

The interval between subsequent internal inspections shall be determined in accordance with either the corrosion rate procedures or RBI.

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) 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.

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 RP 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/operator 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/ operator procedure.

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

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.

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) detail (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).

**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 in section 4 (bottom plate thickness, API 653 clause 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.

**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.

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

# Records

**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.

**Construction Records:** Construction records may include nameplate information, drawings, specifications, construction completion report, and any results of material tests and analyses.

**Inspection History:** The inspection history includes all measurements taken, the condition of all parts inspected, and a record of all examinations and tests. A complete description of any unusual conditions with recommendations for correction of details which caused the conditions shall also be included. This file will also contain corrosion rate and inspection interval calculations.

**Repair/Alteration History:** The repair/alteration history includes all data accumulated on a tank from the time of its construction with regard to repairs, alterations, replacements, and service changes (recorded with service conditions such as stored product temperature and pressure). These records should include the results of any experiences with coatings and linings.

# Reports

**General:** For each external inspection performed as per API 653 clause 6.3.2 and each internal inspection performed as per API 653 clause 6.4, the authorized inspector shall prepare a written report. These inspection reports along with inspector recommendations and documentation of disposition shall be maintained by the owner/operator for the life of the tank. Local jurisdictions may have additional reporting and record keeping requirements for tank inspections.

**Report Contents:** Reports shall include at a minimum the following information:

a. date(s) of inspection
b. type of inspection (external or internal)
c. scope of inspection, including any areas that were not inspected, with reasons given (e.g., limited scope of inspection, limited physical access)
d. description of the tank (number, size, capacity, year constructed, materials of construction, service history, roof and bottom design, etc.), if available
e. list of components inspected, and conditions found (a general checklist such as found in Annex C may be used to identify the scope of the inspection) and deficiencies found
f. inspection methods and tests used (visual, MFL, UT, etc.) and results of each inspection method or test
g. corrosion rates of the bottom and shell
h. settlement survey measurements and analysis (if performed)
i. recommendations per API 653 clause 6.9.3.1
j. name, company, API 653 certification number and signature of the authorized inspector responsible for the inspection
k. drawings, photographs, NDE reports, and other pertinent information shall be appended to the report.

**Recommendations:** Reports shall include recommendations for repairs and monitoring necessary to restore the integrity of the tank per this standard and/or maintain integrity until the next inspection, together with reasons for the recommendations. The recommended maximum inspection interval and basis for calculation of that interval shall also be stated. Additionally, reports may include other less critical observations, suggestions, and recommendations.

It is the responsibility of the owner/operator to review the inspection findings and recommendations, establish a repair scope, if needed, and determine the appropriate timing for repairs, monitoring, and/or maintenance activities. Typical timing considerations and examples of repairs are:

a) **prior to returning the tank to service** - repairs critical to the integrity of the tank (e.g., bottom or shell repairs)
b) **after the tank is return to service** - minor repairs and maintenance activity (e.g., drainage improvement, painting, gauge repairs, grouting, etc.)
c) **at the next scheduled internal inspection** - predicted or anticipated repairs and maintenance (e.g., coating renewal, planned bottom repairs, etc.)
d) **monitor condition for continued deuteriation** - (e.g., roof and/or shell plate corrosion, settlement, etc.)

The owner/operator shall ensure that the disposition of all recommended repairs and monitoring is documented in writing and that reasons are given if recommended actions are delayed or deemed unnecessary.

**Nondestructive Examination (NDE):** Personnel performing NDE shall meet the qualifications identified in API 653 clause 12.1.1.2, but need not be certified in accordance with Annex D. The results of any NDE work, however, must be considered in the evaluation of the tank by an authorized inspector.

# Section 7 - Materials

**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.

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

## Original Materials for Reconstructed Tanks

**Shell and Bottom Plates Welded to the Shell:** 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 following section. After identification, determination shall be made as to suitability of the material for intended service.

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, API 650 Section 4.2.10, API 650 Section 4.2.11, and API 650 Table 4.4a or API 650 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.

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.

**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.

**Flanges and Fasteners:** Flange material shall meet the minimum requirements of the material specifications in the as-built standard. Fasteners shall meet the material specifications of the current applicable standard.

**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).

**Welding Consumables:** Welding consumables shall conform to the AWS classification that is applicable to the intended use.

# Section 8 - Design Considerations for Reconstructed Tanks

**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.

**New Weld Joints:** Weld joint details shall meet the welding requirements of the current applicable standard. All new shell joints shall be butt-welded joints with complete penetration and complete fusion.

**Existing Weld Joints:** Existing weld joints shall meet the requirements of the as-built standard.

**Shell Design:** Thickness to be used for each shell course when checking tank design shall be based on measurements taken within **180 days** prior to relocation. For details refer API 653 clause 8.4.

**Shell Penetrations:** Replacement and new penetrations shall be designed, detailed, welded, and examined to meet the requirements of the current applicable standard. Existing penetrations shall be evaluated for compliance with the as-built standard.

**Windgirders and Shell Stability:** Top and intermediate windgirders for open top tanks shall meet the requirements of the current applicable standard. 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.

**Roofs:** Roof designs shall meet the requirements of the as-built standard. 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.

**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.

# Section 9 - Tank Repair and Alteration

**General:** The basis for repairs and alterations shall be an API 650 equivalence. Hydrostatic testing requirements, NDE requirements, acceptance criteria for the welds, and repairs to shell plate and existing welds are specified in Section 12.

All repair work must be authorized by the authorized inspector, or an engineer experienced in storage tank design, before commencement of the work by a repair organization. Authorization for alterations to storage tanks that comply with API 650 may not be given without prior consultation with, and approved by, an engineer experienced in storage tank design. The authorized inspector will designate inspection hold points required during the repair or alteration sequence and minimum documentation to be submitted upon job completion. The authorized inspector may give prior general authorization for limited or routine repairs as long as the authorized inspector is sure that the repairs will not require hydrostatic testing or do not require an engineering evaluation.

All proposed design, work execution, materials, welding procedures, examination, and testing methods must be approved by the authorized inspector or by an engineer experienced in storage tank design. The authorized inspector or an engineer experienced in storage tank design shall approve all specified repair and alteration work at the designated hold points and after repairs and alterations have been completed in accordance with the requirements of this standard.

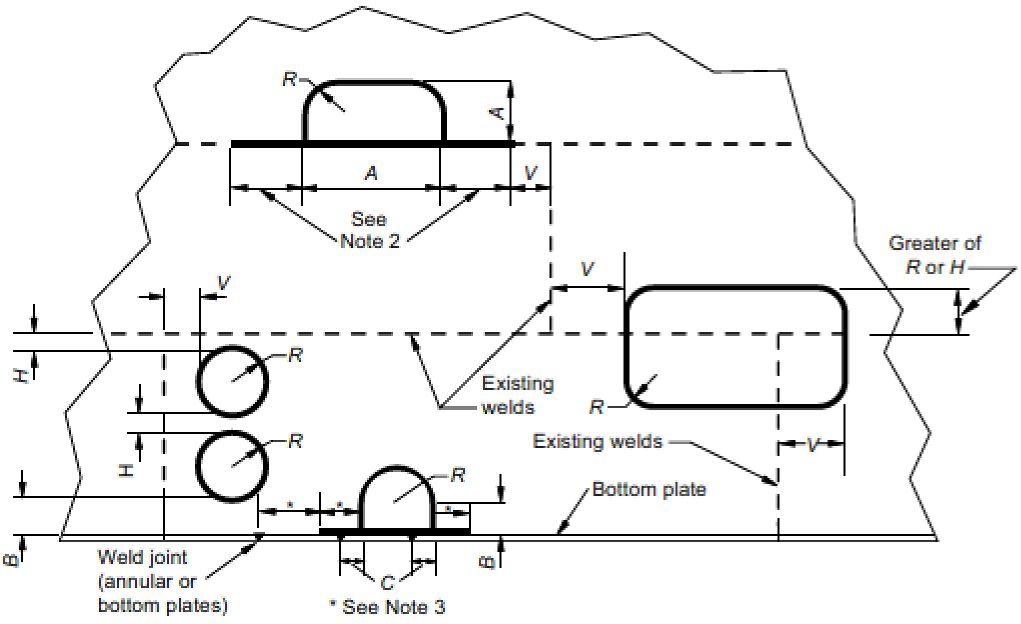
Annex F summarizes the requirements by method of examination and provides the acceptance standards, examiner qualifications, and procedure requirements. Annex F is not intended to be used alone to determine the examination requirements for work covered by this document. The specific requirements as listed in Section 1 through Section 12 shall be followed in all cases.

## Removal and Replacement of Shell Plate Material

**Minimum Thickness of Replacement Shell Plate:** The minimum thickness of the replacement shell plate material shall be calculated in accordance with the as-built standard. The thickness of the replacement shell plate shall not be less than the greatest nominal thickness of any plate in the same course adjoining the replacement plate except where the adjoining plate is a thickened insert plate. Any changes from the original design conditions, such as specific gravity, design pressure, liquid level, and shell height, shall be considered.

**Minimum Dimensions of Replacement Shell Plate:** The minimum dimension for a replacement shell plate is **12 in.** or **12 times** the thickness of the replacement plate, whichever is greater. The replacement plate may be circular, oblong, square with rounded corners, or rectangular with rounded corners except when an entire shell plate is replaced. See Figure 9.1 for typical details of acceptable replacement shell plates.

Where one or more entire shell plates or full height segments of shell plates are to be removed and replaced, the minimum spacing requirements specified in Figure below for vertical weld joints shall be maintained. It is acceptable to remove and replace entire shell plates or full height segments of shell plates by cutting and rewelding along the existing horizontal weld joints. Prior to welding the new vertical joints, the existing horizontal welds shall be cut for a minimum distance of **12 in.** beyond the new vertical joints. The vertical joints shall be welded prior to welding the horizontal joints.




| Table | | |
|---|---|---|
| Dimension | **Minimum Weld Spacing Between Edges (Toes) of Welds for Thickness of Replacement Shell Plate, *t*, (inches)** | |
| | ***t* <= 0.5 in.** | ***t* > 0.5 in.** |
| ***R*** | **6 in.** | **Greater of 6 in. or 6*t*** |
| ***B*** | **6 in.** | **Greater of 10 in. or 8*t*** |
| ***H*** | **3 in.** | **Greater of 10 in. or 8*t*** |
| ***V*** | **6 in.** | **Greater of 10 in. or 8*t*** |
| ***A*** | **12 in.** | **Greater of 12 in. or 12*t*** |
| ***C*** | **Greater of 3 in. or 5*t*** | |

NOTE 1: All weld intersections shall be at approximately **90°.**

NOTE 2: Prior to welding new vertical joints, cut existing horizontal weld for a minimum of **12 in.** beyond the new vertical joints. Weld the horizontal joint last.

NOTE 3: Prior to welding new vertical joints, cut existing shell-to-bottom weld for a minimum of **12 in.** beyond the new vertical joints. 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.

**Weld Joint Design:** Shell replacement plates shall be welded with butt joints with complete penetration and complete fusion, except as permitted for lapped patch shell repairs.

Weld joint design for replacement shell plates shall be in accordance with API 650, Section 5.1.5.1 through Section 5.1.5.3. Joints in lap-welded shell tanks may be repaired according to the as-built standard. Lap-welded joint design for lapped patch shell repairs shall meet the requirements of 9.3. Details of welding shall be in accordance with 7.2 of API 650, and Section 9 of this standard.

For existing shell plates over **½ in.** thick, the outer edge of the butt weld attaching the replacement shell plate shall be at least the greater of **8 times** the weld thickness or **10 in.** from the outer edge of any existing butt-welded shell joints. For existing shell plates **½ in.** thick and less, the spacing may be reduced to **6 in.** from the outer edge of vertical joints or **3 in.** from the outer edge of horizontal joints. See Figure 9.1 for minimum dimensions.

For existing shell plates over **½ in.** thick, the outer edge of the butt weld attaching the replacement shell plate shall be at least the greater of 8 times the weld size or **10 in.** from the edge (toe) of the fillet weld attaching the bottom shell course to the bottom except when the replacement shell plate extends to and intersects the bottom-to-shell joint at approximately **90°**. For existing shell plates **½ in.** thick and less, this spacing may be reduced to **6 in.** For shell plates of unknown toughness not meeting the exemption criteria of Figure 5.2 of API 653, the edge of any vertical weld joint attaching a replacement plate shall be at **3 in.** or **5t** from the edge of a weld joint in the bottom annular ring or **18** weld joints in bottom plates under the tank shell. Figure 9.1 has minimum dimensions.

To reduce the potential for distortion of an existing tank due to welding a replacement plate into an existing tank shell, fit-up, heat input, and welding sequence must be considered.

**Door Sheet Installation:** This section describes the requirements for reinstallation or replacement of a door sheet. The removed shell plate section of a door sheet in a butt-welded tank may be reinstalled in its original **19** location or the section may be replaced with new shell plate material. In either case the door sheet installation shall utilize joints with complete penetration and complete fusion. Large door sheets should have the top and/or sides of the opening stiffened to prevent

a) sagging and deformation of the shell at the top of the opening, and
b) shell deformations at the sides and upper corners resulting when the door sheet is first removed or when it is replaced and welded into the shell.

Installation of the stiffening members should be done prior to cutting the door sheet, providing it is safe to do so, and the members should remain in place until the door sheet is completely and satisfactorily reinstalled. The specific arrangement and details of the stiffening should be determined by a storage tank engineer. Door sheet stiffening, when used, usually consists of one or a combination of angle, channel, or wide flange section members.

For lap-welded and riveted tanks, reinstallation of an original plate section that crosses an existing horizontal seam is not permitted. Door sheets that cross vertical riveted or lap-welded seams are not permitted in any case.

If a door sheet vertical cutline crosses an existing seam in a butt-welded tank without an offset and the removed section is reinstalled, then additional weld examination shall be required at the intersection of the new vertical weld seam and existing horizontal weld seam. In addition to the examination requirements of 12.1.5.1, the back gouged surface of the root pass and the final pass (each side) of the new welds shall be examined by magnetic particle or liquid penetrant methods. The existing horizontal weld seam intersected by the new vertical weld shall also be examined by magnetic particle or liquid penetrant methods for a 6 in. distance on both sides.

NOTE: "Offset" is the horizontal distance between the vertical welds above and below a horizontal seam, as shown in Figure 9_1, Figure 9_2, and Figure 9_3.

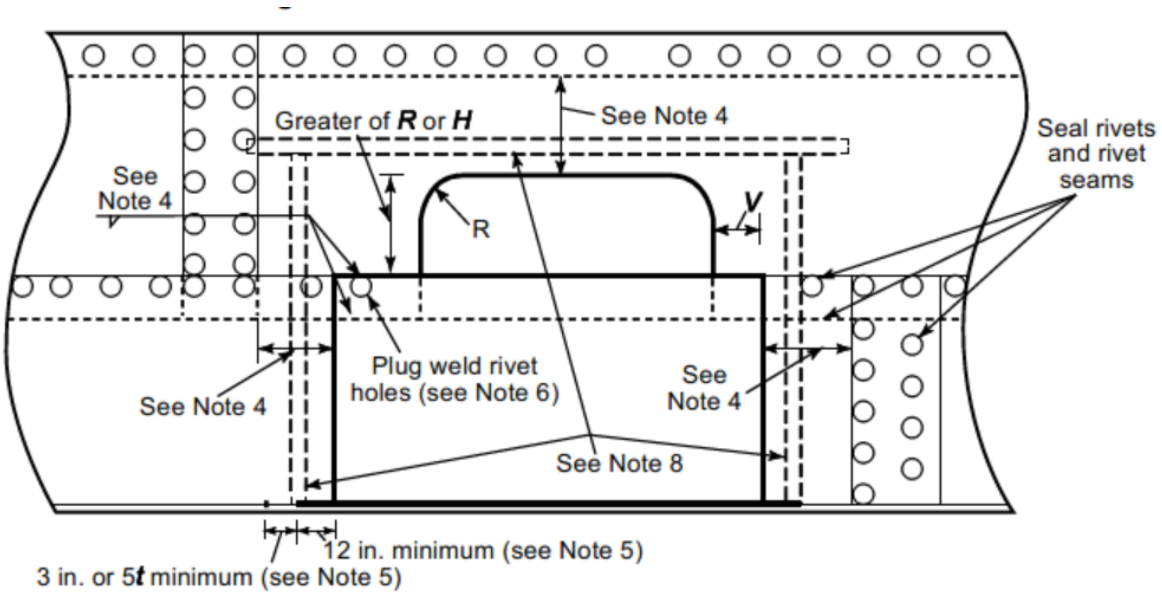



**Figure 9_1: Details for Door Sheets in Lap-welded Seam Tank**

**NOTES:**

1. See table above for minimum weld spacing and dimensions **H, R,** and **V.**
2. When a door sheet crosses the horizontal joint between two courses, a replacement door sheet assembly shall be constructed of two separate plates. The upper door sheet thickness shall be the same as the higher shell course thickness. The lower door sheet thickness shall be the same as the lower shell course thickness.
3. Fillet Weld size shall be equal to thickness of thinner of two plates.
4. Rivets and existing lap rivet seams located within **12 in.** of a weld may need to be sealed with caulk/coating or seal-welded to prevent product seepage.
5. Prior to welding new vertical 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.
6. Plug weld all rivet holes in the shell plate where rivets are removed. Filler weld to full plate thickness and grind flush.
7. Door sheets need not extend to shell-to-bottom weld provided that weld spacing, and corner radii are in accordance with Table above.
8. Stiffener arrangement may vary from that shown.

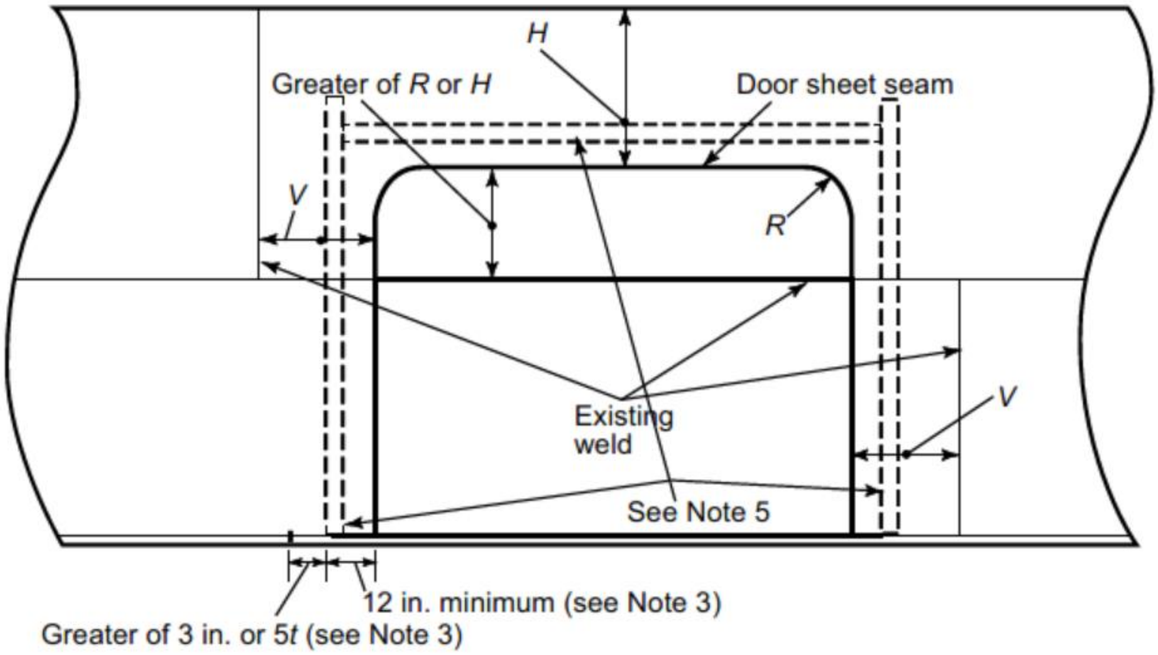



**Figure 9_2: Details for Door Sheets in Butt-welded Shell Steam Tank – No Vertical Seam Offset**

NOTES:

1. See table in Figure 9.1 for minimum weld spacing and dimensions
2. When a door sheet crosses the horizontal joint between two courses, a replacement door sheet assembly shall be comprised of two separate plates. The upper door sheet thickness shall be the same as the higher shell course thickness. The lower door sheet thickness shall be the same as the lower shell course thickness.
3. Fillet Weld size shall be equal to thickness of thinner of two plates.
4. Prior to welding new vertical joints which intersect the bottom plate, cut 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 5.** Weld the shell-to-bottom weld last.
5. Door sheets need not extend to shell-to-bottom weld provided that weld spacing, and corner radii are in accordance with Table above.
6. Stiffener arrangement may vary from that shown.

New weld seams in riveted tanks shall be located a minimum of **12 in.** from existing rivet seams to minimize potential for rivet and rivet seam leaks or the rivets and existing lap rivet seams shall be seal welded or sealed by the application of caulk or coating that is compatible with the specified stored product.

NOTE: The heat created by welding may cause nearby rivets and rivet seams to leak.

**Shell Repairs Using Lap-welded Patch Plates:** 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/operator. 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.

All repair material shall comply with the requirements of the current applicable standard of construction and API 653. Lapped patch shell repairs shall not be used on any shell course thickness (original construction) that exceeds **½ in.**, nor to replace door sheets or shell plates. Except as permitted in 9.3.3.2 and 9.3.4.3, the repair plate material shall be the smaller of **½ in.** or the thickness of the shell plate adjacent to the repairs, but not less than **$^{3}/_{16}$ in.** 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. 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.

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. 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.

Shell openings and their reinforcements shall not be positioned within a lapped patch shell repair. Prior to application of a lapped patch shell repair, the areas to be welded shall be ultrasonically examined for plate defects and remaining thickness.

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. 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.

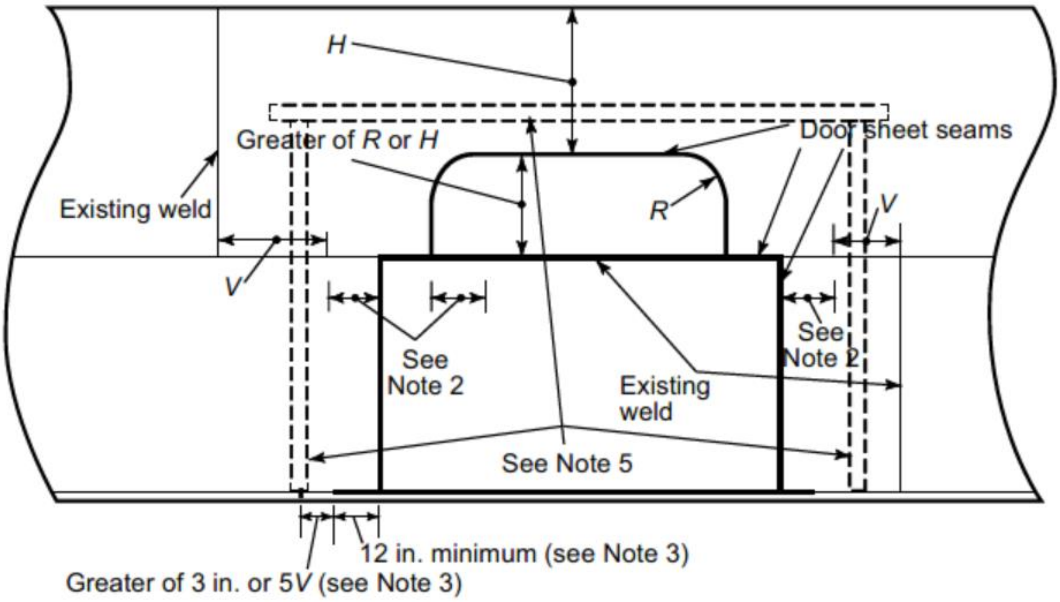
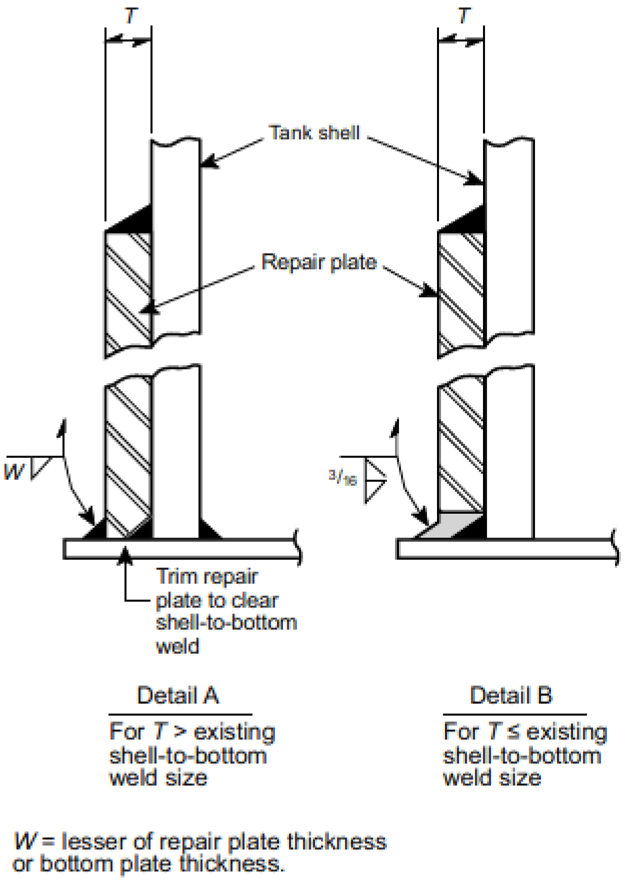



**Figure 9_3: Details for Door Sheets in Butt-welded Shell Steam Tank – Vertical Seam Offset**

**NOTES:**

1. See above Table 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 Table.




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.**

Nozzle necks and reinforcing plates shall be entirely removed prior to installation of a repair plate. 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. The repair plate thickness shall not exceed the nominal thickness of the shell plate adjacent to the repair. Lapped patch repair plates may be used to reinforce areas of severely deteriorated shell plates that are not able to resist the service loads to which the tank is to be subjected. Lapped patch repair plates may also be used for shell plates that are below the retirement thickness, providing the following additional requirements are satisfied. The selection of the repair plate thickness shall be based on a design that conforms to the as-built standard and API 653, using a joint efficiency not exceeding **0.35.** The perimeter weld shall be a full fillet weld. The repair plate thickness shall not exceed the shell plate thickness at the perimeter of the repair plate by more than one-third, but no more than **$^{1}/_{8}$ in.** The repair plate thickness shall not exceed **½ in.** The remaining strength of the deteriorated areas under the repair plate shall not be considered as effective in carrying the calculated service or hydrotest loads. Lapped patch repair plates may be used to repair small shell leaks or minimize the potential from leaks from severely isolated or widely scattered pitting if the following requirements are satisfied. The existing shell thickness, excluding the holes and pitting, meets the minimum acceptable shell thickness as determined by 4.3.2 and 4.3.3. The repair plate is designed to withstand the hydrostatic pressure load between the repair plate and the shell assuming a hole exists in the shell using a joint efficiency of **0.35.**

The repair plate thickness shall not exceed the shell plate thickness at the perimeter of the repair plate by more than one-third, but no more than **$^{1}/_{8}$ in**. The repair plate thickness shall be no thinner than $^{3}/_{16}$ **in.** nor thicker than **½ in.** A full fillet perimeter weld is required. This repair method shall not be used if exposure of the fillet welds to the product will produce crevice corrosion or if a corrosion cell between the shell plate and repair plate is likely to occur. This repair method shall not be used to repair shell leaks if the presence of product between the shell plate and repair plate will prevent gas freeing from the tank to perform hot work. The existing shell plate under the repair plate shall be evaluated at each future inspection to ensure it satisfies the requirements of 9.3.4.1. If the existing shell plate thickness does not satisfy 9.3.4.1 or the repair plate does not satisfy 9.3.3, the area is to be repaired in accordance with 9.2 or 9.3.2.

**Repairs Using Nonmetallic Materials:** This section of API 653 together with Annex J provides the specific options, deletions, additions, or modifications to the requirements and design options for nonmetallic repairs. It identifies the required inputs and decisions by the Purchaser. It also provides recommendations, requirements, and information that supplements ASME PCC-2 Article 4.1. This section and Annex J become requirements only when the Purchaser specifies an option covered by that Annex (not at the Contractor's discretion). The Owner/Operator shall also utilize an experienced storage tank engineer to identify the life span (temporary or fixed time limitation) requirements for the repair system.

Nonmetallic repairs can be made on shell plate or nozzle neck to restore hoop strength capacity lost due to corrosion. The Owner/Operator, storage tank engineer, and composite manufacturer shall evaluate the ability of the nonmetallic repair to restore the hoop strength and consider the possibility of non-tensile related forces damaging the composite repair in the selection of the repair method and in the risk assessment. The tank shall be assessed to confirm it is sufficient to handle tensile, external, axial, dead and seismic loads.

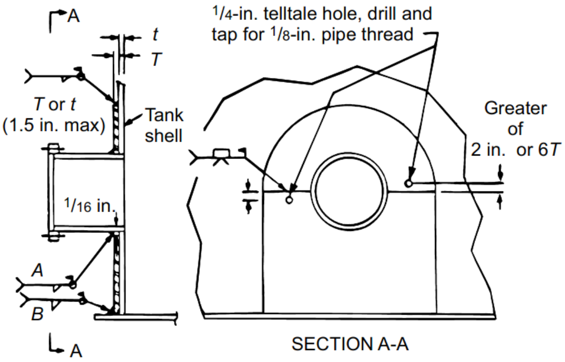
**Repair of Defects in Shell Plate Material:** The need for repairing indications such as cracks, gouges or tears (such as those often remaining after the removal of temporary attachments), widely scattered pits, and corroded areas discovered during an inspection of the tank shell shall be determined on an individual case basis in accordance with Section 4. In areas where the shell plate thickness exceeds that required by design conditions, it is permissible to grind surface irregularities to a smooth contour so long as the remaining thickness is adequate for the design conditions. Where grinding to a smoothly contoured surface will result in unacceptable shell plate metal thickness, the shell plate may be repaired by deposition of weld metal, followed by examination and testing in accordance with 12.1.8. If more extensive areas of shell plate require repair, use of butt-welded shell replacement plate or lap-welded patch plate shall be considered.

**Alteration of Tank Shells to Change Shell Height:** Tank shells may be altered by adding new plate material to increase the height of the tank shell. The modified shell height shall be in accordance with the requirements of the current applicable standard and shall take into consideration all anticipated loadings such as wind and seismic.

**Repair of Defective Welds:** Cracks, lack of fusion, and rejectable slag and porosity that need repair shall be removed completely by gouging and/or grinding and the resulting cavity properly prepared for welding and then welded. Excessive reinforcement shall be repaired by grinding if required. Existing weld undercut deemed unacceptable shall be repaired by additional weld metal, or grinding, as appropriate. Welded joints that have experienced unacceptable loss of metal due to corrosion shall be repaired by grinding and/or welding. Unacceptable surface defects shall be repaired by grinding and/or welding. After repairs of weld defects, the repaired areas shall be examined in accordance with the requirements of Claus 12.1.3 of API 653, except that repair for undercut, corrosion, and surface defects in butt welds do not require radiographic or ultrasonic examination.

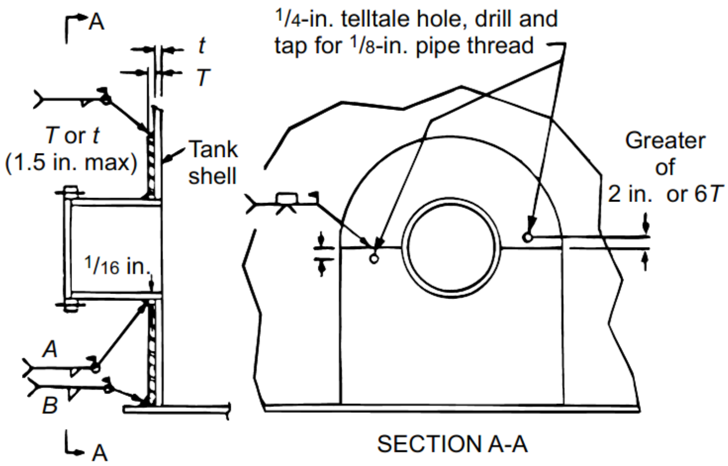
# Repair of Shell Penetrations

Repairs to existing shell penetrations shall be in compliance with API 650, Section 5.7. Reinforcing plates may be added to existing unreinforced nozzles when deemed appropriate. The reinforcing plate shall meet all dimensional and weld spacing requirements of API 650, Section 5.7. See Figure 1 and 2 for acceptable details.




| *t* and *T* (maximum) | *A* | *B* |
|---|---|---|
| 9/16 in. | 1/4 in. | 1/4 in. |
| 3/4 in. | 5/16 in. | 1/4 in. |
| 15/16 in. | 3/8 in. | 5/16 in. |
| 1 1/8 in. | 7/16 in. | 5/16 in. |
| 1 5/16 in. | 1/2 in. | 3/8 in. |
| 1 9/16 in. | 9/16 in. | 3/8 in. |
| 1 3/4 in. | 5/8 in. | 3/8 in. |

**Figure 1: Typical Details for Addition of Reinforcing Plate to Existing Shell Penetration**




| *t* and *T* (maximum) | *A* | *B* |
|---|---|---|
| 9/16 in. | 1/4 in. | 1/4 in. |
| 3/4 in. | 5/16 in. | 1/4 in. |
| 15/16 in. | 3/8 in. | 5/16 in. |
| 1 1/8 in. | 7/16 in. | 5/16 in. |
| 1 5/16 in. | 1/2 in. | 3/8 in. |
| 1 9/16 in. | 9/16 in. | 3/8 in. |
| 1 3/4 in. | 5/8 in. | 3/8 in. |

**Figure 2: Typical Details for Addition of "Tombstone" Shape Reinforcing Plate to Existing Shell Penetration**

NOTE All details, dimensions, and weld spacing shall be in accordance with the requirements of API 650.

As an alternative, the reinforcing plates may be added to the inside of the tank provided that sufficient nozzle projection exists.

**Addition or Replacement of Shell Penetrations:** For the existing shell plate; use **20,000 lbf/in.$^2$** if of unknown material. A joint efficiency of **1.0** may be used.

Penetrations larger than **NPS 4** shall be installed with the use of an insert plate or thickened insert plate, if the shell plate thickness is greater than **½ in.** and the shell plate material does not meet the current design metal temperature criteria. In addition, the following requirement shall be met:

a) for a circular insert plate or thickened insert plate, the minimum diameter shall be at least the greater of:
   - twice the diameter of the opening in the insert plate that accommodates the radial oriented nozzle, or
   - the diameter of the opening in the insert plates plus **12 in.**

b) for a noncircular insert plate or thickened insert plate, the minimum dimension across the insert plate from end to end in any direction (if other than circular), shall be at least the greater of:
   - twice the dimension of the opening in the insert plate or thickened insert plate in that direction, or
   - the dimension of the opening in the insert plate or thickened insert plate in that direction plus **12 in.**

**Alteration of Existing Shell Penetrations:** Existing shell penetrations may be altered if the altered details comply with the requirements of API 650, Section 5.7 including the requirements for minimum reinforcing area and the requirements for spacing of welds around connections.

When installing a new tank bottom above the existing bottom, it may be necessary to alter existing shell penetrations in the bottom course of a tank shell. If the new bottom is slotted through the tank shell several inches above the existing bottom, the spacing between existing welds around penetrations and the new bottom-to-shell weld may not comply with API 650 requirements. Options for altering the penetrations and/or reinforcing plates are given in 9.10.2.1 through 9.10.2.3.

The existing reinforcing plate may be trimmed to increase the spacing between the welds provided that the altered detail complies with the requirements of API 650, Section 5.7. Care must be exercised during the trimming operation to avoid damaging the shell material beneath the reinforcing plate. The existing weld attaching the portion of the reinforcing plate to be removed shall be completely removed by gouging and grinding. The required spacing of the welds may be reduced per 9.11.2.7(a) or (b) if the requirements of 9.11.2.7(c), (d), and (e) are met.

The existing reinforcing plate may be removed, and a new reinforcing plate added except that reinforcing plate replacement is not permitted in existing stress relieved assemblies unless the requirements of 11.3 are met. If it is not known whether the assembly was thermally stressed relieved, then the alteration shall meet the requirements of API 650, Section 5.7.4. Care must be exercised when removing the existing reinforcing plate to avoid damaging the shell plate beneath the reinforcing plate. When the upper half of the existing reinforcing plate meets all requirements of API 650, it can be left in place with approval of the purchaser. In this case, only the lower half of the existing reinforcing plate need be removed and replaced with the new one. The existing upper half of the reinforcing plate and the new lower section shall be provided with a new telltale hole, if needed, or drilled hole, and a welded pipe, coupling for the pneumatic test. The shell plate thickness under the telltale hole or drilled hole shall be checked 18 after drilling and the thickness shall not be less than

½ $t_{min}$, as calculated in 4.3.3.1, plus any required corrosion allowance. The welds to be replaced around the perimeter of the reinforcing plate and between the reinforcing plate and neck of the penetration shall be completely removed by gouging and grinding. The new reinforcing plate shall be in accordance with Figure 1. If required to maintain weld spacing, a tombstone-shaped reinforcing plate may be used (see Figure 2).

The existing penetration may be moved by cutting the section of the shell containing the fitting and reinforcing plate and raising the entire assembly to the correct elevation (see Figure 9.9). The new shell seams made to raise the penetration shall comply with Figure below, including the shell to bottom seam.

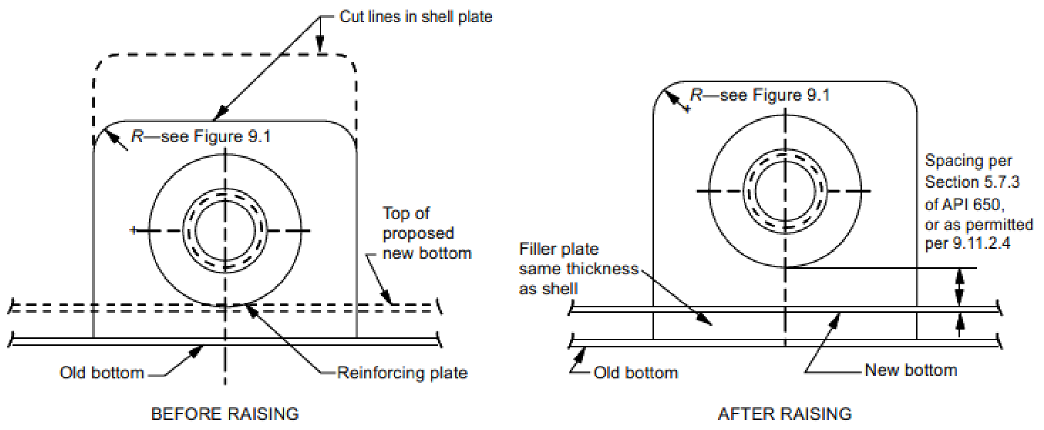



**Figure: Method for Raising Shell Nozzles**

**Repair of Tank Bottoms:** Repairing a Portion of Lap-welded or Butt-welded Tank Bottoms - The use of welded-on patch plates for repairing a portion of uniformly supported tank bottoms is permitted with few limitations. Refer code for details.

**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 provided requirements and the following additional requirements are met:

a) Maximum plate thickness for welded-on patch plates within the critical zone is **¼ in.** and must meet the toughness requirements of API 650
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
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, 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 **5t**
h) Minimum dimension between two welded-on patch plates in the critical zone shall be one-half of the dimension approximately parallel to the shell of the smaller patch.
i) The maximum dimension along the shell for welded-on patch plates in the critical zone is **24 in.**
j) Dimensions to vertical shell welds apply to shells of unknown toughness.

**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.

**Replacement of Tank Bottom Plates:** Suitable noncorrosive material cushion such as sand, gravel, or concrete shall be used between the old bottom and the new bottom. 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. 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 **½ in.** above the bottom-to-shell weld 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.

Installation of a new tank bottom, after removal of the existing tank bottom, shall meet all requirements of API 650. Existing shell penetrations shall be raised or their penetration reinforcing plates modified if the elevation of the new bottom results in inadequate nozzle reinforcement. New weld joints in the bottom or annular ring shall be spaced at least the greater of **3 in.** or **5t**.

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. 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 to contain and channel any bottom leak to a location where it can readily be observed from outside of the tank.

For tanks constructed from materials having **50,000 lbf/in.$^2$** yield strength or less, the required spacing of the welds may be reduced provided 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 **2½t** shall be maintained between the shell-to-bottom weld toe and the nearest penetration attachment weld toe.
c) The following shall be welded with low hydrogen electrodes and with welding procedures that are designed to limit 18 distortion and residual stress:
    i) shell-to-bottom weld
    ii) re-welding of trimmed reinforcing plate

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.

**Additional Welded-on Plates:** 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 9.11.1, and examined in accordance with 12.1.7. For these additional welded-on plates, if the lap-weld spacing requirements 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. Welded-on plates that fall within the critical zone (see 3.10 for definition) shall be installed in accordance with 9.11.1.2 and comply with all of its requirements.

## Repair of Fixed Roofs

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

Supported Cone Roofs: The minimum thickness of new roof plates shall be **$^{3}/_{16}$ 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 9.12.2.2).

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.

**Self-supporting Roofs:** The nominal thickness of new roof plate shall be **$^{3}/_{16}$ 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.

## Repair of Floating Roofs

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

**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.

**Repair of Leaks in Pontoons:** All leaks in pontoons or compartments of double deck floating roofs shall be repaired by re-welding the leaking joints and/or use of patch plates.

## Repair or Replacement of Floating Roof Perimeter Seals

1. Primary Seals
2. Secondary Seals
3. Seal-to-shell Gap
4. Mechanical Damage

# Hot Taps

General: The requirements given herein cover the installation of radial hot tap connections on existing in-service tanks. For API 653 for more details.

| Hot Tap Connection Sizes and Shell Plate Thicknesses | |
|---|---|
| **Connection Size, NPS (in.)** | **Minimum Shell Plate Thickness (in.)** |
| < 6 | $^{3}/_{16}$ |
| < 8 | $^{1}/_{4}$ |
| < 10 | $^{5}/_{16}$ |
| < 14 | $^{3}/_{8}$ |
| < 16 | $^{7}/_{16}$ |
| < 18 | $^{1}/_{2}$ |

## Section 10 – Dismantling and Reconstruction: Refer code for details

# Section 11 – Welding: Refer code for details

**WELDING QUALIFICATIONS:** Welding procedure specifications (WPS) and welders and welding operators shall be qualified in accordance with Section IX of the ASME Code. 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.

**IDENTIFICATION AND RECORDS:** 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.

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.

# SECTION 12 - EXAMINATION AND TESTING

**General:** Nondestructive examinations shall be performed in accordance with API Std 650 and any supplemental requirements given herein. Personnel performing nondestructive examinations shall be qualified in accordance with API Std 650 and any supplemental requirements given herein. Acceptance criteria shall be in accordance with API Std 650 and any supplemental requirements given herein. 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. Appendix 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.

**Shell Penetrations:** 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.

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.

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 having a maximum thickness more than **½ in.** or to shell plates of unknown toughness having a minimum shell design metal temperature below the MDMT curve.

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

**Repaired Weld Flaws:** Cavities resulting from gouging or grinding operations to remove weld defects shall be examined by the magnetic particle or liquid penetrant methods. Completed repairs of butt-welds shall be examined over their full length by radiographic or ultrasonic methods. Completed repairs of fillet welds shall be examined over their full length by the appropriate nondestructive examination method listed herein.

**Temporary and Permanent Attachments to Shell Plates:** 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. Completed welds of new permanent attachments (not including shell-to-bottom welds) and areas where temporary attachments have been removed (API Std 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).

**Shell Plate to Shell Plate Welds:** New welds attaching existing shell plate to existing or new shell plate shall be examined by radiographic methods. 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.

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 Std 650.

**Shell-To-Bottom Weld:** New welding on the shell-to-bottom joint shall be inspected 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 inspected 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 inspected for wicking action. The oil shall be removed before the weld is completed. As an alternative, 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 psi(g)** 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.

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.

**Bottoms:** 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 Std 650. 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 inspected by one of the methods specified in API Std 650. Leaking areas shall be repaired by grinding and rewelding as required, and the repaired area shall be retested.

The root and final pass of a welded-on patch plate weld in the critical zone shall be visually examined and examined by either magnetic particle or liquid penetrant method over its full length.

In addition, 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.

## Shell Plate

**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).

**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.

**Roofs:** Newly welded roof joints and repairs shall be examined in accordance with API Std 650.

### RADIOGRAPHS

**Number and Location of Radiographs:** The number and location of radiographs shall be in accordance with API Std 650 and the following additional requirements:

<u>For vertical joints:</u>

a) New replacement shell plates to new shell plates, no additional radiographs required, other than those required by API Std 650 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.

For horizontal joints:

a) New replacement shell plates to new shell plates, no additional radiographs required, other than those required by API Std 650 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.

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 Std 650 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.

For reconstructed tanks, each butt-welded annular plate joint shall be radiographed in accordance with API Std 650. For reconstructed tanks, radiographic inspection is required for **25** percent of all junctions of new welds over existing seams. The owner/operator shall, with the consent of the contractor, determine the extent of further inspection and repair that may be required. Any further inspection or repair of existing welds will be handled by contractual agreement between the owner/operator and tank reconstruction contractor.

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.

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. 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.

The minimum diagnostic length of each radiograph shall be **6 in.** For penetrations installed using insert plates, the completed butt welds between the insert plate and the shell plate shall be fully radiographed.

**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 current standards, the existing welds may be evaluated according to the original standard of construction.

**Marking and Identification of Radiographs:** 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. Radiographs and radiograph records of all repaired welds shall be marked with the letter **"R".**

## HYDROSTATIC TESTING

When hydrostatic testing is required, a full hydrostatic test, held for **24 hours**, shall be performed on:

a) A reconstructed tank.
b) Any tank that has undergone major repairs or major alterations unless exempted 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, and using tanks that have been damaged.

The terms major repair and major alteration refer to operations that require cutting, addition, removal and/or replacement of the annular plate ring, the shell-to-bottom weld, or a sizable portion of the shell. Within this context, major repairs and major alterations would include:

a) The installation of any shell penetration beneath the design liquid level larger than **12 in. NPS**, or any bottom penetration located within **12 in.** of the shell.
b) The removal and replacement or addition of any shell plate beneath the design liquid level, or any annular plate ring material where the longest dimension of the replacement plate exceeds **12 in.**
c) The 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.
d) The installation of a new bottom. This does not include new bottoms in tanks where the foundation under the new bottom is not disturbed and either condition **1 or 2** are met:
    1. For tanks with annular rings, the annular ring remains intact.
    2. For tanks without annular rings, the repair does not result in welding on the existing bottom within the critical zone for a definition of the critical zone.
e) The removal and replacement of any part of the weld attaching the shell to the bottom or to the annular plate ring.
f) Jacking of a tank shell.

## When Hydrostatic Testing Is Not Required

**General:** A full hydrostatic test of the tank is not required for major repairs and major alterations when both paragraphs a and b of the following:

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

**Shell Repair:** 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 Std 650, 7.2.2 and shall be specified in the repair procedure.

New materials used for the repair shall meet the current edition of API Std 650 requirements. Existing tank materials in the repair area shall meet at least one of the following requirements:

a) API Std 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:

$$S = (2.6\ H\ D\ G)/t$$

Where,

**S** = shell stress in **lbf/in.$^2$**,

**H** = tank fill height above the bottom of repair or alteration in ft,

**t** = shell thickness at area of interest in in.,

**D** = tank mean diameter in ft,

**G** = specific gravity of product.

New vertical and horizontal shell butt-welds shall have complete penetration and fusion. The finished weld shall be fully radiographed.

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. 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.

**Bottom Repair Within the Critical Zone:** Repairs to the annular ring or bottom plates, within the critical zone should 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.

**Shell-To-Bottom Weld Repair:** 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 Std 650, 3.1.5.7, and the portion replaced does not represent more than 50 percent 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** per-cent 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.

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.

**Minor Shell Jacking:** 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.

**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.

**LEAK TESTS:** New or altered reinforcing plates of shell penetrations shall be given an air leak test in accordance with API Std 650.

## MEASURED SETTLEMENT DURING HYDROSTATIC TESTING

**Initial Survey:** Where settlement is anticipated, a tank receiving a hydrostatic test shall have the foundation checked for settlement.

Tank settlement shall initially be surveyed with the tank empty using the number of bottom plate projection elevation measurement points, N, uniformly distributed around the circumference, as indicated by the following formula:

$$N = D/10$$

were,

**N** = minimum required number of settlements measurement points, but no less than eight. All fractional values shall be rounded to the next higher whole number. The maximum spacing between settlement measurement points shall be **32 ft.**

**D** = tank diameter, in ft.

**Survey During Hydrostatic Testing:** Settlement shall be measured during filling and when water reaches **100** percent of test level. Excessive settlement in accordance with Appendix B shall be caused to stop the test for foundation investigation and/or repair.

# SECTION 13 - MARKING AND RECORDKEEPING

**NAMEPLATES:** Tanks reconstructed in accordance with this standard shall be identified by a corrosion-resistant metal nameplate. Letters and numerals not less than $^5/_{32}$ 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 original applicable 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.

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 Std 650.